ECONOMICALLY SUSTAINABLE PUBLIC SECURITY AND EMERGENCY NETWORK EXPLOITING A BROADBAND COMMUNICATIONS SATELLITE

by

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Submitted for the degree of Doctor of Philosophy

at the University of Sussex

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Brighton

August, 2014

Declaration and Statement of Originality

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August, 2014

I hereby declare that this thesis has not been submitted, either in the same or different form to this or any other University for a degree.

It is original work of Lawal Lasisi Salami with contributions from training and experiences of Nigerian Communications Satellite Projects (NIGCOMSAT-1R) as well as implementation of National Public Security Communications System.

L.S LAWAL

Signature

Dedication

I dedicate this thesis to my amiable family.

Acknowledgement

Special thanks go to Almighty Allah for granting me the strength, mercy and grace throughout the course of the doctorate's degree program and project.

I wish to express my sincere appreciation to Professor Chris R. Chatwin for his support, teachings and guidance throughout the program and in the course of this project including preparation of the manuscript. In addition, special thanks to staff and lecturers of school of engineering and informatics for the exposition and tutelage especially Dr. Rupert Young; my second supervisor and colleagues.

I also appreciate extra research lectures, training and development course received from other departments and schools, which immensely contributed to the success of my work and short stay in the university especially the researcher development unit.

My sincere thanks also go to the management of Nigerian Communications Satellite Ltd especially to the Managing Director and Chief Executive Officer for the sponsorship and support.

Thanks also to professional friends, colleagues and associates including NIGCOMSAT Ltd technology partners (CAST, CGWIC, Messers ZTE) for their valuable inputs.

Finally, my sincere appreciation goes to my wife, children and siblings for their sacrifice and the peace I enjoyed at home throughout the course of this program.

It is my pledge to continue to apply my knowledge and skills for the benefit of my society and humanity and at the same time strive towards excellence and professional proficiency at all times, in all positions and circumstance.

Abstract

The research contributes to work in Rapid Deployment of a National Public Security and Emergency Communications Network using Communication Satellite Broadband. Although studies in Public Security Communication networks have examined the use of communications satellite as an integral part of the Communication Infrastructure, there has not been an in-depth design analysis of an optimized regional broadband-based communication satellite in relation to the envisaged service coverage area, with little or no terrestrial last-mile telecommunications infrastructure for delivery of satellite solutions, applications and services.

As such, the research provides a case study of a Nigerian Public Safety Security Communications Pilot project deployed in regions of the African continent with inadequate terrestrial last mile infrastructure and thus requiring a robust regional Communications Satellite complemented with variants of terrestrial wireless technologies to bridge the digital hiatus as a short and medium term measure apart from other strategic needs.

The research not only addresses the pivotal role of a secured integrated communications Public safety network for security agencies and emergency service organizations with its potential to foster efficient information symmetry amongst their operations including during emergency and crisis management in a timely manner but demonstrates a working model of how analogue spectrum meant for Push-to-Talk (PTT) services can be re-farmed and digitalized as a “dedicated” broadband-based public communications system. The network’s sustainability can be secured by using excess capacity for the strategic commercial telecommunication needs of the state and its citizens. Utilization of scarce spectrum has been deployed for Nigeria’s Cashless policy pilot project for financial and digital inclusion. This effectively drives the universal access goals, without exclusivity, in a continent, which still remains the least wired in the world.

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List of Acronyms

ACRONYMS	DEFINITION
2G	Second Generation
3DTV	3D Television
3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
AAA	Authentication, Authorization and Accounting
ACM	Adaptive Code Modulation
ACU	Antenna Control Unit
ADM	Antenna Deployment Mechanism
AIT	Assembly, Integration and Testing
ALC	Automatic Level Control
AM	Amplitude Modulation
AOCS	Attitude Orbit and Control Subsystem
APC	Automatic Power Control
APM	Antenna Pointing Mechanism
APME	Antenna Pointing Mechanism Electronics
ARIB	Association of Radio, Industries and Business
ASL	Antenna System Layout
ASO	Analogue Switch-Off
ASST	Antenna Support Structure
ATC	Automatic Train Control
ATM	Asynchronous Transfer Mode
ATP	Acceptance Test Plan
ATS	Application Technology Satellite
ATSC	Advanced Television Systems Committee
AVTS	Automatic Vehicle Tracking System
BBC	British Broadcasting Corporation
BCR	Battery Charge Regulator
BDR	Battery Discharge Regular
BER	Bit Error Rate
BNC	Bayonet Neil Concelmen
BOL	Beginning of Life
Bps	Bits Per Second
BSC	Base Station Controller

BSS	Broadcasting Satellite Services
BTS	Base Transceiver Station
BUC	Block-Up Converter
BWT	Broadband Wireless Trunking Project
C4ISR	Command , Control, Communications, Computer, Intelligence, Surveillance and Reconnaissance
C/A	Coarse Acquisition Code
CAD	Computer Aided Design
CAE	Computer Aide Engineering
CAF	Communications Auxiliary Facility
CAMP	Channel Amplifier
CAST	China Academy of Space Technology
CATR	Compact Antenna Test Range
CBN	Central Bank of Nigeria
CC	Convolutional Coding
CCIR	International Consultative Committee for Radio
CD	Compact Disc
CDMA	Code Division Multiple Access
CDMA-EVDO	Code Division Multiple Access-Evolution Data Only
CDMA-REV A	Code Division Multiple Access-Revision A
CDMA-REV B	Code Division Multiple Access-Revision B
CDR	Critical Design Review
CERS	Coalition Emergency Response Sub-system
CFR	Coordinated First Response
CFRP	Carbon Fiber Reinforced Plastics
CGWIC	China Great Wall Industry Corporation
CID	Carrier Identification
CM	Communication Module
COMSAT	Communication Satellite
COMSEC	Communication Security
COTM	Communications-on-the Move
COTP	Communication-on-the Pause
CPE	Customer Premise Equipment
CPI	Cross Polarization Isolation
CPM	Continuous Phase Modulation
CR	Cognitive Radio
CT	Counselling and Testing

CTC	Community Telecommunication Center
CTS	Communications Technology Satellites
DAB	Digital Audio Broadcasting
DAE	Digital Agenda for Europe
DARS	Digital Audio Radio Service
dB	Decibels
dBc/Hz	Decibels Relative to the Carrier Per Hertz
dBd	Decibels Relative to Dipole Reference Antenna
dBi	Decibels in relative to Isotropic Reference Antenna
dB/K	Decibels per degree Kelvin
dBm	Decibels referenced to One milliWatt (mW)
DBS	Direct Broadcasting by Satellite
dBW	Decibels above to 1 watt
DC	Direct Current
DevCIS	Development Control Information System
DMB	Digital Multimedia Broadcasting
DMC	Disaster Monitoring Constellation
DML	Digital Mobile License
DFH-4	DongFangHong-4 (Chinese High Power Satellite Bus)
DoD	Department of Defense
DOD	Depth of Discharge
DOP	Dilution of Precision
DPCM	Differential Pulse Code Modulation
DRA	Direct Radiating Array
DSL	Digital Subscriber Line
DSO	Digital Switch Over
DSS	Dispatching Service System
D-TDMA	Deterministic-Time division Multiple Access
DTH	Direct-To-Home
DTT	Digital Terrestrial Television
DVB	Digital Video Broadcast
DVB-ASI	Digital Video Broadcast-Asynchronous Serial Interface
DVB-C	Digital Video Broadcast-Cable
DVB-CID	Digital Video Broadcast-Carrier Identification
DVB-CPCM	Digital Video Broadcast-Content Protection and Copy Management
DVB-EWS	Digital Video Broadcast-Emergency Warning System

DVB-GEM	Digital Video Broadcast-Globally Executable Middleware
DVB-GSE	Digital Video Broadcast-Generic Stream Encapsulation
DVB-H	Digital Video Broadcast-Handheld
DVB-MHP	Digital Video Broadcast-Multimedia Home Platform
DVB-RCS	Digital Video Broadcast-Return Channel over Satellite
DVB-RCT	Digital Video Broadcast-Return Channel over Terrestrial
DVB-S	Digital Video Broadcast –Satellite
DVB-S2	Digital Video Broadcast –Second Generation Satellite
DVB-SH	Digital Video Broadcast-Satellite Services to Handhelds
DVB-SI	Digital Video Broadcast-Specification for Service Information
DVB-SUB	Digital Video Broadcast-Subtitling
DVB-T	Digital Video Broadcast-Terrestrial
DVB-T2	Digital Video Broadcast-Second Generation Terrestrial
DVD	Digital Video Disc
E	East
EADS	European Aeronautic Defense and Space Company
EC	European Commission
ECOWAS	Economic Community of West African States
ECV	Emergency Communications Vehicle
EDGE	Enhanced Data Rates for GSM Evolution
EED	Electro Explosive Device
EGNOS	European Geostationary Navigation Overlay Service
EIRP	Equivalent Isotropic Radiated Power
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMS	Element Management System
EMTEL	Emergency Telecommunications
EOL	End of Life
EPC	Electronic Power Conditioner
EPS	Electrical Power Subsystem
EPON	Ethernet Passive Optical Network
EPS	Electrical Power Subsystem
ESA	European Space Agency
ESD	Electrostatic Discharge
ESS	Econet Satellite Services
ETSI	European telecommunications Standards Institute
EU	European Union

EWI	Econet Wireless International
EWS	Emergency Warning System
FAC	Frequency Agile Converter
FAT	Factory Acceptance Test
FCC	Federal Communications Commission
FCT	Federal Capital Territory
FEC	Forward Error Correction
FEC	Federal Executive Council
FFM	Flicker Frequency Modulation
FGM	Fixed Gain Mode
FGN	Federal Government of Nigeria
FIT	Failure in Time
FM	Frequency Modulation
FMECA	Failure Mode Effects and Critical Analysis
FMEA	Failure Mode Effects Analysis
FMS	Fleet Management System
FOM	Field Office Meetings
FNO	First National Operator
FOC	Full Operational Capability
FPGA	Field Programmable Gate Array
FPM	Flicker Phase Modulation
FSS	Fixed Satellite Services
FTA	Free-to-Air
FW	Flexible Waveguide
GAGAN	GPS-Aided Geo-Augmented Navigation
GBAS	Ground-Based Augmentation System
Gbps	Gigabits Per second
GCL	Global Collaborative Learning
GCS	Geostationary Communication Satellites
GOE	Government Owned Enterprise
GOTA	Global Open Trunking Architecture
G/T	Gain/ Total System Noise Temperature (Figure of Merit)
GPS	Global Positioning System
GHz	Gigahertz
GIS	Geographic Information System
GLONASS	Globalnaya Navigatsionnaya Sputnikovaya Sistema (Russian Global Navigation Satellite System)

GMT	Greenwich Mean Time
GNSS	Global Navigation Satellite System
GPON	Gigabit Passive Optical Network
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
GSMA	Global System for Mobile Communications Association
GUI	Global Unique Identifier
GVF	Global Vsat Forum
GUI	Graphic User Interface
H	Horizontal
HAP	High Altitude Platform
HD	High Definition
HDTV	High-Definition Television
HFSS	High Frequency Structural Simulator
HGDP	High Gain Diversely Polarized Antenna Array
HIV/AIDS	Human Immunodeficiency Virus Infection / Acquired Immunodeficiency Syndrome
HLR	Home Location Register
HLS	Higher Layers Satellite Specification
HP	Horizontal Polarization
HPA	High Power Amplifier
HRM	Hold-Down and Release Mechanism
HSPA	High Speed Packet Access
HTS	High Temperature Superconductor
HTS	High Throughput Satellite
Hz	Hertz
ICAN	International Commission for Air Navigation
iDEN	Integrated Digital Enhanced Network
IDI	ICT Development Index
IDU	Indoor Unit
IEC	International Electrotechnical Committee
I/F	Intermediate Frequency
I/P	Input
IP	Internet Protocol
IP/MPLS	Internet Protocol/Multiprotocol Label Switching
IpoS	Internet Protocol over Satellite

ICD	Interface Control Document
ICT	Information and Communication Technology
IDI	ICT Development Index
IF	Intermediate Frequency
IMUX	Input Multiplexer
InGaAs	Indium Gallium Arsenide
IOC	Initial Operational Capability
IOD	In Orbit Delivery
IOT	In Orbit Test
IPTV	Internet Protocol Television
IRD	Integrated Receiver Decoder
IRIS	Internet Routing in Space
ISDN	Integrated Services Digital Network
ISDR	International Strategy for Disaster Reduction
ISO	International Standards Organization
ISP	Internet Service Provider
ITC	Input Test Coupler
ITU	International Telecommunication Union
ITU-D	International Telecommunication Union-Development Sector
ITU-T	International Telecommunication Union-Standardization
IXP	Internet eXchange Point
JPEG	Joint Photographic Expert Group
K	Kelvin
Kbps	Kilobits Per Second
KHz	Kilohertz
KHTT	Know How Technology Transfer
LAE	Liquid Apogee Engine Same as LAM
LAM	Liquid Apogee Motor same as LAE
LAN	Local Area Network
LBS	Location Based Services
LEO	Low Earth Orbit
LGA	Local Government Area
LHCP	Left Hand Circular Polarization
LLS	Lower Layers for Satellite Standard
LM-3B	Long March 3B (Chinese GEO-Orbit Launch Vehicle)
LM-3BE	Long March 3B Enhanced Launch Vehicle
LNA	Low Noise Amplifier

LNB	Low noise Block
LNBF	Low Noise Block-Down Converter Feed horn
LO	Local Oscillator
LOS	Line-of-Sight
LTD	Limited
LTE	Long –Term Evolution
LTWT	Linearized Travelling Wave Tube
LTWTA	Linearized Travelling Wave Tube Amplifier
LCTWTA	Linearized Channel Travelling Wave Tube Amplifier
MAC	Media Access Control
MBA	Multi-Beam Antennas
Mbps	Megabits Per Second
MCS	Master Control Station
MCU	Multipoint Control Unit
MCXO	Microcomputer Compensated Crystal Oscillator
MDA	Ministries, Departments and Agencies
MD/CEO	Managing Director and Chief Executive Officer
MEA	Main Error Amplifier
MEMs	Micro-Electro-Mechanical System
MEO	Medium Earth Orbit
MFN	Multiple Frequency Networks
MF-TDMA	Multi-Frequency – Time Division Multiple Access
MGW	Multimedia Gateway
MHP	Multimedia Home Platform
MHz	Megahertz
MIL-STD	Military Standard
MIMO	Multiple-Input Multiple-Output
MLI	Multilayer Insulation
MMH	MonoMethyl Hydrazine
MMIC	Monolithic Microwave Integrated Circuits
MODCOD	Modulation and Coding
MON-1	Nitrogen Tetroxide
MPEG	Motion Picture Expert Groups
MRL	Master Register List
MSAS	MTSAT Satellite Augmentation System
MSC	Mobile Switching Center
MSCE	Mobile Switch Center Emulator

MSS	Mobile Switching System
MTSAT	Multi-functional Transport SATellite
N	North
NASA	National Aeronautics and Space Administration
NASRDA	National Space Research And Development Agency
NAVSTAR	Navigation System with Timing and ranging
NBC	National Broadcasting Commission
NCC	Nigerian Communications Commission
NCC	Network Control Center
NCERC	National Coalition Emergency Response Center
NEMA	National Emergency Management Agency
NGO	Non-Government Organizations
NIBSS	National Inter-Bank Settlement System Plc
NIGCOMSAT-1	First Nigerian Communication Satellite
NIGCOMSAT-1R	Nigerian Communications Satellite-Replacement
NIGCOMSAT Ltd	Nigerian Communications Satellite Limited
NIGERIASAT-1	Nigeria's First Observation Satellite
NIGERIASAT-2	Nigeria's Second Observation Satellite
NIGERIASAT-X	Nigerian Engineers'-Built Observation Satellite
NITDA	National Information Technology Development Agency
NITEL	Nigerian Telecommunications Ltd
NLOS	Non-Line-of -Sight
NMC	Network Management Center
NMS	Network Management System
NOS	Navigation Overlay Service
NPF	Nigeria Police Force
NPSCS	National Public Safety Communications System
NPSTC	National Public Safety Telecommunications Council
NSAS	Nigerian Satellite Augmentation System
NSF	National Science Foundation
NSR	Northern Sky Research
NTA	Nigerian Television Authority
NTIA	National Telecommunications and Information Administration
NTSC	National Television System Committee
O3B	Other 3(Three) Billion
OBDH	On-Board Data Handling Subsystem
OCHA	Office for the Coordination of Humanitarian affairs

OCXO	Ovenized Control Crystal Oscillator
ODU	Outdoor Unit
OECD	Organization for Economic Co-operation and Development
OfCom	Office of Communications
OFDM	Orthogonal Frequency Division Multiplexing
OGTV	Ogun State Television
OMC	Operation & Maintenance Center
O/P	Output
OMM	Operation Management Module
OMT	Orthogonal Mode Transducer
OMUX	Output Multiplexer
OPEX	Operational Expenditure
OTC	Output Test Coupler
OTS	Orbital Test Satellite
PAL	Phase Alternating Line
PCU	Power Control Unit
PDA	Personal Digital Assistant
PDR	Preliminary Design Review
PDSN	Packet Data Support Node
PDSS	Packet Data Service System
PFD	Power Flux Density
PFDU	Platform Distribution Unit
PFRTU	Platform Remote Terminal Unit
PLDU	Payload Distribution Unit
PLRTU	Payload Remote Terminal Unit
PIM	Passive Intermodulation
Pin	Input Power
PIU	Pyrotechnic Integration Unit
PLL	Phase Locked Loop
PLMN	Public Land Mobile Network
PMR	Private Mobile Radio
PMTCT	Prevention of Mother-to-Child Transmission
POC	Proof-of-Concept
POP	Point of Presence
Pout	Output Power
POS	Point of Sales
PP	Protocol Processor

PPM	Parts Per Million
PSDN	Packet Data Support Node
PSTN	Public Switch Telephone Network
PSK	Phase Shift Keying
PSS	Public Security Services
PSWAC	Public safety Wireless Advisory Committee
PTO	Private Telephone Operators
PTT	Push-to-Talk
QAM	Quadrature Amplitude Modulation
QoE	Quality of Experience
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RASCOM	Regional African Satellite Communication Organization
R	R Switch
RbXO	Rubidium Crystal Oscillator
RF	Radio Frequency
RFI	Radio Frequency Interference
RFI-EUI	RF Interference-End Users Initiative
RFP	Request for Proposal
RHCP	Right Hand Circular Polarization
RNP	Required Navigation Performance
ROI	Return on Investment
RCST	Return Channel Satellite Terminal
RRC	Regional Radiocommunications Conference
Rx	Receive
RWFM	Random Walk Frequency Modulation
S	South
S3R	Sequential Switching Shunt Regulator
SA	Solar Array
SA	Selective Availability
SADA	Solar Array Drive Assembly
SADAE	Solar Array Drive Assembly Electronics
SADA-M	Solar Array Drive Assembly Motor
SAT	Site Acceptance Test
SAT-3	South Atlantic-3 Cable
SATCOM	Satellite Communication
SBAS	Satellite-Based Augmentation Systems

SCADA	Supervisory Control and Data Acquisition
SCERC	State Coalition Emergency Response Center
SCPC	Single channel Per Carrier
SDCM	System Differential Correction and Monitoring
SDTV	Standard-Definition Television
SDR	Software Defined Radios
SECAM	Sequential Couleur A Memoire
SFD	Saturated Flux Density
SFN	Single Frequency Network
SFP	Single Failure Point
SIA	Satellite Industry Association
SIM	Subscriber Identity Module
sIRG	Satellite Interference Reduction Group
SKM	Station Keeping Mode
SLA	Service Level Agreement
SME	Small and Medium Enterprises
SMSC	Short Message Service Center
SNAS	Satellite Navigation Augmentation System
SNG	Satellite News Gathering
SNO	Second National Operator
SOA	Service-oriented Architecture
SOL	Safety of Life
SOHO	Small Office, Home Office
SSA	Sub-Saharan Africa
SSPA	Solid State Power Amplifiers
SUSSEXSAT-1	Virtual Communication Satellite from University of Sussex.
SSTL	Surrey Satellite Technology Limited
STB	Set-Top Box
STK	Satellite Tool Kit
SWOT	Strengths, Weaknesses, Opportunities and Threats
T	T Switch
T	System Noise Temperature
TBC	To Be Confirmed
TBD	To Be Determine
TBR	To Be Reviewed
TBS	To be Specified
TC	Telecommand

TCS	Thermal Control Subsystem
TC&R	Telemetry Command and Ranging
TCXO	Temperature Compensated Crystal Oscillator
TD CDMA	Time Division-Code Division Multiple Access
TDM	Time Division Multiplexed
TD SCDMA	Time Division-Synchronous Code Division Multiple Access (Chinese National Standard)
TEDS	Tetra Enhanced Data Service
TETRA	Terrestrial Trunked Radios
TIA	Telecommunications Industry Association
TM	Telemetry
TM/TC	Telemetry/ Telecommand
TNC	Threaded Neil Concelman
TPC	Turbo Product Coding
TRANSEC	Transmission Security
TS	Transport Streams
TT&C	Telemetry, Telecommand and Ranging
TV	Television
TWT	Travelling Wave Tube
TWTA	Travelling Wave Tube Amplifiers
Tx	Transmit
Tx/Rx	Transmit/Receive
UHF	Ultra High Frequency
UK OfCom	United Kingdom Office of Communications
UMTS	Universal Mobile Telecommunications System
UNESCO	United Nations Educational, Scientific and Cultural Organization
UPC	Uplink Power Control
UPS	Unified Propulsion Subsystem
USA	United States of America
USB	Universal Serial Bus
USD	United States Dollar
US FCC	United States Federal Communications Commission
USO	Ultra-Stable Oscillator
V	Vertical
VCE	Video Conferencing Equipment
VCO	Voltage Controlled Oscillator

VCS	Video Conference Sub-system
VCXO	Voltage Control Crystal Oscillator
VHF	Very High Frequency
VNO	Virtual Network Operator
VOD	Video-on-Demand
VoIP	Voice Over Internet Protocol
VP	Vertical Polarization
VPN	Virtual Private Network
VSAT	Very Small Aperture Terminal
VSS	Video Surveillance Sub-system
VSWR	Voltage Standing Wave Ratio
W	Watt
W	West
WAAS	Wide Area Augmentation System
WAN	Wide Area Network
WBU-ISOG	World Broadcasting Union-international Satellite Operations Group
W-CDMA	Wideband Code Division Multiple Access
WFM	White Frequency Modulation
WG	Waveguide
WGET	Working group on Emergency Telecommunications
WGS	Wideband Global Satcom
WIFI	Wireless Fidelity
WIMAX	Worldwide Interoperability for Microwave Access
WPM	White Phase Modulation
WRC	World Radiocommunications Conference
XO	Crystal Oscillator
XPI	Cross Polarization Isolation
XPD	Cross Polarization Discrimination
XSLC	Xichang Satellite Launch Center
ZTE	Zhong Xing Telecommunication Equipment Corporation

List of Symbols with Dimensions

S/n	Symbol	Meaning	Dimension
1	c	Velocity of light	$3x\frac{10^8 m}{s}$
2	EIRP	Equivalent Isotropic Radiated Power	dBW
3	f	Frequency	Hz
4	Fdown	Downlink Frequency	GHz
5	Fup	Uplink frequency	GHz
6	Gr	Receive Antenna Gain	dBi
7	Gt	Transmit Antenna Gain	dBi
8			
9	G/T	Figure of Merit (Gain/Total System Temperature)	dB/K
10	i	Angle of inclination	Degrees (°)
11	IL	Insertion Loss	dB
12	i_{sp}	Specific impulse of the thrusters or liquid Apogee Engine (LAE)	Seconds (s)
13	k	Boltzmann's constant expressed in dB	-228.6 dBW/K-Hz
14	m_o	Initial mass	Kg
15	N	Number of cells in a battery	
16	Pbol	Power at Beginning of Life	Watts (W)
17	Pdis	Dissipated Power (Heat)	Watts (W)
18	Pe	Error of Probability	
19	Peol	Power at end of Life	Watts (W)
20	Pin	Input Power	W
21	Pout	Output Power	W
22	Pr	Received Power	dBW+30=dBm
23	Pt	Transmitted Power	dBW
24	SFD (ψ)	Saturated Flux Density	$\frac{dBW}{m^2}$
25	R	Satellite range	km
26	Rb	Data transmission rate	Bits per second (bps)
27	R_e	Radius of earth	6378.137km
28	T	Absolute Temperature	Kelvin (K)
29	λ	Wavelength of radio frequency signal	Meters (m)
30	π	Pie	3.142

31	η	Efficiency	%

List of Publications and Successful Launch of Communications Satellite (NIGCOMSAT-1R) during DPhil Programme.

Provided in Appendix F.

CHAPTER 1: Introduction

1.1General Introduction and Literature Review of National Public Security and Emergency Network.

Under peaceful and normal operations, public safety and security networks are meant for protection of life and property in order to facilitate maintenance of law and order. The same network should be able to meet the needs of disaster response (man-made or natural) when required. Thus, just like the International Space Station, which remains a triumph of cooperation, communication and Complex logistics; convergence in communication networks through integrated connectivities, be it satellite, fiber optics, radio and auxiliary networks are required to optimize national public security and emergency networks especially in underdeveloped and developing nations with inadequate or little communication infrastructure with extreme security needs for the networks (McGee, Coutiere, & Pala,ara, 2012). Communications satellites transcend national boundaries and engendered cooperation and integration with inter and intra connectivity among nations just as the whole system of bilateral partnerships is crumbling (Scott, 1994; Stuart, 1997b;1997c). Communications satellite as noted by Cosper (1997) and Conte (2005) are known to offer easy and elegant solutions for those in need of ready-made global communications infrastructure, which could be remote villages, seafaring vessels, airline passengers and cabin crew etc.

It is believed that Government of almost all Nations recognizes the pivotal role of ICT in socio-economic development, sustainability of law and order, crime prevention and combat particularly in the context of achieving a secure integrated communications network through convergence of all forms of communications infrastructure with the potential to foster information symmetry among and within nations and its security operatives. Communication Satellites have that unique role of fostering information symmetry among several different networks via satellite communications independent of the distance across the ground or geography. Infrastructure costs of communications via communication satellites are no longer a function of distance (Stuart, 1997b; James & Andrew, 1999).

The rapid growth in both population and socio-economic activities especially in developing and underdeveloped countries requires a guarantee of public safety, protection of lives and the property of law abiding citizens, reduced crime rate, effective and timely disaster response.

Furthermore, considering the need for collaborative efforts amongst not just government agencies but regional, national and international non-government agencies (NGO) for effective, timely and efficient disaster response, an emergency management system of public crisis with networked governance for unified operations is required. A model as suggested by Wei (2011) was a case study of management of the congelation public crises in Xiuwen county of Guizhou Province in China, which helped bridge the gap of government agencies' defects. Building such a system requires a communication satellite network, which operates reliably regardless of the level of destruction of terrestrial communications. Portable satellite backhauling solutions are becoming fundamental element in emergency communication networks to help coordinate disaster operations and relief (Estrem & Werner, 2010). The "emergency.lu"; a communications platform initiated by three companies based in Luxembourg, with additional world agency partners is essentially a satellite infrastructure, which proved itself as a critical Emergency Telecommunications Cluster during the South Sudan crisis and that the emergency preparedness was a fundamental phase of the response (Donven & Hall, 2012). The inherent advantage is its pervasiveness in terms of broadcast capability, seamless integration for articulated coordination, ease of setup while the network is centrally controlled with remote stations setup wherever it is required helping government and disaster responders to gather information as well as inform and broadcast information including communications-on-the-move (COTM) capability (Choi & Lee, 2008).

The Public Safety wireless data network in New York City has exemplified a working example of a dedicated broadband public safety wireless network using IP Wireless 3GPP TD-CDMA MIMO technology with high-speed data and video delivery reaching 7Mbps. Wireless communication technologies and network will continue to play an irreplaceable role to meet the needs of public protection and disaster relief in emergency situations and they must be broadband based to support data and real-time communications (Sallent, 2013). The National Public Safety Telecommunications Council (NPSTC) and other organizations in the US endorsed LTE technology as early as 2009 as the technological standard for mobile broadband based public safety and emergency networks (Ferrus et al, 2013).

Research and standardization activity at national and international level to define modern, interoperable communications and networking standards for emergency response and public safety are being studied and implemented including several initiatives aimed at effective emergency response services by international bodies, institutes and stakeholders. For instance, the GSMA, which represents the interests of mobile operators worldwide, initiated the deployment of a single, in-vehicle emergency call services known as eCall, across Europe aimed at establishing voice connection with the emergency services alongside critical data such as time, location, direction of travel, vehicle identification etc. The International Telecommunication Union (ITU), Inmarsat and Vizada SAS initiated improved emergency communications for disaster preparedness via satellite-based solutions among others (GSMA International Report, 2009). ITU has identified emergency communications as a key priority with several work groups including ITU- Development sector (ITU-D) to develop technical recommendations and implementations guidelines on disaster response planning.

Boukerche (2008) provided an overview of the next generation wireless networks for emergency preparedness and arrays of applications necessary for public safety and security while China's broadband Wireless trunking project (BWT) seeks to incorporate mission-critical features on long-Term Evolution (LTE) as future Public safety Communications Network (Li, Chen, Yu, Meng, & Tan, 2013). Advanced and reliable research is being conducted with applications using Software Defined Radios (SDR) and Cognitive Radio (CR) technologies towards better spectrum utilization and management (Gorcin & Arslan, 2008).

The United Nations International Strategy for Disaster Reduction (ISDR) promotes national capacities. Since 1994 after recognition and adoption of the Tampere Convention (treaty) on Emergency Telecommunications, the Working Group on Emergency Telecommunications (WGET) is regularly convened by the United Nations Office for the coordination of Humanitarian Affairs (OCHA) as a focal point for emergency telecommunication related issues. WGET encompasses all partners in humanitarian assistance and emergency telecommunications, experts from private and academic sectors, UN entities including national, international, governmental and non-governmental organizations (Oh, 2003).

1.2 Growing Needs for National Public Security and Effective Disaster Management.

Timely disaster response in 21st century has become a priority issue in disaster and crisis management. Despite all the advances in science and technology, humankind remains vulnerable to the effect of natural and man-made disasters. Disasters such as floods, volcanic eruptions, earthquakes, tsunamis, avalanches, landslides, hurricanes, tropical storms, typhoons, wild-fires etc leave behind devastating destruction encompassing: human injury and loss of life, environmental damage, health hazards, economic disruption and many other challenges.

Lenka (2010) stressed the importance of unifying communication plans, solutions to problems associated with crisis communication and the need to evaluate operational communication processes and behavior during crisis situations. (Musavi Memon, & Chawdhri, 2011) and (Villaveces, 2011) concluded that the imperative of secured and efficient integrated Information and Communication Technology (ICT) infrastructure becomes a prerequisite for a successful response to the incessant and frequent occurrence of natural and man-made disasters including public safety and utilization of newer technologies. Post-disaster management system are facilitated by integrated wireless-based communication infrastructure Next-Generation public safety and security networks must be broadband networks to support the growing transmission and reception requirements of video, voice, data and heavy graphical applications such as map and pictures as well as being Internet Protocol (IP) based for an integrated common platform (McGee et al, 2012). Countries with high risks of natural disasters require advanced planning in pre and post disaster relief operations on instant delivery of emergency communications infrastructure (Beebe, 2014).

Poorly wired countries with inadequate terrestrial infrastructure require space-based ICT infrastructure (Communication Satellite) for advanced planning and disaster preparedness. Developed countries with adequate terrestrial ICT infrastructure still require a space-based system for strategic needs, as established ICT infrastructure can be rendered inoperable. In Europe, the ETSI recommendation TS 102 181 recognizes the importance of Location services in the Emergency Telecommunications framework (EMTEL), which emphasizes the integration of navigation and communications systems as well as integration of satellite networks with High Altitude Platforms (HAPs), terrestrial networks such as Terrestrial Trunked Radios (TETRA) or Universal Mobile Telecommunications System (UMTS). Satellite Communications have a unique and important role to play in emergency telecommunications (Del Re, Morosi, Jayousi, Ronga & Suffritti, 2009). Considering the criticality of telecommunications at all phases of disaster management, the International Telecommunications Union (ITU) currently has a focus-group working on: disaster relief, network resilience and recovery. The focus-group is co-ordinating the ITU Telecommunication (ITU-T) Standardization sector work in the disaster relief field.

Guarantee of public safety, reduced crime rate as well as timely disaster response and management can be achieved by exploiting broadband telecommunications, video services, high speed internet, video conference technology, high speed IP-based cameras, emergency response alert systems all integrated into a multimedia public security communications system with the ability to deliver information symmetry between the country's security operatives and other similar organizations nationwide to address the security and emergency challenges of a sovereign Nations sustainably. (Bowman,2007; Lawal & Chatwin, 2014).

However, existing terrestrial infrastructure especially in the African hinterlands are usually grossly inadequate, thus the need to develop national, sub-regional and regional carrier of carriers and digital links with cross-border inter-connectivity. Though, presently the continent has adequate capacity on submarine fibre optic cable along the shores of the African coast, it lacks adequate infrastructure within African countries including cross-border connectivity. The demand projections suggest the need for a robust passive infrastructure build-out, in and around Africa to address this large un-met demand for information and communication services. To address the shortfall in terrestrial ICT infrastructure especially in Africa and as a means of closing up on the infrastructural gap, communications via satellite complemented by terrestrial wireless systems using variants of Wifi, Wimax, CDMA, GSM to build the required networks for broadband telecommunications and the required efficiency, user experience and speed of transactions and operations to meet short and medium term plans as well as meeting strategic requirements for emergency communications during disasters (Anonymous, 1994; Cosper, 1997; Lawal & Chatwin, 2010a, 2010b, 2011, 2012, 2013 Lawal, Ahmed-Rufai, Chatwin & Young, 2013, Lee, Ku, & Ahn, 2010; Dempsey, 2010).

The pivotal role of a secured integrated communications public safety network for security agencies, emergency service organizations (i.e Police, Fire, Road safety outfits, medical services etc) has the potential to foster information symmetry between their operations efficiently and effectively (Dervin, Buret, & Loisel, 2009) & (Del Re, 2012). Such networks with huge data requirements drive investment in new broadband technologies built on an advanced IP network supporting IP/MPLS and 4G technologies such as Long-Term Evolution (LTE) for real time video streaming, VoIP, e-mails, web browsing and applications support for operation. Introduction of digital video broadcasting (DVB) systems to communications satellites was a milestone paradigm shift for the important role of communication satellites in broadcasting, telecommunications, mobile communications, convergence with voice, video and data as well as terrestrial telecommunications technologies (Ong et al, 2007; Liang et al, 2007, Lawal, Ahmed-Rufai, Chatwin & Liu, 2013). LTE and LTE-Advanced uses orthogonal frequency division multiplexing (OFDM) as the multiple-access technology using multiple antenna (MIMO) technique and carrier aggregation with improved higher data rates, low latency, better coverage and enhanced system capacity.

Least wired Countries with inadequate terrestrial infrastructure require space-based ICT infrastructure (Communication Satellite) for disaster preparedness including developed countries with adequate terrestrial ICT infrastructure because tolerance of such terrestrial ICT infrastructure is almost zero in a disaster event. The disaster may either destroy the little ICT infrastructure offered by private companies or the disaster event happened in areas with no ICT infrastructure. The research offered a proposed disaster communications interoperability plan with features such as redundant transmission plan, more sophisticated vital equipment, backup subscriber management center, emergency hot lines, paging systems for spreading disaster warnings, rapid deployment techniques for Base stations during response among others. Wireless communications technologies and network will continue to play an irreplaceable role to meeting the needs of public protection and disaster relief in emergency situations and they must be broadband based to support data and real-time communications.

1.3 Common Problems associated with Public Safety and Emergency Networks.

In 1994, the National Telecommunications and Information Administration (NTIA) and Federal Communications Commission (FCC) of the United States established the Public Safety Wireless Advisory Committee (PSWAC) to evaluate the wireless communications needs of public safety agencies at local, state and federal level to, identify problems and recommend possible solutions. The PSWAC concluded its study in 1996, emphasizing three important issues as problems for public safety communication systems, which are still prevalent today, these are: Lack of spectrum resources, Interoperability issue due to incompatible radio equipment and use of multiple frequency bands and reluctance to adopt new emerging wireless technologies with high data rate applications (Gorcin & Arslan, 2008). Getha-Taylor(2007) noted that twentieth century bureaucracies are unable to handle twenty-first century problems, and one such problem amongst other disasters was Hurricane Katrina, where the time to react was so short that no single organization had all the answers with enormous failure as a result. The White House report on the Federal Response to Hurricane Katrina stressed the importance of unity and shared responsibility as part of lessons learned. Vanderford et al (2007) also seek to show emergency communication challenges in response to Hurricane Katrina from the perspective of: Centers for Disease Control and Prevention. The aftermath of the London terrorist attack on 7th July 2005 tested the resilience of overloaded mobile phone networks similar to Hurricane Katrina until the National Guard shipped in two satellite communications vehicles. The Australian black Saturday bushfire in 2009 in which 173 people died and 414 people were injured shows how vulnerable terrestrial telecoms infrastructure are as the heat of the fires melted radio and telecoms infrastructures (Evans-Pughe & Bodhani, 2013). Of interest also, was the great East Japan Earthquake with the resulting large-scale tsunami on March, 11, 2011 and the best effort-based disaster recovery that followed with lessons learned (Mase, 2012). The efficiency of early warning systems in terms of unawareness in realizing vulnerabilities to disasters and weak coordination between stakeholders, and lack of political-will was reported by Musavi et al (2011) while Meng-Hsun Tsai et al (2011) also noted the deficiency of existing emergency communications system during the 2009 Typhoon Morakot in Taiwan with serious damage as a result of flooding and mudslides. Terrestrial Trunked Radio (TETRA) could offer a resilient and secured digital radio service for voice and short messaging especially in Europe developed by European Telecommunications Standards Institute (ETSI) with extensive mission–critical performances and services but has limitations in data transfer with a maximum multi-slot packet data-rate of 12-15kbps (Salkintzis, 2006). The Tetra Enhanced Data Service (TEDS) delivers user bit-rates of 100 to 500kbps using the same air-interface technique as wireless standard such as WiMax and LTE (3GPP Long-Term Evolution) but still falls short of the 21st century broadband and throughput requirements (Evans-Pughe, 2011). A pilot project was tried successfully in the UK by the National Police Improvement Agency (NPIA) on 872 to 876MHz and 918 to 921MHz spectrum. Most European TETRA systems occupy two 5MHz slots within the 380 to 400MHz band reserved for European Public safety and security forces. 410MHz to 430MHz is a harmonized band, used across Europe including the UK as Private Mobile Radio (PMR). The allocation of appropriate radio spectrum to enable a broadband-based network for public safety and an emergency network has been a challenge with most spectrum regulatory authorities requiring a regulatory framework and business model to address the upsurge of spectrum demands by commercial mobile operators to meet consumer needs (Sallent, 2013). Radio spectrum dedication for occasional transmission during emergency is not efficient in the 21st century. Ferrus et al (2013) argued that spectrum for public networks and disaster relief should exploit dedicated and shared spectrum with synergies from commercial mobile operators for effective sustainability and management of scare frequency resource. In furtherance to having National ICT infrastructure and capacity, UNESCO established a consortium for mitigation of disasters through the United Nation's International Strategy for Disaster Reduction (ISDR), which includes a funding commitment for developing national capacities. Disaster management could be viewed from two perspectives: the Pre-Disaster phase, which involves mitigation, preparation and planning with technological solutions such as monitoring, prediction and early warning systems etc whereas the post-disaster phase involves response, recovery and rehabilitation requiring ICT infrastructure for telecommunications, mapping, GIS, health facilities, telemedicine etc. Musavi et al. (2011) highlighted the importance of an integrated interoperable wireless communication network for effective disaster response citing weaknesses and lapses in terms of lack of coordination between agencies and absence of a single command and control system in the response phase of recent large scale disasters such as the 2005 Kashmir earthquakes, the Margala heights plane crash in Islamabad in August 2010 and floods in Pakistan in 2010. The disaster may either destroy the little ICT infrastructure offered by private mobile companies or the disaster event happens in areas with no ICT infrastructure. Other related issues are organizational and operational hierarchy of assembling emergency response teams, evacuation and transporting emergency patients, paying for services as it relates to medical care and health insurance (Joshi et al, 2013; Lawal & Chatwin, 2014).

1.4 Research Objectives

The aim of the research is to provide a satellite–based National Public Security and Emergency Network and to make it financially sustainable by utilizing the excess bandwidth capacity from the deployed broadband–based network to drive the national cashless policy. The objectives to achieve this are as follows:

- To identify and analyse needs assessment, feasibility and suitable design specifications for a Regional Communications Satellite in Sub-Saharan Africa.

- To redesign, modify and optimize the payload of Nigeria's regional Communications Satellite (NIGCOMSAT-1R) to reflect the growing and prevailing market trends and potentials beyond the African Continent.

- To establish factors governing Antenna Layout Design for optimal performance of Geostationary Communications Satellite.

- To investigate and describe how to present satellite technologies used in the current commercial satellite bus with the required innovations to meet the increasing telecommunications, broadcasting and navigation service needs with enhanced In-orbit service life time and capacity through systemic implementation of new technologies at unit, subsystem and the system level of a geostationary communication satellite

- Validation of techniques, improvements and methodologies required for a high powered spacecraft bus of Geostationary Communications Satellite.

- To examine the critical role that Space-Borne Oscillators play in improving performance of Satellite-Based Augmentation Systems and the strategic role of NIGCOMSAT-1R as a nascent African contribution to the Global Navigation Satellite System (GNSS) as well as its importance in emergency preparedness and effective crisis management.

- To examine the critical role of Communication Satellites in driving the national ICT revolution in providing cost effective solutions and affordable access to meet the telecommunications and electronic services of the nation as well as providing revenue diversification for the nation.

- To illustrate how a regionally designed Communications Satellite complemented with variants of terrestrial wireless technologies can be used to bridge the digital hiatus as a short and medium term measure to rapidly meet growing ICT needs of people and nation.

- To compare and analyse prediction performance results of the NIGCOMSAT-1R Communications Satellite with In-Orbit Test (IOT) results to validate key performance parameters of the Communication Satellite.

- To exploit Communication Satellites as an alternative broadcast platform to Digital Terrestrial Television (DTT).

- To develop and describe solutions, applications and services exploiting communications satellite and national public security and emergency network.

- To utilize such “dedicated and broadband-based” public security service (PSS) and emergency network to drive national strategic and commercial needs in locations lacking sufficient last mile infrastructure.

- To clarify needs assessment of the National Public Security Communications System (NPSCS) and description of its Service Oriented Architecture (SOA) exploiting NIGCOMSAT-1R and Wireless Radio technologies.

- To define the requirements for nationwide financial and digital inclusion without exclusivity by exploiting the combined resources of the NPSCS and NIGCOMSAT-1R.

- To develop a long term sustainability model for Public Security Services (PSS) and Emergency Network by utilizing the excess capacity of NPSCS for Nigeria's national cashless policy implementation.

1.5 Achievements

The research not only addresses the pivotal role of a secured integrated communications Public safety network for security agencies and emergency service organizations for their integrated operations but demonstrates a working model of how analogue spectrum meant for Push-to-Talk (PTT) services can be re-farmed and digitalized as a "dedicated" broadband-based public communications system. The network's sustainability can be secured by using excess capacity for the strategic commercial telecommunication needs of the state and its citizens**.**
Nigeria's National Public Security and Communications System (NPSCS) Network was deployed using new emerging broadband-based wireless technologies with high data and video applications support with the excess capacity being used to support and drive the Nation's Cashless Policy project for financial and digital inclusion and at the same time promoting sustainability of the network's operations and maintenance. This effectively drives the universal access goals, without exclusivity, in a continent, which still remains the least wired in the world. The combined hybrid solution of the NPSCS and NIGCOMSAT-1R network is promoting effective crisis communication as a coordinated first-response (CFR) during a crisis situation and remains a key factor for success in crisis and emergency management as shown in figure 1.1, which illustrates the big picture.

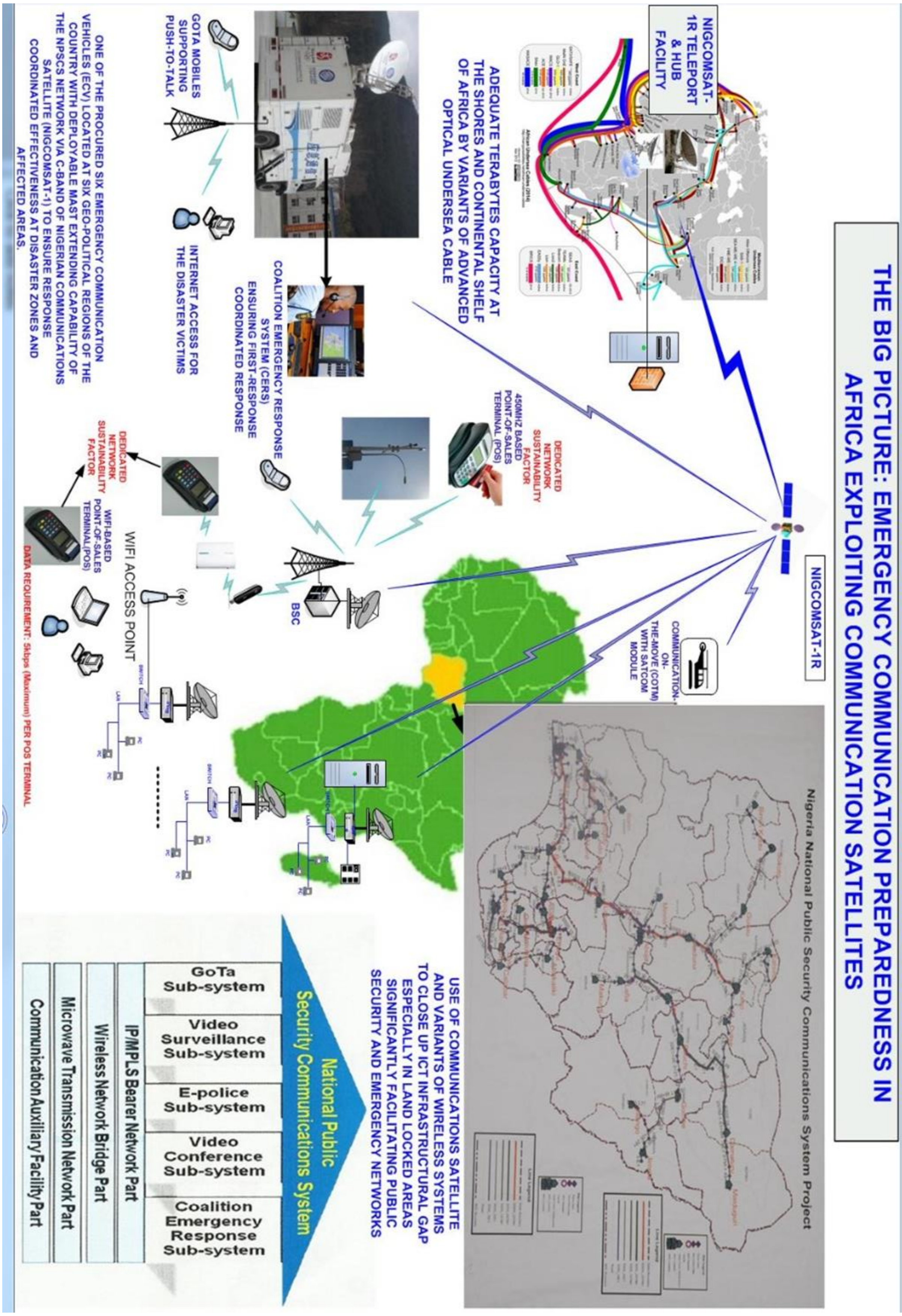


Figure 1.1: The Big Picture: Emergency Communication Preparedness in Africa Exploiting Communication Satellites with complementary terrestrial radio technologies

The big picture as illustrated in figure 1.1 is required to deliver immediate effects in facilitating relief coordination in disaster zones as well as the first phase of Nigeria's C4SIR system (Fixed and Mobile Command and Control, Communication Computers, Surveillance, Intelligence and Reconnaissance system), a system with the capability to support operations for general security alarm, emergency alarm and alarm handling, and cooperative security systems such as surveillance, interception, information gathering, analysis, preplanning, etc. The Security Communications system shall allow for collection, management, analysis, fusion and interpretation of relevant information to commanders, operators to guide planning, resources deployment, tactical response and strategic planning as well as information sharing and symmetry with similar organizations and other relevant organizations. A holistic nationally integrated emergency communication response system will be effective given the political will, state support, legislation, interconnected ICT network grids and infrastructure. A dedicated National public security communications network pilot project in Nigeria demonstrates a model that not only addresses emergency preparedness but the broadband communication needs of emergency and disaster recovery while leveraging on strategic commercial and non-commercial telecommunication needs of the state and citizens thus addressing the sustainability factor, optimization of spectrum utilization, digital and financial inclusion.

The pilot project offered a proposed disaster communications interoperability plan with features such as redundant transmission, more sophisticated vital equipment, backup subscriber management center, emergency hot lines, paging systems for spreading disaster warnings, rapid deployment techniques for base stations during response *inter alia.*

1.6 Thesis Organization

This thesis focuses on the importance and exploitation of communications preparedness for public safety, effective security and disaster response to emergencies, which may be man-made or natural. It explores uses of hybrid communications infrastructure, which comprises of a communications satellite complemented with terrestrial wireless technologies in locations with little or no terrestrial last-mile ICT infrastructure considering the criticality of communications in all phases of disasters, public safety and emergencies. Although studies in Public Security Communication networks have examined the use of communications satellite as an integral part of the Communication Infrastructure, there has not been an in-depth design analysis of an optimized regional broadband-based communication satellite in relation to the envisaged service coverage area.

In this chapter, a general introduction and literature review of national public security and emergency network is provided as well as growing needs for network for national public security and effective disaster management. Also, common problems associated with public safety and emergency networks were examined. The research objectives and achievements as contributions are summarised with exploitation of Nigerian Communications Satellite (NIGCOMSAT-1R) and National Public Security Communications System (NPSCS) as a case study.

The second chapter investigates the present satellite technologies used in the current commercial satellite bus with the required advancement and innovations to meet increasing telecommunication, broadcasting and navigation service needs as well as enhanced service life time and capacity through systemic implementation of new technologies at: unit, subsystem and the system level of a geostationary communication satellite with reference to the NIGCOMSAT-1R project and program.

In chapter three, the situational analysis of Information Communications Technology (ICT) infrastructure in Africa is examined with identification of a strong need for passive Global Space-based ICT Infrastructure (Communications Satellite System and associated technologies) as a short and medium term measure to bridge the huge digital hiatus based on needs assessment and viability despite the arrival of sufficient and adequate undersea cables at the shores of the African continent in recent years. A well-planned and implemented Very Small Aperture Terminal (VSAT) with a suitable regional domestic communications satellite will significantly improve access to telecoms services in rural areas as a niche market as well as address other strategic needs of the region.

Chapter four presents the design and implementation of Nigerian Communications Satellite (NIGCOMSAT-1R), which takes cognizance of the situational analysis made in chapter three as regards needs assessment and feasibility with service coverage area (footprints) of NIGCOMSAT-1R designed to provide qualitative telecommunications and broadcast needs within Sub-Saharan Africa and beyond including a Navigational piggyback payload repeater. The insurance replacement Nigerian Communications Satellite (NIGCOMSAT-1R) after de-orbiting of the first Nigerian Communications Satellite (NIGCOMSAT-1) as a result of an irreparable identified single point of failure (SPF) of an on-board subsystem provided the opportunity to modify and optimize the payload of the COMSAT to reflect the growing and prevailing market trends and potential beyond the African continent. The design performance is presented and the actual performance measured during In-Orbit Test (IOT) is also presented.

Chapter five examines the critical role that Space-Borne Oscillators play in improving Performance of Satellite-Based Augmentation Systems and the strategic role of NIGCOMSAT-1R as a nascent African contribution to the Global Navigation Satellite System. Furthermore it shows externalized 10 MHZ Master Oscillators in 3 X 4 hybrid array configuration and the effectiveness of Location Based Services utilizing Navigation for Emergency and Crisis management amongst other applications.

In chapter six, the background and needs assessment of the National Public Security Communications System (NPSCS) is outlined. The system design of the NPSCS has a service-oriented architecture (SOA) that is integrated with the Nigerian Communications Satellite (NIGCOMSAT-1R). The technology review to reflect medium and long terms needs of the nation in terms of supporting broadband and higher throughput needs is presented. For long-term sustainability, the excess bandwidth capacity is utilised for Nigeria's national cashless policy implementation and thus a self-sustaining network is being created.

Chapter seven describes solutions, applications and services exploiting the Nigerian Communications Satellite (NIGCOMSAT-1R) and National Public Security Communications System (NPSCS). Also discussed is the growing penetration of communication satellite applications as well as an alternative to Digital Terrestrial Television in migration to digital broadcasting especially in Africa, Eastern & Central Europe and the Asia-Pacific as we move closer to the ITU deadline for Analogue Switch-Off (ASO) by June, 2015.

Chapter eight examines the role of Communication Satellite Systems and in particular the Nigerian Communications Satellite complemented by the National Public Security and Emergency Network as last mile wireless infrastructure to drive the National ICT revolution in pursuit of national e-readiness especially the national cashless policy implementation for a Knowledge-based economy to enable the socio-economic development of Nigeria, which in turn provides a self-sustaining demonstrator for the dedicated broadband-based National Public Security and Emergency Network. Utilization of scarce spectrum re-farmed from single channel Walkie-Talkie single channel analogue system of Public security Services (PSS) demonstrates without compromise of how such broadband-based network model effectively drive the universal access goals, without exclusivity, in a continent which still remains the least wired in the world. Nigeria's Cashless policy pilot project is a proof-of-concept driving financial and digital inclusion for all.

Finally, chapter nine gives conclusions, challenges/limitations, recommendations and future research works.

Some of the research work and experiential results have been presented and published in several conferences, international workshops and journals as listed in appendix F.

CHAPTER 2: Communication Satellite Technologies Supporting Broadband Applications And Rapid Deployment

2.0 Summary:

The continuously increasing demand for services provided by geostationary satellites requires a capable and enhanced satellite bus to support multi-mission communication satellites. The importance of optimizing the mass/volume ratio in efficient and advanced spacecraft in terms of mass, power, thermal and other requirements should not be underestimated. A global passive communication infrastructure remains an attractive method to meet communication market demand especially in areas with inadequate terrestrial telecommunication networks. There is an immediate requirement for advanced leading-edge spacecraft missions supporting telecommunications, broadcasting and navigational services, the systems deployed will complement terrestrial communication networks. Continuous increase in demand for services provided by geostationary satellites has challenged satellite system designers' ingenuity resulting in highly complex design requirements for communication satellite spacecraft, which require multi-transponders, multi-frequency, multi-polarization capability antennas for high capacity data communications. The dramatic increase in satellite communications capacity, capability and flexibility in recent times has been made possible through High Throughput Satellites (HTS).

This chapter investigates the present satellite technologies used in the current commercial satellite bus with the required advancement and innovations to meet increasing telecommunication, broadcasting and navigation service needs as well as enhanced service life time and capacity through systemic implementation of new technologies at unit, subsystem and the system level of a geostationary communication satellite.

2.1 Communications Satellite: Past, Present and Future.

The space age began with Russian launch of the first man-made satellite, SPUTNIK, on 4^{th} October, 1957(Drury, 1994). Tremendous changes in communication satellite technologies have evolved and blossomed over the years and remarkably two decades following the era of Comstar D1 and D2; RCA Americom's Satcom I and II, and Western Union's Westar I and II. (Morgan, 1997). The remarkable changes as noted by Morgan (1997) were transition from analogue to digital satellite transmissions, better coding and error corrections, optimized low noise devices and increase in transmitted satellite power levels with resultant reduction in customer premises dish (CPE) to as low as 45 centimeter, increased number of channels and throughput of transponders, use of higher frequency spectrum such as Ku and Ka band other than C-band, competitive cost of launch and launch vehicle innovations amongst others. The changes also include transition from purchase of whole satellite transponder for television broadcasting and and providing backup capacity for long-distance telephone traffic to fractionalized or bite-sized piece of transponders to give end users the required bandwidth for their services with a resultant explosive growth of communication satellite usage and Internet at a competitive prices (Primmer, 1998). Communication over satellites has been reliably complementing terrestrial networks to meet communication, broadcast and navigational needs of people across the world from the second half of the 20th century. Jakel (2000) referred to communication satellites as ageless bird in a particularly reference to Marisat F-2, which after 24 years of continued services got another one year contract with the U.S Navy Space and Naval Warfare Systems Center on behalf of USA-based National Science Foundation (NSF) for scientific use in the south pole. It is important to note that the design life of Marisat F-2; a geosynchronous and non-geostationary communications satellite launched in 1976 was five (5) years, yet it became ageless after being used for nearly five times its design lifetime. Where would some parts of the world be without earth station equipment as explicitly questioned by "show stoppers" (1997). Show stoppers went further to note that there is a relationship between satellite and terrestrial technologies as the integration of communications satellite and terrestrial technologies continues to grow spontaneously and simultaneously. The industry has over the years sustainably addressed the cost of acquisition of very small aperture terminal (VSAT) as the essential customer premises equipment for communications satellite connectivity with continued improvement of quality. The VSAT system, the mobile satellite telephony systems and the introduction of Ka-band high data and Internet system was a formidable combination for the satellite industry as well as its convergence and integration with telecommunications and terrestrial telecommunications networks. (Gifford, 1997). The age of computational plenty in science and technology is driving the revolution in the communications satellite industry with the advancement in super-fast microprocessors for computers, space technologies, high–tech electronics with fall outs in the form of numerous constellations of small, commercial, low-cost satellites amongst others.(Francis & Will, 1994). As a global utility, the Global Positioning System (GPS) offers users endless opportunities ranging from government; military to civil users with continuous improvement in accuracy of location-based applications especially air traffic control. (Francis & Will, 1994; Lawal & Chatwin, 2011).

It has helped catalyze and complement the modernization of a significant portion of networks in some parts of the world, especially Africa, raising tele-densities and broadband access across countries and borders through seamless integration with terrestrial networks. Satellite communication has its own vantage point in addressing effective universal access, accelerating cross border connectivity, broadcasting and provision of Internet access that overcomes the terrestrial limitation in a timely and effective manner.

Communications over satellite ensures that landlocked communities and nations are not isolated from the global economy and worldwide communications network growth(Stuart, 1997). Satellite system design engineers have continue to evolve an enhanced satellite bus with advanced broad-band based communication payloads to support not just broad-band capabilities but also advanced payload capabilities incorporating on-board switching techniques, multi-frequency, multi-polarization and multi-spot beams and large geographical coverage areas, reduced on-orbit cost per transponder, increased service capacity from a single orbital slot, implemented frequency reuse techniques and especially the utilization of the upper region of the satellite spectrum i.e Ka Band and extended orbital life.

The improvements in satellite technologies, efficiency techniques and methodologies for satellite appendage design, particularly solar arrays and antenna aperture and improved performance in energy/mass ratio of batteries including overall mass/volume optimization of communication satellites has resulted in high powered communication satellites with the capability to support several hundred transponders to meet the increasing market demands made on communication satellite resources for high-definition and digital 3D broadcasting, broadband communications and other satellite-based services. High satellite capacity – of the order of 100 Gbps coupled with multiple beams and multiple gateways, is already resulting in comparatively low cost satellite bandwidth. The adoption of High Throughput Satellite (HTS) systems has introduced a paradigm shift in satellite broadband access services and the satellite industry.

The multi-billion dollar communications satellite industry will continue to evolve with faster, high throughput and innovative systems far superior to the technologies of the 70’s, 80’s and 90’s; to meet the requirements of the modern digital economy. Recent examples are the High Throughput Satellites (HTS) and the next-generation satellite networks that are being deployed by O3B Networks enabled by the Ka-Band spectrum. The Ka-band spectrum is a new technology with new possibilities that allows transmission over a higher frequency spectrum range with frequency re-use up to six times using space diversity, whilst optimizing scarce space resources such as orbital slots and frequencies.

Such multi-mission spacecraft will build and promote connections across cities and underdeveloped countries to promote digital inclusion without exclusivity as it raises the ICT Development Index (IDI) of nations with inadequate terrestrial ICT infrastructure. The trend in the communications satellite industry shows no satellite nirvana any time soon as the industry continues to push the risk envelope. Marc Pierrat (Show Stoppers, 1997) sums it up best by saying it is an industry of risk takers. The possibilities seem endless with GPS and Communications satellite as the bond in global system of systems, vast network of networks as well as ensuring affordable universal coverage. Satellites especially the low earth orbit (LEO) and Medium Earth Orbit (MEO) satellites use the position location signal and the time signal from GPS for in-space navigation and satellite control (Francis & Will, 1994). The future of communications systems as expressed by Stuart (1997) lies in providing capacity at specific levels of quality of service (QoS) or quality of experience (QoE), not in the commodity transport of digital bits, which innovations and advancement in communications satellite systems tries to match in terms of capability, capacity as well as commercial structure of the new satellite communications systems. As Arthur C. Clarke who is the visionary father of satellite communication said, “The Future isn’t what it used to be.” Because, the horizon of the future widens with more knowledge and innovations (Cosper, 1997).

2.2 Communications Satellite Architecture and Communications

Typical communication satellite architecture is made up of the payload and its platform referred to as the satellite bus as illustrated in figure 2.1, with the sub-system made analogous to human body functions. The platform comprises of:

- Telemetry, Command and Ranging Subsystem (TC&R)
- Onboard Data Handling Subsystem (OBDH)
- Electrical Power Subsystem (EPS)
- Attitude and Orbit Control Subsystem (AOCS)
- Unified Propulsion Subsystem (UPS)
- Thermal Control Subsystem
- Structure Subsystem

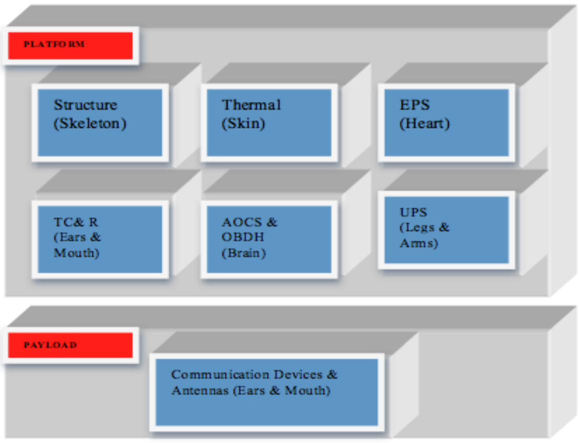


Figure 2.1: Analogy of a Typical Communication Satellite Architecture with the Human Body (Lawal, 2009).

The Payload comprises of:

- Repeater Subsystem (Transponder)
- Antenna Subsystem

The repeater subsystem of a communication satellite can be: transparent or provide signal amplification, frequency conversion, switching and processing via a series of communication devices such as filters, receiver, input multiplexer, high power amplifier, output multiplexer etc.

The antenna system is referred to as ears & mouth in analogy with the human body, as illustrated in figure 2.1. It is an energy transducer, which transforms guided electromagnetic signals into electromagnetic waves propagating in free space when it transmits, or transforms received electromagnetic waves into guided electromagnetic signals when it is used for reception.

The satellite bus provides the required platform for: power, mechanical strength, propulsion and thermally controlled environment so that the spacecraft can carry out its mission.

Figure 2.2 shows Nigeria's Communication Satellite (NIGCOMSAT-1R); a five (5) tonne high powered, quad-band satellite frequencies (C, Ku, Ka and L-band) COMSAT meant for telecommunications, broadcasting and navigation overlay services.

Figure 2.2 : Nigeria's Communication Satellite; NIGCOMSAT-1R.

The multi-disciplinary interest areas that have been investigated for the COMSAT subsystems are: repeater subsystem, antenna subsystem, propulsion subsystem, power subsystem, onboard data handling subsystem and attitude and orbit control subsystem. These sub-systems must be optimized to deliver the necessary functional performance requirements, processing capabilities with a standardized, cost-effective and advanced satellite bus. These technologies are described below:

2.2.1 Antenna Subsystem

Continuous increase in demand for services provided by geostationary communication satellites has challenged satellite system designers' ingenuity resulting in highly complex design requirements for communication satellite spacecraft, which require multi-transponders, multi-frequency, multi-polarization capability antennas for high capacity data communications and throughput. Such a high capacity requirement can only be delivered via innovative antenna design. The antenna is one of the most critical components in any radio frequency (RF) communication system, which is responsible for receiving and transmitting electromagnetic signals for broadcast, relay, communication and satellite control as illustrated in figure 2.1. The antenna performance plays an essential role in controlling the quality, quantity and continuity of data and information flow in all directions. The dramatic increase in satellite communications capacity, capability and flexibility in recent times has been made possible by improvements in technology and in the design, geometry and composition of antenna components both in the space and ground segments particularly in antenna system layouts of geostationary communication satellite platforms. The satellite antenna provides the vital link between the ground and the satellite in orbit, performing many more complex operations in today's high powered and high capacity satellites; such as: simultaneous reception and transmission of multi-band communication signals through multiple-antennas, rejection of interference from neighboring satellites and systems in both the space and terrestrial domains, maintaining accurate pointing and alignment between earth stations and the satellite, antenna pointing mechanisms (APM) to steer the satellite footprints to areas not initially designated (Lawal & Chatwin, 2012).

The main goal in antenna selection, amongst other requirements, is determining the optimal type and size of antenna needed in space systems, especially for Geo-Communication Satellites. The main constraints on antenna size are the weight and power requirements. Thus, load balancing and performance parameter trade-offs require a common level of understanding between system designers, system integrators, sub-system specialists, users and antenna suppliers. Antenna performance is of paramount importance in today's world of advanced communications satellite systems especially the High Throughput Satellites (HTS). The joint goal of system designers, integrators and other stakeholders are to maximize the performance standard of the total system whilst minimizing cost.

The main key factor in achieving high performance communication satellite system is attributable to advances in antenna technologies.

A variety of forms of antenna can be used for transmitting and receiving from/to a communication satellite. The actual type of antenna depends largely on the overall application and the mission requirements.

There is fundamentally no difference between the antennas on satellites and those on the ground, however; there are a number of different requirements that need to be taken into account for antenna space-based systems. Some of these are:

- Harsh space environmental conditions with varying temperature causing expansion and contraction.
- Limited power availability.
- Weight, Mass/Volume ratio limitation (Lawal & Chatwin, 2011b).
- Antenna earth coverage specification in relation to the required satellite service zones.
- Receive and transmit coverage area variations etc.

2.2.1.1 Satellite Antenna Design Stages and Factors

The satellite antenna design steps, *inter alia*, are:

- Consideration of the requirements of the electric and mechanical performance.
- Creation of a preliminary design based on comprehensive antenna knowledge and engineering experience of the space environment.
- Analyzing design performance in compliance with the required specifications using Computer Aided Designs (CAD) and Computer Aided Engineering (CAE). These utilize but are not restricted to: HFSS, POS4, GRASP, Nastran, TMD, etc.
- Optimization of the design via iteration using engineering analysis and prototyping.

2.2.1.2 The Factors that Determine the Type, Size, and Shape of the Satellite Antenna

In order to achieve a practical communication antenna design, system designers must consider the following factors:

- The operating frequency
- The radiated power (EIRP: Equivalent Isotropic Radiated Power)
- The radiation pattern
- Direction of Antenna
- The required polarisation
- The required Gain
- Cross Polarization Isolation (CPI) or Cross Polarization Discrimination (XPD)
- The maximum allowable VSWR
- Antenna composition
- Types of connector interface involved
- Power requirement of the antenna
- The mechanical structure
- Mounting and deployment
- Pointing mechanism and coverage
- Protection requirements.

2.2.1.3 Antenna System Layout in Geostationary Spacecraft.

Antenna System Layout (ASL) in geostationary spacecraft platform refers to the arrangement of the antenna subsystem on the West, East side and Earth deck of the spacecraft body in accordance with the principles of Antenna layout design. Figure 2.3 shows the in-orbit antenna layout configuration of the Nigerian Communication Satellite (NIGCOMSAT-1R) ready for the Compact Antenna Test Range (CATR). Table 2.1, 2.2 2.3 and 2.4 shows Uplink Polarization Verification, Downlink Polarization Verification, EIRP and G/T test results of Nigerian Communication Satellite (NIGCOMSAT-1R) Compact Antenna Test Range (CATR) . The test results meets performance requirements and serves as a good reference for validation and performance verification of the spacecraft during In-Orbit Test (IOT) after launch.

Figure 2.3: In-Orbit Antenna Layout configuration with deployed East and West Antenna of the NIGCOMSAT-1R in the Compact Antenna Test Range (CATR) Room (NIGCOMSAT-1R, 2009).

Table 2.1: *TEST RESULTS AND CONCLUSION OF NIGERIAN COMMUNICATION SATELLITE (NIGCOMSAT-1R) COMPACT ANTENNA TEST RANGE (CATR).*

Table 2.1: Uplink Polarization Verification of Antennas

No.	Config. No.	Config	Uplink Beam	Req.	Result	C/NC
1	10	KUWHR11L_C04T105KUWVP0_	ECOWAS1	H	H	C
2	30	KUEVR15L_C08T110KUEHP0_	ECOWAS2	V	V	C
3	59	KUKVR13L_C11T114KUKHP0_	KASHI	V	V	C
4	75	C__RR21L_C01T201C__LP0_	C	R	R	C
5	94	CL_LR32L2C01T301CL_RP0_	NAVI.	L	L	C
6	108	KANLR45L_C08T410KANRP0_	KA NIGERIA	L	L	C

Table 2.2: Downlink Polarization Verification of Antennas

No.	Config. No.	Config	Downlink Beam	Req.	Result	C/NC
1	10	KUWHR11L_C04T105KUWVP0_	ECOWAS1	V	V	C
2	30	KUEVR15L_C08T110KUEHP0_	ECOWAS2	H	H	C
3	59	KUKVR13L_C11T114KUKHP0_	KASHI	H	H	C
4	75	C__RR21L_C01T201C__LP0_	C	L	L	C
5	94	CL_LR32L2C01T301CL_RP0_	NAVI.	R	R	C
6	108	KANLR45L_C08T410KANRP0_	KA NIGERIA	R	R	C

Table 2.3: EIRP Transmit Antenna Pointing to Abuja Location (positioner) for all the Antenna Beams

Ku Band West Antenna (ECOWAS 1) Beam

No. of Config.	Config.	Beam	CH	UF (MHz)	DF (MHz)	EIRP Spec.	EIRP (dBW)	C/NC	App.
1	KUWHR11L_C01T101KUWVP0_	Ku-ECOWAS1	C01	14014.25	12514.25	52.60	54.23	C	Abuja
4	KUWHR11L_C02T103KUWVP0_	Ku-ECOWAS1	C02	14049.75	12549.75	52.60	53.93	C	Abuja
7	KUWHR11L_C03T104KUWVP0_	Ku-ECOWAS1	C03	14085.25	12585.25	52.60	53.87	C	Abuja
10	KUWHR11L_C04T105KUWVP0_	Ku-ECOWAS1	C04	14120.75	12620.75	52.60	53.85	C	Abuja
13	KUWHR11L_C05T107KUWVP0_	Ku-ECOWAS1	C05	14156.25	12656.25	52.60	54.20	C	Abuja
16	KUWHR11L_C06T108KUWVP0_	Ku-ECOWAS1	C06	14191.75	12691.75	52.60	54.22	C	Abuja
20	KUWHR11L_C07T109KUWVP0_	Ku-ECOWAS1	C07	14227.25	12727.25	52.60	54.16	C	Abuja
2	KUWHR11L_C01T106KUWVP1_	Ku-ECOWAS1	C01	14014	12514	53.73	53.89	C	Abuja

Ku Band East Antenna (ECOWAS 2) Beam

No. of Config.	Config.	Beam	CH	UF (MHz)	DF (MHz)	EIRP Spec.	EIRP (dBW)	C/NC	App.
30	KUEVR15L_C08T110KUEHP0_	Ku-ECOWAS2	C08	14014.25	12514.25	50.10	51.86	C	Abuja
34	KUEVR15L_C09T111KUEHP0_	Ku-ECOWAS2	C09	14049.75	12549.75	50.10	51.21	C	Abuja
38	KUEVR15L_C10T112KUEHP0_	Ku-ECOWAS2	C10	14085.25	12585.25	50.10	51.58	C	Abuja
41	KUEVR15L_C11T114KUEHP0_	Ku-ECOWAS2	C11	14120.75	12620.75	50.10	51.18	C	Abuja
44	KUEVR15L_C12T115KUEHP0_	Ku-ECOWAS2	C12	14156.25	12656.25	50.10	51.56	C	Abuja
47	KUEVR15L_C13T116KUEHP0_	Ku-ECOWAS2	C13	14191.75	12691.75	50.10	51.63	C	Abuja
50	KUEVR15L_C14T118KUEHP0_	Ku-ECOWAS2	C14	14227.25	12727.25	50.10	51.75	C	Abuja
31	KUEVR15L_C08T113KUEHP1_	Ku-ECOWAS2	C08	14014.25	12514.25	51.36	51.37	C	Abuja

Ku Band Kashi Antenna (ECOWAS 2) Beam

No. of Config.	Config.	Beam	CH	UF (MHz)	DF (MHz)	EIRP (dBW)	App.
59	KUKVR13L_C11T114KUKHP0_	Ku-KASHI	C11	14120.75	12620.75	58.17	KASHI
60	KUKVR13L_C12T115KUKHP0_	Ku-KASHI	C12	14156.25	12656.25	58.20	KASHI
61	KUKVR13L_C13T116KUKHP0_	Ku-KASHI	C13	14191.75	12691.75	58.11	KASHI
62	KUKVR13L_C14T118KUKHP0_	Ku-KASHI	C14	14227.25	12727.25	58.11	KASHI

C Band Antenna (ECOWAS 1) Beam

No. of Config.	Config.	Beam	CH	UF (MHz)	DF (MHz)	EIRP Spec.	EIRP (dBW)	App.	App.
75	C__RR21L_C01T201C__LP0_	C-ECOWAS1	C01	6463.90	3538.90	42.60	45.05	C	Abuja
78	C__RR21L_C02T203C__LP0_	C-ECOWAS1	C02	6503.90	3578.90	42.60	45.38	C	Abuja
81	C__RR21L_C03T204C__LP0_	C-ECOWAS1	C03	6543.90	3618.90	42.60	45.48	C	Abuja
84	C__RR21L_C04T206C__LP0_	C-ECOWAS1	C04	6583.90	3658.90	42.60	45.35	C	Abuja
76	C__RR21L_C01T202C__LP1_	C-ECOWAS1	C01	6463.90	3538.90	44.65	44.65	C	Abuja
82	C__RR21L_C03T205C__LP1_	C-ECOWAS1	C03	6543.90	3618.90	45.08	45.16	C	Abuja

Ka Band Antenna Nigerian Spot Beam

No. of Config.	Config.	Beam	CH	UF (MHz)	DF (MHz)	EIRP Spec.	EIRP (dBW)	C/NC	App.
105	KANLR45L_C06T407KANRP0_	KaN	C06	29619	19819	55.00	57.96	C	Peak
106	KANLR45L_C06T408KANRP1_	KaN	C06	29619	19819	57.61	58.10	C	Peak
107	KANLR45L_C06T406KANRP2_	KaN	C06	29619	19819	57.71	57.92	C	Peak
108	KANLR45L_C08T410KANRP0_	KaN	C08	29919	20119	55.00	58.08	C	Peak
109	KANLR45L_C08T408KANRP1_	KaN	C08	29919	20119	57.73	57.76	C	Peak
110	KANLR45L_C08T409KANRP2_	KaN	C08	29919	20119	57.83	57.98	C	Peak
117	KASLR41L_C04T405KANRP0_	KaN	C04	29319	19519	53.50	57.80	C	Peak
118	KASLR41L_C04T403KANRP1_	KaN	C04	29319	19519	57.45	57.53	C	Peak
122	KAELR43L_C05T406KANRP0_	KaN	C05	29469	19669	53.50	57.78	C	Peak
125	KAELR43L_C07T409KANRP0_	KaN	C07	29769	19969	53.50	57.94	C	Peak

Ka Band Antenna European Spot Beam

No. of Config.	Config.	Beam	CH	UF (MHz)	DF (MHz)	EIRP Spec.	EIRP (dBW)	C/NC	App.
96	KANLR45L_C01T401KAERP0_	KaE	C01	28869	19069	53.50	57.28	C	Peak
99	KANLR45L_C02T402KAERP0_	KaE	C02	29019	19219	53.50	57.61	C	Peak
97	KANLR45L_C01T403KAERP1_	KaE	C01	28869	19069	56.93	57.38	C	Peak

Ka Band Antenna South African Spot Beam

No. of Config.	Config.	Beam	CH	UF (MHz)	DF (MHz)	EIRP Spec.	EIRP (dBW)	C/NC	App.
102	KANLR45L_C03T404KASRP0_	KaS	C03	29169	19369	53.5	57.16	C	Peak
103	KANLR45L_C03T403KASRP1_	KaS	C03	29169	19369	56.81	57.05	C	Peak
104	KANLR45L_C03T405KASRP2_	KaS	C03	29169	19369	56.91	57.06	C	Peak

L Band (Navigation) Antenna Beam

No. of Config.	Config.	Beam	CH	UF (MHz)	DF (MHz)	EIRP (dBW)	App.
90	CL_LR31L1C01T301CL_RP0_	NAVI.	C01	6697.95	1574.95	31.53	Abuja
92	CL_LR33L1C05T303CL_RP0_	NAVI.	C05	6639.10	1176.1	30.28	Abuja
91	CL_LR31L1C01T302CL_RP1_	NAVI.	C01	6697.95	1574.95	31.27	Abuja
93	CL_LR33L1C05T304CL_RP1_	NAVI.	C05	6639.10	1176.1	30.10	Abuja

Table 2.4: Corresponding G/T Receive Antenna Pointing to Abuja Location (positioner) for all the Antenna Beams.

Ku Band West Antenna (ECOWAS 1) Beam

No. of Config.	Config.	Beam	CH	UF (MHz)	DF (MHz)	G/T Spec.	G/T (dB/K)	C/NC	App.
1	KUWHR11L_C01T101KUWVP0_	Ku-ECOWAS1	C01	14014.3	12514.3	6.40	9.53	C	Abuja
10	KUWHR11L_C04T105KUWVP0_	Ku-ECOWAS1	C04	14120.8	12620.8	6.40	9.55	C	Abuja
20	KUWHR11L_C07T109KUWVP0_	Ku-ECOWAS1	C07	14227.3	12727.3	6.40	9.44	C	Abuja
24	KUWHR12L_C01T101KUWVP0_	Ku-ECOWAS1	C01	14014.3	12514.3	9.33	9.56	C	Abuja
25	KUWHR12L_C04T105KUWVP0_	Ku-ECOWAS1	C04	14120.8	12620.8	9.35	9.74	C	Abuja
26	KUWHR12L_C07T109KUWVP0_	Ku-ECOWAS1	C07	14227.3	12727.3	9.24	9.74	C	Abuja

Ku Band East Antenna (ECOWAS 2) Beam

No. of Config.	Config.	Beam	CH	UF (MHz)	DF (MHz)	G/T Spec.	G/T (dB/K)	C/NC	App.
30	KUEVR15L_C08T110KUEHP0_	Ku-ECOWAS2	C08	14014.3	12514.3	2.40	4.59	C	Abuja
41	KUEVR15L_C11T114KUEHP0_	Ku-ECOWAS2	C11	14120.8	12620.8	2.40	4.36	C	Abuja
50	KUEVR15L_C14T118KUEHP0_	Ku-ECOWAS2	C14	14227.3	12727.3	2.40	4.13	C	Abuja
53	KUEVR14L_C08T110KUEHP0_	Ku-ECOWAS2	C08	14014.3	12514.3	4.39	4.68	C	Abuja
54	KUEVR14L_C11T114KUEHP0_	Ku-ECOWAS2	C11	14120.8	12620.8	4.16	4.17	C	Abuja
55	KUEVR14L_C14T118KUEHP0_	Ku-ECOWAS2	C14	14227.3	12727.3	3.93	4.53	C	Abuja

Ku Band Kashi Antenna (ECOWAS 2) Beam

No. of Config.	Config.	Beam	CH	UF (MHz)	DF (MHz)	G/T Spec.	G/T (dB/K)	C/NC	App.
59	KUKVR13L_C11T114KUKHP0_	Ku-KASHI	C11	14120.8	12620.8	\	11.86	\	KASHI
62	KUKVR13L_C14T118KUKHP0_	Ku-KASHI	C14	14227.3	12727.3	\	11.95	\	KASHI
63	KUKVR12L_C11T114KUKHP0_	Ku-KASHI	C11	14120.8	12620.8	11.66	11.70	C	KASHI
64	KUKVR12L_C14T118KUKHP0_	Ku-KASHI	C14	14227.3	12727.3	11.75	12.22	C	KASHI

C Band Antenna (ECOWAS 1) Beam

No. of Config.	Config.	Beam	CH	UF (MHz)	G/T Spec.	G/T (dB/K)	C/NC	App.
75	C__RR21L_C01T201C__LP0_	C-ECOWAS1	C01	6463.9	3.20	4.35	C	Abuja
84	C__RR21L_C04T206C__LP0_	C-ECOWAS1	C04	6583.9	3.20	5.36	C	Abuja
87	C__RR22L_C01T201C__LP0_	C-ECOWAS1	C01	6463.9	4.35	4.49	C	Abuja
89	C__RR22L_C04T206C__LP0_	C-ECOWAS1	C04	6583.9	5.36	5.38	C	Abuja

Ka Band Antenna Nigerian Spot Beam

No. of Config.	Config.	Beam	CH	UF (MHz)	G/T Spec.	G/T (dB/K)	C/NC	App.
96	KANLR45L_C01T401KAERP0_	KaN	C01	28869	12.00	13.87	C	PEAK
102	KANLR45L_C03T404KASRP0_	KaN	C03	29169	12.00	14.11	C	PEAK
108	KANLR45L_C08T410KANRP0_	KaN	C08	29919	12.00	14.30	C	PEAK
111	KANLR44L_C01T401KAERP0_	KaN	C01	28869	13.77	14.59	C	PEAK
112	KANLR44L_C03T404KASRP0_	KaN	C03	29169	14.01	14.61	C	PEAK
113	KANLR44L_C08T410KANRP0_	KaN	C08	29919	14.20	14.66	C	PEAK
116	KANLR43L_C08T410KANRP0_	KaN	C08	29919	14.20	14.21	C	PEAK

Ka Band Antenna European Spot Beam

No. of Config.	Config.	Beam	CH	UF (MHz)	DF (MHz)	EIRP Spec.	EIRP (dBW)	C/NC	App.
96	KANLR45L_C01T401KAERP0_	KaE	C01	28869	19069	53.50	57.28	C	Peak
99	KANLR45L_C02T402KAERP0_	KaE	C02	29019	19219	53.50	57.61	C	Peak
97	KANLR45L_C01T403KAERP1_	KaE	C01	28869	19069	56.93	57.38	C	Peak

Ka Band Antenna South African Spot Beam

No. of Config.	Config.	Beam	CH	UF (MHz)	G/T Spec.	G/T (dB/K)	C/NC	App.
117	KASLR41L_C04T405KANRP0_	KaS	C04	29319	12.00	14.61	C	PEAK
120	KASLR42L_C04T405KANRP0_	KaS	C04	29319	14.51	15.43	C	PEAK

L Band (Navigation) Antenna Beam

No. of Config.	Config.	Beam	CH	UF (MHz)	G/T (dB/K)	App.
90	CL_LR31L1C01T301CL_RP0_	NAVI.	C01	6697.95	-8.79	Abuja
92	CL_LR33L1C05T303CL_RP0_	NAVI.	C05	6639.10	-9.36	Abuja
94	CL_LR32L2C01T301CL_RP0_	NAVI.	C01	6697.95	-8.98	Abuja
95	CL_LR34L3C05T303CL_RP0_	NAVI.	C05	6639.10	-9.62	Abuja

The antenna layout design in geostationary spacecraft considers the following factors:

- Antenna Size.
- Field of view of each antenna
- Better isolation between receiving and transmitting signals which optimizes performance with greater value of Cross Polarization Isolation(XPI) or Cross Polarization Discrimination (XPD). The XPI performance analysis requirements of Nigerian Communications Satellite (NIGCOMSAT-1R) service antennas are expected

to be 27dB or more for optimal performance of NIGCOMSAT-1R with effective service delivery and services. Table 2.5, 2.6, 2.7 and 2.8 shows specified City XPI Analysis of Ku-Band ECOWAS 1 Beam, Ku- Band ECOWAS 2 Beam and C-Band ECOWAS 1 Beam respectively.

- Connections with repeater devices
- Mass of Antenna
- Desired ground coverage area.
- Degrees of freedom of antenna pointing mechanisms (APM) and Antenna Hold and Release Mechanisms (HRM).
- Composition and geometry of the antenna system i.e arrangement of antenna main reflectors, sub reflector, feed assembly, Antenna Deployment Mechanism (ADM), Hold Down Release Mechanism (HRM) etc as illustrated in figure 2.4.

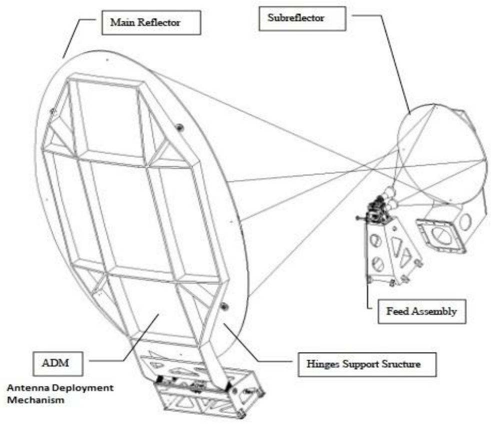


Figure 2.4: Composition and Geometry of deployable West Antenna of Nigerian Communications Satellite (NIGCOMSAT-1R). (NIGCOMSAT-1R, 2009).

- Complexity of Antenna main reflectors i.e curled stowed or mounted on the Earth deck such that electromagnetic compatibility is optimized. Figure 2.5 shows the Nigerian Communications Satellite with the stowed main antenna reflector in preparation for launch.

Table 2.5: The XPI Performance Analysis Requirements of Nigerian Communications Satellite (NIGCOMSAT-1R) Service Antennas.

Item			Analysis (dB)	Requirement (dB)	Margin (dB)
West Antenna	Uplink		≥30	≥30	0
	Downlink		≥30	≥30	0
East Antenna	Uplink		≥30	≥30	0
	Downlink		≥30	≥30	0
C-band Communications Antenna	Uplink	80% Zone	≥31.8	≥30	1.8
		100% Zone	≥30.3	≥27	3.3
	Downlink	80% Zone	≥32	≥30	2
		100% Zone	≥29	≥27	2
Ka-band Receiving Antenna	Uplink	Europe	≥29	≥28	1
		Nigeria	≥29	≥28	1
		South Africa	≥29	≥28	1
Ka-band Transmitting Antenna	Downlink	Europe	≥29	≥28	1
		Nigeria	≥29	≥28	1
		South Africa	≥29	≥28	1
C-band Navigation Antenna	Uplink	C1	≥32	≥27	5
		C5	≥29	≥27	2

Table 2.6:Specified City XPI Analysis of Ku-Band ECOWAS 1 Beam

No.	City	ECOWAS 1(Uplink)			ECOWAS 1(Downlink)		
		XPI(dB)	Requirement(dB)	Margin(dB)	XPI(dB)	Requirement(dB)	Margin(dB)
1	Lagos	33	32	1	35	34	1
2	Kano	30.3	30	0.3	34	33	1
3	Zaria	30.6	30	0.6	35	32.8	2.2
4	Kaduna	30.5	30	0.5	35	33.1	1.9
5	Maiduguri	30.3	29.7	0.6	30	30	0
6	Bauchi	31	30	1	35	32.9	2.1
7	Sokoto	30	30	0	34	33	1
8	Ogbomosho	32	31	1	34	33	1
9	Ibadan	32	31	1	35	34	1
10	P.Harcourt	31	30	1	36	34.8	1.2
11	Bamako	30.5	30	0.5	35	33	2
12	Niamey	30.2	29.5	0.7	34	33	1
13	Dakar	30	30	0	32	30	2
14	Bissau	31.5	30.5	1	32	31	1
15	Conakry	33	32	1	32	31	1

No.	City	ECOWAS 1(Uplink)			ECOWAS 1(Downlink)		
		XPI(dB)	Requirement(dB)	Margin(dB)	XPI(dB)	Requirement(dB)	Margin(dB)
16	Freetown	34.5	33	1.5	34	33	1
17	Monrovia	32.0	31	1	35	32.1	2.9
18	Abidjan	30.5	30	0.5	34	33	1
19	Libreville	30.1	29.4	0.7	34	32.8	1.2
20	Accra	30.5	30	0.5	34	33	1
21	Lome	33.5	32.5	1	34	33	1
22	Novo	34	33	1	35	34	1
23	Yaounde	30.5	30	0.5	32	30.3	1.7
24	Ouagadougou	30.3	29.3	1	35	32.3	2.7
25	Fort-Lamy	30.5	30	0.5	31	30	1
26	Kinshasa	30.5	30	0.5	32	30	2
27	Abuja	33.5	33.5	0	36	36	0
28	Kogi	30.0			32		

Table 2.7: Specified City XPI Analysis of Ku-Band ECOWAS 2 Beam

No.	City	ECOWAS 2(Uplink)			ECOWAS 2(Downlink)		
		XPI(dB)	Requirement(dB)	Margin(dB)	XPI(dB)	Requirement(dB)	Margin(dB)
1	LAGOS	32.5	31.5	1	33	32	1
2	Kano	30	29.5	0.5	31	30	1
3	Zaria	30.5	30	0.5	31.8	30.8	1
4	Kaduna	30	30	0	32	31.5	0.5
5	Maiduguri	30	29.5	0.5	30.4	30	0.4
6	Bauchi	30	29.5	0.5	31.5	30.5	1
7	Ogbomosho	32	31	1	34	33	1
8	Ibadan	32	31	1	34.5	33	1.5
9	P.Harcourt	32	31	1	31.5	30.5	1
10	Novo	33	32	1	35	33	2
11	Yaounde	31	30	1	33.5	32.5	1
12	Libreville	33	32	1	32.5	32.5	0
13	Fort-Lamy	30	29	1	30.1	30	0.1
14	Bangui	31.5	30.5	1	33	32	1
15	Kinshasa	31	30	1	31.5	30	1.5
16	Pt. Noire	34.5	33	1.5	35	33	2
17	Luanda	34	33	1	36	34	2
18	Lusaka	32.5	31.5	1	30.3	29.5	0.8
19	Bulawayo	31.5	30.5	1	30.1	28.5	1.6
20	Kanye	30	29	1	30.1	28.5	1.6
21	Windhoek	32	31	1	30.8	29.5	1.3
22	Abuja	31	30.5	0.5	33.5	33	0.5
23	Kogi	30			30		

Table 2 8: Specified City XPI Analysis of C-Band ECOWAS 1 Beam

No.	City	ECOWAS 1(Uplink)			ECOWAS 1(Downlink)		
		XPI(dB)	Requirement(dB)	Margin(dB)	XPI(dB)	Requirement(dB)	Margin(dB)
1	Lagos	33.94	32.5	1.44	32.65	30	2.65
2	Kano	32.68	31.5	1.18	33.85	31	2.85
3	Zaria	32.68	31.6	1.08	33.65	31	2.65
4	Kaduna	32.69	32.5	0.19	33.35	31	2.35
5	Maiduguri	32.6	31.4	1.2	32.95	31	1.95
6	Bauchi	32.36	31.3	1.06	32.85	31	1.85
7	Sokoto	32.11	31	1.11	35.82	31	4.82
8	Ogbomosho	33.46	32	1.46	32.65	31	1.65
9	Ibadan	33.82	32.3	1.52	32.65	30	2.65
10	P.Harcourt	33.29	32	1.29	32.15	30	2.15
11	Bamako	33.97	32.5	1.47	35.75	32	3.75
12	uagadougou	32.77	32	0.77	36.85	32	4.85
13	Niamey	31.91	31.8	0.11	36.55	31	5.55
14	Dakar	32.38	31	1.38	31.25	30	1.25
15	Bissau	33.18	32	1.18	33.15	33	0.15
16	Conakry	33.73	32.1	1.63	32.35	32	0.35
17	Freetown	33.94	32.6	1.34	32.05	31	1.05
18	Monrovia	33.73	32.1	1.63	31.65	31	0.65
19	Abidjan	34.81	33	1.81	32.15	31	1.15
20	Accra	34.86	33	1.86	32.35	30	2.35
21	Lome	34.55	33	1.55	32.65	30	2.65
22	Novo	34.15	33	1.15	32.65	30	2.65
23	Nouakchott	30.8	30.8	0	27.65	27	0.65
24	Tinbuktu	30.99	30.9	0.09	35.75	32	3.75
25	Zinder	32.79	31.2	1.59	35.52	31	4.52
26	Yaounde	32.78	31	1.78	32.45	29	3.45
27	Bangui	33.33	32	1.33	31.35	29	2.35
28	Fort-Lamy	32.82	31.3	1.52	32.85	31	1.85
29	Khartoum	30.6	30	0.6	30.85	29	1.85
30	Adis Ababa	29.95	29.9	0.05	30.65	29	1.65
31	Nairobi	29.7	29.7	0	27.85	27	0.85
32	Kampala	30.12	30	0.12	29.45	29	0.45
33	Kigali	31.66	30	1.66	30.55	29	1.55
34	Bujumbura	32.93	31.3	1.63	31.65	30	1.65
35	Mwanza	30.53	30	0.53	29.65	29	0.65
36	Kisangani	35.52	33	2.52	30.65	29	1.65

Figure 2.5: Shows Stowed Main Antenna Reflector of the Nigerian Communications Satellite Spacecraft (NIGCOMSAT-1R) during the Launch Campaign. (NIGCOMSAT-1R, 2009).

Antenna System Layout and geometry has helped immensely in the realization of wideband, high throughput communication satellites and satellite communications - through frequency-reuse using space diversity and antenna diversity in high frequency bands such as the Ka-band with spot beam coverage making more usable communication bandwidth available and over a wide area.

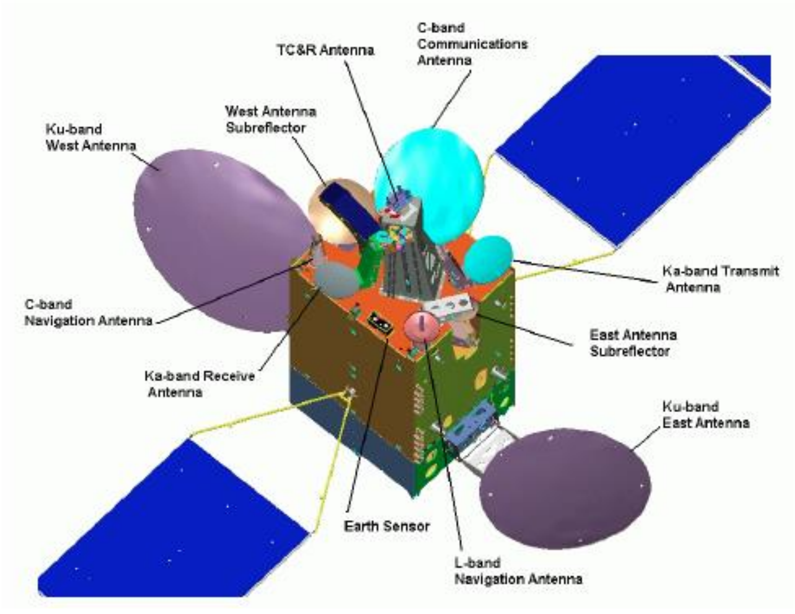


Figure 2.6: Antenna System Layout of NICOMSAT-1R on L, C, Ku and Ka Band (NIGCOMSAT-1, 2005).

Examples of modern satellites with optimized antenna system design layout to support high throughput links and wideband communications are the Wideband Global Satcom (WGS) series initiated by United States Department of Defense, High Throughput Satellites (HTS) series i.e

Viasat-1, Ka-Sat, Jupiter-1 and NIGCOMSAT-1R satellite. Figure 2.6 illustrates the layout of 7 antenna systems on the NICOMSAT-1R satellite on Ku, C, Ka and L band.

Antenna System layout has helped immensely in independent digital channelization and routing of communications geographically using Space-based routers with the required Internet Routing in Space (IRIS - CISCO) Payload Architecture (Intelsatgeneral, 2009).

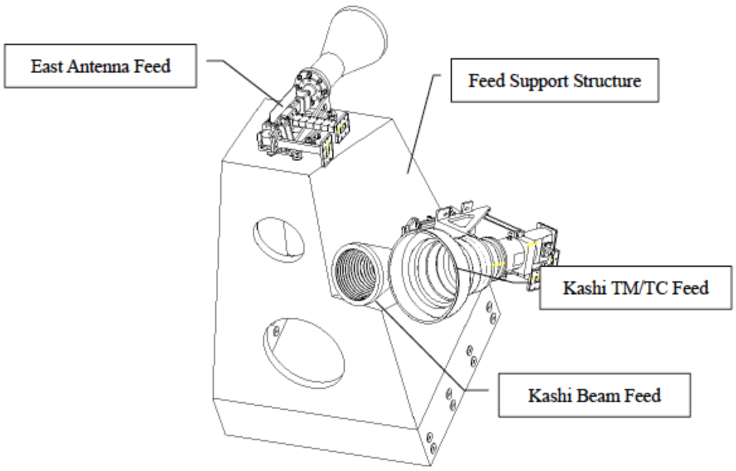


Figure 2.7: Dual feed arrangement on feed support structure of NIGCOMSAT-1R East Ku Antenna providing zonal beam coverage to the East African region using East Antenna Feed and part of Asia using Kashi Beam Feed (NIGCOMSAT-1R, 2009).

The typical antenna system layout in figure 2.4 was geometrically arranged, illuminated and optimized, such that the dual feed as illustrated in figure 2.7 provides two zonal coverages as shown in figures 2.8 and 2.9; covering the East African region and Part of Asia. This was achieved with a minimal antenna size delivering the required field of view using the feed geometry arrangement illustrated in the feed support structure of figure 2.7. The connectors were located in close proximity to the repeater device, which reduced signal attenuation due to cable and waveguide lengths. The design optimized electromagnetic compatibility to ensure isolation of the receive and transmit signals to minimize electromagnetic interference. The mass of the antenna and its support structure were minimized.

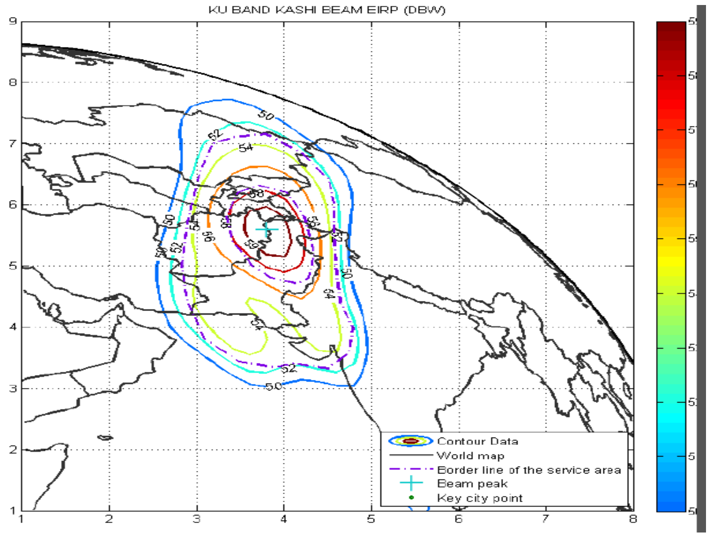


Figure 2.8: Ku band Asian Beam Coverage of the NIGCOMSAT-1R satellite using the Antenna system geometry illustrated in figure 2.4 and 2.7. (NIGCOMSAT-1R, 2009).

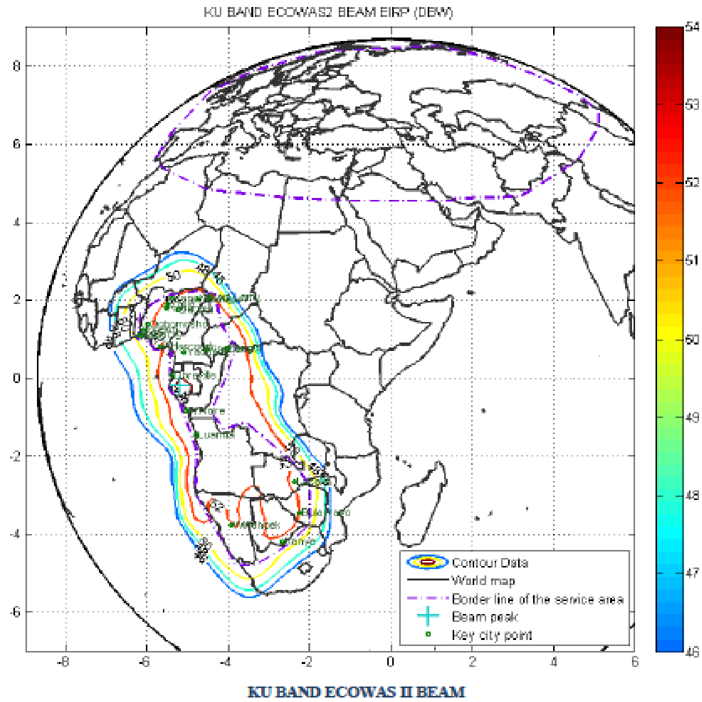


Figure 2.9: Ku band East African Beam Coverage of NIGCOMSAT-1R satellite using the Antenna system geometry illustrated in figure 2.4 and 2.7 (NIGCOMSAT-1R, 2009).

NIGCOMSAT-1R as shown in figure 2.5 is a high power quad-band geostationary communication satellite designed with more than a 15-year service life; it is based on the Chinese DFH-4 satellite bus platform with a launch mass of 5080kg. The 9kW (BOL) satellite with Ku, Ka, C and L-band is a critical ICT backbone element of the global infrastructure meant to drive Nigeria's National ICT revolution by providing revenue diversification for the Nation and offering a cost effective solution with affordable ICT access to meet Nigeria's telecommunications, broadcast, aviation, maritime, defense and security needs and Africa in general.

Antenna system layout methodologies supports antenna designs and configurations on advanced high capacity spacecraft with the goal of providing multi-frequency, multi-polarization and multi spot beams such that the bandwidth flexibility, high throughput communication links, area coverage and EMC compatibility of the antenna systems are optimized whilst also minimizing cost. (Lawal & Chatwin, 2012).

Use of improved multibeam antennas and applications of digital signal processing on the communication satellite payload to help provide better broadband capabilities and enhanced bit-error-rate (BER) performance including frequency re-use using polarization and space diversity. In recent years, optimization of satellite bandwidth and high data rate transmission were enhanced on COMSAT with the Ka band through frequency reuse over multiple antenna spot beams spatially separated but with overlapping coverage areas which are ideal and effective for connecting lowly populated areas that are geographically separated.

Enhanced use of gimbaled antenna pointing mechanism (APM), precise shape-beam antennas coupled with onboard switching and processing capabilities to provide flexible, reconfigurable and processed transponders thus helping the satellite to provide telecommunication services outside their primary coverage areas to hot spots such as places devastated by an: earthquake, war, undersea cable disruption or big sporting events with an optimum return on investment (ROI). (Lawal & Chatwin, 2010).

2.2.2 Repeater Subsystem

Use and application of Micro-Electro-Mechanical systems (MEMs) in radio frequency switches and filters for channelization, multiplexing and demultiplexing of radio frequency signals results in drastic reduction in mass, volume and power requirement of the repeater subsystem with enhanced RF performance and reduced RF power and insertion loss (Nguyen, Katehi, & Rebiez, 1998). High packaging density of RF devices, switches and amplifiers, use of high temperature super conducting materials (HTS) for filters, input multiplexers (IMUX) etc, radiation hardened and advanced Monolithic Microwave Integrated Circuits (MMICs) with multi-layers, development of high power, temperature compensated cavity filters for output multiplexers (OMUX) should be tested as a piggy-back payload onboard a COMSAT, this will play an important role in the miniaturization of active and passive RF components of the repeater subsystem as we evolve towards a promising new generation of small communication transponders with a smaller form factor, low insertion loss, low power consumption, lower mass and most importantly adaptation for space-based applications through improved stability and radiation-hardened technology. Such advanced technologies will deliver delay-tolerant and secure virtual networks in real time (Ivancic, Et al, 2005). through implementation of onboard routers to support routing of voice, video and data communications to multiple areas in one-hop will expand networking capabilities and broadband services worldwide. On 18th January, 2010, Cisco announced successful in-orbit test of Its Internet Routing in Space (IRIS) technology which was deployed on the IS-14 satellite launched on Nov.23, 2009. This underscores the importance of the deployment of Internet Protocl (IP) routers aboard geostationary satellites.

2.2.3 Enhanced Payload Components and Subsystem Layout Designs

Multi-band support through effective layout configuration of RF devices and equipment on the communication module of a geo-stationary satellite using computer aided software analyzers to enhance Electromagnetic Compatibility (EMC), RF power loss minimization, eliminating Electromagnetic Interference (EMI) to the barest minimum. Optimized redundancy switches and network designs of either transparent or processed transponders also improves RF performance.

Optimization and enhancing the capability of the COMSAT bus platform could also be achieved through implementation of the following advanced technologies at subsystem levels:

2.2.4 On Board Data Handling Subsystem (OBDH)

MIL-STD was developed on shared bus topology and has been in use for application in military aircraft and control of spacecraft's onboard communications and data handling. Its reliability, fault tolerance and simple bus configuration endeared it to system designers for adoption. However, it has limitations especially support for high data rates in real-time. Use of radiation hardened Field Programmable Gate Array (FPGA) devices and SpaceWire bus standardized by the European Space Agency (ESA) (Klar, Mangels, Dykes, & Brysch, 2008) to replace legacy communication technologies such as the MIL-STD-11553B and RS-422 will enhance high speed communications, facilitate the use of intelligent software control, autonomous management and low power consumption. Xilinx recently launched Xilinx Virtex® 5QV FPGA; a high density radiation hardened reconfigurable FPGA for space applications (Bruce, 2010).

2.2.5 Unified Propulsion Subsystem (UPS)

Use of plasma (Electric) Thrusters against traditional use of bi-propellant chemical based thruster lowers propellant mass requirements for the spacecraft mission and gives higher efficiency. NIGCOMSAT-1R uses a liquid bipropellant Mono Methyl Hydrazine (MMH) and Nitrogen Tetroxide (MON-1) in a pressure-fed system. The use of a plasma (electric) thruster as part of propulsion system will generate high exhaust velocities (specific impulses) with higher efficiency (through gas ionization and plasma charged particle acceleration method*)* than those reached by chemical propulsion system. It is of interest to note that the propellant mass of most geostationary satellites constitute between 55%-65% of the total mass of a COMSAT spacecraft.

Implementation of an advanced xenon ion propulsion system (XIPS), pioneered by Boeing in its 702 satellite bus, increases the efficiency of its platform in terms of prolonged service life, weight savings, satellite mass, power and marginal cost savings.

The use of electrical power for propulsion, Orbit raising and De-orbiting after end of life (EOL) reduces the mass of propellant budget required for mission life; facilitating additional mass for payload components, additional power subsystem mass requirements and other subsystems for advanced spacecraft (Lawal, 2009; Lawal & Chatwin, 2010;2011).

2.2.6 Structure/Mechanical Subsystem

Use of enhanced materials through advanced manufacturing processes, digital simulation using computer aided design and engineering to optimally modularize subsystem layouts with consideration for thermal engineering, concurrent assembly, integration and test operations (AIT) while reducing development cycle time and fortifying the spacecraft against harsh space environment. For instance, Astrium in recent times used Siemens' femap software with other Computer Aided Engineering software (CAE) to extensively iterate the process of creating, checking and viewing bus models while exploring alternatives of complex subsystem interactions within a concurrent engineering environment used on Astrium's newer and enhanced Eurostar family, the E3000 satellite (Nicholas, 2010).

2.2.7 Electrical Power Subsystem (EPS)

Increasing demands for broadband services from Geostationary Communication Satellites (GCS) and the high power requirements of high definition and 3D-TV digital broadcasting and increasing communication spectrum demands have resulted in a major increase in GCS power requirements. This stems from power hungry repeater components, heat rejection requirements of the high power amplifiers, large mass and the advanced designs required for satellite appendages such as antennas and solar arrays for admissibility of the spacecraft within the launch vehicle envelope and capability. This section examines the methodologies and technologies that support advanced modular power technologies for large spacecraft power subsystems and the importance of improvements in solar cell technology, energy/mass ratio, improved battery technologies and other power sub-system units and equipment optimised via integrated systems engineering processes.

2.2.7.1 Background of Spacecraft Power Systems

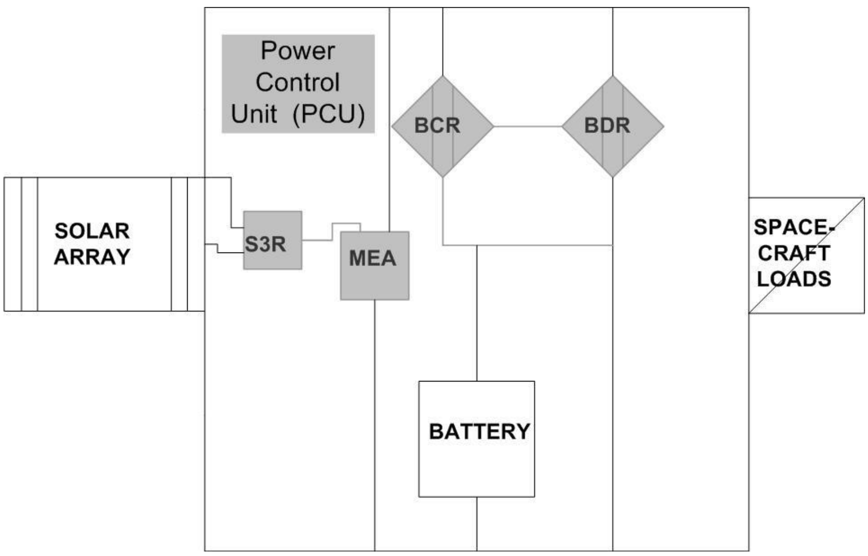
All satellites whether scientific, military, communication or observation must be equipped with suitable and reliable electrical power for its equipment and various sub-systems if it is to succeed in its mission. The Electrical Power Supply (EPS) is an essential and necessary subsystem in any spacecraft system and consists of all the required on-board hardware and software necessary to generate, store, convert, condition and distribute electrical power reliably and safely as required by all on-board equipment during all phases of the spacecraft mission. Development of the power systems and technologies for a spacecraft mission including manned space missions to the moon has evolved over five decades and developed rapidly using increasingly advanced technologies for sophisticated space missions. The mission type determines the suitable energy source, performance, lifetime, volume, mass and efficiency. One of the basic functions of the EPS is to convert: light energy, nuclear energy or chemical energy into electrical energy by means of physical or chemical changes and then store, regulate and convert the electrical energy in accordance with the spacecraft specifications and requirements.

Of all power sources, the most suitable for geostationary satellites within the solar system is the photovoltaic system, which converts solar energy to electrical energy using solar panel arrays to charge regulated battery systems. Power is provided to the satellite through solar arrays during sunlight and batteries during eclipse.

Generally, over 90% of spacecrafts adopt the solar array-battery systems. Solar array-battery unified electrical power system provides clean, safe and reliable electrical energy for geostationary satellites.

The satellite electrical power system hardware configuration is typically composed of: electrical power source, power control unit, power conversion unit, power distribution unit and electrical harness.

A Solar Array-battery unified electrical power system as illustrated in Figure 2.10; can provide reliable, clean and safe electrical energy to geostationary satellites with a deployable solar array oriented about one or more axes to maximize energy collection from the sun with various designs in terms of regulation mode and bus voltage dependent on bus platform, manufacturers technology and spacecraft design architecture.



PCU: Power Control Unit

BCR: Battery Charge Regulator

BDR: Battery Discharge Regulator

S3R: Sequential Switching Shunt Regulator

MEA: Main Error Amplifier

Figure 2.10: Typical Diagram of Solar Array-Battery Unified Electrical Power System.

Typically sketched in Figure 2.10 and as may be found on some geo-communication satellites, power is provided during sunlight operation by the use of photovoltaic solar cells mounted on two deployable, independently steerable solar array wings. The power from each array is supplied to the spacecraft body via a Solar Array Drive Assembly (SADA), which contains the necessary power and signal slip rings. The two SADA mechanisms are respectively controlled by dedicated SADA Electronics (SADAE). Through the SADA mechanism, power is transmitted to the Power Control Unit (PCU) and the Sequential Switching Shunt Regulator (S3R) which resides inside the PCU. The S3R is fully controlled by a reliable main error amplifier (MEA) and performs solar array power regulation and controls the voltage regulated power bus. The PCU also contains the Battery Discharge Regulators (BDR) for discharge of power during eclipse or low solar power conditions and the Battery Charge Regulators (BCR) to charge the battery during sunlight conditions

2.2.7.2 Technology Design Development to meet High Power Requirements Of A Modern Communication Satellites

Current trends in the design requirements of communications satellites, especially commercial satellites, to meet the growing demands of broadband internet services, high definition TV and 3D-TV digital broadcasting has continually challenged satellite system design engineers in stretching the power capability and capacity of the satellite bus to meet the payload power requirements of its high power amplifiers and related components. Satellite EPS design is an important facilitating element of all communication satellites. EPS design and manufacture necessitate high quality, reduced weight, performance compliances, interfaces with other system and devices, advanced thermal design, EMC design, reliability design, test requirements etc.

Over the decades, System designers have always used modern science and the technological achievements of research and development and systems engineering practice to evolve a balanced, modularized and scalable spacecraft platform that can support the high power requirements of advanced payloads with due consideration being given to reliability and cost.

Some general basic design principles of Electrical Power System are:

a. *Reliable, advanced and economical.*
b. *Adopting modular design which is standardized and serialized.*
c. *Adopting a mature software engineering design process.*
d. *System design requirements analysis, optimization, test with iterative modifications.*
e. *Mission requirements:*

i. *Orbit: sunlight versus eclipse time*
ii. *Solar incidence angle for the designated orbit*
iii. *Influence of satellite lifetime on solar cell design and size.*
iv. *Influence of temperature on solar design*
v. *Influence of discharge depth on the battery lifetime.*
vi. *Effect of temperature on battery design*
vii. *Effect of shunt regulator, discharge and charge regulators on system topological structure.*

f. *Electrical power bus voltage for long term power requirements*
g. *Electrical power quality in terms of bus ripple voltage, change in bus voltage characteristics, in-rush current capability and bus voltage leap rate in and out of eclipse.*
h. *Lifetime and reliability requirement with consideration to design with End-of-Life (EOL) requirements*
i. *Mass, Volume and Cost.*
j. *Structure and System arrangement considerations:*
   i. *Influences of harness power consumption in energy transmitting path and spacecraft load.*
   ii. *Solar array size and mass as an appendage in launch vehicle and orbit.*
   iii. *Battery thermal design and dispersion analysis*
   iv. *Battery Thermal control in different operating environments and different charge and discharge modes.*
   v. *Thermal design and analysis of solar array in stowed and curled mode and when deployed.*
k. *Requirements of Electromagnetic Compatibility (EMC), Electromagnetic Interference (EMI), and Electrostatic Discharge (ESD) of Power system and Spacecraft.*
l. *Electrical power distribution design with consideration for EMI, EMC, load protection etc.*
m. *Structural layouts and electrical harness to reduce circuit loss, minimize EMI and optimize EMC with consideration for modularity and accessibility during integration, assembly and test (AIT).*
n. *Environmental test requirements such as qualification test, check and acceptance test results and analysis under simulated and conditioned thermal vacuum and thermal cycle environments.*

2.2.7.3 Techniques, Improvements and Methodologies required for High Powered Spacecraft Bus for Geostationary Orbit.

Key bus platform spacecraft design options and units that allow innovative techniques and methodologies through systems engineering in enhancing the capability and capacity of spacecraft to support and accommodate high power payloads for broadband communications and high definition TV broadcasting involves amongst other requirements improvements in solar cell and battery technologies, use of electric propulsion systems to minimize the propellant budget of the mission etc. Some of these techniques, methodologies and improvements are as follows:

2.2.7.3.1 Solar Array Size and Structure

To accommodate the required solar energy generation for higher power spacecraft, solar array panels can now be structured in such a manner that allows eight or more panels by using advanced deployment techniques. Figure 2.11 shows a typical High Powered Communication Satellite undergoing a deployment test of its three panel solar arrays from its stowed position on the North Panel side of the spacecraft.

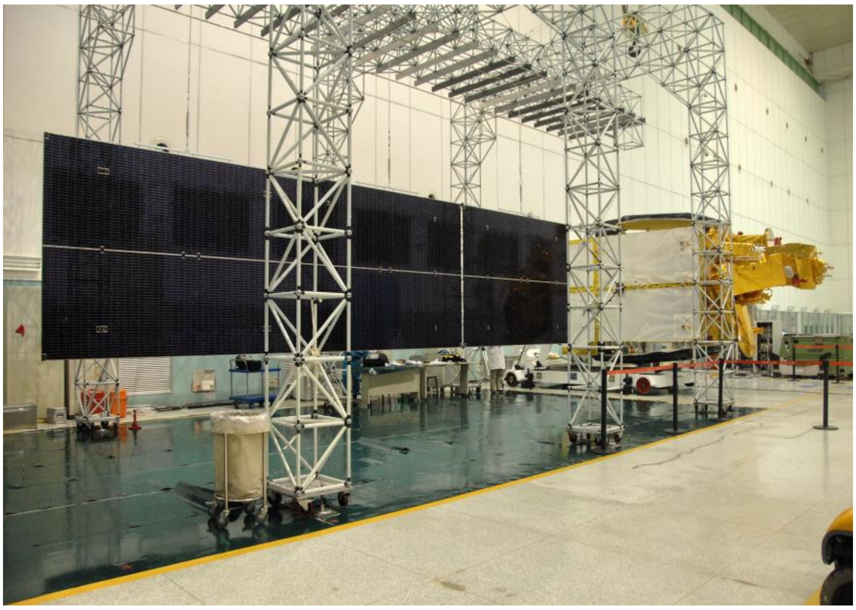


Figure 2.11: NIGCOMSAT-1R Stowed Three-Panel Solar Arrays undergoing Deployment Test under Zero Gravity (NIGCOMSAT-1R, 2009).

2.2.7.3.2 Advanced Solar Array Drive Assembly (SADA)

The mechanism caters for the high current demand using advanced slip ring technology with the required reliability and mechanical support for the solar arrays. The slip ring design requirements must cater for both power and control signals. The Solar Array Drive Assembly Motor (SADA-M) rotates the solar panel wing to keep the array facing the sun always via a shaft assembly. The power slip ring assembly consists of slip ring and brushes to help deliver solar array output power to power control unit (PCU) with the structure and brushes remaining fixed to the satellite as it rotates. Figure 2.12 shows a schematic of solar array, slip ring, brushes and PCU arrangement while figure 2.13 shows typical SADA-M as used in NIGCOMSAT-1R.

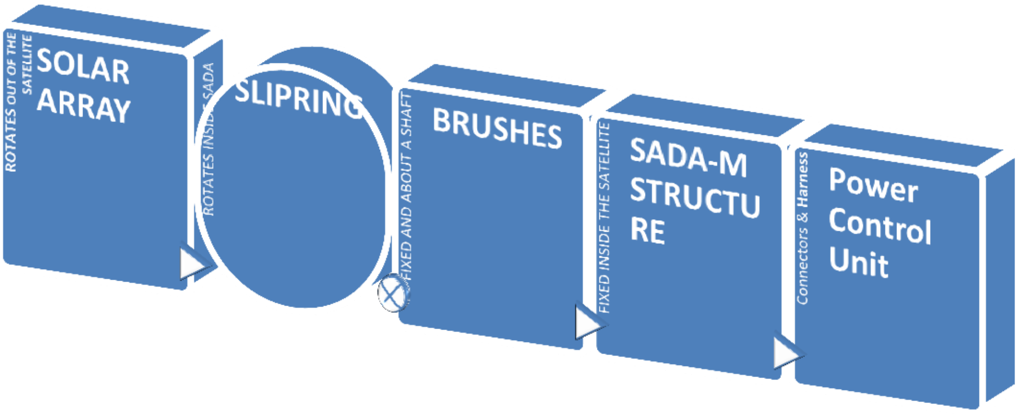


Figure 2.12: Schematic of Solar Array Output Power to Power Control Unit (PCU) Via Slip ring and Brush arrangement about a shaft of SADA-M.

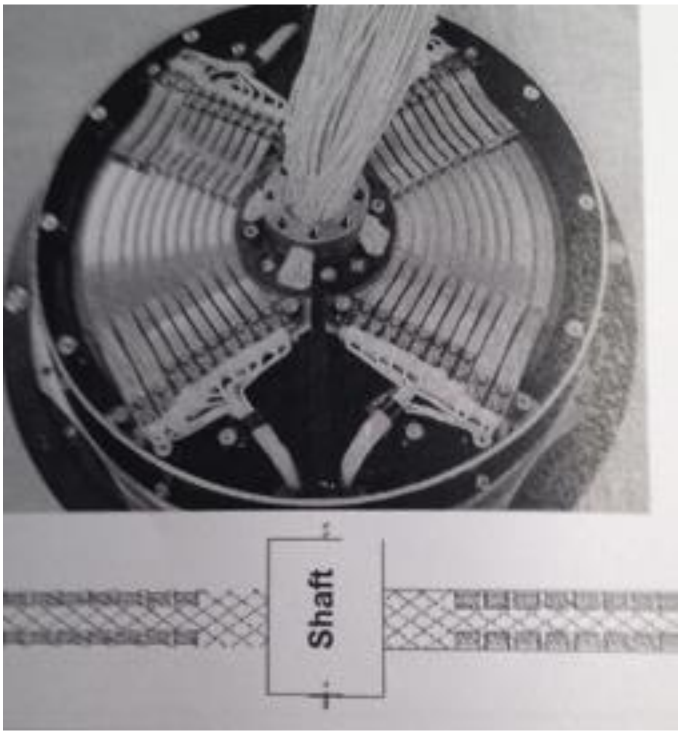


Figure 2.13: A Typical Solar Array Drive Assembly Motor (SADA-M) as used in NIGCOMSAT-1 showing internal structure.

2.2.7.3.3 Advanced Solar Cells

Improvement in solar cells using triple junction cells provides efficient energy conversion and greater output with the same cell area and mass. Sharp Corporation recently achieved the world's highest solar cell conversion efficiency of 36.9% using a triple-junction solar cell utilizing photo-absorption layers in which the solar cell has a stacked three-layer structure consisting of two or more elements such as indium and gallium. The bottom layer of the stacked triple structure was InGaAS (Indium Gallium Arsenide) while output maximum power was ensured through reduced resistance of the junction areas of the solar cell layers. Innovative solar cells with a lightweight structure are maturating currently (Sharp Corporation, 2011).

Solar cells employed for spacecraft use must undergo intense environmental testing including mechanical and thermal requirement tests. Other key tests include humidity, high and low temperature impact test, ultra-radiation and particle radiation tests to ensure reliable long term performance of the power subsystem.

A good semi-conductor compound solar cell must have the following characteristics:

i. High photoelectric conversion efficiency
ii. Good anti-radiation performance
iii. Good high temperature performance
iv. Support film or the super-thin solar cell.
v. Support for heterogeneous-substrate and multiple-junction level-connection solar cell.

For effectiveness and efficiency of the power supply system even towards the end of life (EOL) of the system, degradation coefficients of solar cells including assembly, sunlight and mission degradation factors amongst others must be considered when computing solar array power designs. Some of the degradation factors that must be considered are:

i. Insulation
ii. Sun Orientation
iii. Glassing gain
iv. Micromet, cover glass particle loss
v. UV radiation
vi. Thermal properties and thermal cycling
vii. Calibration errors
viii. Mismatch, fabrication and process loss etc

2.2.7.3.4 Improved Battery Performance and Cell Technologies

Batteries are used for energy storage, they convert chemical to electrical energy for use during eclipse, emergency mode of the satellite including early launch phase of the satellite before acquisition of the sun after deployment of the solar arrays. They have increased capability and capacity through higher efficiency and increased energy/mass performance using improved elements and compounds (Lawal & Chatwin, 2011). Battery requirements for High power geostationary EPS design among other factors should have the following characteristics:

i. High conversion efficiency
ii. High Output Power
iii. Reliable pressurization without leakage
iv. Ease of management
v. Effective electrical performance measure through singular or combined effects of pressure, voltage or temperature.

There are a variety of batteries suitable for spacecraft based on performance parameters such as energy density, cycle life, reliability, depth of discharge (DOD), discharge and charge rate and low-temperature performance and control. Some of these batteries are Nickel-Hydrogen, Nickel-Cadium, Lithium Ion etc. Other compounds such as sodium-sulphur battery etc are in the development stage. The most mature, reliable and commonly used battery for Geo-Satellites is the Nickel-Hydrogen battery with continuously improving performance for higher reliability and longer lifetime. However, there are higher energy density technology batteries such as Lithium ion and Sodium–Sulphur batteries but they still require considerable improvement to be suitable for Geo-orbit for the necessary long lifetime, charge/discharge cycle performance and reliability.

Battery main functions are:

i. Delivery of Electrical Power
ii. Storage of Electrical Power through optimized Charging
iii. Capability to retain the stored Electrical Power

Additional battery functions are:

i. Reconditioning in orbit
ii. Pressure Monitoring
iii. Voltage and Temperature Remote Telemetry

Battery Stress Functions to consider are:

i. Mechanical, Thermal and Electrical Environment of Satellite and Space
ii. Sustain Environmental conditions from manufacturing to Launch
iii. EMC and EMI
iv. Ease to transport and Assembly, Integration and Test (AIT)
v. Maintainability

Some design conditions to consider are:

i. The longest eclipse time
ii. Maximum Depth of Discharge of battery (DOD), which is a measure of the degree of battery utilization.
iii. Battery supporting energy requirements of the spacecraft during initiation phase (Between launch and sun acquisition after deployment of solar arrays).
iv. Battery must be designed to meet the requirements and functions enumerated above and to meet service life requirements in orbit with provision for at least 3 years storage before launch.

2.2.7.3.5 Power Control Unit (PCU)

This refers to all equipment and units for control, protection, adjustment and interfacing with other sub-units and subsystems of the electrical power system for effective, efficient, safe, continuous and reliable power. Configuration of power control units varies depending on the manufacturer and architecture of the power system design.

Via a telemetry interface, the PCU must support the requirements for instructions via tele-command and monitoring through telemetry for the required operational mode, which may not necessarily be autonomous and monitoring of the various EPS operation states and its performance including temperature control and monitoring of the batteries through thermistors.

Figure 2.14 shows a fully qualified Power Control Unit (PCU) for a Solar Array–Battery Unified Power system. A PCU is typically composed of the following modules:

i. Battery Charge Regulators (BCR) including output switches
ii. Battery Discharge Regulators (BDR).
iii. Sequential Switching Shunt Regulator (S3R) for regulation of the solar array voltage .
iv. Reliable Main Error Amplifier (MEA) for main bus voltage regulation amongst other functions.
v. Telemetry (TM) / Telecommand (TC) Interface including over voltage protection.

Power Control Unit functions, amongst others, are:

i. Provides the electrical power bus and the necessary bus voltage filter measures
ii. Regulates the output voltage of the solar array in sunlight and eclipse conditions and restricts high voltage of the bus to spacecraft load.
iii. Carries out charge control for the optimal performance of the battery.
iv. Carries out battery discharge regulation for optimal performance of the battery and spacecraft load.
v. Controls and regulates spacecraft load switching from battery to solar array and vice versa under sunlight and eclipse conditions respectively.

vi. Reconditions batteries whilst in-orbit through ground tele-command for optimal performance of the battery over its long service life-time.

vii. Provides interfaces between EPS and other subsystems

Figure 2.14: A Typically Qualified and Flight Proven PCU (NIGCOMSAT-1, 2005).

2.2.7.3.6 Interface Requirements and Harness

Electrical Power System design must support the following interfaces and requirements:

1. Electrical interface for:
    a. Power supply requirements of each satellite subsystem
    b. Equipment and converters with failure isolation circuit and load protective device including insulation, material types and their conductivity.
    c. Telecommand support
    d. Telemetry parameter support
2. Mechanical Interface with consideration to the followings:
    a. Size of the interface
    b. Mass of the interface
    c. Centroid position
    d. Inertia moment
    e. Installation mode
    f. Material and physical properties
3. Thermal interface: The thermal interface between units, equipment, subsystems and systems must be designed to requirements especially as it concerns the inside walls and the inner part of equipment since the thermal control system of the satellite is only responsible for ambient and surface temperature of equipment.
4. Harness Design: Aside from the primary function of connecting separate units and integration of distributed equipment and loads. Harness electromagnetic compatibility must be ensured for low-frequency cable, high frequency cable and electrical power cables for high and small current loads including pyrotechnic and Electro-Explosive Devices (EED). The harness materials and physical properties must be safe, reliable and

meet all test requirements. The weight and its accessibility must also be considered for assembly, integration and test (AIT) requirements. Others are shielding layer, insulation, D.C resistance and harness mechanical movement requirements.

2.2.7.3.7 Pyrotechnic Integration System (PIS).

The subsystem is responsible for safe and reliable operations of all Electro-Explosive Devices meant for deployment of satellite appendages such as antennas and multiple solar array panels in high-powered satellites including actuation of propulsion system valves. The EED power is usually independently provided from the spacecraft batteries through the activation of relay circuits. The pyrotechnic control and actuation technologies must be reliable and advanced if the mission of any high-powered communication satellite is going to be successful.

2.2.7.4 Advancement in Electrical Power Subsystems

Enhanced use of semiconductor technology to produce more reliable solar cells with higher conversion efficiency. Use of enhanced compounds to produce deep cycle cell of battery with prolonged life span of battery and reduced weight are goals for design requirements and EPS manufacture for performance targets, High power capability, reliability including thermal and EMC design requirements. Conceptual design of power subsystem redundancy at the system level to eliminate single point of failure increases reliability and reduction of space junk.

Some of these innovative requirements have been demonstrated in the Chinese DFH-4 and Boeing 702 satellite bus using triple-junction Gallium Arsenide solar cells with greater conversion efficiency yielding power generation as high as 18kW with smaller solar arrays. The same can be said of the Lockheed Martin A2100 series capable of producing as much as 15kW using innovative solar “pleated shades” with higher efficiency solar cells.

2.2.8 Attitude and Orbit Control Subsystem (AOCS)

Use of radiation hardened FPGAs over traditional microcontrollers and implementation of advanced attitude determination using innovative star trackers, advancement in star sensors, sun sensors and deep space application of GPS technology (Lau, Lichen, Young, & Haines, 1996) improves pointing accuracies to give fully autonomous attitude determination and corrections in three stabilized axes of the spacecraft. Orbit corrections and station keeping are also being improved upon through efficient use of thruster plumes and their layouts, particularly ion thrusters through modeling and analysis of the plasma environment in space. Alcatel Alenia recently demonstrated the use of an in-built star tracker in Spacebus 4000.

2.2.9 Thermal Subsystem

Reduction of use of heaters through effective utilization of dissipated heat from high power amplifiers via conduction (I.e TWTAs, SSPAs etc) over traditional use of space as a heat sink with radiating fins around high powered TWTAs and SSPAs. Efficient thermal controls have been demonstrated and flown using deployable radiators and improved thermal dissipation using thermal design software such as SINDA, TRASYS, FEMAP etc, which also helps conserve onboard power. This helps to support the requirements for greater thermal heat rejection for the high power payload components and sub-systems**.**

2.3 Higher Spectral Bands; The Ka-Band: New Possibilities and Capabilities.

Ka-band is a high radio frequency typically between 20-40 GHz that allows high volume and faster data throughput to be transmitted and received with relatively very small ground antennas at competitive prices. Ka-band is distinguished from C-band and Ku-band by its higher frequency spectrum. The Ka- band uplink frequencies are usually between 24.75 GHz and 31 GHz and downlink uses frequencies are between 17.3 GHz to 21.2 GHz depending on ITU region, satellite usage, national regulators etc.

Ka-band also offers another technology advantage of frequency re-use through space diversity by reusing the same frequency up to as much as six times allowing regionalized content space-based bandwidth resources to be shared between simultaneous users giving rise to today's High Throughput Satellites (HTS) with prospect of achieving a terabit/s geostationary satellite system (Lutz, 2013).

Ka band has moved from experimental laboratory demonstrators to application in high speed networks with digital channelization using onboard routers for broadcasting, telecommunications, IP trunking services, Communications –on-the-Move (COTM) etc.

Italian Space Agency was the sponsor of the world's first Ka-band satellite, Italsat F-1 as the important step forward to underscore the importance of the technology in orbit (Gargione, & Brandon, 1999) while the first commercial Ka-band success was with the launch of Telesat's Anik F2 on July 17, 2004, which gave Canadians the best hope of bridging their digital gap especially in the rural areas. The satellite, Anik F2; also had an early breakthrough by using smaller spot beams to cover specific geographic areas; a transformation from the usual and traditional one large zonal or large spot beam with other frequency bands. Telesat's Anik f2 used 45 smaller "spot beams" to cover specific geographic areas with 15 spot beams covering Canada and 30 spot beams covering the lower 48 US States.

With continuing advances in Ka-band technologies and systems, users have a superior online broadband experience and high–speed satellite Internet and data services equivalent to fiber-based services as seen in recent Ka-band High Throughput Satellites (HTS) and Wideband Global Satcom (WGS) satellites.

These achievements are not feasible without the cooperation of system engineers, integrators for the needed high-precision and high performance ground Ka-band infrastructure and product developments such as Ka-band antennas, feeds, HPAs, Receivers, High performance cables, waveguides, Power control, Converters etc including rain attenuation mitigation techniques such as adaptive coding and modulation(ACM), rate reduction, automatic power control (APC) etc to suppress the rain-fade column which is the main propagation impairment in the high frequency band. (Garcia-Rubi, Riera, Garcia-del-Pino, & Benarroch, 2011; Lawal & Chatwin, 2013).

Throughput Satellite (HTS) systems have introduced a paradigm shift in satellite broadband access services and the satellite industry. The satellite industry has begun a process of "remaking" the satellite broadband access market into an unprecedented offering that compares favorably to a DSL and fiber-based services in many unserved or underserved markets.

Ka-band systems and technologies hold great promise for Africa in complementing the inadequate terrestrial networks and ensuring that its nations are not isolated from the global economy and world-wide communications network growth (Lawal & Chatwin, 2012). The Ka band spectrum has helped the satellite industry in optimal utilization and availability of the Satellite frequency spectrum and management through digital channelization and frequency re-use. African Leaders and key stakeholders through institutional frameworks have recognized the role of ICT infrastructure and the multiplier effect it has on other development sectors. As a means of closing the infrastructure deficiency and after due process and a request for proposals from various communications satellite companies, the Federal Government of Nigeria took the bull by the horns by signing a Communication Satellite contract with the China Great Wall Industry Corporation in December 2004. The high powered, Quad band (Ku, Ka, C and L Band) geostationary satellite, with a service life span of 15 years, had 8 active transponders on the Ka-band, which were based on a feasibility field trial assessment of bandwidth demand projection for Sub-Saharan Africa required to carry Africa's international voice and data traffics and the success of the ANIK F2 satellite with Ka-band.

The National priority project and first Nigerian Communication Satellite (NIGCOMSAT-1) was eventually launched on the 13th of May 2007 becoming the first communication satellite to provide users with Ka-band resources over African soil. The satellite suffered an onboard subsystem failure and was de-orbited on 10th of November 2008 bringing all broadcast, telecommunication services and strategic navigational plans to an abrupt end. An insurance replacement was launched on 20th December, 2011 as NIGCOMSAT-1R with an improved Ka-band satellite system over its predecessor; NIGCOMSAT-1. (Haris Caprock, 2012; Lawal & Chatwin, 2013; NIGCOMSAT-1, 2005; NIGCOMSAT-1R, 2009).

Non-geostationary Ka-band satellites such as the O3B Ka-band satellite designed for medium earth orbit offers lower latency and throughput equivalent to an optic fiber cable system. NIGCOMSAT Ltd, as the first satellite operator to provide Ka-band resources over African soil, will continue to drive the national ICT revolution by the provision of cost effective and affordable solutions involving: broadcasting, Internet, seamless integration of telecommunication connectivity and backbone and IP trunking, *inter alia*, by exploiting its Ka-

band resource combined with the use of gateways and hubs complemented by the other bands onboard NIGCOMSAT-1R and the future fleet of HTS satellites over the African continent and the globe at large. Well implemented Ka-band multimedia services and applications with international distribution networks and local service providers remains a key success factor in driving the new and enhanced satellite service business including new market opportunities such as Internet-in-the-sky, 3D Digital TV, HDTV, Videos-on-Demand , Interactive multimedia etc. It remains part of the corner stone for guaranteeing universal access and digital inclusion in a continent with the least wired terrestrial communications network.
(Lawal, Ahmed-Rufai, Chatwin, & Young, 2013).

2.4 Satellite Communications Network Technologies for Communications Satellite.

As explained earlier in the literature review of chapter one, introduction of digital video broadcasting (DVB) systems to communications satellites was a milestone paradigm shift for the important role communications satellites are playing today in broadcasting, telecommunications, mobile communications, convergence with voice, video and data as well as terrestrial telecommunications technologies. (Ong et al, 2007; Liang et al, 2007). The emergence of variants of mobile technologies, increased demand for communication satellite-based multimedia and ubiquitous service requirements by end users encouraged by the modern day knowledge economy (Lawal, Ahmed-Rufai, Chatwin & Liu, 2013; Liang et al, 2007) has led to worldwide convergence of networks and fusion of technologies as it concerns not just voice, video and data but some innovative techniques involving digital television, broadband Internet, mobile communications as illustrated in figure 2.15. Chapter seven provides further details with applications.

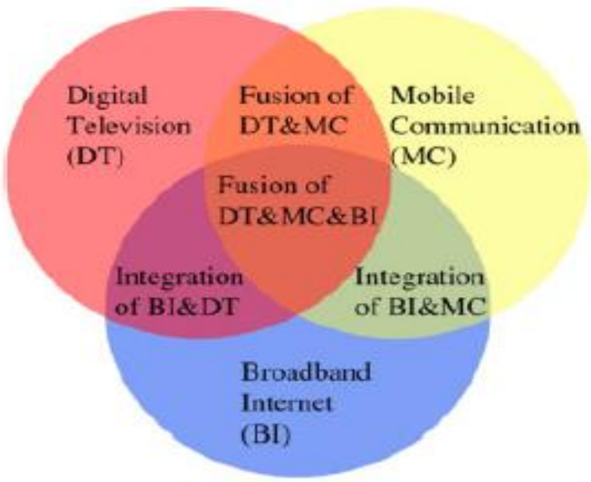


Figure 2.15:Fusion of Digital Television, Broadband Internet and mobile Communications. (Source: Liang et al, 2007).

2.5 Conclusion

The overall effect of implementing these technologies at unit, sub-system and system level on present commercial geostationary spacecraft will be an optimized communication satellite bus system with a broader spectrum of: capacity, capability, reliability, intelligence with reduced cost and small form factor to bridge and complement digital gaps across communities, nations and continents.

Research intensification in enabling advanced technologies for reliable future commercial satellite communications could be stimulated among stakeholders (COMSAT manufacturers, telecommunication users, satellite and Internet service providers, COMSAT system designers, sub-system satellite designers, AIT experts [assembly, integration & test], research & academic communities, satellite insurance firms etc) through forums and professorial chairs in academic institutions to move today's billion-dollar large spacecraft technologies to a more advanced level.

The high-risk activities of the satellite industry make use of mature technologies with flight heritage at the expense of newer technologies especially in the commercial satellite industry; satellite insurance companies acting on history, experience and launch failure data largely drive this. Most commercial in-orbit satellites do not have the latest and most advanced technologies due to the use of matured but mostly obsolete technologies required by insurance companies. A paradigm shift could therefore be delivered by the use of advanced technologies as piggyback payloads, hoisted payloads or experiments on commercial geostationary spacecraft as test grounds for use of advanced technologies with capacity and capability to enable connectivity and digital inclusion across the globe, not only as a passive (transparent) global communication infrastructure but also as an active (processed) global infrastructure.

Such active global communication infrastructures will help promote the use of ICT, which is central to the well-being of emerging knowledge-based nations that are currently on the wrong side of the digital divide. These new technologies will play an important role in accelerating growth, promoting sustainable development and eradicating poverty; in general the digital divide will be reduced greatly through speedy implementation of COMSAT development projects and programmes that are designed to have a positive effect on the lives of ordinary citizens living in remote hamlets, rural and semi-urban areas.

As it complements and connects with terrestrial networks, advanced communication satellites (COMSAT) remains the corner stone for universal access to the Internet with its huge knowledge resources.

CHAPTER 3: Needs Assessment, Feasibility and Suitable Design Specifications for Nigerian Communications Satellite.

3.0 Summary

In this chapter, the situational analysis of Information Communications Technology (ICT) infrastructure in Africa was examined and identified a strong need for passive Global Space-based ICT Infrastructure (Communications Satellite System and associated technologies) as a short and medium term measure to bridge the huge digital hiatus based on needs assessment and viability despite arrival of sufficient and adequate undersea cables at the shores of the African continent in recent years. A well-planned and implemented Very Small Aperture Terminal (VSAT) with a suitable regional domestic communications satellite will significantly improve access to telecoms services in rural areas as a niche market as well as address other strategic needs of the region.

3.1 Introduction of Communications Satellite and Broadband-Based Services.

Africa is the least wired continent in the world in terms of robust telecommunications infrastructure and systems to cater for its more than one billion people. The International Telecommunications Union (ITU) identified in the report released on measuring the information society (ITU) (2010) that African nations are mostly still in the early stages of Information Communications Technology (ICT) development as verified by the relatively low ICT Development Index (IDI) values of all countries in the African region. In developing nations, mobile broadband subscriptions and penetration between 2000-2009 was increasingly more popular than fixed broadband subscriptions. To achieve the goal of universal access, with rapid implementation of ICT infrastructure to complement the sparsely distributed terrestrial networks in the hinterlands and leveraging the adequate submarine cables along the African coastline, African nations and their stakeholders are promoting and implementing Communication Satellite systems, particularly in Nigeria, to help bridge the digital hiatus. This chapter amongst others things, examines the effectiveness of communication satellites in delivering broadband-based services.

3.1.1 What is Broadband?

Broadband has different meanings for different people depending on whether their focus is in terms of capability, capacity, speed, etc. The acceptable baseline for broadband all over the world is the definition of broadband given by The Organization for Economic Co-operation and

Development (OECD), which defines broadband as a service (not a technology) that can provide an Internet speed or data transmission rate at least 256 kilobits per seconds (kbps) in at least one direction (Agustin, 2009).

According to Singer (2003), broadband should have sufficient two-way transmission capacity and speed to allow interactive high-quality full-motion video, data and voice applications simultaneously via one “pipe.”

The United States Federal Communications Commission (FCC) has up to now used a slightly different terminology in the United States. “High-speed lines” are connections to end-user locations that deliver services at speeds exceeding 200 kbps in at least one direction (either enabling the end-user to send information – upstream – or receive information from the Internet – downstream), while “advanced services lines”, a subset of high-speed lines, are connections that deliver services at speeds exceeding 200 kbps in both directions. For the purpose of information collection, the FCC has used “broadband connections” as a synonym of “high-speed lines”. In June 2008, the FCC modified its requirements for reporting broadband lines largely based on consumer trends and usage of applications such as high-quality graphics and video telecommunications such as video conferencing, high definition video streaming etc. Specifically, it established eight download speed tiers and nine upload speed tiers, which providers must employ in reporting broadband index. The Sixth Broadband Progress Report increased the Commission’s speed benchmark for broadband to 4 Mbps download and 1 Mbps upload because network capabilities, consumer applications and expectations have evolved in ways that demand increasing amounts of bandwidth in the United States. However, there was consideration on the extent of broadband deployment and measures of the current threshold definition to the varying technologies such as fixed–terrestrial broadband, mobile broadband and satellite broadband (US FCC, 2012). The broadband definition threshold keeps changing on a regional and national basis driven by usage and applications. In Asia, in particular India with over 1.3 billion people, the definition of broadband was revised from 256 kbps to 512 kbps on 1st January, 2011. Considering consumer trends and projections, particularly on mobile network data speeds, the Government of India approved stipulated download speed of 2 mbps for any broadband connection based on any technology with effect from January 1, 2015 based on its national broadband plan (India TRA, 2010). Under the voluntary code of practice of the Office of communications (OfCom), United Kingdom, Broadband speed definitions as used in the code are categorized based on headline or advertised speed by an Internet Service Provider (ISP), access line speed based on the maximum speed of the data connection, actual throughput speed based on consumer user experience at a particular time and average throughput speed, which is the average actual throughput speed for each broadband product offered by an ISP (UK OfCom, 2012).

The International Telecommunication Union definition of broadband combines connection capacity (bandwidth) and speed. Recommendation I.113 of the ITU Standardization Sector defines broadband as a "transmission capacity that is faster than primary rate Integrated Services Digital Network (ISDN) at 1.5 or 2.0 Megabits per second (Mbits)" (ITU, 2003). The trend in threshold definition of broadband will continue to change within the foreseeable future due to the level of change of our technologies to support such forecasts driven by demands. For instance, the European Commission provided an update on implementation of national broadband plans in the EU-27 countries, along with Croatia, Norway and Switzerland in which the Digital Agenda for Europe (DAE) required all member states to devise and make operational by 2012, and national broadband plans, which would enable the EU to meet the broadband targets for Europe by 2020. Those targets are as follows:

- Basic broadband (512 kbps to 4 Mbps) to all by 2013
- Fast broadband by 2020: broadband coverage at 30 Mbps or more for 100% of EU citizens.
- Ultra-fast broadband by 2020: 50% of European households should have subscriptions above 100 Mbps.

To date, about 22 member states have national broadband plans while the rest are either under review or in the drafting process (European Commission, 2012). Threshold definition of broadband in African nations beyond 256 kbps should be within the context of the level of access to telecommunications infrastructure, usage of applications such as: high-quality graphics, video streaming, video conferencing and the level of new generation networks deployed and envisaged to be deployed within mid-term future projections.

Evolution of Broadband Networks

Before the arrival of the Internet and Packet-Switching Technology, which allows voice to ride over Internet Protocol systems (VoIP) designed for data networks; speech, telegraph, paging and fax systems were run on legacy systems and networks, which were basically narrow-band systems.

The arrival of Packet-switching techniques and the Internet resulted in a sharp and continuous increase in demand for converging data networks supporting data, voice, fax and video services, which led to the development of broadband technologies in both satellites and terrestrially based networks (i.e DSL over legacy telephone networks and fiber-based networks, which led to the introduction of multi-core fibers).

Broadband is widely used to describe high-speed access to support today's converged networks of not only voice or data as well as multimedia traffic of high-quality voice, data, graphics, streamed videos and video conferencing. High-speed mobile technologies are becoming increasingly important particularly as services and applications in broadband delivery. However, second generation mobile technologies and their improved versions such as GSM and GPRS (2.5G), cannot be considered broadband, when their download rates reach only 60 to 80 kbps, well short of the OECD threshold. EDGE/Evolved EDGE, W-CDMA (UMTS), CDMA-2000 3G, TD-SCDMA (Chinese National Standard), HSPA and LTE mobile technologies can deliver well above the 256 kbps OECD threshold with higher speed throughputs. Hence, governments of developing countries and their communication regulators should encourage mobile operators to roll out 3G networks rather than investing huge capital sums to upgrade 2G systems.

3.1.2. Why Broadband?

Broadband-based technologies accelerate economic and social development. The introduction of broadband technologies through fiber, satellite and variants of fixed and mobile wireless systems has enabled traditional and new forms of communication to become a reality throughout the world. Most traditional and legacy technologies do not meet the high bandwidth requirements for emerging applications for triple play services (voice, video and data).

The importance of broadband has been highlighted by the Managing Director and Chief Executive Officer (MD/CEO) of NIGCOMSAT LTD; Engr. Timasaniyu Ahmed-Rufai (2012) in the quest for NIGCOMSAT Ltd to target 40% of the Nigerian Broadband Market by 2015 through NIGCOMSAT-1R stated*"...In today's challenging economic climate, the dividing line between progress and chaos, the rich and poor nations is the Broadband connectivity. Looking at the near future, Broadband connectivity will be similar to the difference between life and death. For us to be alive as a nation, we must lay a solid foundation for a knowledge-based economy—with ubiquitous broadband and a declining cost of connectivity"*.

Broadband has the potential to facilitate and boost entire new industries, improve the education system, deliver and enhance health care, enhance farming, monitor and ensure public safety and engage with government. Increasingly, broadband is used to access, organize and disseminate knowledge, increase market productivity, facilitate the generation of new jobs and improve the quality of life through e-Government, distance learning, e-Commerce, e-Banking, e-Village, e-Agriculture and national Security amongst others.

3.1.3 Communications Satellite

Communications Satellite abbreviated as COMSAT is an artificial satellite placed in an orbit; mostly geostationary orbit to aid broadcasting, telecommunications and/or navigation by reflecting, relaying or processing a radio signal. Figure 3.1 shows a pictorial diagram of a communications satellite in orbit oriented towards the earth.

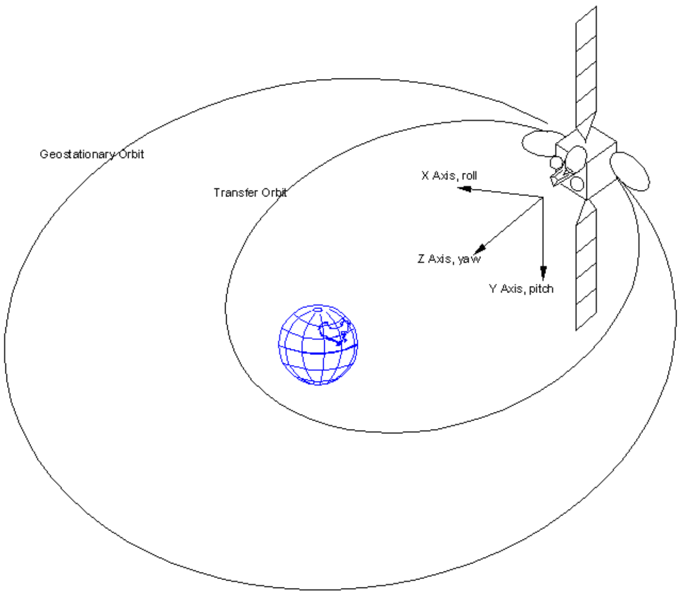


Figure 3.1: Communication Satellite in Orbit

The impact of communications satellites on business, culture, human relations, education and humanity in general can be historically likened to that of the railroad in the last century or the development of modern transportation. (Francis & Will, 1994). It has aided international communications with access to broadband, broadcast and value-added services. (Logue, 1996). Communication Satellites and the Internet collided at the Internet's very beginning according to Puetz (1999). Puetz (1999) reiterated that the original five super computer centres were interconnected under the National Science Foundation (NSF) in 1985 with 56 kilobits per second (kbps) SCPC links using a Ku-band Communications satellite. Today, Internet-2 is the high bandwidth backbone dedicated for university research. Communications satellites have played and will continue to play a very significant role in the expansion of the Internet across the world. It has today helped bridged the information access gap in the early beginning of Internet, which was thought of as not a universally available, global phenomenon. (Stuart, 1997). Communications Satellite impact is not only limited to Internet, TV Broadcast and multimedia but also satellite-based Digital Audio Radio Service (DARS). Boyer (1998) noted that the essential lure of satellite radio aside Compact-Disk (CD) quality, is a service that people can enjoy in their vehicles without ever driving beyond the range of the transmitter. In the beginning, vehicles used Amplitude Modulation (AM). Then came Frequency Modulation (FM) and now comes DARS on S-band in the history of radio as noted by Lon Levin, the president and founder of American Mobile Radio, which was a subsidiary of American Mobile Satellite Corporation (Boyer, 1998).

3.2 Needs Assessment and Feasibility Studies for Nigerian Communications Satellite

3.2.1 General Overview

Nigeria successfully placed its first national satellite; NigeriaSat-1 in orbit in September 2003. Based on the success of the earth observation satellite, the federal government decided to explore the possibility of a national communication satellite system to improve the country's comatose ICT infrastructure considering growing needs of telecommunications needs of its citizens amongst other requirements since deregulation in 1993, which allowed private sector participation and investment for the country's telecommunications service delivery. The mobile phone services, Internet, VSAT services significantly changed the face of communications in Nigeria. It is often remembered with nostalgia how the VSAT services transformed the banking sector in the early 90's from paper-based and manual based systems to an Information Technology driven sector particularly the new generation banks with a wildfire effect on old generation banks who struggled to remain competitive. The demand and utilization of communication satellite services surged with enormous traffic considering the inadequacy of terrestrial networks despite the rising cost of subscription to satellite services from international satellite operators with little or no local presence neither was there adequate postal service support.

An extensive data collection exercise on needs assessment was embarked upon covering 36 states of the federation including the Federal Capital Territory (FCT). The data collection was centered on prospects of a national communication satellite system with coverage over Africa and Europe, the immediate two key trading partners of Nigeria. Other complementary data collection methodologies were field survey, telephone interviews, consultations with ICT stakeholders, review of government policy papers, company brochures, conference reports and proceedings, journals, specialized magazines on ICT, websites, press releases, desk studies, internal and external research by project team members and officials of the National Space Research and Development Agency (NASRDA) as well as data compilation on communication requirements of African countries. Table 3.1 shows fixed telephony services status in Nigeria as at the end of September, 2004 in a country with over 130 Million at that time.

Table 3.1 : Fixed Telephone Services in Nigeria as at the end of September, 2004

S/N	OPERATOR	SYSTEM CAPACITY	NO. OF CONNECTED LINES	% CONNECTED
1	NIGERIAN TELECOMMUNICATIONS LTD	733,611	518,976	71%

	(NITEL)			
2	PRIVATE TELECOMMUNICATION OPERATORS (PTO)	341,740	200,000	59%
	TOTAL	**1,075,351**	**718,976**	**67%**

63% (452,955) of the connected lines were for homes while the remaining 37% (266,021) accounts for office connections.

Table 3.2 shows a summary of estimated current capacity requirement of data bandwidth as at 2004 utilized by key sectors of the Nigerian economy.

Table 3.2: Estimated Bandwidth Utilization and Requirement for the Nigerian Economy.

S/N	**SECTOR**	**BANDWIDTH REQUIREMENT/UTILIZATION (MB)**
1	BANKS	12
2	OIL SECTOR	137
3	GOVERNMENT AGENCIES	12
4	NITEL	221.5
	CURRENT TOTAL	**544.5MB**
	ESTIMATED TOTAL REQUIREMENTS IN FIVE YEARS	**1536.2MB**

While a conservative estimate of 1536.2 Mbps was expected in 2009 based on current macro-economic indicators, optimistic data service growth projection and demand was expected to be 3,301Mbps by year 2009.

Nigeria's outbound international traffic was estimated to be between 350-600 million minutes yearly mainly generated from NITEL network and carried mostly via NITEL satellite Earth Stations in Lagos, Lanlate-Oyo, Enugu and Kaduna across six geo-political regions of the country. It was also projected to rise to about 1 billion minutes in the next three years considering the increasing growth of mobile phone subscription dominated by GSM operators.

The mobile subscription figures as shown in table 3.3 was about 6.9 million as at the end of September, 2004.

Table 3.3: Estimated Mobile Subscription as at the end of September, 2004.

S/N	MOBILE PHONE OPERATOR	CONNECTED SUBSCRIPTION (MILLIONS)
1	MTN	3
2	GLOBACOM	1.7
3	V MOBILE (NOW AIRTEL)	1.6
4	MTEL (MOBILE SUBSIDIARY OF NITEL)	0.6
	TOTAL	**6.9 MILLIONS**

Increasingly, mobile operators carry more voice traffic than the fixed-line and by December, 2004, Africa was expected to have over 50 million mobile subscribers and 20 million fixed-line subscribers. Mobile operators possess international gateway licenses and thus use communication satellites to carry international traffic. Thus, African cellular operators were in the driving seat to meet demand for capacity in the last three to four years prior to 2004. For example, MTN Nigeria, a mobile operator uses communication satellite links to provide its international connectivity using the then PanAmSat and New Skies, as well as to carry GSM traffic between mobile switching centers (MSCs) in Lagos, Port Harcourt and Abuja. Most mobile operators also use the satellite links for their transmission networks such as backhauling traffic from remote base stations to central MSCs or between various MSCs. In the Democratic Republic of Congo, new entrant mobile operator, Vodacom utilize a satellite backbone due to inadequate terrestrial transmission networks and infrastructure. This brings to fore the importance of satellite transmission in African mobile network and thus their engagement into satellite business. Telecel International, for instance uses M-Link based in Belgium to provide a gateway service for each Telecel's African subsidiaries that are routing telephone traffic out of their respective countries and deliver traffic from international carriers into Africa using Telecel networks. Econet Satellite Services (ESS), based in the UK, was set up by Zimbabwean-based operator Econet to operate and market international carrier services using satellite-based infrastructure. ESS also aimed to provide a routing service for traffic emanating from operations in which Econet Wireless International (EWI) acts as the operator. In February, 2002; MSI cellular, a mobile operator with subsidiaries in thirteen African countries announced the acquisition of satellite operator, LinkAfrica from Intercel to improve data and voice connectivity within and between these countries and areas that can't be reached with terrestrial solutions. Celtel DRC, MSI Cellular's subsidiary in the Democratic Republic of Congo became market leader with 70,000 customers since launching their service in December, 2000 and LinkAfrica's largest single customer. With the installation of earth station in Kinshasa in 1992, LinkAfrica built out a VSAT network covering DRC cities and also in Guinea and Madagascar where

Telecel has networks with a whole transponder on the Intelsat 707 satellite to connect international traffic via teleports in the USA and Belgium.

Internet usage grew with over 40 licensed Internet Service Providers (ISP) by the National Communications Commission (NCC), Nigeria's Telecommunication regulator as at December, 2003. However, the services were unreliable and made worse by the gross inadequacy of last mile connection from the ISP access points of presence (POP) to the user premises.

Estimated total number of Internet Access Points (Host computers connected to Internet) in Nigeria is 685,459 with composition as shown in table 3.4

Table 3.4: Estimated Total Number of Internet access in Nigeria as at December, 2003.

S/N	USERS	NUMBER OF HOST COMPUTERS	PERCENTAGE (%)
1	OFFICES	530,968	77.4
2	HOMES	122,431	18.9
3	CYBERCAFES	32,060	4.7
	TOTAL	**685,459 Internet Access Points**	

3.2.2 Summary of Internet Usage in Nigeria as at 2004.

The summary of Internet usage in Nigeria reveals the followings:

i. There are about 700,000 Internet Access points in Nigeria.
ii. A growing number of Internet Cafes are using VSAT to connect to the backbone.
iii. The quality of service are rated higher and better where VSAT is used as against dial up.
iv. The churning rate amongst users is high- most subscribers have used at least three ISPs.
v. Revenue from Internet alone in Nigeria is over N11.63 billion annually.
vi. Internet penetration in Nigeria is less than 0.5
vii. 33% of Internet users encounter problems when establishing a link to the ISP as a result inadequate last mile infrastructure for dial-up and wireless services.
viii. 51% encounter problems when establishing an Internet session as a result of inadequate bandwidth capacity for international access largely due to high cost of acquisition.
ix. Less than 2% of the population of Nigeria (130 million) have used the Internet.
x. It takes about 15 to 30 Minutes to access a Cybercafe in Urban areas in Nigeria.
xi. At least 60 to 120 minutes to access a Cybercafe outside urban areas.

3.2.3 The Impact of Confidentiality and Security on Internet Growth.

Below shows the level of concern expressed by Nigerians over the issue of confidentiality and security of their Internet access as follows:

i. 47% of Internet users expressed some concern
ii. 36% expressed serious concern (very concerned)
iii. 11% were not concerned
iv. 6% were indifferent.

The survey result shows an overwhelming 83% of Internet users consider confidentiality and security of their information over the Internet as an important issue and thus this affects utilization and rate of Internet growth and by extension sensitive sectors and services such as E-commerce, E-banking etc.

3.2.4.Viability Assessment of Nigerian Communications Satellite based on ICT Access Parameters of the Country.

Table 3.5:The Table provides comparative parameters of selected number of countries on access to ICT sourced from ITU in 2003.

Country	Telephone Subscriber Lines per 100 inhabitants	Mobile Subscribers per 100 Inhabitants	Internet Tariff as % of Gross National Income Per capita	Intl. Internet Bandwidth Per 100 Inhabitants	Broadband Subscribers Per 100 inhabitants	Internet Users per 100 Inhabitants
Sweden	65.2	88.9	1.1	10611.2	8	57.3
Korea	48.6	67.9	1.2	361.5	21.9	55.2
USA	65	47.3	0.5	1323.6	6.9	55.1
South Africa	9.5	30.4	15.4	12.4	0	6.8
Gabon	2.5	21.6	46.9	12.6	0	1.9
Cameroon	0.7	4.3	110.7	0.6	0	0.4
Ghana	1.3	2.4	177.8	0.6	0	0.8
Nigeria	**0.6**	**1.3 (2.5)***	**353.7**	**0.6**	**0**	**0.3 (2.6)***
Senegal	2.3	5.6	103.7	8.1	0	1.1
Cote d' Ivoire	2.0	6.2	132.1	0.4	0	0.5
Benin	1.0	3.3	146.5	0.3	0	0.8
Angola	0.6	0.9	143.3	0.5	0	0.3

The 2003 Internet study by the ITU verified Nigeria as having one of the highest Internet tariffs in the world with Internet tariff standing at 353.7% of the Gross National Income Per Capita compared to neighbouring Ghana with 177.8% and South Africa with 15.4% on the same continent.

20 hours of local dial-up Internet access per month in Nigeria is about:

i. 500% higher than in India
ii. 140% higher than in South Africa and Namibia
iii. About the same as Uganda
iv. Over 300% higher than OECD countries
v. ISP costs are less than 50% of the average end-user costs in all countries, the rest being Telco charges.
vi. International Internet Connectivity accounts for about 30% of ISP costs.
vii. International Internet Connectivity has two parts:
    - International leased circuits; over-priced most often
    - Global Internet connectivity : rarely identified separately
viii. Reluctance by operators to disclose information suggests that it is key to competiveness.

Prevailing average price for 64kbps VSAT bandwidth before NIGCOMSAT-1 in Nigeria was $8,340 per year.

128/1024 kbps bandwidth costs about $2,000 monthly, this implies that 2MB (E1) would cost $3,500 per month or $42,000 yearly

Comparatively, equivalent capacity of 2Mbps (E1) full circuit on SAT-3 fibre optic cable from Lagos to Europe (Portugal). The only operating cable, was: $144,500 per year by NITEL. NITEL (Nigerian Telecommunications Ltd) is Nigerian Government owned telecommunication company managing the only landing cable in Nigerian Shores (Lagos).

3.2.5 Analytic Summary of Viability of Nigerian Communications Satellite as a Passive Regional ICT Infrastructure

Internet eXchange Points (IXPs) are presently few in a handful of countries facilitating peering between ISPs, however the bulk of Internet traffic in most countries is international and a growing number of companies are diversifying into becoming ICT infrastructure providers using satellite and fiber, as applicable, to deliver growing end-to-end services as well as IP based services. Pan African Communications Network (PACONET), a regional IP operator acquired full international VSAT operating licenses in a number of countries with a vision of providing low-cost international telecommunications services to Africa and creating a fully meshed African voice and data network with Points of Presence (PoPs) in all major African cities. These PoPs were to carry international telecommunication traffic throughout the continent as well as to and from the rest of the world. A fully operational Pan African Network will allow African nations to communicate directly with each other, rather than having to switch through one of the major US or European hubs. In the Democratic Republic of Congo, Paconet took a step further and in addition to licenses to operate international VSAT Gateways, rolled out Wireless local loop networks. They also got licenses to offer Voice over Internet Protocol (VoIP) services including providing Internet access and rural telephony services. Interestingly, 70% of Nigerians live in rural areas, which translates to over 90 million people. Although most rural folks in Nigeria, as in most African countries are less economically endowed, the implications of such a large population cannot be ignored or dismissed. There are 774 local Government areas and headquarters in Nigeria, survey data shows only about 220 are connected to the national grid of NITEL and mostly at the Local Government Headquarters level and some of the telecom facilities in these Local Government headquarters are not even functional considering maintenance challenges, unreliable power supply services etc. In theory, the estimated number of people served by available telecoms services in the 220 Local Governments mostly located in urban areas is about 53 Million served by about 509, 443 connected telephone lines based on field survey and as supported by data in table 3.1. The rest of the 77 Million people of the estimated 130 Million people as at 2003 do not have even theoretical access to telecoms services. The practical reality is that much less than 53 million people in the 220 Local Governments have access to telecoms service considering difficulty of access as a result of long distance travel of over 20km especially on not all-seasons roads, thus a large number of people are without access.

To achieve e-Governance in Nigeria, at least 200GB of bandwidth was the projected requirement to be effective; undoubtedly, a significant proportion of this bandwidth will be satellite-based considering the office locations with non-existent or adequate terrestrial ICT infrastructure.

NITEL, the government-owned First National Operator (FNO) and manager of SAT3 optic-fibre in Nigeria has 3 digital and one analogue Satellite Earth Stations with an estimated combined total of 7,500 voice channels. With an assumed 64Kbps per channel implies a combined total capacity of 480Mbps. This makes a very significant demand on the satellite space segment and resources.

Thus, NITEL, the four GSM operators, over 20 Private Telephone operators (PTOs), over 30 active ISPs, numerous VSAT groups and the Second National Operator (SNO) amongst others are potential strategic partners and consumers for the Nigerian Communication Satellite project.

Nearly all Africa’s international bandwidth is provided through Communications Satellite except countries, which are connected to and utilising submarine fiber-optic cables such as Algeria, Djibouti, Egypt, Morocco, Senegal, South Africa, Tunisia, Canary Islands and Cape Verde and more recently countries with landing points of Sat-3 viz: Senegal, Cote d’Ivorie, Ghana, Benin, Nigeria, Cameroun, Gabon, Angola and South Africa.

A well-planned and implemented VSAT network will significantly improve access to telecoms services in rural areas and a conservative estimate of 20 satellite channels per local Government areas for at least 500 local government areas is a good candidate for satellite communication.

3.3 Suitable Design Specifications and Technical Requirements for Nigerian Communications Satellite (NIGCOMSAT-1) within the African Sub region to meet desirable Availability and Quality of Service (QoS).

3.3.1 General System Design Approach

A Bottom-to-Top design approach was used for the Nigerian Communications Satellite (NIGCOMSAT) project dictated by market requirements, needs assessment within the spectrum allocated by the ITU with weather and climatic consideration of Sub-Saharan Africa to ensure availability at all times and seasons as well as good user quality of experience (QoE).

The needs assessment was based on current and projected demand for satellite communications while taking into account future development in competitive systems such as planned optical fiber backbone networks, future plans of existing satellite operators and new potential satellite operators such as the Regional African Satellite Communication Organization (RASCOM) project. However, accurate evaluation is quite impracticable considering the number of unlicensed operators and service providers as well as an unwillingness by stakeholders to disclose or provide sensitive confidential information.

Current utilization of satellite capacity for domestic communications in Nigeria alone was conservatively estimated at 25 x 36 MHz transponders and envisaged to grow to at least 38 transponders within the next three years. The conservative projections for domestic satellite communications for Nigeria and Sub-Saharan Africa are as provided in Table 3.6 and 3.7 respectively:

Table 3.6: Satellite Capacity Utilization and Projections in Nigeria

	SATELLITE CAPACITY UTILIZATION & PROJECTIONS FOR DIFFERENT USER GROUPS IN NIGERIA			
S/N	**USER GROUP**	**USAGE AS AT 2004 (No. of of Transponders)**	**PROJECTED USAGE FOR 2007 (No. of of Transponders)**	**PROJECTED USAGE FOR 2010 (No. of Transponders)**
1	MAIN TELECOM OPERATORS	7	10	12
2	VSAT/ISP	10	15	20

	OPERATORS			
3	BROADCASTERS	7	10	14
4	OTHERS	1	3	2
	TOTAL	**25**	**38**	**48**

Table 3.7: Satellite Capacity Utilization and Projections within Sub-Saharan Region

	PROJECTED NUMBER OF 36MHz TRANSPONDERERS UTILIZATION FOR NIGERIA AND SUB-SAHARAN AFRICA				
USER GROUP	**2004**	**2007**	**2010**	**2015**	**2020**
NIGERIA	**20**	**30**	**48**	**58**	**70**
AFRICA (SUB-SAHARAN)	**65**	**80**	**95**	**110**	**140**

The revenues due from NewSkies direct sales to customers in Nigeria is about US$14m yearly representing 60% of New Skies revenues from Africa and ranks 4th in the world in terms of country revenues for the company. The estimate is considered conservative because it does not include capacity leased from NewSkies by entities outside Nigeria and which are for the purpose of providing communication links to Nigeria. The satellite capacity utilization as at 2004 was provided by international satellite service providers namely Eutelsat, New Skies, Intelsat and the then PanAmSat. 16% of Intelsat revenues come from Africa. The baseline assumptions for projections of utilization was validated and endorsed by stakeholder forums comprising of Government agencies, major commercial and private end-users among which are National Information Technology Development Agency (NITDA), First Bank of Nigeria, MTN (major mobile operator in Nigeria), Nigerian Telecommunications Ltd (NITEL), Zenith Bank, Guaranty Trust Bank PLC, National Emergency Management Agency (NEMA), National Broadcasting Commission (NBC), Nigerian Television Authority (NTA), a host of private television houses i.e Ogun State Television (OGTV) TITV.

3.3.2 Services to be Carried

Expected traffic for the Nigerian Communication Satellite based on utilization pattern, projections and deliberations of the stakeholders’ forum are as follows:

I. Internet Access
II. Broadcasting services for Direct-to-Home (DTH), TV distribution, radio broadcasting, newsgathering etc.
III. Trunking services for domestic, inter-African and international traffic.
IV. Rural communications
V. Corporate and private networks

VI. Defence and security needs

VII. Transponder lease for ISP use and others.

3.3.3 Satellite Technology

Based on the review of the trends of satellite communications technology, a high powered dedicated communication satellite system optimally designed to provide coverage for Nigeria, Africa and Europe will result in cheaper space segment charges for service providers and translate to lower end user costs. The modern communication satellite with high power, long lifetime, high reliability and zonal beams will require use of small dishes as customer premise equipment (CPE), thus lowering the cost of CPEs with the required availability, Quality of Service (QoS) and Quality of Experience (QoE).

3.3.4 Frequency Band Considerations

3.3.4.1 C-Band (4-6GHz)

C-Band has a long heritage for fixed satellite services (FSS) and was considered for existing services and end-users to retain compatibility especially in the VSAT and broadcast sector as well as feeder link. Rain attenuation is not as severe as at higher frequencies such as Ku and Ka band. Though it requires large user terminals with antenna diameters in excess of 1.5 meters.

3.3.4.2 Ku-Band (12-14GHz)

Ku band is the most suitable band for broadband and broadcast services to medium size terminals with antenna sizes from about 0.6m to 1.8m diameter. It is also suitable for feeder link once the feeder link design has sufficient margin to cope with heavy rain fades reaching up to 12dB in certain areas. This can effectively be taken care off with Uplink Power Compensation systems.

3.3.4.3 Ka-Band (18-30GHz)

The Ka-band has a bright future but however bears the risk of bringing the user terminal technology to the market. It is affected by rain and other environmental conditions such as water vapour. Ground terminals as well as innovative payload technology requires continuous research and development for broadband, broadcast and trunking needs with smaller user terminals.

3.3.4.4 Navigation Band (1.5-1.6GHz)

A dedicated part of L-band has been exclusively allocated to Navigation. Such services are in exclusive use considering its importance to security and defence. These parts of the L-band are protected due to its importance for navigation.

3.3.5 General Recommendations on Frequency Bands for a Nigerian Communication Satellite

Provision of broadband and broadcast services in competitive market with the aim of introducing smaller user terminals, higher performances and lower costs implies an all Ku-band satellite as the ideal satellite model in the absence of all other constraints.

Addition of C-band is justified to retain customers currently operating in the C-band range considering its sizeable market.

Inclusion of the Ka band payload is justifiable if Ku-band return channels could not be accommodated as a result of frequency co-ordination constraints particularly over Europe for small user terminals based on a cursory look at the various satellites in the ITU Master Register List (MRL)

Transparent navigation transponder could technically be added to the payload for its potential for the military, aviation and maritime industry to provide augmentation of the GPS system.

However, introduction of the navigation transponder comes with the following penalties:

I. Reduces the remaining capacity of the main payload of the satellite system
II. Increase in schedule complexity and risks of delay of Satellite system delivery
III. Increase in performance risks
IV. Increase in ground segment and operational cost .

Summarily, the frequency bands for the Nigerian Communications Satellite will naturally be a function of compromise between user requirements, budget limitations, frequency co-ordination pressures, strategic considerations and commercial promise/viability.

3.3.6 Coverage Possibility and Capability as well as Frequency Band Options from 42 Degrees East.

From a coverage point of view from the orbital slot 42°E, as illustrated in figure 3.2, addresses key market targets within wealthy pockets of Africa.

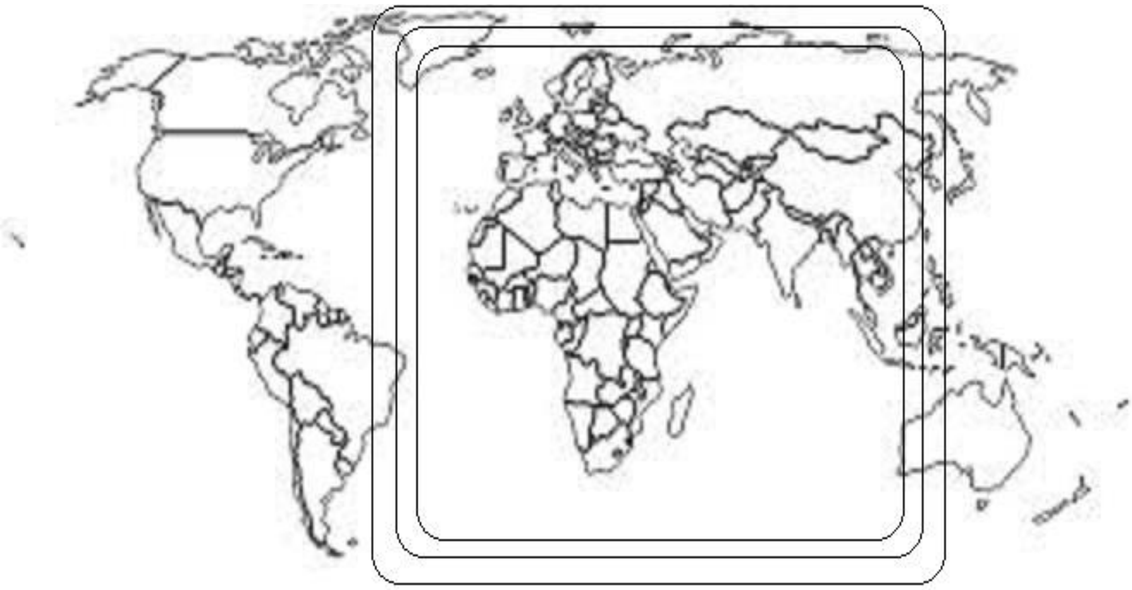


Figure 3.2: Achievable Coverage (footprint) from orbital location 42°E with contours 0°, 5° and 10° elevation (Feasibility Report, 2003).

The minimum coverage requirement includes the West African region, East Africa and Southern Europe, whilst maximum coverage is the whole of Africa including Madagascar and la reunion in the Indian Ocean and at least up to London including optional inclusion of a spot beam coverage on C or Ku band for the Eastern coast of the USA subject to frequency coordination from baseline orbital slot of 42 degrees East.

3.3.7 Final Technical Goals and Objectives of NIGCOMSAT-1 after Considerations of Several Options.

Provision of Broadcast, Telecommunications and Navigational Services over Europe and Central & West Africa delivered through quad band payload (C band, Ku band, Ka band and L band) for a minimum service life of 15 years.

Inclusion of a navigation band is to help improve the performance of the Global Positioning System (GPS) through an augmentation system based on a geostationary navigation transponder for aviation, maritime and defense needs.

Other possible alternatives to explore for Nigeria are:

a. Exclude the navigation payload and join the Galileo project through partnership
b. Consider including the navigation payload in a second-generation communication satellite.

The identified requirements for a Nigerian Communications satellite System is feasible subject to receiving quotations from suppliers within the capability and capacity of the manufacturer's satellite bus. The spacecraft shall be designed to operate in a geostationary orbit and delivered to orbit location of 42ºE. The satellite shall be capable of transmitting and receiving multichannel and multiband signals operated in continuous as well as intermittent modes (i.e voice activation, data burst) to all desirable service areas.

3.3.8 Communication Design Requirement of NIGCOMSAT-1R based on Needs Assessment and DFH-4 Satellite Bus.

The C-band payload with **4** operational channels to cover West Africa.

The Ku-band payload with **14** operational channels, 2 fixed beams over Africa region.

The Ka-band payload shall have **8** operational channels with spot beams to cover Europe, Nigeria and South Africa providing trunking and broadcast capabilities.

The L-band payload for navigation services over Europe and Africa providing a Navigation Overlay Service (NOS) with functionality similar to the European Geostationary Navigation Overlay Service (EGNOS).

The TC & R system shall be provided on C-band and located at Abuja, Nigeria with a backup station in China.

3.3.9 Desired Communications Service Coverage Areas through Polygon Definition to ensure Effective Satellite Service Delivery.

The polygon definition for the service area within the African sub-region based on needs assessment of section 3.2 and earlier sections of section 3.3 of this chapter is presented in table 3.8 using coordinates of African cities for the Ku band West Antenna coverage.

Figure 3.3 shows the result of the service area for Ku band West Antenna Tx/Rx beam using the coordinates of the African cities in Table 3.8 as the edge of the service coverage area. Table 3.9 shows specified cities within the polygon for verification of expected and required communication satellite performance parameters to ensure good quality of service experience.

Table 3. 8: Ku-Band ECOWAS 1(West Africa) Coverage Polygon Points.

POLYGON 1			**POLYGON 2**		
Polygon Point	**Latitude (ºN)**	**Longitude (ºE)**	**Polygon Point**	**Latitude (ºN)**	**Longitude (ºE)**
A1	3.5	5.5	A2	4.5	6.0
B1	4.5	3.5	B2	6.5	4.0
C1	5.0	1.0	C2	6.5	1.0
D1	4.5	-2.0	D2	5.0	-2.8

E1	5.0	-4.5	E2	5.5	-4.5
F1	4.0	-8.0	F2	4.5	-7.5
G1	7.5	-12.5	G2	7.0	-10.5
H1	12.0	-16.4	H2	10.0	-13.7
I1	15.0	-17.6	I2	13.8	-16.5
JI	16.7	-16.5	J2	16.0	-15.5
KI	15.0	0.0	K2	15.5	-12.0
L1	13.0	9.0	L2	15.5	-8.0
M1	13.7	13.0	M2	13.0	-1.0
N1	12.5	15.5	N2	8.5	4.0
O1	10.0	15.6	O2	8.5	6.0
P1	9.5	14.6	P2	6.5	8.5
Q1	7.5	16.0	Q2	5.5	8.7
R1	5.0	15.2	R2	4.7	8.2
S1	2.8	16.6	A2	4.5	6.0
T1	1.5	16.7			
U1	0.0	14.6			
V1	-2.5	14.4			
W1	-4.0	11.2			
X1	-1.5	8.8			
Y1	2.8	8.0			
A1	3.5	5.5			

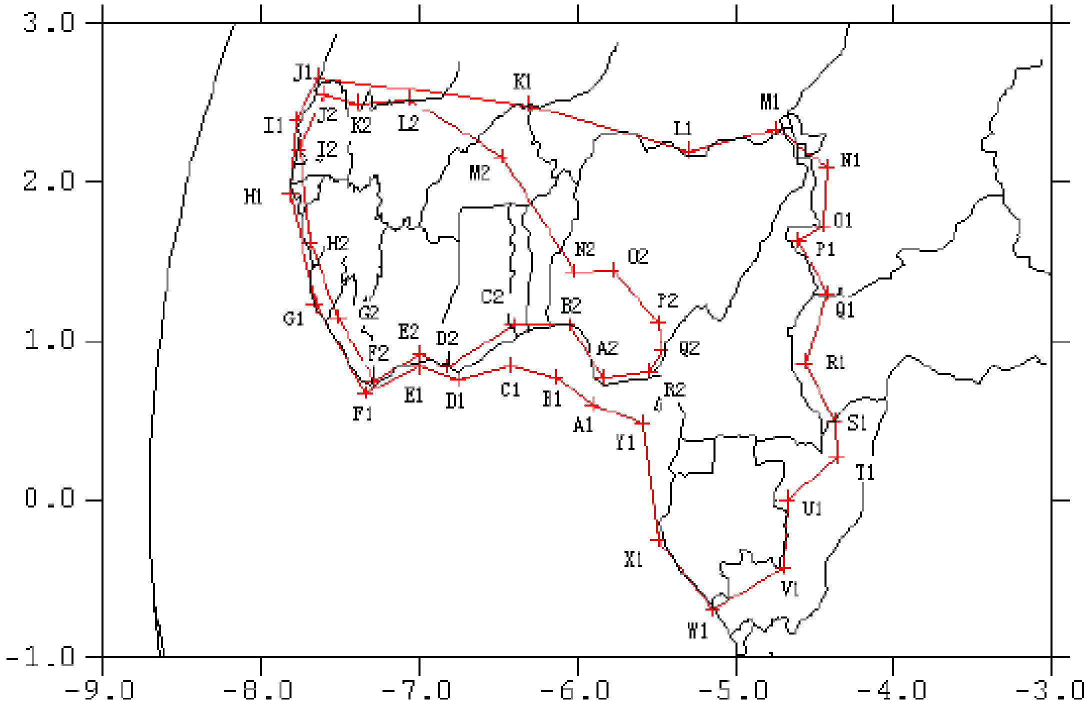


Figure 3.3: Ku Band ECOWAS 1 (West Africa) Specified Polygons

Table 3.9: Ku-Band ECOWAS1(West Africa) Region with Specified Cities

VALID CITIES FOR IN-ORBIT TEST RESULTS		
CITIES IN AFRICA	**Latitude (ºN)**	**Longitude (ºE)**
LAGOS	6.45	3.40
KANO	12.00	8.50
ZARIA	11.12	7.73
KADUNA	10.55	7.45
MAIDUGURI	11.85	13.17
BAUCHI	10.32	9.83
SOKOTO	13.07	5.27
OGBOMOSHO	8.13	4.25
IBADAN	7.28	3.50
PORT HARCOURT	4.72	7.08
BAMAKO	12.65	-8.00
NIAMEY	13.52	2.12
DAKAR	14.67	-17.43
BISSAU	11.85	-15.58
CONAKRY	9.50	-14.72
FREETOWN	8.50	-13.25

MONROVIA	6.30	-10.78
ABIDJAN	5.32	-4.03
LIBREVILLE	0.38	9.45
ACCRA	5.55	-0.22
LOME	6.13	1.22
NOVO	6.48	2.62
YAOUNDE	3.87	11.52
OUAGADOUGOU	12.37	-1.52
FORT-LAMY	12.12	15.05
KINSHASA	4.30	15.30

Similarly, table 3.10 represents the coordinates of African cities for the Ku band East Antenna coverage, while figure 3.4 shows the expected coverage service area of Ku band East Antenna Tx/Rx beam defined using the coordinates of such African cities as the edge of coverage. Table 3.11 shows specified cities within the polygon for verification of expected and required communication satellite performance parameters to ensure a good quality of service experience as well.

Table 3.10: Ku-Band ECOWAS 2 (East Africa) Coverage Polygon Points.

POLYGON POINTS FOR EAST AFRICAN ANTENNA (ECOWAS 2)		
Polygon Point	**Latitude (ºN)**	**Longitude (ºE)**
A1	4.3	6.0
B1	6.0	4.5
C1	6.0	2.0
D2	10.0	2.5
E2	12.5	7.0
F2	13.0	13.0
G2	12.5	16
H2	8.0	17.5
I2	4.5	20
J2	0.0	18.5
K2	-5.0	16
L2	-7.5	18
M2	-6.5	21.5
N2	-12.5	28.5
O2	-16.0	30.5

P2	-22.0	-30
Q2	-25.5	26.0
R2	-29.3	19.5
S2	-29.3	16.0
T2	-23.0	13.8
U2	-17.5	11.0
V2	-11.0	13.2
W1	-4.0	11.0
X1	-1.5	8.8
Y1	4.0	9.2
A1	4.3	6.0

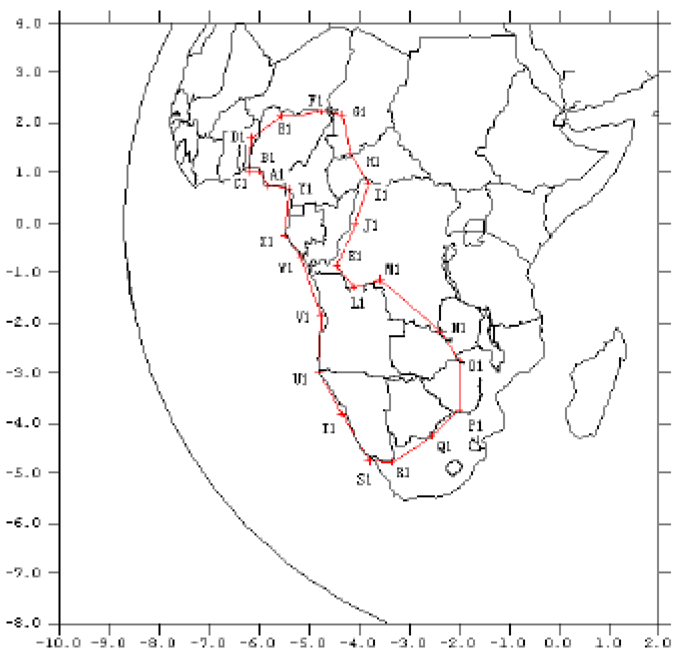


Figure 3.4: Ku Band ECOWAS 2 (East Africa) Specified Polygons

Table 3.11: Ku-Band Ecowas2 Region with Specified Cities

VALID CITIES FOR IN-ORBIT TEST RESULTS		
CITIES IN AFRICA	**Latitude (ºN)**	**Longitude (ºE)**
LAGOS	6.45	3.40
KANO	12.00	8.50
ZARIA	11.12	7.73
KADUNA	10.55	7.45
MAIDUGURI	11.85	13.17

BAUCHI	10.32	9.83
OGBOMOSHO	8.13	4.25
IBADAN	7.28	3.50
PORT HARCOURT	4.72	7.08
NOVO	6.48	2.62
YAOUNDE	3.87	11.52
LIBREVILLE	0.38	9.45
FORT-LAMY	12.12	15.05
BANGUI	4.37	18.58
KINSHASA	4.30	15.30
PORT NOIRE	-4.80	11.85
LUANDA	-8.50	13.33
LUSAKA	-15.42	28.28
BULAWAYO	-20.15	28.60
KANYE	-24.98	25.32
WINDHOEK	-22.50	17.00

For the new beam covering Eastern Asia, table 3.12 represents the coordinates of Asian cities for the Ku band East Asia Antenna coverage while figure 3.5 shows expected coverage service area of Ku band East Asia Antenna Tx/Rx beam defined using the coordinates of the Asian cities as the edge of coverage.

Table 3.12: Ku-Band (Kashi) East Asian Beam Coverage Polygon Points.

POLYGON 1			**POLYGON 2**		
Polygon Point	**Latitude (ºN)**	**Longitude (ºE)**	**Polygon Point**	**Latitude (ºN)**	**Longitude (ºE)**
A1	70.95	40.52	A2	62.01	30.72
B1	73.81	41.66	B2	64.44	36.86
C1	76.48	40.88	C2	67.44	42.07
D1	76.28	37.51	D2	72.79	48.18
E1	74.72	32.75	E2	76.50	49.53
F1	72.89	29.74	F2	82.38	50.61
G1	71.62	28.97	G2	84.12	47.29
H1	69.38	29.58	H2	83.63	43.22
I1	68.21	30.96	I2	81.08	39.50
J1	67.41	33.88	J2	78.67	36.06
K1	68.06	37.03	K2	76.25	31.35
			L2	74.80	27.03

			M2	75.04	24.33
			N2	73.87	21.66
			O2	71.55	19.79
			P2	68.73	20.21
			Q2	67.22	19.73
			R2	64.43	20.28
			S2	62.20	22.59
			T2	61.57	26.53

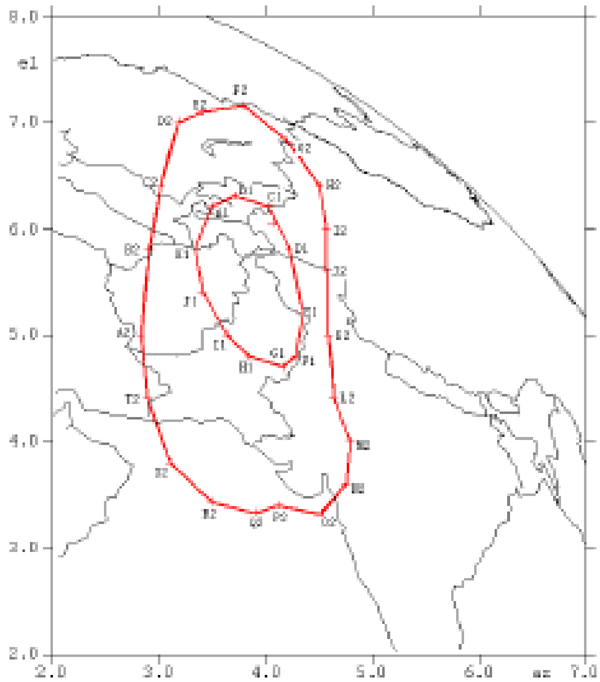


Figure 3.5: Ku- Band East Asia (Kashi Beam) Specified Polygons

For the C-band payload, table 3.13 represents the coordinates of African cities for the C band Antenna coverage on the earth deck of the spacecraft while figure 3.6 shows expected coverage service area of C Band ECOWAS 1 Antenna Tx/Rx beam defined using the coordinates of such African cities as the edge of coverage. Table 3.14 shows specified cities within the polygon for verification of expected and required communication satellite performance parameters to ensure good quality of service.

Table 3.13 : C-Band ECOWAS 1(West Africa) Coverage Polygon Points.

POLYGON 1			**POLYGON 2**		
Polygon Point	**Latitude (ºN)**	**Longitude (ºE)**	**Polygon Point**	**Latitude (ºN)**	**Longitude (ºE)**

A1	4.3	6.0	A1	4.3	6.0
B1	6.0	4.5	B2	3.0	10.0
C1	6.0	2.0	C2	2.5	15.0
D1	4.5	-2.0	D2	4.5	24.5
E1	5.0	-4.5	E2	0.0	28.0
F1	4.0	-8.0	F2	-5.0	29.5
G1	7.5	-13.0	G2	-4.0	38.0
H1	12.0	-17.0	H2	1.0	41.0
I1	15.0	-18.0	I2	9.0	40.0
JI	16.7	-16.5	J2	15.0	36.0
KI	15.7	-5.0	K2	17.0	31.0
L1	14.5	5.0	L2	11.0	26.5
M1C	12.0	14.0	M2	13.7	13.0
N1C	10.0	13.0	N2	16.5	5.0
O1C	6.3	11.2	O2	17.5	-5.0
P1C	6.7	9.8	P2	17.5	-17.0
Q1C	4.5	9.0	J1	16.7	-16.5
A1	4.3	6.0	K1	15.7	-5.0
			L1	14.5	5.0
			M1C	12.0	14.0
			N1C	10.0	13.0
			O1C	6.3	11.2
			P1C	6.7	9.8
			Q1C	4.5	9.0
			A1	4.3	6.0

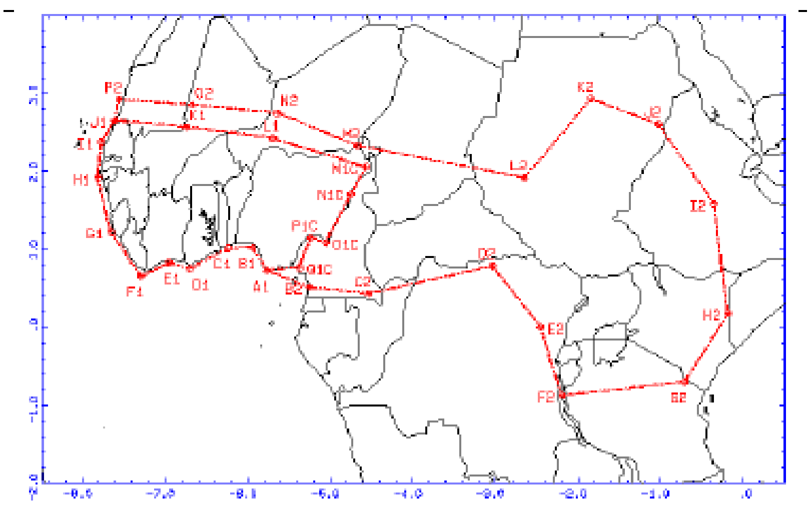


Figure 3.6: C Band ECOWAS 1 (West Africa) Specified Polygons

Table 3.14: C-Band ECOWAS-1 Region with Specified Cities

POLYGON 1			POLYGON 2		
CITIES	**Latitude (ºN)**	**Longitude (ºE)**	**CITIES**	**Latitude (ºN)**	**Longitude (ºE)**
LAGOS	6.45	3.40	NOUAKCHOTT	18.10	-15.95
KANO	12.00	8.50	TINBUKTU	16.77	-3.02
ZARIA	11.12	7.73	ZINDER	13.80	8.98
KADUNA	10.55	7.45	YAOUNDE	3.87	11.52
MAIDUGURI	11.85	13.17	BANGUI	4.37	18.58
BAUCHI	10.32	9.83	FORT-LAMY	12.12	15.05
SOKOTO	13.07	5.27	KHARTOUM	15.60	32.53
OGBOMOSHO	8.13	4.25	ADDIS ABABA	9.00	38.83
IBADAN	7.28	3.50	NAIROBI	-1.28	36.82
PORT HARCOURT	4.72	7.08	KAMPALA	0.32	32.42
BAMAKO	12.65	-8.00	KIGALI	-1.95	30.67
OUGADOUGOU	12.37	-1.52	BUJUMBURA	-3.38	29.37
NIAMEY	13.52	2.12	MWANZA	-2.52	32.90
DAKAR	14.67	-17.43	KISANGANI	2.48	26.58
BISSAU	11.85	-15.58			
CONAKRY	9.50	-14.72			
FREETOWN	8.50	-13.25			
MONROVIA	6.30	-10.78			
ABIDJAN	5.32	-4.03			
ACCRA	5.55	-0.22			
LOME	6.13	1.22			
NOVO	6.48	2.62			

Coverage over Europe with Ka Band was considered appropriate for Internet contents and trunking to help meet the Nigerian telecommunications and broadcast needs of the people with complementary alternative to South Africa as well. Figure 3.7 shows the service area for Ka TX/Rx antenna beams centered around Europe, Nigeria and South Africa respectively with consideration for cities that can serve as Gateways for trunking.

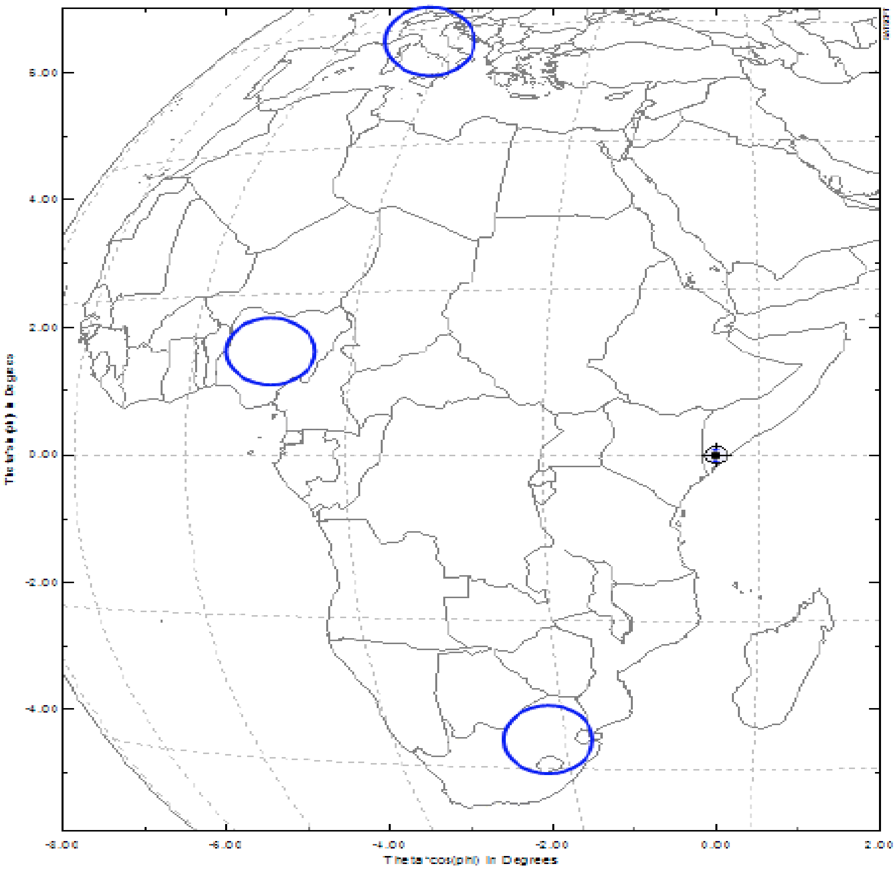


Figure 3.7: Ka Transmit and Receiving Beam Coverage over Europe, Nigeria and South Africa.

The inclusion of the navigation band to help improve the performance of the Global Positioning System (GPS) through the augmentation system based on a geostationary navigation transponder was considered important for aviation, maritime and defence needs not only for Nigeria but the African continent and thus Figure 3.8 shows the receive coverage service area for the Navigation band with a boresight angle of ±7.5 degrees, while figure 3.9 shows the uplink service area for C-band navigation with Northern Africa including Nigeria and Europe as a minimum.

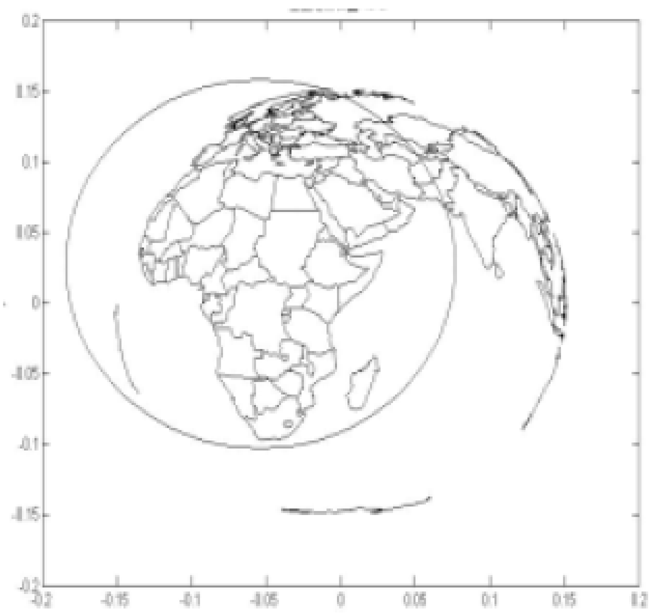


Figure 3.8: C-Band (Uplink) Navigation Antenna Beam coverage

Figure 3.9: L Band (Downlink) Navigation Antenna Beam Coverage

3.3.10 Allotted Frequencies

The following frequency ranges for Ku-band, C-band, Ka-band and L-band were allotted by the International Telecommunication Union (ITU) for NIGCOMSAT-1(R) operations and services.

Ku-band:

Down link 12.50～12.75 GHz   Uplink 14.00～12.50GHz

C-band:

Down link 3.40～3.70 GHz Uplink 6.425～6.725GHz

Ka-Band:

Down link 19.0～20.20 GHz Uplink 28.8～30.0GHz

L-Band:

Down link 1166.45～1577.42MHz Uplink 6629.45～6700.42MHz

3.3.11 Channel Assignment and Polarization

Ku band Channels receive in one polarization and transmit in the orthogonal polarization. The channel plan is based on 35.5 MHz frequency separation between centers of adjacent channels and the bandwidth of each channel is 31.5MHz.

Table 3.15 and 3.16 shows the uplink and downlink Ku-band frequency and polarization plan respectively with frequency reuse through polarization to double the 250MHz frequency block from International telecommunications Union (ITU) to 500MHz. The conversion frequency from Uplink to downlink is 1500MHz. Figure 3.10 shows the block diagram of the frequency block utilization for 14 active transponders with their respective center frequencies and 4 MHz band separation with adjacent transponders.

Table 3.15: Uplink Frequency and Polarization Plan of Ku-Band

Bands	**Frequency**	**Polarization**	**Bands**	**Frequency**	**Polarization**
Channel 1	14018	H	Channel 8	14018	V
Channel 2	14053.5	H	Channel 9	14053.5	V
Channel 3	14089	H	Channel 10	14089	V
Channel 4	14124.5	H	Channel 11	14124.5	V
Channel 5	14160	H	Channel 12	14160	V
Channel 6	14195.5	H	Channel 13	14195.5	V
Channel 7	14231	H	Channel 14	14231	V

Table 3.16: Downlink Frequency and Polarization Plan of Ku-Band

Bands	**Frequency**	**Polarization**	**Bands**	**Frequency**	**Polarization**
Channel 1	12518	V	Channel 8	12518	H
Channel 2	12553.5	V	Channel 9	12553.5	H
Channel 3	12589	V	Channel 10	12589	H
Channel 4	12624.5	V	Channel 11	12624.5	H
Channel 5	12660	V	Channel 12	12660	H
Channel 6	12695.5	V	Channel 13	12695.5	H
Channel 7	12731	V	Channel 14	12731	H

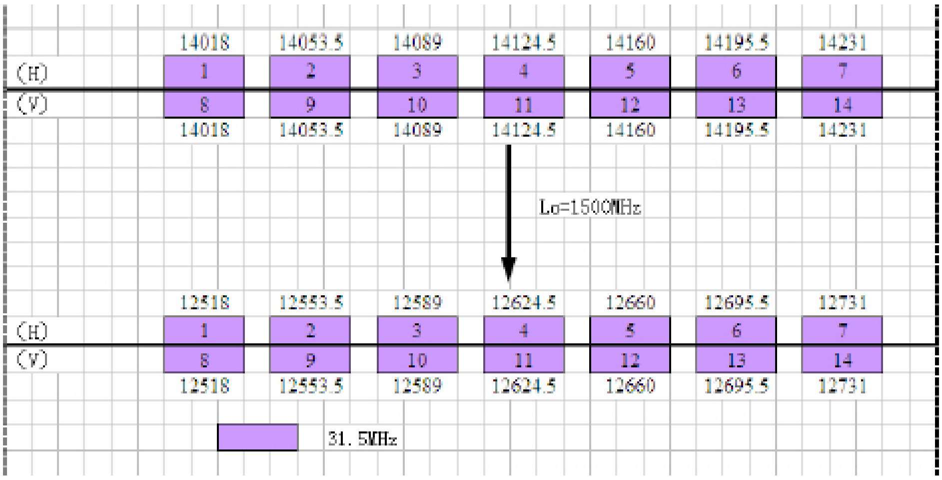


Figure 3.10: Block diagram of frequency block utilization for 14 active transponders with their respective center frequencies and 4 MHz band separation with adjacent transponders.

C band Channels shall be FSS payload for reception and transmission of circularly polarized RF signals. The channel plan is based on a 40MHz frequency separation between centers of adjacent channels and the bandwidth of each channel is 36MHz.

Table 3.17 and 3.18 shows the uplink and downlink C-band frequency and polarization plan respectively. The conversion frequency from Uplink to downlink is 3025MHz. Figure 3.11 shows the block diagram of the frequency block utilization for 4 active transponders with their respective center frequencies and 4 MHz band separation with adjacent transponders.

Table 3.17: Uplink Frequency and Polarization Plan of C-Band

Bands	**Frequency**	**Polarization**
Telecommand 1	6429	RHCP
Telecommand 2	6439	RHCP
Channel 1	6465	RHCP
Channel 2	6505	RHCP
Channel 3	6545	RHCP
Channel 4	6585	RHCP

Table 3.18: Downlink Frequency and Polarization Plan of C-Band

Bands	**Frequency**	**Polarization**
Channel 1	3440	LHCP

Channel 2	3480	LHCP
Channel 3	3520	LHCP
Channel 4	3560	LHCP
Telemetry 1	3696.84	LHCP
Telemetry 2	3694.14	LHCP

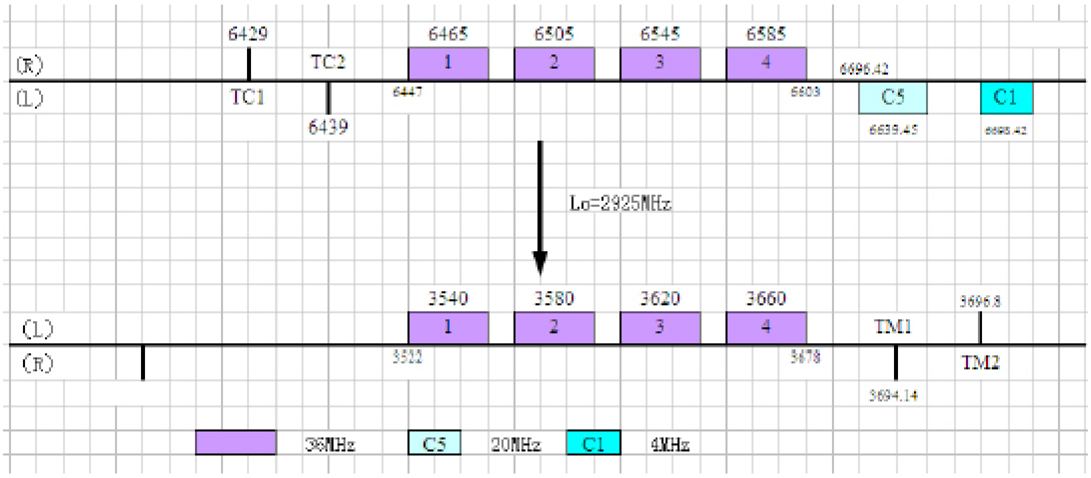


Figure 3.11: Block diagram of the frequency block utilization for 4 active transponders with their respective center frequencies and 4 MHz band separation with adjacent transponders.

The Ka-band Channels with bi-directional capability has a channel planned with a 150MHz frequency separation between the centers of adjacent channels and a bandwidth of 120MHz per transponder with circularly polarized RF signals. Table 3.19 and 3.20 shows the uplink and downlink Ka-band frequency and polarization plan respectively. The conversion frequency from Uplink to downlink is 9800MHz. Figure 3.12 shows the block diagram of the frequency block utilization for 8 active transponders with their respective center frequencies and 30 MHz band separation with adjacent transponders, while figure 3.13 shows the channel plan for trunking and broadcasting over the spot beams.

Table 3.19: Uplink Frequency and Polarization Plan of Ka-Band

Bands	**Frequency**	**Polarization**
Channel 1	28875	LHCP
Channel 2	29025	LHCP
Channel 3	29175	LHCP
Channel 4	29325	LHCP
Channel 5	29475	LHCP
Channel 6	29625	LHCP
Channel 7	29775	LHCP

Channel 8	29925	LHCP

Table 3.20: Downlink Frequency and Polarization Plan of Ka-Band

Bands	Frequency	Polarization
Channel 1	19075	RHCP
Channel 2	19225	RHCP
Channel 3	19375	RHCP
Channel 4	19525	RHCP
Channel 5	19675	RHCP
Channel 6	19875	RHCP
Channel 7	19975	RHCP
Channel 8	20125	RHCP

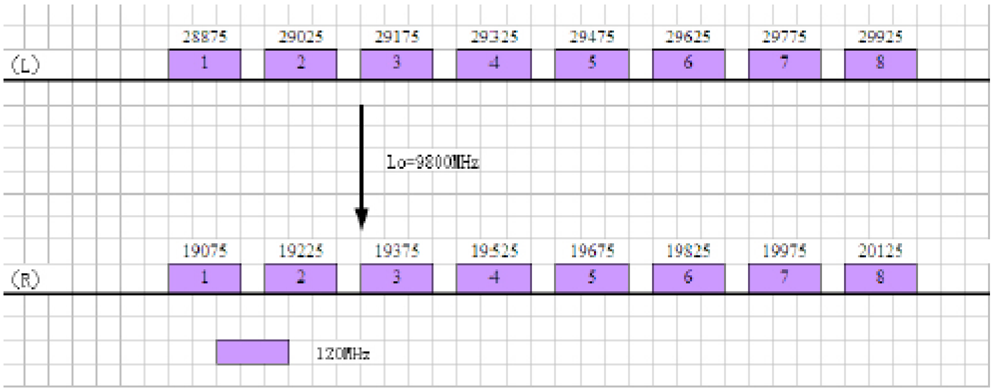


Figure 3.12: Block diagram of the Ka-Band frequency block utilization for 8 active transponders with their respective center frequencies and 30 MHz band separation with adjacent transponders.

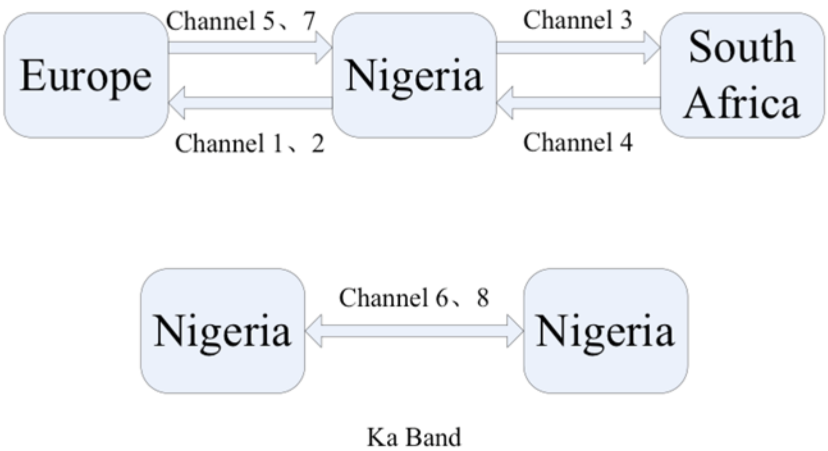


Figure 3.13: Ka-band channel configuration for Trunking and Broadcasting.

L-Band Navigation payload is meant to augment the Global Positioning System (GPS) signals on L1 and L5 frequencies. It is a Navigation Overlay Service (NOS) with functionality similar to the European Geostationary Navigation Overlay Service (EGNOS). The frequency assignment and polarization plan for both uplink and downlink frequencies is as presented in table 3.21

Table 3.21: Frequency and Polarization Plan of L-Band (Navigation).

Channel	Frequency MHz	Polarization	Bandwidth
C1 - Uplink	6698.42	LHCP	4 MHz
C5 - Uplink	6639.45	LHCP	20 MHz
L1 - Downlink	1575.42	RHCP	4 MHz
L5 - Downlink	1176.45	RHCP	20 MHz

3.3.12 Service Capability and Minimum Performance Parameters of the Nigerian Communications Satellite (NIGCOMSAT-1R)

All RF performances to be fulfilled inside the angular aperture defined by the contour as required.

The C-band payload with **4** operational channels and coverage over West Africa.

The Ku-band payload with **14** operational channels, 2 fixed beams over West , East Africa and East Asia.

The Ka-band payload with **8** operational channels and spot-beams over Europe, Nigeria and South Africa and with trunking and broadcast capability.

The L-band payload shall serve as Navigation Overlay Service (NOS) with functionality similar to the European Geostationary Navigation Overlay Service (EGNOS) over Europe and Africa.

3.3.12.1 Service Capabilities

TV Broadcast (C, Ku and Ka Band)

Audio Broadcast (C, Ku and Ka Band)

Telecommunication (C, Ku and Ka Band)

Navigation Services (L-Band)

3.3.12.2 Minimum Figure of Merit (G/T) for all the Bands

The G/T for the specified coverage shall be equal or more than the value defined in table 3.22.

Table 3.22: Minimum Figure of Merit (G/T) for the Bands

Ku Band

G/T	(dB/K)
Beam 1 Zone 1 (West Antenna)	+5.0
Beam 1 Zone 2 (West Antenna)	+4.5
Beam 2 (East Antenna)	+1.0
Beam 3 Zone 1 (Kashi East Asia Beam)	+6.5
Beam 3 Zone 2 (Kashi East Asia Beam)	+2.0

C Band

G/T	(dB/K)
Beam 1 Zone 1	1.0
Beam 1 Zone 2	-5.0

Ka Band

G/T	(dB/K)
Ka Band Spot Beam Europe	+12 (Peak)
Ka Band Spot Beam Nigeria	+12 (Peak)
Ka Band Spot Beam South Africa	+12 (Peak)

L Band

G/T	(dB/K)
Navigation	-12

3.3.12.3 Minimum Equivalent Isotropic Radiated Power (EIRP) for all the Bands

The EIRP inside the specified coverage shall be equal or more than the value defined in table 3.23 below.

Table 3.23: Minimum Equivalent Isotropic Radiated Power(EIRP) for the Bands

Ku Band

EIRP	dBW
Beam 1 Zone 1	53
Beam 1 Zone 2	52.5

Beam 2	48.0
Beam 3 Zone 1	52
Beam 3 Zone 2	48

C Band

EIRP	dBW
Beam 1 Zone 1	41
Beam 1 Zone 2	35

Ka Band

EIRP	dBW
Ka Beam Europe	52
Ka Beam Nigeria	55
Ka Beam South Africa	52

L Band

EIRP	dBW
L5 EIRP	26.2
L1 EIRP	28.1

3.3.12.4 Saturated Flux Density (SFD) Requirements(Minimum and Maximum Range) for the Bands

SFD Requirement for Ku-Band **-(77+G/T)dBw/m^2~ -(97+G/T) dBw/m^2**

SFD Requirement for C-Band **-(78.5+G/T)dBw/m^2 ~ -(98.5+G/T) dBw/m^2**

SFD Requirement for Ka-Band **-(63+G/T)dBw/m^2 ~ -(83+G/T) dBw/m^2**

SFD Requirement for L-Band **-80dBw/m^2 ~ -96 dBw/m^2**

3.4 Conclusion

The use of communication satellite for Internet, Digital Television transmission and reception and the consequence of Voice over IP (VoIP) increased the demands for communication satellite resources and on a long-term contract beyond even the life span of a typical satellite.

Satellite communications technology remains a tremendous force for change and innovation. The global coverage of the Olympics had more than 3 billion viewers. Communication Satellite and satellite communications technology has helped to create a world community and global village. From over $300 trillion annual electronic fund transfers to hundreds of millions of airline reservations with communication satellites playing critical roles in finance, business and international trades especially in countries and regions with inadequate terrestrial communications. Despite growth in fibre optic cables, over 50% of all overseas communications is satellite based. More than 200 countries and territories rely on about 200 satellites for domestic, regional and/or global linkages, defence communications, direct broadcast services, navigation, data collection, mobile communications etc. Generally, the satellite communications industry is a $15 billion per year business as at 2003 and was expected to grow to $30 billion per year within the next decade.

The Nigerian market for satellite equipment and services is significant and conservatively estimated at over US$250 million yearly and growing.

Communication Satellites and satellite communications technologies remains one of the fastest growing areas for data communications as it is a valuable supplement and alternative to existing and available terrestrial ICT networks. A regional and domestic Communications Satellite with suitable design specifications and zonal coverages to Nigeria, African continent and coverage over Europe for Internet content and trunking will help meet the telecommunications and broadcast needs of the people especially the financial sectors, manufacturing, oil and gas, commercial companies, government agencies, transport and tourism including schools and Universities. Conclusively, the Nigerian Communications Satellite project is an economically viable project as a regional communication satellite service provider in Sub-Saharan Africa. The Insurance replacement Nigerian Communications Satellite (NIGCOMSAT-1R) after de-orbiting of the first Nigerian Communications Satellite (NIGCOMSAT-1) as a result of identified single point of failure (SPF); provided the opportunity to modify and optimize the payload and its repeaters to reflect the growing and prevailing market trends and potential beyond the African continent.

CHAPTER 4:

The Redesign of Nigerian Communications Satellite Insurance Replacement (NIGCOMSAT-1R) with Navigation Capability for Optimal Performance and Test Results.

4.0 Summary:

The design and implementation of Nigerian Communications Satellite takes cognizance of the situational analysis made in chapter three as regards needs assessment and feasibility with service coverage area (footprints of NIGCOMSAT-1(R) designed to provide qualitative telecommunications and broadcast needs within Sub-Saharan Africa and beyond including a Navigational piggyback payload repeater. The Insurance replacement Nigerian Communications Satellite (NIGCOMSAT-1R) after de-orbiting of the first Nigerian Communications Satellite (NIGCOMSAT-1) as a result of an irreparable identified single point of failure (SPF) of an on-board subsystem provided the opportunity to modify and optimize the payload of the COMSAT to reflect the growing and prevailing market trends and potential beyond the African continent. The design performance is presented and the actual performance measured during In-Orbit Test (IOT) is also presented.

4.1 Antennas and Payload Design of Nigerian Communications Satellite (NIGCOMSAT-1R) to meet Specified Regional Performance Requirements and Service Coverage Areas.

4.1.1 Summary of Results for Ku Band Antenna and Payload Design of NIGCOMSAT-1R

Figure 4.1 gives overview block diagram of the Ku band to meet the designed configuration. Details of Ku-Band Antenna and Payload Design with Gain and Loss Computations is provided in Appendix A.

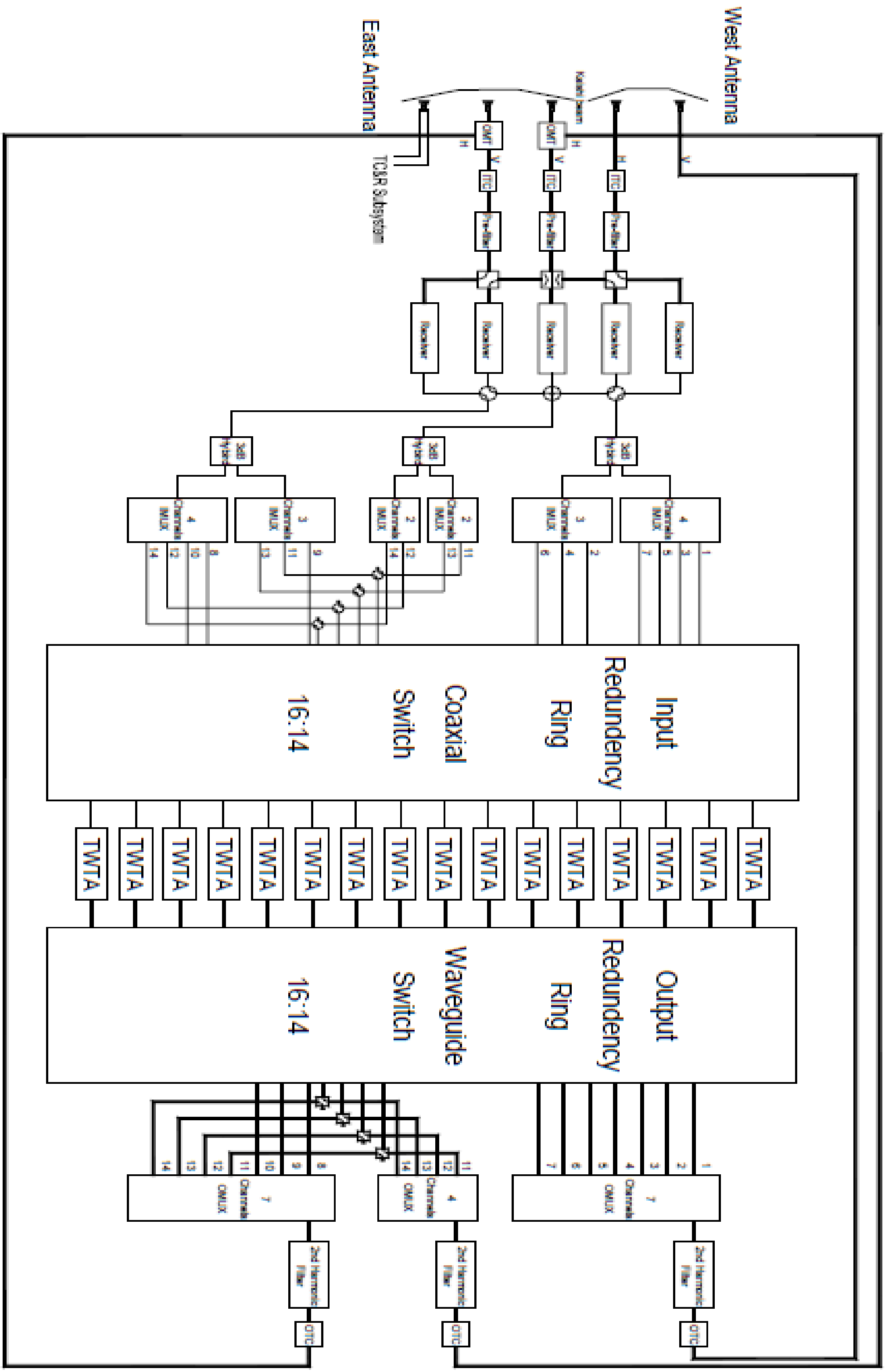


Figure 4.1: Block Diagram Overview of Ku-Band Payload Repeater.

The Ku band antenna analytic design for the service area coverage for beam 1(ECOWAS1-WEST AFRICA) and beam 2 and beam 3 (ECOWAS 2-EAST AFRICA & KASHI EAST ASIA

BEAM) are presented in table 4.1 and 4.2 respectively. Detailed computations are provided in table A1.2 and A1.4 of Appendix A. The antennas for the Ku-band are Gregorian type, deployable double off-set reflector with shaped main paraboloid reflector as illustrated in figure 4.2.

The main reflector surface optimization was computed with TICRA POS4 and the antenna patterns are computed with GRASP8 software.

Table 4.1: Analytical Parameters of Ku-Band Beam 1 Antenna of NIGCOMSAT-1R

Items	**Ku-Band Beam 1(West Antenna)**
Coverage Zone	7 Operational Channels of 31.5MHz over fixed beam1 covering West African Subregion.
Frequency bandwidth (MHz)	Transmit: downlink, 12500.0MHz-12750MHz Receive: uplink, 1400MHz-14500MHz
Gain(dBi)	32.8 (Downlink); 32.6 (Uplink) Reference to Table A1.4 and A1.2 respectively of Appendix A.
Polarization	Dual Linear Polarization
Antenna type (unit:m)	Gregorian type, deployed double off-set reflector Shaped main paraboloid reflector: D=3.0 X 2.2 Shaped elliptic-sphere sub-reflector: Deployed double off-set reflector Receive and transmit feed shared Design software: GRASP 8-Co-polarization coverage area POS-4- Shaped reflector design
Feed Assembly	Feed assembly: Radial corrugated horn Square-circular transition Orthogonal Mode Transducer (OMT) Low pass filters High Pass Filters Dual Polarization Ports Design and simulated Software ANSOFT-HFSS

Table 4.2: Analytical Parameters of Ku-Band Beam 2 Antenna of NIGCOMSAT-1R

Items	**Ku-Band Beam 2 (East Antenna)**
Coverage Zone	7 Operational Channels of 31.5MHz over fixed beam 2 covering East Africa.
Frequency bandwidth (MHz)	Transmit: downlink, 12500.0MHz-12,750MHz Receive: uplink, 14000MHz-14250MHz
Gain(dBi)	28.4 (Downlink); 29.1 (Uplink) Reference to Table A1.4 and A1.2 respectively of Appendix A
Polarization	Dual Linear Polarization
Antenna type (unit:m)	Gregorian type, deployed double off-set reflector [1] Shaped main paraboloid reflector: D=2.6 X2.16 Shaped elliptic-sphere sub-reflector: Deployed double off-set reflector Receive and transmit feed shared Design software: GRASP 8-Co-polarization coverage area POS-4- Shaped reflector design
Feed Assembly	Feed assembly: Radial corrugated horn Square-circular transition Orthogonal Mode Transducer (OMT) Low pass filters High Pass Filters Dual Polarization Ports Design and simulated Software ANSOFT-HFSS

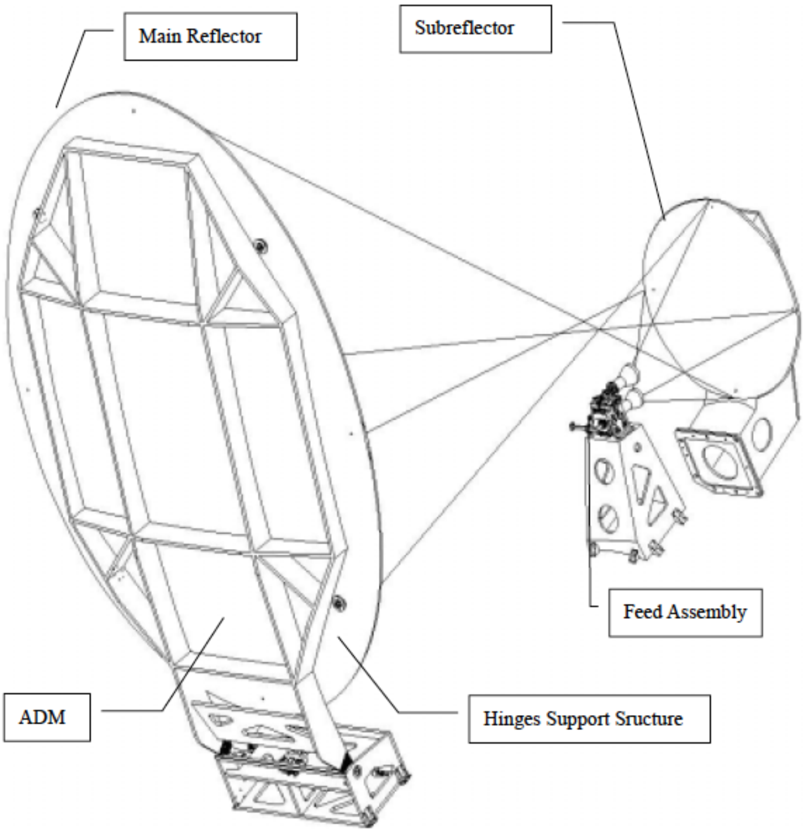


Figure 4.2: The Composition and Configuration of Ku-Band Deployable Double Off-set West Antenna for the desired coverage.

The resulting XPI Contours at 12.625GHz, Corresponding XPI Contours at 14.125GHz, G/T and EIRP of Ku Band West Antenna (ECOWAS 1) of NIGCOMSAT-1R based on African cities coverage are provided in Figure 4.3, 4.4, 4.4 and 4.6 respectively. Table 4.3 is verification of the satellite performance on a region-by-region basis.

Similarly, the G/T and EIRP of Ku Band East Antenna (ECOWAS 2) are provided in Figure 4.7 and 4.8 respectively as well as G/T and EIRP of East Asian Beam as figure 4.9 and 4.10 respectively using Ku-Band East Antenna with deployable double off-set reflector as shown in figure 4.11.

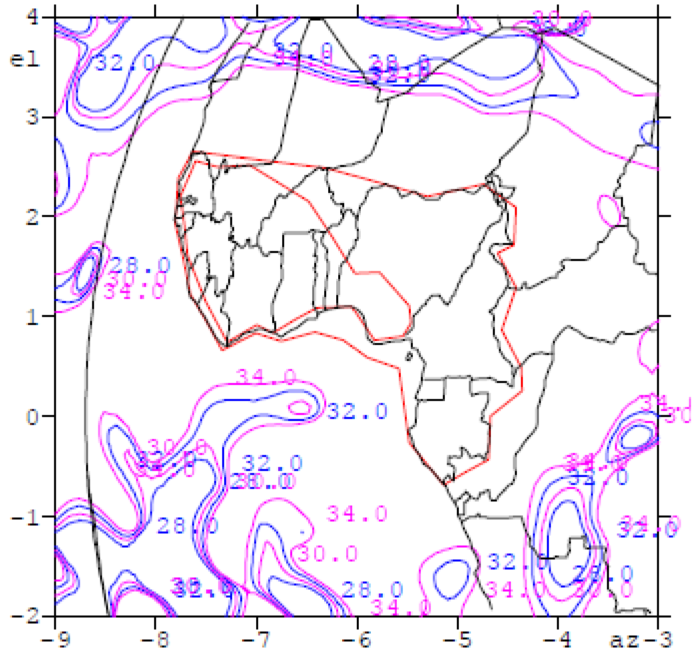


Figure 4.3:XPI Contours of West Antenna Ku Band (ECOWAS 1) of NIGCOMSAT-1R at 12.625GHz (Downlink).

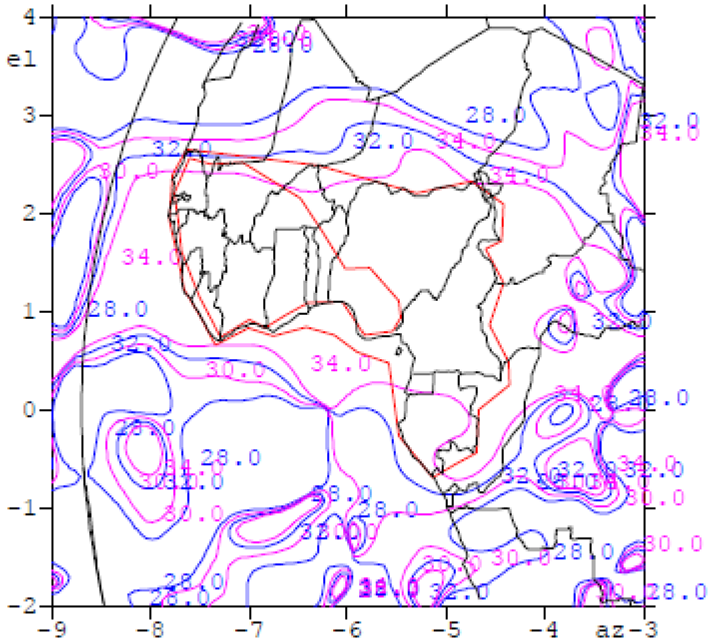


Figure 4.4: XPI Contours of West Antenna Ku Band (ECOWAS 1) of NIGCOMSAT-1R at 14.125GHz (Uplink)

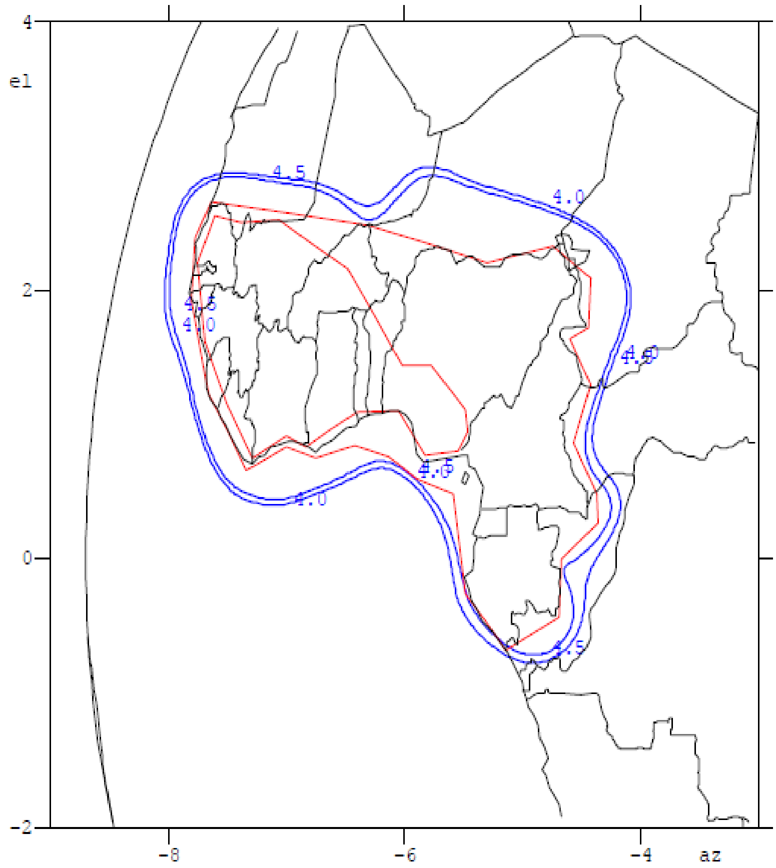


Figure 4 5: G/T Contour of Ku Band West Antenna (ECOWAS 1) of NIGCOMSAT-1R.

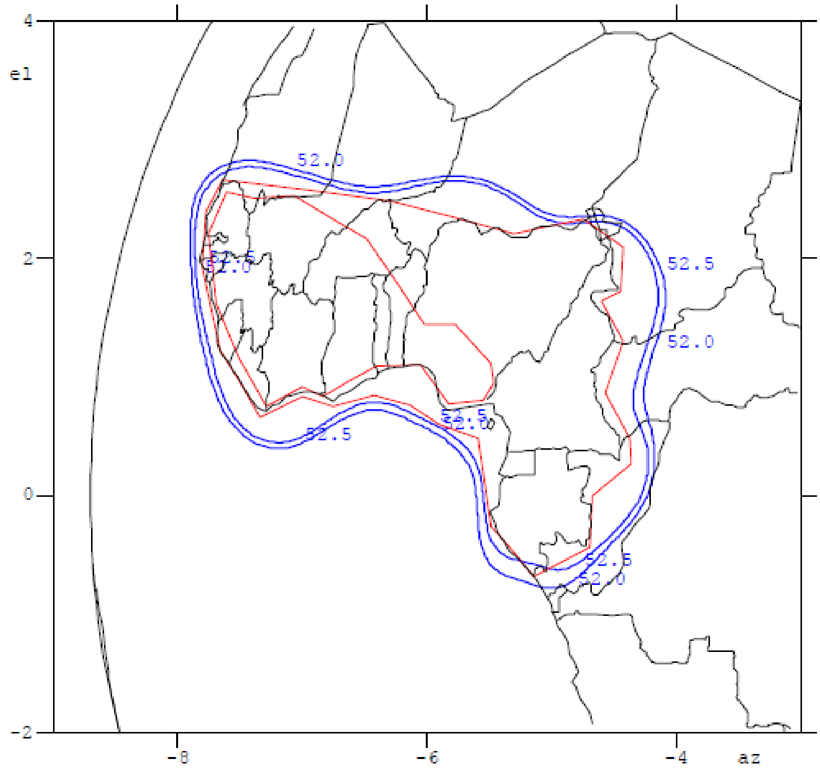


Figure 4.6: EIRP Contour of Ku Band West Antenna (ECOWAS 1) of NIGCOMSAT-1R.

Table 4.3: Ku-Band West Antenna (ECOWAS 1) and East Antenna (ECOWAS 2) Specified African City Performance Parameters Verification Table.

Ku-Band West Antenna (ECOWAS 1) Specified African City Performance Parameters Verification Table (Table A1.2 and A1.4 of Appendix A).

		Downlink		Uplink	
	City	EIRP	XPI	G/T	XPI
1	Lagos	53	34	5.5	32
2	Kano	53.2	33	5.7	30
3	Zaria	52.5	32.8	5.7	30
4	Kaduna	52.8	33.1	6.1	30
5	Maiduguri	53.2	30	5.9	29.7
6	Bauchi	52.5	32.9	6.2	30
7	Sokoto	53.7	33	5.9	30
8	Ogbomosho	53	33	6.5	31
9	Ibadan	53	34	5.5	31
10	P.Harcourt	53	34.8	5.5	30
11	Bamako	54.2	33	5.5	30
12	Niamey	52.5	33	4.8	29.5
13	Dakar	51.9	30	5.2	30
14	Bissau	52.4	31	5.2	30.5
15	Conakry	51.7	31	4.2	32
16	Freetown	52.1	33	4.8	33
17	Monrovia	52.5	32.1	5.4	31
18	Abidjan	53.4	33	5.4	30
19	Libreville	52.1	32.8	4	29.4
20	Accra	52.7	33	4.8	30
21	Lome	52.9	33	5.3	32.5
22	Novo	53	34	5.7	33
23	Yaounde	52.8	30.3	5.5	30
24	Ouagadougou	53.2	32.3	4.7	29.3
25	Fort-Lamy	52.4	30	5.3	30
26	Kinshasa	52.2	30	4	30
27	Abuja	52.6	36	6.4	33.5
28	Kogi				

Ku-Band East Antenna (ECOWAS 2) Specified African City Performance Parameters Verification Table (Table A1.2 and A1.4 of Appendix A).

		Downlink		Uplink	
	City	EIRP	XPI	G/T	XPI
1	LAGOS	48.8	32	2.3	31.5
2	Kano	49.3	30	2.5	29.5
3	Zaria	49.5	30.8	2.5	30
4	Kaduna	49.7	31.5	2.5	30
5	Maiduguri	50.2	30	3.6	29.5
6	Bauchi	50.2	30.5	2.5	29.5
7	Ogbomosho	49.3	33	2.6	31
8	Ibadan	49	33	2.6	31
9	P.Harcourt	49.4	30.5	1.9	31
10	Novo	48.4	33	2.3	32
11	Yaounde	50.3	32.5	2	30
12	Libreville	51.4	32.5	3.6	32
13	Fort-Lamy	50	30	3.1	29
14	Bangui	51	32	4.1	30.5
15	Kinshasa	50.4	30	2.1	30
16	Pt. Noire	50.7	33	3.6	33
17	Luanda	50.9	34	3.8	33
18	Lusaka	49.8	29.5	3.1	31.5
19	Bulawayo	50.1	28.5	3.1	30.5
20	Kanye	49.8	28.5	1.9	29
21	Windhoek	50.1	29.5	1.9	31
22	Abuja	50.1	33	2.4	30.5
23	Kogi				

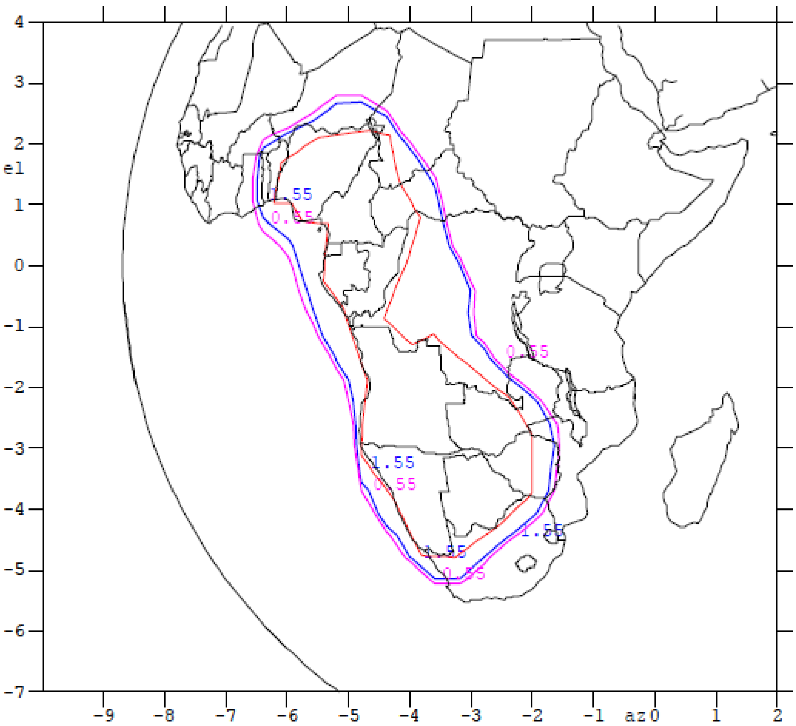


Figure 4.7: G/T Contour of Ku Band East Antenna (ECOWAS 2) of NIGCOMSAT-1R.

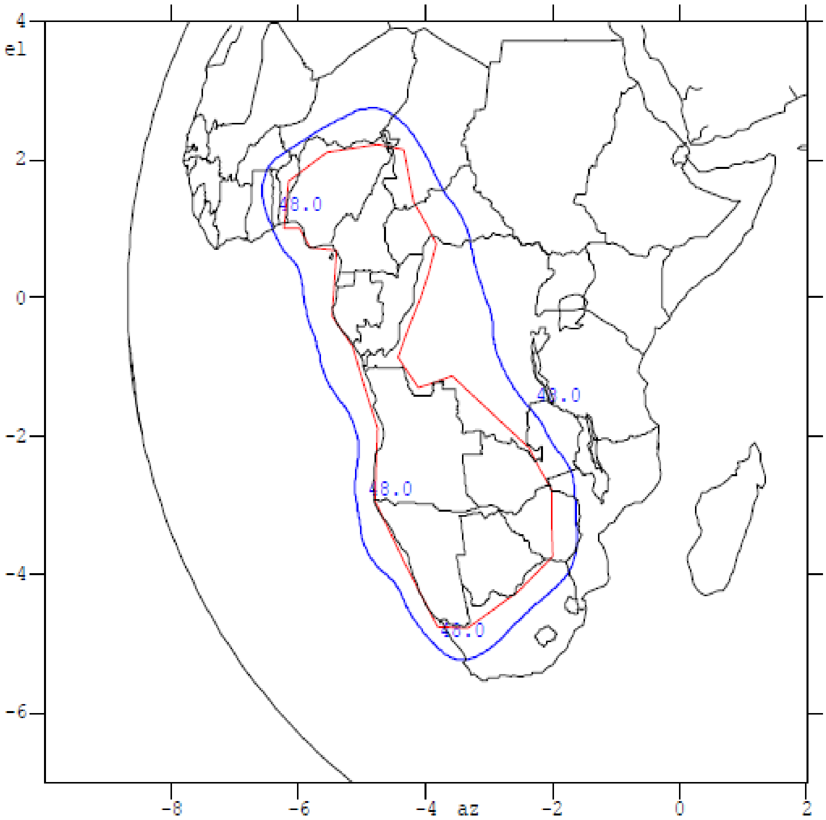


Figure 4.8: EIRP Contour of Ku Band East Antenna (ECOWAS 2) of NIGCOMSAT-1R.

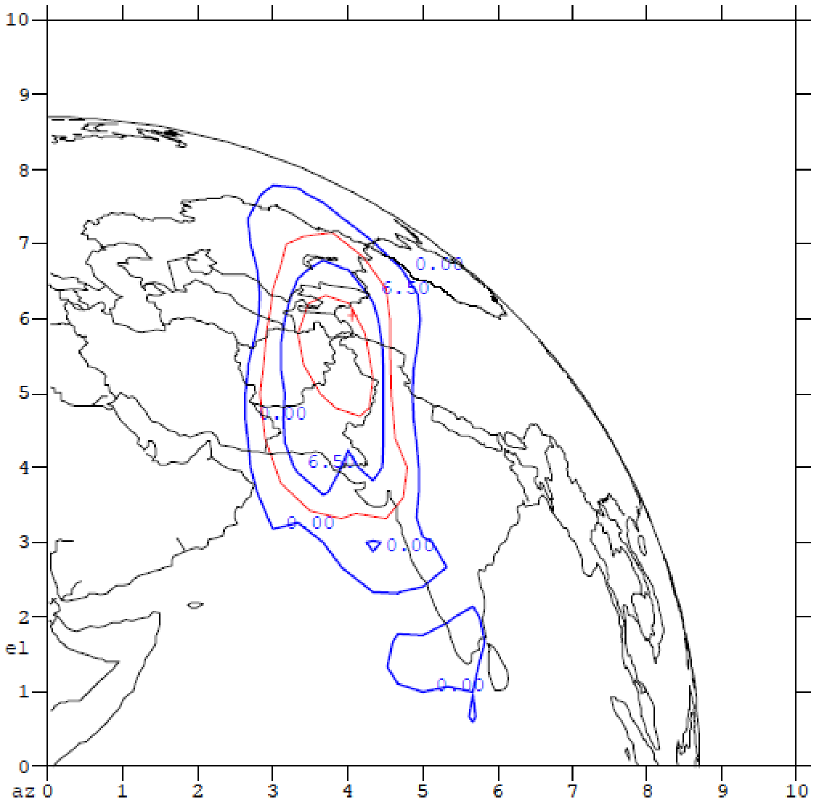


Figure 4.9: G/T Contour of East Asian Beam using Ku Band East Antenna (ECOWAS 2) of NIGCOMSAT-1R.

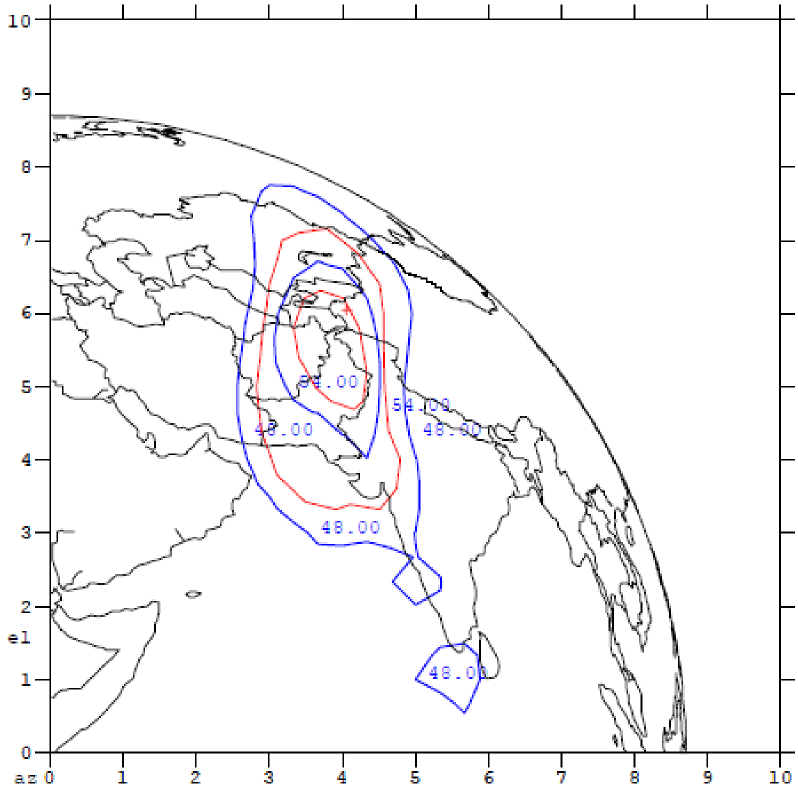


Figure 4.10: EIRP Contour of East Asian Beam using Ku Band East Antenna (ECOWAS 2) of NIGCOMSAT-1R.

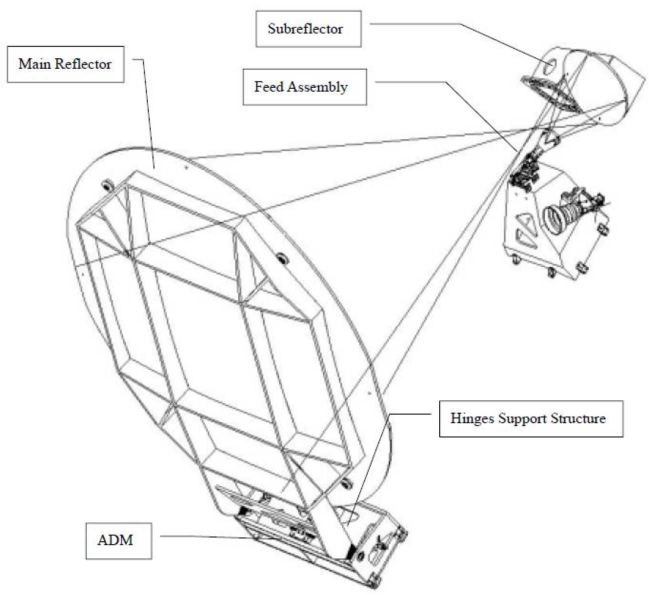


Figure 4.11: The Composition and Configuration of Ku-Band Deployable Double Off-set East Antenna for the Desired Coverage.

4.1.2 Summary of Results for C Band Antenna and Payload Design of NIGCOMSAT-1R

Figure 4.12 gives overview block diagram of the C band to meet the designed configuration. Details of C-Band Antenna and Payload Design with Gain and Loss Computations is provided in Appendix B.

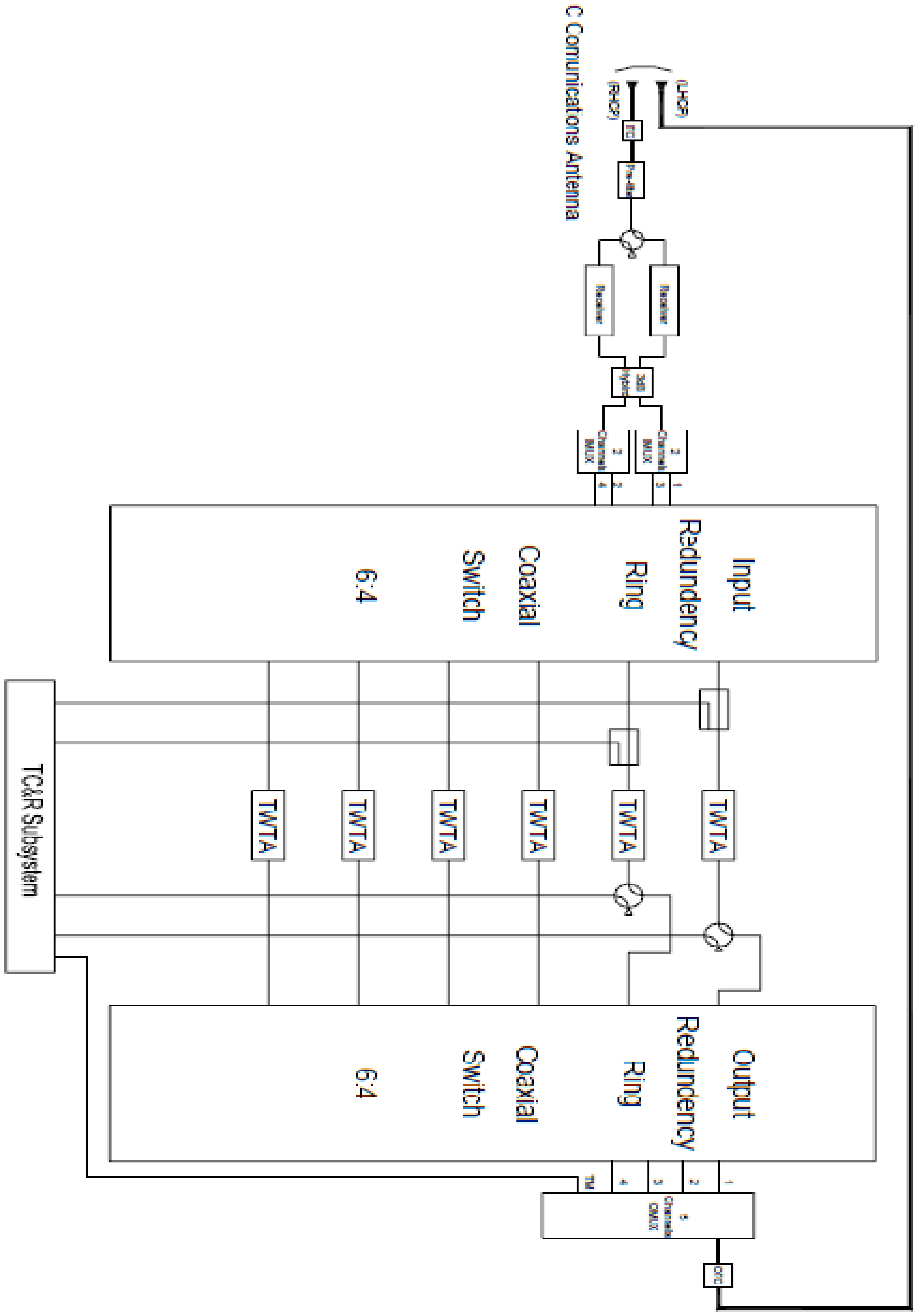


Figure 4.12: Block Diagram Overview of C-Band Payload Repeater.

The C band antenna analytic design for the service area coverage for beam 1(ECOWAS1-WEST AFRICA) is presented in table 4.4. The antenna for the C-band is Shaped single off-set reflector with circular aperture as illustrated in figure 4.13.

The analytical design was perfected and optimized with the use of TICRA POS 4 software while Grasp 8 software was used to compute the antenna patterns including co-polarization coverage gain.

Table 4.4: Analytical Parameters of C-Band Beam 1 Antenna of NIGCOMSAT-1R

Items	**C-Band Beam 1(West Antenna)**
Coverage Zone	4 Operational Channels of 36MHz over fixed beam1 covering West African Subregion.
Frequency bandwidth (MHz)	Transmit: downlink, 3400.0MHz-3600MHz Receive: uplink, 6425MHz-6625MHz
Gain(dBi)	26.0 (Downlink); 23.0 (Uplink) Reference to Table B2.4 and B2.2 respectively of Appendix B
Polarization	Circular Polarization
Antenna type (unit:m)	Off-set single shaped reflector Shaped main paraboloid reflector: D=1.6 Receive and transmit feed shared Design software: GRASP 8-Co-polarization coverage area Pos-4- Shaped reflector design
Feed Assembly	Feed assembly: Ring-loaded corrugated horn Orthogonal Mode Transducer (OMT) Low Pass Rectangular Waveguide Filters High Pass Rectangular Waveguide Filters Tx/ Rx Polarizers Design and simulated Software ANSOFT-HFSS

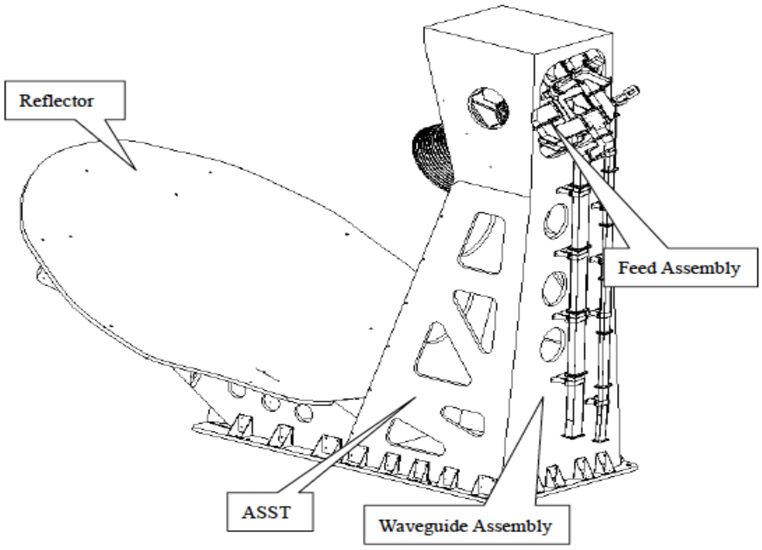


Figure 4.13: The Composition and Configuration of C-Band Single Off-set Antenna for the desired coverage.

The resulting Gain Contours at 3.45GHz, Corresponding Gain Contours at 6.475GHz, XPI Contours at 3.45GHz, Corresponding XPI Contours at 6.475GHZ, G/T and EIRP of C Band West Antenna (ECOWAS 1) of NIGCOMSAT-1R based on African cities coverage are provided in Figure 4.14, 4.15, 4.16, 4.17, 4.18 and 4.19 respectively. Table 4.5 is verification of the satellite performance on a region-by-region basis.

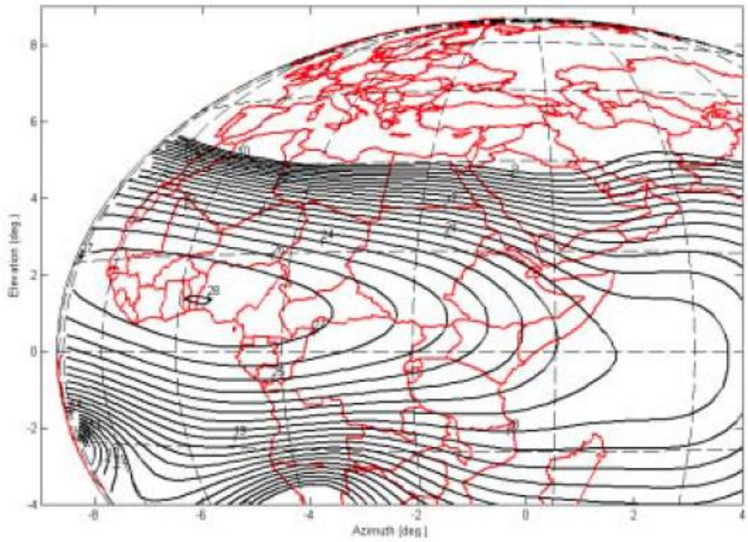


Figure 4.14: Gain Contours of C-Band Antenna (ECOWAS 1) of NIGCOMSAT-1R at 3.45GHz.

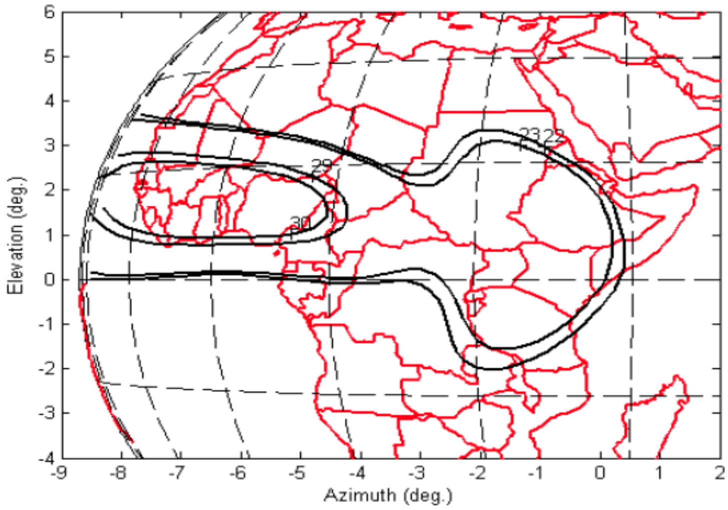


Figure 4.15: Gain Contours of C-Band Antenna (ECOWAS 1) of NIGCOMSAT-1R at 6.475GHz.

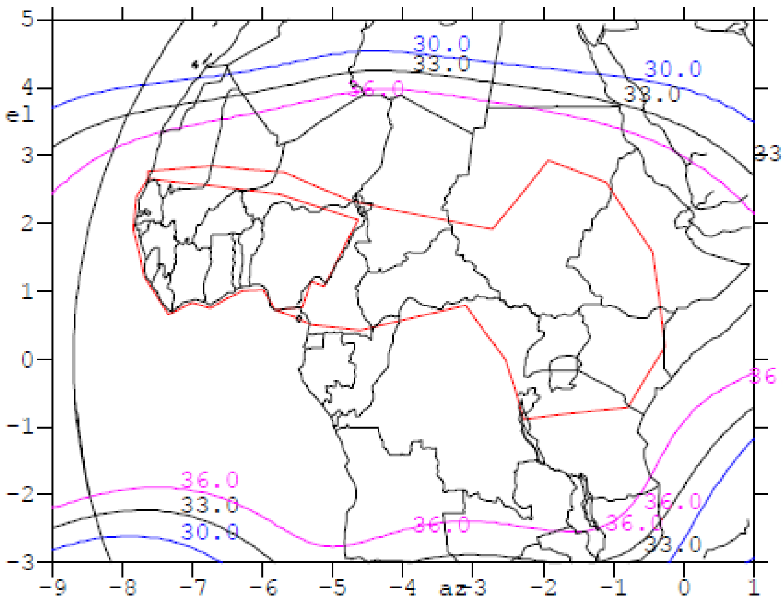


Figure 4.16: XPI Contours of C-Band Antenna (ECOWAS 1) of NIGCOMSAT-1R at 3.45GHz (Downlink).

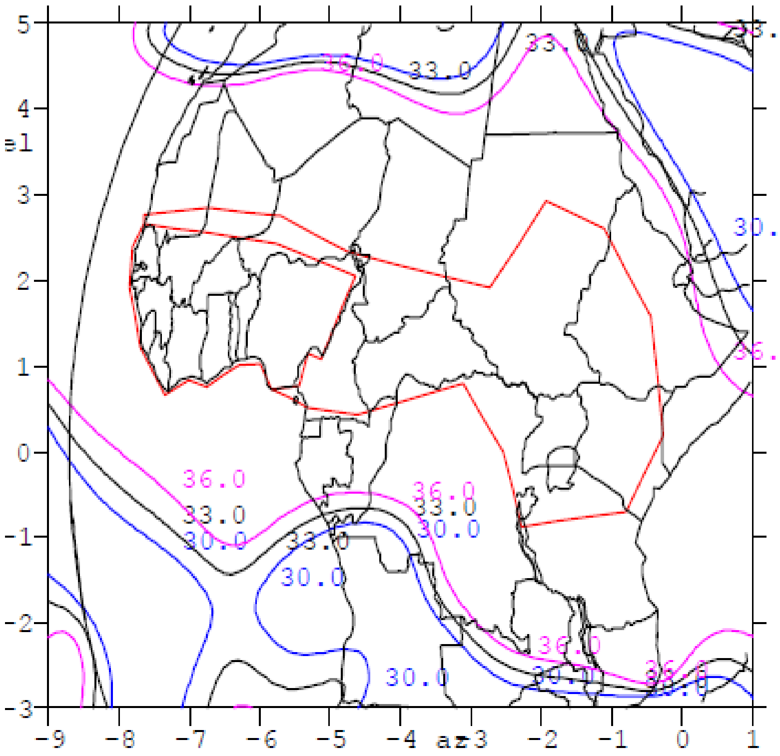


Figure 4.17: XPI Contours of C-Band Antenna (ECOWAS 1) of NIGCOMSAT-1R at 6.475GHz (Uplink).

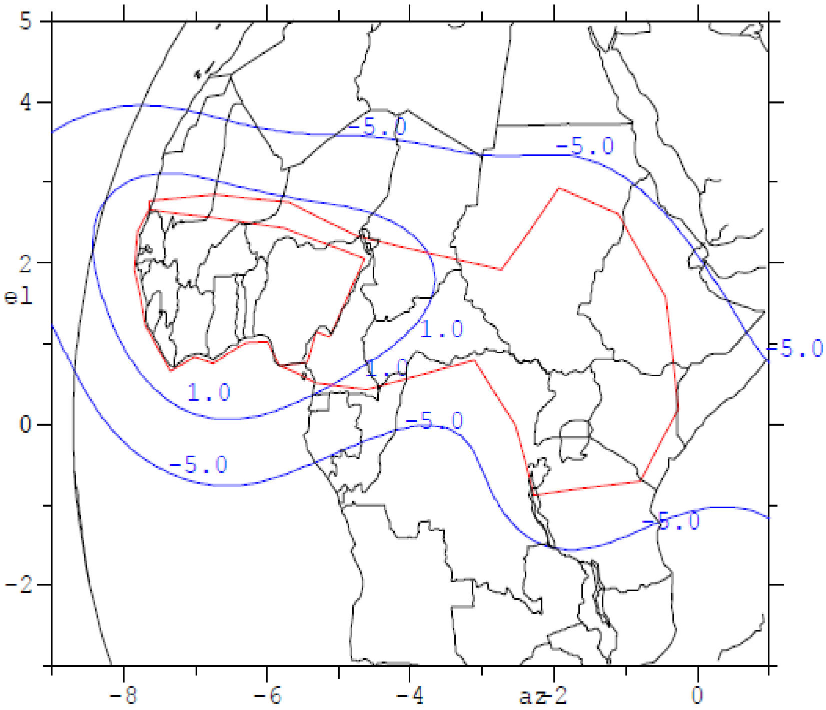


Figure 4.18: G/T Contour of C Band Antenna (ECOWAS 1) of NIGCOMSAT-1R.

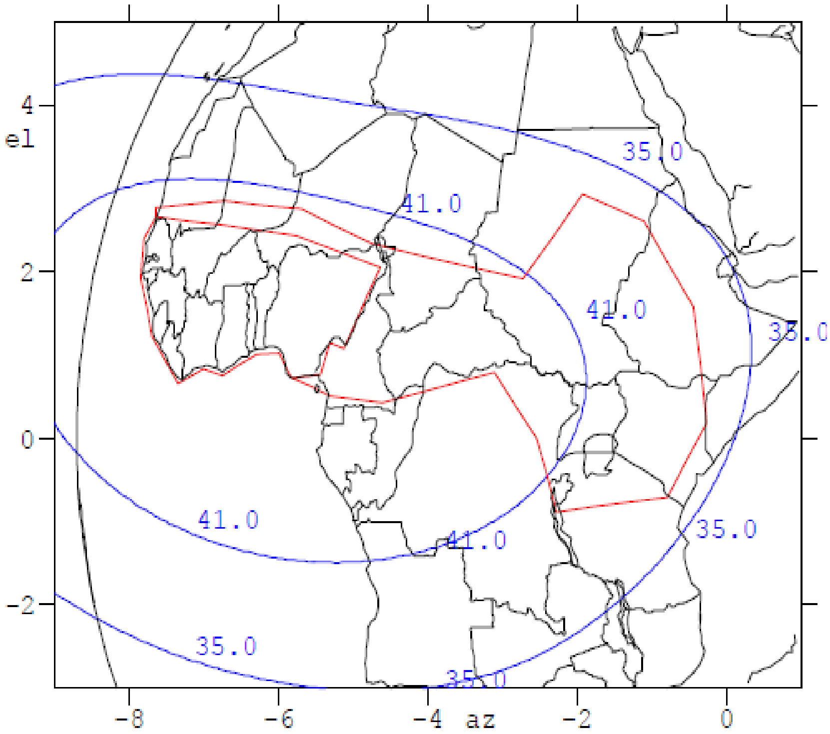


Figure 4.19: EIRP Contour of C Band Antenna (ECOWAS 1) of NIGCOMSAT-1R.

Table 4.5: C-Band Antenna Specified African City Performance Parameters Verification Table.

		Downlink		Uplink	
	City	EIRP	XPI	G/T	XPI
1	Lagos	42.8	30	2.8	30
2	Kano	42.1	31	2.6	31
3	Zaria	42.4	31	3	31
4	Kaduna	42.5	31	3.1	31
5	Maiduguri	41.8	31	1.7	31
6	Bauchi	42.4	31	2.9	31
7	Sokoto	42.1	31	2.3	31
8	Ogbomosho	42.8	31	3.3	31
9	Ibadan	42.8	30	3.1	30
10	P.Harcourt	42.6	30	1.5	30
11	Bamako	42.7	32	3	32
12	uagadougou	42.7	32	3.1	32
13	Niamey	42.2	31	2.3	32
14	Dakar	42.4	33	1.8	31
15	Bissau	42.7	33	2.6	31
16	Conakry	42.7	32	2.6	31
17	Freetown	42.7	32	2.6	31
18	Monrovia	42.5	31	2.1	30
19	Abidjan	42.6	31	2	30
20	Accra	42.7	30	2.3	30
21	Lome	42.7	30	2.6	30
22	Novo	42.8	30	2.8	30
23	Nouakchott	41.6	33	-0.2	32
24	Tinbuktu	41.5	32	0	32
25	Zinder	41.5	31	1.3	31
26	Yaounde	42.3	29	0.5	30
27	Bangui	41.7	29	-0.8	30
28	Fort-Lamy	41.4	31	0.8	31
29	Khartoum	37.2	32	-3.9	30
30	Adis Ababa	38.2	30	-4	30
31	Nairobi	38.6	29	-3.1	30
32	Kampala	39.5	29	-3	30
33	Kigali	39.1	29	-3.7	30
34	Bujumbura	38.8	28	-4.4	29
35	Mwanza	38.8	29	-3.2	30
36	Kisangani	40.6	29	-4	30
37	Abuja	42.6	31	3.2	31
38	Okene				

4.1.3 Summary of Results for Ka Band Antennas and Payload Design of NIGCOMSAT-1R

Figure 4.20 gives overview block diagram of the Ka band to meet the designed configuration. Details of Ka-Band Antenna and Payload Design with Gain and Loss Computations is provided in Appendix C.

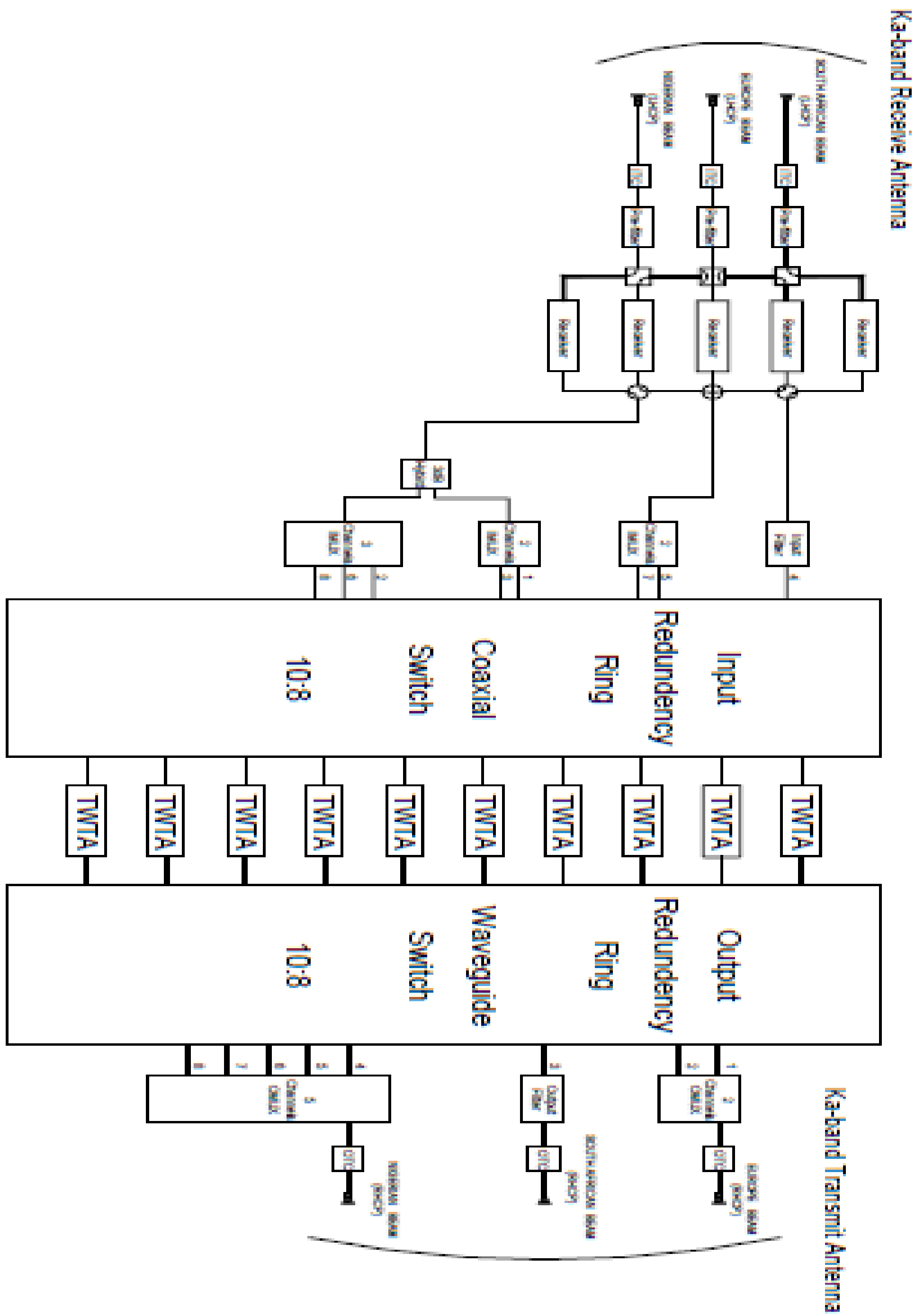


Figure 4.20: Block Diagram Overview of Ka-Band Payload Repeater.

The Ka band transmit antenna is a standard 0.7m off-set reflector antenna mounted on the earth deck of NIGCOMSAT-1R Spacecraft. The Antenna composition is illuminated by three feeds located at the focal plane and provides service coverages for Europe, Nigeria and South Africa as shown in figure 4.21. The analytic design for the service area spot beam coverages by the Ka band Transmit Antenna is presented in table 4.6.

The performance of the polarizer assembly was analyzed and optimized using Ansoft HFSS, while antenna pattern are computed by TICRA GRASP 8 Software including co-polarization coverage gain.

Similarly, the Ka Receive antenna is a standard, 0.65m off-set reflector antenna mounted on the earth deck of NIGCOMSAT-1R spacecraft. The Antenna composition is also illuminated by three feeds located at the focal plane and provides service coverages for Europe, Nigeria and South Africa. The analytic design for the service area spot beam coverages by the Ka band Transmit Antenna is presented in table 4.7.

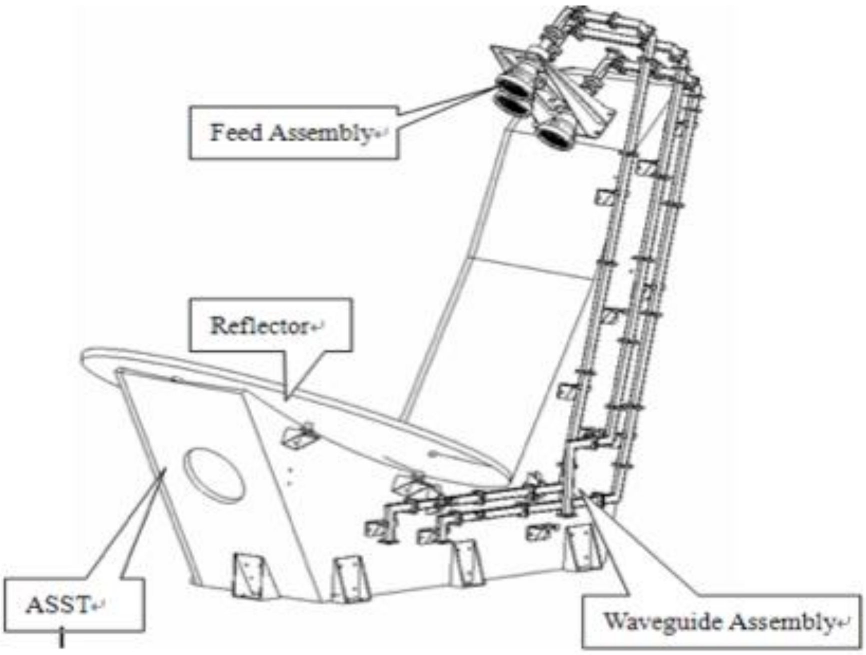


Figure 4.21: Composition and Configuration for Ka Transmit or Receive Antenna.

Table 4.6: Analytical Parameters of Ka-Band Transmit Antenna of NIGCOMSAT-1R

Items	**Ka Band Transmit Antenna**
Coverage Zone	The coverage is defined by boresight angle of ±8.7 degrees.
Frequency bandwidth (GHz)	Transmitting: downlink, 19.0 ~ 20.2
Gain(dBi)	Downlink 36.1 Reference to Table C3.4 of Appendix C
Polarization	Downlink: RHCP

Mount Plane	Southeast of the Earth Deck of Spacecraft.
Antenna type and feed	Φ 700mm(Circle) off-set reflector Antenna is illuminated by three feeds located in the focal plane and provides coverage for Europe, Nigeria and South Africa through spot beams. Each feed is made of a radially corrugated horn, rectangle-to-circular transition and polarizer. The performance of the polarizer assembly is analyzed by Ansoft HFSS.

Table 4.7: Analytical Parameters of Ka-Band Receive Antenna of NIGCOMSAT-1R

Items	**Ka Band Receive Antenna**
Coverage Zone	The coverage over Europe and Africa is defined by boresight angle of ±7.5 degrees.
Frequency bandwidth (GHz)	Receiving: uplink, 28.8 ~ 30.0
Gain(dBi)	Uplink 38.3 Reference to Table C3.2 of Appendix C
Polarization	Uplink: LHCP
Mount Plane	Northwest of the Earth Deck of Spacecraft.
Antenna type and feed	Φ 650mm(Circle) off-set single reflector Antenna is illuminated by three feeds located in the focal plane and provides coverage for Europe, Nigeria and South Africa through spot beams.

The resulting Gain Contours at 19.0GHz, Corresponding Gain Contours at 28.8GHz, XPI Contours at 19.0GHz, Corresponding XPI Contours at 28.8GHZ, G/T and the EIRP of Ka Band Spot beams of NIGCOMSAT-1R are provided in Figure 4.22, 4.23, 4.24, 4.25, 4.26 and 4.27 Respectively.

The output channel frequency response and input performance of the Band-Pass filter of Ka Band are provided in figure 4.36 and 4.37 verifying performance of the Ka Band repeater units and passive components.

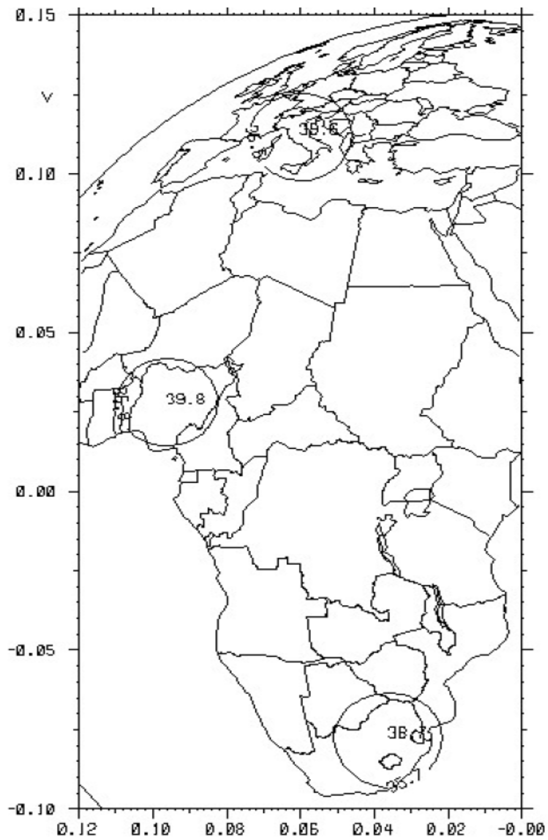


Figure 4.22: Gain Contours of Ka-Band Antenna of NIGCOMSAT-1R at 19.0GHz (Downlink)

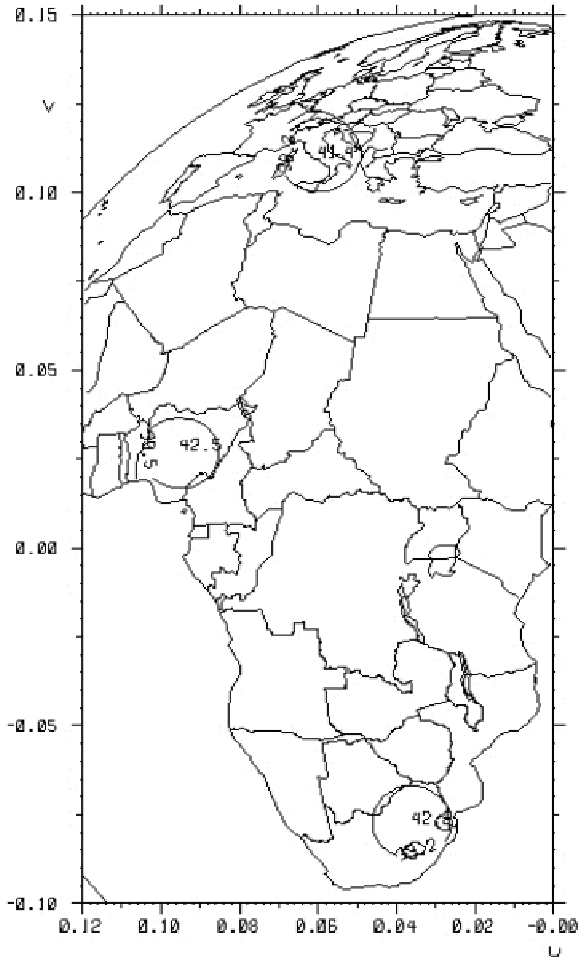


Figure 4.23: Gain Contours of Ka-Band Antenna of NIGCOMSAT-1R at 28.8GHz (Uplink).

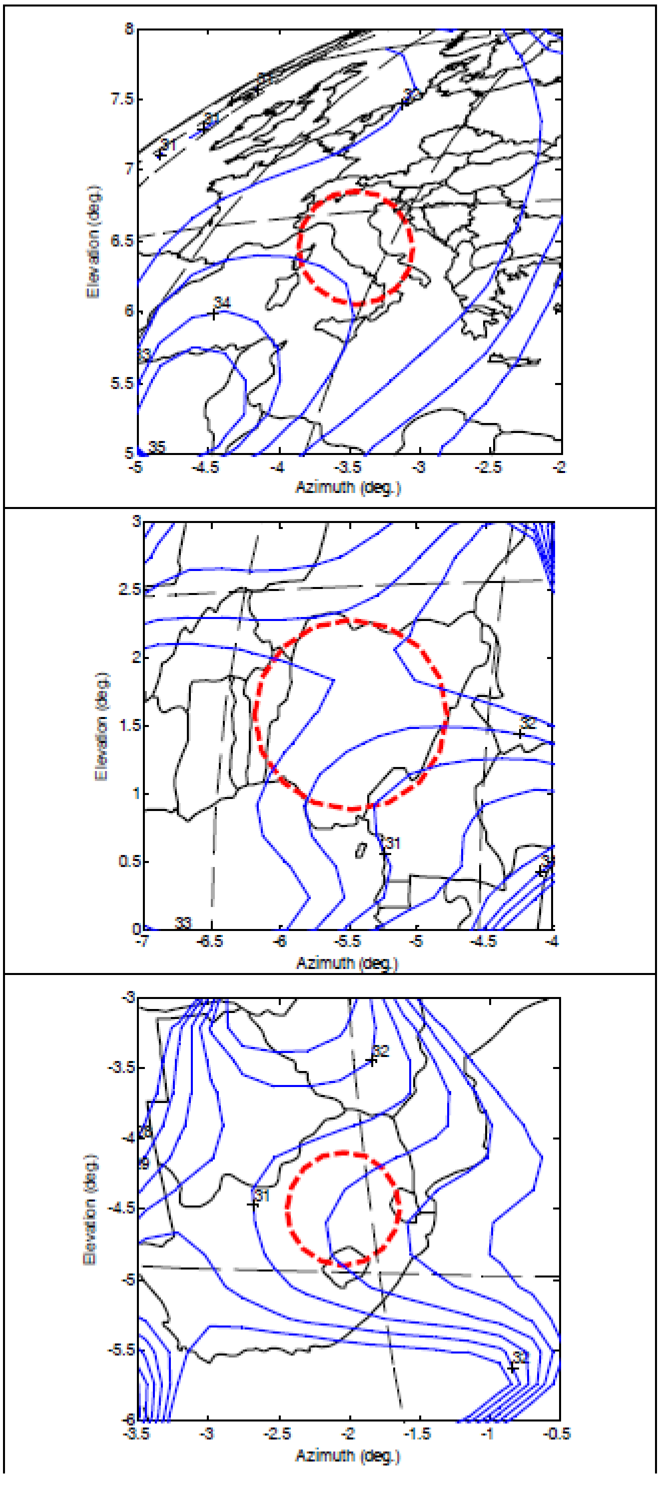


Figure 4.24: XPI Contours of Ka-Band Antenna of NIGCOMSAT-1R at 19.0GHz (Downlink).

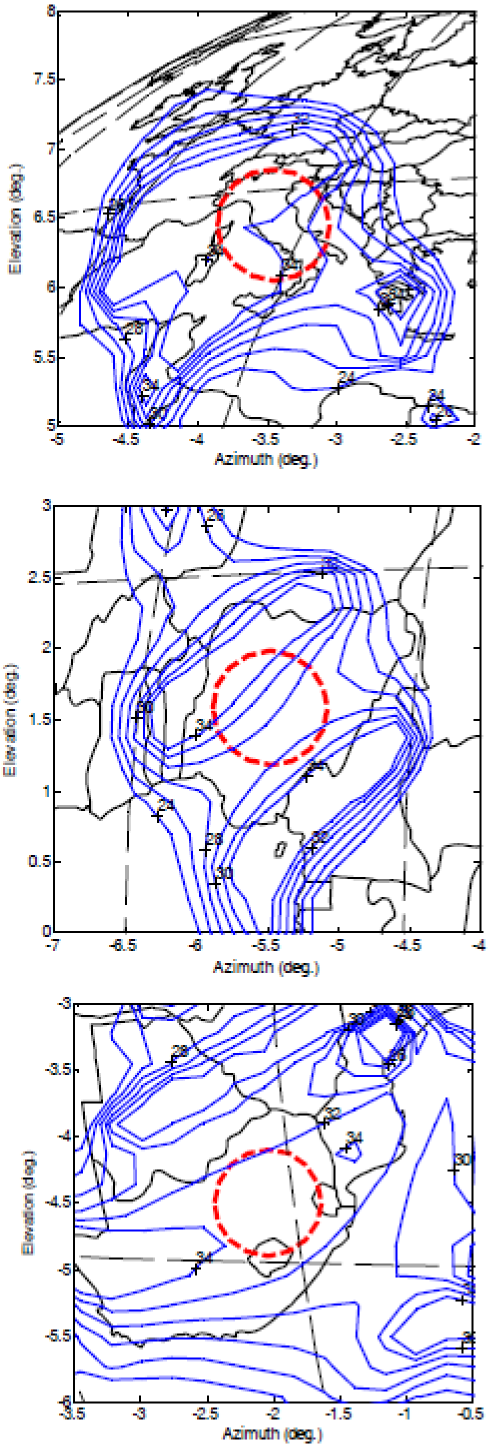


Figure 4.25: XPI Contours of Ka-Band Antenna of NIGCOMSAT-1R at 28.8GHz(Uplink).

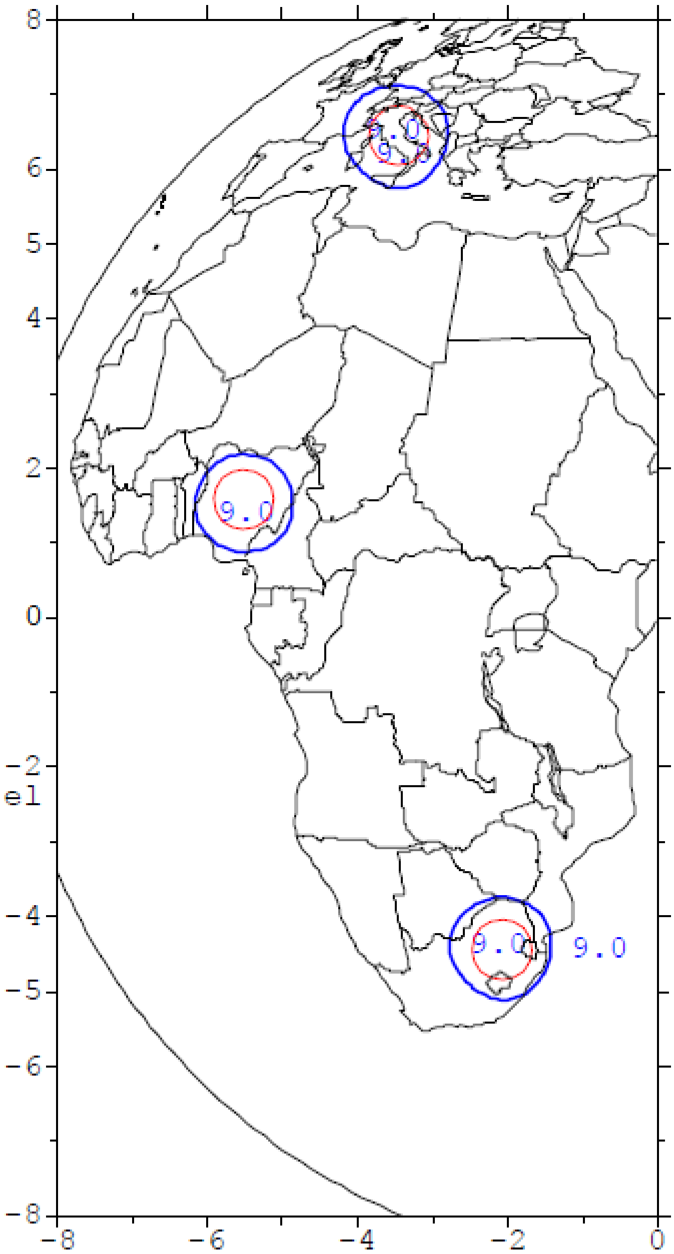


Figure 4.26: G/T Contour of Ka Band Antenna of NIGCOMSAT-1R.

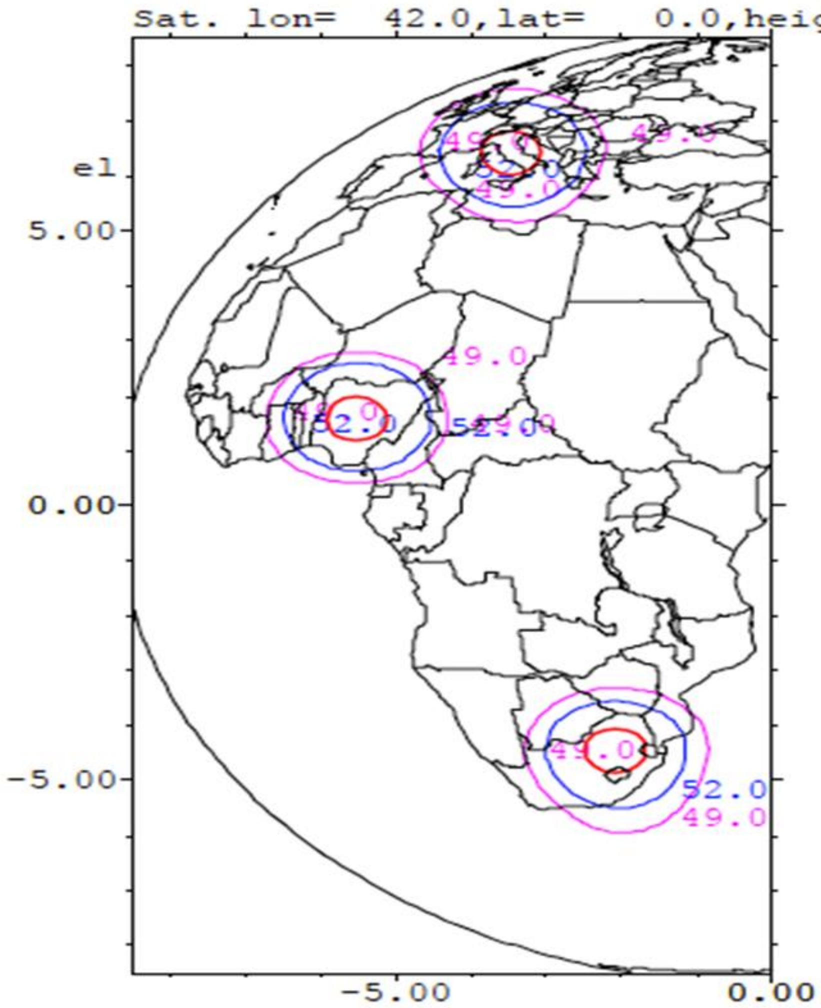


Figure 4.27: Ka Band Broadcast and Trunking EIRP Spot Beam of NIGCOMSAT-1R

4.1.4 Summary of Results for L Band Antenna and Payload Design of NIGCOMSAT-1R

Figure 4.28 gives overview block diagram of the L band piggy payload to meet the designed configuration. Details of L-Band Antenna and Payload Design with Gain and Loss Computations is provided in Appendix D.

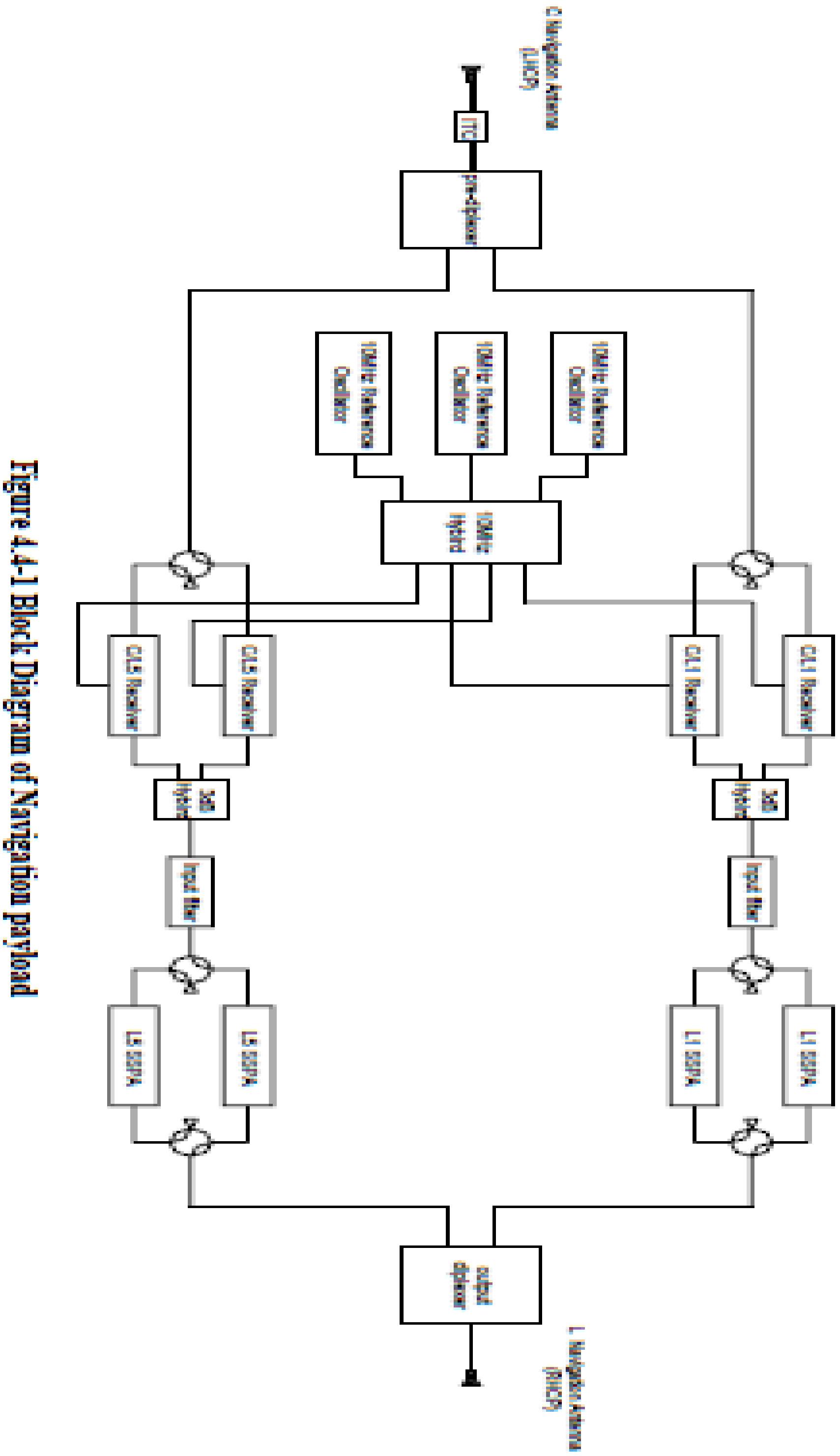


Figure 4.28: Block Diagram Overview of L-Band Payload Repeater.

The C band Navigation antenna defined by boresight of ±7.5 degrees for the minimum uplink service area coverage over Africa and Europe is presented in table 4.8. The antenna for the C-band accommodates LHCP and is dual-frequency conical horn antenna mounted on the earthy deck of NIGCOMSAT-1R spacecraft as illustrated in figure 4.29.

The antenna cut patterns were analyzed using Ansoft HFSS as shown in figure 4.30 and 4.31 at 6698.42MHz (C1)and 6639.45MHz (C5) respectively while the contour patterns are computed by TICRA GRASP 8 software as shown in Figure 4.32 and 4.33 at 6698.42MHz and 6639.45MHz respectively. The corresponding Cross-Polarization gain contours at 6698.42MHz and 6639.45MHz are shown in figure 4.34 and 4.35 respectively.

The L Band Navigation Antenna defined by boresight angle of ±8.7degrees has a global coverage as presented in table 4.9 The L Band navigation antenna accommodates RHCP and is a dual-frequency helical antenna with a backfire cavity mounted on the earth deck of NIGCOMSAT-1 spacecraft. It is comprised of helical unit, coaxial line, backfire cavity and antenna support structure (ASST) as shown in figure 4.36. The backfire cavity is used to reflect the EM waves and improve the gain of the center insert of the reflector. The antenna cut patterns was analyzed using Ansoft HFSS as shown in figure 4.37 and 4.38 at 1575.42MHz (L1) and 1176.45MHz (L5) respectively while the contour patterns are computed by TICRA GRASP 8 software as shown in Figure 4.39 and 4.40 at 1575.42MHz and 1176.45MHz respectively.

Table 4.8: Analytical Parameters of C-Band Uplink Navigation Antenna of NIGCOMSAT-1R

Items	**C Band Navigation Antenna**
Coverage Zone	Coverage over Europe and Africa defined by boresight angle of ±7.5 degrees.
Frequency Bandwidth (MHz)	Receiving: Uplink 6629.45～6700.42MHz
Gain(dBi)	Uplink: 16.5 Reference to TableD4.2 of Appendix D
Polarization	Uplink: LHCP
Mount Plane	Northwest of the Earth Deck of Spacecraft.
Antenna type and Assembly	Conical Horn Antenna Horn, Square to Circular Transition, Polarizations, Waveguide Assembly, Support Structure.

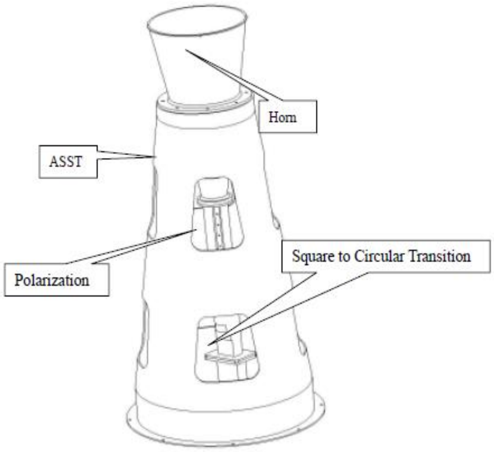


Figure 4.29: C-Band Navigation Antenna Structure Configuration

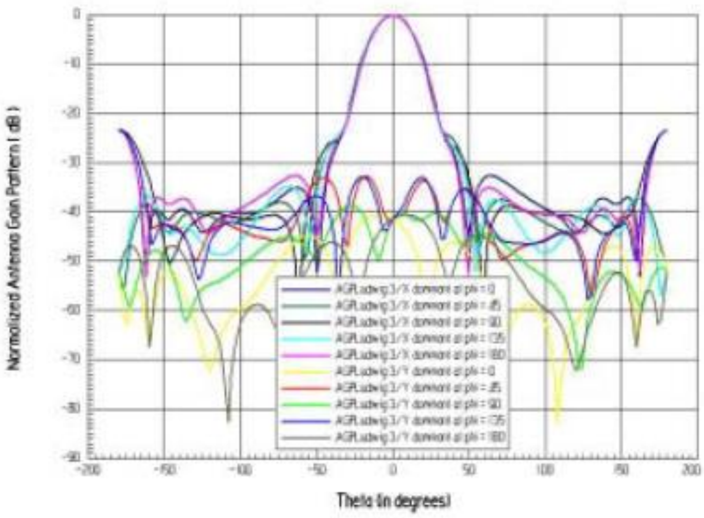


Figure 4.30: Directional Antenna Cut Pattern at 6698.42MHz.

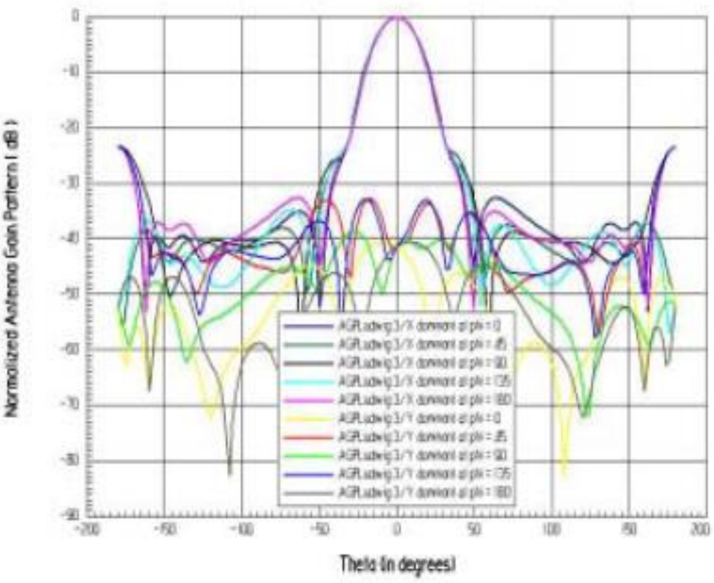


Figure 4.31: Directional Antenna Cut Pattern at 6639.45MHz.

Figure 4.32: The Gain Contours of the Receive C-Band Navigation Antenna at 6698.42MHz (LHCP).

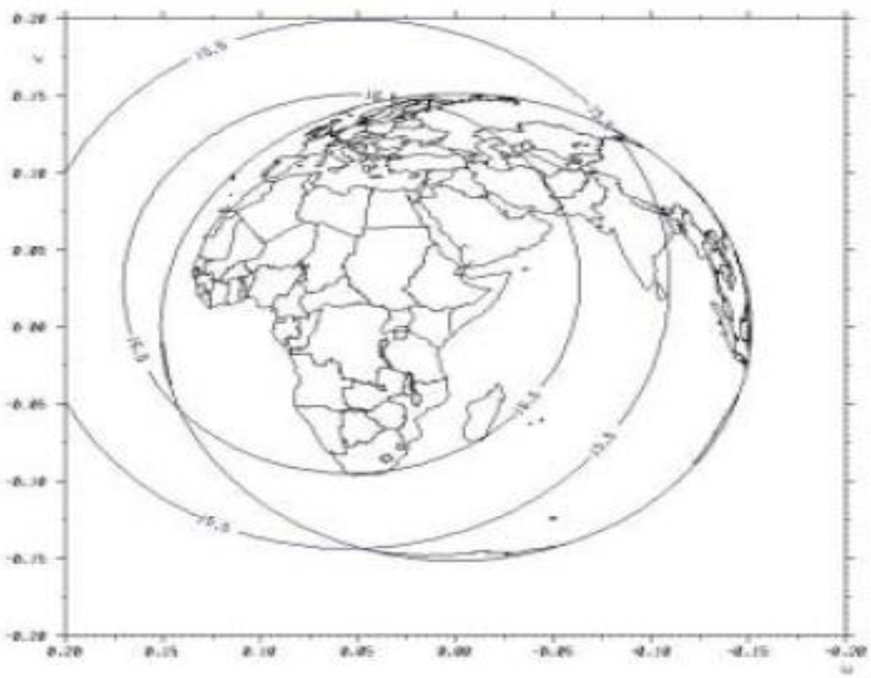


Figure 4.33: The Gain Contours of the Receive C-Band Navigation Antenna at 6639.45MHz (LHCP).

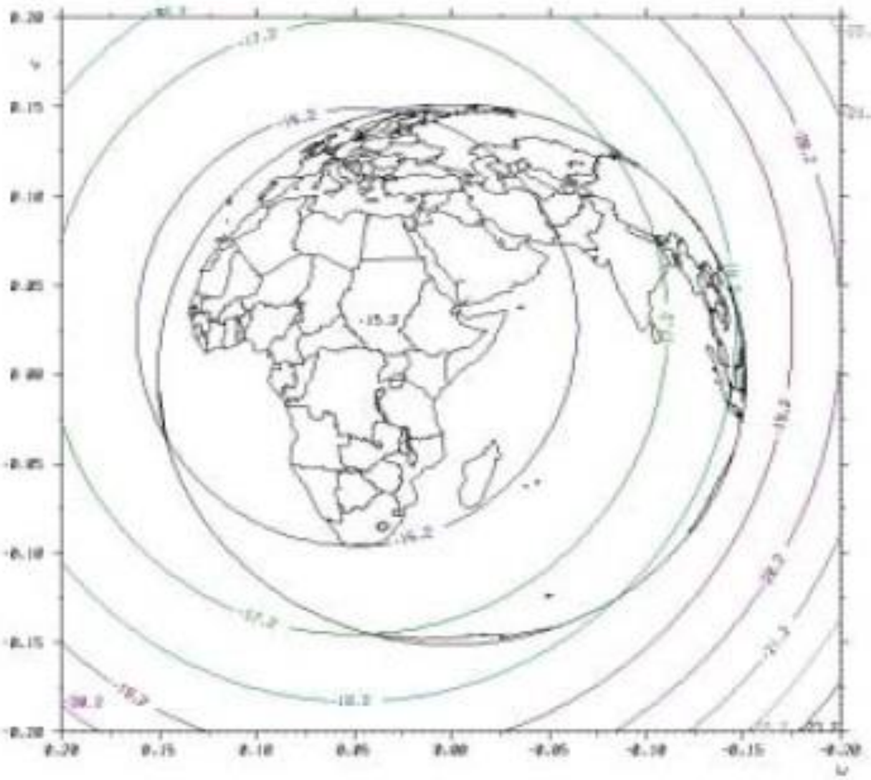


Figure 4.34: The Cross-Polarization Gain Contours of the Receive C-Band Navigation Antenna at 6698.42MHz (RHCP).

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Figure 4.35: The Cross-Polarization Gain Contours of the Receive C-Band Navigation Antenna at 6639.45MHz (RHCP).

Table 4.9: Analytical Parameters of L-Band Downlink Navigation Antenna of NIGCOMSAT-1R

Items	**L Band Navigation Antenna**
Coverage Zone	Global coverage defined by boresight angle of ±8.7 degrees.
Frequency bandwidth (MHz)	Transmitting: Down link 1166.45～1577.42MHz
Gain(dBi)	Downlink; 13 Reference to Table D4.5 of Appendix D
Polarization	Downlink: RHCP
Mount Plane	Northeast of the Earth Deck of Spacecraft.
Antenna type and Assembly	Helical Antenna Reflector (Reflector Aperture Φ 514mm) and Support Structure.

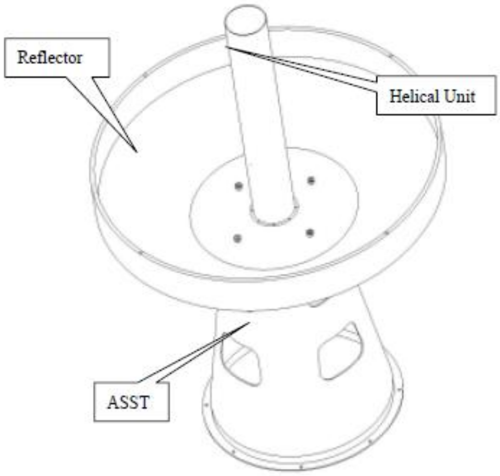


Figure 4.36: L-Band Navigation Antenna Structure Configuration

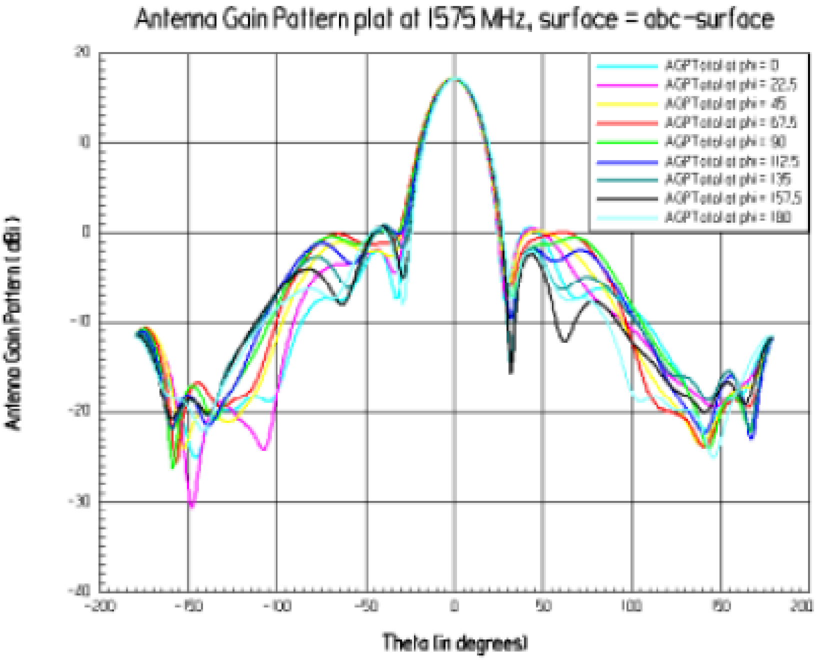


Figure 4.37: Directional Antenna Cut Pattern at 1575.42MHz (L1).

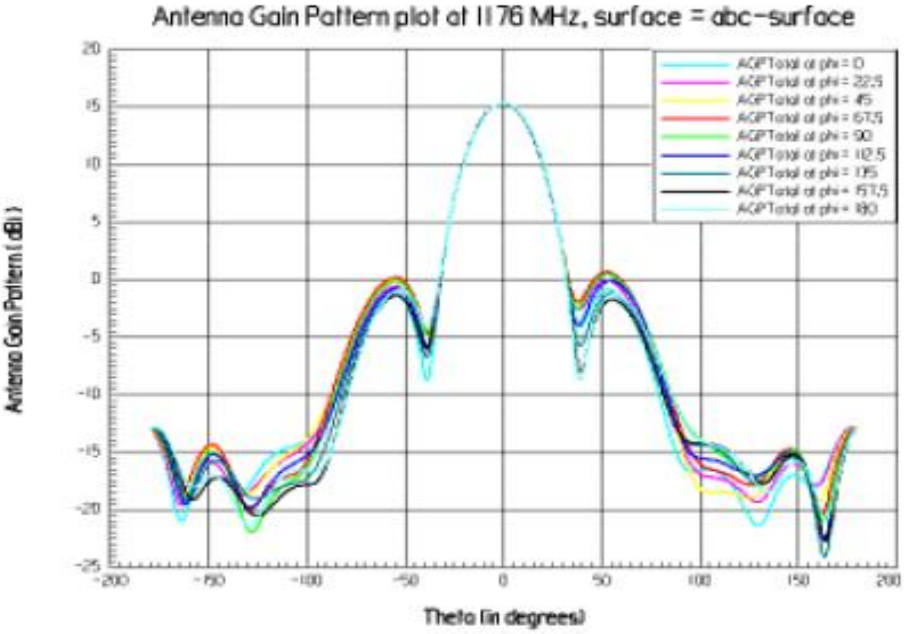


Figure 4.38: Directional Antenna Cut Pattern at 1176.45MHz (L5).

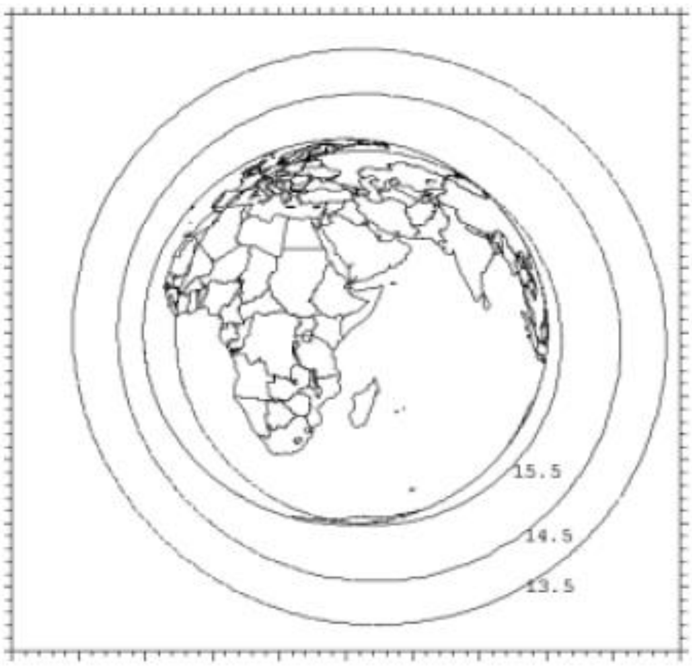


Figure 4.39: The Gain Contours of the Transmit L-Band Navigation Antenna at L1, 1575.42MHz (RHCP).

Figure 4.40: The Gain Contours of the Transmit L-Band Navigation Antenna at L5, 1176.45MHz (RHCP).

4.1.5 The Antenna System Design Layout of NIGCOMSAT-1R.

In accordance with principles of Antenna layout design, the followings were considered in the layout design of NIGCOMSAT-1R (Lawal and Chatwin, 2012c).

- Antenna Size;
- Field of view of each antenna;
- Isolation between receiving and transmitting
- Connection with repeater;
- Mass of Antenna
- Desired coverage area.

The communications subsystem provides simultaneously Fixed Satellite Service (FSS) operational at C-band, Ku-band and Ka band with Navigational services through L band piggy back payload. These require receiving and transmitting microwave signals within the defined coverage service areas.

The antenna subsystem of NIGCOMSAT-1R Spacecraft accordingly consists of seven antennas as illustrated in figure 4.41.

- Ku-Band Beam 1 Antenna (West Antenna; 3m X 2.2m)
- Ku-Band Beam 2 Antenna (East Antenna; 2.6m X 2.16m)
- C-Band Antenna Beam 3 (Center of Earth Deck ϕ1.6m)
- Ka-Band Transmit Antenna (Southeast of Earth Deck ϕ 0.7m)
- Ka-Band Receive Antenna (Northwest of Earth Deck ϕ 0.65m)
- C Band Navigation Antenna (Northwest of Earth Deck, Horn Antenna)

- L Band Navigation Antenna (Northeast of Earth Deck, Helix Antenna)

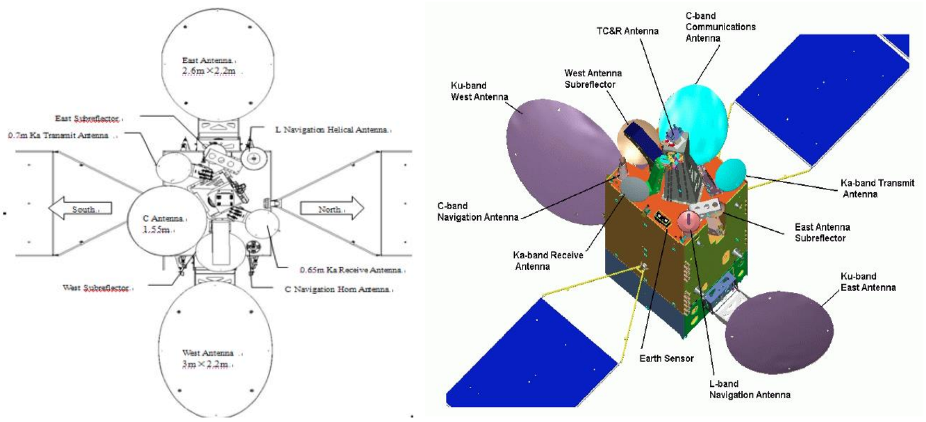


Figure 4.41: Illustration of NIGCOMSAT-1R Spacecraft Antenna Layout viewed from the Earth Deck with Deployed Main Ku-Band Reflectors.

4.2 Regional Communications Satellite in Africa, Insurance Replacement of Nigerian Communications Satellite (NIGCOMSAT-1R) and the its Predecessor (De-Orbited NIGCOMSAT-1).

In Africa, the communications satellites compliment the inadequate and sparsely distributed terrestrial telecommunications infrastructure. As a means of catching up on the infrastructural gap, communications via satellite and terrestrial wireless systems has had significant success in facilitating information technology policies and infrastructure for most African nations. Initiatives at both regional and national levels have been taken with appropriate policies and frameworks related to ICT network infrastructures and ICT related projects including a campaign of pilot projects to showcase its benefits to the people (Lawal & Chatwin, 2012; Lawal, Ahmed-Rufai, Chawin, & Young, 2013). Satellite infrastructure remains the most desirable when it comes to point-to-multipoint. Maintenance is simple and affordable, free from disadvantages of fiber-optic cable that can be cut or damaged etc as a result of poor urban and regional planning. It is noteworthy that satellite communications outperform their terrestrial counterparts in the sense that they are not affected by natural disasters such as earthquakes, floods, etc.(Berioli, Courville, & Werner, 2007; Fazli, Werner, Courville, Beriolli, & Boussemart, 2008).

Satellite communications provide advanced communications infrastructure to regions that do not have adequate terrestrial infrastructure, as is the case in Africa. Satellite networks can be rolled out to hundreds or thousands of locations in a fraction of the time required for a comparable terrestrial network to be established. A VSAT installation requires only a single vendor; and multi-vendor coordination is not required. An installation can usually be completed in a matter of hours, no matter where the site is located, meaning complete wide area network deployment can be accomplished in a matter of weeks, rather than months. Satellite network installation and deployment are indeed quick and simple.

High satellite capacity of the order of 100 Gbps coupled with multiple beams and multiple gateways, has already resulted in comparatively low cost satellite bandwidth. Satellite systems are optimized for services like Internet access, Virtual Private Networks (VPN), personal access, etc. The adoption of High Throughput Satellite (HTS) systems has introduced a paradigm shift in satellite broadband access services and the satellite industry. The satellite industry has begun a process of "remaking" the satellite broadband access market into an unprecedented offering that compares favourably to a DSL and fiber-based services in many unserved or underserved markets.

Nigeria is in the history books as the first African country to deploy a Ka-band based Communication Satellite covering the African continent and Europe with the launch of NIGCOMSAT-1 spacecraft on 13th May, 2007 (GMT+1, Nigerian Time). Figure 4.42 Shows the NIGCOMSAT-1 spacecraft atop Chinese launch vehicle LM 3B at Xichang Satellite Launch Center (XSLC) in China shortly before launch at exactly 00.04am (Beijing Local Time) of 14th May, 2007 (GMT+8).

Figure 4.42: Long March 3B Launcher ready to launch NIGCOMSAT-1 Spacecraft at Xichang Satellite Launch Center of China.

After successful launch with In-Orbit Test (IOT), the In-Orbit Delivery (IOD) followed which marked the commencement of commercial operations with significant entry into the satellite market sector providing affordable and qualitative services in local currency as a regional operator and player before it suffered an on-board subsystem abnormality in regions termed as single point of failure (SPF) in the spacecraft reliability table, which are capable of reducing or ending the mission service years of the spacecraft. The on-board abnormality was Solar Array Drive Assembly Motor (SADA-M) failure. The SADA-M failure implies Solar Array Output current will not be able to meet the lowest load requirement of the spacecraft as well as battery recharge requirement and thus spacecraft power exhaustion. Before the exhaustion of the spacecraft battery power and as part of risk management to avoid in-orbit collateral damage especially with neighbouring Communication satellite within 42.5 degrees east, the spacecraft was de-orbited safely above the geostationary arc on 10th November, 2008 (Nigerian Time) after 18 months In-orbit operation.

Figure 4.43 shows NIGCOMSAT-1R Spacecraft undergoing Compact Antenna Range Test (CATR) before the Launch Campaign Activities while figure 4.44 shows NIGCOMSAT-1R undergoing West and East Antenna Main Reflector Deployment Mechanism Test. Figure 4.45 shows the writer monitoring and inspecting the integrated and interfaced NIGCOMSAT-1R spacecraft atop enhanced Chinese Launch Vehicle (LM-3BE) in accordance with design analysis and specification of the spacecraft while Figure 4.46 shows readiness of the integrated NIGCOMSAT-1R with Launch Vehicle ready for launch.

Figure 4.43: High Powered Quad-Band NIGCOMSAT-1R Spacecraft Undergoing Compact Antenna Range Test (CATR) before the Launch Campaign Activities.

Figure 4.44: NIGCOMSAT-1R Spacecraft undergoing West and East Antenna Main Reflector Deployment Mechanism Test.

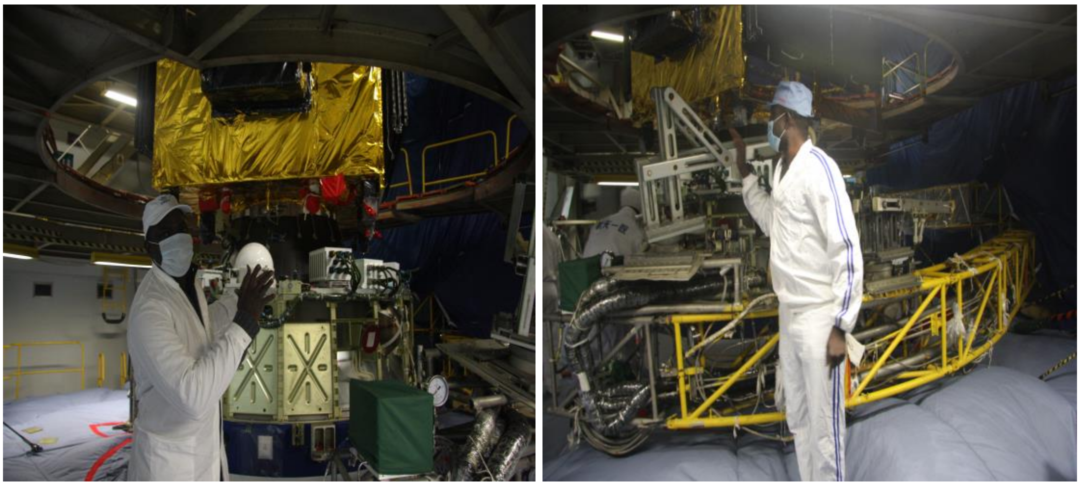


Figure 4.45: Integrated and Interfaced NIGCOMSAT-1R Spacecraft atop Enhanced Chinese Launch Vehicle (LM-3BE).

Figure 4.46: Shows Readiness of the integrated NIGCOMSAT-1R Spacecraft with Launch Vehicle (LM-3BE) ready for launch.

Nigeria's High-Powered, quad-band Communications Satellite carrying Ku, Ka, C and L-Band was re-launched as NIGCOMSAT-1R with enhancements on 19th December, 2011 (Nigerian Time) as shown in figure 4.49.

Figure 4.47: The Lift-off of NIGCOMSAT-1R Spacecraft Launcher (China's Long March Launch Vehicle, LM-3BE) on 19th December, 2011 (Nigerian Time).

The replacement satellite had better performance parameters based on further design inputs related to the weather and climatic conditions of the African Environment, lessons learnt from operations and market experience of the de-orbited first Nigerian Communication Satellite and inclusive participation of Nigerian Engineers and Managers in the Communication Satellite project and program as presented in section 4.1. Communication Satellites over Africa, particularly over the Sub-Saharan region, should be designed with higher Equivalent Isotropic Radiated Power (EIRP) particularly if the satellite utilizes the upper region of the satellite spectrum i.e Ku and Ka Band to appreciably compensate for the rain fade column with other complementary measures such as adaptive code modulation (ACM), Uplink Power Control (UPC) system implementation etc.

The second Nigerian Communication Satellite (NIGCOMSAT-1R) with quad-band high power communications; whose geostationary orbit is positioned at 42.5^{o}E and with a launch mass of 5,080 kg has a service life of more than 15 years while the design life is 22.5 years. The satellite has a reliability value of 99.7% with more than a 75% reliability value at the end of its service life. Analytical Design optimization in antenna and payload units and subsystem layout significantly improved performance parameters of the Insurance replacement beyond specifications as evident in the test results of NIGCOMSAT-1R shown in Test Data Results, Uncertainty Analysis, Validity Criteria and Test Result Analysis of Section 4.3.

The satellite provides Ku-band, C-band, Ka-band and Navigation payloads capability. The Ku-band payload has 14 operational channels, 2 fixed beams over Western and Eastern Africa. The C-band payload has 4 active channels with coverage of Western Africa. The Ka-band payload has 8 channels providing a communications and trunking capability using 3 fixed spot beams over Europe, South Africa and Nigeria. The Navigation payload has 2 receive uplink signals on C-band covering Nigeria and Europe, and 2 transmit downlink signals on L-band: L1 and L5, giving global coverage.

The additional enhancements aside improvements of the satellite performance parameters of NIGCOMSAT-1R over the de-orbited NIGCOMSAT-1 are as follows:

i. Introduction of Kashi Ku band Beam by modifying the Ku-Band East Antenna composition as shown in figure 4.50. With an additional feed using Snell’s basic principle. The modified East Antenna composition provided two Service coverage beams as East (ECOWAS 2) Ku Band Beam and Kashi Beam is shown in figure 4.48. The beam was introduced based on new market potentials of Asian countries with West African Countries and Africa in general. It is important to note that the de-orbited NIGCOMSAT-1 only provided Ecowas 2 beam coverage over East Africa.

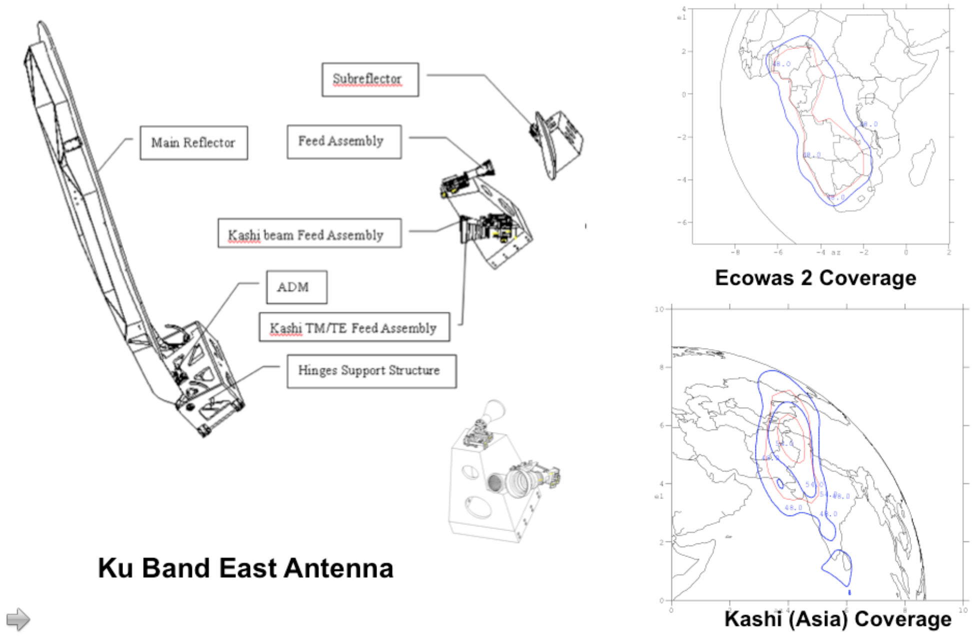


Figure 4.48: The Modified Ku Band East Antenna Composition for NIGCOMSAT-1R Spacecraft with the resulting two zonal service coverages.

ii. Change of Trunking TWTA power amplifiers of the Ka Band repeater from 50Watts to 70Watts RF output power. The 70Watt TWTA significantly suppressed rain attenuation with other compensation measures and it also allowed single redundancy ring of 10: 8 as shown in the Ka Band block diagram of Figure 4.22 Instead of the double redundancy ring of 6:4 for 50watts and 70watts meant for trunking and broadcasting respectively as shown in figure 4.49.

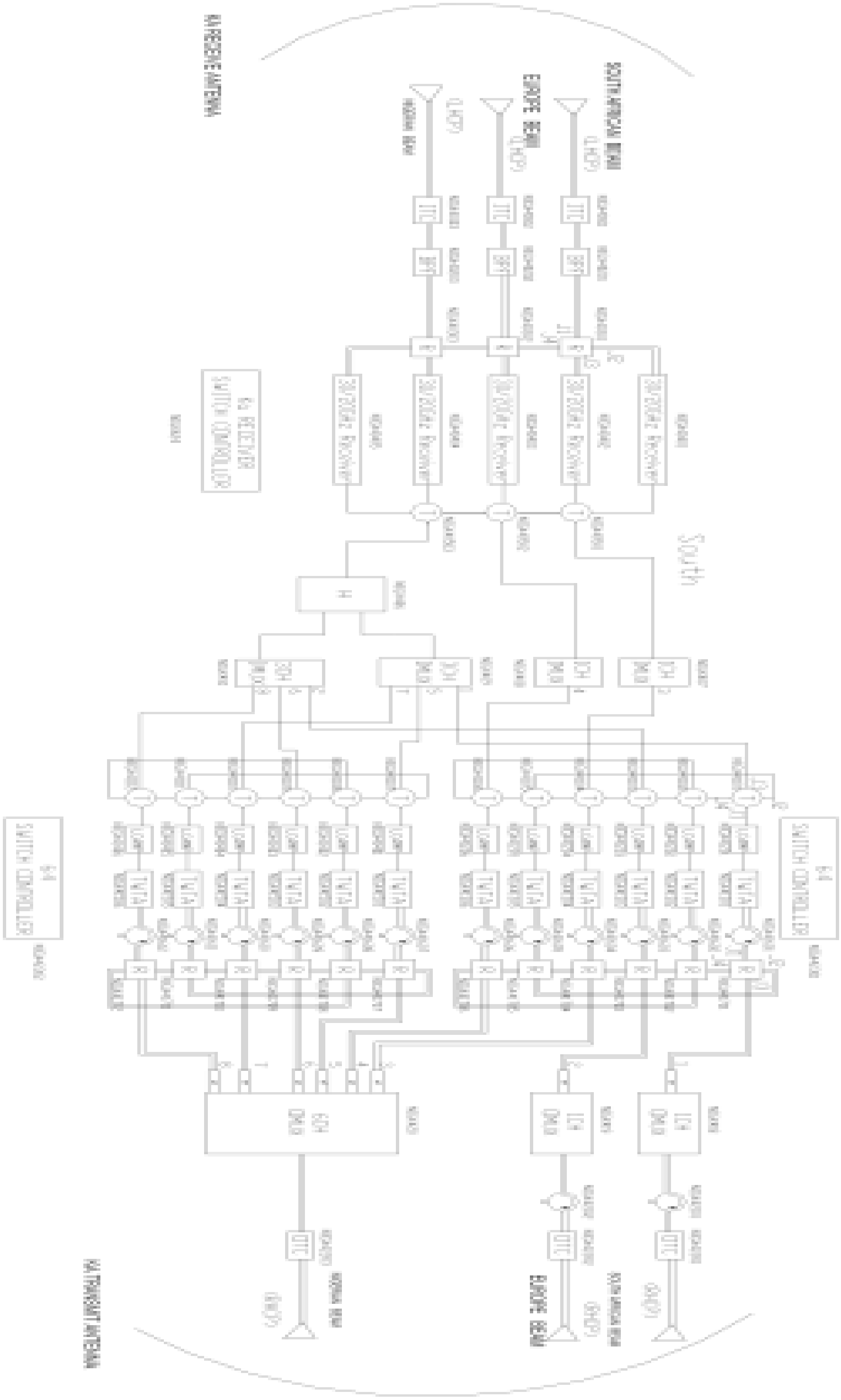


Figure 4.49: Previous Block Diagram of NIGCOMSAT-1 Ka Band Repeater with Double Redundancy Ring of 6:4.

iii. The European transmit and receive feed were aligned in its antenna support structure as shown earlier in figure 3.23 such that the maximum gain of the main antenna lobe as exemplified in figure 4.50 falls within Raisting, Germany; a major teleport and gateway region for trunking services from Europe to Africa. Figure 4.51 shows the European spotbeam of NIGCOMSAT-1R Ka-band. Generally, the level of the side lobe radiation relative to maximum of the antenna main lobe is used to characterise the antenna-roll off contour patterns in undefined service areas.

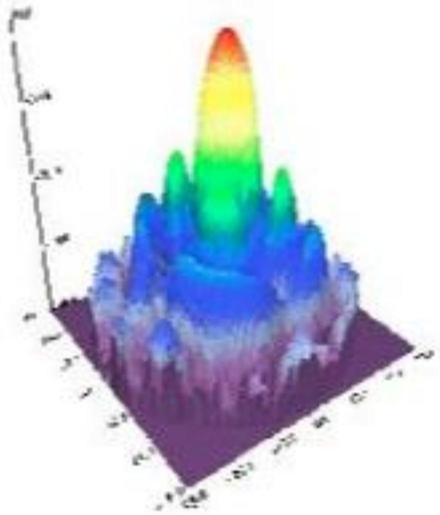


Figure 4.50: Typical illustration of Antenna Radiation Patterns showing the Amplitude of Antenna Main Lobe and Side lobes in 3D Contour Holography.

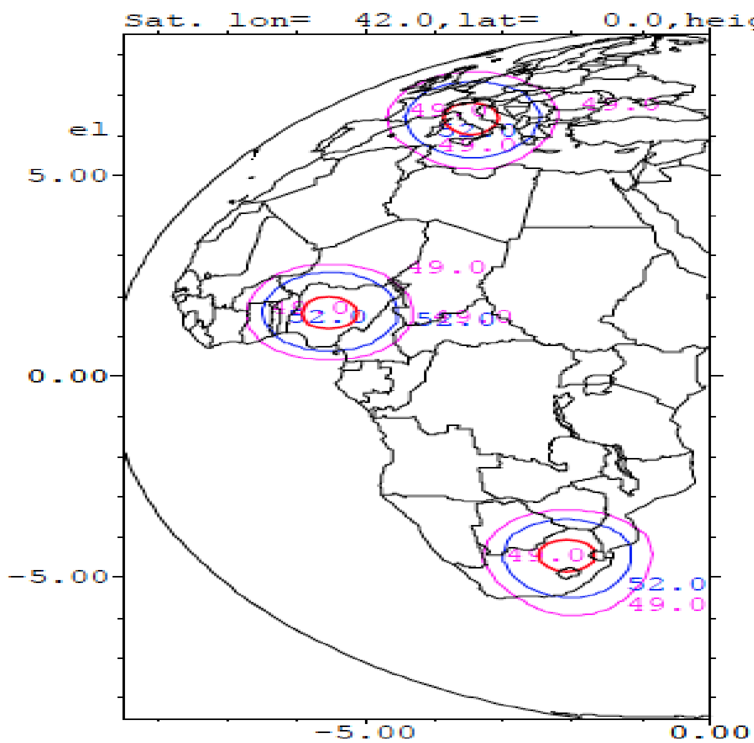


Figure 4.51: Ka Band Spot beams of NIGCOMSAT-1R.

iv. In addition to modification of the Ka-band repeater, change in the switching configuration matrix of the trunking channels to support two transponders to and fro Europe. This implies baseline configuration of a total of 6 transponders for trunking needs and 2 transponders for broadcasting needs based on prevailing market realities, trends, demands and potentials. Figure 4.52 illustrates the baseline Ka band channel configuration of NIGCOMSAT-1R and improvement over channel configuration of NIGCOMSAT-1 as shown in figure 4.53

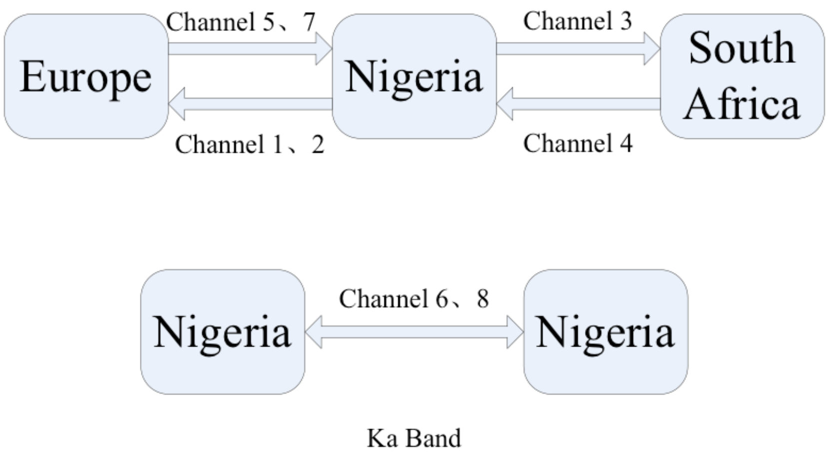


Figure 4.52: The Baseline Channel Configuration of Ka Band Payload of NIGCOMSAT-1R.

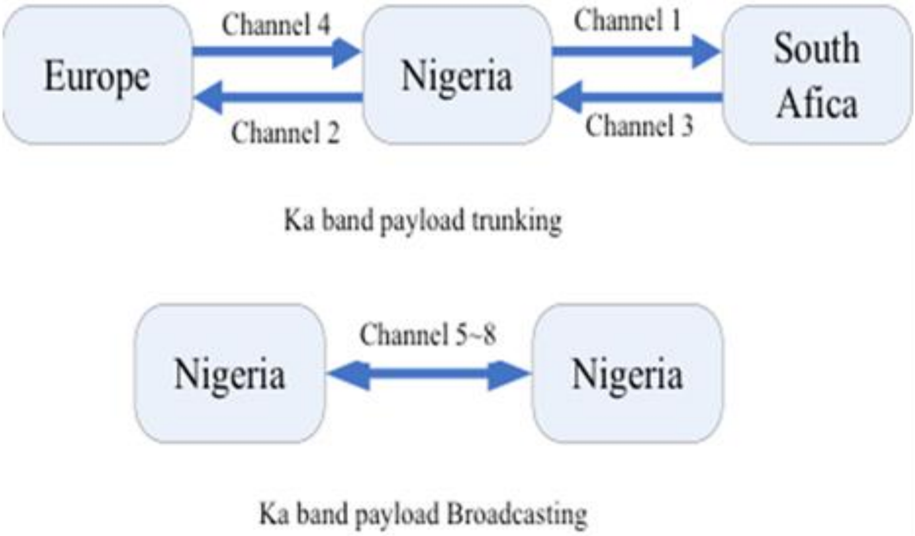


Figure 4.53: The Baseline Channel Configuration of Ka Band Payload of NIGCOMSAT-1 which was improved in NIGCOMSAT-1R as presented in Figure 4.52.

v. The EIRP of performance of the navigation payload was improved to meet 30dBW requirements of European coverage area through improved optimization and antenna system layout and harnessing of the spacecraft (Lawal & Chatwin, 2011; 2012C). The L1 and L5 EIRP of 28.1dBW and 26.2dBW respectively improved to over 30dBW at even edge of coverage service areas as shown in Figure 4.61 and Figure 4.62 respectively. Chapter five provides further details on Navigation, Augmentation and Nigerian Communications Satellite Navigation Payload.

4.3 Test Data Results, Uncertainty Analysis, Validity Criteria and Test Result Analysis

4.3.1 Test Data Results

Below are results to confirm Payload In-orbit test (IOT) requirements especially key tests that are related to performance in communication satellite resource service delivery.

4.3.1.1 EIRP Results

Figures 4.54 to 4.62 below shows the predicted EIRP coverage test results of the NIGCOMSAT-1R satellite across Africa, Part of Europe and Asia including global navigation coverage in the C-Band, Ku Band Ecowas-1, Ku Band Ecowas 2, Ku-Band Asia, Ka-Band European spot beam, Ka-Band Nigerian spot beam, Ka-Band South African spot beam and the Global Navigational band coverages, respectively based on Compact Antenna Test Range (CATR).

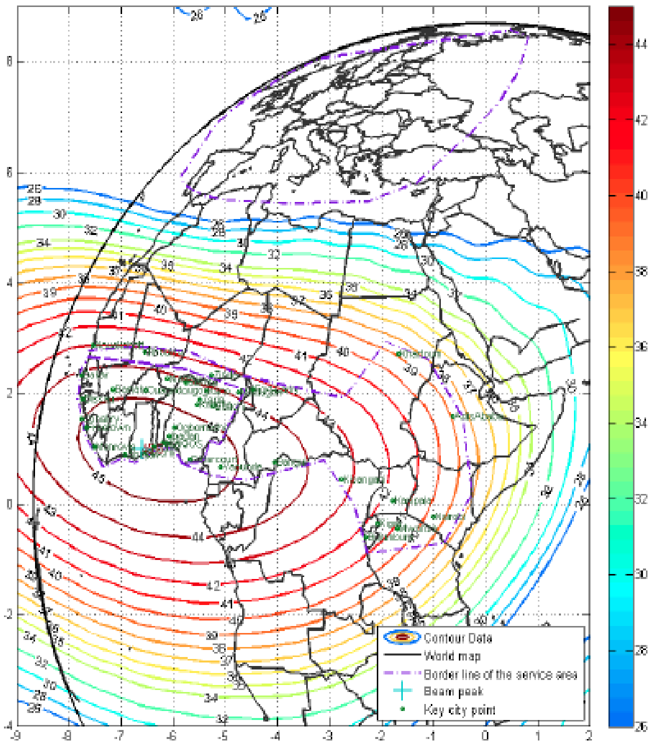


Figure 4.54: C-Band Coverage EIRP Test Result of NIGCOMSAT-1R over West Africa.

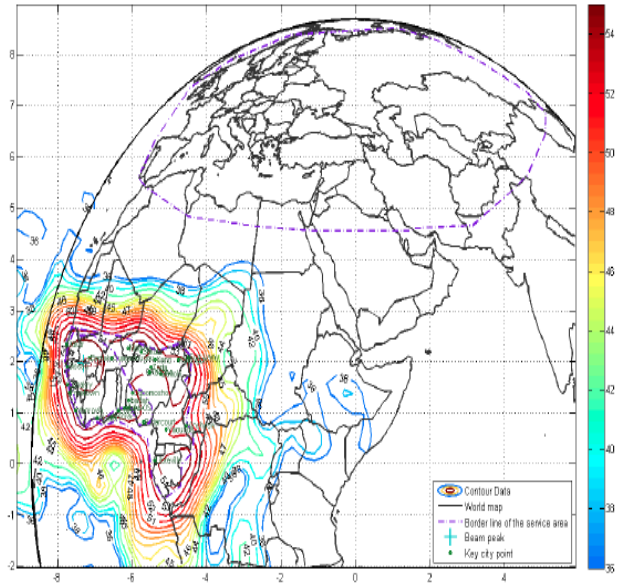


Figure 4.55: Ku-Band ECOWAS-1 Coverage EIRP Test Result of NIGCOMSAT-1R covering West Africa

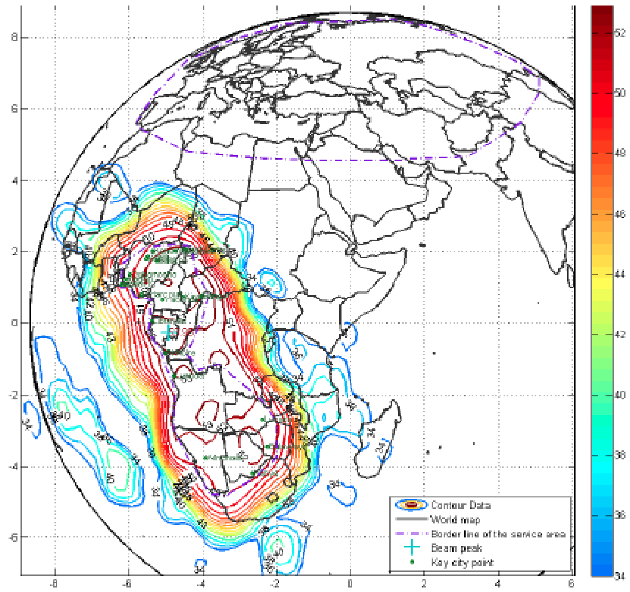


Figure 4.56: Ku-Band ECOWAS-2 EIRP Test Result of NIGCOMSAT-1R covering South And East Africa.

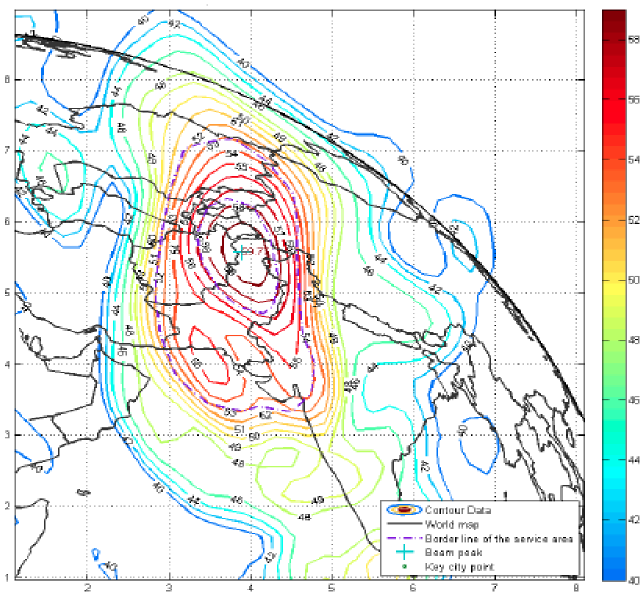


Figure 4.57: Ku-Band (Kashi Beam) EIRP Test Result of NIGCOMSAT-1R covering Asia

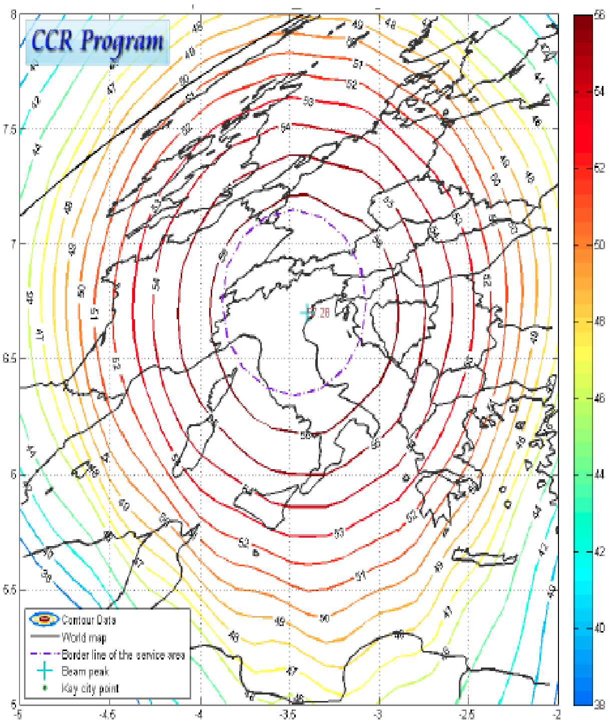


Figure 4.58: Ka Band European Spot Beam EIRP Test Result of NIGCOMSAT-1R covering Europe

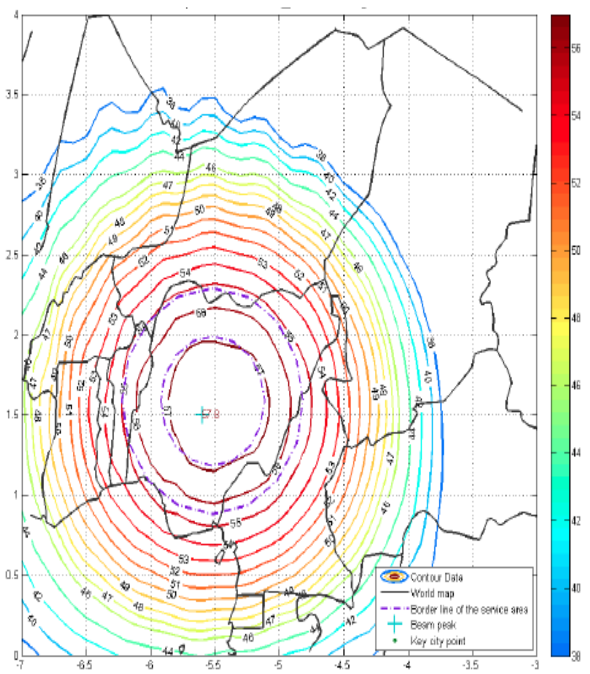


Figure 4.59: Ka Band Nigerian Spot Beam EIRP Test Result of NIGCOMSAT-1R covering Nigeria

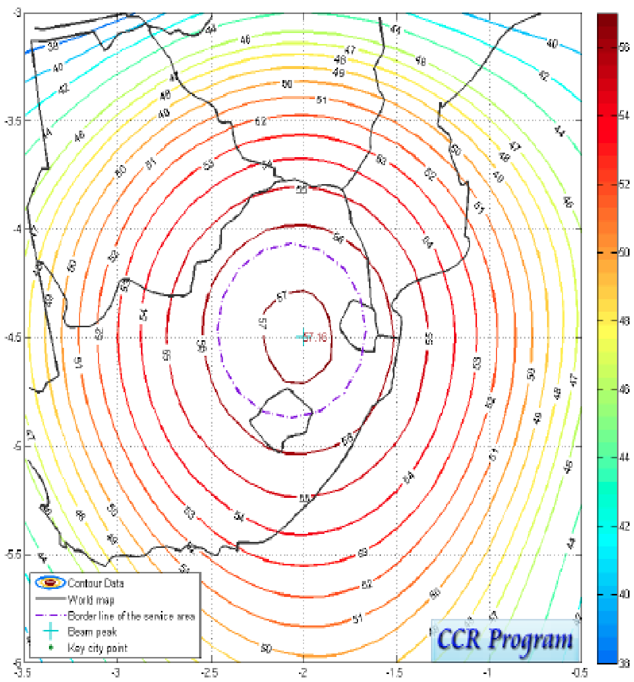


Figure 4.60: Ka Band South African Spot Beam EIRP Test Result of NIGCOMSAT-1R covering South Africa.

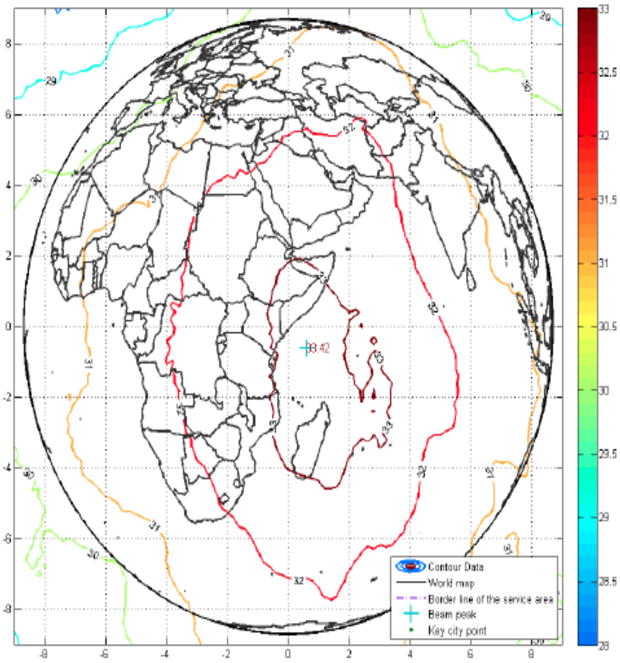


Figure 4.61: Global Navigational Band Coverage EIRP Test Result of NIGCOMSAT-1R in L1-Band

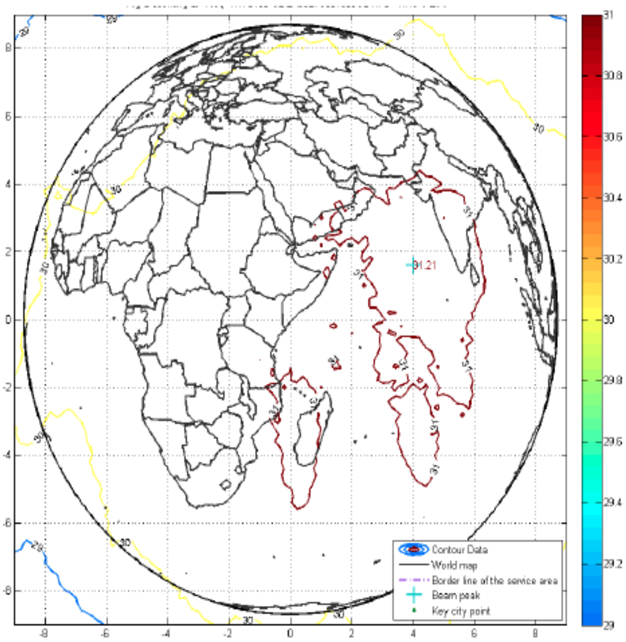


Figure 4.62: Global Navigational Band Coverage EIRP Test Result of NIGCOMSAT-1R in L5-Band

4.3.1.2 G/T Results

The G/T test establishes the gain-to-noise temperature ratio on receiver beams for the primary and redundant receivers across the frequency band. Figure 4.63 shows specific Gain-to-Noise ratio of Ka-Band Transponder over Nigeria. The result for channel 8 under sunny conditions from Nigeria was 15.33dB/K.

General results over the entire bands and coverages as obtained from CATR are as provided in figure 4.64 to 4.72.

Spacecraft:	NIG1R
Transponder:	NIG1R_T_Ka_08
Time:	2012-01-07 14:01:49
Polarization:	B(L/R)
Measurement:	GT
Method:	Y-factor
Uplink Frequency:	29925 MHz
Downlink Frequency:	20125 MHz
Bandwidth:	120 MHz
Configuration:	KaNL_R44L_C08T410_KaNR_P0; GainStep = 12dB; FGM
Condition:	Sunny

Frequency(MHz)	Time	G/T(dB/K)
29925	2012-01-07 14:01:49	15.33

Figure 4.63: Specific Gain-to-Noise ratio of Ka-Band Transponder over Nigeria.

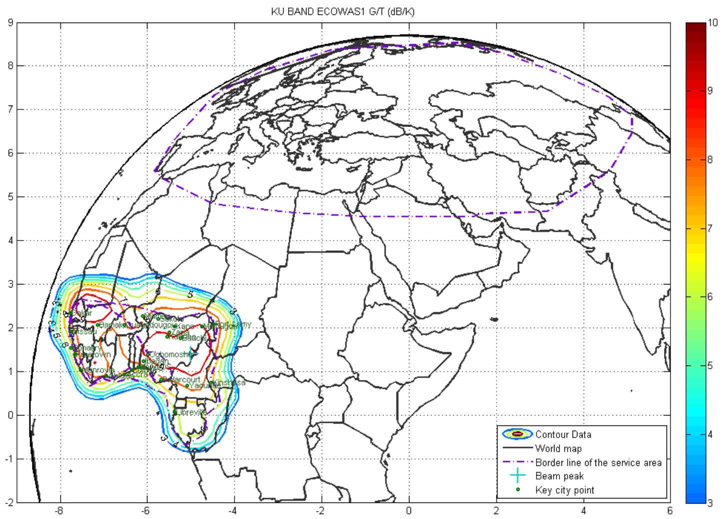


Figure 4.64: G/T Result of NIGCOMSAT-1R West Ku-Band Antenna Coverage (ECOWAS-1)

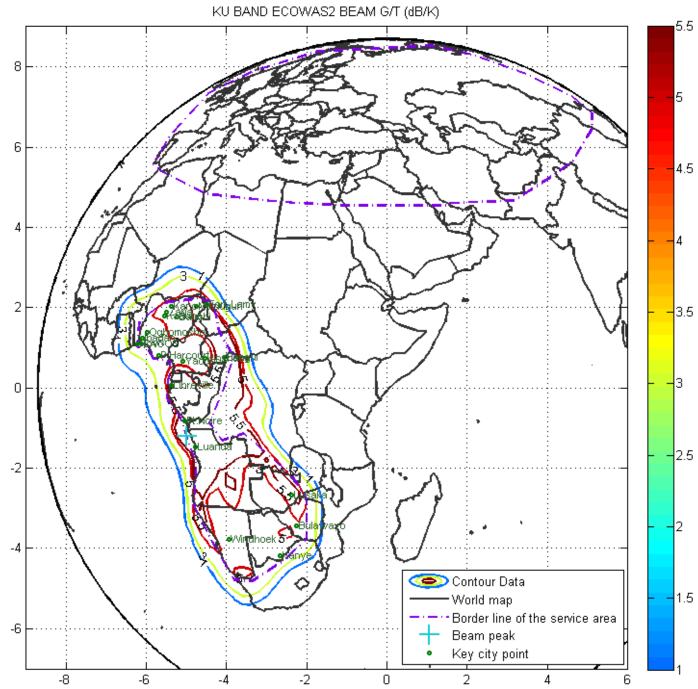


Figure 4.65: G/T Result of NIGCOMSAT-1R East Ku-Band Antenna Coverage (ECOWAS-2)

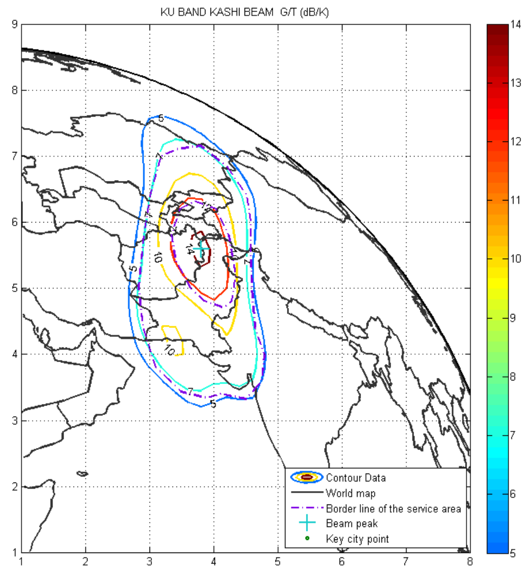


Figure 4.66: G/T Result of NIGCOMSAT-1R East-Asia Ku-Band Antenna Coverage (KASHI BEAM)

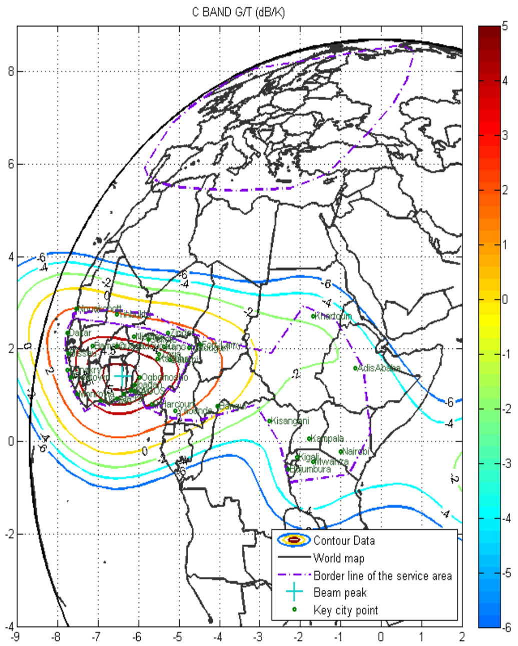


Figure 4.67: G/T Result of NIGCOMSAT-1R C-Band Antenna Coverage (ECOWAS-1)

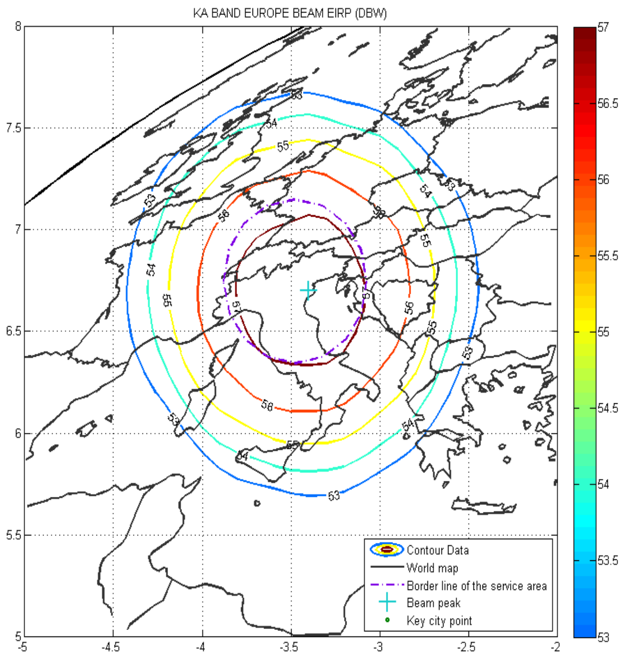


Figure 4.68: G/T Result of NIGCOMSAT-1R Ka-Band European Spot Beam Coverage

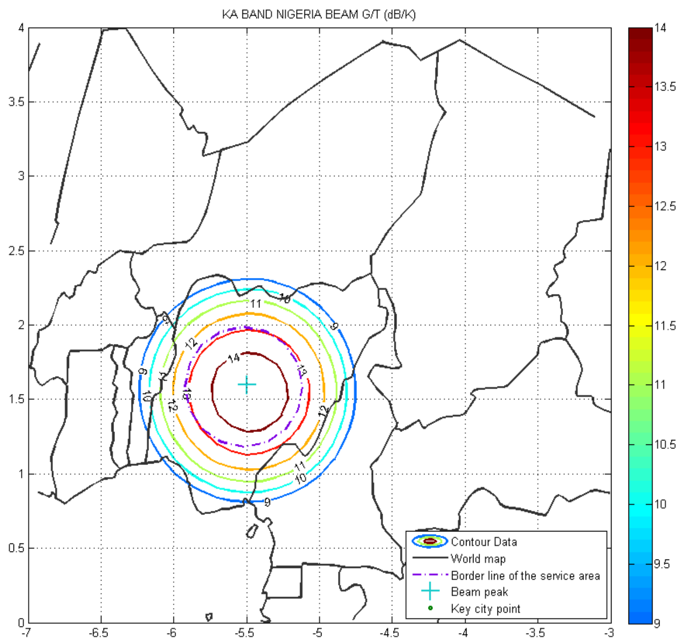


Figure 4.69: G/T Result of NIGCOMSAT-1R Ka-Band Nigerian Spot Beam Coverage

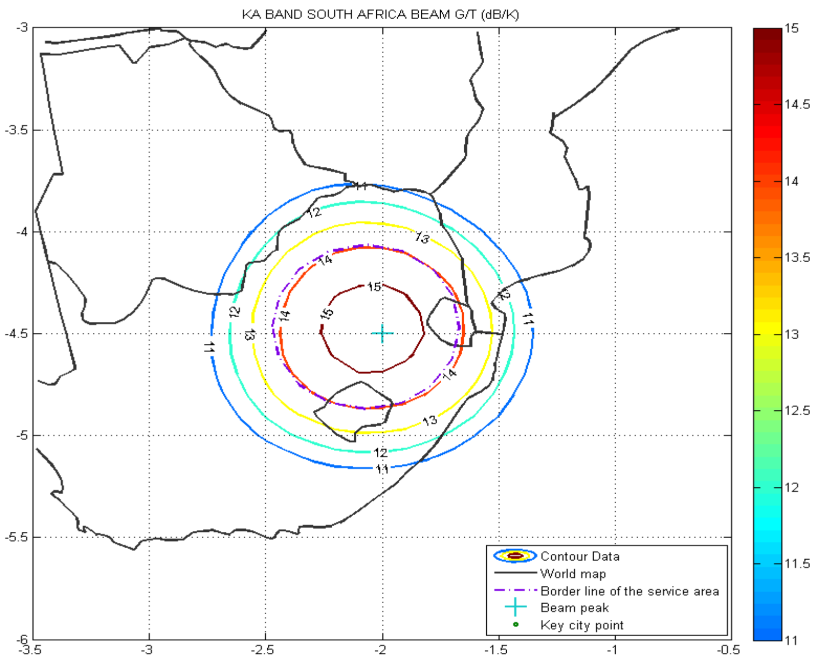


Figure 4.70: G/T Result of NIGCOMSAT-1R Ka-Band South African Spot Beam Coverage

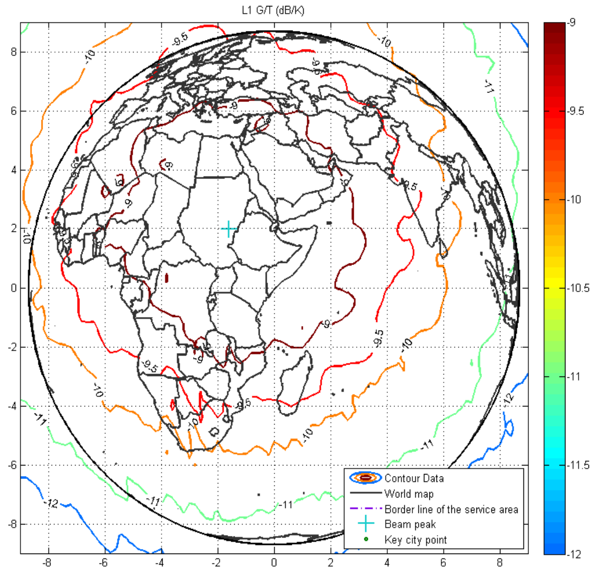


Figure 4.71: G/T Result (L1) of NIGCOMSAT-1R L-Band Navigation Coverage

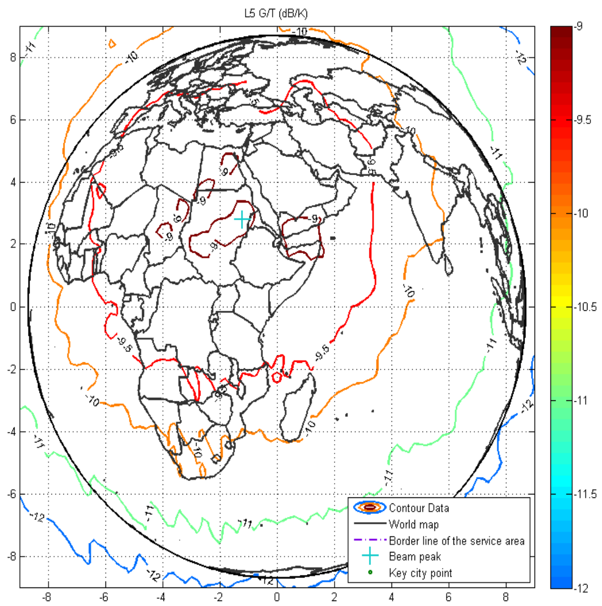


Figure 4.72: G/T Result (L5) of NIGCOMSAT-1R L-Band Navigation Coverage

4.3.1.3:THE ANTENNA CUT MEASUREMENT RESULTS

The Antenna Cut measurement was performed to verify correct antenna pointing and shape as well as good correlation with the measured antenna results over the entire pattern. Figure 4.73 shows the C-Band Communication Antenna IOT pattern Cut Line while table 4.10 shows the 42 points C-Beam IOT pattern Cut lines. Figure 4.73, 4.74 and 4.75 shows the C-Band Ecowas 1 Beam plot with minimum and maximum errors at line 2 (Roll=0°), line 3 (Roll=-0.6°) and line 1 (Roll=0.6°) respectively. The results show good correlation with the measured relative position after alignment of the antenna verification with the satellite coordinate. The positive direction for pitch is east while the positive direction for roll is north.

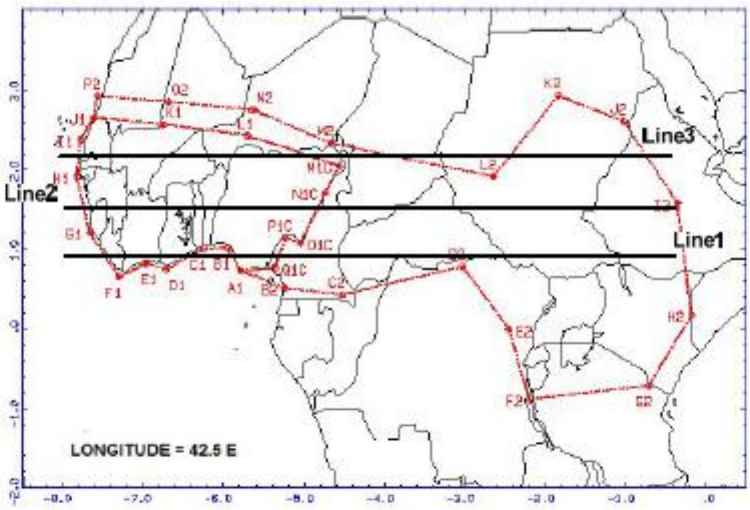


Figure 4.73: The C-Band Communication Antenna IOT pattern Cut Line

Table 4.10:The 42 points of the C-Band Communication Antenna IOT pattern Cut Line and the Relative Positions.

City	Log.	Lat.	Point	Relative Position	
				Roll(°) (S-N)	Pitch(°) (W-E)
Abuja	7.32E	9.05N	1	0	0
Line 1			13	0.6	-5.1, -4.5, -3.9*, -3.3, -2.7, -2.1, -1.5, -0.9, -0.3, 0.3, 0.9, 1.5, 2.1
Line 2			14	0	-5.1, -4.5, -3.9, -3.3, -2.7, -2.1*, -1.5, -0.9, -0.3, 0.3*, 0.9, 1.5*, 2.1, 2.7
Line 3			14	-0.6	-5.1, -4.5, -3.9*, -3.3, -2.7, -2.1, -1.5, -0.9, -0.3, 0.3, 0.9, 1.5, 2.1, 2.7
point			42		

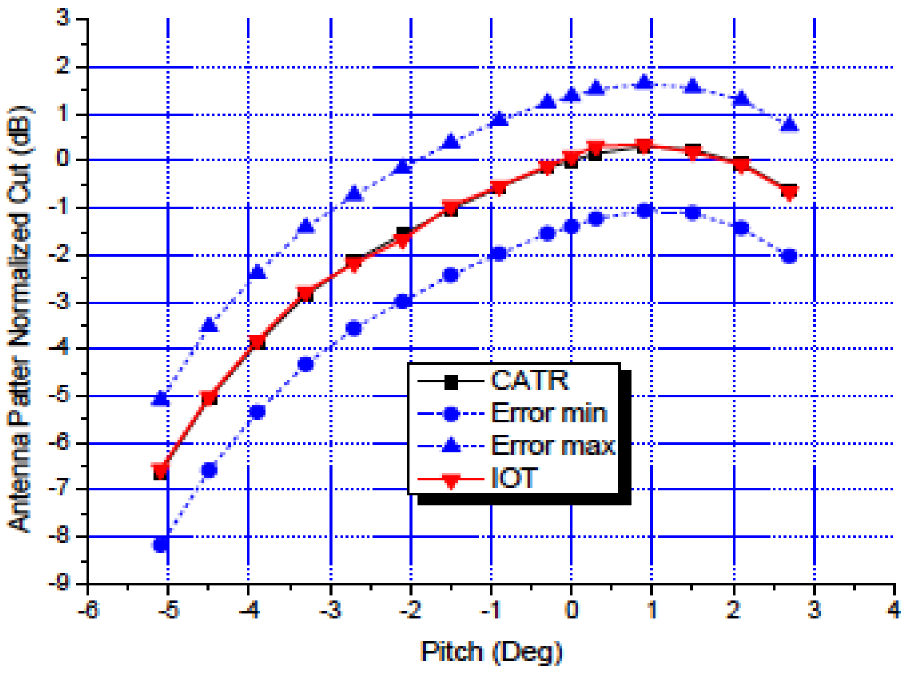


Figure 4.74: C-Band Ecowas 1 Beam Cut line 2 (Roll=0°) of NIGCOMSAT-1R.

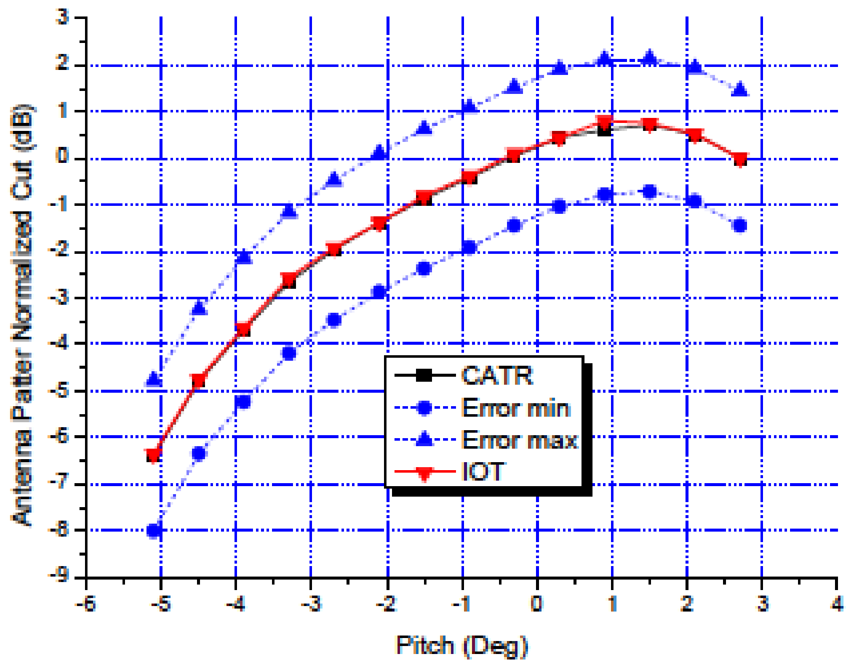


Figure 4.75: C-Band Ecowas 1 Beam Cut line 3 (Roll=-0.6°) of NIGCOMSAT-1R.

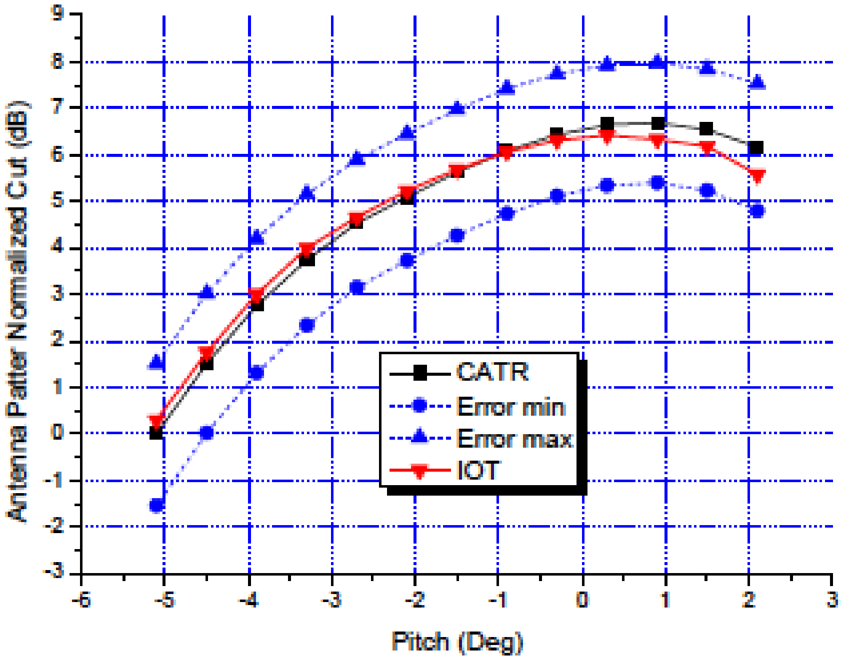


Figure 4.76: C-Band Ecowas 1 Beam Cut line 1 (Roll=0.6°) of NIGCOMSAT-1R.

4.3.1.4 The AM/AM Test.

The AM/AM test was performed on all High Power Amplifiers including redundant amplifiers. TWTA Helix current, TWT Anode voltage and CAMP input power levels were record during AM/AM transfer test from -20dB to +6dB relative to input saturation. The test was performed at nominal gain setting to establish saturation flux density and saturated EIRP. The Gain transfer responses were measured for input drive levels from 20dB below the operating point to +2dB above the operating point of the HPA. Figure 4.77 shows gain transfer curve test result of channel 11 of Ku-Band Transponder of NIGCOMSAT-1R measured during sunny conditions with an uplink frequency of 14,124.5MHz and Downlink Frequency of 12,624.5MHz. The Saturated Flux Density and EIRP was -90.4dBW/m^2 and 51.58dBW respectively (point of intersection of the curves in figure 4.77) with saturated HPA gain of 186.44dB. All test results were validated and acceptable.

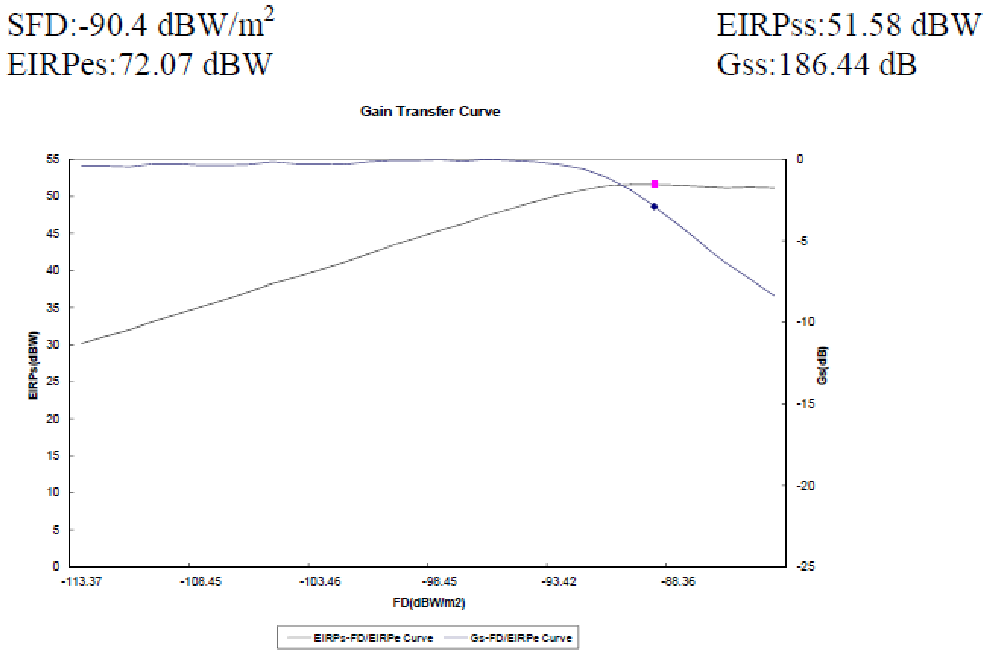


Figure 4.77: Gain Transfer Curve Test Result of Channel 11 of Ku-Band Transponder of NIGCOMSAT-1R.

4.3.1.5: The Gain Step and Automatic Level Control (ALC) Mode Functionality of the High Power Amplifiers (HPA) of all Transponders.

The Fixed Gain Mode (FGM) was verified for all HPAs on level setting in three steps (normal step ±1 step). The ALC mode functionality for Ku-Band, Ka-Band and C-Band HPAs transponders were verified by observing its stability, change in downlink power and consistency. Figure 4.78 and 4.79 shows the ALC stability and transfer curve respectively of Channel 8 Ku band transponder measured during sunny conditions.

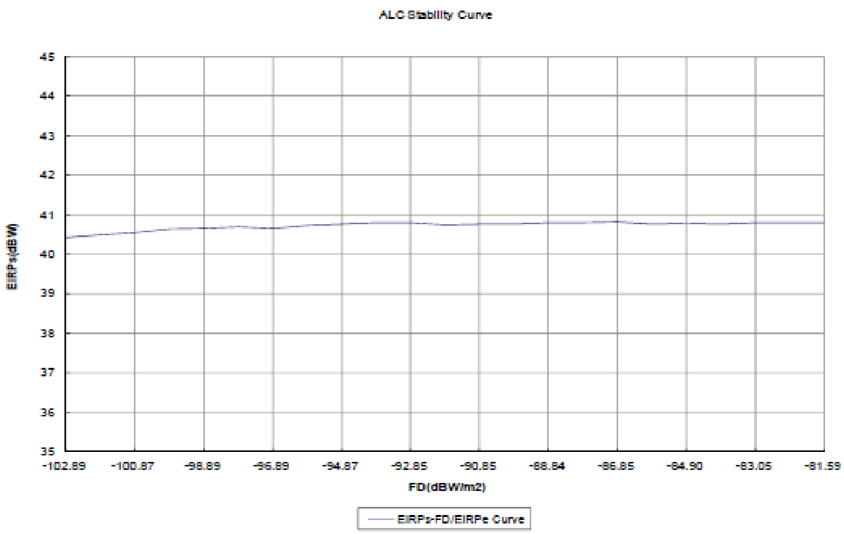


Figure 4.78: The ALC stability curve of Channel 8 Ku Band transponder measured during sunny condition.

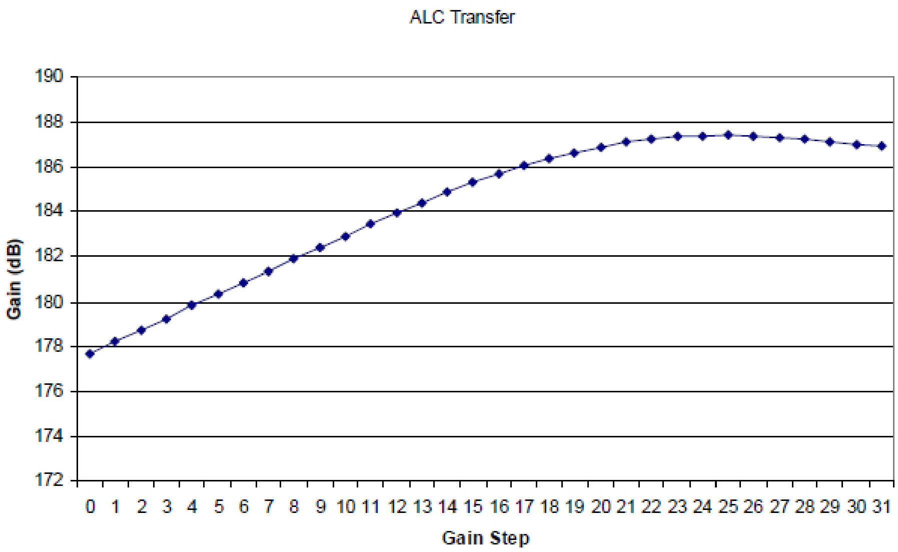
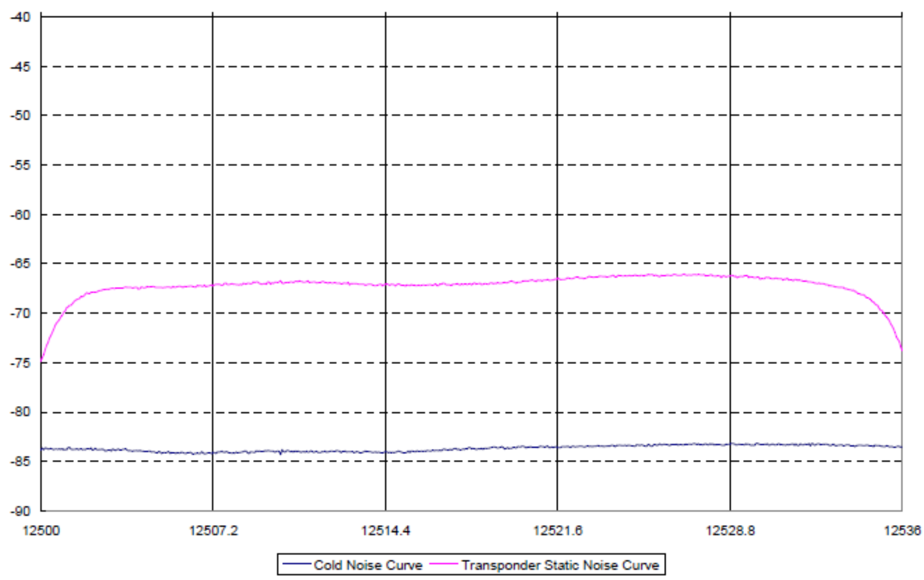


Figure 4.79: The ALC Transfer curve of Channel 8 Ku Band transponder measured during sunny conditions.

4.3.1.6: The In-Band Frequency Response and Group Delay of Transponder.

The in-band frequency response helps verify channel passband performance at nominal gain setting in fixed gain mode (FGM) of the transponder's HPA. Figure 4.80 shows the static spectrum curve of channel 8 Ku-Band Transponder of NIGCOMSAT-1R showing the transponder's cold noise level and static noise curve.



Center	12518 MHz	Span :	36 MHz
Start Freq:	12500 MHz	Stop Freq:	12536 MHz
RBW: 100 kHz		VBW: 10 Hz	

Figure 4.80: The static spectrum curve of channel 8 Ku-Band Transponder of NIGCOMSAT-1R showing the transponder's cold noise level and static noise curve.

4.3.1.7: Frequency Conversion Accuracy and Stability of Receivers

The frequency conversion and stability of all receiver units were tested and verified at mid-frequency including that of Navigation Band, which were externalized outside the receiver and ovenized considering the criticality of frequency stability and conversion accuracy to time-based signals for precision in applications. Figure 4.81 and 4.82 shows frequency conversion accuracy test results of NIGCOMSAT-1R Ka band receiver and the active externalized 10MHz Ultra-Stable Crystal Oscillator of NIGCOMSAT-1R. Uplink Frequency conversion to Downlink frequency is 9800MHz while Uplink C1-Band frequency conversion (6698.42MHz) to Downlink L1-Band frequency (1575.42MHz) is 5123MHz. The 8.98 x 10^{-9} of figure 4.82 of the L1 transponder of NIGCOMSAT-1R Navigation was a very good result considering requirement of at least 2.0 x 10^{-7} over service life time of the spacecraft (15 years).

Spacecraft:	NIG1R
Transponder:	NIG1R_T_Ka_04
Time:	2012-01-07 18:18:12
Polarization:	B(L/R)
Measurement:	Translation Frequency
Uplink Frequency:	29325 MHz
Downlink Frequency:	19525 MHz
Bandwidth:	120 MHz
Configuration:	KaNL_R43L_C04T405_KaNR_PE; GainStep = 12dB; FGM
Condition:	Sunny

The starting time of test	Translation Frequency(MHz)
2012-01-07 18:18:12	9799.998388

Frequency Accuracy: 1.64×10^{-7}.

Figure 4.81: Frequency Conversion Accuracy Test Result of NIGCOMSAT-1R Ka Band Receiver.

Spacecraft:	NIG1R
Transponder:	NIG1R_T_CL_01
Time:	2012-01-02 15:57:31
Polarization:	B(L/R)
Measurement:	Translation Frequency
Uplink Frequency:	6698.42 MHz
Downlink Frequency:	1575.42 MHz
Bandwidth:	4 MHz
Configuration:	CL_LR32L2_C01T301_CLRP0; GainStep = 10dB; FGM
Condition:	Sunny

The starting time of test	Translation Frequency(MHz)
2012-01-02 15:57:31	5122.999954

Frequency Accuracy: 8.98×10^{-9}

Figure 4.82: Frequency Conversion Accuracy Test Results of NIGCOMSAT-1R Active Externalized 10MHz Ultra-Stable Crystal Oscillator of NIGCOMSAT-1R.

4.3.2 Uncertainty Tests Analysis

4.3.2.1 Test Setup Uncertainty Analysis

The equipment test setup introduces uncertainty and errors based on configuration and parameters used during In-orbit test (IOT) result confirmation. The IOT result is validated by eliminating total uncertainty elements from the results as computed below in table 4.11 to 4.17 for the EIRP, IPFD, G/T, Amplitude Vs Frequency Response, Gain Step, ALC stability and Translation Frequency Tests respectively.

Table 4.11: Table of EIRPs Test Uncertainties

Error Factors	C band	L band	Ku band	Ka band
Power Meter Readings（ΔPm）	±0.2dB	±0.2dB	±0.2dB	±0.3dB
Cable Loss（ΔLi）	±0.2dB	±0.2dB	±0.2dB	±0.3dB
Coupling of Coupler（ΔCi）	±0.3dB	±0.3dB	±0.3dB	±0.5dB
Insert Loss of Coupler（ΔICi）	±0.05dB	±0.05dB	±0.05dB	±0.1dB
Attenuator（ΔAtt）	±0.20dB	±0.20dB	±0.20dB	±0.3dB
Coupling of Coupler（ΔCr）	±0.3dB	±0.3dB	±0.3dB	±0.5dB
Insert Loss of Coupler（ΔICr）	±0.05dB	±0.05dB	±0.05dB	±0.1dB
Antenna Feed Loss（ΔFlRx）	±0.1dB	±0.1dB	±0.1dB	±0.2dB
Antenna Gain（ΔGaRx）	±0.8dB	±0.5dB	±0.8dB	±1.2dB
Atmosphere Loss（ΔLd）	±0.05dB	±0.05dB	±0.15dB	±0.25dB
Tracking Loss(ΔLt2)	±0.4dB	±0.2dB	±0.6 dB	±0.8dB
Other	±0.5 dB	±1.0 dB	±0.7 dB	±0.8 dB
Total Uncertainty of EIRPs	**±1. 26dB**	**±1.44dB**	**±1. 49dB**	**±2.20dB**

Table 4.12: Table of G/T Test Uncertainties

Error Factors	C band	Ku band	Ka band
Y-factor	±1.0dB	±1.5dB	±2.0dB
EIRPe	±0.68dB	±0.67dB	±1.23dB
Lu	±0.05dB	±0.15dB	±0.25dB
C/N	±0.25dB	±0.5dB	±0.75dB
Total Uncertainty of G/Ts	**±1.30dB**	**±1.32dB**	**±2.80dB**

Table 4.13: Table of IPFD Test Uncertainties

Error Factors	C band	Ku band	Ka band
Power Meter Readings（ΔPm）	±0.2dB	±0.2dB	±0.3dB
Cable Loss（ΔLpTx）	±0.2dB	±0.2dB	±0.3dB
Coupling of Coupler（ΔCp）	±0.3dB	±0.3dB	±0.5dB
Insertion Loss of Coupler（ΔICp）	±0.05dB	±0.05dB	±0.1dB
Antenna Feed Loss（ΔFITx）	±0.1dB	±0.1dB	±0.2dB
Antenna Gain（ΔGaTx）	±0.8dB	±0.8dB	±1.2dB
Tracking Loss (ΔLt2)	±0.4dB	±0.6 dB	±0.8dB
Other	±0.5 dB	±0.7 dB	±0.8 dB
Total Uncertainty of IPFD	**±1.19dB**	**±1.77dB**	**±2.02dB**

Table 4.14: Table of Amplitude Vs Frequency Response Test Uncertainties

Error Factors	C band	L band	Ku band	Ka band
Uplink Calibration	±0.3dB	±0.3dB	±0.4dB	±0.5dB
Downlink Calibration	±0.3dB	±0.3dB	±0.4dB	±0.6dB
Antenna	±0.3dB	±0.25dB	±0.2dB	±0.2dB
Atmosphere	±0.3dB	±0.1dB	±0.1dB	±0.1dB
Total Uncertainty of AF	**±0.48dB**	**±0.50dB**	**±0.61dB**	**±0.81dB**

Table 4.15: Table of Gain Step Uncertainties

Error Factors	L band	C band	Ku band	Ka band
Stability of Uplink	±0.2dB	±0.2dB	±0.2dB	±0.2dB
Gain Stability of Downlink	±0.2dB	±0.2dB	±0.2dB	±0.2dB
Atmosphere	±0.1dB	±0.1dB	±0.2dB	±0.3dB
Tracking	±0.1dB	±0.1dB	±0.2dB	±0.2dB
Spectrum Analyzer Readout	±0.8dB	±0.1dB	±0.2dB	±0.4dB
Accumulation Effect	±0.4dB	±0.4dB	±0.4dB	±0.4dB
Total Uncertainty of Gain Step	**±0.95dB**	**±0.52dB**	**±0.60dB**	**±0.73dB**

Table 4.16: Table of ALC Stability Test Uncertainties

Error Factors	Ku band	Ka band
Power Meter Readings（ΔPm）	±0.2dB	±0.3dB
Cable Loss（ΔLi）	±0.1dB	±0.1dB
Coupling of Coupler（ΔCi）	±0.1dB	±0.1dB
Insertion Loss of Coupler（ΔICi）	±0.05dB	±0.05dB
Coupling of Coupler（ΔCr）	±0.1dB	±0.1dB
Antenna Gain（ΔGaRx）	±0.1dB	±0.1dB
Atmosphere Loss（ΔLd）	±0.1dB	±0.3dB
Tracking Loss(ΔLt2)	±0.2dB	±0.2dB
Other	±0.5 dB	±0.5 dB
Total Uncertainty of ALC	**±0.62dB**	**±0.72dB**

Table 4.17: Table of Translation Frequency Test Uncertainties

Error Factors	L band	C band	Ku band	Ka band
Spectrum Analyzer Readout(Relative)	±200Hz	±700Hz	±900Hz	±1000Hz
Doppler Shift（Uplink and downlink）	±50Hz	±100Hz	±200Hz	±400Hz
Total Uncertainty of Translation Frequency	**±205Hz**	**±707Hz**	**±922Hz**	**±1077Hz**

4.3.2.2 Antenna Effects Analysis

During IOT, the influence of antenna pointing error errors was considered with respect to normal mode or station keeping mode of the satellite in its orbit. Based on the satellite specification and requirement, the antenna pointing error should be less than 0.1 degree in normal mode. Based on test point as the center, the maximum and minimum performance were obtained from the CATR results of figure 4.54 to 4.62 for the EIRPs and 4.64 to 4.72 for the G/Ts within 0.1 degree circle. Table 4.18 to 4.26 shows the antenna effects analysis used in validity criteria for the test data obtained.

Table 4.18: Ku Band West Antenna (ECOWAS 1) Antenna Effects Analysis

Beam	Up/Down	Channel	Gain	Gain min	Gain max	delta
Ku ECOWAS1	DOWN LINK	C01	33.30	33.09	33.53	0.44
		C02	33.45	33.27	33.69	0.42
		C03	33.39	33.15	33.65	0.50
		C04	33.82	33.56	34.11	0.55
		C05	33.75	33.50	34.02	0.52
		C06	33.72	33.48	33.99	0.51
		C07	33.87	33.49	34.17	0.68
Ku ECOWAS1	UP LINK	C01	35.80	35.65	35.90	0.25
		C02	35.34	35.18	35.46	0.28
		C03	35.37	35.22	35.48	0.26
		C04	35.42	35.26	35.51	0.25
		C05	35.48	35.30	35.55	0.25
		C06	35.52	35.34	35.62	0.28
		C07	35.43	35.27	35.53	0.26

Table 4.19: Ku Band East Antenna (ECOWAS 2) Antenna Effects Analysis

Beam	Up/Down	Channel	Gain	Gain min	Gain max	delta
Ku ECOWAS2	DOWN LINK	C08	31.62	31.24	31.94	0.70
		C09	31.74	31.34	32.18	0.84
		C10	31.70	31.29	32.01	0.72
		C11	31.68	31.30	31.99	0.69
		C12	31.71	31.31	32.03	0.72
		C13	31.92	31.54	32.23	0.69

Beam	Up/Down	Channel	Gain	Gain min	Gain max	delta
		C14	32.07	31.72	32.33	0.61
Ku ECOWAS2	UP LINK	C08	31.45	31.30	31.60	0.30
		C09	31.09	30.90	31.24	0.34
		C10	31.21	31.09	31.31	0.22
		C11	30.75	30.90	31.04	0.14
		C12	30.86	30.70	31.00	0.30
		C13	30.78	30.63	30.96	0.33
		C14	30.90	30.68	31.10	0.42

Table 4.20: C Band Antenna (ECOWAS 1) Antenna Effects Analysis

Beam	Up/Down	Channel	Gain	Gain min	Gain max	delta
C ECOWAS	DOWN LINK	C01	29.19	29.06	29.30	0.24
		C02	29.15	29.02	29.27	0.25
		C03	29.29	29.15	29.41	0.26
		C04	29.37	29.23	29.48	0.25
C ECOWAS	UP LINK	C01	32.07	31.98	32.15	0.17
		C02	32.11	32.00	32.20	0.20
		C03	32.21	32.10	32.30	0.20
		C04	32.17	32.07	32.27	0.20

Table 4.21: Ka Band Nigerian Beam Antenna Effects Analysis

Beam	Up/Down	Channel	Gain	Gain min	Gain max	delta
Ka Nigeria Beam	DOWN LINK	C04	40.89	40.58	40.89	0.30
		C05	40.88	40.50	40.99	0.49
		C06	40.92	40.60	41.11	0.51
		C07	40.89	40.68	41.04	0.36
		C08	41.09	40.78	41.09	0.31
Ka Nigeria Beam	UP LINK	C01	43.18	42.86	43.38	0.52
		C02	43.30	42.99	43.47	0.48
		C03	43.38	43.07	43.54	0.47
		C06	43.50	43.18	43.67	0.49
		C08	43.57	43.25	43.73	0.48

Table 4.22: Navigation Band Beam Antenna Effects Analysis

Beam	Up/Down	Channel	Gain	Gain min	Gain max	delta
Navigation	DOWNLINK	L1	15.30	15.17	15.37	0.20
		L5	15.80	15.69	15.89	0.20
Navigation	UPLINK	L1	18.00	17.96	18.03	0.07
		L5	18.31	18.25	18.32	0.07

Table 4.23: Ku Band West Antenna (ECOWAS 1) Beam Cuts Antenna Effects Analysis

roll	pitch	Gain	Gain min	Gain max	delta
-0.60	-1.20	32.53	31.44	33.37	1.93
-0.60	-0.90	33.80	32.94	34.29	1.35
-0.60	-0.30	34.48	34.06	34.83	0.77
-0.60	0.00	35.40	35.08	35.71	0.63
-0.60	0.90	34.72	34.66	34.96	0.30
-0.60	1.50	36.31	36.01	36.38	0.37
-0.60	2.10	35.82	35.30	36.07	0.77
0.00	-1.20	33.58	33.01	34.09	1.08
0.00	-0.90	34.75	34.39	34.84	0.45
0.00	-0.30	33.42	33.34	33.74	0.40
0.00	0.00	33.82	33.56	34.12	0.56
0.00	0.30	34.50	34.30	34.56	0.26
0.00	0.90	34.73	34.63	34.85	0.22
0.00	1.50	35.79	35.54	35.97	0.43
0.00	2.10	35.34	34.82	35.62	0.80
0.00	2.40	33.46	32.50	34.41	1.91
0.60	-1.20	32.20	31.71	32.68	0.97
0.60	-0.90	33.33	32.90	33.68	0.78
0.60	-0.30	33.55	33.48	33.68	0.20
0.60	0.00	34.08	33.85	34.34	0.49
0.60	0.30	34.66	34.40	34.74	0.34
0.60	0.90	34.10	33.68	34.40	0.72
0.60	1.50	35.21	34.93	35.32	0.39
0.60	2.10	34.15	33.28	34.64	1.36
0.60	2.40	31.57	30.32	32.69	2.37

Table 4.24: Ku Band East Antenna (ECOWAS 2) Beam Cuts Antenna Effects Analysis

roll	pitch	Gain	Gain min	Gain max	delta
-0.90	-1.20	27.88	26.40	29.00	2.60
-0.60	-1.20	30.10	29.17	30.85	1.68
-0.30	-1.20	31.46	30.90	31.80	0.90
0.00	-1.20	32.18	31.92	32.31	0.39
0.30	-1.20	32.39	32.33	32.45	0.12
0.60	-1.20	32.18	32.13	32.28	0.15
0.90	-1.20	32.38	32.20	32.58	0.38
1.20	-1.20	32.90	32.66	33.05	0.39
1.50	-1.20	32.99	32.93	33.11	0.18
-0.90	-0.60	30.63	30.10	31.18	1.08

roll	pitch	Gain	Gain min	Gain max	delta
-0.60	-0.60	31.96	31.53	32.25	0.72
-0.30	-0.60	32.53	32.37	32.76	0.39
0.00	-0.60	32.82	32.60	33.06	0.46
0.30	-0.60	33.10	32.92	33.22	0.30
0.60	-0.60	32.86	32.63	33.01	0.38
0.90	-0.60	32.28	32.18	32.45	0.27
1.20	-0.60	32.25	32.15	32.51	0.36
1.50	-0.60	33.00	32.72	33.24	0.52
-0.90	0.00	29.64	28.92	30.23	1.31
-0.60	0.00	30.75	30.38	31.04	0.66
-0.30	0.00	31.23	30.90	31.58	0.68
0.00	0.00	31.68	31.31	31.98	0.67
0.30	0.00	31.67	31.34	31.99	0.65
0.60	0.00	31.22	30.84	31.59	0.75
0.90	0.00	31.00	30.52	31.43	0.91
1.20	0.00	31.30	30.62	31.87	1.25

Table 4.25: C Band Antenna (ECOWAS 1) Beam Cuts Antenna Effects Analysis

roll	pitch	Gain	Gain min	Gain max	delta
0.00	-5.10	22.67	22.39	22.95	0.56
0.00	-4.50	24.24	23.97	24.50	0.53
0.00	-3.90	25.43	25.21	25.63	0.42
0.00	-3.30	26.43	26.23	26.61	0.38
0.00	-2.70	27.16	27.00	27.31	0.31
0.00	-2.10	27.73	27.57	27.88	0.31
0.00	-1.50	28.27	28.12	28.42	0.30
0.00	-0.90	28.74	28.58	28.89	0.30
0.00	-0.30	29.15	29.01	29.27	0.25
0.00	0.00	29.29	29.16	29.41	0.25
0.00	0.30	29.45	29.33	29.56	0.22
0.00	0.90	29.60	29.50	29.68	0.18
0.00	1.50	29.53	29.45	29.60	0.15
0.00	2.10	29.24	29.13	29.34	0.21
0.00	2.70	28.66	28.53	28.78	0.25
-0.60	-5.10	21.72	21.37	22.07	0.70
-0.60	-4.50	23.31	23.02	23.59	0.57
-0.60	-3.90	24.42	24.14	24.69	0.56
-0.60	-3.30	25.45	25.19	25.69	0.50
-0.60	-2.70	26.14	25.90	26.36	0.47
-0.60	-2.10	26.72	26.49	26.95	0.46

roll	pitch	Gain	Gain min	Gain max	delta
-0.60	-1.50	27.24	27.00	27.46	0.46
-0.60	-0.90	27.69	27.45	27.93	0.48
-0.60	-0.30	28.15	27.93	28.36	0.44
-0.60	0.30	28.55	28.33	28.76	0.42
-0.60	0.90	28.72	28.60	28.97	0.37
-0.60	1.50	28.82	28.65	28.98	0.33
-0.60	2.10	28.62	28.45	28.77	0.33
-0.60	2.70	28.11	27.93	28.28	0.35
0.60	-5.10	23.14	22.87	23.40	0.53
0.60	-4.50	24.67	24.43	24.90	0.47
0.60	-3.90	25.90	25.72	26.08	0.36
0.60	-3.30	26.88	26.73	27.03	0.30
0.60	-2.70	27.67	27.56	27.77	0.21
0.60	-2.10	28.23	28.13	28.33	0.20
0.60	-1.50	28.76	28.67	28.84	0.17
0.60	-0.90	29.22	29.14	29.30	0.16
0.60	-0.30	29.57	29.53	29.61	0.08
0.60	0.30	29.78	29.74	29.81	0.07
0.60	0.90	29.83	29.81	29.85	0.04
0.60	1.50	29.68	29.64	29.72	0.08
0.60	2.10	29.31	29.19	29.41	0.22

Table 4.26: Ka Band Nigerian Beam Cuts Antenna Effects Analysis

roll	pitch	Gain	Gain min	Gain max	delta
0.00	-1.20	34.71	32.75	35.65	2.90
0.00	-0.90	37.60	36.67	38.44	1.77
0.00	-0.60	39.83	39.26	40.22	0.96
0.00	-0.30	40.83	40.51	41.11	0.60
0.00	0.00	40.93	40.70	41.12	0.42
0.00	0.30	40.32	39.61	40.71	1.10
0.00	0.60	38.65	37.84	39.10	1.26
0.00	0.90	35.68	34.74	36.72	1.98
-0.60	-1.20	31.85	30.01	33.68	1.98
-0.60	-0.90	35.55	34.35	36.61	1.98
-0.60	-0.60	38.02	36.86	38.69	1.98
-0.60	-0.30	39.10	38.27	39.65	1.98
-0.60	0.00	39.34	38.54	39.86	1.98
-0.60	0.30	38.54	37.61	39.14	1.53
-0.60	0.60	36.66	35.58	37.69	2.11
0.60	0.60	36.50	35.32	37.40	2.08

roll	pitch	Gain	Gain min	Gain max	delta
0.60	0.30	38.12	37.30	38.89	1.59
0.60	0.00	38.88	38.11	39.48	1.37
0.60	-0.30	38.80	37.96	39.46	1.50
0.60	-0.60	37.61	36.63	38.48	1.85
0.60	-0.90	35.43	34.76	36.56	1.80
0.60	-1.20	32.08	30.55	33.50	2.95

4.3.3 Validity Criteria for the Test Data.

The IOT results particularly EIRP, SFD and G/T; key performance parameters of communication satellite service delivery were analysed and validated over reference spacecraft tests based on prediction result carried out (CATR results in particular as final benchmark test before launch campaign) and test uncertainty analysis during In-Orbit Tests (IOT).

Considering antenna effect analysis as ∂_0, let the test result be Y with uncertainty as ∂_1 and the prediction result as X with uncertainty as ∂_2, then the test results are valid and accepted when $|Y-X| \leq \sqrt{\partial_1^2 + \partial_2^2 + \partial_0}$

$$|Y-X| \leq \sqrt{\partial_1^2 + \partial_2^2 + \partial_0} \qquad \text{……………………………………………..Equation 4.1}$$

4.3.4 Test Result Analysis

Test results validations

4.3.4.1 EIRP Test Result Analysis

The EIRP results during IOT are consistent with the predicted CATR results and the delta is within the uncertainties. The EIRP results analysis of selected channel configurations of all bands as presented in table 4.27 to 4.31 are consistent and compliant and within the uncertainties of equation 4.1.

Table 4.27: Ku Band West Antenna (ECOWAS 1) Beam EIRP Test Results.

No.	No. of Config.	Name of Config.	UB	UP	REVR	CH	TWTA /SSPA	DB	DP	Spec. (dBW)	CCR EIRP (dBW)	IOT EIRP (dBW)	Delta	ERROR (dB)				C/NC
														CCR	Ground Stat.	Antenna Point	Total	
1	1	KUWHR11L_C01T101KUWVP0_	KUW	H	R11	C01	T101	KUW	V	52.60	54.23	54.65	0.42	0.41	1.49	0.44	1.56	C
2	2	KUWHR11L_C01T106KUWVP1_	KUW	H	R11	C01	T106	KUW	V	52.10	53.89	54.01	0.12	0.41	1.49	0.44	1.56	C
3	4	KUWHR11L_C02T103KUWVP0_	KUW	H	R11	C02	T103	KUW	V	52.60	53.93	54.63	0.70	0.41	1.49	0.42	1.56	C
4	7	KUWHR11L_C03T104KUWVP0_	KUW	H	R11	C03	T104	KUW	V	52.60	53.87	54.64	0.77	0.41	1.49	0.50	1.58	C
5	10	KUWHR11L_C04T105KUWVP0_	KUW	H	R11	C04	T105	KUW	V	52.60	53.85	54.23	0.38	0.41	1.49	0.55	1.59	C
6	13	KUWHR11L_C05T107KUWVP0_	KUW	H	R11	C05	T107	KUW	V	52.60	54.20	54.05	-0.15	0.41	1.49	0.52	1.58	C
7	16	KUWHR11L_C06T108KUWVP0_	KUW	H	R11	C06	T108	KUW	V	52.60	54.22	54.64	0.42	0.41	1.49	0.51	1.58	C
8	20	KUWHR11L_C07T109KUWVP0_	KUW	H	R11	C07	T109	KUW	V	52.60	54.16	54.40	0.24	0.41	1.49	0.68	1.62	C

Table 4.28: Ku Band East Antenna (ECOWAS 2) Beam EIRP Test Results.

No.	No. of Config.	Name of Config.	UB	UP	REVR	CH	TWTA /SSPA	DB	DP	RE ERIP (dBW)	GT ERIP (dBW)	CCR EIRP (dBW)	IOT EIRP (dBW)	Delta	ERROR (dB)				C/NC
															CCR	Ground Stat.	Antenna	Total	
1	30	KUEVR15L_C08T110KUEHP0_	KUE	V	R15	C08	T110	KUE	H	50.10	51.69	51.86	51.51	0.35	0.41	1.49	0.70	1.63	C
2	31	KUEVR15L_C08T113KUEHP1_	KUE	V	R15	C08	T113	KUE	H	49.60	51.46	51.13	50.71	0.42	0.41	1.49	0.70	1.63	C
3	34	KUEVR15L_C09T111KUEHP0_	KUE	V	R15	C09	T111	KUE	H	50.10	51.60	51.21	50.93	0.28	0.41	1.49	0.84	1.68	C
4	38	KUEVR15L_C10T112KUEHP0_	KUE	V	R15	C10	T112	KUE	H	50.10	51.74	51.58	51.73	-0.15	0.41	1.49	0.72	1.63	C
5	41	KUEVR15L_C11T114KUEHP0_	KUE	V	R15	C11	T114	KUE	H	50.10	51.56	51.18	51.36	-0.18	0.41	1.49	0.69	1.62	C
6	44	KUEVR15L_C12T115KUEHP0_	KUE	V	R15	C12	T115	KUE	H	50.10	51.82	51.56	51.41	0.15	0.41	1.49	0.72	1.63	C
7	47	KUEVR15L_C13T116KUEHP0_	KUE	V	R15	C13	T116	KUE	H	50.10	52.03	51.63	51.35	0.28	0.41	1.49	0.69	1.62	C
8	50	KUEVR15L_C14T118KUEHP0_	KUE	V	R15	C14	T118	KUE	H	50.10	52.18	51.75	52.02	-0.27	0.41	1.49	0.61	1.60	C

Table 4.29: C Band Antenna (ECOWAS 1) Beam EIRP Test Results.

No.	No. of Config.	Name of Config.	UP	REVR	CH	TWTA /SSPA	DP	CCR EIRP (dBW)	IOT EIRP (dBW)	Delta	ERROR (dBW)				C/NC
											CCR	Ground Stat.	Antenna Point	Total	
1	75	C_RR21L_C01T201C_LP0_	R	R21	C01	T201	L	45.05	45.10	0.05	0.47	1.26	0.24	1.34	C
2	76	C_RR21L_C01T202C_LP1_	R	R21	C01	T202	L	44.60	44.69	0.09	0.47	1.26	0.24	1.34	C
3	78	C_RR21L_C02T203C_LP0_	R	R21	C02	T203	L	45.38	45.30	-0.08	0.47	1.26	0.25	1.34	C
4	81	C_RR21L_C03T204C_LP0_	R	R21	C03	T204	L	45.48	45.78	0.30	0.47	1.26	0.26	1.34	C
5	82	C_RR21L_C03T205C_LP1_	R	R21	C03	T205	L	45.16	45.57	0.41	0.47	1.26	0.26	1.34	C
6	84	C_RR21L_C04T206C_LP0_	R	R21	C04	T206	L	45.35	45.84	0.49	0.47	1.26	0.25	1.34	C

Table 4.30: L Band (Navigation) Antenna Beam EIRP Test Results.

No. of Config.	Name of Config.	UP	REVR	OS	CH	TWTA /SSPA	DP	CCR EIRP (dBW)	IOT EIRP (dBW)	Delta	ERROR (dB)				C/NC
											CCR	Ground Stat.	Antenna Point	Total	
90	CL_LR31L1C01T301CL_RP0_	L	R31	L1	C01	T301	R	31.53	31.70	0.17	0.7	1.44	0.20	1.56	C
91	CL_LR31L1C01T302CL_RP1_	L	R31	L1	C01	T302	R	31.27	31.49	0.22	0.7	1.44	0.20	1.56	C
92	CL_LR33L1C05T303CL_RP0_	L	R33	L1	C05	T303	R	30.28	29.48	-0.80	0.7	1.44	0.20	1.56	C
93	CL_LR33L1C05T304CL_RP1_	L	R33	L1	C05	T304	R	30.10	28.84	-1.26	0.7	1.44	0.20	1.56	C

Table 4.31: Ka Band Nigerian Antenna Spot Beam EIRP Test Results.

No.	No. of Config.	Name of Config.	UB	UP	REVR	CH	TWTA /SSPA	DB	DP	CCR EIRP (dBW)	IOT EIRP (dBW)	Delta	ERROR (dB)				C/NC
													CCR	Ground Stat.	Antenna Point	Total	
1	105	KANLR45L_C06T407KANRP0_	KAN	L	R45	C06	T407	KAN	R	57.82	57.33	-0.49	0.4	2.20	0.51	2.25	C
2	106	KANLR45L_C06T408KANRP1_	KAN	L	R45	C06	T408	KAN	R	57.95	57.50	-0.45	0.4	2.20	0.51	2.25	C
3	108	KANLR45L_C08T410KANRP0_	KAN	L	R45	C08	T410	KAN	R	58.08	57.28	-0.80	0.4	2.20	0.31	2.23	C
4	E1	KANLR43L_C04T405KANRPE_	KAN	L	R43	C04	T405	KAN	R	57.84	57.32	-0.52	0.4	2.20	0.30	2.23	C
5	E2	KANLR45L_C05T406KANRPE_	KAN	L	R45	C05	T406	KAN	R	57.74	57.60	-0.14	0.4	2.20	0.49	2.25	C
6	E3	KANLR45L_C07T409KANRPE_	KAN	L	R45	C07	T409	KAN	R	57.83	57.45	-0.38	0.4	2.20	0.36	2.23	C
7	E4	KANLR45L_C04T401KANRPE_	KAN	L	R45	C04	T401	KAN	R		57.30		0.4	2.20	0.30	2.23	
8	E5	KANLR45L_C04T402KANRPE_	KAN	L	R45	C04	T402	KAN	R		57.48		0.4	2.20	0.30	2.23	
9	E6	KANLR45L_C04T403KANRPE_	KAN	L	R45	C04	T403	KAN	R		57.53		0.4	2.20	0.30	2.23	

4.3.4.2 G/T Result Analysis

The G/T results during IOT are consistent with the predicted G/T results and the delta is within the uncertainties of equation 4.1. The G/T results analysis of selected channel configurations of bands as presented in table 4.32 to 4.35 are consistent and compliant and within the uncertainties. The Antenna noise temperature difference (Delta) is used to compensate the noise temperature between ground test and IOT. It is estimated that the antenna noise temperature during IOT was 200K while antenna noise temperature of earth is 290K.

Table 4.32: Ku Band West Antenna (ECOWAS 1) Beam G/T Test Result.

No.	No. of Config.	Name of Config.	UB	UP	REVR	CH	TWTA /SSPA	DB	DP	Spec. (dB/K)	CCR G/T (dB/K)	IOT G/T (dB/K)	Delta	ERROR				C/NC
														CCR	Ground Stat.	Antenna Point	Total	
1	1	KUWHR11L_C01T101KUWVP0_	KUW	H	R11	C01	T101	KUW	V	6.40	9.53	10.34	0.81	0.53	1.32	0.25	1.40	C
5	10	KUWHR11L_C04T105KUWVP0_	KUW	H	R11	C04	T105	KUW	V	6.40	9.55	9.97	0.42	0.53	1.32	0.25	1.40	C
8	20	KUWHR11L_C07T109KUWVP0_	KUW	H	R11	C07	T109	KUW	V	6.40	9.44	11.33	1.89	0.53	1.32	0.26	1.40	C
9	25	KUWHR12L_C04T105KUWVP0_	KUW	H	R12	C04	T105	KUW	V	6.20	9.74	10.31	0.57	0.53	1.32	0.25	1.40	C
10	28	KUWHR13L_C04T105KUWVP0_	KUW	H	R13	C04	T105	KUW	V	6.20	9.65	9.82	0.17	0.53	1.32	0.25	1.40	C

Table 4.33: Ku Band East Antenna (ECOWAS 2) Beam G/T Test Result.

No.	No. of Config.	Name of Config.	UB	UP	REVR	CH	TWTA /SSPA	DB	DP	Spec. (dB/K)	GT G/T (dB/K)	CCR G/T (dB/K)	IOT G/T (dB/K)	Delta	ERROR (dB)				C/NC
															CCR	Ground Stat.	Antenna Point	Total	
1	30	KUEVR15L_C08T110KUEHP0_	KUE	V	R15	C08	T110	KUE	H	2.40	4.62	4.59	5.55	-0.96	0.53	1.32	0.30	1.41	C
2	41	KUEVR15L_C11T114KUEHP0_	KUE	V	R15	C11	T114	KUE	H	2.40	4.03	4.36	4.21	0.15	0.53	1.32	0.14	1.39	C
3	50	KUEVR15L_C14T118KUEHP0_	KUE	V	R15	C14	T118	KUE	H	2.40	3.80	4.13	5.80	-1.67	0.53	1.32	0.42	1.43	C
4	54	KUEVR14L_C11T114KUEHP0_	KUE	V	R14	C11	T114	KUE	H	2.20	4.03	4.12	4.20	-0.08	0.53	1.32	0.14	1.39	C

Table 4.34: C Band Antenna (ECOWAS 1) Beam G/T Test Result.

No.	No. of Config.	Name of Config.	UP	REVR	CH	TWTA /SSPA	DP	CCR G/T (dB/K)	IOT G/T (dB/K)	Delta	ERROR (dB)				C/NC
											CCR	Ground Stat.	Antenna Point	Total	
1	75	C_RR21L_C01T201C_LP0_	R	R21	C01	T201	L	4.35	**6.29**	1.94	0.59	1.30	0.20	1.40	C
2	84	C_RR21L_C04T206C_LP0_	R	R21	C04	T206	L	5.36	**6.45**	1.09	0.59	1.30	0.20	1.40	C
3	87	C_RR22L_C01T201C_LP0_	R	R22	C01	T201	L	4.49	**6.40**	1.91	0.59	1.30	0.20	1.40	C

Table 4.35: Ka Band Nigerian Antenna Spot Beam G/T Test Result.

No.	No. of Config.	Name of Config.	UB	UP	REVR	CH	TWTA /SSPA	DB	DP	CCR G/T (dB/K)	IOT G/T (dB/K)	Delta	ERROR (dB)				C/NC
													CCR	Ground Stat.	Antenna Point	Total	
1	105	KANLR45L_C06T407KANRP0_	KAN	L	R45	C06	T407	KAN	R		15.00		0.52	2.80	0.49	2.83	
2	108	KANLR45L_C08T410KANRP0_	KAN	L	R45	C08	T410	KAN	R	14.10	14.64	0.54	0.52	2.80	0.48	2.83	C
3	113	KANLR44L_C08T410KANRP0_	KAN	L	R44	C08	T410	KAN	R	14.45	15.33	0.88	0.52	2.80	0.48	2.83	C
4	E1	KANLR43L_C04T405KANRPE_	KAN	L	R43	C04	T405	KAN	R		15.63		0.52	2.80	0.49	2.83	

4.3.4.3 SFD Result Analysis

The SFD results during IOT are consistent with the predicted G/T results and the delta is within the uncertainties. The SFD results analysis of selected channel configurations of bands as presented in table 4.36 to 4.40 are consistent and compliant and within uncertainties of equation 4.1.

Table 4.36: Ku Band West Antenna (ECOWAS 1) Beam SFD Test Result

No.	No. of Config.	Name of Config.	UB	UP	REVR	CH	TWTA /SSPA	DB	DP	CCR SFD (dBW/m^2)	IOT SFD (dBW/m^2)	Delta	ERROR				C/NC
													CCR	Ground Stat.	Antenna Point	Total	
1	1	KUWHR11L_C01T101KUWVP0_	KUW	H	R11	C01	T101	KUW	V	-95.10	**-95.78**	-0.68	0.41	1.77	0.25	1.81	C
2	2	KUWHR11L_C01T106KUWVP1_	KUW	H	R11	C01	T106	KUW	V	-93.60	**-93.82**	-0.22	0.41	1.77	0.25	1.81	C
3	4	KUWHR11L_C02T103KUWVP0_	KUW	H	R11	C02	T103	KUW	V	-95.67	**-96.23**	-0.56	0.41	1.77	0.28	1.81	C
4	7	KUWHR11L_C03T104KUWVP0_	KUW	H	R11	C03	T104	KUW	V	-95.28	**-95.97**	-0.69	0.41	1.77	0.26	1.81	C
5	10	KUWHR11L_C04T105KUWVP0_	KUW	H	R11	C04	T105	KUW	V	-96.08	**-96.29**	-0.21	0.41	1.77	0.25	1.81	C
6	13	KUWHR11L_C05T107KUWVP0_	KUW	H	R11	C05	T107	KUW	V	-95.42	**-95.72**	-0.30	0.41	1.77	0.25	1.81	C
7	16	KUWHR11L_C06T108KUWVP0_	KUW	H	R11	C06	T108	KUW	V	-95.83	**-96.33**	-0.50	0.41	1.77	0.28	1.81	C
8	20	KUWHR11L_C07T109KUWVP0_	KUW	H	R11	C07	T109	KUW	V	-95.36	**-95.76**	-0.40	0.41	1.77	0.26	1.81	C
9	25	KUWHR12L_C04T105KUWVP0_	KUW	H	R12	C04	T105	KUW	V	-96.28	**-96.28**	0.00	0.41	1.77	0.25	1.81	C
6	28	KUWHR13L_C04T105KUWVP0_	KUW	H	R13	C04	T105	KUW	V	-95.60	**-95.30**	0.30	0.41	1.77	0.25	1.81	C

Table 4.37: Ku Band East Antenna (ECOWAS 2) Beam SFD Test Result

No.	No. of Config.	Name of Config.	UB	UP	REVR	CH	TWTA /SSPA	DB	DP	CCR SFD (dBW/m^2)	IOT SFD (dBW/m^2)	Delta	ERROR (dB)				C/NC
													CCR	Ground Stat.	Antenna Point	Total	
1	30	KUEVR15L_C08T110KUEHP0_	KUE	V	R15	C08	T110	KUE	H	-91.60	**-91.76**	0.16	0.41	1.77	0.30	1.81	C
2	31	KUEVR15L_C08T113KUEHP1_	KUE	V	R15	C08	T113	KUE	H	-90.60	**-90.98**	0.38	0.41	1.77	0.30	1.81	C
3	34	KUEVR15L_C09T111KUEHP0_	KUE	V	R15	C09	T111	KUE	H	-90.67	**-90.32**	-0.35	0.41	1.77	0.34	1.82	C
4	38	KUEVR15L_C10T112KUEHP0_	KUE	V	R15	C10	T112	KUE	H	-90.58	**-90.71**	0.13	0.41	1.77	0.22	1.81	C
5	41	KUEVR15L_C11T114KUEHP0_	KUE	V	R15	C11	T114	KUE	H	-90.48	**-90.49**	0.01	0.41	1.77	0.14	1.80	C
6	44	KUEVR15L_C12T115KUEHP0_	KUE	V	R15	C12	T115	KUE	H	-91.12	**-91.23**	0.11	0.41	1.77	0.30	1.81	C
7	47	KUEVR15L_C13T116KUEHP0_	KUE	V	R15	C13	T116	KUE	H	-91.33	**-92.78**	1.45	0.41	1.77	0.33	1.82	C
8	50	KUEVR15L_C14T118KUEHP0_	KUE	V	R15	C14	T118	KUE	H	-91.06	**-90.94**	-0.12	0.41	1.77	0.42	1.83	C
9	54	KUEVR14L_C11T114KUEHP0_	KUE	V	R14	C11	T114	KUE	H	-90.08	**-90.40**	0.32	0.41	1.77	0.14	1.80	C

Table 4.38: C Band Antenna (ECOWAS 1) Beam SFD Test Result

No.	No. of Config.	Name of Config.	UP	REVR	CH	TWTA /SSPA	DP	CCR SFD (dBW/m^2)	IOT SFD (dBW/m^2)	Delta	ERROR (dB)				C/NC
											CCR	Ground Stat.	Antenna Point	Total	
1	75	C_RR21L_C01T201C_LP0_	R	R21	C01	T201	L	-92.79	**-92.81**	-0.02	0.47	1.19	0.17	1.26	C
2	76	C_RR21L_C01T202C_LP1_	R	R21	C01	T202	L	-92.09	**-92.68**	-0.59	0.47	1.19	0.17	1.26	C
3	78	C_RR21L_C02T203C_LP0_	R	R21	C02	T203	L	-93.24	**-92.85**	0.39	0.47	1.19	0.20	1.26	C
4	81	C_RR21L_C03T204C_LP0_	R	R21	C03	T204	L	-93.36	**-92.60**	0.76	0.47	1.19	0.20	1.26	C
5	82	C_RR21L_C03T205C_LP1_	R	R21	C03	T205	L	-93.76	**-93.64**	0.12	0.47	1.19	0.20	1.26	C
6	84	C_RR21L_C04T206C_LP0_	R	R21	C04	T206	L	-93.68	**-94.23**	-0.55	0.47	1.19	0.20	1.26	C
7	87	C_RR22L_C01T201C_LP0_	R	R22	C01	T201	L	-92.09	**-92.75**	-0.66	0.47	1.19	0.20	1.26	C

Table 4.39: Ka Band Nigerian Spot Beam Antenna Beam SFD Test Result

No.	No. of Config.	Name of Config.	UB	UP	REVR	CH	TWTA /SSPA	DB	DP	CCR SFD (dBW/m^2)	IOT SFD (dBW/m^2)	Delta	ERROR (dB)				C/NC
													CCR	Ground Stat.	Antenna Point	Total	
1	105	KANLR45L_C06T407KANRP0_	KAN	L	R45	C06	T407	KAN	R	-86.57	**-86.89**	-0.32	0.4	2.02	0.49	2.07	C
2	106	KANLR45L_C06T408KANRP1_	KAN	L	R45	C06	T408	KAN	R	-86.57	**-86.74**	-0.17	0.4	2.02	0.49	2.07	C
3	108	KANLR45L_C08T410KANRP0_	KAN	L	R45	C08	T410	KAN	R	-86.65	**-86.69**	-0.04	0.4	2.02	0.48	2.07	C
4	113	KANLR44L_C08T410KANRP0_	KAN	L	R44	C08	T410	KAN	R	-86.75	**-86.76**	-0.01	0.4	2.02	0.48	2.07	C
5	E1	KANLR43L_C04T405KANRPE_	KAN	L	R43	C04	T405	KAN	R		**-85.81**		0.4	2.02	0.49	2.07	
6	E2	KANLR45L_C05T406KANRPE_	KAN	L	R45	C05	T406	KAN	R		**-86.15**		0.4	2.02	0.49	2.07	
7	E3	KANLR45L_C07T409KANRPE_	KAN	L	R45	C07	T409	KAN	R		**-86.17**		0.4	2.02	0.49	2.07	
8	E4	KANLR45L_C04T401KANRPE_	KAN	L	R45	C04	T401	KAN	R		**-84.08**		0.4	2.02	0.49	2.07	
9	E5	KANLR45L_C04T402KANRPE_	KAN	L	R45	C04	T402	KAN	R		**-83.63**		0.4	2.02	0.49	2.07	
10	E6	KANLR45L_C04T403KANRPE_	KAN	L	R45	C04	T403	KAN	R		**-83.71**		0.4	2.02	0.49	2.07	

Table 4.40: L Band (Navigation) Antenna Beam SFD Test Result

No.	No. of Config.	Name of Config.	UP	REVR	OS	CH	TWTA /SSPA	DP	CCR SFD (dBW/m^2)	IOT SFD (dBW/m^2)	Delta	ERROR (dB)				C/NC
												CCR	Ground Stat.	Antenna Point	Total	
1	90	CL_LR31L1C01T301CL_RP0_	L	R31	L1	C01	T301	R	-89.59	**-89.57**	0.02	0.47	1.19	0.07	1.25	C
2	91	CL_LR31L1C01T302CL_RP1_	L	R31	L1	C01	T302	R	-89.69	**-89.78**	-0.09	0.47	1.19	0.07	1.25	C
3	92	CL_LR33L1C05T303CL_RP0_	L	R33	L1	C05	T303	R	-90.09	**-89.48**	0.61	0.47	1.19	0.07	1.25	C
4	93	CL_LR33L1C05T304CL_RP1_	L	R33	L1	C05	T304	R	-89.99	**-89.88**	0.11	0.47	1.19	0.07	1.25	C
5	94	CL_LR32L2C01T301CL_RP0_	L	R32	L2	C01	T301	R	-90.59	**-90.87**	-0.28	0.47	1.19	0.07	1.25	C
6	95	CL_LR34L3C05T303CL_RP0_	L	R34	L3	C05	T303	R	-90.29	**-89.72**	0.57	0.47	1.19	0.07	1.25	C

4.3.4.4 Antenna Pattern Verification Analysis

Compared with CATR results, the results of the antenna pattern verification shows that the pointing of antennas was correct and beam shape is same with CATR results. After lift-off and Low Earth Orbit Phase and Manoeuvre, the antenna pointing does not require adjustment based on results in figure 4.74 to 4.76 for C-Band Antenna. For Ku Band Antennas and Ka Band Antenna. Figure 4.83 to 4.91 also shows acceptable antenna pattern verifications.

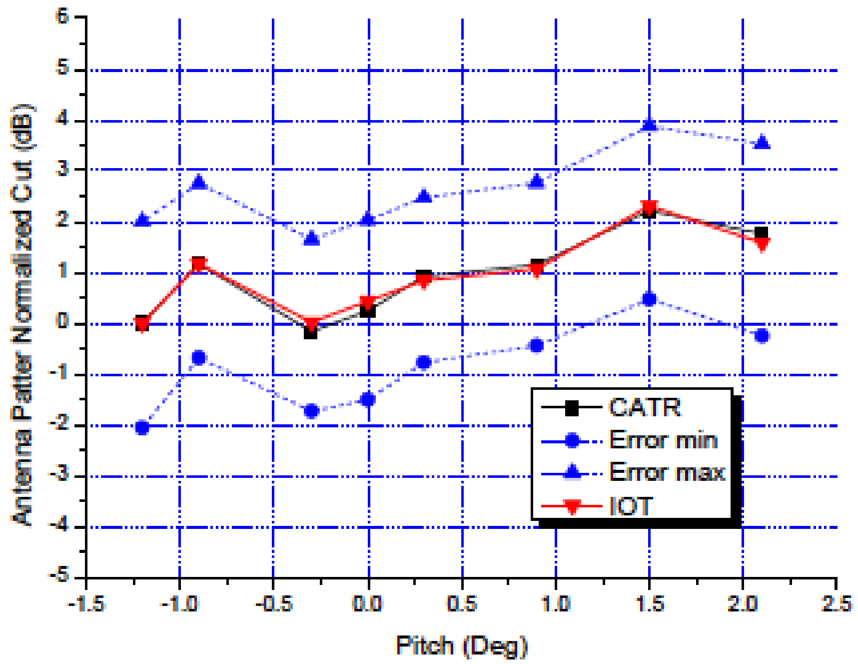


Figure 4.83: Ku Band West Antenna (ECOWAS 1) Beam Cut Line 2 (Roll=0°)

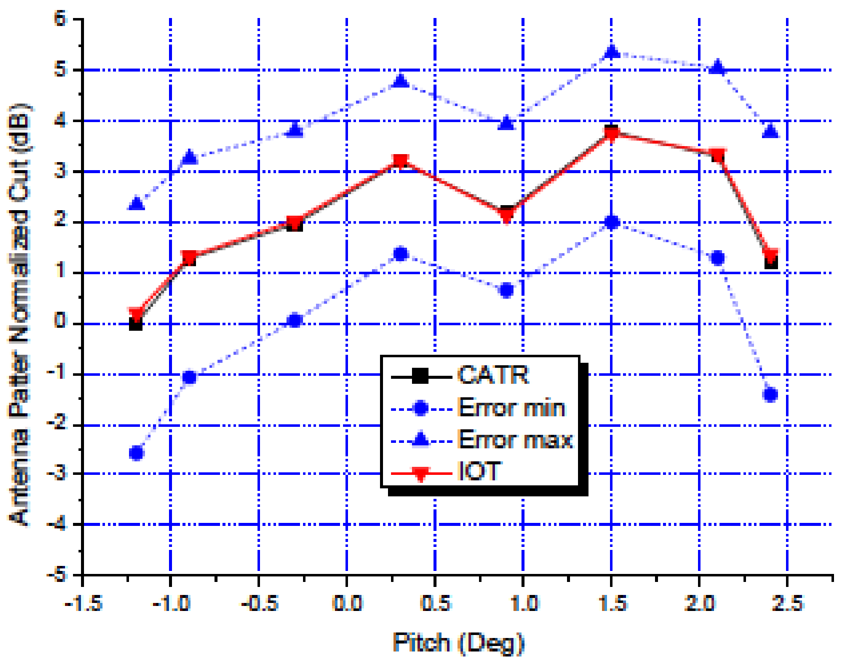


Figure 4.84: Ku Band West Antenna (ECOWAS 1) Beam Cut Line 3 (Roll=-0.6°)

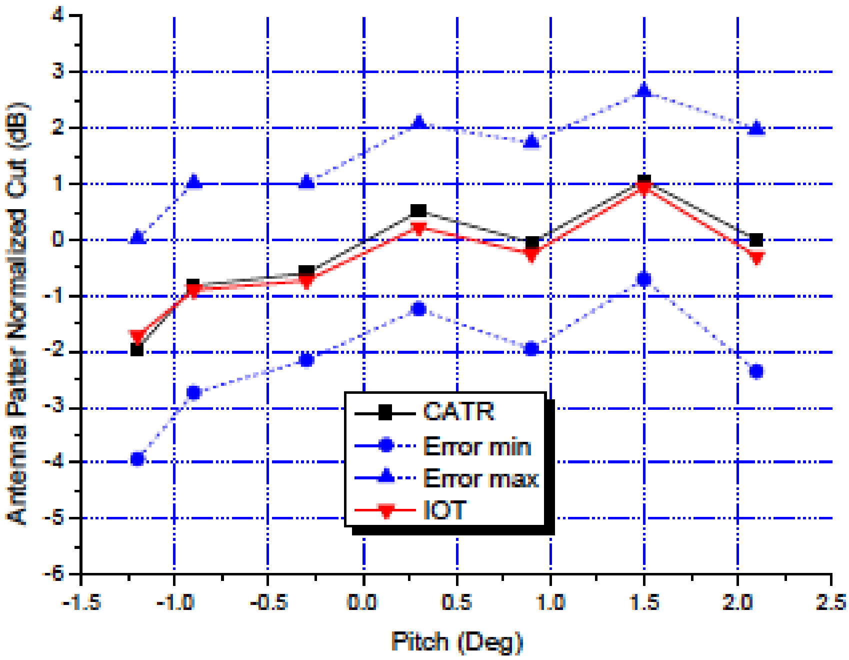


Figure 4.85: Ku Band West Antenna (ECOWAS 1) Beam Cut Line 1 (Roll=0.6°)

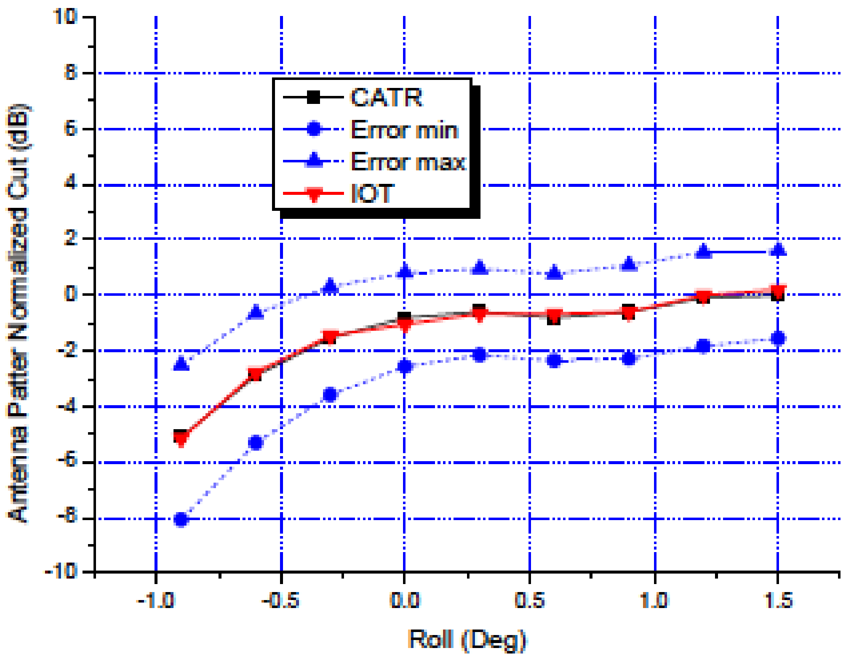


Figure 4.86: Ku Band East Antenna (ECOWAS 2) Beam Cut Line 3 (Pitch=-1.2°)

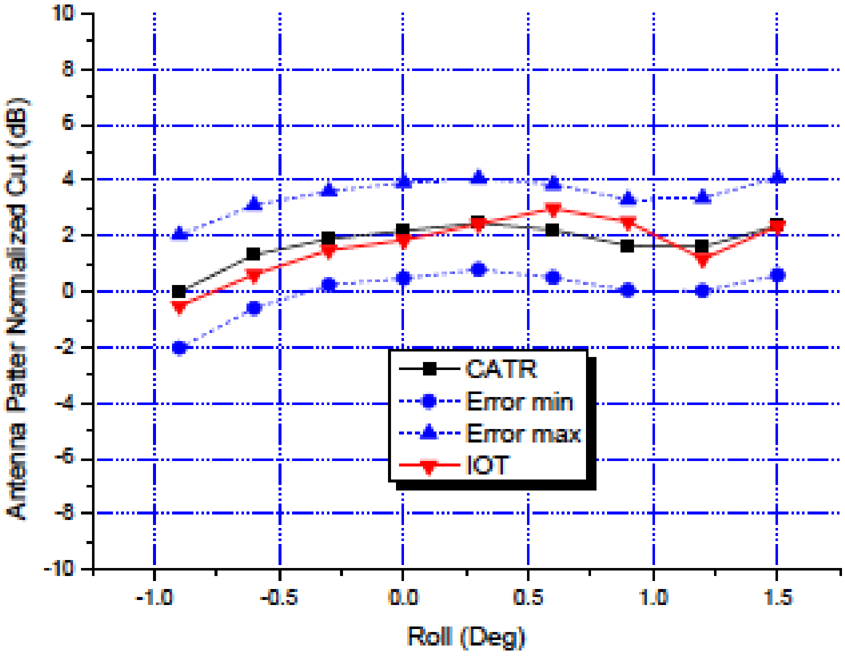


Figure 4.87: Ku Band East Antenna (ECOWAS 2) Beam Cut Line 2 (Pitch=-0.6°)

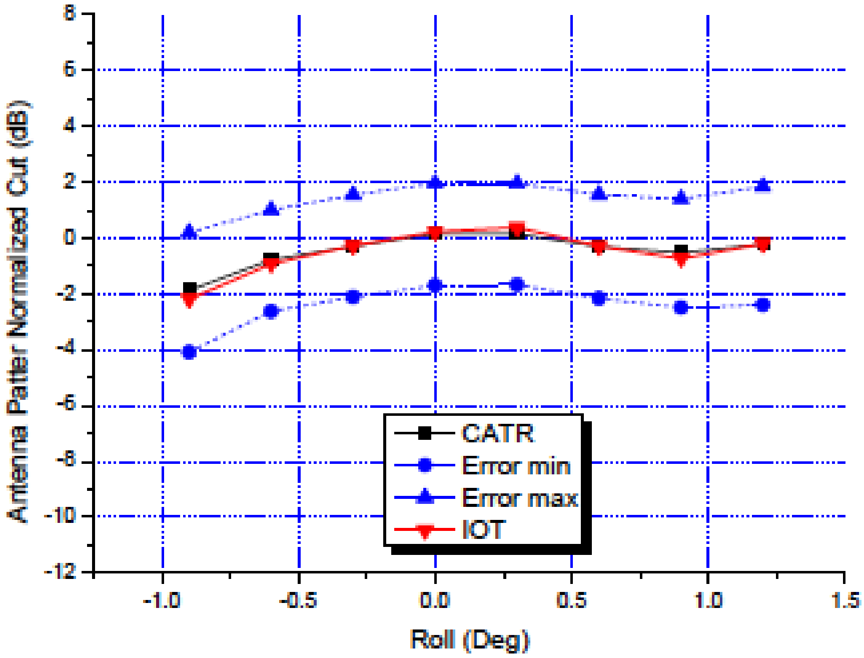


Figure 4.88: Ku Band East Antenna (ECOWAS 2) Beam Cut Line 1 (Pitch=0°)

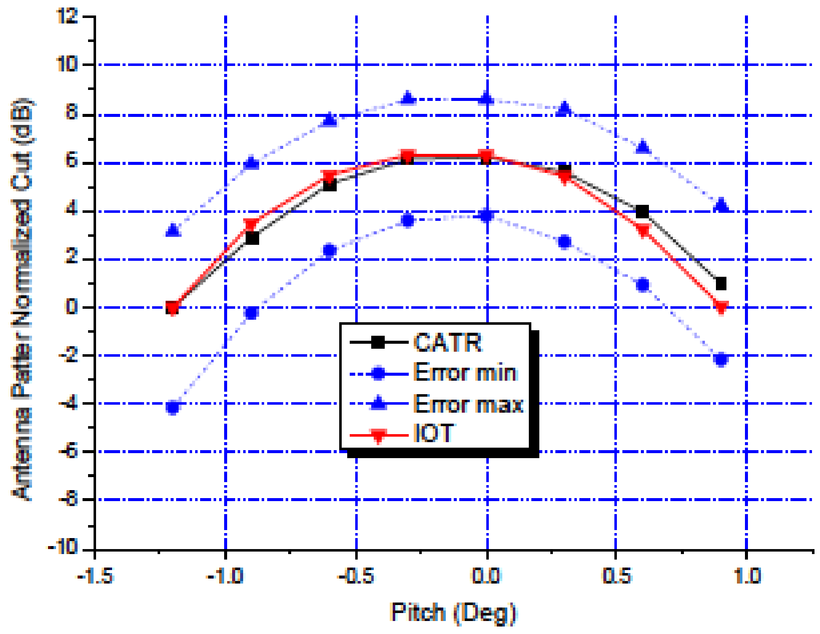


Figure 4.89: Ka Band Nigerian Spot Beam Antenna Cut Line 1 (Pitch=0°)

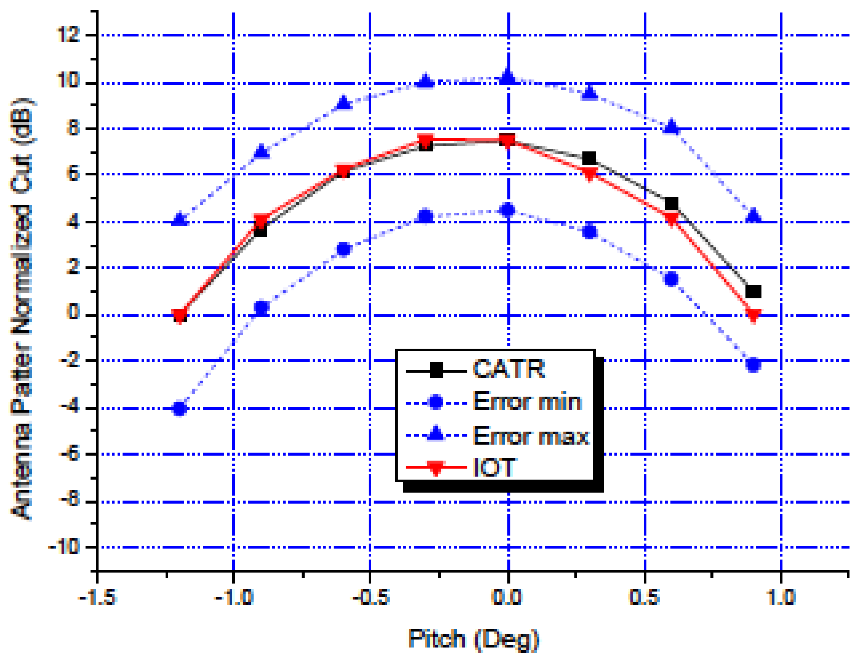


Figure 4.90: Ka Band Nigerian Spot Beam Antenna Cut Line 2 (Pitch=-0.6°)

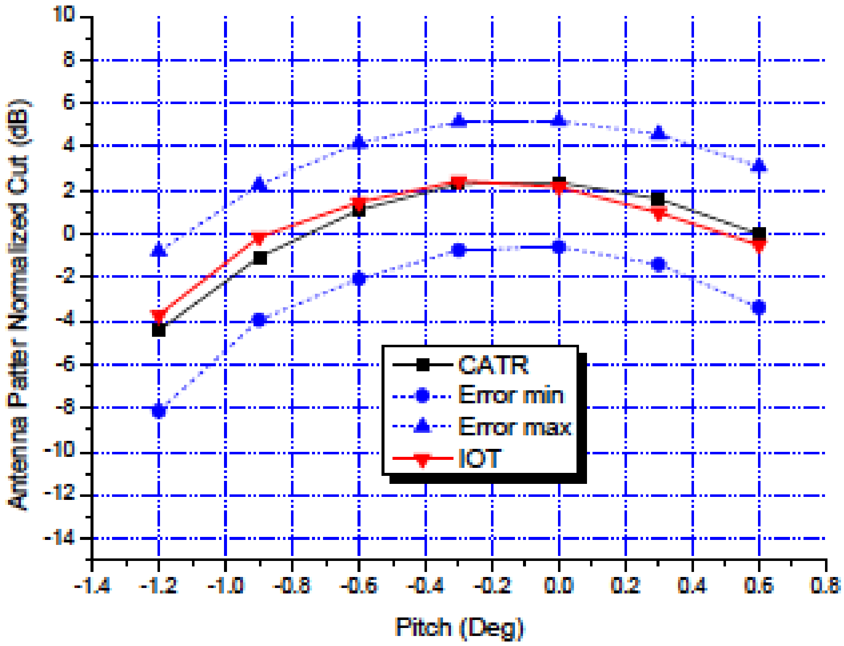


Figure 4.91: Ka Band Nigerian Spot Beam Antenna Cut Line 3 (Pitch=0.6°)

4.3.4.5 AM/AM Analysis

AM/AM test was performed on all HPAs of the transponders including redundant HPAs. And the test results are acceptable as shown in figure 4.77.

4.3.4.6 The Frequency Response Analysis

The frequency response test was performed on each channel including primary and redundant channels and the test results are acceptable and within IOT uncertainties.

4.3.4.7 The Gain Step Test Analysis

The frequency response test was performed on each LCTWTA and the test results are acceptable within IOT uncertainties with considerations of interference from adjacent satellites.

4.3.4.8 The ALC Stability Analysis.

The ALC stability test was performed on each LCTWTA and the test results are acceptable within IOT uncertainties of equation 4.1 as exemplified in figure 4.78.

4.3.4.9 The ALC Transfer Test Analysis

The ALC transfer test was performed on each LCTWTA and the IOT test results are consistent with the on ground tests and acceptable within IOT uncertainties as exemplified in figure 4.79.

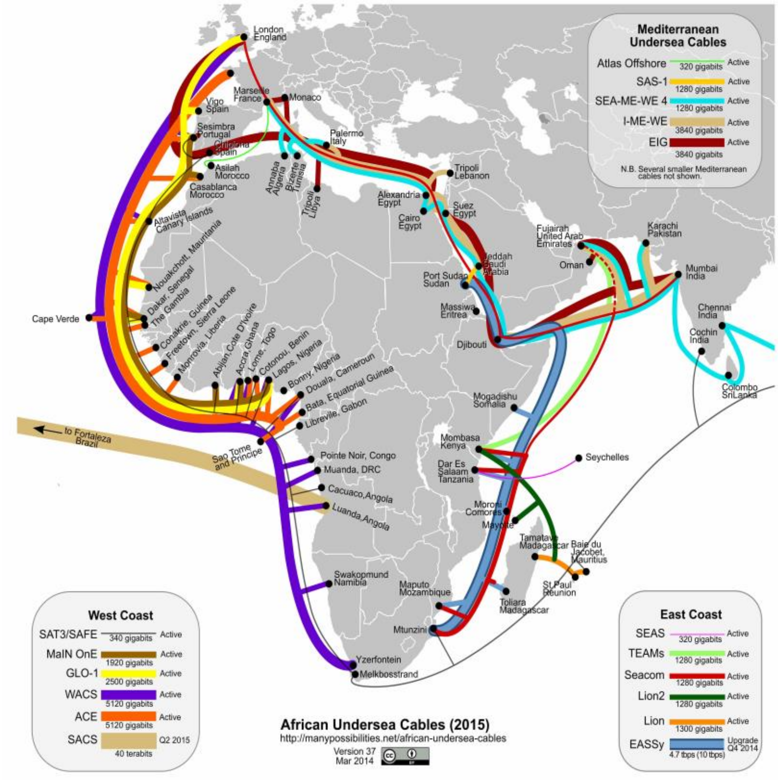
4.3.4.10 The Frequency Accuracy Analysis

The frequency accuracy test was performed on each receiver at mid-frequency and the test results are consistent with the on ground tests (CATR) and acceptable within IOT uncertainties of equation 4.1 and as exemplified in figure 4.81 and 4.82.

The spacecraft is designed so that each Radio Frequency (RF) channel meets the specified requirements, works reliably throughout its Service Life including eclipse conditions; and it has a conservative allowance for degradation, wear-out and radiation damage. The In-Orbit Test (IOT) data review including the platform (satellite bus) IOT data performance review was satisfactorily in compliance with design specifications and requirements and meets mission statement and requirement as defined in chapter three. The acceptance of the NIGCOMSAT-1R payload and platform IOT based on performance analysis marks successful In-Orbit Delivery (IOD) of the COMSAT and milestone commencement of commercial communications satellite service delivery on 19th March, 2012.

4.4 Broadband Delivery over Communications Satellite

The percentage of the world's population using the Internet is just 39.0% as at December, 31, 2013 while Africa's penetration stood at 21.3% (Internet Usage Statistics, 2013). Africa is the least wired continent in the world, with over one billion people; approximately 90% lack Internet access. Though, Africa has adequate capacity on submarine fiber optic cables deployed along the continental shores, as shown in figure 4.92 below; however, Africa lacks adequate regionally planned connectivity into the hinterlands and adequate metro fibre rings within cities and rural areas.



SOURCE: Steve Song

Figure 4.92: Diagram of various African Undersea Cables.

Based on the ICT Development Index (IDI) of all countries in Africa, as reported in the ITU 2010 report- Measuring the information Society (ITU, 2010), which reiterated slow ICT development as verified by the relatively low IDI values of all countries in the region. Thus, to achieve an all-inclusive goal of universal access, Communication Satellites and variants of other wireless systems such as Code Division Multiple Access (CDMA), Global System for Mobile Communications (GSM), Wireless Fidelity (WiFi), Long-Term Evolution (LTE) etc remain the cornerstones for rapid implementation of ICT infrastructure to complement the sparsely distributed terrestrial networks in the hinterlands.

Communication Satellites represent an attractive option for businesses, government surveillance in rural areas, semi-urban and underserved urban centers enable new applications that provide services to mobile sites such as ships, trains, planes and vehicles. Aside from fast deployment of satellite services, broadcasting can serve large geographical areas using a single beam. This is one of the major advantages of satellite communications.

The satellite telecommunications technology of today has the potential to accelerate the availability of high-speed Internet services in developing countries, including the least-developed countries, the land-locked and island nations to meet the requirements of new knowledge-based economies (Back Haul, 1999; O'Rourke, 1999; Gifford, 1996; Gargione & Brandon, 1999). There is a close link between the availability of a large-scale broadband infrastructure and the provision of public education, health, trade services and on-line access to e-government and e-trade information.

Satellites can deliver a robust infrastructure, independent of terrains and distances, and as well provide service solutions in various ways servicing–backhaul with last mile via wireless, Internet cafes, or directly to homes via dishes. The effectiveness of satellite broadband is unmatched in emergency situations during natural disasters, acts of terrorism and even theft. Nortel recounts the vulnerability of terrestrial –only technology in Mexico where 97 miles fiber-optic cables serving rural communities with much needed voice services by a telecommunications provider were exhumed within days and used as new and creative jewelry in the form of colorful flowers in local markets (Show Stoppers, 1997).

Satellite system design engineers have developed the enhanced satellite bus with advanced broad-band based communication payloads to support not just broad-band capabilities but also advanced payload capabilities incorporating on-board switching techniques, multi-frequency, multi-polarization and multi-spot beams and large geographical coverage areas, reduced on-orbit cost per transponder, increased service capacity from a single orbital slot, implemented frequency reuse techniques and extended orbital life.

The improvements in satellite technologies, efficiency techniques and methodologies for satellite appendage design, particularly solar arrays and antenna aperture and improved performance in energy/mass ratio of batteries including overall mass/volume optimization of communication satellites has resulted in high powered communication satellites with the capability to support several hundred transponders to meet the increasing market demands made on communication satellite resources for high-definition and digital 3D broadcasting, broadband communications and other satellite-based services (Lawal & Chatwin, 2010, 2010a, 2011, 2012 & 2012a; Fidler, Hernandez, Lalovic,Pell, & Rose, 2002).

4.5 High-Definition Television (HDTV), Digital 3D Broadcast over Communications Satellites and the London 2012 Olympic Games.

High–definition Television (HDTV) provides a resolution that is substantially higher than that of standard-definition television (SDTV) improving the quality and performance of direct-to-home and high definition television broadcasting. Standard Definition resolution could be National Television System Committee (NTSC) mostly used in North America and South America with 640 x 480 pixels or Phase Alternating Line (PAL) mostly used in Western Europe and African countries with 720 x 576 pixels using either 4:3 or 16:9 aspect ratio and in France, the Sequential Couleur A Memoire (SECAM) system is used. High Definition uses far more data for a better and enhanced image using higher resolutions. The International Consultative Committee for Radio (CCIR) defined HDTV systems as those with more than 1000 lines and some of the proposals for HDTV standards are 1250 lines (Europe), 1125 lines (Japan), 1050 lines (USA) amongst others. High Definition signal resolution could be 1280 x 720 pixels or 1920 x 1080 pixels with 16:9 aspect ratio. (Drury, 1994; Sugawara, Mitani, Kanazawa, Okano, & Nishida, 2006). 3DTV is achieved by sending two video streams required to provide the perceived depth characteristics of the displayed images, thus doubling the bandwidth requirements of HDTV. The digital bandwidth requirements to transmit video signals for High Definition Television broadcast and 3DTV calls, with the required colour depth, video resolution and frame rate for a single uncompressed HD-quality 3D video stream can be as much as 13 Gbps. To reduce this huge bandwidth requirement, the industry developed standards and formats such as MPEG-2, MPEG-4 etc that set the requirements for audio and video compression for HD video transport over both terrestrial systems and satellites. The goal of these compression tools is to reduce the bandwidth requirements of a video file or stream as much as possible whilst the quality of the video is optimized. This also includes a requirement for migration to enhanced Digital Video Broadcasting (DVB-S2), which increases spectral efficiency of broadcast services.

The London Olympics 2012 games was attestation to not just the broadband capability of Communication Satellites but also the HDTV and 3DTV transmission quality assurance. The 2012 Olympic games was the first Genuine Major Carrier Cooperation for DVB satellite television transmissions, achieving historic levels of broadcast quality that was enabled by collaboration of the international broadcast and satellite industries, which jointly launched the first in a series of carrier-ID implementations. The break-through initiative, which benefited billions of viewers, was supported by major broadcasters, satellite operators, encoder and modulator manufacturers and uplink service providers, and proved that it is possible to increase satellite TV quality assurance during major international events. The effort was also supported by four industry associations: the RF Interference – End Users Initiative (RFI-EUI), the World Broadcasting Union-International Satellite Operations Group (WBU-ISOG), the GVF (Global VSAT Forum) and the sIRG (satellite Interference Reduction Group). (Satnews Publishers, 2012).

4.6 Conclusion

Africa is rapidly becoming one of the most important Telecom (Voice & Data) markets in the world facilitated by wireless telecommunication infrastructure comprising of Communication Satellites and variants of terrestrial wireless systems such as GSM, CDMA, LTE, WIFI, WIMAX etc to complement the adequate tens of terabytes of capacity at the shores of the African continent in providing last mile services. Wireless Systems such as Satellite communications and terrestrial radio technologies hold great promise for Africa in the short and medium term plans to ensure that its nations are not isolated from the global economy and world-wide communications network growth considering inadequacy or lack of intra-city and inter-city metropolitan optic fiber system and sparsely distributed terrestrial link extensions across hamlets and villages. The Nigerian Communications Satellite was designed to cater for the regional telecommunications, broadcast, Internet and navigational needs of the Sub-Saharan region based on needs assessment and feasibilities carried out. The first communications satellite (NIGCOMSAT-1) was launched on 13th May, 2007 and 18 months later suffered an on-board subsystem failure in one of the identified single point of failures (SPF) capable of reducing or ending the mission of the spacecraft. The spacecraft was immediately de-orbited to avoid in-orbit collateral damage to neighboring satellites within 42.5 degrees east window based on risk assessment and management on 10th November, 2008. The insurance replacement of the Communication Satellite was launched on 20th December, 2011 with improvement of the payloads to further cater for prevailing market trends and potentials beyond Africa.

Definition of broadband by African nations should be led by the telecommunications regulatory agencies and commissions based on each African country's needs assessment, demand and the industry statistics at their disposal. Broadband Based Satellites with efficient technologies allows more throughputs from the same bandwidth, which saves operational expenditure (OPEX). In technical terms, efficient technologies push more bits (bps) through the same bandwidth. Without broadband-based Communication Satellites, High Definition Television transmission of the Olympic Games to over 6 billion people around the globe would have been impossible.

Broadband penetration is further being aided with a newer generation of communication satellites such as High Throughput Satellites (HTS) with high efficient technology thus changing the business model of the satellite industry while competing strongly with terrestrial broadband technologies. There is a paradigm shift from legacy satellite technologies to satellites with higher bandwidth capacity at lower prices per Megabit sustaining satellite service provider's growth, relevance and profitability. While, the mass-volume requirements of the Piggyback payload limited the capacity of the spacecraft to about 5Gbps with a focus on qualitative satellite service delivery with high performance units and sub-systems, the subsequent fleet shall be High Thoughput Satellite-based to meet the growing space-based resource requirements of the region. A questionnaire response from users and subscribers of Nigerian Communication Satellite services across six geo-political regions of Nigeria with different social status confirmed satisfactory quality of experience (QoE) in service delivery with excellent pre-sales and post-sales service support.

Generally, with participation in design analysis, optimized harnessing and layout of antennas and equipment especially in the L-band repeater to minimize cable and waveguide loss including change of 50W TWTA power amplifier to 70W in the Ka-band repeater payload to improve rain attenuation compensation with other complementary technologies; as Project team member at Beijing Space City during offsite research from school also as a DPhil student of the University of Sussex, the insurance replacement of Nigerian Communications Satellite

(NIGCOMSAT-1R) launched on 20th December, 2011 was a success, with acceptable and improved results compared to its predecessor (the de-orbited NIGCOMSAT-1 COMSAT) based on specified service capability and minimum performance parameters of NIGCOMSAT-1R as projected and defined in chapter three and evident in the payload In-Orbit Test (IOT) results and report conducted between 1st to 14th January, 2012. The results are as summarized in Test Data Results, Uncertainty Analysis, Validity Criteria and Test Result Analysis of chapter four (section 4.3) before In-Orbit Delivery (IOD on 19th March, 2012), which signified successful validation of the Communications Satellite performance parameters at both payload and satellite bus of the spacecraft and thus milestone commencement of operational and commercial services by NIGCOMSAT Ltd. Figure 4.93 shows the writer deploying 1.2m VSAT Antenna on Ku-band transponder of NIGCOMSAT-1R for multimedia and Internet access at home. It is a critical ICT backbone infrastructure driving the National ICT revolution in providing revenue diversification for the nation and offers a cost effective solution and affordable access to meet not only Nigeria's telecommunication, broadcast and broadband needs including financial inclusion through cashless policy implementation as detailed in chapter 7 and 8.

The Nigerian-Based regional indigenous Communications Satellite beacons in Sub-Saharan Africa and beyond, as a paradigm shift for Nigeria, which previously was just a satellite bandwidth consumer.

Figure 4.93: Deployment of 1.2m VSAT Antenna using Ku-Band Transponder of NIGCOMSAT-1R Communications Satellite.

CHAPTER FIVE: Space-Based Augmentation System (SBAS) and the Nigerian Communications Satellite (NIGCOMSAT-1R) with Navigation Capability as a Piggy-Back Payload with Performance Results

5.0 Summary:

The chapter seek to examine the critical role that Space-Borne Oscillators play in improving Performance of Satellite-Based Augmentation Systems and the strategic role of NIGCOMSAT-1R, the nascent African contribution to the Global Navigation Satellite System. Furthermore it shows externalized 10 MHZ Master Oscillators in 3 X 4 hybrid array configuration and the effectiveness of Location Based Services utilizing Navigation for Emergency and Crisis management amongst other applications.

5.1 Introduction of Space-Based Augmentation System (SBAS) and Nigerian Communications Satellite (NIGCOMSAT-1R).

Satellite-Based Augmentation System (SBAS) arose from the need to provide continuity, availability, integrity and accuracy of global positioning signals to eliminate errors and compensate for discrepancies associated with GPS signals and other navigation systems. The NigComSat-1R Navigation (L-band) payload as illustrated and designed in section 4.1.4 of chapter four with payload repeater diagram in figure 5.1 is a Space Based Augmentation System meant to provide a Navigation Overlay Service (NOS) similar to the European Geostationary Navigation Overlay Service (EGNOS).

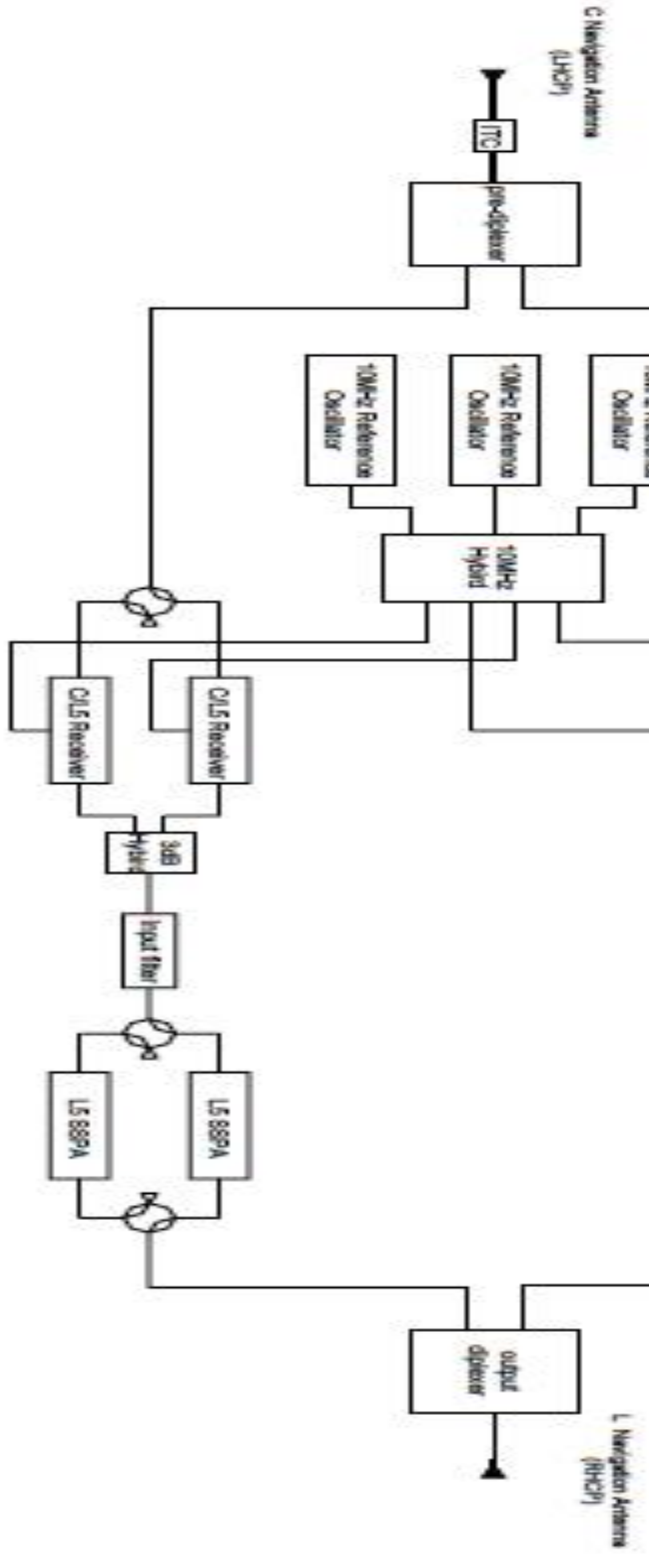


Figure 5.1: Illustrating the Navigation Payload of NIGCOMSAT-1R with externalized 10 MHz Master Oscillator in 3X 4 10MHz Hybrid Array Configuration.

5.2 Overview of Augmentation System

An augmentation system can be Ground-Based (GBAS) or Satellite-Based (SBAS) and arises from the need to provide continuity, availability, integrity and accuracy of Global positioning signals to eliminate errors and compensate for discrepancies associated with GPS signals.

Augmentation is important in applications that involve safety of life, i.e all phases of flight, which requires improved accuracy of the global positioning signals to eliminate errors and compensate for discrepancies through differential corrections associated with GPS signals and other navigation systems in terms of positioning, velocity and timing requirements of aviation, maritime and land-based transport systems.

The most effective augmentation system, especially for coverage capability, is the Satellite-Based Augmentation System (SBAS), which involves the use of Geostationary Communication Satellites to transmit signals over a wide geographic area creating and contributing to the Global Navigation Satellite System (GNSS).

Oscillators are found on all spacecraft vehicles as a primary element of their onboard clocking system, which is required for systems control, signal generators and transponders, whether in a communications satellite or a navigation payload. When using satellites for Navigation, time precision is the key determinant of accuracy in locating position, displacement and velocity.

5.3 Overview of Global Position System Technique

After the First World War, radio time signals offered alternative technology for determination of the Greenwich time and thus longitude at sea. The first manifestation of new technology capable of usurping the super accurate mechanical chronometers occurred in 1904, when the United States Navy began to experiment with the transmission of radio-time signals as an aid to the determination of longitude (Davies, 1978; Lawal & Chatwin, 2011a). The challenge in precision continued with precision in Navigation systems, which depends on electromagnetic waves travelling at 300,000,000 m/s, which means that one microsecond error in a vessel's time will result in 300metres of navigational error.

The Global Positioning System (GPS) originated from the Navigation System with Timing and Ranging known as NAVSTAR, which was initiated by the Joint Program Office (JPO) of the U.S. Department of Defence (DoD) in 1973.The first GPS satellite was sent into orbit in 1978. Initial Operational Capability (IOC) was reached in July 1993 with 24 satellites, while Full Operational Capability (FOC) was declared on July, 17th, 1995. The primary goals were military but the U.S Congress directed the Department of Defense (DOD) to promote civil use free of charge. As a result, the C/A signal on the L1 carrier was made public but intentionally degraded by Selective Availability (SA). Final deactivation of the selective availability was stopped on the 2nd May 2000 and improvement for civilian users went from 100m to about 20m accuracy (Parkinson & Spilker, 1996; Gregory, 1996; Kowoma, 2009; Dana, 1999).

Improvement in accuracy for general transportation, especially in aviation, ushered in the Regional Augmentation System. The quest for performance focused on the ability to accurately transmit and keep time signals stable up to the picosecond level and more in receivers and clock reference of space systems especially in navigation satellites using high performance oscillators ranging from ultra-stable quartz crystals with ovenized control to high performance atomic circuits (Lawal & Chatwin, 2011a).

The Global Positioning System (GPS) is primarily a ranging system as it tries to find how far an object is from itself (satellite). Thus, GPS operates on the principle of trilateration, which refers to determination of an unknown point by measuring the lengths of the sides of the triangle between the unknown points and two or more known points of the satellites (their orbits). Triangulation gives more meaning as it takes angular bearings from two or more known distances and computes the unknown points from the resultant triangle. The satellite carries out position determination by transmitting a radio signal code that is unique to each satellite. The GPS receivers receive these satellite signals and measure the time taken for the signal to be received. Thus, ranged distance is mathematically computed by multiplying the signal's speed (c) with the time it takes the signal to travel. But the ranged distance is not enough to give the exact location of the object on the surface of the earth as it does not contain other vector information such as bearing and azimuth, thus the need for two more satellites to evaluate the precise location. Additional information from more satellites increases the accuracy of the position of the object. At least four satellites are required for precise determination of position as the fourth satellite acts as a time reference for the receiver's accuracy. Each satellite carries four atomic clocks on board (two rubidium and two cesium clocks) which are precise to within billionths of a second per month. (Gregory, 1996; Sung, Gyu, Hun, &Sung, 2004; Kowoma, 2009; Lawal & Chatwin, 2011a).

Generally, for a GPS receiver to work properly, it is expected to carry out four tasks, namely:

(i) Find GPS signals i.e frequency, code phase

(ii) Track and demodulate the message from each GPS satellite at the same time.

(iii) Calculate the position based on distances to the satellites

(iv) Calculate the correction to your local clock.

The C/A code navigational information illustrated in figure 5.2, consists of a 50Hz signal and data such as satellite orbits, clock corrections and other system parameters of the satellite status. The correction for the satellite clocks is important as runtime measurement of the signals through the process of cross-correlation and Doppler effect helps in determination of position and speed. Each satellite continuously transmits this data.

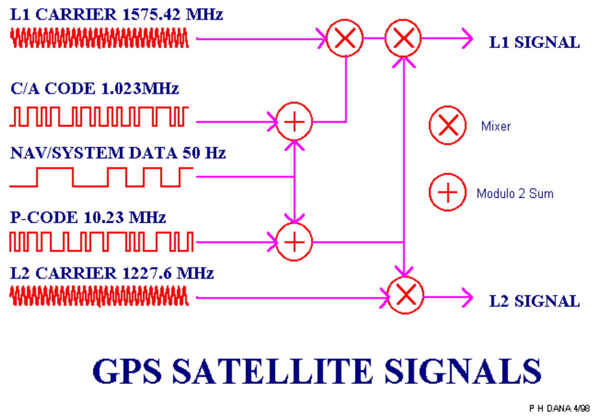


Figure 5.2: Composition of the signals from GPS satellites showing roles of Oscillators (Sourced from: Dana, 1999 with permission).

5.4 Roles of Space-Borne Oscillators for Improved Performance of Satellite-Based Augmentation System (SBAS).

An oscillator is basically an electronic circuit that produces a repetitive clock signal that drives and regulates radio receivers, radar, guidance systems, aviation, TV, computers, video games, toys, celestial navigation and satellite transponders. The satellite transponders may be for communication or navigation.

Oscillators come in various forms, shapes and sizes depending on applications and working environment.

Commonly used oscillators are listed in Table 5.1:

Table 5.1: Commonly used Oscillators.

S/n	Acronyms	Terms	Degree of Accuracy (Seconds)	Application
1	XO	Crystal Oscillators	10^{-5} to 10^{-4}	Toys, Video Games etc
2	VCXO	Voltage Controlled Crystal Oscillator	10^{-6}	Frequency control in tactical radios etc
3	TCXO	Temperature Compensated	10^{-6}	Frequency control

		Crystal Oscillator		applications etc
4	*OCXO*	*Ovenized Controlled Crystal Oscillators*	10^{-8} *to* 10^{-10}	*Navigation System , Radar, frequency standard etc*
5	MCXO	Microcomputer Compensated Crystal Oscillator	10^{-8} to 10^{-7}	Spread Spectrum System Clock, Radio etc
6	Atomic Circuit i.eRbXO	Rubidium Crystal Oscillator	10^{-8}	Radar, GPS Satellite etc

General guidelines for the selection of oscillators are as follows (Vig, 2007; John, 1992; TemexSpace, n.d.):

(i) Choice of Nominal Frequency i.e variable: VCXO or Fixed: XO, TCXO or OCXO

(ii) Choice of stability i.e low stability: XO, Medium stability: TCXO, High Stability: OCXO, USO etc.

(iii) Frequency accuracy or reproducibility for the system to operate properly?

(iv) Recalibration Interval requirement i.e. How long must this accuracy be maintained. Will the oscillator be calibrated or replaced periodically or should the oscillator maintain the required accuracy for the service life of the satellite?

(v) Power availability and conditions

(vi) Required or allowable warm-up time

(vii) Operating environmental conditions of the oscillator.

(viii) Short-term stability (phase-noise) requirement

(ix) What is the size/mass constraint?

Generally and for the stringent requirements of stability, space-borne oscillators use customized ovenized controlled oscillators designed to suit the orbit and space environment in which they will be deployed; particularly in terms of radiation and temperature variations. Figure 5.3 shows a typical OCXO Block diagram while Figure 5.4 shows the 10MHz Master oscillator used in the navigation payload of Nigerian Communications Satellite (NIGCOMSAT-1R).

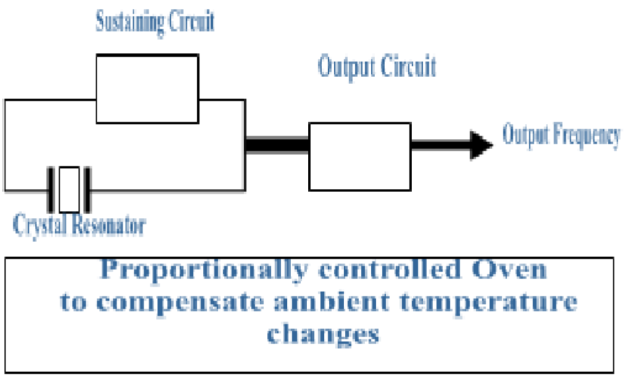


Figure 5.3: A Typical Ovenized Crystal Oscillator (OXCO) showing its Crystal Resonator and external circuits in a proportionally controlled oven to compensate ambient temperature changes.

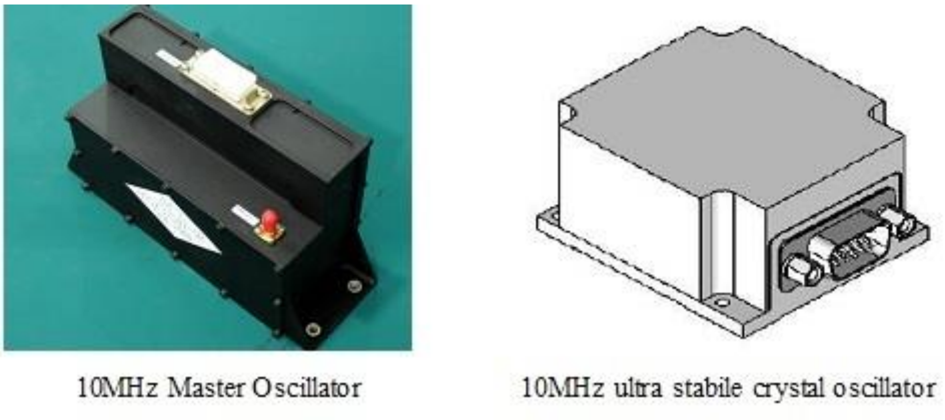


Figure 5.4: shows the 10MHz Master oscillator used in the navigation payload of Nigerian Communications Satellite (NIGCOMSAT-1R).

At steady state, the closed –loop gain of a stable oscillator is 1, if a phase perturbation $\Delta\phi$ occurs, the frequency of oscillation shifts by Δf in order to maintain the $2n\pi$ phase condition.
i.e for a series –resonance oscillator,

$$\frac{\Delta f}{f} = -\frac{\Delta\phi}{2Q_L}$$

Where Q_L is the loaded Q of the crystal in the network circuit as illustrated in Figure 5.3.

Generally, frequency of oscillation is determined by the requirements of the closed loop shift equivalent to $2n\pi$, where n is an integer and could be 0 or 1. An oscillator when initialized or energized generates undesirable noise until the component of frequency satisfies the phase condition as it propagates around the circuit with increasing amplitude. For short-term stability, a high Q factor of the circuit guarantees better tuning of the circuit as well as filtration of undesired harmonics and noise.

The following also helps reduce phase noise in oscillators:

(i) The Q-factor of the resonating circuit should be maximized.

(ii) Use of low LC ratio to maximize reactive energy across the resonating circuit

(iii) Active device should have a low noise figure

(iv) Saturating devices should be avoided.

In the course of oscillation, they exhibit varieties of instabilities ranging from noise, frequency changes with noise, aging, ionized radiation, variation in voltage and power supply, acceleration, frequency changes with temperature amongst others. The terms stability, accuracy and precision are often used to describe an oscillator's quality in relation to functions of instabilities as illustrated in analogy to a Marksman's bullets hole's distance to the center of the target of figure 5.5 as the measured quantity, figure 5.5 (Vig, 2007; John, 1992).

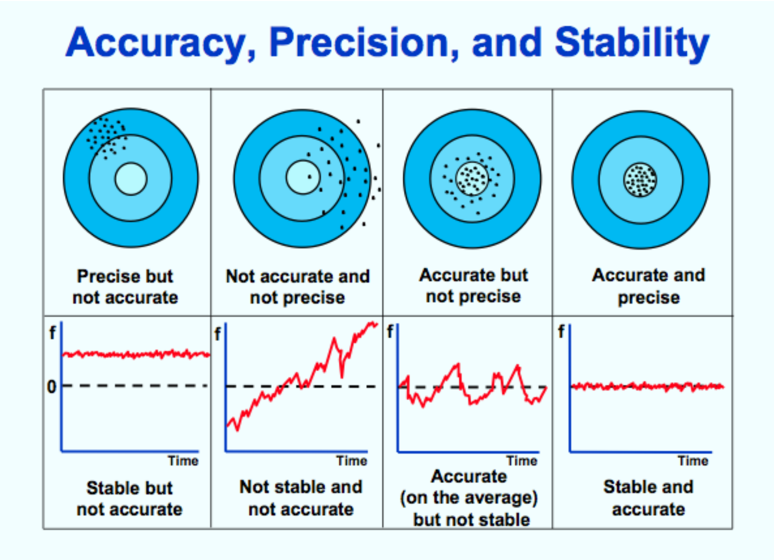


Figure 5.5: Illustration of accuracy, Precision and stability of oscillators for a marksman's bullets hole's distance to the center of the target in relation to the Oscillator's Quality. Source: (Vig, 2007; John, 1992).

For long term precision, accuracy and stability especially in positioning, navigation systems and defense systems the requirements are for stability over a wide range of parameters such as: timing, power, phase, voltage, low noise, frequency changes measured over minutes, hours, days and years. High and maximized Q of the resonator as illustrated in figure 5.3 helps to guarantee stability and performance of the Oscillator. Factors that could affect the Q of the resonator are Overtone, Surface finish of the crystal, Material impurities and defects, Mounting stresses, Bonding stresses, Temperature, Electrode geometry and type, Blank geometry (contour, dimensional ratios), Drive level, Gases inside the enclosure(pressure, type of gas), Interfering modes, Ionizing radiation etc (Vig, 2007; Ambrosini, 2000; Hong, Xiaohung, & John, 2008; Yung, Trong, Che, Chia, & Rong, 2006; Zedong, Kangling, & Xu, 2006; Parkinson, Dempster, Mumford, & Rizos, 2006; Jun & Xuchu, 2008; Gregory, Mathew, & Mihran,2004; Asmar, 1997; Bloch, Mancini, & McClelland, 2009).

Of particular interest here, as it concerns space-borne oscillators performance requirements are the following, especially during the Preliminary Design Review (PDR) and Critical Design Review (CDR) of the unit assembly:

5.4.1 Systems Requirement and Interface

To guarantee a seamless interface between the navigation subsystem and the satellite systems, the followings needs validation, qualification, technical adequacy and acceptance in conformity with system requirements.

(i) Detailed functional description

(ii) Circuit diagrams, drawings and pictures

(iii) Packaging Techniques and Circuitry (i.e PCB technology, substrate, interconnect, Package Design, ASIC, Hybrids etc).

(iv) Interface Specifications and Interface Control Documents (ICDs)

(v) Test requirements including thermal vacuum test results and records.

(vi) Software and its validation

(vii) Summary of available test data and reports of measured performance.

5.4.2 Mechanical Analysis and Environmental Conditions of the Unit

The checklist below ensures reliability through advanced enclosures within ambient environments that guarantee performance, mass budget and mechanical stress limits:

(i) Weight and Mass properties analysis

(ii) Humidity limits

(iii) Thermal analysis of unit

(iv) Mechanical, Structural and protection performance of unit packaging demonstrating Stress Analysis, dynamic responses during flight vibration, harmonic random vibration limits, shock levels requirements within operational limits. Apart from structural damage, shock and flight vibrations outside set limits can produce large phase deviations on performance of circuits particularly those with phase locked loops (PLL) or Phase Shift Keying (PSK).

(v) Ambient (Operating) temperature range and limits that guarantees stability of frequency oscillation.

(vi) Radiation analysis, testing and worst case of shielding material and effects as required and specified for digital and mixed signal devices.

5.4.3 Reliability

The followings ensure reliability of space-borne oscillators throughout the service life time of the spacecraft in a harsh space environment (Lawal & Chatwin, 2010):

(i) Single Point of Failure analysis (SPF)

(ii) Failure Mode, Effects and Criticality Analysis (FMECA) and failure detection methods

(iii) Thermal Reliability of unit assembly.

(iv) Flight heritage of the unit assembly

5.4.4 Electrical Analysis and Performance Requirements

(i) **Output Frequency:** Nominal output frequency should meet design requirement with expected initial frequency accuracy limits and short-term frequency stability for various set time requirements.

In Navigation systems, the tunability of the oscillator over a wide frequency range must be avoided as it degrades stability of the circuit in both the short term and long term. A highly stable ovenized 10MHz voltage controlled oscillator may have a tuning range of 50ppm and an ageing rate of 2 ppm per year. Long-term frequency stability is desirable and characterized with the ageing effect. (Asmar, 1997; Gregory, Mathew, & Mihran, 2004).

(ii) Effects of Radiation on performance must be simulated, modeled, specified and controlled especially response to pulses of ionizing radiation. Maximum radiation level at component level must be specified and met.

(iii) Phase Noise outside acceptable limits causes inaccurate detection of phase transition resulting in high bit error rates in applications (Vig, 2007). Phase Noise levels for various set frequencies must be complied with.

(iv) Variations in temperature both during operation or storage must be predicted and controlled. Intensive research is being used to reduce the long-term drift of space-based frequency reference. Frequency stability over different operating temperature ranges at specified voltages must be within the acceptance limits of the system design requirements. Figure 5.6 shows measured frequency stability of NIGCOMSAT-1R 10MHz Ovenized Crystal Oscillator versus Temperature under vacuum conditions.

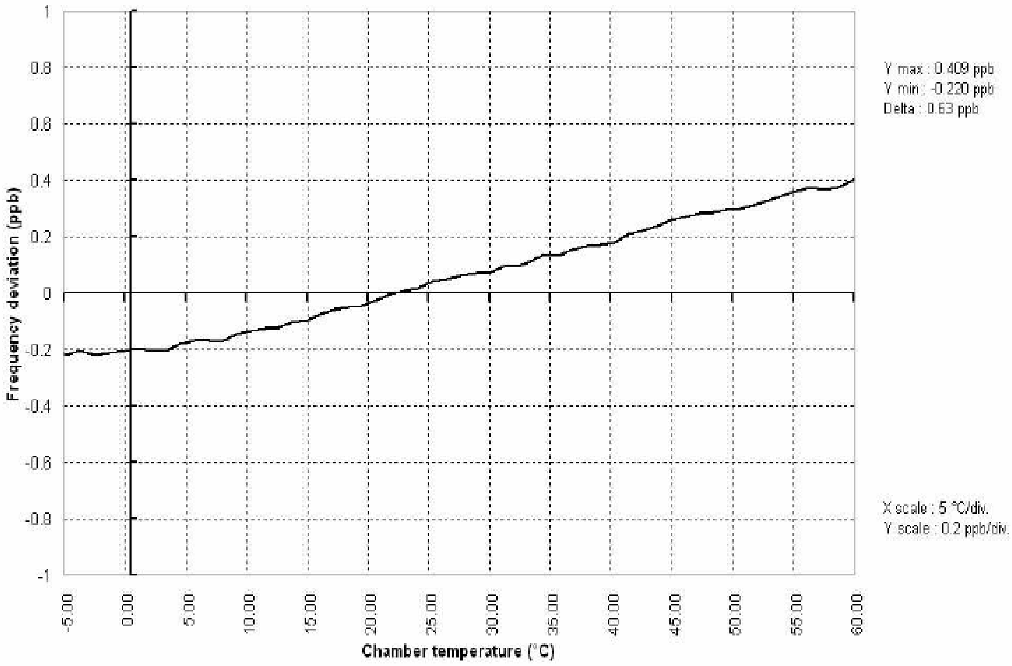


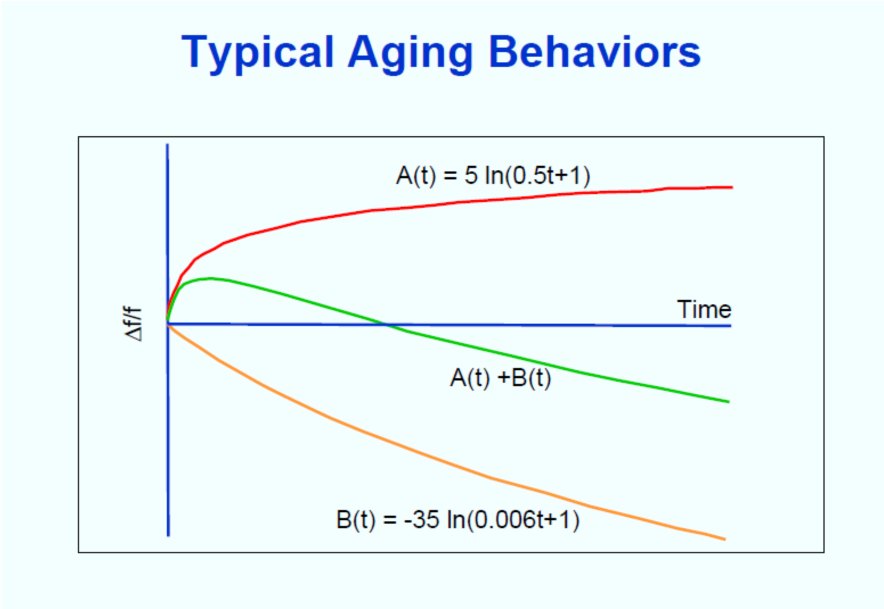
Figure 5.6: Measured Frequency Stability of NIGCOMSAT-1R 10MHz Ovenized Crystal Oscillator versus Temperature under vacuum conditions.

(v) Variations in solar flares must be predicted and controlled including radiation sensitivity of the resonators within the orbit operating parameters (Gregory, Mathew, & Mihran, 2004).

(vi) Other environmental stresses and perturbations including shocks from the flight sequence must be predicted and controlled

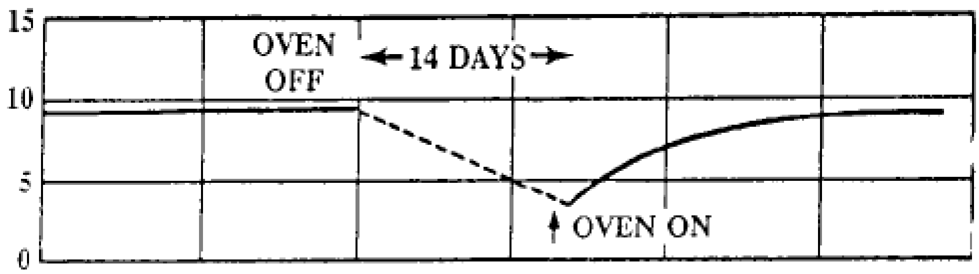
(vii) Effects of Aging: Aging rate and its total effect on frequency at the beginning of life (BOL) and the end of life (EOL) of the Navigation Satellite (5 to 20 years) should be predicted and taken into account with tests result analysis during PDR and CDR of a spacecraft project particularly for navigation. Ageing improvements relative to crystals helps in long-term performance. Crystals could age positively or negatively as analyzed and documented by Dr. John Vig (2007). requirements over one day, one month, one year and service lifetime must be specified and complied with. Figure 5.7 shows modelled aging behavior of a typical crystal with occasional reversal in aging direction. The aging rate of an oscillator is at its peak when first turned on and generally referred to as the stabilization period. Thereafter, at a constant temperature, the aging usually has an logarithmic dependence on time as exemplified by the computer simulated aging model of figure 5.7 The reversal is the sum of the other two curves. In the aging model, A(t) initially dominates, then decays faster than B(t) and thereafter, the aging mechanism described by B(t) dominates the aging. A new aging cycle is initiated when the temperature of a crystal unit is changed as characterized by figure 5.8, where an

ovenized controlled crystal oscillator (OXCO) was switched off and switched on later. The ageing rates per year should be minimal for applications that require optimal precision. For instance, the aging rates of a cheap watch oscillator range from 5 to 10 Parts Per Million (ppm) per year, TCXO ranges from 0.5 to 2 ppm per year, and an OCXO ranges from 0.05 to 0.1 ppm per year. More expensive and higher precisioned OCXOs can age less than 0.01ppm per year



(Frequency Change in Parts Versus Time)

Figure 5.7: A diagram showing the typical theoretical ageing process of a crystal. Aging effects can be positive or negative Source: (John, 1997; Vig, 2007).



(Frequency change parts in 10^9 (Parts Per Billion, ppb) Vs Time in Days)

Figure 5.8: Typical Ageing Behaviour with an Ovenized Controlled Crystal Oscillator (OCXO) Interruption (Meeker & Vig, 1991).

Thus, ageing specifications should be specified for systems that require a high level of precision. It may be expressed as a normalized frequency change per unit after a specified time period, which could be a day or as a total normalized frequency change over a specified time duration or lifetime. For instance, Figure 5.9 shows frequency ageing of NIGCOMSAT-1R 10MHz Ovenized Oscillator over days while figure 5.10 shows the ageing behavior after turn on. It was warmed up at 25 degrees Celcius, after two (2) hours in switch-off mode, it was switched on for three (3) hours.

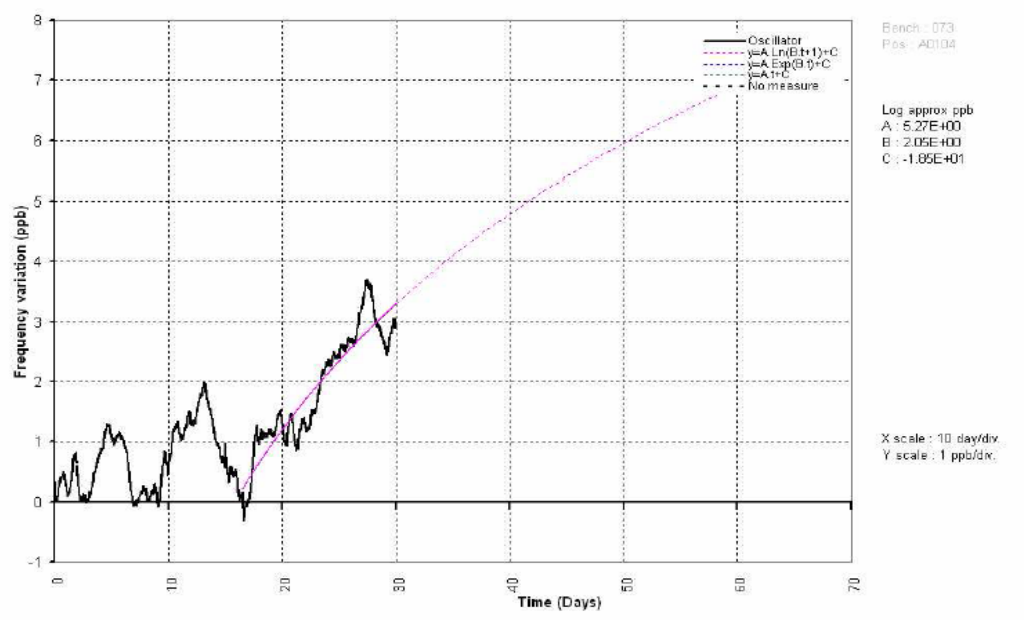


Figure 5.9: Frequency Ageing of NIGCOMSAT-1R 10MHz Ovenized Oscillator

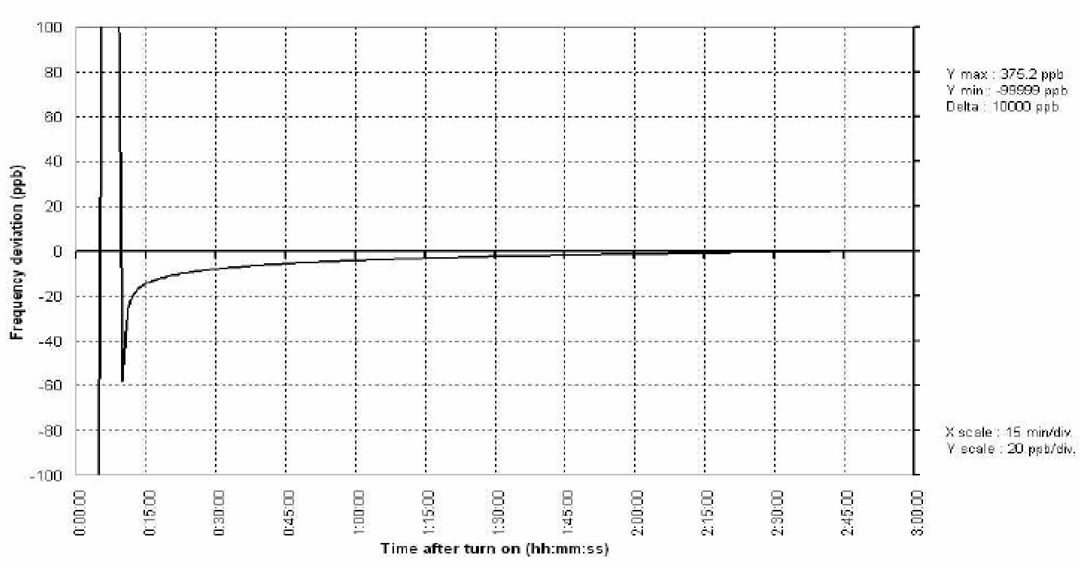


Figure 5.10: Ageing Behaviour of NIGCOMSAT-1R 10MHz Ovenized Oscillator After Turn On.

(viii) Effects of Drift: It must be noted that while aging is the variation of frequency with time due to internal changes in the oscillator as standardized by the International Radio Consultative Committee (CCIR), Drift is variation due to aging including changes in the environment and other factors that are external to the oscillator. Drift effects can be minimized and isolated using succeeding stages of amplification of well-designed buffers.

(ix) Harmonics Level: Harmonic spurs should be low and within acceptable limits and spurious frequency generation under vibration should be minimized through mechanical designs of the crystal, crystal cut etc.

(x) Phase Noise in Static and dynamic conditions should be low and within acceptable limits as may be specified. Improvement should apply primarily close to the carrier since the noise floor is determined by circuit design not necessarily by the crystal.

(xi) Static and dynamic frequency stability versus temperature effects must be critically reviewed and analyzed in relation to operating orbit environment including during warm-up, thermal hysteresis, retrace and accelerations.

(xii) Allan Variance limits which measures frequency stability within noise processes using M-Sample variance (example of Noise types are White Phase Modulation (WPM); Flicker Phase Modulation (FPM); White Frequency Modulation (WFM); Flicker Frequency Modulation (FFM); Random Walk Frequency Modulation (RWFM). (Ambrosini, 2000).

(xiii) Power consumption should be low, clean and well regulated. Good grounding techniques should be deployed with a good overall efficiency. Most Space-borne oscillators have dedicated Dc/Dc converter integrated into the oscillator unit assembly to guarantee a reliable power source while taking care of variations. Power consumption requirements for warm-up and steady state should be taken into account during preliminary and critical design reviews.

(xiv) Other output performance: Input Voltage, Linearity, VSWR ratio specifications, Settling Time, Post-Tuning drift requirements, magnetic-field effects, ambient pressure change during altitude change, Frequency tolerance against voltage, EMC & EMI considerations, Electric field change effects, fast warm up requirements and system interactions on stability must be taken into account and controlled.

Table 5.2, 5.3 & 5.4 shows test results of the (3) three 10MHz Reference Oscillators before acceptance for integration on the piggy back navigation payload of Nigerian Communications Satellite (NIGCOMSAT-1R) considering its criticality in the optimal performance of time-based signals. It shows electrical performance compliance level before and after mechanical environment tests at unit level.

Table 5.2: Shows 10MHz Reference Oscillator 1 Test Data Summary of Nigerian Communications Satellite (NIGCOMSAT-1R).

No	Test Item	Requirement	Initial Test	Final Test (Post Vibration Test)	Compliance	Power Voltage
	Output Frequency (MHz)	10	9.9999999512	10.0000004602	√	95V
			9.9999999512	10.0000004612	√	100V
			9.9999999512	10.0000004618	√	105V
	Initial Frequency Accuracy	$\leq 6\times10^{-8}$	-4.88×10^{-8}	4.60×10^{-8}	√	95V
			-4.88×10^{-8}	4.61×10^{-8}	√	100V
			-4.88×10^{-8}	4.62×10^{-8}	√	105V

No	Test Item	Requirement	Initial Test	Final Test (Post Vibration Test)	Compliance	Power Voltage
	Short-Term Stability	10ms：≤±1X10^{-11}	1.48×10^{-11}	1.03×10^{-11}	×	95V
		100ms：≤±2X10^{-12}	1.95×10^{-12}	1.70×10^{-12}	√	
		1s：≤±2X10^{-12}	2.00×10^{-12}	1.85×10^{-12}	√	
		10ms：≤±1X10^{-11}	1.38×10^{-11}	1.17×10^{-11}	×	100V
		100ms：≤±2X10^{-12}	1.93×10^{-12}	1.71×10^{-12}	√	
		1s：≤±2X10^{-12}	1.86×10^{-12}	1.90×10^{-12}	√	
		10ms：≤±1X10^{-11}	1.30×10^{-11}	1.22×10^{-11}	×	105V
		100ms：≤±2X10^{-12}	1.90×10^{-12}	1.78×10^{-12}	√	
		1s：≤±2X10^{-12}	1.88×10^{-12}	1.93×10^{-12}	√	
	Output Power(dBm)	≥10	10.91	11.05	√	95V
			10.90	11.05	√	100V
			10.91	11.05	√	105V
	Phase Noise(dBc/Hz)	@1Hz：≤-100	-100.3	-102.5	√	95V
		@10Hz：≤-130	-131.7	-132.3	√	
		@100Hz：≤-140	-148.4	-148.4	√	
		@1kHz：≤-150	-154.5	-154.6	√	
		@10kHz：≤-155	-156.7	-156.3	√	
		@100kHz：≤-157	-157.1	-157.1	√	
		@1MHz：≤-160	-161.9	-164.1	√	
		@1Hz：≤-100	-101.9	-101.5	√	100V
		@10Hz：≤-130	-130.5	-132.3	√	
		@100Hz：≤-140	-148.8	-148.6	√	
		@1kHz：≤-150	-154.0	-155.4	√	
		@10kHz：≤-155	-157.2	-156.6	√	
		@100kHz：≤-157	-157.1	-157.2	√	
		@1MHz：≤-160	-163.7	-164.2	√	
		@1Hz：≤-100	-103.7	-102.7	√	105V
		@10Hz：≤-130	-130.0	-131.1	√	
		@100Hz：≤-140	-147.1	-148.5	√	
		@1kHz：≤-150	-154.6	-154.9	√	
		@10kHz：≤-155	-156.8	-157.4	√	
		@100kHz：≤-157	-157.6	-157.2	√	
		@1MHz：≤-160	-165.4	-163.7	√	
	Harmonics(dBc)	≤-30 dBc	-64.22	-62.28	√	95V
			-64.33	-62.37	√	100V
			-64.18	-62.34	√	105V
	500Hz-100kHz Spurious(dBc)	≤-120 dBc	<-120	<-120	√	95V
			<-120	<-120	√	100V
			<-120	<-120	√	105V
	100kHz-500kHz Spurious(dBc)	≤-100 dBc	<-120	<-120	√	95V
			<-120	<-120	√	100V
			<-120	<-120	√	105V
	VSWR	≤2.0	1.54	1.61	√	
	Power Consumption	≤10	/	/	√	95V

No	Test Item	Requirement	Initial Test	Final Test (Post Vibration Test)	Compliance	Power Voltage
	Warm-Up(W)		7.73	7.73	√	100V
			/	/	√	105V
	Power Consumption Steady State(W)	≤8	5.85	5.85	√	95V
			5.97	5.97	√	100V
			6.12	6.12	√	105V
	TM(V)	0~5	3.13	3.13	√	100V
			3.13	3.13	√	95V
			3.13	3.13	√	105V
	Inrush Current(A)	≤0.5	0.090	0.090	√	100V

Table 5.3: 10MHz Reference Oscillator 2 Test Data Summary of Nigerian Communications Satellite (NIGCOMSAT-1R).

No	Test Item	Requirement	Initial Test	Final Test(Post Vibration Test)	Compliance	Power Voltage
	Output Frequency(MHz)	10	10.000000051	10.000000068	√	95V
			10.000000050	10.000000068	√	100V
			10.000000050	10.000000068	√	105V
	Initial Frequency Accuracy	$\leq 6\times10^{-8}$	5.1×10^{-9}	6.8×10^{-9}	√	95V
			5.0×10^{-9}	6.8×10^{-9}	√	100V
			5.0×10^{-9}	6.8×10^{-9}	√	105V
	Short-term Frequency Stability	10ms ： $\leq\pm1X10^{-11}$	$9.45X10^{-12}$	$8.10X10^{-12}$	√	95V
		100ms ： $\leq\pm2X10^{-12}$	$1.3X10^{-12}$	$9.48X10^{-13}$	√	
		1s ： $\leq\pm2X10^{-12}$	$2.7X10^{-13}$	$5.10X10^{-13}$	√	
		10ms ： $\leq\pm1X10^{-11}$	$9.67X10^{-12}$	$8.13X10^{-12}$	√	100V
		100ms ： $\leq\pm2X10^{-12}$	$1.45X10^{-12}$	$9.25X10^{-13}$	√	
		1s ： $\leq\pm2X10^{-12}$	$3.67X10^{-13}$	$5.00X10^{-13}$	√	
		10ms ： $\leq\pm1X10^{-11}$	$9.95X10^{-12}$	$8.10X10^{-12}$	√	105V
		100ms ： $\leq\pm2X10^{-12}$	$1.45X10^{-12}$	$7.42X10^{-13}$	√	
		1s ： $\leq\pm2X10^{-12}$	$3.78X10^{-13}$	$4.40X10^{-13}$	√	
	Output Power(dBm)	≥10	10.95	10.93	√	95V
			10.90	10.93	√	100V
			10.93	10.93	√	105V
	Phase Noise(dBc/Hz)	@1Hz： ≤-100	-100.9	-111.0	√	95V

No	Test Item	Requirement	Initial Test	Final Test(Post Vibration Test)	Compliance	Power Voltage
		@10Hz：≤-130	-131.5	-132.7	√	
		@100Hz：≤-140	-145.7	-152.7	√	
		@1kHz：≤-150	-153.9	-157.2	√	
		@10kHz：≤-155	-156.9	-158.1	√	
		@100kHz：≤-157	-157.8	-158.3	√	
		@1MHz：≤-160	-163.0	-164.3	√	
		@1Hz：≤-100	-103.0	-112.6	√	100V
		@10Hz：≤-130	-131.5	-132.7	√	
		@100Hz：≤-140	-145.7	-152.2	√	
		@1kHz：≤-150	-153.9	-156.6	√	
		@10kHz：≤-155	-156.9	-158.8	√	
		@100kHz：≤-157	-159.3	-158.6	√	
		@1MHz：≤-160	-163.0	-164.3	√	
		@1Hz：≤-100	-101.9	-110.5	√	105V
		@10Hz：≤-130	-135.0	-132.7	√	
		@100Hz：≤-140	-146.0	-152.2	√	
		@1kHz：≤-150	-152.7	-157.0	√	
		@10kHz：≤-155	-157.2	-158.3	√	
		@100kHz：≤-157	-157.8	-158.4	√	
		@1MHz：≤-160	-163.0	-164.3	√	
	Harmonics(dBc)	≤-30	-54.63	-54.74	√	95V
			-54.89	-54.88	√	100V
			-54.61	-54.80	√	105V
	500Hz-100kHz Spurious(dBc)	≤-120	<-120	<-120	√	95V
			<-120	<-120	√	100V
			<-120	<-120	√	105V

No	Test Item	Requirement	Initial Test	Final Test(Post Vibration Test)	Compliance	Power Voltage
	100KHz-500kHz Spurious(dBc)	≤-100	-108.81	-109.05	√	95V
			-108.06	-108.16	√	100V
			-110.12	-108.20	√	105V
	VSWR	≤2.0	1.68	1.67	√	
	Power Consumption warm-up(W)	≤10	7.6	7.6	√	95V
			7.7	7.8	√	100V
			7.77	7.88	√	105V
	Power Consumption steady state(W)	≤8	5.13	5.32	√	95V
			5.30	5.40	√	100V
			5.36	5.56	√	105V
	TM(V)	0~5	3.10	3.10	√	100V
			3.10	3.10	√	95V
			3.10	3.10	√	105V
	Inrush Current(A)	≤0.5	0.11	0.11	√	100V

Table 5.4: 10MHz Reference Oscillator 3 Test Data Summary of Nigerian Communications Satellite (NIGCOMSAT-1R).

No	Test Item	Requirement	Initial Test	Final Test(Post Vibration Test)	Compliance	Power Voltage
1.	Output Frequency (MHz)	10	9.999999878	9.999999897	√	95V
			9.999999879	9.999999898	√	100V
			9.999999879	9.999999897	√	105V
	Initial Frequency Accuracy	$\leq 6\times10^{-8}$	-1.22×10^{-8}	-1.03×10^{-8}	√	95V
			-1.21×10^{-8}	-1.02×10^{-8}	√	100V
			-1.21×10^{-8}	-1.03×10^{-8}	√	105V
	Short-Term Stability	10ms ; $\leq\pm1X10^{-11}$	$1.00X10^{-12}$	$6.95X10^{-12}$	√	95V
		100ms : $\leq\pm2X10^{-12}$	$1.28X10^{-12}$	$7.16X10^{-13}$	√	
		1s： $\leq\pm2X10^{-12}$	$4.07X10^{-13}$	$5.40X10^{-13}$	√	
		10ms ; $\leq\pm1X10^{-11}$	$9.91X10^{-12}$	$6.97X10^{-12}$	√	100V
		100ms : $\leq\pm2X10^{-12}$	$1.22X10^{-12}$	$7.10X10^{-13}$	√	
		1s： $\leq\pm2X10^{-12}$	$3.21X10^{-13}$	$5.40X10^{-13}$	√	
		10ms ; $\leq\pm1X10^{-11}$	$9.97X10^{-12}$	$6.96X10^{-12}$	√	105V
		100ms : $\leq\pm2X10^{-12}$	$1.41X10^{-12}$	$7.17X10^{-13}$	√	
		1s： $\leq\pm2X10^{-12}$	$3.97X10^{-13}$	$4.80X10^{-13}$	√	
	Output Power(dBm)	≥10	10.94	10.93	√	95V
			10.91	10.93	√	100V
			10.93	10.94	√	105V
	Phase Noise(dBc/Hz)	@1Hz：≤-100	-107.3	-110.4	√	95V

No	Test Item	Requirement	Initial Test	Final Test(Post Vibration Test)	Compliance	Power Voltage
		@10Hz：≤-130	-133.4	-132.8	√	
		@100Hz：≤-140	-145.7	-152.1	√	
		@1kHz：≤-150	-154.1	-157.1	√	
		@10kHz：≤-155	-156.5	-158.2	√	
		@100kHz：≤-157	-157.6	-158.8	√	
		@1MHz：≤-160	-164.0	-163.9	√	
		@1Hz：≤-100	-107.3	-108.9	√	100V
		@10Hz：≤-130	-133.4	-132.8	√	
		@100Hz：≤-140	-145.7	-151.4	√	
		@1kHz：≤-150	-154.1	-156.3	√	
		@10kHz：≤-155	-156.5	-157.5	√	
		@100kHz：≤-157	-157.6	-158.3	√	
		@1MHz：≤-160	-164.0	-164.3	√	
		@1Hz：≤-100	-104.5	-108.9	√	105V
		@10Hz：≤-130	-133.4	-132.8	√	
		@100Hz：≤-140	-146.3	-152.0	√	
		@1kHz：≤-150	-153.9	-156.3	√	
		@10kHz：≤-155	-156.5	-158.4	√	
		@100kHz：≤-157	-158.4	-158.7	√	
		@1MHz：≤-160	-162.7	-164.5	√	
	Harmonics(dBc)	≤-30 dBc	-52.87	-53.02	√	95V
			-53.09	-53.09	√	100V
			-52.95	-53.03	√	105V
	500Hz-100kHz Spurious(dBc)	≤-120 dBc	<-120	<-120	√	95V
			<-120	<-120	√	100V
			<-120	<-120	√	105V
	100kHz-500kHz Spurious(dBc)	≤-100 dBc	-107.48	-109.50	√	95V
			-110.50	-107.98	√	100V
			-109.33	-107.14	√	105V
	VSWR	≤2.0	1.66	1.66	√	
	Power Consumption Warm-Up(W)	≤10	7.6	7.6	√	95V
			7.80	7.8	√	100V
			7.88	7.98	√	105V
	Power Consumption Steady State(W)	≤8	5.22	5.42	√	95V
			5.50	5.60	√	100V
			5.56	5.78	√	105V
	TM(V)	0~5	3.10	3.10	√	100V
			3.10	3.10	√	95V
			3.10	3.10	√	105V
	Inrush Current(A)	≤0.5	0.11	0.1	√	100V

5.5 Regional Satellite-Based Augmentation System

Global Navigation Satellite System (GNSS) as it is, whether GPS, GLONASS, GALILEO or BEIDOU are not type approved for critical and demanding sectors that involves safety of life (SOL) such as aviation, maritime and professional applications. They also lack real-time monitoring and application with dynamic positioning system except newer generation with modernization concepts. Thus, Augmented systems are meant to provide integrity, availability, accuracy, continuity and fleet management capability.

Augmentation can be ground-based (Ground-Based Augmentation System, (GBAS) or Satellite-Based Augmentation System (SBAS). SBAS systems using Geostationary Communication Satellite are ubiquitous and over wide area compared to localized GBAS system. Global and Regional satellite-based augmentation systems are part of efforts geared towards GPS integrity enhancement techniques, with enhanced accuracy service guarantee and improved performance providing additional ranging capability, integrity of information, differential corrections using geo-satellites and ground-related infrastructures. Table 5.5 shows summarized technical characteristics of GPS and three other navigation systems of the Global Navigation Satellite System (GNSS) while Figure 5.11 shows sketches of regional Augmentation systems in the world in both planned and operational status while some are already expanding and extending their operational reach. Regional SBAS across the world (operational and planned) are as follows:

a. USA: Wide Area Augmentation System (WAAS), expanded to Canada as CWAAS and planned expansion to South America.

b. Europe: European Geostationary Navigation Overlay System (EGNOS) with expansion over Africa.

c. China: Chinese Satellite Navigation Augmentation System (SNAS).

d. Japan: MTSAT Satellite Augmentation System (MSAS).
MTSAT means Multi-functional Transport SATellite.

e. India: GPS-Aided Geo-Augmented Navigation (GAGAN).

f. Russian Federation: System Differential Correction and Monitoring (SDCM).

g. AFRICA: Nigerian Satellite Augmentation System (NSAS): First with Nigeria and expansion to African countries including oceans to the extent of NIGCOMSAT-1R coverage.

Table 5.5: Summary of Technical Characteristics of the Four Regional GNSS Systems.

System	No. of Satellites	Nominal Altitude (Km)	Orbit Inclination *i* (º)	Service Launch

GPS	31+1 (January, 2014)	20,200	55	1995
GLONASS	24 + 4 (January, 2014)	19,100	64.8	1996, 2010 2010
GALILEO	Presently 4 as at 12th Oct. 2012 (30)	24,000	56	2014 (IOC) 2020 (FOC) tentatively
COMPASS	Presently 4 as at 12th Oct. 2011. (30)	19-24000		2020

Key:

IOC: Initial Operational Capability

FOC: Full Operational Capability

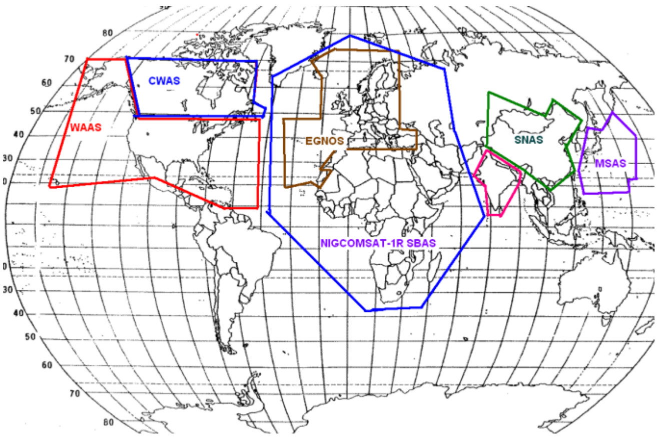


Figure 5.11: Illustration of Regional Satellite Based Augmentation System.

WAAS: US Wide Area Augmentation System and planned expansion to South America.

EGNOS: European Geostationary Navigation Overlay Service could be expanded to cover Africa,Russia that are within the broadcast coverages of the geostationary satellites when fully operational(Dana, 1999)..

CWAAS: Canadian Wide Area Augmentation System, expanded US WAAS

MSAS: Japanese MTSAT Satellite Augmentation System. MTSAT means Multi-functional Transport SATellite.

SNAS: Chinese Satellite Navigation Augmentation System

While some of the augmentation systems above are fully operational such as the WAAS in the US and Canada, others are at initial operational capability (IOC) i.e EGNOS of Europe, GAGAN of India, SNAS of China and MSAS of Japan.

5.6 NIGCOMSAT-1R Navigation Payload

Nigeria's first communication satellite (NIGCOMSAT-1), a quad-band high powered satellite with navigational capability and capacity launched on 13th May, 2007 was Africa's first contribution to the Global Navigation Satellite System. It was however de-orbited on the 10th of November, 2008 due to an irreparable single point of failure on-board the satellite.

All broadcast, telecommunication services being offered by the satellite including strategic navigational plans and objectives were disrupted.

The NIGCOMSAT-1R spacecraft project, as shown in figure 5.12, is the insurance replacement for the NIGCOMSAT-1 satellite, NIGCOMSAT-1R was launched on 20th December, 2011.

Figure 5.12: NIGCOMSAT-1R Spacecraft Project hoisted on Mechanical Ground Support Equipment (MGSE) in Assembly, Integration and Test (AIT) Room.

The NigComSat-1R Navigation (L-band) payload is meant to provide a Navigation Overlay Service (NOS) similar to the European Geostationary Navigation Overlay Service (EGNOS) system. The system will augment the Global Navigation Satellite System (GNSS) over Europe and Africa. Recognizing the important advance of dual user frequencies over the single L1 frequency capabilities of previous GNSS, the planned modernization of the GPS constellation will produce an additional civil signal on the L5 frequency. The incoming GALILEO system will broadcast Safety-of-Life signals on both the L1 and L5 frequencies, the navigation payload of NigComSat-1R has been designed to support and operate in both the L1 and L5 frequencies.

Unlike the transponders of communication satellites, the receiver of navigation transponders (as is the case in the NIGCOMSAT-1R system design) uses a 10MHz ultra stable crystal oscillator to meet the performance requirements of frequency conversion stability and accuracy. The system functionality is identical and similar to European geostationary Navigation Overlay Service (EGNOS), where a number of ground reference stations monitor the GPS satellites' signals and provide their observations to one or more Master Control stations

(MCS). An augmentation message is then generated by the MCS and two (2) signals, C1 and C5, are transmitted via uplink stations within the uplink coverage areas on the C-band. The navigation payload down converts the C-band signals to L-band, L1 and L5, and retransmits these signals globally to users as earlier shown in figure 5.11 and 5.12 respectively. Figure 5.13 illustrates the coverage of the C-band uplink signals. The NOS augments the GPS standard positioning service by providing three types of information to users: Ranging information, Differential GPS corrections and Integrity monitoring information (NIGCOMSAT-1R, 2009).

The onboard navigation payload has various component redundancies. It is a dual-channel bent-pipe transponder that down-converts two C-band (C1 and C5) uplink signals from a ground earth station to two downlink signals in the two separate bands, L1 and L5. A 4.0 MHz-wide C1 band uplink channel relays in the L1 downlink channel and allows the transmission of the L1 signal while a 20.0 MHz-wide C5 band uplink channel relays in the L5 downlink channel and allows transmission of the L5 signal.

Table 5.6: Downlink Frequency and Polarization of NIGCOMSAT-1R L-Band Payload.

Channel	Frequency (MHz)	Polarization	Bandwidth (MHz)
L1-Downlink	1575.42	RHCP	4
L5-Downlink	1176.45	RHCP	20

The beam from the downlink L-band navigation antenna is global, ensuring that NigComSat-1R is capable of broadcasting to its coverage area, GEO ranging signals and Satellite Based Augmentation System (SBAS) signals through the L1 and L5 frequencies as depicted in Table 5.6. The In-Orbit Test (IOT) was used to validate the functional capability of the navigation payload and its readiness for function and purpose. Figure 5.14 and 5.15 shows the EIRP results of the re-launched Nigerian Communications Satellite (NIGCOMSAT-1R) in L1 and L5 signal bands respectively.

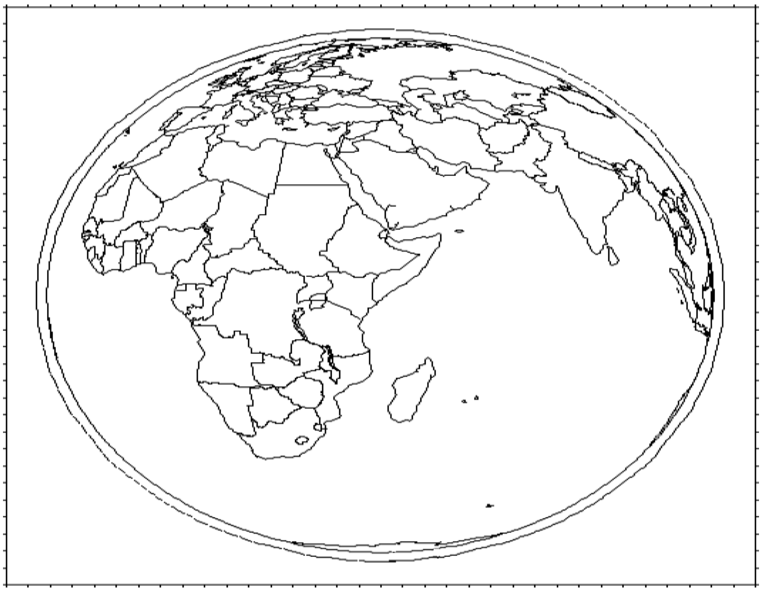


Figure 5.13: The uplink coverage beam of NIGCOMSAT-1R Geo-Navigation Satellite using C-Band Navigation Antenna.

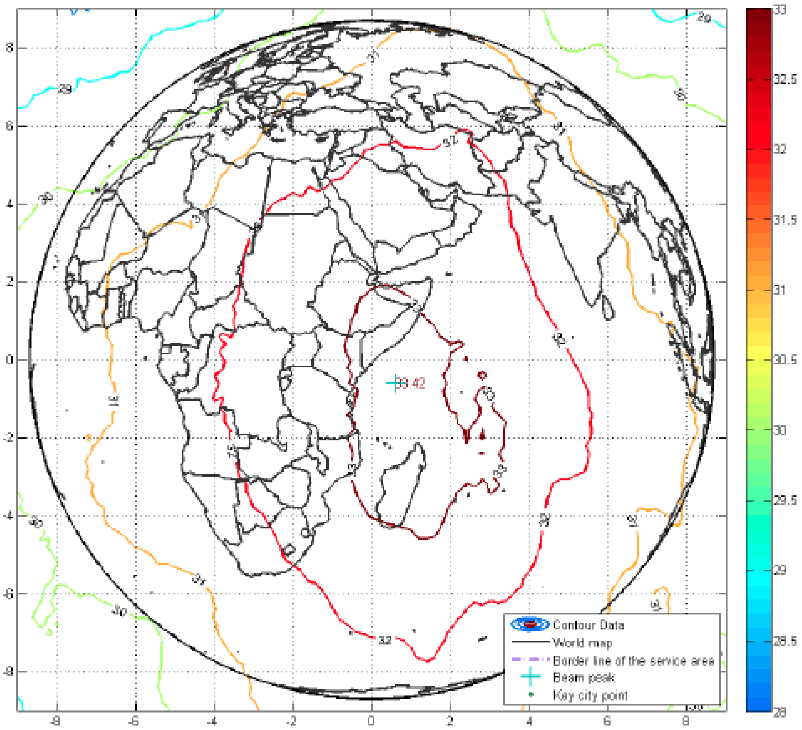


Figure 5.14: The Downlink coverage beam (L1-Band) of NIGCOMSAT-1R Geo-Navigation Satellite using Dual L-Band Helix Antenna.

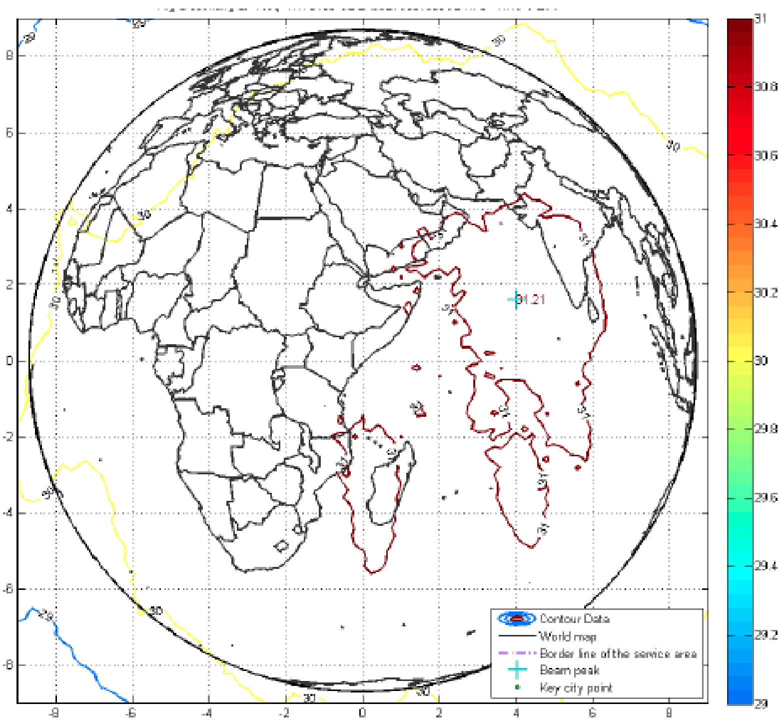


Figure 5.15: The Downlink coverage beam (L5-Band) of NIGCOMSAT-1R Geo-Navigation Satellite using Dual L-Band Helix Antenna.

5.7 Africa's Contribution to Satellite-Based Augmentation System (SBAS) and Global Navigation Satellite System (GNSS) using NIGCOMSAT-1R Navigation Payload.

The NigComSat-1R Navigation (L-band) payload as earlier explained is meant to provide a Navigation Overlay Service (NOS) similar to the European Geostationary Navigation Overlay Service (EGNOS) system. The system can augment the Global Navigation Satellite System (GNSS) over Europe and Africa. Recognizing the important advance of dual user frequencies over the single L1 frequency capabilities of previous GNSS, the modernization of the GPS constellation produces additional civil signal on the L5 frequency as safety-of-life signals. The navigation payload of NigComSat-1R has been designed to support and operate in both the L1 and L5 frequencies.

The system functionality is identical and similar to European geostationary Navigation Overlay Service (EGNOS), where a number of ground reference stations monitor the GPS satellites' signals and provide their observations to one or more Master Control station (MCS). An augmentation message is then generated by the MCS and two (2) signals, C1 and C5, are transmitted via uplink stations within the uplink coverage areas on the C-band. The navigation payload down converts the C-band signals to L-band, L1 and L5, and retransmits these signals globally to users. The NOS augments the GPS standard positioning service by providing three types of information to users: Ranging information, Differential GPS corrections and Integrity monitoring information with precision and accuracy with the above benefits over GPS:

- A single digit of the received signal of about 3 – 5 m or better.
- Reduce delay as a result of good ground station design.
- Real time application with dynamic positioning system
- Fleet management
- Extended regional coverage.
- Reduce error with increase in precision for three dimensional positioning
- National and augmented worldwide coverage.
- Unlimited number of users
- 24 hours availability and operation in all weather (NIGCOMSAT-1R, 2009).

5.7.1 Benefits, Applications and Derivable Services of NIGCOMSAT-1R Navigation Payload

The NIGCOMSAT-1R L-B and SBAS together with complementary ground infrastructure i.e master station and reference stations will meet the Required Navigation Performance (RNP) aviation, maritime and other critical sectors thus filling a great gap in the augmentation system in Africa.

5.7.1.1 Defence and Surveillance Applications by Military for Territorial Protection

With the required precisioning and timing nature of navigation payload, the system is fit for application on land, air and sea during military operations or normal routine surveillance.

The navigation payload improves greatly the highly accurate position, velocity and time information provided by the GPS. This concept provides the means to locate an enemy follow-on force as early as possible, determine its route of advance, and direct an attack against it in order to cause delay, disruption, and attrition.

A follow-on-force attack concept, which requires navigation application systems capable of all-weather surveillance for moving and fixed target acquisition, weapon delivery, processing and fusing of information in near real-time.

Naval and civilian ships are better monitored considering the precision and real-time vessel management facilities.

5.7.1.2 Emergency & Recovery Services

Natural disaster has become part of our existence; hence adequate preparation must be made for immediate recovery and future planning. With a well-integrated satellite imagery and navigation technology, evacuation of disaster victims would be easily addressed.

Man-made disasters like fire outbreak, building collapse, vehicular accidents etc, are better managed if the city satellite map is available both for precise site location and road navigation for evacuation. A typical example is the fire service city navigation and nearest hospital location for instant treatment of disaster victims and thus effectiveness emergency preparedness and management (Lawal & Chatwin, 2014).

5.7.1.3 Transportation

From land to sea and air, safe navigation continues to generate concern and need for an appropriate solution.

5.7.1.3.1 Land: Road traffic technology would be enhanced with navigation systems integrated into the national road network. Also the navigation electronic tolling system would help to monitor movement and ticketing.

Major services are:

- Automatic Vehicle Tracking System (AVTS)
- Fleet Management System (FMS)

These would serve in both facility and human management, reducing car theft and mismanagement. The rail system is best managed under support of Automatic Train Control (ATC), which among others things can be used to monitor goods from different geopolitical ends on the nation.

5.7.1.3.2 Maritime: Ocean, coastal, port approach and port maneuvers, under all weather conditions are better achieved under a space-based navigation system, which NIGCOMSAT-1R is set to provide with its L1 & L5 transponders. The satellite system provides precise navigation along inland waterways, inland ports, surveys and other maritime activities.

5.7.1.3.3 Aviation: The air traffic management today depends on the navigation precision for airplanes landing and taking-off. Electronic landing systems are used to keep airplanes landing in all kinds of weather. GPS permits a much cheaper and easier means of providing these capabilities but with less precision and other value-added services such as tracking and fleet management.

Other services to be provided by the L-band transponder include;

- Airport Surveillance
- Search and Rescue

5.7.1.4: Land Surveying (Mapping)

Precision mapping and land surveying today can better be done through a satellite positioning system to one millimeter (1mm) accuracy. Precision equipment like hand-held GNSS device and stations has replaced the old theodolite technology used for land survey and mapping.

5.7.1.5: Agriculture

Precision farming and agricultural productivity has improved tremendously today by exploiting satellite navigation system applications such as enhanced fish farming with navigation and positioning support provided by navigation satellite, even distribution of chemicals and fertilizers for even fertility of agricultural soil & field, the movement of the aquatic food supply can be monitored for a precision harvest etc.

5.7.1.6: Utility Management: Remote Asset Management Solution – (Telematics)

Heavy-duty equipment and facilities could be monitored using the navigation system. The human location of the facility using real-time alarm system would help prevent intruders and mismanagement.

5.8 Conclusion

Improvements on space-borne oscillators not only enhances the precision of Satellite Based Augmentation systems but the general performance of the system in terms of fast acquisition of navigation signals, lower power consumption, optimized spectrum utilization, improved error rates, longer service life, improved recalibration requirements, improved navigation capability, and improved defense application requirements in terms of target detection and tracking and jamming resistance. Table 5.2, 5.3 and 5.4 shows performance analysis of the 3(three) 10MHz TEMEX reference oscillators used on NIGCOMSAT-1R. The result of the last two newly supplied Oscillators (2 & 3 are presented in table 5.3 and 5.4 respectively) complied completely with the required specifications while the first oscillator (1) with test results in table table 5.2 which was a backup oscillator for NIGCOMSAT-1 launched in 2007 suffered slight non-compliance in 10mS Short-Term stability as a result of frequency aging after storage. Armed with research knowledge of performance requirements and parameters of oscillators for time-based signals, the writer campaigned strongly for use of family of 10MHz oscillators over other products during field office meetings (FOM) at Assembly, Integration and Test facility of Beijing Space City after test and comparative performance analysis as a field project officer of NIGCOMSAT-1R project considering its criticality to ensure frequency accuracy and stability of the global signals and in turn efficiency and effectiveness of positioning accuracy and location based services (LBS). Timing and ranging accuracy of SBAS are further improved and corrected using reference signals from related ground infrastructures, which again rely on high quality oscillators for exact time measurement, ranging and calibration. The African Regional Satellite Based Augmentation System through NIGCOMSAT-1R SBAS will improve emergency & Recovery services, Fleet management systems, Transportation (Land, Maritime, and Aeronautical applications), Agriculture, Land Surveying and Utility Management. The drive for improved performance has also encouraged improved system architecture that allows convergence of all regional and continental navigational systems into compatible and interoperable Global Navigational Satellite Services (GNSS). Combined use of GPS, GLONASS and any other regional or GNSS system, considering increased number of satellites in different orbital planes reduces Dilution of Precision (DOP) (position in 3 dimensions and Geometric) thus saving time in acquisition of signals and improved performance by using multi-chip receivers for Location Based Services (LBS). For instance, Smartphones like iPhone 4S supports both the GLONASS and GPS system using a multi-chipset receiver to improve the phone's geo-positioning applications and Location Based Services (LBS) compared to iPhone 4, which supports the GPS system only.

Generally, with active participation in design analysis, optimized harnessing and layout of antennas and equipment especially in the L-band repeater to minimize cable and waveguide loss as Project team member at Beijing Space City during offsite research from school as a DPhil student of the University of Sussex, the insurance replacement of Nigerian Communications Satellite (NIGCOMSAT-1R) launched on 20th December, 2011 is successful, with acceptable and improved results compared to its predecessor (the de-orbited NIGCOMSAT-1 COMSAT). This is evident in the EIRP results shown of Navigation Bands of L1 and L5 shown in figure 5.14 and 5.15 respectively. Location Based Services utilizing Navigation systems and technologies are desirable for emergency preparedness and effective crisis management.

With a well-integrated satellite imagery and navigation technology in National Public Security and Emergency Network of Chapter Six, it handles the evacuation of disaster victims easily. Disasters like fire outbreak, building collapse, vehicular accidents etc, are better managed if the city satellite map is available both for precise site location and road navigation for evacuation. A typical example is the fire service city navigation and nearest hospital location system for instant treatment of disaster victims. NIGCOMSAT-1R Navigation transponder amongst others has addressed such solutions including locations of e-health services and applications, makeshift medicare and medication centers facilitated and coordinated with the hybrid public security and emergency network.

CHAPTER 6: Service-Oriented Architecture (SOA) overview of Nigerian Public Security Communications System (NPSCS).

6.0 Summary:

In this chapter, the background and needs assessment of the National Public Security Communications System (NPSCS) is outlined and the system design of the NPSCS integrated into the regional communications satellite (NIGCOMSAT-1R) is discussed as well as the review of technology to reflect medium and long terms needs of the nation as well as supporting broadband and higher throughput needs. For long term sustainability, the excess bandwidth capacity is utilised for Nigeria's national cashless policy implementation and thus a self-sustaining network is being created.

6.1 Introduction and Background of The National Public Security Communications System (NPSCS) Project

The importance of a very effective and efficient information and communication technology (ICT) infrastructure has come to the fore to fast track disaster relief as a first line of emergency response (Musavi, Memon & Chawdhri, 2011). Phillip and Hodge (1995) also acknowledged the role of effective communication in the Northridge expanse and complex disaster response and recovery effort. A Public safety and emergency communications network must be simple to operate, robust, reliable, interoperable, secure, cost-effective and ubiquitous as reiterated by Backof (2013). As mentioned earlier in Chapter One, the Governments of almost all Nations recognize the pivotal role of ICT in socio-economic development, sustainability of law and order, crime prevention; particularly in the context of achieving a secure integrated communications network through convergence of all forms of communications infrastructure with the potential to foster information symmetry between and within nations and it's security operatives. Communication Satellites can facilitate information symmetry among several different networks via satellite communications independent of the distance across the ground or geography. Infrastructure costs of communications via communication satellites are no longer a function of distance (Stuart, 1997; James & Andrew, 1999).

Evans et al (2005) also noted the niche areas of Communications Satellite and its role in convergence of terrestrial communications infrastructure.

Security has been identified as the major issue facing the Nigerian nation. Problems ranging from kidnapping, piracy, political and electioneering conflicts, socio-economic agitations, ethno-religious crises, ethnic militias, criminality and organized crimes are on the rise. These problems constitute threats to the peace, security and economic development of Nigeria.

Currently communications by top level government officials and security operatives are carried on the network of private telecommunications operators with the result that security and privacy of communications is not guaranteed. In addition, communications in emergency situations in order to obtain critical help and assistance required in life or death circumstances is also presently non-existent. The needs assessment of the project is therefore founded on provision of independent, secure, reliable and broadband communications system using the Ultra High Frequency band of 450MHz spectrum re-farmed from 2-way radio Push-to-Talk (PTT) system for national security agencies and departments for provision of an information system platform for public security management. The deployed network uses Code Division Multiple Access (CDMA) Evolution –Data Optimized(EV-DO) Revolution B (Rev. B) technology on 450MHz. Revolution B (Rev. B) is a natural evolution from Revolution A (Rev. A) with multicarrier broadband experience supporting higher data rates and lower latency for bursty applications. It supports software upgrade with a peak downlink speed of 14.7Mbps and uplink speed of 5.4Mbps. However, considering constraints on the initial contract agreement for CDMA 1X technology, our recommendation and technology of choice for CDMA-Rev. B was reduced to CDMA EVDO REV A technology with peak downlink speed of 3.1Mbps and peak uplink speed of 1.8Mbps. Considering the highlights made on seamless migration of CDMA-Rev. B technology to Long Term Evolution (LTE) supporting a rich multimedia experience, high-level agreement was reached with equipment manufacturers for a trade-off of the CDMA-Rev. A to LTE equipment during the second phase development term as the network nears 70-80% capacity utilization.

The Federal Government of Nigeria (FGN) recognizes the pivotal role of ICT in crime prevention and combat particularly in the context of achieving a secured integrated communications network with the potential to foster information symmetry among the country's security operatives nationwide.

The Nigerian National Public Security Communications System (NPSCS) Project, provides a visionary and strategic infrastructure-driven pilot project was designed to address the current security challenges in the country.

After full deployment of the three phases of the project as recommended in our review, design modification and appraisal of the project, the system will be integrated to form the core of the Nigerian C4SIR system (Fixed and Mobile Command and Control, Communication Computers, Surveillance, Intelligence and Reconnaissance system), an intelligence system with the capability to support operations for general security alarm, emergency alarm and alarm handling, and cooperative security systems such as surveillance, interception, information gathering, analysis, preplanning, etc. The Security Communications system shall allow for collection, management, analysis, fusion and interpretation of relevant information to commanders, operators to guide planning, resources deployment, tactical response and strategic planning as well as information sharing and symmetry with similar organizations and other relevant organizations. The excess network capacity is being used for strategic national ICT such as Central Bank of Nigeria cashless society pilot projects and programmes currently supported using a hybrid solution comprising of Communication Satellites with Wifi and Ethernet based

Point-of–Sales Terminal on one hand and CDMA-EVDO 450MHz Solution with CDMA-Based POS terminals on the other hand. The state-commercial dedicated security model promotes self-sustainability of the network while effectively driving the universal access goals, without exclusivity, in a continent, which still remains the least wired in the world.

6.2 The NPSCS Project System Technology And Architecture

The first phase of the project network design was meant to cover the Federal Capital Territory (FCT), all thirty-six states capitals and major highways/expressways with Code Division Multiple Access (CDMA) 1X technology. The equipment type includes mobile base station equipment, core network equipment, dispatch equipment, high speed packet data equipment, video surveillance equipment, video conference equipment, E-police equipment, Coalition emergency response equipment, transportation equipment, communication auxiliary facility and terminals. In contrast, Code Division Multiple Access-Revolution B (CDMA-REV B), which allows both hardware and software, upgrades to 3GPP LTE was recommended as the technology of choice. Considering constraints on initial specification, the design was reviewed and based on CDMA EVDO REV A technology. The system architecture is a CDMA-based trunking solution utilizing Global Open Trunking Architecture (GOTA) with all-TO technology as shown in figure 6.1.

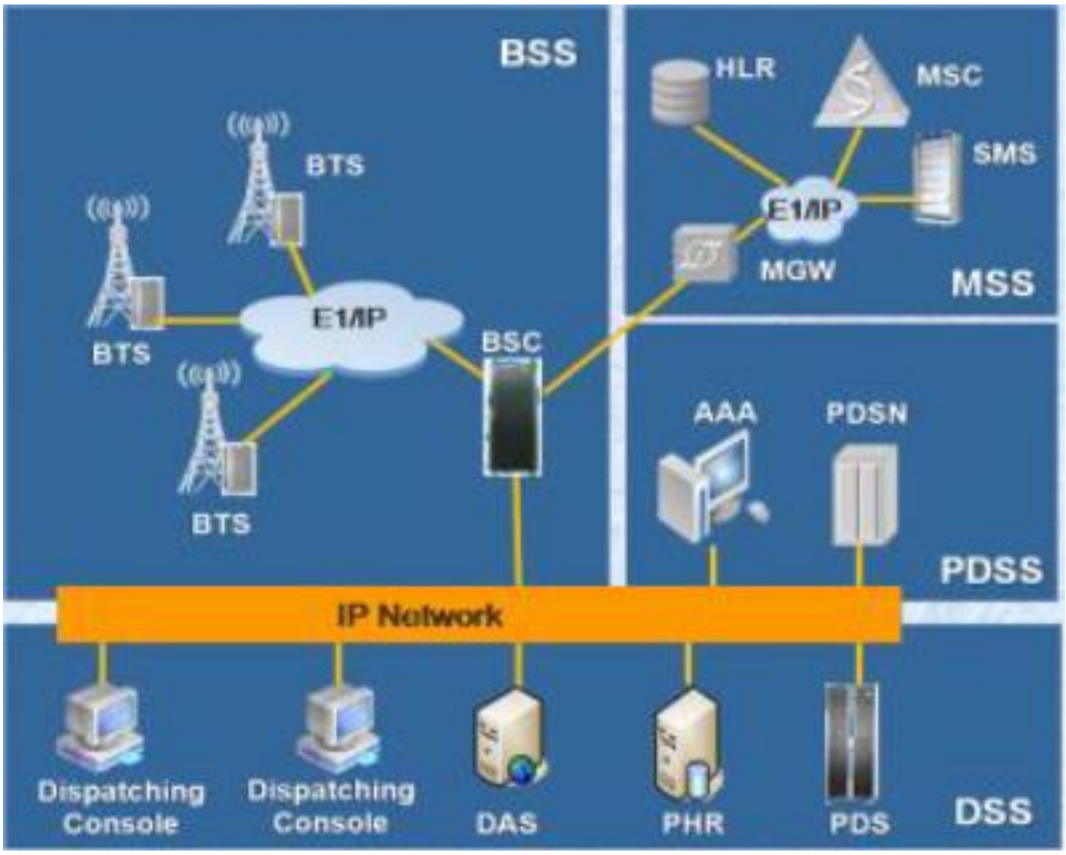


Figure 6.1: 3G CDMA-Based Trunking Solution Utilizing Global Open Trunking Architecture (GOTA).

The GOTA technology aside common services such as voice calls, interconnection, short message services and high speed data services supports group calls, emergency calls, broadcast calls, private calls, location based services (LBS), dynamic regrouping, unified dispatching platform, inter-fleet calls , group management, trunked video services etc as shown in figure 6.2.

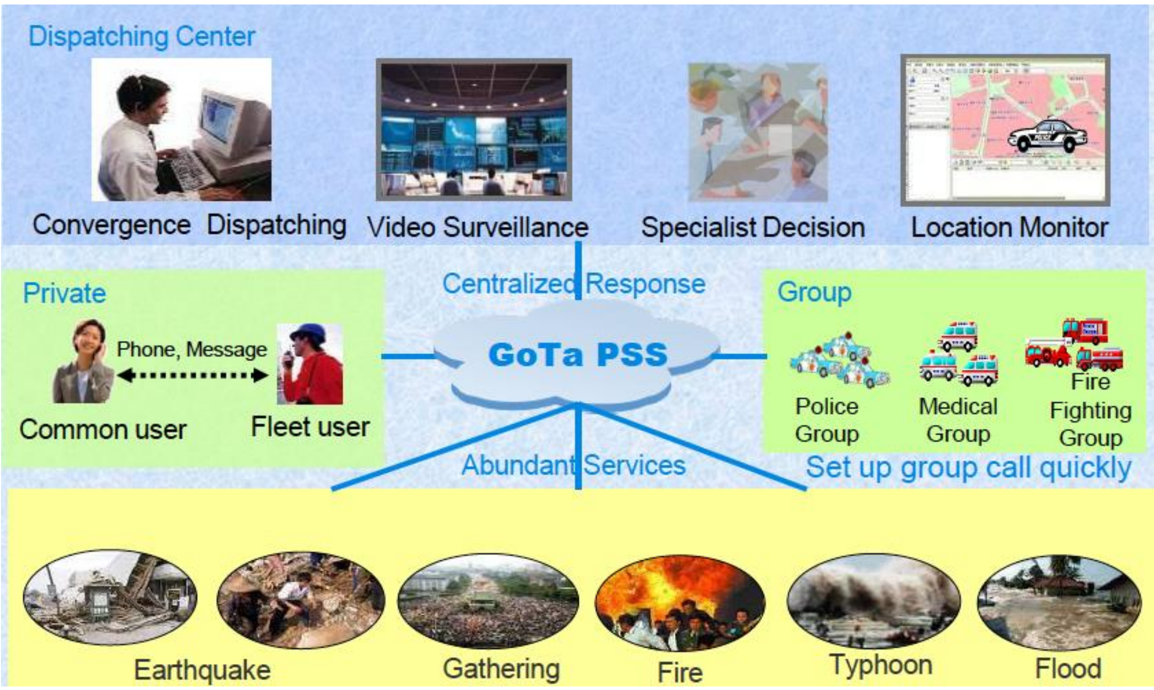


Figure 6.2: Unique Services Supported by GOTA Technology including Emergency Response Services.

The first phase of the network is deployed across 36 states of the federation and the Federal Capital Territory (FCT) using Internet Protocol/Multiprotocal Label Switching (IP/MPLS) bearer over Microwave backbone with 697 base stations; the physical location of important data including user information are in Abuja and Lagos with wireless video surveillance services.

Figure 6.3 shows the IP/MPLS bearer network topology of the NPSCS network while figure 6.4 is a map of Nigeria showing architecture of the terrestrial telecommunications infrastructure deployed in various locations and capital cities of the nation.

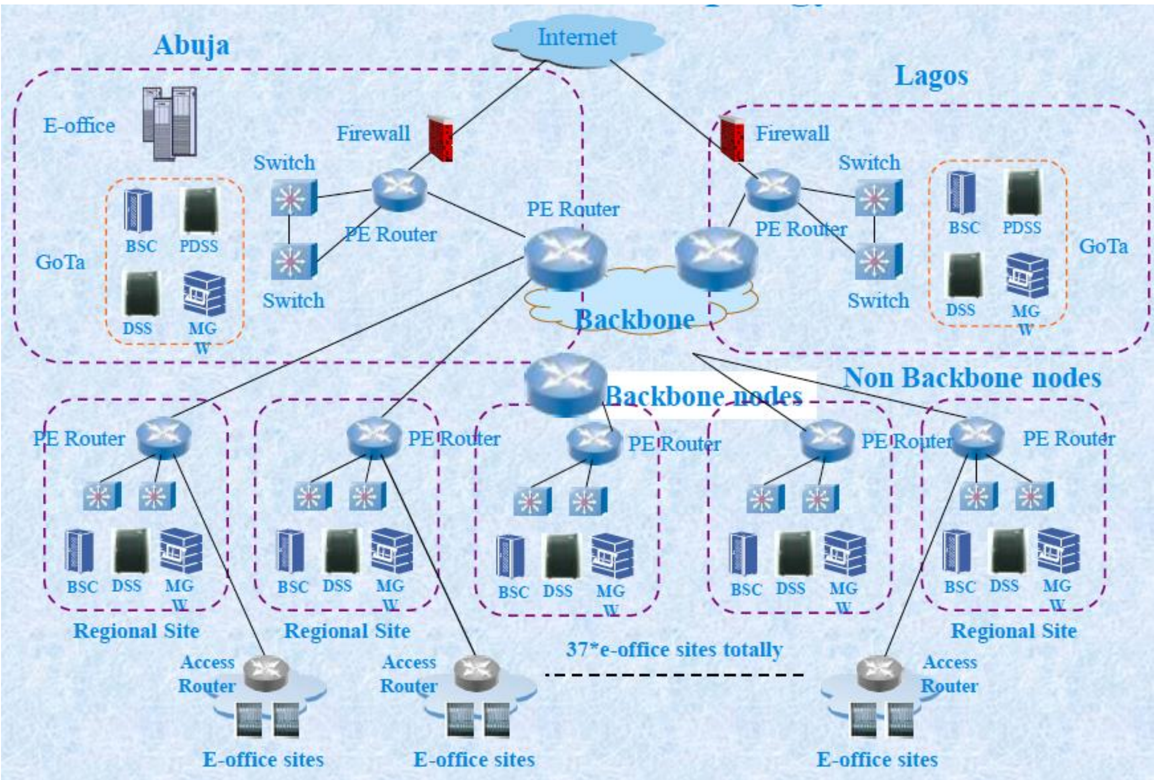


Figure 6.3: The IP/MPLS bearer network topology of the NPSCS network.

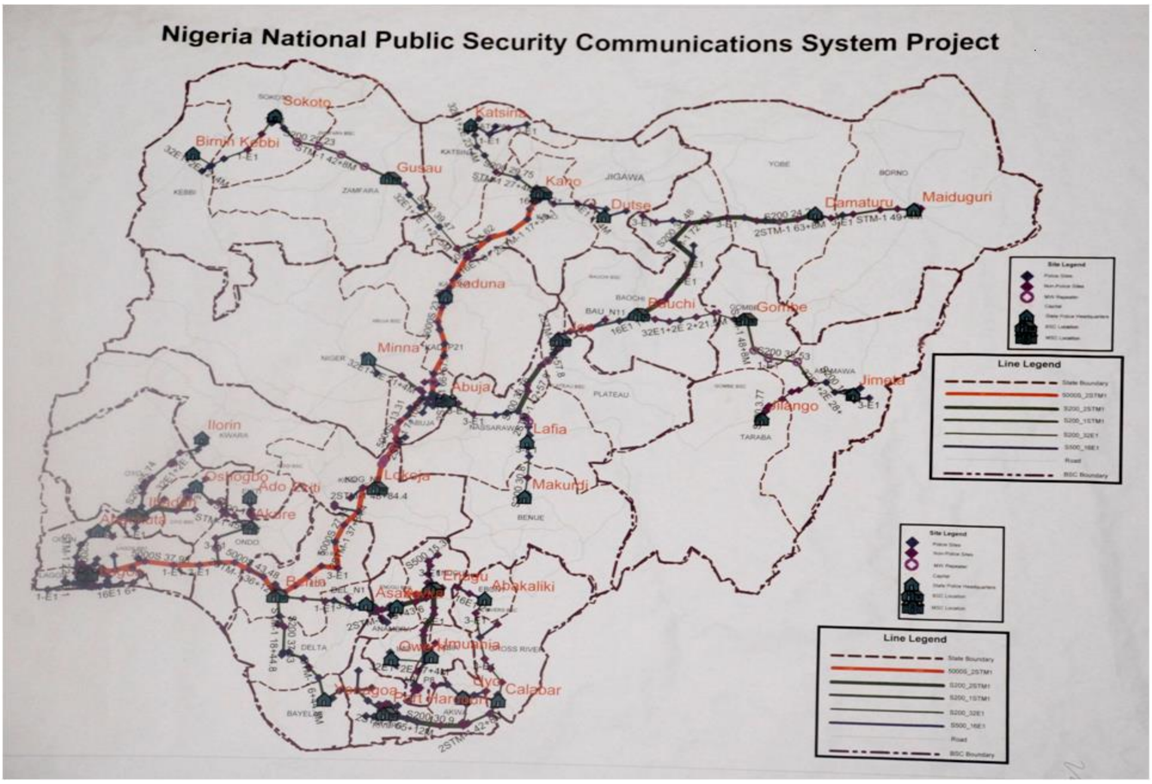


Figure 6.4: Map of Nigeria with overview of National Public Security Communication System Network across capital cities of the Nation (NPSCS, 2011).

Figure 6.5 shows the microwave transmission network across northern and southern part of the country. To ensure a reliable and robust network with network resilience especially in areas prone to disasters such as floods, the regional Nigerian Communications Satellite (NIGCOMSAT-1R) was used as backup to its microwave link infrastructure as shown in the network topology of figure 6.6. Figure 6.6 illustrates one of the state's backup communication satellite network topology to the base stations from one of the master switching centers (MSC).

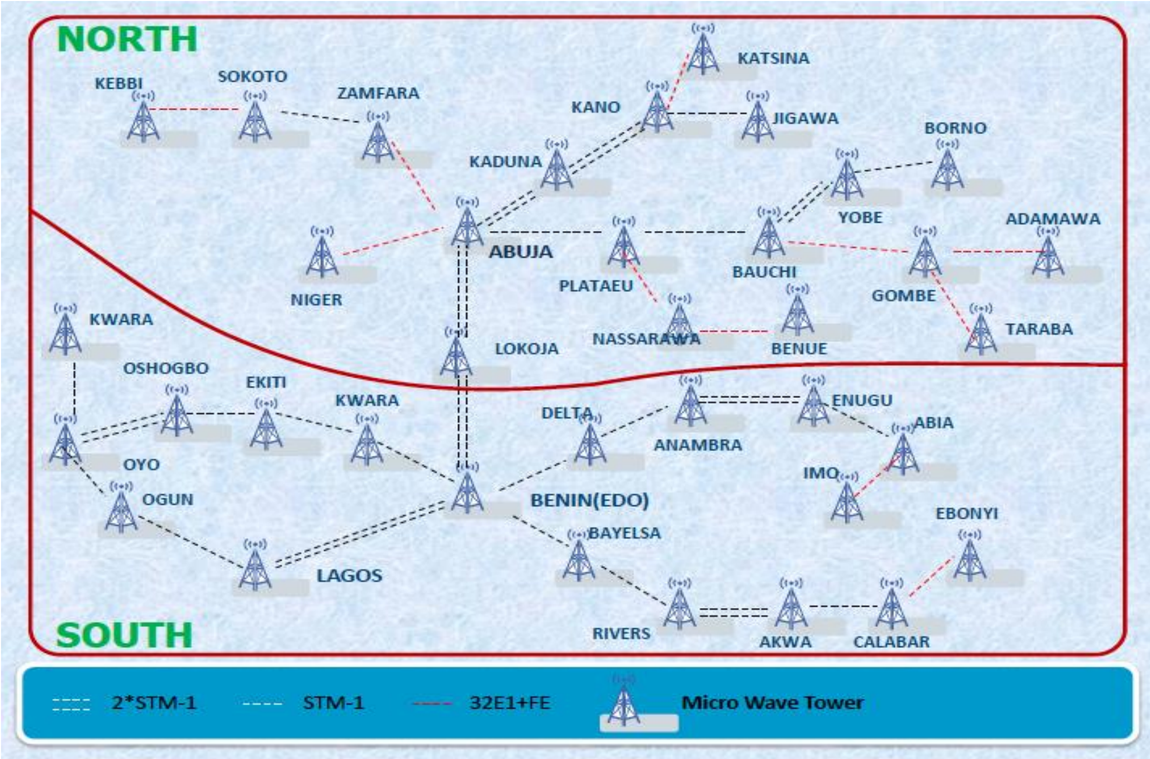


Figure 6. 5: The microwave transmission network across northern and southern part of the country.

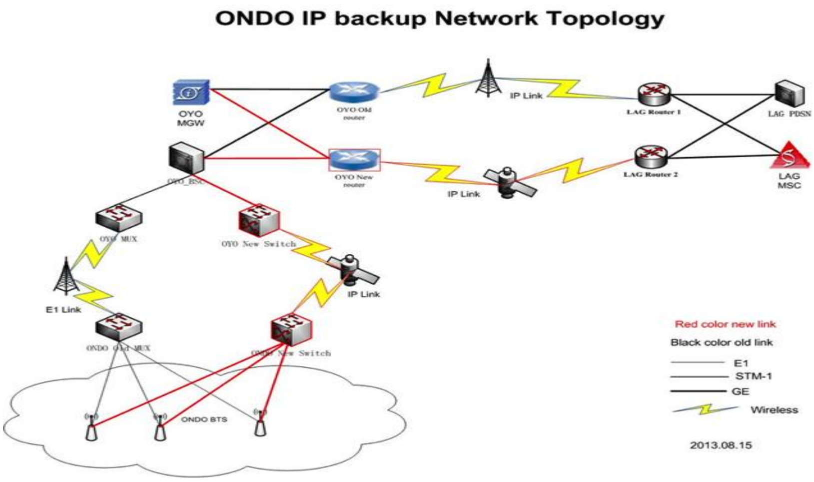


Figure 6.6: Ondo State (Nigeria) IP Backup Topology to the Microwave Link using the C-band of Nigerian Communication Satellite (NIGCOMSAT-1R).

The Federal Government of Nigeria with ambitious ICT policies and regulations as well as favorable laws and de-regulation, which has commensurately enhanced private sector participation to transform business practices and expedite the required diffusion of ICTs rolled out the National Public Security Communications Network based on CDMA EVDO technology across the nation for public safety use, security organizations using re-farmed national spectrum on 450-470MHz from initial single frequency, single channel walkie-Talkie system.

6.3 Overall System Design Overview of the NPSCS Project

The project is composed of five sub-systems to provide communications and tracking capability for security agencies. The Architecture is Service Oriented Architecture (SOA) with five sub-systems as follows:

1. Global Open Trunking Architecture (GoTa) Sub-system (a digital trunking communication system independently developed by ZTE, based on the Third Generation (3G) wireless communication technology — CDMA2000 REV.A)
2. Video Surveillance Sub-system
3. E-Police Sub-system
4. Video Conference Sub-system
5. Coalition Emergency Response Sub-system (CERS)

The Figure 6.7 illustrate the general overall architecture of the National Public Security Communications System (NPSCS) with its five sub-systems while figure 6.8 shows top-level service oriented architecture (SOA) integrated on an IP/MPLS bearer network over Microwave and complemented with NIGCOMSAT-1R as transmission backbone infrastructure.

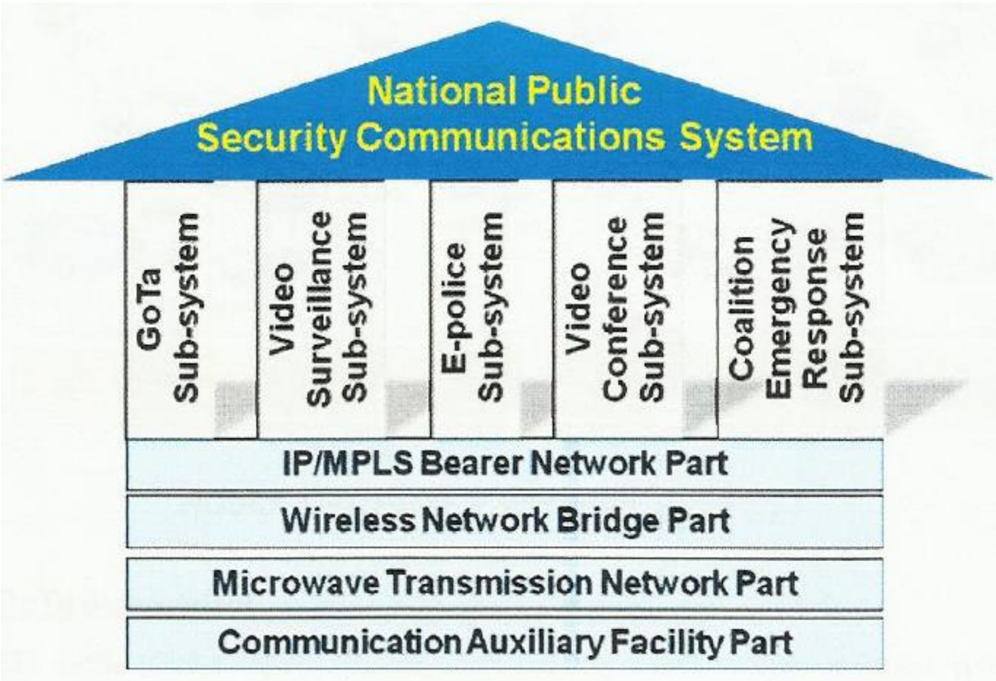


Figure 6.7: A diagram illustrating the general architecture of the National Public Security Communications System (NPSCS) Project. (NPSCS, 2011).

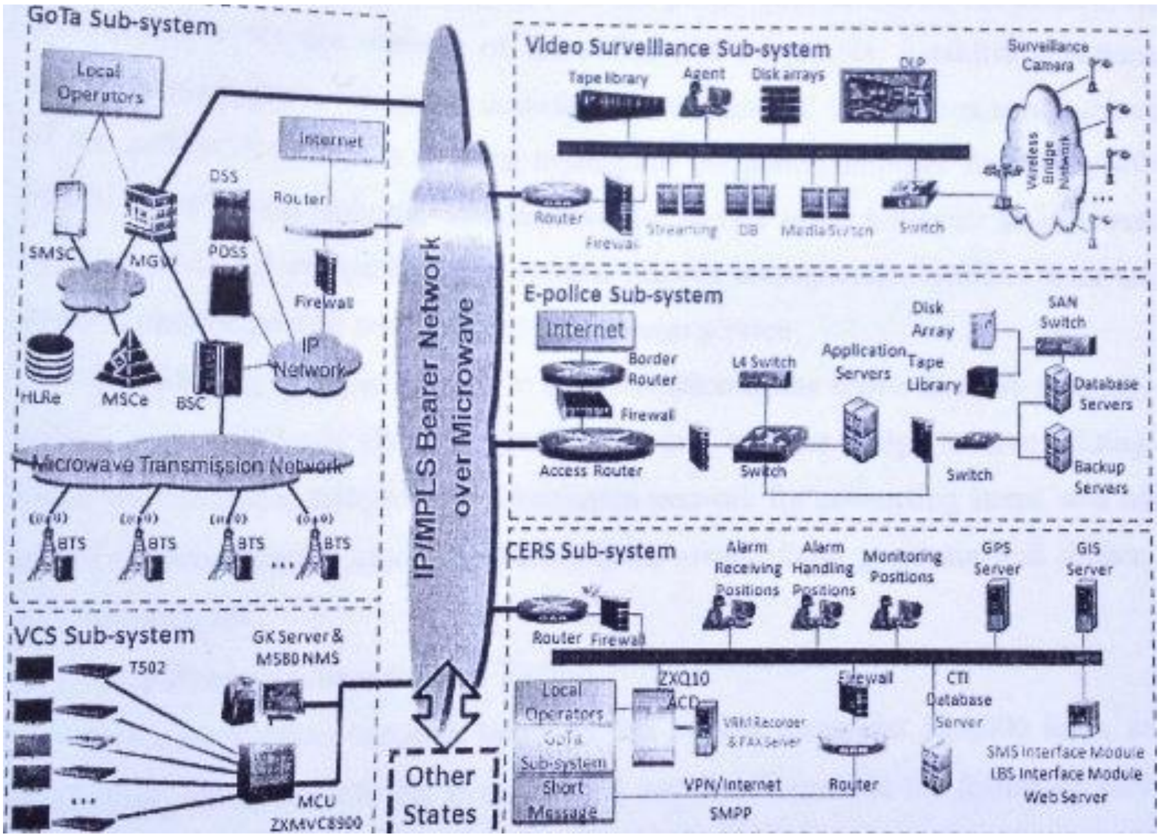


Figure 6.8: Illustrates the Top-Level Service Oriented Architecture (SOA) integrated on an IP/MPLS Bearer Network over Microwave and Complemented with NIGCOMSAT-1R as Transmission Backbone Infrastructure.

The network is being built with an integrated network infrastructure comprising of: Communication satellite, Microwave links, Wireless network etc as shown in the figure 6.7. The microwave topology aided rapid deployment in the first phase being a wireless terrestrial infrastructure complemented with NIGCOMSAT-1R.

The Fiber optic backbone deployment will be used to complement the microwave topology network in the second phase to meet medium and long term plans as video and data traffic grows exponentially. Figure 6.9 shows the NPSCS backbone with microwave technology expected to be complemented with optic fiber backbone in the second and third phase of the NPSCS project to meet medium and long-term needs.

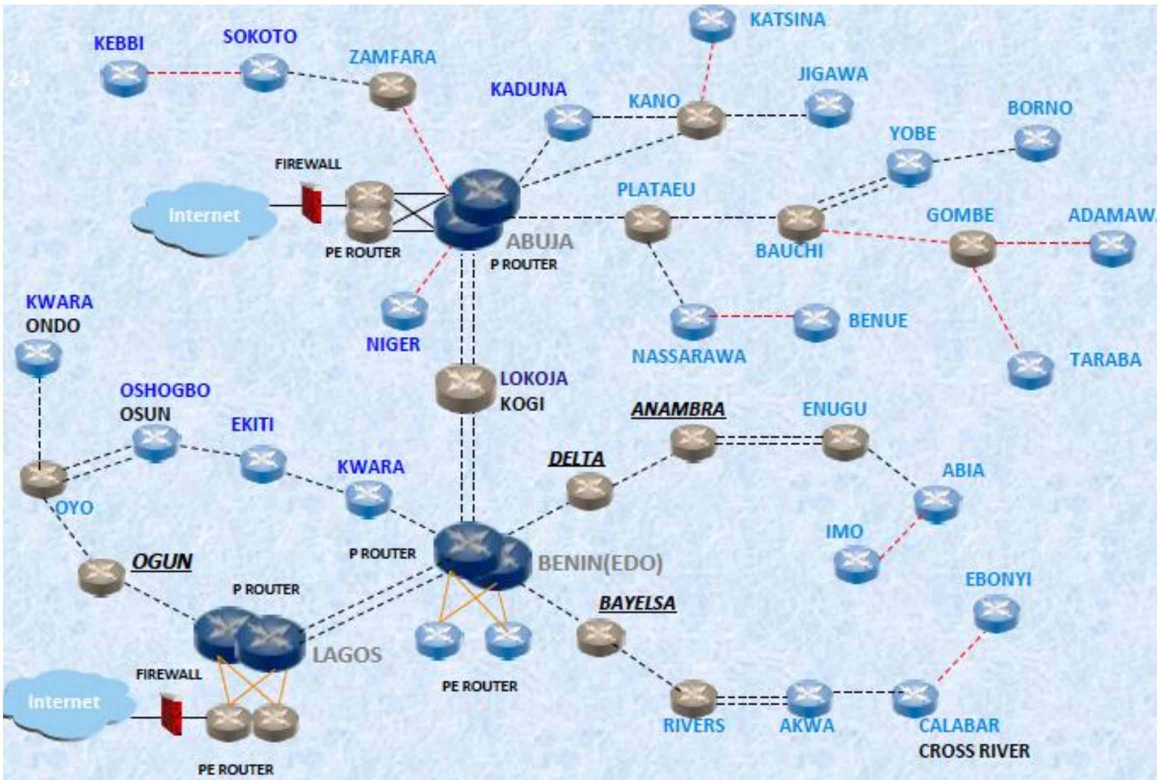


Figure 6.9: The NPSCS backbone with microwave technology backbone as dotted lines expected to be complemented with optic fiber backbone in the second and third phase of the NPSCS project to meet medium and long term needs.

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6.4 Descriptions of the Five (5) Sub-Systems and Components of The NPSCS.

6.4.1 Global Open Trunking Architecture (GOTA) Sub-System

A digital trunking communication system independently developed by ZTE, based on the Third Generation (3G) wireless communication technology — CDMA2000

The GoTa system for the first phase of the project deployment consists of 100,000 GoTa terminals, 675 Outdoor BTS (Base Transceiver Station), 21 Repeater Stations, 12 BSC (Base Station Controller), 12 DSS (Dispatching Service System), 2 MSS (Mobile Switching System) and related OMC (Operation & Maintenance Centre), 2 PDSS (Packet Data Service System), 1 SC (Short message Centre) and the transmission network (mainly microwaves). The Network deployed covers the entire state capitals of the federation as shown in figure 6.3 to 6.9.

6.4.2 Video Surveillance Sub-System

Wide coverage of the surveillance network and surveillance contents was implemented. The surveillance network covered all-important areas. For the first phase pilot project, Two thousand

(2000) cameras were deployed in Lagos and Abuja cities. Figure 6.10 shows top-level system architecture with reconnaissance capability.

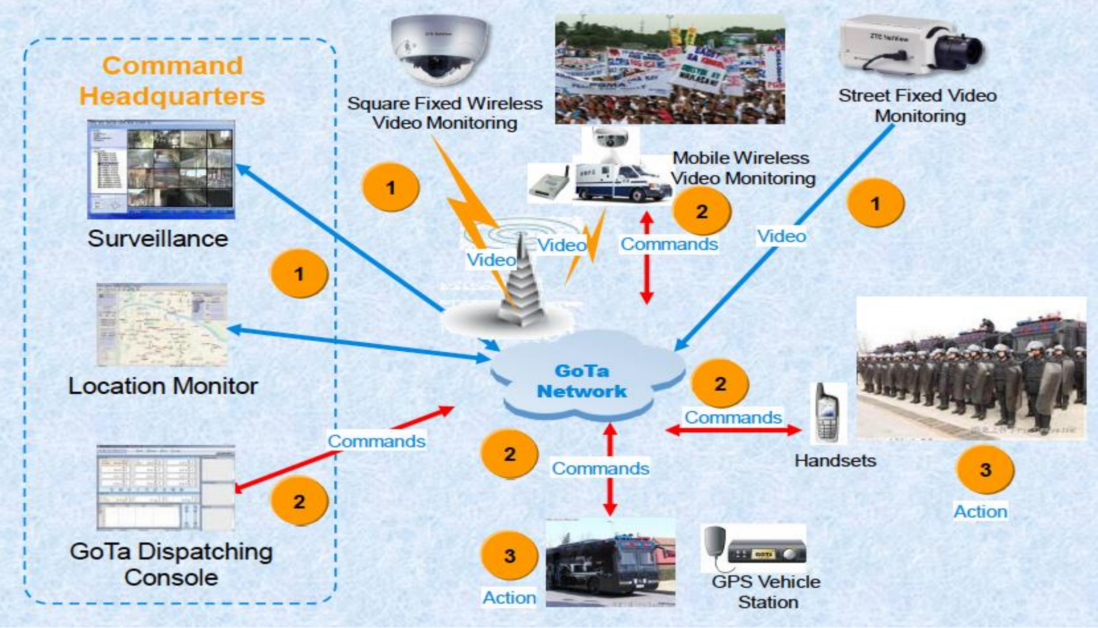


Figure 6.10: Top-Level System Architecture of the Video Surveillance System of the NPSCS with Reconnaissance.

6.4.3 E-Police Sub-System

The E-Police sub-system aims to create an all-round electronic and hi-tech network platform by integrating the criminal records management, pursuit of fugitives, biometrics, and police mails with case management activities at its core. This sub-system helps set up a criminal pursuit and identification system network for the nation. In the first phase, the E-Police System consists of a Police Portal, Mail/Push Mail system, Training system and Police Information System in all the 36 states of the federation and the FCT.

6.4.4 Video Conference Sub-System

Video Conference Sub-system enables the Nigeria Police Force (NPF) with geographically dispersed workforces to communicate and collaborate more effectively with enhanced productivity time over distance. The Video Conference system consists of 19 MCU Equipment, 38 video conferencing system terminals and Network Management System for the Video Conferencing system.

6.4.5 Coalition Emergency Response Sub-System (CERS)

The Coalition Emergency Response Sub-system (CERS) is an integrated, seamless and complete system for processing of public emergency events for police, fire, hospital, traffic etc. The Coalition Emergency Sub-system (CERS) consists of 1 Display Wall Hardware, 12 CERS systems, 25 CERS Main Equipment, 20 CERS Terminals-Q10, 219 CERS Terminals-Lenovo

M7150 PC, 340 CERS Terminals-17 inch Television Screen. The pilot project offered a proposed disaster communications interoperability plan with features such as redundant transmission, more sophisticated vital equipment, backup subscriber management centre, emergency hot lines, paging systems for spreading disaster warnings, rapid deployment techniques for base stations during response *inter alia*. The Coalition Emergency Response Sub-system (CERS) of the National Public Security Communications System (NPSCS) meets such requirements, with two different levels of emergency centre. They are the National Coalition Emergency Response Center (NCERC) and State Coalition Emergency Response Center (SCERC) as shown in figure 6.11. The NCERC is the top level control centre for the national emergency response network as well as critical and the major emergency case that transcends state level while the SCERCs, with presence in 36 states of the federation, are meant to receive and process common and non-emergency cases within its area of jurisdiction. The NCERC and SCERC are connected beyond the NPSCS network to the Public Switched Telephone Network (PSTN), Public Land Mobile Network (PLMN) via digital trunks and IP-based networks as shown in figure 6.12. The Geographical information and Command system (Xu, Chen & Ma, 2010) are integrated into the CERS to support dynamic handling and planning, as well as providing effective tools for visual and global command to security agencies, emergency service organizations (i.e Police, Fire, Road safety outfits, medical services etc) and thus facilitating information symmetry amongst their operations efficiently and effectively.

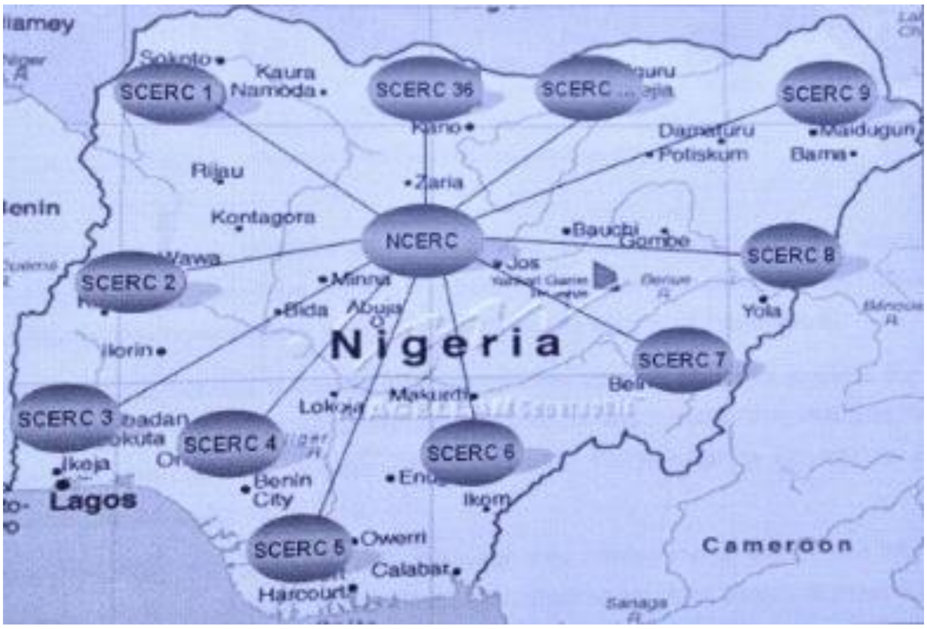


Figure 6.11: Map of Nigerian with Coalition Emergency Response System (CERS) Architecture.

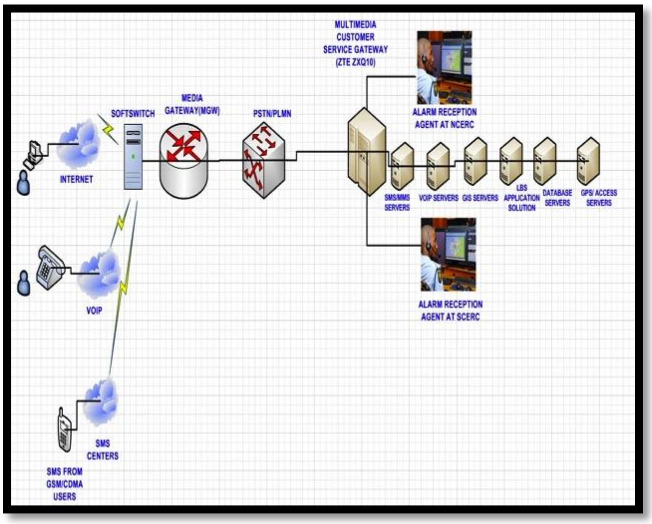


Figure 6.12: Simplified overview of Integrated Coalition Emergency Response System (CERS) Network with Application Servers at National and State Centres.

6.5 The NPSCS Project Implementation Results

The Followings are highlights and summary of the project Implementation in the first phase:

- The first call was made on 17th May, 2011 after completion of the central equipment room building for Abuja with CDMA core network equipment installed.
- The 2000 cameras pilot was deployed and integrated with VSS in city centre locations of Abuja; the Federal Capital City and Lagos State including the two (2) international airports.
- Building of Central Equipment Room in Lagos completed.
- The building of 35 States' Central Equipment Rooms to house CERS, VSS, VCE were completed.
- BTS Tower deployment and Integration completed.

Table 6.1 shows the CDMA-EVDO Forward Link Budget and Coverage forecast on 450MHz in an Urban Environment.

Table 6.1:The CDMA-EVDO Forward Link Budget and Coverage Forecast on 450MHz of an Urban Environment.

Terminal Type	Single Antenna								
Data Rate(kbps)	38.4	76.8	153.6	307.2	614.4	921.6	1228.8	1843.2	2457.6
BTS Tx Power(Watt)	20	20	20	20	20	20	20	20	20
BTS Tx Power(dBm)	43.01	43.01	43.01	43.01	43.01	43.01	43.01	43.01	43.01

BTS Antenna Gain(dBi)	14	14	14	14	14	14	14	14	14
BTS Jumper Loss(dB)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
BTS Cable Loss(dB/100m)	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
BTS Cable Length(m）	40	40	40	40	40	40	40	40	40
Other Loss(dB)	1	1	1	1	1	1	1	1	1
BTS Cable Loss(dB)	2.46	2.46	2.46	2.46	2.46	2.46	2.46	2.46	2.46
BTS EIRP(dBm)	54.55	54.55	54.55	54.55	54.55	54.55	54.55	54.55	54.55
Terminal Antenna Gain(dBi)	0	0	0	0	0	0	0	0	0
Body Loss(dB)	0	0	0	0	0	0	0	0	0
Thermal Noise(dBm/Hz)	-174	-174	-174	-174	-174	-174	-174	-174	-174
Target PER(%)	2	2	2	2	2	2	2	2	2
Multi-user Diversity Gain(dB)	2	2	2	2	2	2	2	2	2
Rx Diversity Gain(dB)	0	0	0	0	0	0	0	0	0
Receiver Sensitivity(dBm)	-109.81	-105.81	-102.01	-99.71	-95.41	-91.91	-87.91	-81.91	-76.41
Log-normal Std. Deviation(dB)	8	8	8	8	8	8	8	8	8
Edge Coverage Probability(*100%)	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Log-normal Fade Margin(dB)	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40
Soft Handoff Gain(dB)	0	0	0	0	0	0	0	0	0
Maximum Path Loss(dB)	160.96	156.96	153.16	150.86	146.56	143.06	139.06	133.06	127.56
Coverage									

Forecast									
Building Penetration Loss (dB)	20	20	20	20	20	20	20	20	20
Down Link Path Loss(dB)	140.96	136.96	133.16	130.86	126.56	123.06	119.06	113.06	107.56
BTS Antenna Height(m)	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Terminal Antenna Height(m)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Frequency(MHz)	460.00	460.00	460.00	460.00	460.00	460.00	460.00	460.00	460.00
Hata Terrain Correction(dB)	0	0	0	0	0	0	0	0	0
1km Path Loss(dB)	117.07	117.07	117.07	117.07	117.07	117.07	117.07	117.07	117.07
Slope	34.41	34.41	34.41	34.41	34.41	34.41	34.41	34.41	34.41
Radius of Coverage(km)	4.95	3.79	2.94	2.52	1.89	1.49	1.14	0.76	0.53

6.5.1 CDMA Core Network Elements and Results

The CDMA core network consists of:

MSCE (Mobile Switch Centre Emulator), MGW (CDMA Multimedia Gateway), PDSN: (Packet Data Support Node), HLR (Home Location Register), AAA: (Authentication, Authorisation and Accounting Server) and EMS (Element Management System). Figure 6.13 shows picture of MSCE installed in the Abuja switching room within the headquarters of Nigeria Police Headquarters.

- **MSCE** Installed for both Abuja and Lagos
- **HLR** Installed for both Abuja and Lagos
- **MGW** installed with locations at Abuja, Lagos, Kano, Zamfara, Bauchi, Gombe, Plateau, Kogi, Edo, Rivers, Enugu, Oyo
- **PDSN** installed
- **AAA** installed
- **EMS** installed.

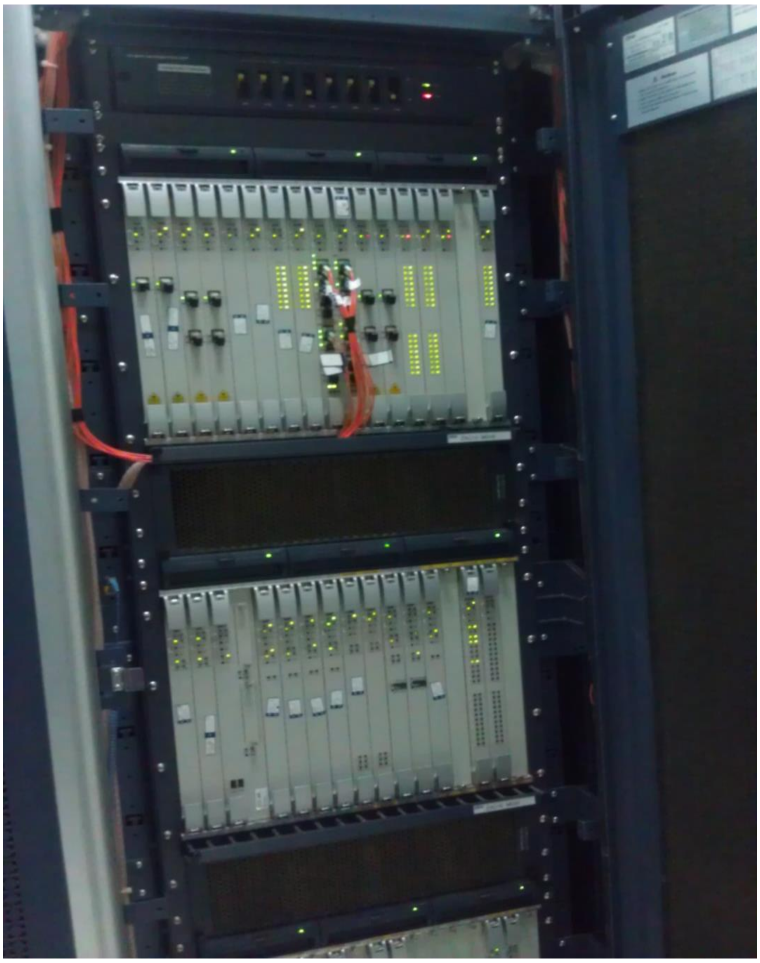


Figure 6.13: Installed MSCE in Switch room within Nigeria Police Force Headquarter, Abuja.

6.5.2 BSS (Base Station Subsystem) Implementation and Results

The **BSS** comprises of three main systems, the Base Transceiver Station (**BTS**), Operation Management Module (**OMM**) and the Base Station Controller (**BSC**). Figure 6.14 shows the deployed Abuja switch tower located close to the Abuja switching centre and within the premises of the Nigeria Police Force Headquarters, Abuja while figure 6.15 shows picture of installed BSS cabinet at Abuja and Figure 6.16 to 6.22 shows the selected coverage power levels and performance of Abuja and six geo-political regions of the country namely Lagos, Abia, Anambra, Kano, Ogun and Rivers State respectively.

Figure 6.14: Abuja Switch Tower located within the premise of Nigeria Police Force Headquarter, Abuja.

Figure 6.15: A picture showing BSS cabinet installed at Abuja.

- **OMM** installation - deployed in Abuja and Lagos and ten (10) other locations.
- **BSC** installation - deployed in Abuja and Lagos and ten (10) other locations.

- **BTS** installation - 37 BTSs installed and completed in all locations.
- **BSC and OMM Locations** are Abuja, Lagos, Kano, Zamfara, Bauchi, Gombe, Plateau, Kogi, Edo, Rivers, Enugu, Oyo.

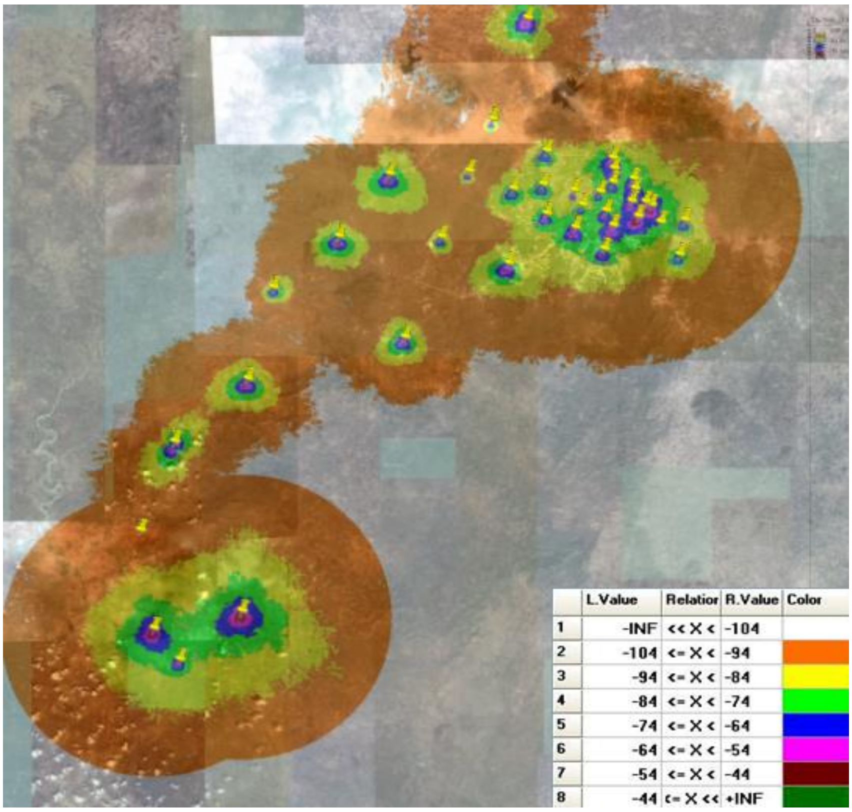


Figure 6.16: Measured Coverage Power level and performance of Abuja; the Federal Capital Territory (FCT).

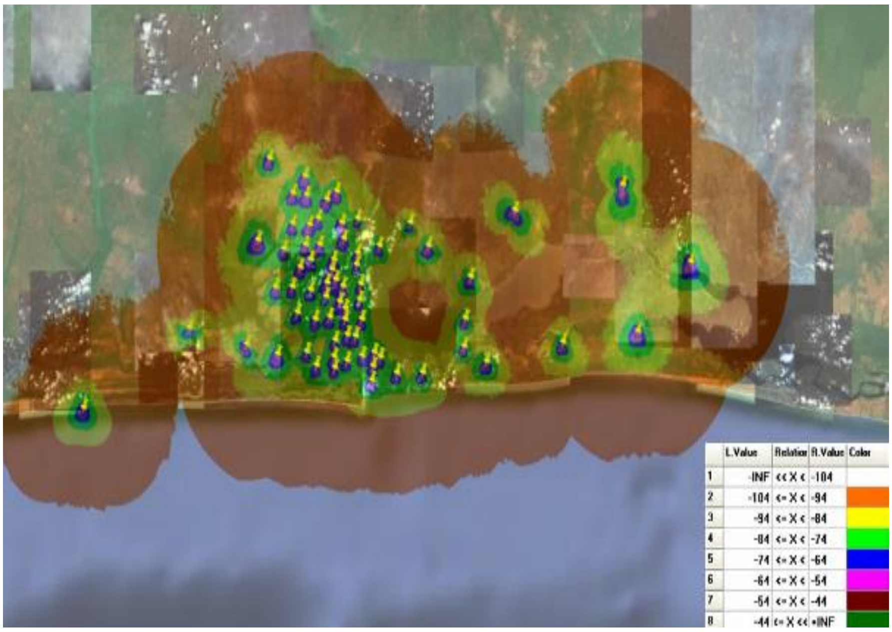


Figure 6.17: Measured Coverage Power level and performance of Lagos State.

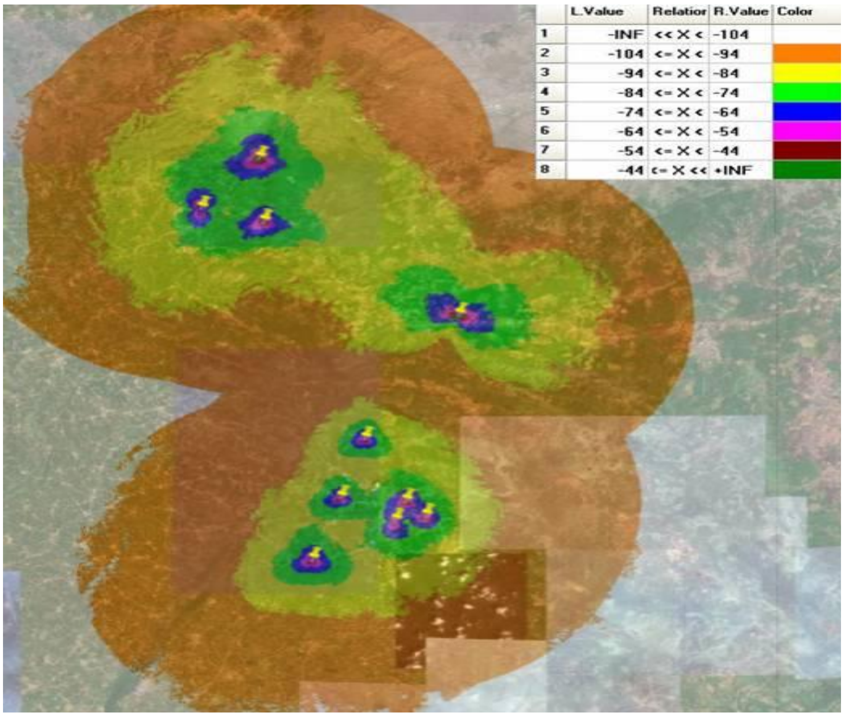


Figure 6.18: Measured Coverage Power level and performance of Abia State.

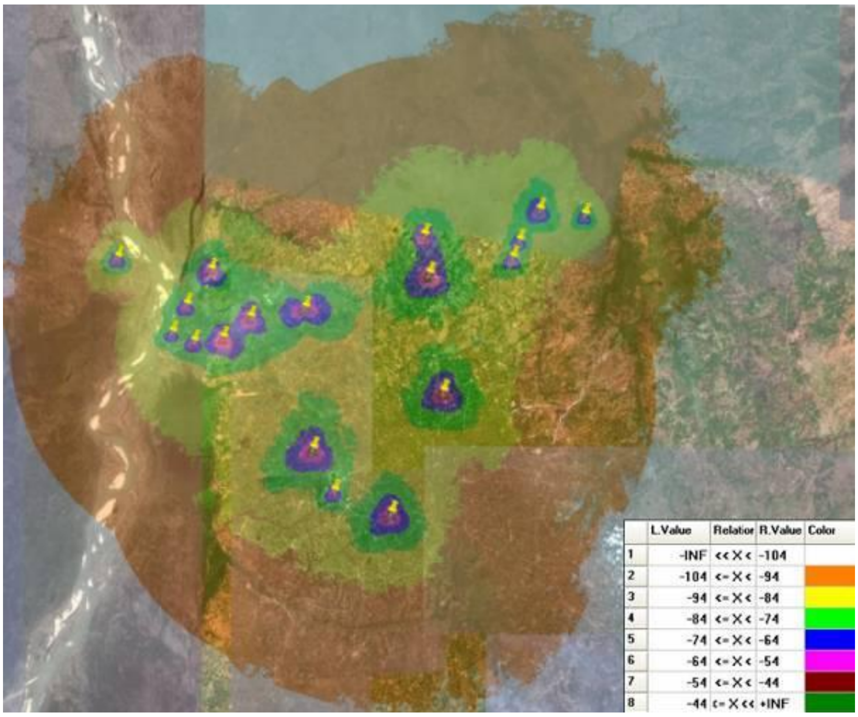


Figure 6.19: Measured Coverage Power level and performance of Anambra State.

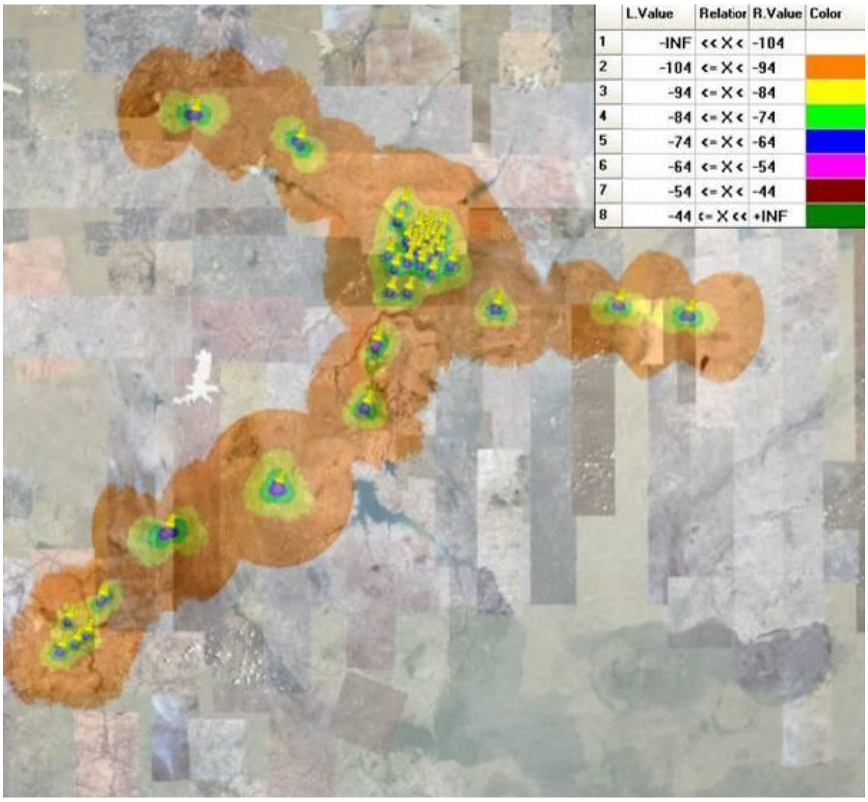


Figure 6.20: Measured Coverage Power level and performance of Kano State.

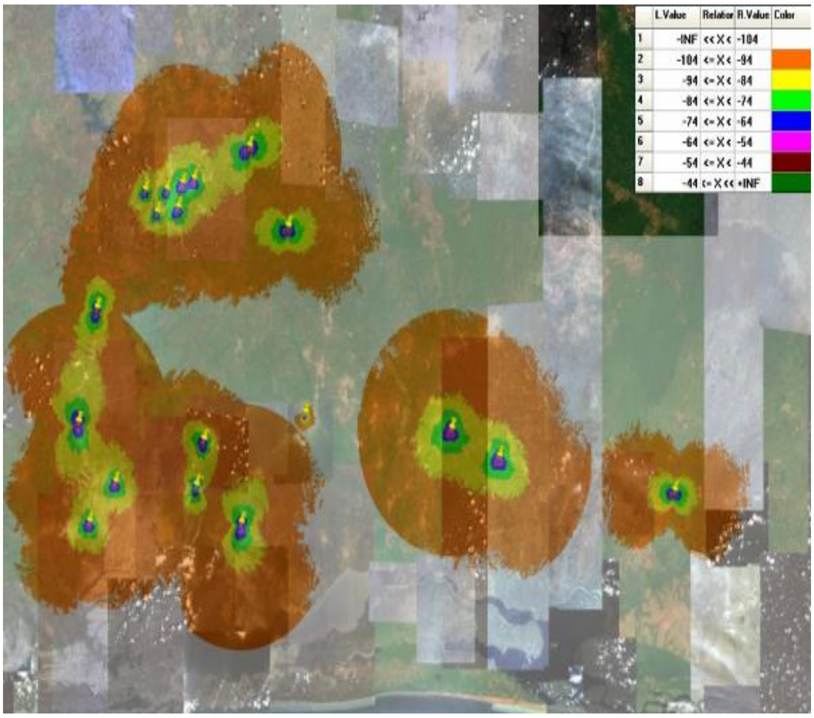


Figure 6.21: Measured Coverage Power level and performance of Ogun State.

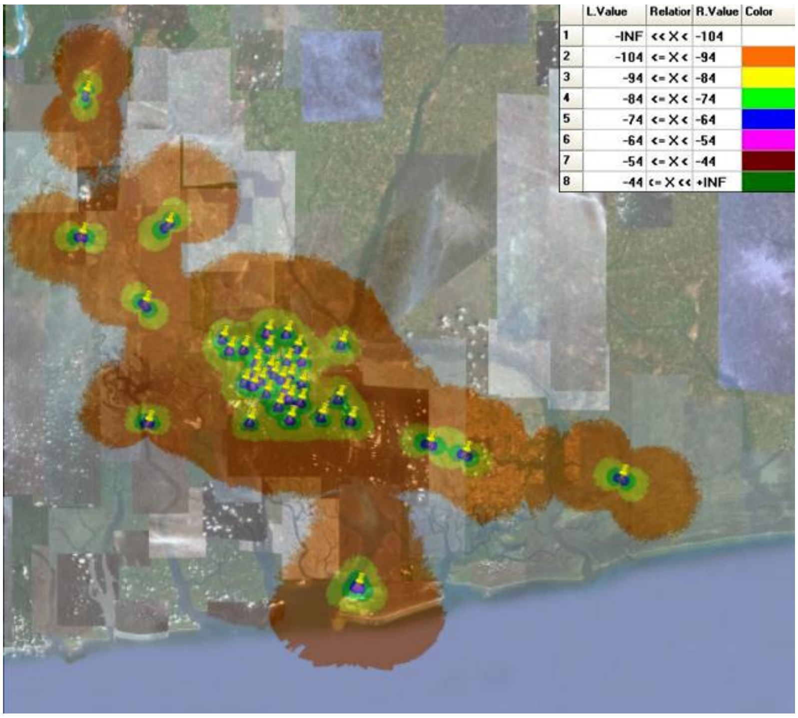


Figure 6.22: Measured Coverage Power level and performance of Rivers State.

6.5.3 DSS (Dispatching Service System) Results

The **DSS** is the GoTa component, which handles Push-to-talk (PTT) and dispatcher services. There are twelve (12) DSS each with capacity of 100,000 subscribers deployed in the Network.

DSS has been installed in Abuja, Lagos and 10 other locations.

One DSS has been installed in each of the 12 BSC regions namely Abuja, Lagos, Kano, Zamfara, Bauchi, Gombe, Plateau, Kogi, Edo, Rivers, Enugu and Oyo state.

6.5.4 Surveillance Network

Wide coverage of the surveillance network and surveillance contents was implemented. The surveillance network covered all-important areas based on inputs provided by Nigerian Police Force. In the first phase, two thousand (2000) cameras and 37 sets of surveillance systems were deployed. The 2000 cameras consist of 860 High Speed Dome Cameras and 1140 Infrared Fixed Cameras.

Video Surveillance System in Abuja and Lagos has been completed.

Figure 6.23 shows one of the high speed dome camera system deployed at Millenium Park with footage from the surveillance screen as viewed from the Abuja Switching Centre, while figure 6.24 shows footages of surveillance from Cameras deployed at the entrance and exit of five star Hilton Hotel at the central business district of Abuja.

Figure 6.23: A picture of high-speed surveillance camera and footage as viewed from the central switch centre in Abuja.

Figure 6.24: A picture of footages at the entrance and exit of Hilton Hotel located at the central business district of Abuja.

Figure 6.25 shows arrays of solar panels with a Series of Batteries stacked inside the cabinet to ensure and guarantee power supply to every installed surveillance camera tower.

Figure 6.25: Arrays of solar panels with a series of Batteries stacked inside the cabinet to ensure and guarantee the power supply to every installed surveillance camera tower.

6.5.5 IP/MPLS (Multiprotocol Label Switching) Bearer Network Status and Results

The IP/MPLS Bearer Network is used for connecting all the services and generates the route for all Internet Protocol (IP-based) services to communicate seamlessly with one another in the network.

IP/MPLS installation - The IP/MPLS implementation was started in Abuja and integrated with the other 36 Central Offices.

13 Routers, 28 Ethernet Switch-Type1, 4 Ethernet Switch-Type 2 and 37 Intelligent Integrated Multi-Service Routers were deployed in the Network to provide interconnectivities and communication of services in the 37 central equipment rooms.

6.5.6 Microwaves

Microwaves are used for point-to-point communication in the Network.

Microwaves and Microwave cabinet implementation has been completed for the 697 microwave transmission hops as shown in figure 6.5 and 6.9 earlier

A total of 697 Microwave Transmission hops, 1 NMS (Network Management System) and 58 Microwave Cabinets were deployed in the Network.

6.5.7 Communications Auxiliary Facility (CAF)

The CAF is the Communication Auxiliary Facility, which consists of Tower, Diesel Generator Set (Double Generators), Shelter, Air Conditioner, Battery and Distribution Product.

Implementation of CAF components and systems has been deployed and integrated.

6.5.8 GOTA Terminals

One hundred thousand (100,000) GoTa Terminals were deployed in the first phase of the network.

Two hundred (200) GoTa terminals were deployed and used during the presidential inauguration on 29th May, 2011.

6.5.9 SMSC, CERS, VCS and E-Police Implementation Status

Police SMSC (Short Message Service Centre) is used for delivering SMS messages in the network. An SMSC was deployed in the Network at the Abuja Central Room. Installation has since been completed.

The CERS (Collation Emergency Response System) is an integrated, seamless and complete system for processing public emergency events for the Police, fire service, hospitals, traffic issues etc. The CERS has been deployed in 37 Central Equipment Room.

The VCS (Video Conference System) enables the Nigerian Ministry of Police with its geographically dispersed workforce to communicate and collaborate effectively and productively over distance. 38 VCS have been deployed. Figure 6.26 shows one of the E-police systems deployed at Sokoto state of Nigeria.

The E-Police System consists of a Police Portal, Mail/Push Mail system, Training system and Police Information System. The system has been deployed and integrated.

Figure 6.26: A picture showing deployed E-police centre at Sokoto State.

6.5.10 The Emergency Communication Vehicle System (ECV)

The Emergency Communication Vehicle shown in figure 6.27 are also veritable assets and equipment for emergency events such as disaster relief, anti-terrorism, fire outbreak control etc to help improve timely response and capability of security agencies. Six (6) Telecommunication Trucks deployed in six geo-political region of the country were deployed in the Network using the C-band of Nigerian Communications Satellite (NIGCOMSAT-1R) to provide satellite link via a very small aperture terminal (VSAT) to the core network of the NPSCS through a 6m antenna earth station in figure 6.28. This greatly enhances the flexibility of the GoTa system in the areas without fixed GoTa BTS. The mobile communication Vehicle forms substantial coverage to provide services such as voice data and video surveillance in stadiums, hot spots areas, big events, emergency areas and disaster locations. The Emergency Communication Vehicle System has improved the response ability of Federal Government of Nigeria considerably but more ECVs are required to increase effectiveness.

Figure 6.27: A picture showing one of the Emergency Communication Vehicle (ECV) with deployable C-Band antenna system and mini-mast serving as Base Transceiver Station (BTS) for communications (Voice, Data & Video & Graphic-based Applications i.e Map).

Figure 6.28: 6M-Antenna Earth Station Serving as Gateway for Integration of the ECV Communication Satellite Links to the core network of the NPSCS using the C-Band of NIGCOMSAT-1R covering Sub-Saharan Africa.

A pilot project has been proposed using DVB Emergency Warning System (EWS) to extend the early warning system to reach wider audience and public through their TV and radio receivers. The Digital Video Broadcasting (DVB) EWS provides the necessary mechanisms and standards to distribute relevant information to a wider audience as a warning system for pre-eminent dangers etc (DVB-EWS, 2013).

Disasters like fire outbreak, building collapse, vehicular accidents etc, are better managed if the city satellite map is available both for precise site location and road navigation for evacuation. A typical example is the fire service city navigation and nearest hospital location system for instant treatment of disaster victims. NIGCOMSAT-1R Navigation transponder amongst others is addressing such solutions viz-a-viz the need for pre-call and post-call preparedness, including convergence of existing emergency numbers setup at state and national agencies. e-health services and applications , makeshift medicare and medication centers are facilitated and coordinated with the hybrid public security and emergency network (Chronaki et al, 2008).

Research and standardization activity at national and international level to define modern, interoperable communications and networking standards for emergency response and public safety are being studied and implemented including several initiatives aimed at effective emergency response services by international bodies, institutes and stakeholders. For instance, the GSMA, which represents the interests of mobile operators worldwide, initiated the deployment of a single, in-vehicle emergency call services known as eCall, across Europe aimed at establishing voice connection with the emergency services alongside critical data such as time, location, direction of travel, vehicle identification etc. The International Telecommunication Union (ITU), Inmarsat and Vizada SAS initiated improved emergency communications for disaster preparedness via satellite-based solutions among others (GSMA International Report[50], 2009). ITU has identified emergency communications as a key priority with several work groups including ITU- Development sector (ITU-D) to develop technical recommendations and implementations guidelines on disaster response planning.

Boukerche (2008) provided an overview of the next generation wireless networks for emergency preparedness and arrays of applications necessary for public safety and security while China's broadband Wireless trunking project (BWT) seeks to incorporate mission-critical features on long-Term Evolution (LTE) as future Public safety Communications Network (Li, Chen, Yu, Meng, & Tan, 2013). Advanced and reliable research is being conducted with applications using Software Defined Radios (SDR) and Cognitive Radio (CR) technologies towards better spectrum utilization and management (Gorcin & Arslan, 2008).

The United Nations International Strategy for Disaster Reduction (ISDR) promotes national capacities. Since 1994 after recognition and adoption of the Tampere Convention (treaty) on Emergency Telecommunications, the Working Group on Emergency telecommunications (WGET) is regularly convened by the United nations Office for the coordination of Humanitarian Affairs (OCHA) as a focal point for emergency telecommunication related issues. WGET encompasses all partners in humanitarian assistance and emergency telecommunications, experts from private and academic sectors, UN entities including national, international, governmental and non-governmental organizations (Oh, 2003).

6.6 Benefits of the NPSCS Project

6.6.1 Security and Confidentiality

a. Improved public safety and security.

b. Keeping information secured within security agencies

c. Private and group calls with group management

6.6.2 Improved Working Efficiency of Security Agencies

d. Efficient and centralized dispatch and intelligence gathering platform.

e. Unified and accessible communication anytime and anywhere

f. Collaborative and efficient emergency response system.

6.6.3 Reduced Government Spend and Job Creation

g. Reduced the usual routine communication expenditure with net savings of over USD480 Million annually.

h. Has encouraged tourism and direct foreign investments in the country including job creation, increased national productivity and development but requires commencement of phase two and three for entire coverage of the nation.

6.6.4 The CDMA-EVDO 450MHZ as an Improved Technology over other Public Security Services (PSS) Technologies.

i. The 3G/4G CDMA-based technology with an all-IP technology is an enhanced improvement over other Public Security Services (PSS) technology such as TETRA; a digital based trunking system but circuit switched with low data rate.

j. The 450MHz has a superior propagation characteristics and better penetration compared to commonly used frequencies such as 800/900/1800/1900MHz and thus is most suitable in sparsely populated and rural areas. A single cell tower can cover 7,521 Km^2 compared to 553Km^2 on 1900MHz. Table 6.2 shows Cell radius versus various Frequency Performance.

Table 6.2 : Cell Radius Versus Various Frequency Performance

Frequency (MHz)	Cell radius (km)	Cell area (km^2)	Relative Cell Count
450	48.9	7521	1
850	29.4	2712	2.8
950	26.9	2269	3.3
1800	14.0	618	12.2
1900	13.3	553	13.6
2500	10.0	312	24.1

6.6.5 Strategic Commercial Telecommunications Need of the State for Sustainability of the Network.

k. The excess capacity as a result of re-farmed spectrum for a digitalized CDMA-EVDO network technology provided excess capacity and utilization of scare spectrum to drive Nigeria's cashless pilot project for financial and digital inclusion and thus effectively promotes universal access goals, without exclusivity. Chapter eight (8) provides further details.

6.7 Conclusion

The National Public Security Communications System (NPSCS) has been deployed and provided on CDMA- EVDO-Rev. A Technology. A total IP technology with services such as Professional GoTa command and dispatch services in response to emergency situations, Prioritized communications between high level users, high quality voice service and short messaging service, high speed data service for data and surveillance and live audio/video streaming, strong encryption technology to ensure system security, emergency alarm service for the general public for pre-emptive and reactive emergencies reporting to police, video surveillance service, video conference service, coalition emergency response service, Police office e-service system, training and after sales support

Highlights of the solution provided by the project include security of the GoTa system, special trunked service to enable individual, group, emergency and broadcast calls as well as calls prioritization, wireless broadband data service, 3G service, low cost network with mature products. In addition all network equipment complied with national environmental protection standards and poses no danger to the citizens and the environment.

The system supports an integrated intelligence system with capability to support operations for general security alarm, emergency alarm and alarm handling, and cooperative security systems such as surveillance, interception, information gathering, analysis, preplanning, etc. The Security Communications system allows for collection, management, analysis, fusion and interpretation of relevant information to commanders, operators to guide planning, resources deployment, tactical response and strategic planning as well as information sharing and symmetry with similar organizations and other relevant organizations.

The NPSCS Network is designed with support to backhaul and integrate with the Nigerian Communications Satellite Limited (NIGCOMSAT) satellite, NigComSat-1R, launched in December, 2011 including subsequent fleets of communication satellites to provide an IP cloud all over the country and facilitate the availability of transmission infrastructure and connection to the national public security communication backbone everywhere in the country and along border areas until there is adequate terrestrial metro-transmission such as fiber optical transmission; Gigabit Passive Optical Network (GPON) and Ethernet Passive Optical Network (EPON) for the huge video transmission as more cameras are deployed in the second and third phase of the project to cover Abuja, Lagos and other big cities and hot spots for the whole nation. The long-term security communications system to complement the deployed 2,000 video surveillance system pilot project requires the deployment of optic fiber link in the third phase to support the huge video traffic transmission for entire coverage of the nation.

The Nigerian National Public Security Communication Network has impacted positively on the security of the nation with social benefits. The project is economically sustainable through utilization of the network for financial and digital inclusion, viable and critical for national security and as well as enhancing the overall total productivity factor of the nation.

CHAPTER 7: Solutions, Applications and Services Exploiting Communications Satellite and National Public Security and Emergency Network.

7.0 Summary:

Africa still remains the least wired continent in the world in terms of robust telecommunications infrastructure and systems to cater for its more than one billion people. Existing communication infrastructure in the African hinterlands is grossly inadequate, thus there is a need to develop intra-city, inter-city, national, sub-regional and regional carrier of carriers and digital links with cross-border inter-connectivity. Although, the continent has adequate capacity on submarine fibre optic cables along the shores of the African coastline, it lacks adequate ICT infrastructure in cities, suburban and especially rural areas. The demand projection suggests that there is a need for a robust passive infrastructure built in and around Africa to address the large un-met demand for information and communication services in the short and medium term. The success of Africa's information technology policy and infrastructure depends greatly on satellite communications in conjunction with variants of wireless technologies to rapidly actualize universal access goals and leverage the tens of terabyte capacity of the marine optical fibres that have been installed along the African coastline. This chapter examines the role of Communication Satellite Systems and in particular Nigerian Communications Satellite including the National Public Security and Emergency Network as last mile terrestrial wireless infrastructure as a vehicle to drive the National ICT revolution in pursuit of: national e-readiness, ICT self-reliance and the skills acquisition required for a Knowledge-based economy to enable the socio-economic development of Nigeria. Also discussed is the growing penetration of communication satellite applications as well as an alternative to Digital Terrestrial Television in migration to digital broadcasting especially in Africa, Eastern & Central Europe and the Asia–Pacific as we move closer to the ITU deadline for Analogue Switch-Off (ASO) by June, 2015.

7.1 Broadband Communications for Internet and Mobile Communications

Communications via satellite is as old as space age itself because whatever is launched into orbit must receive commands from the ground and send telemetry back to ground as was the case with the first man-made earth orbiting satellite called SPUTNIK, which was launched by the Russians on 4th October, 1957. Thereafter applications and services evolved over time for transmissions such as video pictures of the far side of the moon on 26th October, 1959 by the Russian vehicle Lunik III. (Drury, 1994). Syncom meaning synchronous Communications satellite was started in 1961 as NASA program for active geosynchronous communication satellites developed and manufactured by Hughes Space and Communications. Syncom-1 was launched in February, 1963 and was successfully injected into a nearly synchronous orbit but suddenly lost in the final second of the 21-seconds Apogee motor burn. After a series of corrections to preclude occurrence of failure, Syncom-2 was successfully injected into orbit on July 26th 1963, as the world's first geosynchronous communications satellite while Syncom-3 launched in 1964 was the world's first geostationary communications satellite (Bentley & Owens, 1964).This was followed by development of technology with Applications Technology Satellite (ATS) series including the Communications Technology Satellite (CTS) program in cooperation with Canada (Wolff, 1977). As explained earlier in literature review of chapter one, introduction of digital video broadcasting (DVB) systems to communications satellites was a milestone paradigm shift for the important role communication satellites are playing today in broadcasting, telecommunications, mobile communications, convergence with voice, video and data as well as terrestrial telecommunications technologies. (Ong et al, 2007; Liang et al, 2007). The Digital Video Broadcasting (DVB) Project, an industry-led and market-led consortium of private and public organizations including regulatory bodies committed themselves to designing open interoperable standards for global delivery of digital and broadcast services considering the prevalence of proprietary architectures and technologies of communication satellite transmission and broadcast technologies. The specification of DVB has been a European initiative and standardized by the European Telecommunications Standards Institute (ETSI) since 1991 when broadcasters, equipment manufacturers and regulatory bodies came together to discuss issues arising from interoperability, mainly in the satellite industry. A consensus-based framework and memorandum of understanding (MOU) was signed in 1993 and has since produced a wide family of standards beyond broadcasting and satellite services fostering more than 35 countries around the world outside Europe. The DVB project work in the beginning involved establishing standards to enable the delivery of digital TV through the traditional broadcast networks over satellite networks, cable networks and terrestrial networks with the following standards as DVB-S, DVB-C and DVB-T respectively including a whole range of supporting standards such as service information (DVB-SI), Subtitling (DVB-SUB), interfacing (DVB-ASI) etc. The switch from analogue to digital enabled interactive TV and network convergence which led to more development of standards such as return channel standards; DVB-RCS for Satellite, DVB-RCT for terrestrial. These enabled more services such as Multimedia Home Platform (MHP), DVB's open middleware specification including innovative technologies that allow delivery of DVB services over fixed and wireless telecommunications networks (i.e DVB-H and DVB-SH for mobile TV). After content protection and copy management (DVB-CPCM), then came development efforts for standardization efforts for IPTV, Internet TV and Home Networks and most importantly telecommunications services such as telephony and Internet access. The DVB-MHP is actually a collective name for a compatible set of middleware specifications developed by DVB-project as an open standard for interactive TV middleware helping receiver manufacturers to produce interoperable devices for multiple service providers. The three versions of MHP published so far not only supports broadcast-only profile but also broadband connectivity. The MHP allows digital TV receivers to also have interactive TV applications, which could be via satellite, terrestrial, cable or hybrid networks including non-DVB support. Other versions provide variety of applications such as storage, Video on Demand (VOD), DVB-IPTV, monitoring functions etc. (ETSI TS 102 727, 2010; DVB-MHP Factsheet, 2011). For satellite communications, European Telecommunications Standards Institute (ETSI) published two standards for mobile sitcom in late 1990s. These were DVB-RCS early in 2000 and the Internet Protocol via Satellite (IPoS) system released as an ETSI specification in a cross-publishing agreement with TIA in the USA.

The EN 301 790 (ETSI EN 301, 2003) as the first generation of DVB-RCS actually defined and described how to build on the physical and MAC layers to provide return channel capability transporting IP-traffic in a satellite broadcast system on DVB to a full VSAT or RCST using guideline documents of TR 101 790 (ETSI TR 101 790, 2009). This was so because the DVB-S and even DVB-S2 (with 30% spectral efficiency over DVB-S) were actually standards specifically meant for broadcasting and thus the ETSI EN 301 192 document combined with other ETSI report and guidelines went further to specify how data could be transported in transmission media specifically oriented to containing MPEG-2 video and audio. Data Broadcasting in interactive multimedia of today is seen as an important extension of the MPEG-2 based DVB transmission standards for delivery of Internet services over broadcast channels (IP tunnelling), interactive TV etc. (ETSI EN 301 192, 2008).

The DVB-RCS/RCS2 provides Hub-Spoke connectivity typically where all remote user terminals connect centrally to a central system called a hub, which controls the network system and as well as acts as a gateway to terrestrial connectivity and Internet as illustrated in figure 7.1. The user terminals are composed basically of an outdoor antenna, outdoor units (ODU) comprising of Low Noise Block (LNB:Receiver) and Buck Up Converter (BUC: Transmitter) all connected to an antenna feed for transmission and reception of RF Signals to and from the communications satellite to the Indoor Unit (IDU), which is the COMSAT Modem as illustrated in remote location 1 of figure 7.1 and further elaborated in figure 7.4. The LNB amplifies the received signal from COMSAT and down converts the received signal to the L-band between 950Mhz to 1550MHz while the BUC amplifies the uplink communications satellite signal transmission. The user terminal offers IP-over Ethernet from the satellite modem to connected computers directly or indirectly through a local area network (LAN), which may be configured wirelessly via radios, and/or through a wired switch depending on needs assessment of the client or users anywhere within the footprints of the communications satellite for Internet, VoIP, Video Conference, e-mail and other IP-Based applications. The communication satellite transmission scheme is Multi-Frequency Time Division Multiple Access (MF-TDMA) for the return link, which could be fixed or dynamic. All the remote terminals use and share the highly efficient DVB-S2 standard with adaptive transmission as the forward link. The MF-TDMA allows a group of Return Channel Satellite Terminals (RCSTs) to communicate with the gateway using a set of carrier frequencies, each divided into time slots. The network control center as represented by the hub in figure 7.1 allocates each active RCST with a series of bursts defined by frequency, bandwidth, start time and duration. (ETSI EN 301 790, 2003).

2009 was a great year, which saw the completion of family of second-generation delivery standards with DVB-T2 for terrestrial, DVB-C2 for cable and joining the already published and deployed DVB-S2 for satellite enabling broadband access and high throughput. (Ong et al, 2007; ETSI EN 301 790, 2009; ETSI TR 101 790 , 2009; ETSI EN 302 307, 2013; DVB Project Factsheet, 2013). The current DVB standards utilize a series of specifications already published by the International Standards Organization (ISO) known as MPEG-2 as detailed later in section 7.2.2 under Digital Broadcasting of same Chapter 7. At the core of these standards is a time-division multiplex that uses fixed-sized frames, transport stream (TS) packets to deliver streams of data which could be digital video, digital data, digital audio or any form of digitalized contents thus allowing equipment conforming to the DVB standards to be used in any of the six continents of the world. However, other countries have their variants of the standards such as Advanced Television Systems Committee (ATSC) specifications in the USA and the Association of Radio, Industries and Businesses (ARIB) standard used in Japan. The second generation DVB standards have helped shape and modernized how communications satellite networks are built using transmission system such as framing, packet formats etc that now lies at the core of most modern networks beyond the physical or lower layers of the system which provided the opportunity to use components and devices meant for the mass market with some degree of open architecture rather than proprietary network technologies such as the Hughes Network System, IP over satellite from Hughes, had little support beyond original vendor even after receiving widespread deployment for Internet services (Fairhust & Yun, 2013). The first generation of DVB-RCS was only successful as a reference for implementation of systems providing interactive channels for communications satellite broadcast and distribution systems with different solutions addressing varying market segments on mostly closed architectures but without any possible interoperability between terminals and hubs. The first generation focused mainly on physical-layer performance thus allowing interoperability of equipment from different vendors only at the physical-layer level and at a time when Asynchronous Transfer Mode (ATM) was in vogue. Innovations and requirements for additional features such as security, bandwidth efficiency and optimization, return link adaptivity, channel coding, multiple virtual network support, harmonized IP-level QoS, Management and support amongst others are required if it is to be a commercial success as was the case with DVB-S/S2 in broadcasting sector. The articulation of these advanced features and innovations to address the deficiencies in the first generation gave birth to the second-generation standardization effort as DVB-RCS2 to address whole set of the Open Systems Interconnection (OSI) layers from physical to up to the application layer to allow data, management and control planes thus allowing terminals from multiple vendors on the same hub. (Skinnemoen, 2013). The second generation DVB-RCS2 is published in three parts as TS 301 545-1 (Overview and System Level Specification), EN 301 545-2 (LLS, Lower Layers for Satellite Standard) and TS 101 545-3 (Higher Layers Satellite Specification) capable of delivering several tens of Mbit/s down to terminals and up to 10Mbit/s or more as a return link from each terminal. The DVB-RCS2 (Second Generation) is a standard conceived to provide broadband interactivity connection as an extension of the Digital Video Broadcasting Satellite Systems. It defines MAC and Physical layer protocols of the air interface used between the communications satellite operator hub and the interactive user terminals (VSAT or RCST) as shown in figure 7.1. The hub typically combines feeder, gateway together with network control centre (NCC) and Network Management Centre (NMC). The NMC provides overall management of the communication system and manages the service level agreement (SLA) assigned to each user terminal accordingly via IPv4 or IPv6 as management signalling while the NCC is the central entity that supports control signalling via the lower layer signalling (L2S). The DVB-RCS2 embraces both DVB-S and DVB-S2 standards implemented in the commercial broadcasting sector to exploit economics of scale. The modulation schemes supports Continous Phase Modulation (CPM), 8PSK, 16QAM in addition to QPSK. The Forward Error Correction (FEC) for QPSK, 8PSK, and 16QAM is a 16-state turbo code commonly called turbo-phi (turboϕ) while the FEC for CPM is convolutional coding. The architecture at lower layers are designed to deliver performance especially for Ka-band and other higher frequencies using technique such as the adaptive coding and modulation (ACM) in both forward and return links to address effects of rain fading. DVB-RCS2 was designed with higher later satellite architecture as the next generation of DVB with return channel via communications satellite transmission system approved by DVB in 2011 and in 2012, mobility extensions (DVB-RCS2+M) were added, supporting mobile/normadic terminal and direct terminal-to-terminal (mesh) connectivity including live handovers between satellite spot-beams, spread-spectrum features to meet regulatory constraints for mobile terminals and continuous–carrier transmissions for terminals with high traffic aggregations. The DVB-RCS2 is arguably the largest standardization effort conducted for the satellite communication systems following excellent collaboration between industry and research organizations across not only Europe but Asia, USA, several DVB-groups and ETSI enabling interoperability with various manufacturer's equipment and devices with specific Internet functionality via IP. It is the first open standard that specifies Internet Protocol (IP)-level functionality. The IP protocols and techniques on IPv4 or IPv6 in its architecture ensure high performance and efficient use of communications satellite bandwidth in a transponder. The flexible QoS architecture for the higher layers offers integrated link and network function to support IP-based differentiated QoS and thus ensuring maximized spectrum efficiency as well as meeting specific user service agreement (SLAs). The QoS offers ISP some form of performance specifications, which forms part of contract agreement with clients and customer often referred to it as SLA with however considerations of adaptive coding in the forward and return links, which reduces available capacity especially during rain fade events. The QoS mechanisms the network system room to perform QoS traffic engineering, performance optimization and efficiency based on network traffic characteristics and/or user service level agreements (SLAs). The introduced continuous phase modulation (CPM) schemes provides excellent trade-offs between performance and non-linear distortions at low and medium spectral efficiency especially the instability of high power amplifiers thus reducing communications satellite channel impairments and thus the convolutional coding CPM (CC-CPM) solution based on thorough analysis has been proposed and included in the DVB-RCS2 specifications as an alternative mode to the linear modulation schemes especially in mesh networks and even the hub-spoke network scenarios. Additional security features, which have been an important consideration in the design of the DVB-RCS2 waveform, has helped satisfy a wide range of security requirements for professional, consumer and government markets including the military. The security architecture includes Communications Security (COMSEC) at IP (layer 3) and Transmission Security (TRANSEC) performed at link (layer 2). The security in DVB-RCS2 ensures sufficient confidentiality, availability, integrity and indeed non-repudiation of performance in any customer/client scenarios. The DVB-RCS2 is a modern SATCOM commercial market-opener beyond single communications satellite operator networks to a unified platform of multiple communications satellite operators, service providers, equipment vendors and manufacturers and end users addressing SOHO, corporate, SCADA, institutional and backhauling needs with the right quality of service (QoS) and quality of experience (QoE). (Rinaldo, Vazquez-Castro & Morello, 2004; Chatziparaskevas, Kolsidas, & Pavlidou, 2011; ETSI TS 101 545-1, 2012; ETSI EN 301 545-2, 2012; ETSI TS 101 545-3, 2012; Fairhust & Yun, 2013; Beidas, et al, 2013; Bomyer, Erup, & Lexow, 2013; Fairhurst, Secchi, & Yun, 2013; Shinnemoen et al, 2013; Skinnemoen, 2013; DVB RCS2 Factsheet; 2013).

With the commencement of commercial operations, after a very successful In-Orbit Test (IOT) exercise followed by In-Orbit Delivery (IOD) of the replacement communications satellite in March 19, 2012, NIGCOMSAT-1R presently provides ubiquitous broadband services through its various transponders in different bands namely the C, Ku, and Ka-Band. The Communication Satellite partnered with undersea submarine cable operators to expand its coverage into the hinterlands of Africa by strategic deployment and implementation of a teleport hub through a gateway using iDirect equipment vendor on DVB-S2 technology to serve as an African convergence port where the terrestrial fiber can connect and merge with the Communication Satellite Network.

The hub is a gateway for all satellite-based networks into the Internet Superhighway.

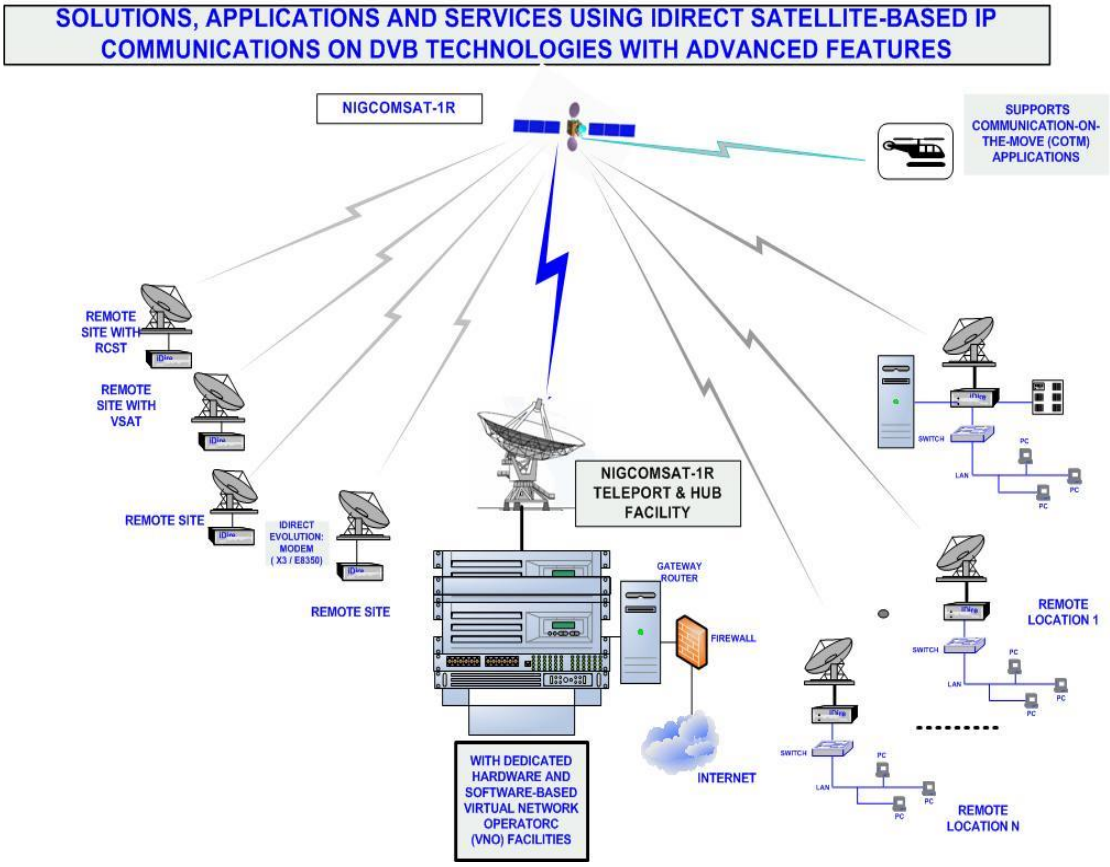


Figure 7.1: Shows Communications Satellite-Based Solutions, Applications and Services using iDirect Vendor Equipment on DVB-S2 Technologies with Advanced Features.

For a complete round trip communication, the network architecture aside the communications satellite as illustrated in figure 7.1 generally comprises of Return Channel Satellite Terminal (RCST) also referred to as Very Small Aperture Terminal (VSAT), The Hub and its components depending on network vendor used and the feeder gateway, which is usually an earth station similar to the 7.6m antenna shown in figure 7.2.

Figure 7.2: 7.6M Co-Located Antenna System. Source: (NIGCOMSAT Ltd, 2012).

The iDirect satellite-based IP communications technology solves communication satellite network challenges and integration with terrestrial networks anywhere and everywhere through combined hardware and software with advanced features using DVB technologies. The DVB-S2 and Adaptive Coding and Modulation (ACM) including the new DVB-RCS2 has dramatically improved bandwidth efficiencies. The iDirect network is a satellite based IP network with a star topology using Time Division Multiplexed (TDM) broadcast downstream channel from a central hub location and shared by as many remotes sites as required. Typically, the iDirect hub equipment is actively comprised of one or more protocol processors (PP), Network Management System (NMS), One or more NMS Server, core or edge router which connects to the Internet Backbone, universal line cards in one or more iDirect Hub Chassis with the required RF equipment connected to a feeder gateway as regional teleport. The remote site is comprised of appropriate iDirect Broadband Router (Satellite modem), and VSAT equipment with end-user utilities i.e computers and accessories.

NigComSat Ltd was the first to launch one of the most modern teleport services in the Sub-Saharan region, using the scalable and flexible iDX 3.0 (As at 2011) supporting backward compatibility of earlier versions and support for future upgrades on DVB-S2 and Adaptive coding and Modulation (ACM) technology and 2D-16 state modulation and coding (MODCOD) technique on the iDirect Network hub system which dramatically enhances inbound (return) link performance as depicted in figure 4.3. iDirect's DVB-S2 supports 20 various MODCODs as at late 2011. DVB-S2 actually embraces many techniques such as varying modulations, Encodings and adaptivity of Coding and modulations to enhance and optimize performance. The 2D-16 states is a new generation of FEC circuit based on quaternary convolutional turbo codes with excellent error correcting performances (BER of 10-10) and improved efficiency over turbo product coding (TPC). Series of earth station antennas in varying bands such as the 7.6 m Ku Band Antenna system as shown in figure 7.2 serves as a feeder to and from the communications satellite and the hub with a fully redundant 100W BUC solution supporting multi-carriers. Series of iDirect communications satellite routers provides connectivity to the shared bandwidth platform of the hub. They are integrated COMSAT modem and IP router with TCP optimization over COMSATs, QoS prioritization and compression. The iDirect families of routers are evolution DVB-S2 and iFINITI TDM models etc. The Evolution Satellite routers as IDU integrated to ODU of a VSAT supports DVB-S2 with ACM for service delivery through the deployed NIGCOMSAT iDirect 15100 hub. These compact satellite modem with IP Routers come in various forms based on need assessment and applications. The evolution series are X1, X5 and X7 satellite modem routers with increasing capability and functionalities.

Figure 7.3: iDIRECT 15100 Series Universal Satellite Hub.

The iDirect satellite hub specifically the 15100 family series is a universal satellite hub operating multiple high performance IP broadband networks. The 5IF with 20 slots for line cards supports multiple bands and transponders of communications satellites of as much as five communications satellites. The hub supports star, mesh and SCPC topologies while the hub line cards consists of Evolution DVB-S2, iSCPC and iNFINITI TDM line cards designed to fit into slots of the universal hub series. The deployed 15100 family series in figure 7.3 is currently used to deploy multiple classes of services on IP broadband networks to various remote locations using variants of Very Small Aperture Terminal (VSAT) systems with maximum data rate of up to 138Mbps on the outbound with DVB-S2 and up to 10.8 Mbps on the inbound via D-TDMA. A typical VSAT with user-end terminals is illustrated in figure 7.4. Network monitoring and management are handled through iMonitor software packages of iDirect, which is part of the iVantage NMS suite of applications. The iDirect iVantage Network Management

(NMS) System is a complete suite of tools for monitoring, configuring and control of the entire communications satellite network from a centralized location. The other two applications of the iVantage suite are iBuilder and iSite.

iMonitor provides network operators with detailed information in real-time and past and present performance of the network including analysis of bandwidth usage, remote site status, and network events amongst others. The iBuider is the software application that allows one to build and configure the network configurations of the system while the iSite is an application primarily used for commissioning new remote (VSAT/RCST) sites quickly and professionally.. It includes functions and calculators for antenna look angles, assistance for antenna pointing, cross polarization, monitoring and aid process in the field. The SatManage solution is a powerful and sophisticated extension to iDirect's iVantage NMS which automates and improves the overall efficiency of the COMSAT network operations end-to-end guaranteeing customers' satisfaction and loyalty. (iDirect iVantage NMS, n.d; Minor, 2011).

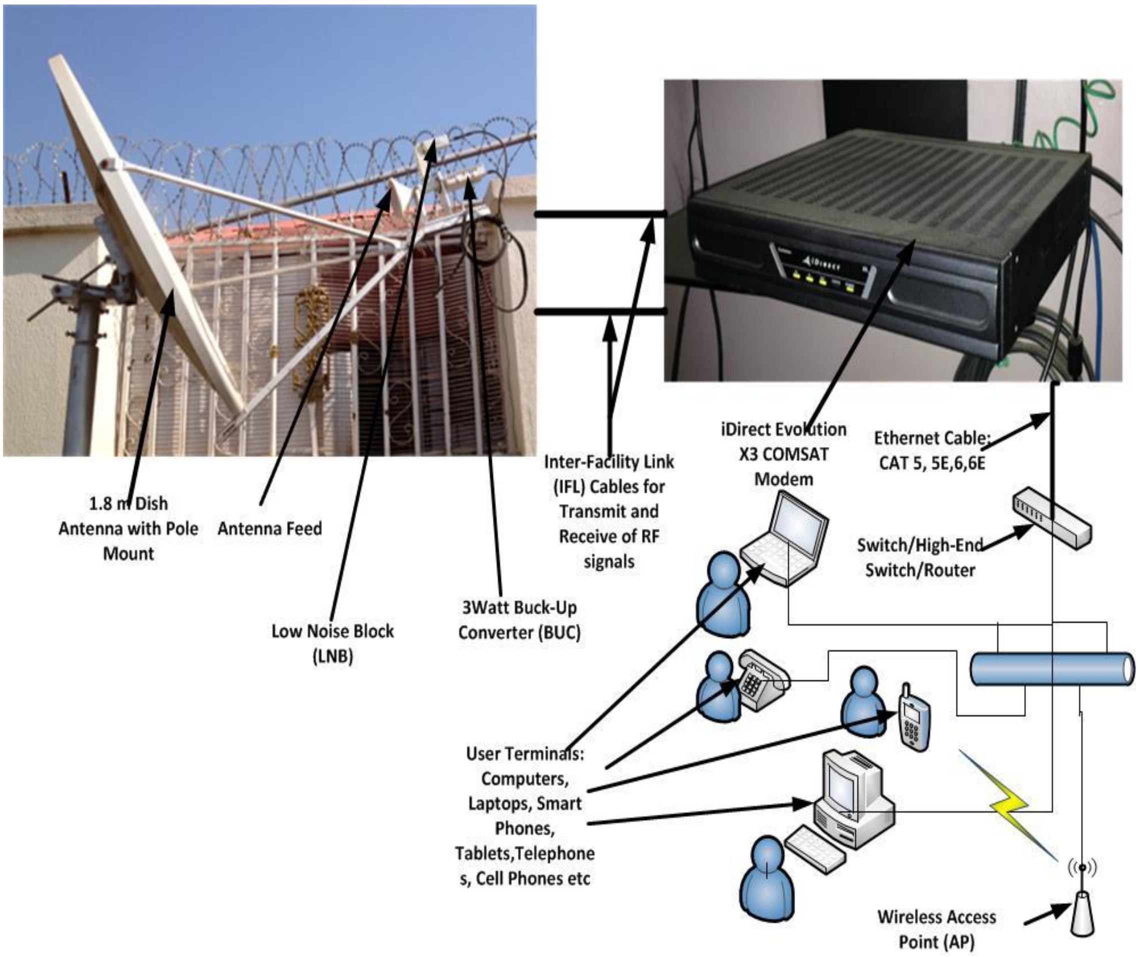


Figure 7.4: A Typical Composition of Communication Satellite Remote Terminal (VSAT) with User-End Terminals.

A typical VSAT system as illustrated in figure 7.4 can be used directly or indirectly for rural and urban telephony and mobile communications especially in areas that lack adequate facilities from Public Switch Telephone Network (PSTN). Integration of communications satellite is essentially achieved by integrating the PSTN to the Communications Satellite Network through the hub network. They can also be used as alternative communications for emergency situations, hotspot events and communication of choice after natural or artificial disasters. There are communications satellites designed specifically and specially for terminal-to-terminal device for local and long distance telephone communications integrated on the same hand-held terminals. These mobile communication satellites are designed to also offer broadband mobile and multimedia services from LEO, MEO or GEO orbits at a global level. These networks such as Thuraya, Iridium, Globalstar (Conte, 2005) provide broadband integrated services digital network (B-ISDN) channel capacity and IP-based or ATM packet switching services to anywhere within the footprint(s) of the communications satellite(s). Phones meant for terrestrial communications can now innovatively be made to communicate directly with communications satellite on a device (adaptor) with an antenna capable of communicating with mobile communications satellite. For instance, Thuraya SatSleeve brings satellite communications to android-based smartphones such as Galaxy S3, S4, iPhone etc by simply docking a smartphone on the SatSleeve adapter to enjoy communications satellite connectivity in emergencies or where there is no terrestrial network after integration with appropriate software applications. (Thuraya SatSleeve, 2014). Similarly, Iridium recently revolutionized personal communications with industry's first global portable Satellite hotspot referred to as “Iridium GO” similar to Globalstar’s Sat-Fi. The device enables voice and data communications on smartphones and tablets anywhere in the world. The SOS functionality creates a fast and reliable bi-directional connectivity with any emergency provider (Kriz, 2014; Globarstar Sat-Fi, 2014).

Key important elements that require consideration for Voice over Internet protocol (VoIP) on a communications satellite network are:

i. Latency: One-way propagation delay of satellite link considering location of geostationary communications satellites is approximately over 250millseconds (ms).

ii. Jitter: This effect amounts to network delays on packets arriving at the receiver at irregular intervals despite transmission of packets from the transmitters at equal intervals. Jitter buffers are techniques used to counteract these network fluctuations by holding incoming packets for a considerable amount of time thus creating smooth packet flow at the receiving end.

iii. Packet Loss: Packet loss causes degradation of voice quality in VoIP. Thus it is important to have a low bit error rates (BER) to ensure low loss or non-corruption of packets considering the fact that voice traffic uses connectionless Internet protocol otherwise known as User Datagram Protocol (UDP).

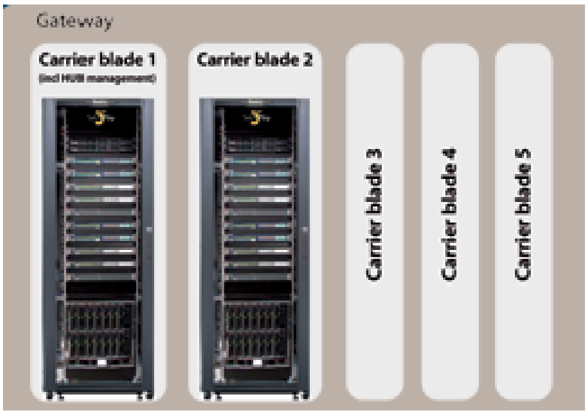
iv. Compression Technologies: The most dominant encoding standard scheme for voice is the G.729 codec requiring minimum of 8kbps. However, between 16-18Kbps is required for implementation considering overheads, equipment vendor and configurations. Other standards are available such as the G.723, which requires only 5.3Kbps.

v. QoS and Traffic Prioritization: It is important to prioritized voice traffic with the required QosS especially in congested network to avoid delayed, dropped or out of sequence VoIP call.

The iDirect VoIP solution is capable of delivering a BER better than 10^{-9}, which is considered a very channel suitable for VoIP applications including QoS implementation with Committed Information Rate (CIR) to guarantee high quality VoIP calls. iDirect platform also supports H.323 or Session Initiation Protocol (SIP) compliant VoIP solutions thus ensuring compatibility with multiple equipment vendors.

In furtherance to the delivery of a broadband solution and the advent of high throughput satellite (HTS) technology to meet the growing market of communications satellite with fast data rates and at a lower cost per Megabyte (MB), next-generation ground infrastructure are required too, to guarantee high-performance remotes. For instance, iDirect released iDX 3.2 operating software upgrades for its network platform as well as the X7 satellite router to help deliver high performance. The iDX 3.2 comes with adaptive TDMA, which improves return channel performance even during rain fade and satellite link degradation considering the increased use of Ka-band satellites and the challenges of weather conditions while the X7 COMSAT Modem and router is built on new multi-core hardware with best-in-class TDMA embedded AC/DC power subsystem and 100Mbps of combined outbound and inbound throughput when using the DVB-S2 demodulator.

To provide seamless migration of services from other satellites to NIGCOMSAT-1R through multiple hub equipment vendor with opportunity for multiple virtual network operators (VNO) thus supporting business development for Nigerians as virtual network operators and Internet Service Providers (ISP). Another advanced hub and gateway with differentiated service classes, was implemented using the NEWTEC Sat3Play Broadband Gateway System.



SOURCE: NEWTEC and Nigerian Communications Satellite Limited, December 2012

Figure 7.5: SAT3PLAY IP Broadband Hub.

The core of the Sat3Play system, as shown in figure 7.5, is a DVB-S2 system that enables the provisioning of both basic and complex services to consumer and business markets. It transmits DVB-S2 carrier with ACM with the forward link to all remote terminals while the remote uses MF-TDMA to communicate back to the hub as return link. The network system is designed for scalability of both traffic and network management capacity with support for a growing range of data, multimedia and voice applications (Newtec Sat3Play Hub, n.d.).

The Sat3play management system offers multi service provider platforms for wholesale parts of the system infrastructure with capacity for several large and medium-sized ISPs and VPN operators. The remote terminal comes mainly with two variants of COMSAT modems as MDM 2200 and MDM3100.

i. MDM 2200 is NEWTEC IP broadband modem meant for Ku and Ka band networks and suitable for SOHO, small and medium enterprises (SME), Point of Sales (POS) and banking as shown in figure 7.6. Supports antenna sizes ranging from 0.75m to 1.2m as well as interactive low noise blocks (iLNB) and BUCs ranging from 0.5W to 2.0W. Maximum download and upload capability are 22Mbps and 3.5Mbps respectively (Newtec MDM2200, n.d.).

Figure 7.6: NEWTEC MDM2200 COMSAT IP Broadband Modem with associated Accessories.

ii. MDM 3100 is NEWTEC IP broadband modem as shown in figure 7.7 is meant for Ku, Ka and C band networks and suitable for small and medium enterprises (SME), Large Enterprises and organizations. Supports antenna sizes ranging from 1.0m to 2.4m as well as interactive low noise blocks (iLNB) and BUCs ranging from 3W to 5W. Maximum download and upload capability are 45Mbps and 5Mbps respectively (Newtec MDM3100, n.d.).

Figure 7.7: NEWTEC Enterprise MDM3100 COMSAT IP Broadband Modem

The teleport facilities are of utmost importance to the economy of the nation; making available high performance IP broadband networks for education, government, military, healthcare system, enterprise organizations, Upstream Internet Service Providers, Government MDAs, Schools, E-Learning initiative drives, smart communities, e-villages etc.

The differentiated classes of services offered by the teleport are capable to improve the ICT, Internet, Broadband penetration and Broadband speed indices of not just Nigeria but the entire African region and beyond.

It is easier to link up every Government office under a wide area network such that every office can talk with one another and be able to share information seamlessly and even have the capacity to implement video conferencing where each party can interact and communicate effortlessly, thus improving the efficiency of governance as well as promoting transparency and accountability.

Corporate Intranet/Extranet and Virtual Private Networks for the government are also easily achieved. These will encourage investors to invest in the enterprise ICT solutions market sector allowing small-scale companies in Nigeria, without physical ownership of communications satellite, satellite hubs, gateways etc to participate in the satellite value chain and extract value by leveraging on NIGCOMSAT's valuable assets through Virtual Network Operators (VNO) thus presenting a new investment opportunity, which will stimulate market growth, development and job opportunities for Nigerians whilst enhancing penetration of services to all.

To ensure continuity of services including the need for communications satellites as backup to serve as risk mitigation if the working satellite fails, NIGCOMSAT Ltd with the support of the federal government, as a government owned enterprise (GOE), is working assiduously to launch two more satellites known as NIGCOMSAT-2 and NIGCOMSAT-3. The entire system network of NIGCOMSAT-1R, 2 & 3 will offer added advantages in reliability, compatibility, security, operations and marketing and increased customer confidence as a client of NIGCOMSAT LTD. The three communication satellites will strengthen the company's corporate vision as *"…the* *leading communications satellite operator and service provider in Africa*.” including strong coverage over other continents such as Europe, South America and a steerable spot beam in the Ku-band for wider market capture and patronage.

NIGCOMSAT Ltd; a Nigerian-Based Satellite operator and satellite service provider beacons as a bandwidth provider in Sub-Saharan Africa and beyond, a paradigm shift for Nigeria, which previously was just a bandwidth consumer.

7.2 Digital Broadcasting

The Space age began with broadcasting when the Russians launched the first man-made satellite, Sputnik on 4th October, 1957 because two years later (Precisely on 26th October, 1959); the feat of transmission to earth of television pictures of the far side of the moon by the Russian vehicle Lunik III took place. The feat marked the beginning of the marriage of Communications Satellite with Broadcasting. But the major public event which brought both technologies together was when TELSTAR was used to transmit live television pictures between the United States of America (U.S.A) and Europe on 11th July, 1962 and followed by the greatest live television event of all time when man first stepped onto the surface of the moon on 21st July, 1969. (Drury, 1994). The pioneering era was made possible through analogue frequency modulation (FM) via communications satellite. In the late 1960’s, the satellite broadcast industry became interested in digital transmission techniques and by early 1970s, time division multiple access (TDMA) had been established. Drury (1994) noted further that, in 1980, experiments were performed in Europe with the Orbital Test Satellite (OTS) before EUTELSAT to investigate the feasibility of transmitting television signals at a bit rate of about 60Mb/s using a whole transponder bandwidth of about 36MHz using coding technique such as differential pulse code modulation (DPCM). Improvement and advancement over the years on digital signal processing, coding and video compression has made digital satellite television domestically possible known mostly as direct-to-home (DTH) and in the context of satellite referred to as direct broadcasting by satellite (DBS). Digital Television is the technological evolution of broadcast television into the digital realm instead of analogue waveforms with resulting higher quality pictures, more channels, multi-lingual delivery of programmes and more capacity than analog and it has lower operating costs in transmission and broadcasting. The digitization of broadcasters’ signals implies convergence of technologies in which computing, telecommunications and broadcasting merges and integrates once in digital format. (Drury, 1994).

Digital Broadcast Migration is simply migration from inefficient analogue broadcasting to efficient digital broadcasting. A global decision on the transition process for sound and television broadcastings to Digital Audio Broadcasting (T-DAB) and Digital Video Broadcasting (DVB-T) standards respectively was reached at the International

Telecommunications Union (ITU) Regional Radiocommunications Conference (RRC-06) held in Geneva, June, 2006. Deadlines were set for a total switchover of all broadcast channels from analogue to digital. Many countries in the ITU regions, including Nigeria as a country, were signatories to the agreement with the deadline set for digital broadcasting services in the Very High Frequency Band (VHF) and Ultra High Frequency Band (UHF). 123-230MHz for the VHF band while the UHF band is 470-862MHz. The transition period for Analogue Switch-Off (ASO) to Digital Switch Over (DSO) started from 17th June, 2006 to 17th June, 2015 with an additional five year extension for some countries in the VHF band till 17th June, 2020. The Digital migration from DSO to complete ASO is revolutionary as it affects all aspects and segments in the broadcasting chain from content production, transmission to reception. The transition comes with opportunities and challenges including dual broadcast illumination before ASO amongst others for the broadcasting industry, regulators and other stakeholders in the value chain. For realization of the inherent benefits, the migration must be fully-fledged across the value-chain; content production, storage/archiving, transmission, distribution, reception and public acceptance encouraged by various national governments, regulators, manufacturers and other stakeholders. As regards reception of digital Television (TV) signals, Analogue TVs owned by millions of viewers are still useful by integrating them to Set-Top Boxes (STB), which converts the digitally transmitted TV signals to Analogue though with limited digital benefits with the Analogue TV, such as storing capability etc. (Berger, 2010; ITU, 2012).

Digital Terrestrial Television (DTT) is the technological evolution of broadcast television into the digital realm with resulting better quality pictures, efficient use of spectrum, more channels than analog signals, more accommodation of programmes with multi-lingual support, new multimedia services using terrestrial resources such as land for numerous transmitters, high power transmitters, terrestrial spectrum. Huge capital, manpower and training are required for the turnkey transition within such a short time frame for countries that have not migrated until now (Ihechu & Uche, 2012). Nigeria, for instance had to reset its target date to migrate to digital broadcasting from 17th of June, 2012 to 1st January, 2015. However, the government-owned media, Nigerian Television Authority is expected to be fully digitalized by June, 2014. Similarly, Ghana had to postpone its original 2012 switch over date (APC, 2011).

7.2.1 Major Challenges and Limitations in Migration to Digital Terrestrial Television (DTT)

- Growing popularity of Non-Terrestrial TV Platforms i.e Satellite -TV Especially Free-To-Air (FTA).
- Sustainable IPTV and Online Videos as a result of adoption of Broadband plans of many Nations.
- Bundling of Pay-TV with Broadband and Telephony with reliable broadband connectivity.

- Funding: Huge capital requirements for deployment of transmitters and equipment, masts, declining advertising volume and rates as a result of alternative platforms such as satellite, broadband video internet etc.
- Operational logistics for numerous sites, civil works, building, mast structures, coverage optimization, signal reliability and interference from neighbors.
- Issues on adoption of Technical standards, Spectrum planning, Compression and Transmission technologies.
- Legislation, Regulatory and Licensing regime issues.
- Human Capital Development and training requirements.
- Adapting to changing business models suitable for economic sustainability.
- Set-Up Box issues on: cost, technical specifications: Open architecture for interoperability and proprietary solutions.
- Irregular Terrestrial power supply to energize site infrastructure.
- Issues with dual broadcast illumination period especially, the costs before Analogue Switch-Off (ASO) by June 17th, 2015.
- Content creation, production and provision to populate new channels.
- New coverage planning and co-ordination with Single Frequency Networks (SFN) and Multiple Frequency Networks (MFN).
- Public awareness.
- Spectrum Re-farming issues for Digital Dividend, which has affected re-allocation of upper UHF band (790-862MHz) of the DTT frequency band for mobile broadband communications as ratified by World Radio communications Conference of 2007 (WRC-07) on co-primary basis; a modification of RRC-06 digital plan as well as WRC-12 resolution 232 lowering the upper UHF band to 694MHz such that 694-790MHz in region 1 is allocated further to mobile communications on a co-primary basis except for aeronautical mobile services and to be identified as International Mobile Telecommunications (IMT) to be effected at WRC-15 and subsequently re-modification of the RRC-06 digital plan requiring further frequency planning and co-ordination (Amana, 2013).
- Issues of Government-led incentives and subsidies for countries with liberalized broadcast sector.

7.2.2 The Growing Need for Communication Satellites for Satellite Communications Especially Broadcasting

Satellite communication has become a major means of broadcast and mass media as well as domestic communication based on improvements and innovations in payload capability, capacity and technologies on communication satellite systems amidst inadequate terrestrial telecommunication infrastructure. The technologies and innovations based on needs assessment resulted in a dramatic increase in the use of space for commercial activity such as Communication Satellites for GPS Navigation, telecommunications for global and mobile telephony, Digital Video Broadcasting (DVB), Data Broadcasting, Multimedia video streaming and high-speed Internet connectivity etc (Vines, 1994; Gifford, 1996; Smith, 1998; Ingley, 2000; Lawal & Chatwin, 2010,2011, 2012a, 2012b; Igor,Riccardo, Hung, Fotini-Niovi, & Takaya, 2010; Hao, 2013).

The world's first digital satellite TV services were launched in Thailand and South Africa at the end of 1994 using the newly released DVB-S system by DVB project. The DVB-S2 delivers efficient and excellent performance and it was a success commercially gaining worldwide acceptance and adoption by the International Telecommunications (ITU) study group on satellite delivery for Digital satellite Broadcasting system as well as laxity on intellectual licensing rights by holders of key DVB-S2 intellectual property rights. (DVB-S2 Factsheet, 2012; ETSI EN 302 307, 2013). The recently concluded 2012 London Olympics games is attestation to not just the broadband capability of Communication Satellites but also the HDTV and 3DTV transmission quality assurance. DVB-3DTV is the first Plano-stereoscopic 3D television developed by DVB project for two images considered as the left and right images and are arranged such that they are directed at the left and right eyes through a combination of screen arrangements and with or without special viewer glasses. The DVB-3DTV aims for a frame-compatible system that could provide a 3D full image color using existing receivers over cable, terrestrial and communications satellite broadcast and broadband channels. (DVB-3DTV, 2011). The 2012 First HD Olympic games was the first Genuine Major Carrier Cooperation for DVB satellite television transmissions, achieving historic levels of broadcast quality that was enabled by collaboration of the international broadcast and satellite industries, which jointly launched the first in a series of Carrier-ID implementations delivering interference-free viewing of the games (Satnews Publishers, 2012). The Carrier-ID is a very important tool for mitigating and reducing interference between COMSAT's signals. The DVB project has developed the DVB carrier identification (CID) for digital satellite transmission that describes the modulation, channel coding and signaling protocol intended for the identification of the host carrier with standards published as ETSI TS 103 129 in May, 2013. The satellite interference reduction group (sIRG) strongly supports the development of the standard, which comes with development of a database to be migrated to the space data association (SDA) for global visibility, security and integration. (DVB-CID Factsheet, 2013; ETSI TS 103 129, 2013). In terms of capacity, Intelsat alone according to Intelsat's Vice President for Europe and Middle East; responded to customer requirements in Asia, Europe and the Americas with 11 satellites in the C and Ku-band supporting approximately 50 channels with 15,000 to 20,000 estimated hours of coverage for the three week international event. Non-terrestrial TV platforms such as satellite and IPTV has become very dominant in Africa and other countries of the world. Northern Sky Research (NSR) predicts TV households in Sub-Saharan Africa (SSA) will grow to 63 million in 2012 to 108 million by 2022. DTH holds great promise in SSA particularly Nigeria with over 160 million people as the TV penetration rate increases rapidly, foreign investments, economic development and political stability will facilitate the development of a truly low-cost operator similar to the Indian experience, that will be able to generate significant revenue from the many untapped market segments (Curcio, 2012). There is continued growth in the number of satellite TV platforms around the world reported to be nearly 140 in 2011 reaching 180 Million subscribers according to the Euroconsult (2012) Satellite TV platforms world Survey and Prospects to 2021, 5th edition released recently; May, 2012. The report estimated revenues in 2011 to be US$90 billion and is projected to reach $150 billion by 2021 with emerging markets in Africa, Asia, the Middle East, Central Europe, Latin America and Russia. The report by Euroconsult (2012) noted that there are over 2,800 High Definition (HD) channels across the different platforms worldwide in 2011, HD & 3D investments maintain attractiveness and value-added services. Almost 600 HD channels were launched in 2011 alone as part of the strategy to drive growth over the coming decade. Curcio (2013) in the NSR's Direct-to-Home Markets, 6th Edition estimates 40 million DTH subscribers in India in 2012 thus the largest DTH market in the world even though other publications and press releases put it at 60 million subscribers with the difference accounting for inactive short-term and pre-paid subscribers. It further reported that nearly 100 million new households will become digital by 2014 as the digitalization process continues in India giving DTH an advantage over cable with its ubiquitous and geographic coverage. Modern houses, high-rise buildings and office complexes are incomplete without a Satellite TV receiver dish on the roof-top, walls, fence or fabricated on masts and towers as shown in figure 7.8.

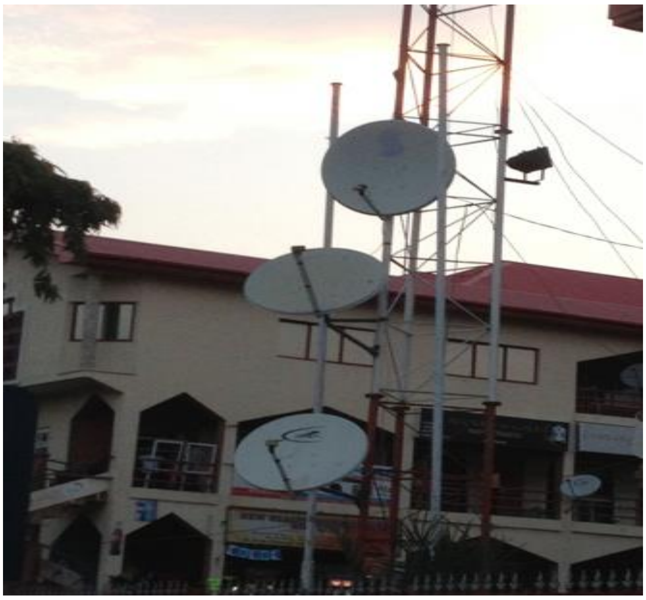


Figure 7.8: shows growing penetration of the Communication Satellite Alternative for Digital TV as satellite TV dishes designed for Walls are even fabricated and deployed on telecoms mast and towers in proximity to homes and offices.

Figure 7.9 shows the National Assembly complex, the highest elective law-making building in the Federal Capital City of Abuja, housing both the House of representatives and Senate, it has arrays of VSAT dishes providing broadcasting services via satellite, to various offices and departments. Arrays of VSAT dishes on residential homes and buildings, office complexes, high-rise buildings, estates etc are common sights in cities, semi-urban, urban and new estates in African countries. The satellite pay-TV subscribers base is expected to hit 250 million by 2018 according to a recent study conducted by Digital TV Research with Africa and Asia Pacific identified as hotspots for DTH. (Homes, 2013).

Figure 7.9: National Assembly Complex of Nigeria showing an array of VSAT dishes providing broadcasting services through satellite to various offices and departments.

Based on the growing needs of Communication Satellite requirements to support satellite-based digital broadcast television, amongst other services i.e telecommunication needs. The Federal Government of Nigeria responded with a communication satellite launch designed to meet the majority of the African Sub-Saharan regional needs.

NIGCOMSAT-1R Communications Satellite is shown in Figure 7.10 undergoing a Compact Antenna Range Test before the launch campaign.

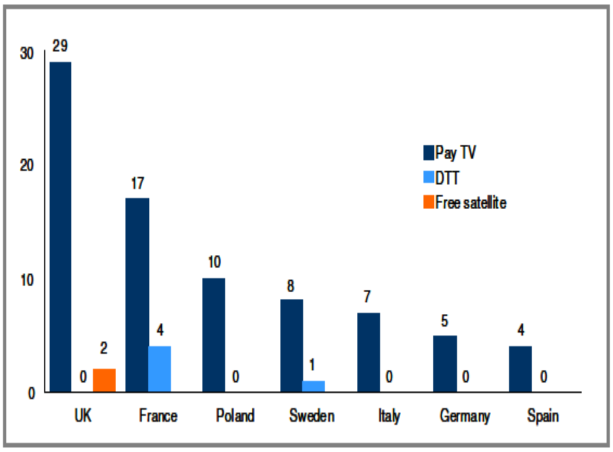
Figure 7.10: High Powered Quad-Band NIGCOMSAT-1R Spacecraft undergoing Compact Antenna Test Range (CATR) before the Launch Campaign Activities.

Satellite platforms for both free-to-air and pay services have proven more suitable for broadcasting a range of HD channels than DTT since the bandwidth spectrum is not scarce (frequency reuse through polarization and space diversity, utilization of higher frequency bands such as the Ka-band etc).

Africa is considered an emerging market for satellite-based platforms in terms of FTA and Pay TV penetration. Year-on-year growth of multi-channels to the second quarter of 2008 was 7% for new satellite subscriptions with South Africa leading the way (12% growth and 23% pay TV penetration). Free-to-Air satellite penetration is stronger in North Africa with Algeria (94%) taking the lead followed by Tunisia (79%). The French free-to-air satellite platform, tntsat has proven successful, so far signing over 1 million customers by the end of 2008. Similarly, we have also seen countries outside Africa with dramatic penetrations in satellite TV. For instance, Cyfrowy Polsat in Poland is one of the fastest growing and most competitive markets for satellite with six different service providers. It grew from 0.65 million subscribers in 2005 to 2.4 million in September 2008 representing 17% of Polish TV households. The same rapid growths were recorded in Eastern Europe recently, in such countries as Romania, Slovakia, Czech Republic etc. (Human Capital, 2009).

Increased use of compression such as MPEG-4, H264 over MPEG-2 and Transmission technologies such as DVB-S2 (Digital Video Broadcast Second Generation enhanced Satellite), DVB-T2 (Digital Video Broadcast second Generation enhanced Terrestrial) over DVB-S and DVB-T standards respectively has resulted in increased High Definition niche market viewers, especially in satellite Pay-TV as depicted in Figure 7.11, which compares HD Channels availability in Pay-TV, Free-to-Air and DTT in Europe. Compression techniques have evolved over the years from the days of the standards developed jointly by the International Standards Organizations (ISO) and International Electrotechnical Committee (IEC) referred to as ISO/IEC

MPEG responsible specifically for Broadcasting, the source coding and multiplexing portions. Sub Committee 29 of the 1st Joint Technical Committee of the ISO/IEC; ISO/IEC/JTCI/SC29 is responsible for the Coding of Moving Pictures and associated audio while the 11th working group of this committee is known as the Motion Picture Expert Group (MPEG). A sister group known as the Joint Photographic Expert Group (JPEG) developed a standard for coding still images. The MPEG developed appropriate source coding standards for video and audio beginning with MPEG I at bit rates of 1.5 Mb/s, compatible improvement at rates of 10Mb/s (MPEG II). However, current products, which employ MPEG-1 standard, can deliver up to 15mb/s and similarly MPEG-2 can deliver beyond 10Mb/s. (Drury, 1994). BBC High Definition are currently delivered over freesat in the UK as a Free-to-Air satellite has proven more suitable for HD broadcasting than Digital Terrestrial Television (DTT) due to comparative bandwidth and spectrum scarcity. TNTsat, the French FTA satellite has proved successful with over one million subscribers at the end of 2008, while similar satellite projects are taking off in countries where terrestrial TV coverage can be poor. i.e New Zealand. African countries should not be an exception where terrestrial spectrums are needed far more for mobile broadband penetration to bridge the digital hiatus (Human Capital, 2009; Richards, 2007; Ofcom, 2007).



Source: Human Capital, 2009

Figure 7.11: HD Channels in Europe.

7.2.3 NIGCOMSAT Ltd Unified Direct-To-Home (DTH) to Promote and Facilitate Digital Migration through the Communications Satellite Alternative.

Considering the challenges that come with digital migration, which are more pronounced in developing nations especially as it requires huge capital, manpower, appropriate technology selection, training, cost/benefit analysis etc for the turnkey transition within such a short time frame amidst growing requirement for a satellite alternative for digital broadcasting. Others modes of digital television are digital cable, digital multimedia broadcasting (DMB), Internet Protocol television (IPTV), multichannel multipoint distribution service (MMDS) as digital microwave, digital video broadcasting handheld (DVB-H). Design breakthroughs in broadband-based satellites (i.e HTS), Digitization, DVB-S2 with improved spectral efficiencies and associated standards supporting interactive TV such as DVB-Globally Executable Middleware (GEM), DVB-Generic Stream Encapsulation (GSE), DVB-Multimedia Home Platform (MHP) etc have permitted NIGCOMSAT Ltd to complete state-of-the art digital satellite TV Direct – To- Home (DTH), which is meant to provide a unified platform for broadcasters, content providers, content distributors as well as open up media business services in Africa for DTH TV broadcasting entrepreneurs thus easing off implementation bottlenecks especially for small and medium enterprises (SME) in the broadcast industry. The DVB-IPTV is a set of open, interoperable technical specifications, developed by the DVB project to ensure delivery of digital TV using the Internet Protocol (IP) over bi-directional fixed broadband networks. While DVB-H is a technical specification for the transmission of digital TV to handheld receivers such as mobile telephones and PDAS primarily over the UHF bands, the DVB-SH is the transmission standard designed to deliver video, audio and data services to handheld and vehicles a hybrid of satellite and terrestrial system using frequencies below 3GHz particularly the S-band as part of mobile TV. The DVB-SH does not define transport protocols rather it is an electronic service guide with a combination of satellite footprint and complementary terrestrial infrastructure to deliver qualitative nationwide coverage to terminals in conjunction with specification standards such as DVB-IPDC which describes the essential components required to deploy a commercial mobile TV service based on Internet Protocol (DVB-IPDC, 2011; DVB-IPTV, 2012; DVB-SH, 2011).

The NIGCOMSAT Direct-to-Home (DTH) system was designed to offer viewers hundreds of channels of Standard Definition (SD) television programming on both the free-to-air (FTA) and pay as you go service delivery model. The system is designed to support and transmit High Definition (HD) channels on demand. The architecture supports MPEG-4 AVC, H.264 algorithms, HD Channels, Ultra HDTV and is 3D compliant.

NIGCOMSAT Ltd’s major function is the carriage of channels (content carrier). The unified multi-platform system can also deliver backhaul services for Digital Terrestrial Television (DTT) transmissions after analogue to digital migration. The unified platform enables participating broadcasters to have on demand uplink satellite capacity for Satellite News Gathering (SNG) purposes without huge investments in reserved satellite capacity anywhere within the footprint of NIGCOMSAT-1R coverage and its future fleets. Figure 7.12 shows a pictorial view of NIGCOMSAT Ltd Unified Direct-To-Home platform. (DVB-GEM, 2013; DVB-GSE, 2011; DVB-MHP Factsheet, 2011).

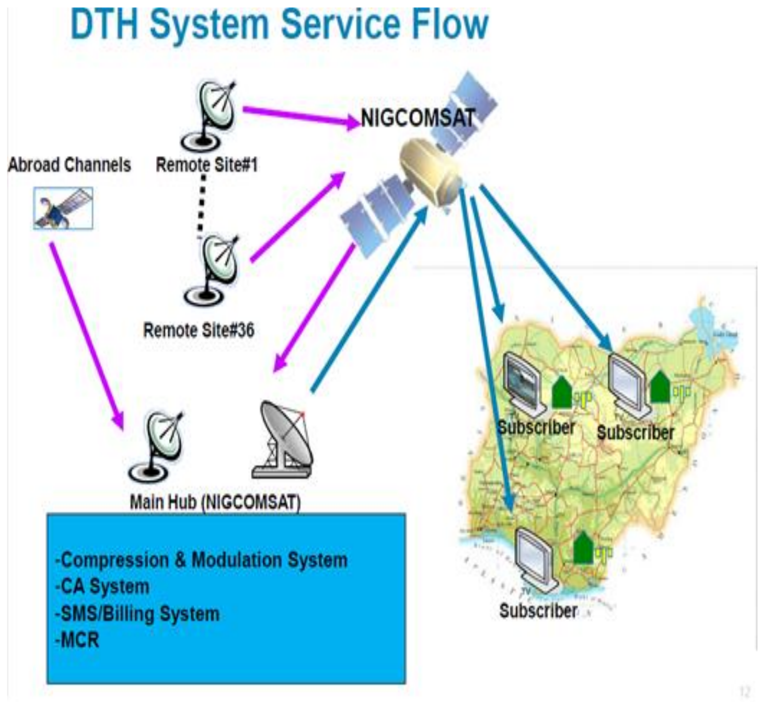
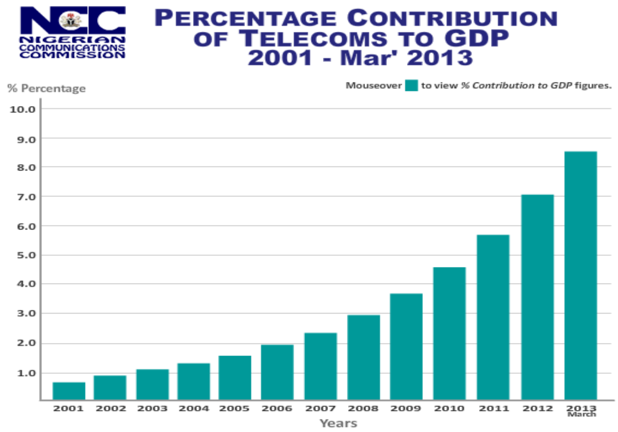


Figure 7.12: NIGCOMSAT Direct-To-Home Unified Platform.

7.2.4 Digital Dividends, Convergence and Promotion of Universal Access.

Guy Berger (2010) in his widely read booklet titled Challenges and Perspective of digital migration for African Media argues that there is no major pressure to free up the air wave spectrum in Africa compared to the European sector and therefore there should be no rush to complete migration by 2015. While the assertion may have been true in the early clamour for digital migration, the African telecommunication environment has since changed, being the least wired continent in the world requiring digital dividends to bridge its digital hiatus. Broadband Internet connectivity, which is required for economic development to take place, is grossly inadequate. Last mile deployment of broadband through wire-lines requires huge investment and is hardly affordable in rural areas, which in Nigeria constitutes 70% of our population and thus is not economically viable for entrepreneurs, furthermore it is time-consuming to create such an infrastructure when compared to mobile broadband. Nigeria is in dire need of a mobile broadband infrastructure to help in the utilization of its adequate capacity at its shores as a short term measure until implementation of its planned intra and inter-city metro-ring fiber network has been completed. As such, communication satellites and variants of terrestrial wireless systems such as GSM, CDMA, WIFI have permeated areas with little or no adequate wired telecommunication infrastructure to optimize access to information and guarantee universal access to almost all African inhabitants, including those in very remote and swampy environments as well as enabling regional and cross-border connectivity with the tens of terabytes of capacity from marine optical cables on the African coastline. (UNESC, 2000; Lawal & Chatwin, 2012;UNESC, 2000; Singer, 2012).

The released terrestrial radio spectrum as, a result of the Digital Switch Over (DSO), known as the "Digital Dividend" is a valuable public resources in the 21st century, especially in Africa with inadequate inter and intra city metro-ring optical fibers for richly enabled smart-based communities and cities. The spectrum is better utilized in value added services such as broadband penetration in the form of mobile broadband communications to bridge the digital hiatus and satisfy the universal Internet access goals that African governments have committed to. Figure 7.13 shows the growing contribution of telecoms to the Gross Domestic Product (GDP) of Nigeria largely as a result of the mobile subscriber base, which stands at 120,362,218 active lines (85.97% Teledensity) as of June, 2013 after the Digital Mobile License (DML) Auction of 2001. Active Internet subscription via the Global System for the Mobile Communications (GSM) network alone stood at 48,165,033 as of June, 2013. (NCC, 2013).



Source: NCC, 2013.

Figure 7.13 shows growing percentage contribution of telecoms to Nigeria's GDP.

Figure 7.14 shows the digital dividend conceptual spectrum allocation as a result of DSO based on needs assessment as it concerns telecommunications infrastructure realities, growing technological innovations and improvements, market realities etc. With the growing alternative satellite scenario that can play a complementary role in Digital Terrestrial Television deployment, additional spectrum allocation to DTT should not only be a function of market realities but technological improvements in compression and transmission technologies with resulting capacity and efficiency increase when using the existing spectrum. Fourth Generation (4G) services are being deployed in countries that have fully migrated from Analogue TV signal transmission i.e United States of America (698-806MHz), Europe (790-862MHz) and Asia-Pacific (698-806MHz) with huge financial benefits from: sales of the spectrum, job creation and new business activities. (RRC, 2006; Amana, 2013;Lawal & Chatwin, 2013; Lawal, Ahmed-Rufai, Chatwin, Liu, 2013).

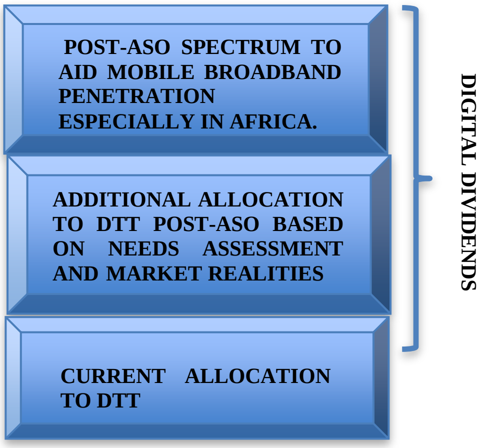


Figure 7.14: Pictorial tabular allocation of spectrum in post –Digital Switch Over (DSO) as Digital Dividends particularly in Africa, which has the least developed terrestrial telecommunications infrastructure.

Overall, the major drive in the legislative and technical policies including technical standards should be on the digital environment, which enhances convergence of broadcasting with telecoms and Internet anchored by the 3As of universal broadband plans: Availability, Accessibility and Affordability. For instance, the architecture of STBs should have return channel capability which could be through terrestrial, cable, satellite or specifically with Subscriber Identity Module (SIM) and/or USB port that allows USB-based mobile broadband dongles with the necessary middleware as a return path to support interactive capability and access to the Internet via the television screen; deepening Government-to-citizens, Government-to-Business and Citizens-to-citizens services and national debate with far reaching impacts in closing up the infrastructural ICT gap as it enables interactive service portals, interactive weather information, knowledge portals, transactional portals, smart communities with database, online marketplaces providing sign post for sustainable e-governance, e-government, e-commerce, e-agriculture, e-health, e-commerce etc. Furthermore, with the rising vulnerability of humankind to the effects of natural and man-made disasters, the DVB project team has also a standard known as the DVB Emergency Warning System (WBS) for every broadcast system to provide the necessary mechanisms to distribute relevant information to the general public in case of emergencies considering the importance of communications-disaster preparedness as the first line of action to facilitate timely disaster response. The DVB-EWS is defined in the DVB-Service Information (SI) standard and in combination with specification for video and audio coding implementable over all broadcast channels which could be terrestrial, cable, IPTV or Communications Satellite. (ETSI EN 300 468,).

7.2.5 Deployment of Efficient System Engineering Framework for Clustered Direct-To-Home (DTH) Users.

The Direct to Home (DTH) industry is generally a multi-billion dollar industry being a digital platform through which millions of customers and subscribers are guaranteed good quality Standard Definition (SD) and High Definition (HD) TV besides other value added services through their Customer Premises Equipment (CPE). The DTH operators are investing heavily in technology platforms, satellite bandwidth with desired footprint, sales & distribution networks, content providers, content creators, broadcasters, installations, customer care, license fees collection, custom duties *inter alia* illustrating the interesting prospects and opportunities for DTH with plenty of room for growth in satellite TV (FTA and Pay-TV) as new markets open up especially in Africa, Eastern Europe and the Asia-Pacific. The universal Low Noise Block-Down converter feed horn (LNBF) as shown in Figure 7.15 normally converts the transmitted satellite signals, which could be C-band, Ku-Band or the newly introduced high frequency Ka-band, from the geostationary orbit to an intermediate frequency (IF) for transmission through coax cable i.e (RG-6 or RG-11) to the Integrated Receiver Decoder (IRD) also referred to as a Satellite Set-Top Box (STB) (Hyun-Chul, 1993).

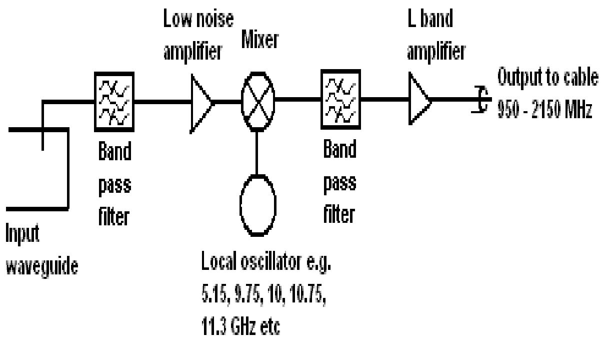


Figure 7.15: Pictorial Diagram of a typical one-way output Low Noise Block Downconverter.

For wideband dual-polarized transponders populated with bouquets, each receiver must control its own LNB output. Polarization switching of the LNB is controlled by direct current (DC) voltage supplied by the Satellite Integrated Receiver Decoder (IRD) as depicted in Figure 7.16 as well as tuning capability from lower band to upper band by a 22 kHz signal at 0.5V peak-peak to switch its Local Oscillator (9.75GHz) to high band i.e 10.75GHz in a Ku-band Low Noise Block-Down converter (LNB) and thus, it is technically wrong to split signal with splitters from one output LNBF and will not work effectively and optimally.

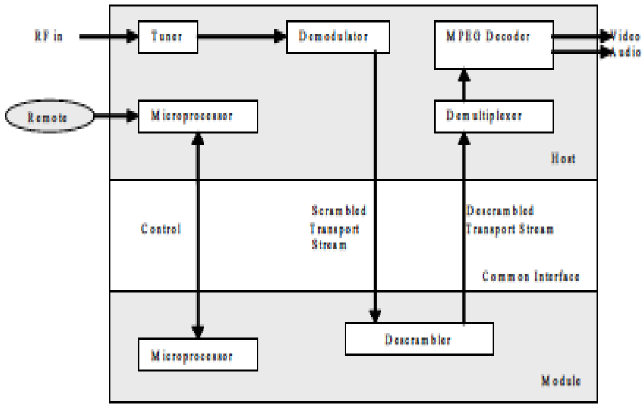


Figure 7.16: Functional Diagram of Typical Satellite Integrated Receiver Decoder (IRD).

The ideal way of splitting signals to one or more receivers is the use of two or more way universal LNBF so designed with alternative local oscillator frequencies with support to handle linear (vertical and/or horizontal) and circular (Left hand and right hand) polarizations with the required frequency stability. Besides the use of dual, quad or octo-output universal LNBF, Quattro LNBF provides four unique outputs at intermediate frequency (IF), as below :

3 Horizontal Polarization low band

4 Horizontal polarization high band

5 Vertical polarization low band

6 Vertical polarization high band

The four unique outputs are then fed to a multi-switch device (i.e 4X 32 way multi-switch) allowing multiple subscribers to connect to one large dish using high quality cables and connectors to ensure optimal signal reception by the various receivers in Clustered DTH users, High-Rise Buildings, residential estates, hotels, office complexes etc. (Hadden & Bruce, 2002; Skorobogatove, 2012).

Figure 7.17: Shows an Eight (8) Users DTH Deployment using 4X8 Output Multi-Switch Combined with Quattro Universal Low Noise Block-Downconverter Feedhorn (LNBF) through a 1.8m Antenna Dish.

Our experience with a 65cm aperture dish during the rainy season was not satisfactory until the acquisition of a 1.8m aperture dish fabricated on a mounting post to fit within a constrained space, as shown in Figure 7.17, which helps guarantee continued good quality of service (QOS) and increased viewing time even during heavy precipitation, which causes signal degradation and loss in the Ku band as a result of rain attenuation. A quattro universal LNBF was used to distribute signals to other rooms and neighboring bungalows using the 1.8m dish instead of proliferating the neighborhood either with eight (8) 65cm or 90cm aperture dish for the eight (8) receivers (IRDs). Figure 7.18 illustrates increasing antenna gain with increased aperture of the receiving antenna dish at an efficiency of 65% using 11.747GHz (Ku band) as simulated with Satmaster Pro software application.

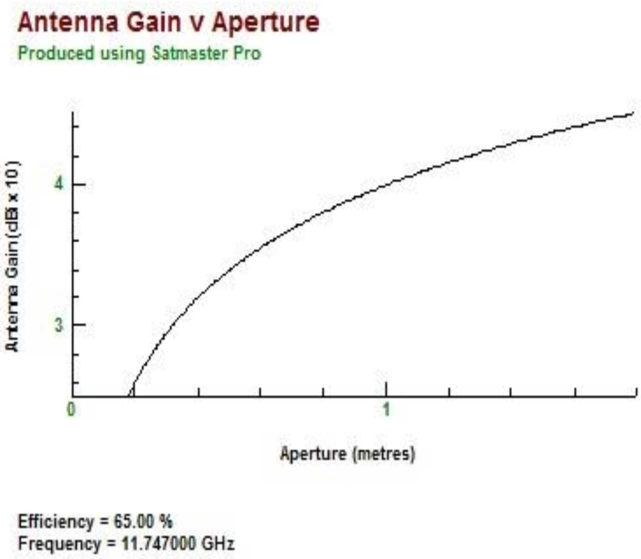


Figure 7.18: Illustration of increased Antenna gain with increased aperture of the receive antenna dish at a frequency of 11.747GHz with an efficiency of 65%.

The use of High quality antennas with rated efficiencies improves the antenna gain of the receiving dish. Figure 7.19 shows increased antenna gains in dBi of antennas with increased efficiencies in percentage (%) and antenna aperture in meters (m) in the 12GHz (Ku band) using Satmaster Pro software.

Antenna Gain at 12.00 GHz

Produced using Satmaster Pro

Columns show antenna gain (dBi) at various efficiencies

Aperture (m)	55%	60%	65%	70%	75%	80%	85%	90%
0.25	27.35	27.73	28.08	28.40	28.70	28.98	29.24	29.49
0.30	28.94	29.31	29.66	29.98	30.28	30.56	30.83	31.08
0.35	30.28	30.65	31.00	31.32	31.62	31.90	32.17	32.41
0.40	31.44	31.81	32.16	32.48	32.78	33.06	33.33	33.57
0.45	32.46	32.84	33.18	33.51	33.81	34.09	34.35	34.60
0.50	33.37	33.75	34.10	34.42	34.72	35.00	35.26	35.51
0.55	34.20	34.58	34.93	35.25	35.55	35.83	36.09	36.34
0.60	34.96	35.33	35.68	36.00	36.30	36.58	36.85	37.10
0.65	35.65	36.03	36.38	36.70	37.00	37.28	37.54	37.79
0.70	36.30	36.67	37.02	37.34	37.64	37.92	38.19	38.43
0.75	36.90	37.27	37.62	37.94	38.24	38.52	38.79	39.03
0.80	37.46	37.83	38.18	38.50	38.80	39.08	39.35	39.59
0.85	37.98	38.36	38.71	39.03	39.33	39.61	39.87	40.12
0.90	38.48	38.86	39.20	39.53	39.83	40.11	40.37	40.62
0.95	38.95	39.33	39.67	40.00	40.30	40.58	40.84	41.09
1.00	39.39	39.77	40.12	40.44	40.74	41.02	41.28	41.53
1.20	40.98	41.36	41.70	42.02	42.32	42.60	42.87	43.12
1.50	42.92	43.29	43.64	43.96	44.26	44.54	44.81	45.05
1.80	44.50	44.88	45.22	45.55	45.85	46.13	46.39	46.64
2.00	45.41	45.79	46.14	46.46	46.76	47.04	47.30	47.55

Figure 7.19 shows increasing Antenna Gain in dBi with increasing antenna efficiency (%) and aperture in meters (m).

The Systems Engineering framework ensures the use of optimized systems as illustrated in Figure 7.17, 7.18 & 7.19 for clustered direct-to-home (DTH) users, office building complexes, high-rise buildings, residential estates, hotels etc, Table 7.1 shows the efficiency and cost-effectiveness of using high performance multi-switch technology combined with universal low noise block-downconverter feedhorn(LNBF) by comparing 65cm antenna dish deployed in 32 homes with 1.8m dish system engineering framework using multi-switch technology and Quattro LNBF.

Table 7.1: The table shows the efficiency and cost-effectiveness of using high performance multi-switch technology combined with a universal low noise block-downconverter feedhorn (LNBF) by comparing 65cm antenna dish deployed in 32 homes with 1.8m dish exploiting systems engineering framework using multi-switch technology and quattro LNBF.

S/n	ITEM	32 Stand-alone 65cm receive-only antenna system	32 distribution network using "Quattro" universal LNB, multi-	Remark

			switch and 1.8m Receive-only Antenna system	
		COST EFFECTIVENESS		
1.	Typical Ku-band Low Noise Block for signal reception	Standard one-port LNB is $20.00 Thus for 32 users; $20*32=$640.00 	“Quattro “universal LNB is $40.00  5X 32 output multi-switch is $300; Thus costing $340.00 	Aggregate of $300 saved for 32 users scenario.
2.	Receive-only Antenna	65cm dish(standard) is $22.00. Thus for 32 users; $22* 32=$704.00 	1.8m receive only dish is $75.00 	Aggregate of $629 saved for 32 users scenario
	Total Cost for a 32-user scenario for CPE without other features that are common to both systems (i.e Inter-frequency cables, Top-up Box(Satellite Receiver), connectors, viewing card, remote control etc	$1,344.00	$415.00	Total amount saved is $929.00 This represents 74% cost savings through an integrated system engineering multi-user delivery framework
		IMPROVED QUALITY OF SERVICE (EFFICIENCY)		
1	Using Satmaster Pro Link	With 0.65m dish, the	With 1.8m dish, the excess	Aggregate excess

	Budget assuming a 7.6m uplink station at Johannesburg, South Africa (26.18S, 28.07E) and a Direct to Home Location in Abuja, Nigeria (9.20N, 7.18E) through Eutelsat W7 built on spacebus 4000C4 satellite bus located 36E with EIRP of 48dBW over Sub-Saharan region	excess link budget under clear sky condition was 7.57dB while downlink rain condition has a value of 1.73dB	link budget under clear sky condition was 10.29dB while downlink rain condition has a value of 8.01dB	link margin of 6.28dB was gained with change of 0.65m to 1.8m antenna dish under ITU rainfall model thus increasing TV viewing time during rainfall.
2	Average (Not Effective) Signal Collection Area in a simplified computation using area of a circle (πr^2)	Radius of 65cm aperture dish is 32.5cm, thus the average signal collection area of the dish is 3.142*32.5cm*32.5cm=3319cm^2.	Radius of 1.8m aperture dish is 90cm, thus the average signal collection area of the dish is 3.142*90cm*90cm=25,304.4cm^2.	The average quantified improvement in signal collection in the bigger dish is over 760% thus increasing availability and quality of TV viewing period during precipitation in Ku band.

The exploitation of the above system engineering framework using large dish receive-only antenna, combined with multi-switch technology should be encouraged by DTH operators especially in the Sub-Saharan region of Africa, which, not only improves the quality of reception as well as providing greater signal availability at all times and seasons especially during rainfall as a result of increased link margin with larger aperture but also attracts more subscribers through its aggregated cost effectiveness and efficiency. Rain attenuation is much more pronounced for high satellite frequencies (Ku and Ka band) compared to traditional C-band. Ku and Ka band are common bands in modern day satellites especially High Throughput Satellites (HTS) to meet the growing demands of Communication satellite services in the telecommunications and broadcast sector. Figure 7.20 shows increasing rain attenuation in dB with increased frequency for the Sub-Saharan location (9.20N, 7.18E) using the SatMaster Pro simulation with the ITU rain model. However, innovative technologies has allowed system design engineers to manufacture high powered satellites with Higher Equivalent Isotropic Radiated Power (EIRP) particularly utilizing the upper region of the satellite spectrum i.e Ku and Ka Band to appreciably compensate for the rain fade column with other complementary measures such as adaptive code modulation (ACM), Uplink Power Control (UPC) system implementation etc. The DTH platforms provide most developing nations, especially Africa, with a good non-terrestrial platform for digitization of television signals in free-to-air (FTA) regimes and Satellite Pay-TV platforms as typified by the few regional service providers and NIGCOMSAT's unified DTH platform.

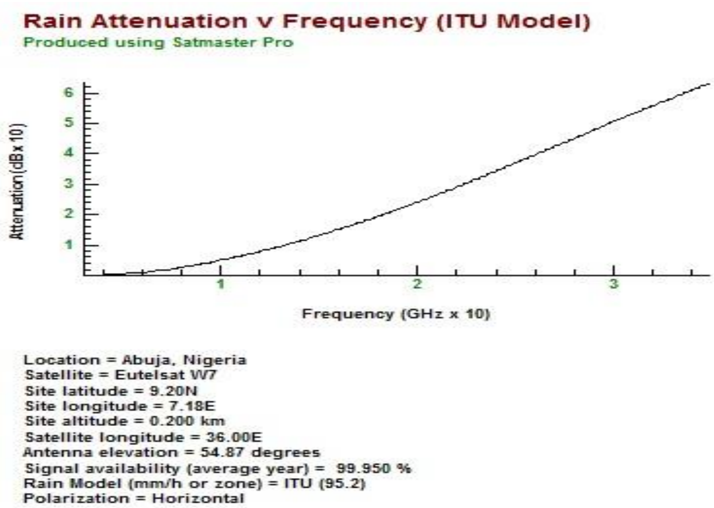


Figure 7.20: Typical Rain Attenuation (dB) as a function of frequency (GHz) for location (9.20N, 7.18E) within Sub-Saharan region of Africa.

Digital Broadcasting comes with huge benefits with resulting higher quality pictures, multiple channel reception, multi-lingual delivery of programmes and more efficient use of the spectrum than analog with lower operating costs in transmission and broadcasting and many other possibilities as digital television converges to also perform the functions of computers and telephone handsets as it provides access to the Internet and Voice over Internet Protocol (VoIP). Implementation of efficient transmission and compression technologies such as DVB-T2 and MPEG-4 respectively, should be encouraged as a minimum requirement for DTT as they deliver more data and video with spectral efficiency than their predecessors i.e DVB-T and MPEG-2. Satellite DTH platform with an open architecture for futuristic technologies offers an economically viable solution for the delivery of high quality digital signals to subscribers as an alternative to Digital Terrestrial Television as we move closer to the ITU deadline for Analogue Switch-Off (ASO) and into the digital era with its numerous benefits including digital dividends for mobile broadband communications, mobile television (DVB-H) and other value added services.

DTH opportunities are boundless and promising for the entire broadcasting industry value chain especially in Africa, Central and Eastern Europe and the Asia-Pacific. The Governments of nations, particularly Africa should put in place adequate measures and resources to digitize and preserve past content and archives in order not to erode past cultural history and values. African regulatory bodies in the broadcast sector should do more in relevant statistics gathering on the broadcast industry to encourage private investment and sustainable growth. For realization of the inherent benefits, the migration must be full-fledged across the value-chain and public acceptance encouraged by various national governments, regulators, manufacturers and other stakeholders through changes in the existing laws, determination of appropriate standards, development of policies, laws and regulations including appropriate modification of the GE-06 digital plan for digital dividends to bridge the digital hiatus particularly in Africa.

To improve the quality of service of subscribers, particularly non C- band subscribers (i.e Ku and Ka band subscribers) in Sub-Saharan Africa, where there is heavy rainfall and reduce the proliferation of outdoor customer premises equipment as observed in most cities, as well as attract more subscribers. DTH service providers should encourage a systems engineering framework for distributed service DTH network design using efficient large aperture antenna dishes with suitable multi-switch technology for identified clustered subscribers, residential estates, high-rise buildings, hotels, office building complexes conveyed through high quality coax cables and connectors to various IRDs and STBs. The systems engineering approach reduces the overall cost of deployment, reduces proliferation of VSAT antennas allowing buildings to retain uninterrupted aesthetic features and most importantly it improves the user experience by providing increased signal to noise performance during rainfall, which is a function of the increased aperture of the receiving dish diameter as well as interference-free operations in environments with numerous DTH operators using different COMSATs. This approach delivers increased TV viewing even during heavy precipitation; performance is a function of the Satellite Power, Satellite Bus Technology, aperture of the uplink station and other complementary technology measures. Small aperture dish i.e 45cm in regions with high precipitation should be discouraged as they lack the required excess link margin to provide link availability under non-clear sky conditions especially in the Sub-Saharan region.

7.3 Emergency Communications Exploiting Communications Satellite with the National Public Security Communication System (NPSCS).

Section 6.4.5 and 6.5.10 as Coalition Emergency Response Sub-system(CERS) and The Emergency Communication Vehicle System (ECV) of Chapter six and Chapter six in general addressed in details Emergency Communications exploiting hybrid of NPSCS and NIGCOMSAT-1R Communications Satellite.

7.4 Telemedicine and Healthcare Delivery

Telemedicine is typically medical practice via telecommunications and interactive video technology with patient and medical experts at both ends while telehealth is differentiated as integration of telecommunication systems with health practice to enhance health care delivery, disease prevention and health promotion. The e-health or electronic health is referred to as the internet-mediated access to health service markets, products and capabilities. Thus, e-healthcare is broader than telemedicine and telehealth. (Tan, Cheng & Rogers, 2002). Telemedicine and healthcare facilitates can be extended to physically inaccessible or under-developed areas using Communication Satellites. Well-equipped and advanced hospitals with specialists could be linked to distant places for provision of clinical services, medical education, and research including diagnosis.

Patients will be able to stay in any remote part of the country and receive his or her medicare from any medical expert located in any part of the country or the world provided there is telecommunication link. It will equally help teams of medical experts to do cross consultation and get second opinions on any medical issues or cases requiring medical brainstorming and/or research without physical travel. Telemedicine practice aids health care delivery but also health profession education, health administration, public health and dissemination, health business, school education in health etc.

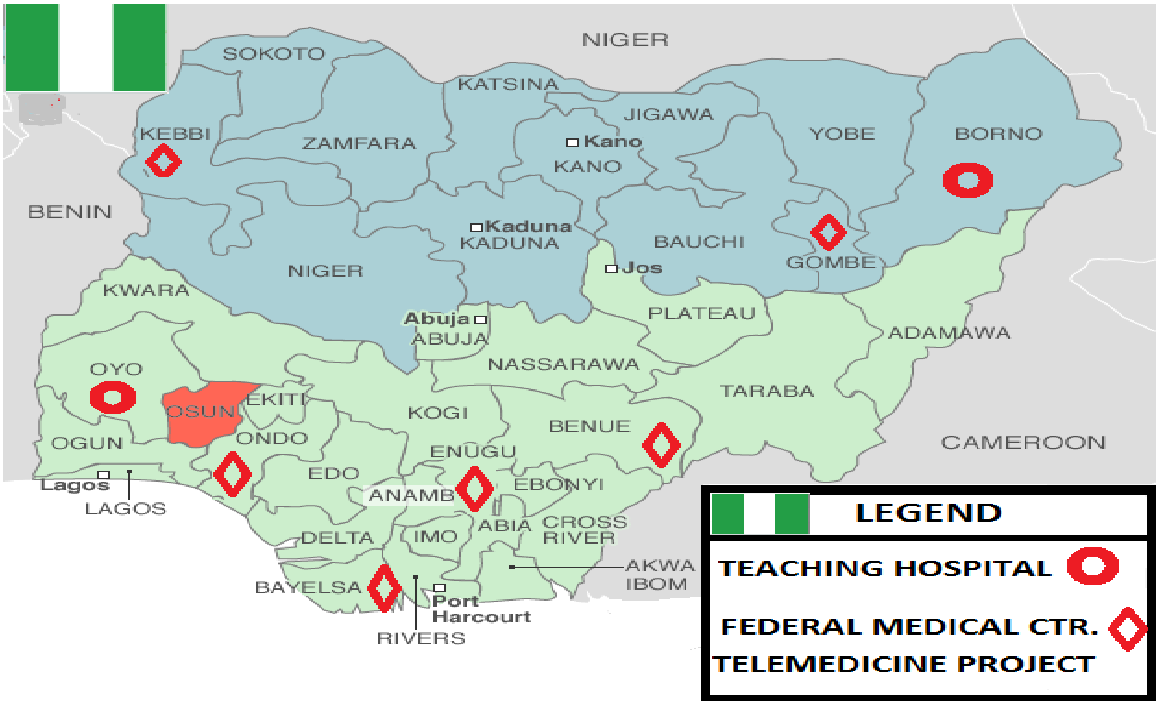


Figure 7.21: A map of Nigeria showing teaching hospitals and federal medical centers involved in the Telemedicine pilot project using NIGCOMSAT-1R.

Considering the derivable benefits of telemedicine and healthcare delivery in Nigeria, immediately after the launch of Nigeria's first communications satellite (NIGCOMSAT-1R) on 13th May, 2007, a pilot project involving Nigerian teaching hospitals and federal medical centers as indicated in figure 7.21 was initiated and implemented using the Ku-band of NIGCOMSAT-1 deployed on an HN Hughes hub. The project greatly improved the quality of lives and the health of Nigerians who accessed the facility including life-saving strategies through timely medical delivery. However, all operations were brought to a halt when NIGCOMSAT-1 was de-orbited on 10th of November, 2008 due to a solar array drive assembly motor (SADA-M) anomaly.

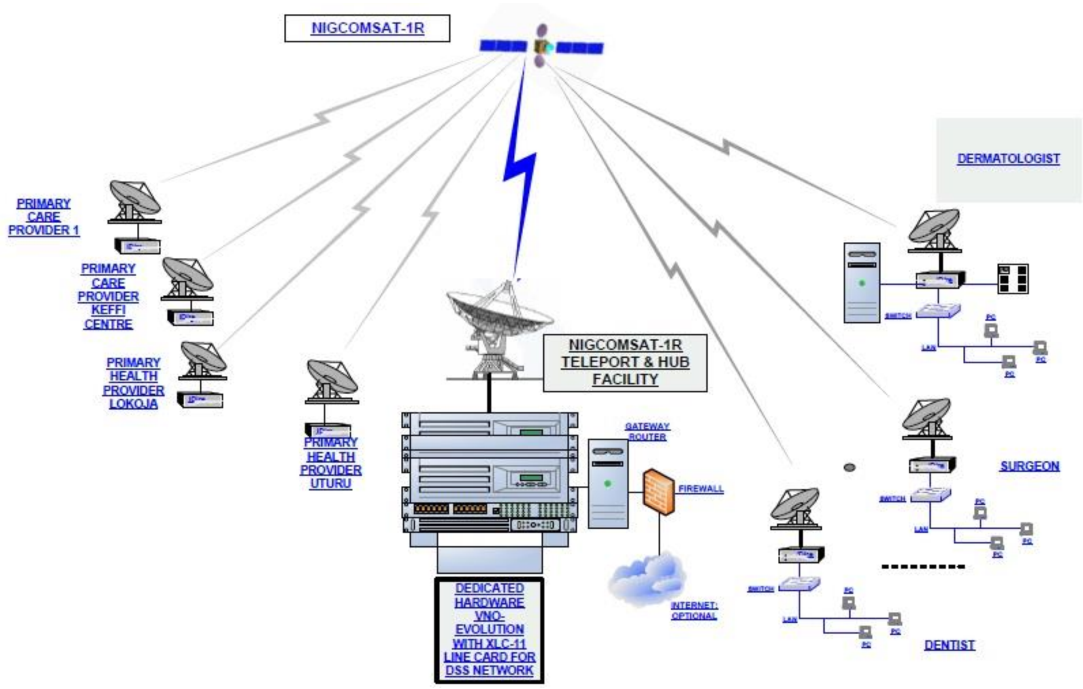


Figure 7.22: Interactive Telemedicine Facility with medical experts serving primary health care providers using Communications Satellite.

With the launch of NIGCOMSAT-1R, NIGCOMSAT Ltd in conjunction with Ministry of Health and other stakeholders intends to achieve an all-inclusive telemedicine project by partnering with both private and public hospitals to establish telemedicine facilities in rural and semi-urban areas in the six geo-political zones of the country including mobile tele-medicine centres as shown in figure 7.22 The mobile tele-medicine centers will be equipped with video conferencing facilities and tele-medicine basic equipment and a set of personal computers, printing and scanning equipment. In collaboration with the Federal Ministry of Health, a Web portal will be established to be accessed by each tele-medicine centre and content will be published on the following:

a. HIV/AIDS prevention and control (for National Quality Management program on adult and paediatric care and treatment, Prevention of Mother-To-Child Transmission (PMTCT), Counselling and Testing (CT) and Early Warning indicators).
b. Malaria Prevention and Control information (use of insecticides, Anti-mosquito nets etc.)
c. Information on Prevention, Control and Management of disease outbreak, Fire disasters, flood, etc.
d. General Community Health programs (How to create and maintain clean environments, etc.)

The portal will provide content published in English and the major ethnic languages within the region of the country.

This will help dissemination of health information in the community, save the lives of Nigerians and the wastage of millions of dollars of foreign reserves spent on antiretroviral, malaria drugs etc while knowledge-based sharing among health personnel and experts is promoted through the global ICT infrastructure; communications satellite. The success of telemedicine, telehealth and e-health services requires the support and co-operation of all stakeholders in the entire value chain ranging from surgeons, physicians, computer scientists, telecommunications engineers, health information systems specialists, health managers, policy makers, patients, people and government for an unprecedented level of acceptance and use (Jarris, R.F, 1994; Tan, Cheng, & Rogers, 2002; Chronaki et al, 2008).

7.5 Tele-Education and E-Learning

The reality of the 21st century is the pervasiveness of Information and Communication Technology (ICT) in all spheres of human life. Modern technology today has presented a new and better way of operationing to support its citizens. Entrepreneurship among the youth has thrived in countries where young people are introduced to ICT products and services at a tender age. Replicating such ICT infrastructure in Nigeria is a daunting and herculean task due to a lack of terrestrial broadband infrastructure required for e-learning and e-Education for socio-economic development, especially in schools.

Other challenges that may affect E-learning initiatives are:

a. Poor resources, including equipment, material and technology;
b. Lack of relevant content in a language understood by the user;
c. Lack or limited access to open education resources;
d. Lack of teachers' training to use technology effectively in the classroom.

Government and relevant stakeholders however recognize the enormous transformative effect ICT has on education regardless of the economic conditions i.e. in very advanced school systems as well as in poorly resourced ones. The vision and the potential of ICT to transform education are universal. ICT can improve student achievement, improve access to schooling, increase efficiency and reduce costs, enhance students' ability to learn, promote their lifelong learning, and prepare them to be part of a globally competitive workforce.

The E-Learning project is considered a national priority project to extend educational opportunities to every one guaranteeing equal access to high quality education including opportunities to the rural areas of Nigeria.

The project is a communications satellite multimedia network supporting Voice, Data and Video content delivered via the Internet, intranet/extranet. It can be self-paced or instructor-led with media aids in the form of text, image, animation, streaming video and audio, video tape, satellite

TV, CD-ROM, DVD etc. The E-learning Initiatives delivered through the Very Small Aperture Terminal system as shown in figure 7.23 is key to National Planning Development and Enhancement for a modern and vibrant education system with the opportunity to deliver maximum potential using competent manpower in secondary (middle) schools, Polytechnics, universities and research institutes. The accruable benefits and advantages are as follows:

a. Motivation to learn and school through provision of multimedia classrooms in our learning institutions with broadband Internet access.
b. Facilitating the acquisition of “21st Century Skills”
c. Improves students’ achievement through increased access to resources and collaboration;
d. Enhances students’ ability to learn and promote their lifelong learning, and prepare them for a globally competitive workforce.
e. Facilitating Global Collaborative Learning (GCL)
f. Development of digital content and distribution via e-Library project that will emerge.
g. Prepares, catalyzes and promotes e-readiness of the nation for e-economy and programs such as eHospital, eSchool, ePost, eGovernance, eBank, ePolice, eMilitary, eCommerce, eCustoms, eID & ePassport, eAgriculture etc
h. Contribute to early industrialization of other sectors of the economy.
i. Melt-down gap between city vs. rural
j. Unification of citizens as one nation regardless of regions, tribes, religion or state.
k. Promoting peace and endurable political stability.
l. Providing cost effective solutions to the ICT requirements of the nation and affordable access to information and communication for Nigerians and the African continent.
m. Diversifying the revenue base of the nation from oil to knowledge and services.
n. Poverty Alleviation
o. Bridging the Digital hiatus and Digital Divide.
p. It shall promote human capacity building and entrepreneurship.
q. To enhance, quantify and qualify Africa’s existing globally diffused ICT expertise with the last frontier of Technology.

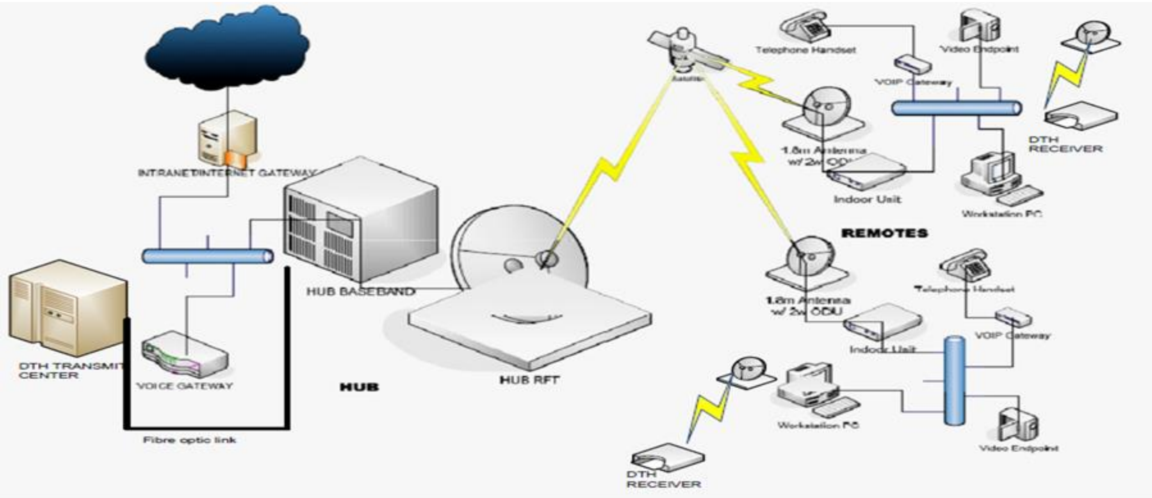


Figure 7.23: Overview of the E-Learning Project providing E-Education in Remote, Rural and Semi-urban Areas via Communications Satellites in Areas with Little or no Terrestrial Facilities.

In furtherance to creating a pool of skilled workers, knowledgeable workforce and entrepreneurs, NIGCOMSAT Ltd with other relevant stakeholders partnered to provide easy learning platform for home-based and office-based distant learning for self-improvement and set of skills required for 21st century workforce as well as creation of new work opportunities. Easy Learning is a respected e-learning program that delivers more than 1500 affordable, certification-level IT, desktop and professional development courses through the Web, allowing students to learn anytime, anywhere for a fraction of the cost of class-based training using a card-based authentication system with pincode to create an account through a web portal; http://www.campus.easylearning.org/nigeria/

as shown in figure 7.24 with access to registered courses. It allows students to achieve the following:

I. Learn new, globally in-demand skills
II. Get affordable, high-quality training with globally recognized certificates.
III. Access flexible, convenient online learning
IV. Choose from 1500+ certification-level courses

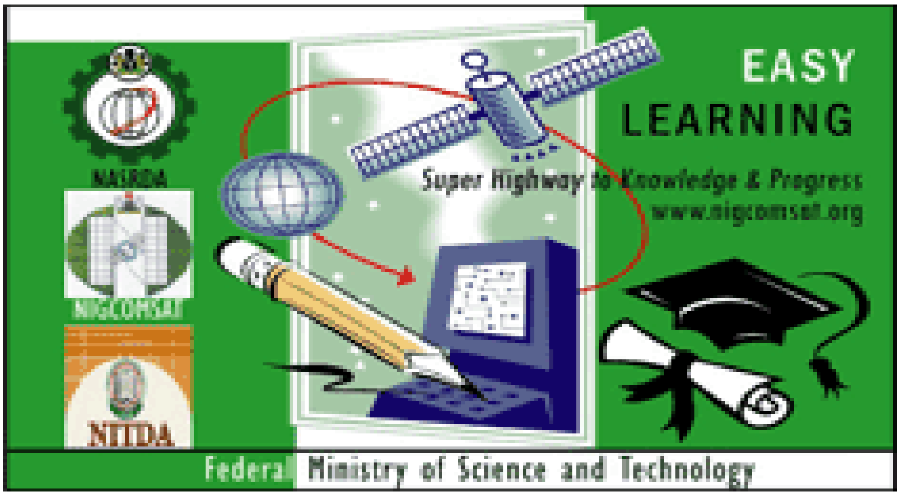


Figure 7.24: Easy Learning Card-based Authentication system with Pin code to create account to access registered courses.

7.6 Community Telecommunications Center (CTC)

Community Telecommunications Center were setup and created to open up access to information and knowledge with more opportunities for people; empowering them to become more self-sufficient including promoting access to e-learning initiatives and programs as discussed in section 7.5. Community Telecommunications Center is a high-speed one-stop shop implemented with structured and wireless infrastructure with triple-play services across six geo-political regions of the country especially in rural areas with little or no terrestrial telecommunications network. Figure 7.25 shows schematic diagram of the community telecommunication center using NIGCOMSAT-1R communications satellite with wireless radio mounted on a 100-150ft mast to provide hotspot in and around the neighborhood and vicinity of the center.

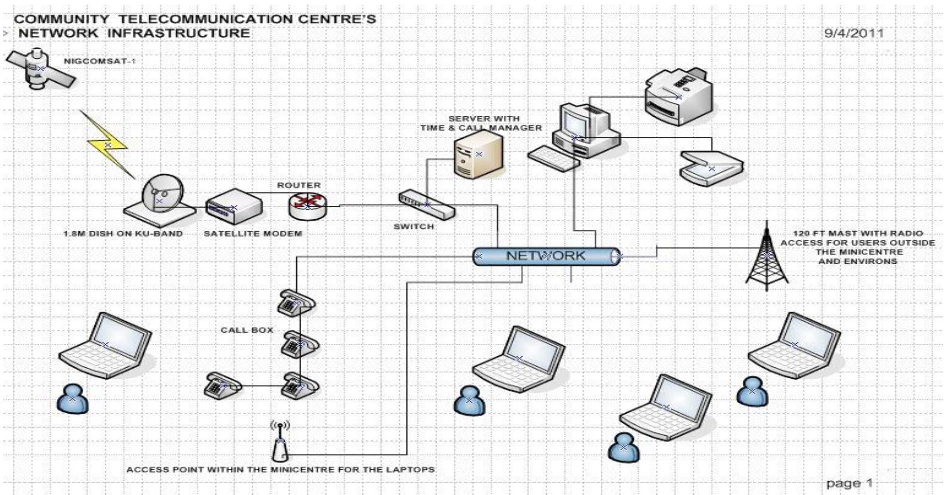


Figure 7.25: Schematic Diagram of NIGCOMSAT's Community Telecommunications Center using NIGCOMSAT-1R Communications Satellite.

The center makes information acquisition and management easier and more efficient and opens up possibilities for universal access to knowledge and markets. Community-based access centres or telecentres such as the NIGCOMSAT CTCs as deployed in Gwagwalada Area council of Federal Capital Territory shown in figure 7.26 provide access to government information, commerce, online training, onsite training etc. The aim is to provide public access to the Internet within walking distance. This in turn provides access to information, government activities and services for the public with immeasurable benefits and increased trust in government's developmental program through information dissemination, which are readily available through Federal, state and local government area (LGA) web portals. The centers are provided with hybrid power solution through arrays of solar panels mounted on the rooftop to provide continued power in the absence of a public power supply (Chen & Liou, 2002; Lawal, Ahmed-Rufai, Chatwin, & Liu, 2013).

Figure 7.26: NIGCOMSAT-1R Community Telecommunications Center equipped with 100ft mast for hotspot around the neighborhood.

7.7 Integrated and Secured Public Communications Network.

Chapter Six provides details of how the problem of poor information gathering and secure data sharing between the security agencies is being solved exploiting the Service –oriented Architecture (SOA) of the NPSCS network.

7.8 Other Spin-Offs from the Integrated Communications Satellite Solutions, Applications and Services.

The global space-based ICT infrastructure; NIGCOMSAT-1R, associated ground stations and complemented by the terrestrially deployed Wireless Network; NPSCS on 450Mhz supported by human resources is driving not only the National ICT revolution in pursuit of socio-economic development but also the country's transformation into an information society. The NIGCOMSAT-1R Communication satellite as a passive global ICT infrastructure and its supporting technologies is fast-tracking development and playing a critical role in delivering

ICT readiness in terms of making Internet access available to unserved and underserved areas with spin-off benefits in technology transfer, wealth and job creation, e-governance, e-education and facilitating the deployment of ICTs to deliver self-reliant services and the required skills for engineering and technology domestication as part of the effort geared towards diversification of the nation's monolithic oil/gas based national revenue to create a knowledge based economy through enhanced ICT readiness, Intensity, usage, impact with skills as reflected in the annual increment of the ICT Development Index (IDI) of Nigerian citizens (UNESC, 2000; Singer, 2003; Fidler, Hernandez Lalovic, Pell & Rose, 2002).

Figure 7.27 shows one of the VSAT broadband Internet service deployed to Ondo State Government for use in hospitals, schools, government and the legislative house with immeasurable benefits while promoting e-education, e-government, e-commerce services as well as interactive service portals for land applications, renewals, licenses, birth and death registrations.

Figure 7.27: Governor's Lodge, Akure; Capital City of Ondo State in Nigeria

Municipalities and other communities are getting connected with mainstream ICTs using Community Telecommunication Centers as exemplified in figure 7.32 for local and community development.

The picture in figure 7.28 shows implementation of a 1.8m VSAT-based Internet access system in an abandoned community library in Bida, Niger State (Northern Nigeria). During deployment, an elected local council leader of the community, youths and good people of the community watched with great enthusiasm delivery of instant access to the Internet super highway in the un-cleared grasslands. The community members with support from their paramount ruler and emir of Bida have since cleared the surroundings of the dilapidated library and now have an increased reading culture and patronage of the library. Plans are ongoing with Niger State Government through the Ministry of Science and Technology to renovate the center and extend similar facilities to villages and communities around the state (Mody, 1979; Lawal & Chatwin, 2012a; Lawal, Ahmed-Rufai & Young, 2013; Brody, Coffin, Cohn, Homayoun & Swanson, 1996; Phillip, 2008).

Figure 7.28: 1.8m VSAT Based Internet access in an abandoned community library in Bida, Niger State (Northern Nigeria).

These centers and others empower individuals, businesses, especially SMEs, local and community groups, women and marginalized or disenfranchised people or groups to do what they do, only better. With ICTs and the capacity to use ICTs, these groups can access the same information that government and large corporations use leveling the playing field through increased participation in economic and human development activities. It expands the range of choices and opportunities by facilitating greater access to economic, educational and development-related information. It helps inform investors of the availability of natural resources in local government areas and verification of such through local government owned-portals thus enhancing and simplifying internal revenue collection in local government areas with rich mineral and agro-allied products.

Environmental Awareness is greatly enhanced through easy access to information about urban and regional planning, weather and the environment with some degree of preparedness against environmental catastrophes and disasters. In Sub-Saharan Africa, earth observation is used to predict crop failure, flood and prepare for emergency and aids relief. The National Space Research and Development Agency (NASRDA) of Nigeria, a sister agency to NIGCOMSAT Ltd, operates a fleet of observation satellites: Nigeriasat-1 (De-orbited), Nigeriasat-2 and Nigeriasat-X for environmental monitoring and urban development including emergencies. NigeriaSat-2, Nigeria's highly advanced Earth observation satellite built by SSTL won the 2012 Sir Arthur Clarke award for "Best Space Activity - Industry / project.

NigeriaSat-2 was launched in 2011 for Nigeria's space agency (NASRDA). It was cited as being "the most powerful UK-built Earth Observation satellite in orbit" providing a very high 2.5m resolution imaging service for natural resource management and urban planning amongst other applications. The satellite has significantly advanced Nigeria's Earth Observation capability. NigeriaSat-2, the first of SSTL's 300kg class satellites, is a major asset in the Disaster Monitoring Constellation (DMC), to which it belongs. Information on urban development, floods and emergencies is provided and distributed using the internet superhighway to even the remotest part of the country using the NIGCOMSAT-1R Communication Satellite data networks and Internet facility. Figure 7.29 shows a picture taken by NIGERIASAT-2 satellite for regional and urban planning

Figure 7.29: Snap shot of an urban area by NIGERIASAT-2 observation satellite (NigeriaSat-2, 2013).

7.10 Conclusion

The success of Nigeria's information technology policy and other developing nations with little or no terrestrial infrastructure depends greatly on satellite communications and its supporting technologies to meet short and medium term plans. Satellite Communications have a competitive advantage as they complement the present sparsely distributed terrestrial links (fiber optic) and radio link extensions contributing to accelerated economic growth, secure communications for security agencies, socio-economic development and launchpad for participation in the global knowledge-based economy thus accelerating sustainable growth and development. The big picture of broadband Internet access and connectivity in Nigeria and Africa as a whole is illustrated in Figure 7.30 below:

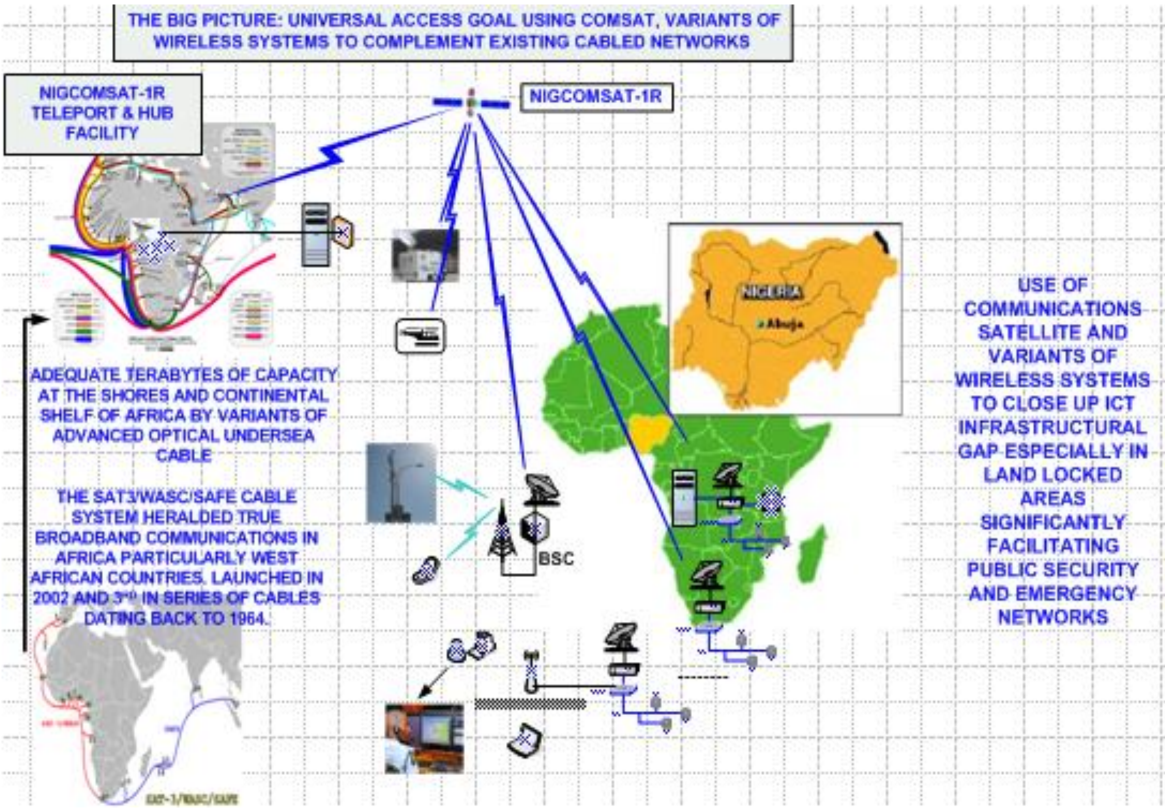


Figure 7.30: The Big Picture of Broadband Internet Access and Connectivity in Nigeria and Africa as a whole to meet Short and Medium term goals of bridging the Digital Hiatus.

ICT is a development enabler. The ICT development process, and a country's transformation to becoming an information society, can be described using the following three-stage model and contexts:

Stage 1: ICT readiness (reflecting the level of networked infrastructure and access to ICTs);

Stage 2: ICT intensity (reflecting the level of use of ICTs in the society);

Stage 3: ICT impact (reflecting the result/outcome of efficient and effective ICT use)

Nigeria's digital opportunity index and access is low due to inadequate networked ICT infrastructure around the country as well as an absence of Inter and intra-metropolitan optical fiber communications networks. The NIGCOMSAT-1R Communication satellite as a passive global ICT infrastructure and its supporting technologies is fast-tracking development and playing a critical role in delivering ICT readiness in terms of making Internet access available to unserved and underserved areas with spin-off benefits in technology transfer, wealth and job creation and empowerment, e-governance, e-education, emergency and recovery services, transportation systems, fleet management as well as driving new and enhanced communications satellite service business and new market opportunities such as qualitative and digitalized High-Definition and 3D direct-to-home broadcast services. To ensure optimized qualitative and quantitative user experience, link budget is exploited for sizing of antennas, high power amplifier (HPA), Low Noise Block (LNB) type while factoring in rain attenuation, solar outage, location and communication satellite data before COMSAT's Customer Premise Equipment (CPE) tailored-designed deployment. Generally, communication satellite systems facilitate timely deployment of ICT infrastructure anywhere.

The NigComSat-1R satellite is a strategic continental ICT and Broadcast infrastructure provider in Sub-Saharan Africa with far reaching impacts in enhancing telecommunications, broadcasting, other value-added telecommunications services, real-time monitoring services and navigation in Africa including transforming Nigeria from just being a consumer of bandwidth to a provider as well as a content carrier/distributor in the broadcast sector as an alternative to Digital Terrestrial Television (DTT) as we move closer to the ITU deadline for Analogue Switch-Off (ASO).

CHAPTER 8: Central Bank of Nigeria's Cashless Policy Implementation as a Self-Sustaining Factor for a Dedicated Broadband-Based Public Security and Emergency Network while Promoting Financial and Digital Inclusion for all.

8.0 Summary:

This chapter examines the role of Communication Satellite Systems and in particular a Nigerian Communications Satellite supporting the National Public Security and Emergency Network and last mile terrestrial wireless infrastructure to drive the National ICT revolution in pursuit of national e-readiness especially the national cashless policy implementation for a Knowledge-based economy to enable the socio-economic development of Nigeria which in turn provides a self-sustaining demonstrator for the dedicated broadband-based National Public Security and Emergency Network. The revenue from the deployment is designed to support the National Public Security and Emergency network making it a sustainable system.

8.1 Introduction, Background and Needs Assessment for Cashless Policy Implementation in Nigeria.

Nigeria lags behind many African countries with regards to provision of financial services. In 2010, 36% of adults which roughly translates to 31 million out of an adult population of 85 million were served by formal financial services. The figure compares to 68% in South Africa and 41% in Kenya (Financial Inclusion in Nigeria, 2012). The existing banking infrastructure has the capacity to accommodate and grow financial inclusion up to 70% when considering the combined total of 5,797 bank branches, 9,958 Automatic Teller Machines (ATMs) and 11,223 Point-of- Sales (POS) terminals as at December, 2010. The available banking infrastructure was operating below its potential because it has the capacity to serve more clients. Average number of clients per branch was 3,882 compared to 3,922 in Kenya and 8,595 in Tanzania. The financial inclusion strategy of Nigeria outlined a framework to significantly increase both access to and use of financial services by 2020. The frame work seeks to increase the formal use of financial services to 70% from current level of 36% of the adult population and as well reach the best-in-class levels while doubling the number of clients each bank branch serves. Financial inclusion is globally becoming a mainstream topic especially amongst emerging economies of how to increase access to and use of financial services. Some countries have made significant progress such as Brazil and Malaysia including Indonesia while Kenya and South Africa are best in class emerging economies in Sub-Saharan Africa. While Nigeria has 36% formal payments penetration, South Africa and Kenya had 59% and 52% payments penetration respectively. Despite high penetration and teledensity of mobile phones in Nigeria, the use of mobile payments in Nigeria is worrisome considering users' experience with incomplete end-to-end transactions. Figure 8.1 shows relative access to formal and informal financial transaction and mobile payment services in selected countries comparatively to Nigeria including South Africa and Kenya.

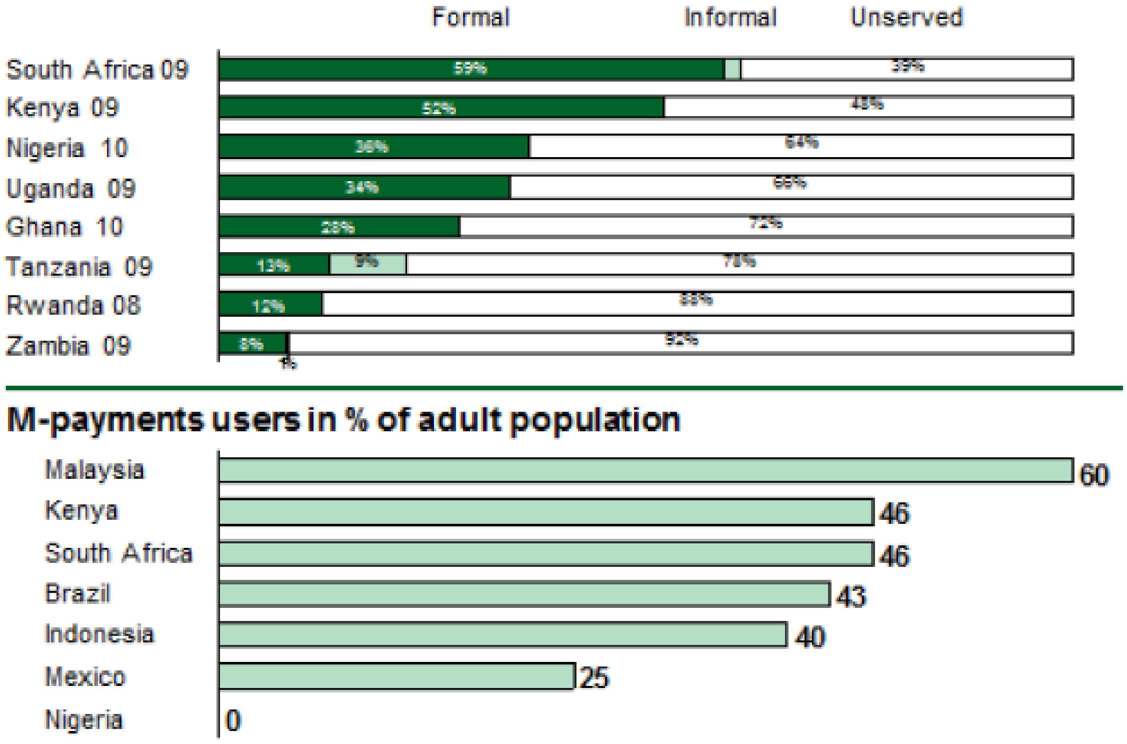


Figure 8.1: Relative Access to Formal and Informal Financial Transaction and Mobile Payment Services in Selected Countries (Financial Inclusion Strategy, 2012)

In order to promote financial inclusion, check corruption and enhance accountability as well as ensure transparency in governance and avoid delays in Government transactions, the Federal Government of Nigeria (FGN) through the Central Bank of Nigeria (CBN) directed all Ministries, Departments and Agencies (MDAs) to adopt E-payment mechanisms for disbursing salaries to employees and also for making third party payments in line with its national financial inclusion strategy 2020 (Financial Inclusion Strategy, 2012).

E-payment is simply an electronic method of transferring funds rather than the usual inconvenient way of carrying large sums of money that may lead to misappropriation. It is a system that seeks to eliminate many of the problems associated with physical cash distribution.

Under the current scheme, the FGN has made it mandatory for the employees, suppliers/vendors, pensioners, utility organisations (water, electricity, telephone bills, etc.), Insurance Organisations, Subscription organisations (clubs, associations, etc.) to indicate their bank account number and other relevant e-payment details so that payment can be transferred via electronic means instead of payment through cheques or Cash.

However, implementation of the E-payment systems by some organisations in the country is marred by payment delays with cumbersome processes and procedures largely attributed to improper implementation and inadequate ICT readiness for the E-payment programme. The system currently implemented has earned a name for its self as “manual e-payment” because the requisite connectivity requirement is not adequate.

8.2 The Lagos Cashless Policy Implementation as a First Trial Project: The Success and Challenges.

The Lagos trial project was an eye opener to all stakeholders in terms the strengths, weaknesses of its performance, opportunities and risks of implementing and enforcing a nationwide cashless policy in Nigeria. Over N80billion ($500 Million) was recorded in volume of daily transactions as at Dec 2012 in Lagos metropolitan city, whilst associated savings in terms of cash handling cost by CBN and banks was estimated at over N14billion ($87.5 Million) per day. The pilot was a success in terms of savings the tremendous costs associated with huge volume of cash transactions and management, increased use of electronic payment systems, enhanced efficacy of the CBN monetary policy etc.

Based on SWOT analysis of the Lagos trial project, a six-states pilot project was conceived before nationwide cashless policy implementation with expected savings amounting to N160 billion ($1 Billion) per day.

The lessons learnt were mainly attributable to the inadequacy of a reliable and consistent communication infrastructure. The inadequacy of consistent telecommunication links grossly affects complete electronic transaction processes and interoperability of Point of Sales (POS) transactions. Affordability of the telecommunication services by merchants also needs to be addressed.

8.3 NIGCOMSAT'S Intervention for The Six States Pilot Project

We followed with special interest the CBN's policies to reduce the high usage of cash, moderate the cost of cash management and encourage the use of electronic payment channels with a view to reduce the dominance of cash in the economy and its attendant implications for the cost of cash management to the banking industry, security and money laundering amongst others. The pilot cash policy started in Lagos State in January 1st, 2012 ("tagged Cashless Lagos") provided the writer (researcher) with an insight of how a combined hybrid solution of the regional Communications Satellite (NIGCOMSAT-1R) and the National Public Security and Emergency Network could be used as a model to mitigate against the failures experienced in the Lagos trial project, drive financial and digital inclusion and thereafter roll out the policy to other regions across the country on a nationwide scale for a win-win scenario.

The policy will no doubt reduce the cost of banking services; improve the effectiveness of monetary policy in managing inflation and driving economic growth, increase tax collection, check corruption, enhance accountability, ensure transparency in governance, avoid delays in government transactions and drive development and modernization of our payment system in line with Nigeria's financial inclusion strategy.

However, the success of this policy depends largely on easy, affordable and the ubiquitous availability of broadband Internet access in the country. Presently, 75% of broadband connectivity exist only in urban areas and does not come cheap. Last mile deployment of broadband through wire-line requires huge investment which is hardly affordable, deployment in rural areas is time consuming and not economical.

Several memos and presentations were exchanged and made with Central Bank of Nigeria and National Inter-Bank Settlement System Plc (NIBSS), (which serves as clearing house for automated processing and settlement of payments and funds transfer instructions between banks, discount houses and card companies in Nigeria) stating the capability and capacity of our hybrid solution to deliver on the six pilot project and nationwide implementation. To clear any doubt that a Government-Owned Enterprise (GOE) can deliver, the writer spearheaded what I called "Proof-of-Concept (POC) and live-demonstrations" of solutions in areas experiencing cashless transactions difficulty as a result of absence of adequate last mile infrastructure offered by commercial mobile operators to guarantee at least consistent 4kbps to enable POS terminals to conduct end-to-end query with the backend E-payment servers of the clearing house (NIBSS).

The bottom-top approach yielded success and combined executives of CBN and NIBSS further provided me and my team with 20 locations across six geopolitical regions of the country slated for the six-state pilot project. The 20 locations given are: shop location, shopping complexes, markets etc experiencing connectivity challenges and transaction difficulties using the inadequate last mile infrastructure of commercial mobile operators.

Areas covered by the NPSCS terrestrial network were identified in the six state locations and Lagos State namely Abuja, Abia, Anambra, Kano and Ogun States as shown in figure 8.2 with detailed coverage performance in figure 6.11 to 6.17 of chapter six. Areas with inactive Base Transceiver Station (BTS) powered down as a result of funds unavailability were immediately activated considering the future potential of the cashless policy implementation sustaining the NPSCS network while areas outside NPSCS coverage were complemented with a Communication satellite solution.

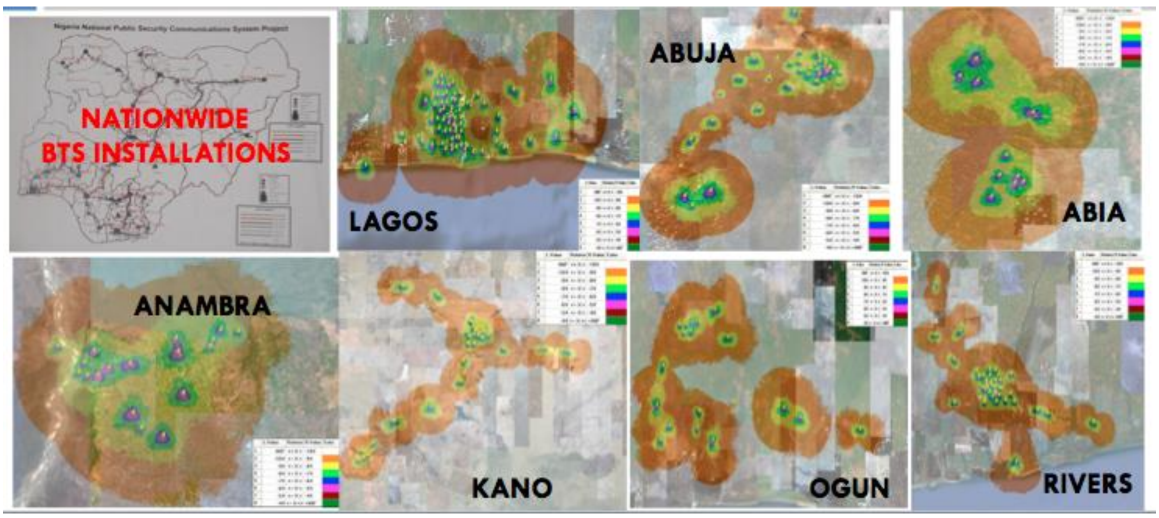


Figure 8.2 shows Signal Strength of the deployed nationwide CDMA network across Six-Geo Political Regions of Nigeria, where the Cashless Policy Pilot Project were implemented on the 450MHz Terrestrial Spectrum.

The NPSCS is a highly secured, efficient and effective Communications platform based on CDMA EVDO technology with exclusive capacity for strategic commercial and socio-economic activities as earlier explained in chapter six. The cashless policy is considered to be a national strategic priority and thus POS terminals with communications channel on CDMA 450MHz were procured on special request from POS manufacturers and suppliers to enable payment transactions to be tunnelled through Internet Protocol (IP) to NIBSS back-end servers. The request is considered special and requires a series of tests as typical POS terminal using CDMA communication links are designed and built to operate on standard 800/1900MHz frequency.

A typical Point-of-Sale (POS) terminal as shown in figure 8.3 are designed and manufactured with standard communication links using Ethernet (LAN Port), General Packet Radio Service (GPRS), Dial-up modem, CDMA, and/or Wifi links which may all be integrated costing more or typically common communications links with others as options.

Figure 8.3: A Typical Point-Of-Sales (POS) Terminal.

The CDMA communication link is standardly built on 800/1900MHz frequency thus requiring a special request and test process to build a 450MHz-based CDMA POS terminal with antenna support to communicate with the terrestrial NPSCS network.

Figure 8.4 and 8.5 provides details of the POS terminal and Telephone built on 450MHz. The POS terminal branded NIGCOMSAT and Model POS E330 as shown in figure 8.4 are designed to work within humidity of 5-95% and supports the following encryptions; ANSI X.9.8/ISO9564, ANSI X9.9/ISO8731, 3DES. It has a high speed thermal printer for POS receipts. The FX200 model shown in figure 8.5 was built to support not just CDMA 450 but also CDMA800/1900MHz for economy of scale. It has battery backup system, USB modem, SMS, display, Stopwatch, Alarm, FM radio, Calendar, POS Support through Ethernet Port and

Wifi, not just to support Cashless policy programme for digital inclusion for all without exclusivity.

Figure 8.4: Specially Built CDMA450MHz POS Terminal for Direct use with the NPSCS Network on 450MHz.

Figure 8.5: Specially Built CDMA450MHz Multimedia Telephone with Value Added Services for Financial and Digital Inclusion without exclusivity utilizing the NPSCS Network on 450MHz.

To complement the success of 450MHz CDMA-based POS terminal in the Nigerian Market, a solution by the writer is depicted in figure 8.6, was rolled out to utilize existing wireless-based and Ethernet based Point-of-Sale (POS) terminal through a 450MHz IP cloud of the nationwide NPSCS network.

Figure 8.6: System utilizing the Nationwide 450MHz-Based CDMA Network to support existing Wifi-Based and Ethernet-Bases POS terminals. and thus driving the National Cashless Policy.

Figure 8.6 illustrates how an off-the shelf 450MHz CDMA-EVDO USB dongle was inserted, integrated and configured as a 3G/4G wireless router, which also has 5-hours battery backup power enabling a wireless-based POS terminal to communicate with the NIBSS back-end E-payment servers through IP for completion of online payment transaction.

A total of 78,482 POS terminals exists in Nigerian E-payment market as at February, 2014. The POS terminals have varying communication modules supporting WIFI, LAN (Ethernet), GPRS, Standard CDMA. Figure 8.7 shows POS distribution across the country utilizing various wireless network technologies. 88% are predominantly utilizing General Packet Radio Service (GPRS) of the Global System for Mobile Communications (GSM). The issues and challenges experienced by users of POS are mostly with the GPRS-based POS terminals considering the fact that most GSM networks were deployed in the early 2000,they are mostly first and second generation systems designed originally for voice and not data.

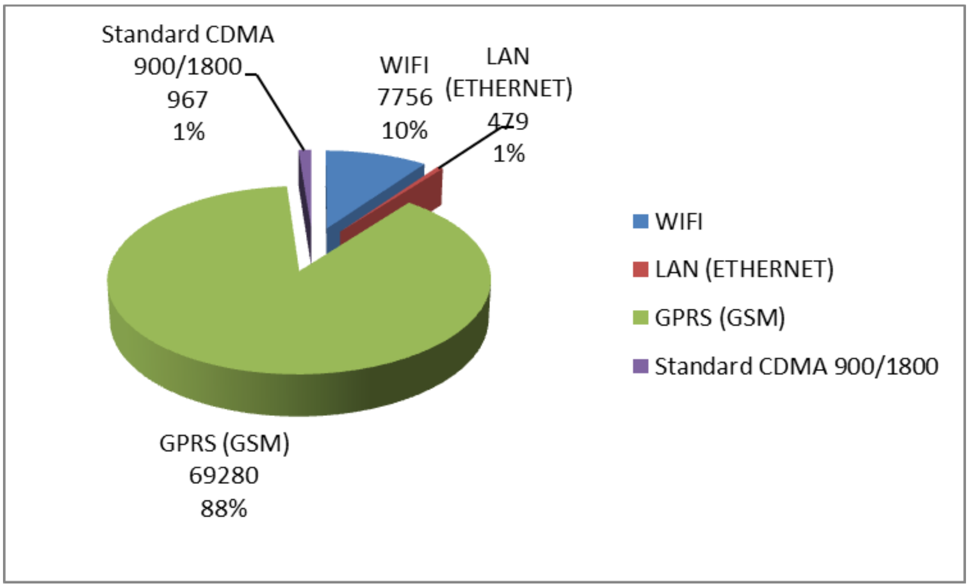


Figure 8.7: Point-of-Sales (POS) Terminal Distribution across the country utilizing various Wireless Network Technologies.

The NigComSat-1R Communication Satellite's complements the National Public Security Communications System (NPSCS) terrestrial network infrastructure especially in rural areas. Each deployed VSAT is equipped with secured hotspot facility within 500 meters radial coverage to enable wifi-based and Ethernet (LAN)-based point-of-sales (POS) terminals in shops, neighbourhood centres, shopping malls especially in areas without NPSCS coverage while good percentage of the GPRS-Based POS are being retrofitted with Wifi modules thus facilitating effective cashless transactions and fast tracking cashless policy implementation and most importantly in urban areas with inadequate terrestrial wireless infrastructure. The IP-based Wide Area Network (WAN) and Local Area Network (LAN) are backhauled to the Nigeria Inter-Bank Settlement Scheme (NIBSS) headquarters for completion of the back-end transaction as the clearing-house of Nigeria as shown in figure 8.8. The NIBSS provides the infrastructure for automated processing, settlement of payments and fund transfer instructions between banks, discount houses, and card companies in Nigeria etc. Figure 8.9 illustrates top-level design of the VSATs with secured hotspots network while Figure 8.10 shows the writer deploying a VSAT solution in a shopping complex location outside the NPSCS coverage.

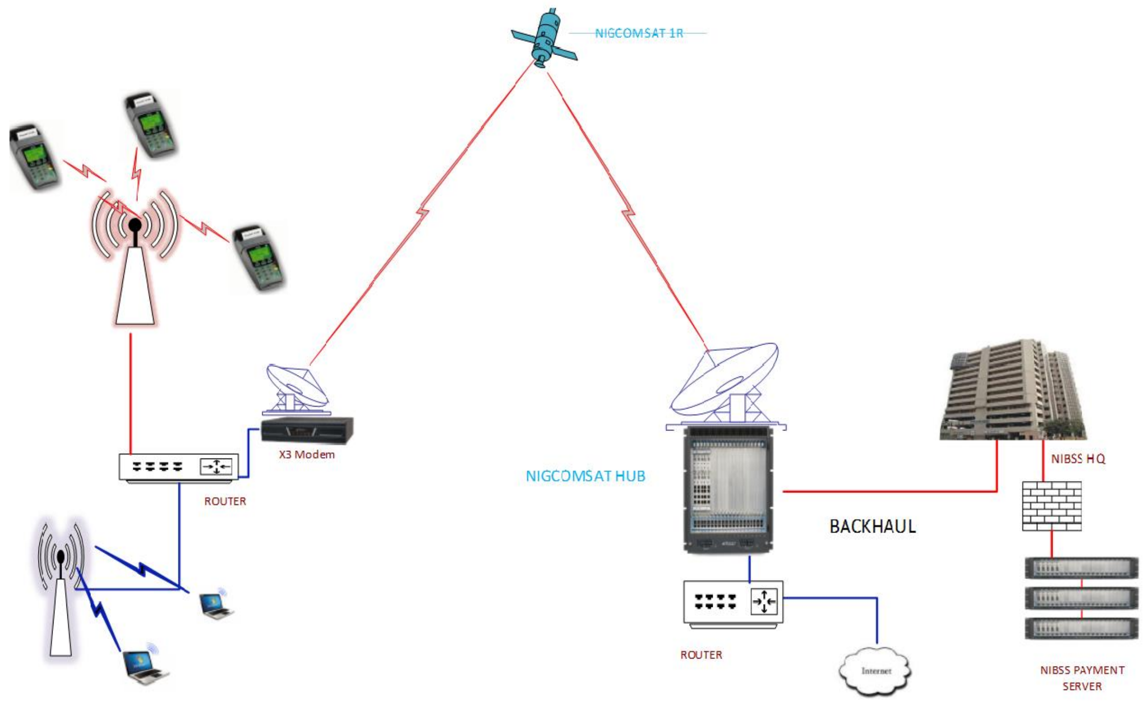


Figure 8.8: Network Overview with NIBSS as Clearing house for E-Payment using NIGCOMSAT-1R as Backbone Infrastructure.

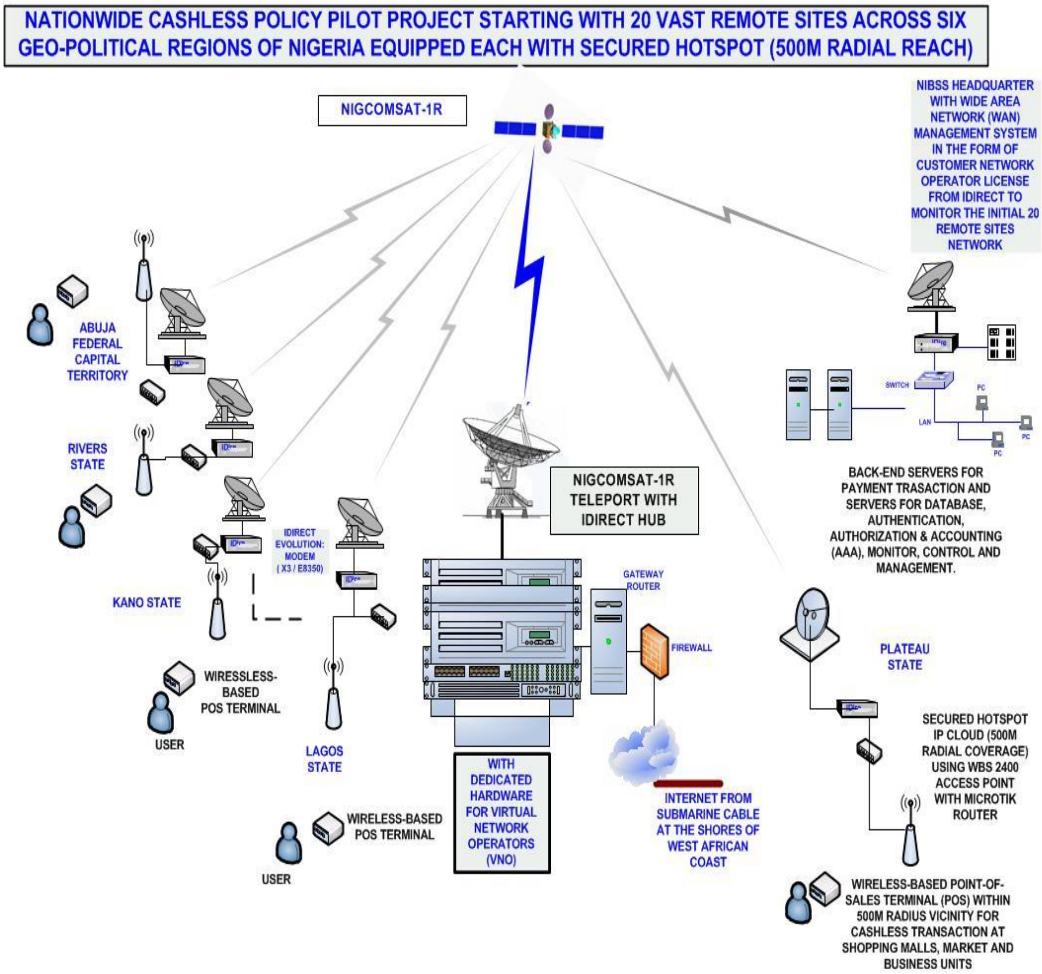


Figure 8.9 Shows Top-Level Design and Implementation of the VSATs across Six Geo-Political Regions of Nigeria each equipped with a secured hotspots network (500m radial reach).

The Satellite Modem of the VSAT as shown in figure 8.8 and 8.9 is integrated into a high powered outdoor access point radio as shown in figure 8.11. The radio has a good multi user performance, high capacity delivery, faster user rates and superior connectivity under both line-of-sight (LOS) and non-line-of-sight (NLOS) conditions. It has a powerful spatially adaptive beamforming technology for optimal performance and interference mitigation as illustrated in figure 8.12. The spatially adaptive beamforming technique helps multiple High Gain Diversely Polarized (HGDP) antenna arrays to track movements and noise variations to effectively adapt, exploits multipaths and coherently combine reflections with focused transmit and receive energy for optimal performance especially in a very noisy environments with radio spectrum users. Table 8.1 shows test description and procedure for acceptance and commissioning of the wireless last mile infrastructure with VSAT backbone Infrastructure as shown in figure 8.8 or NPSCS backbone infrastructure as shown in figure 8.2 and 8.6

Figure 8.10: Deployment of VSAT System outside NPSCS network coverage.

Figure 8.11:Advanced Broadband Outdoor wireless Radio as Last Mile Infrastructure for Wifi-Based POS Terminals and Internet Connectivity.

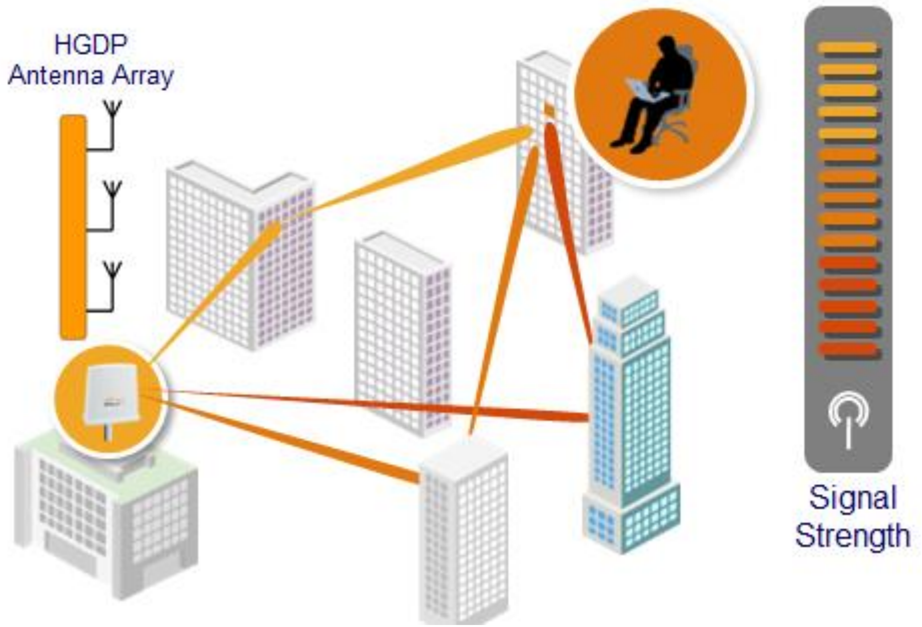


Figure 8.12: Illustration of Two-Way Spatial Adaptive Beamforming for Optimal Performance.

Table 8.1: Acceptance Test Plan for the Wireless Last Mile Infrastructure.

S/N	TEST	TEST DESCRIPTION	TEST PROCEDURE	PASS	FAIL	COMMENTS/REMARKS
1	IPERF TEST	To validate the throughput of end-user while associating with the access point in Line of Sight (LOS) and Non-Line of Sight (NLOS)	RUN IPERF	Ok		
2	PING TEST	To verify wireless NIC association with Access Point To verify LAN Connectivity To verify a Laptop/Computer gets IP address from the network. To verify data path through the access point	PING BETWEEN TWO CONFIGURED END-USERS OR LAPTOPS/COMPUTERS	Ok		
3	Internet Access and Authentication	To test the Authentication Process	Search for the hotspot SSID. Open home page in the Internet Browser Insert provided Username and Password. Try to access	Ok		
4	Point-of – Sale (POS) Terminal TEST	TEST Authentication Process of NIBSS certified Wifi-based POS Terminal with N0.01 transaction	Search the hotspot SSID using the POS Terminal, configure username and password, enter one kobo (N0.01) transaction for payment.	OK		GO FOR COMMERCIAL MARKET

Figure 8.13 shows multi user performance result of radio technology of choice based on an indoor office environment test conducted with 110 active users comprising of laptops, handhelds and other CPEs while figure 8.14 shows live test result of a configured POS terminal belonging to Union Bank and Citiserve merchants. The N0.01 transaction test based test item 4 of table 8.1 was successful which signalled commissioning of the POS terminal for commercial transaction.

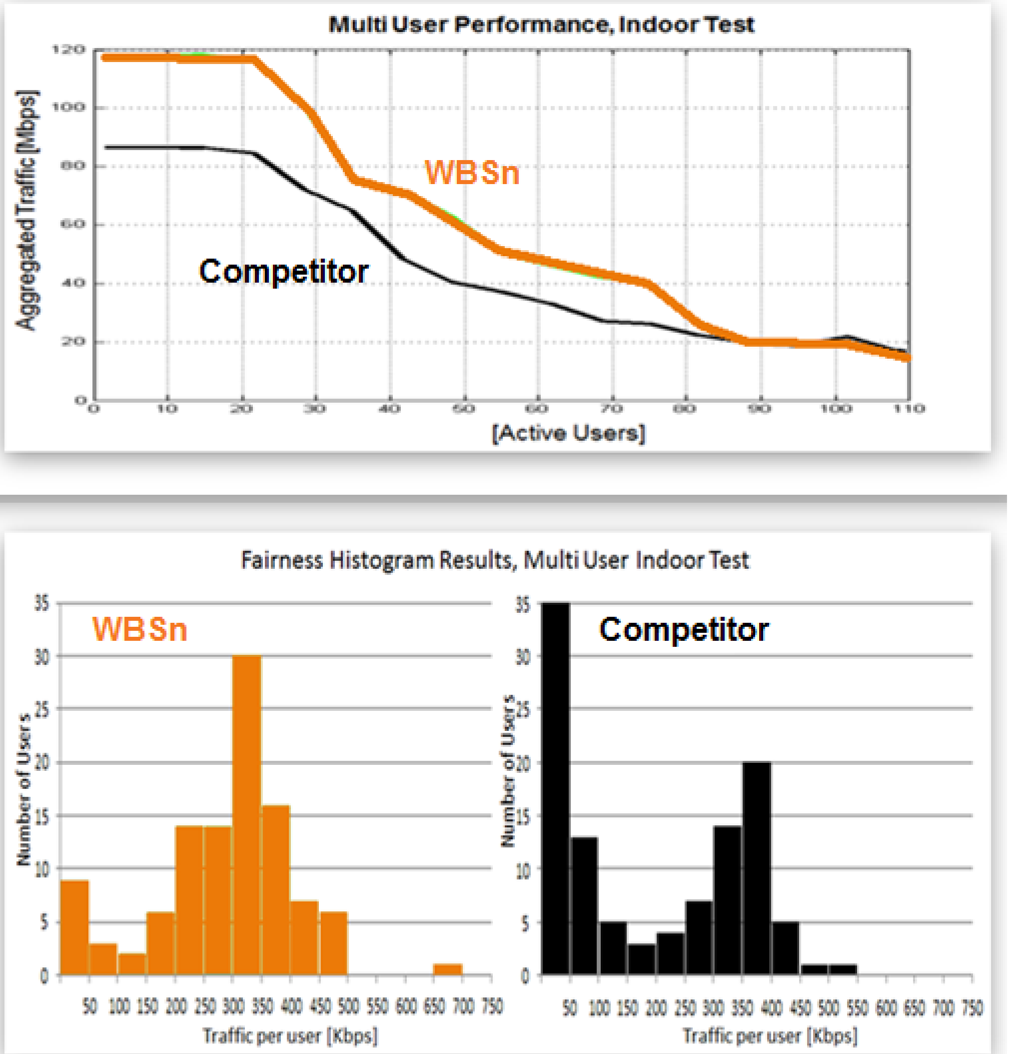


Figure 8.13: Multi-user Performance of Radio with 110 active devices in office environment.

S/N	TEST	TEST DESCRIPTION	TEST PROCEDURE	PASS	COMMENTS/REMARKS
1	Point-of –Sale (POS) Terminal TEST using **CITISERVE'S POS**	TEST Authentication Process of NIBSS certified Wifi-based POS Terminal with several N0.01 transaction of Sight (NLOS)	Search the hotspot SSID using the POS Terminal, configure username and password, enter one kobo (N0.01) transaction for payment.	Ok	GO FOR COMMERCIAL MARKET
2	Point-of –Sale (POS) Terminal TEST using **UNION BANK'S POS**	TEST Authentication Process of NIBSS certified Wifi-based POS Terminal with several N0.01 transaction	Search the hotspot SSID using the POS Terminal, configure username and password, enter one kobo (N0.01) transaction for payment.	OK	GO FOR COMMERCIAL MARKET

Figure 8.14: Successful live test results of a configured POS terminal belonging to Union Bank and Citiserve Merchants in Nigeria using the NPSCS Network and VSAT Network.

8.4 CBN Nationwide Cashless Policy Implementation using NIGCOMSAT-1R and the dedicated National Public Security And Emergency Network as a Self-Sustaining Model to Drive Financial and Digital Inclusion.

With a successful proof-of-concept (POC), twenty sites were deployed across six geo-political zones of the country in the city of Lagos, Abuja, Kano, Anambra, Abia, Ogun and Rivers State. The number shall be increased to 1,000 locations to cater for full coverage of the Cash-less roll-out plan subject to user acceptance of the proof of concept (POC). The deployment for 1,000 locations nationwide is as presented in figure 8.15 using NPSCS network deployment and population distribution while the Nigerian Communications Satellite covers areas outside the first phase of NPSCS coverage reach.

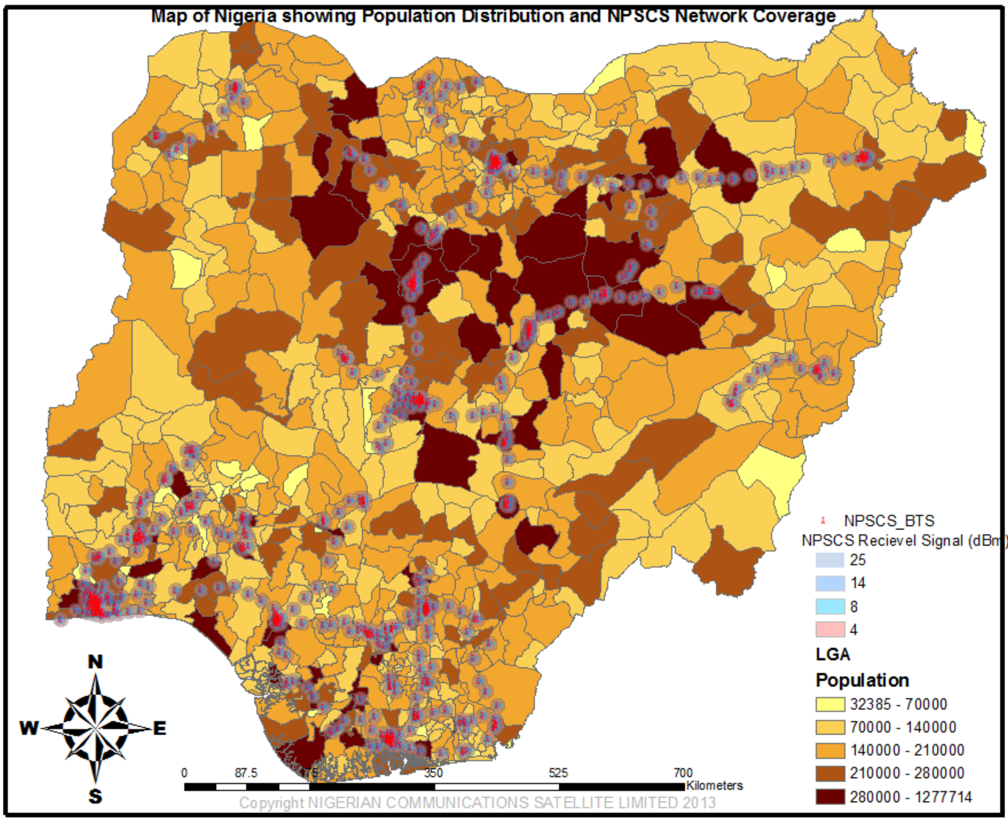


Figure 8.15: Map of Nigeria showing population distribution and NPSCS network coverage.

Leveraging on the NPSCS coverage which presently covers capital cities of 36 states and the Federal Capital Territory (FCT-Abuja) and Population Distribution of Nigeria as illustrated in Figure 8.15, a total of 896 VSAT terminals are required to complement the coverage of NPSCS network especially in rural areas and thus full coverage of the six-states pilot project and the FCT as shown in figure 8.16 to 8.22 for financial inclusion without exclusivity. The data used in the study for projection of number of VSATs to complement the NPSCS network was obtained from Nigeria's most recent national population census.

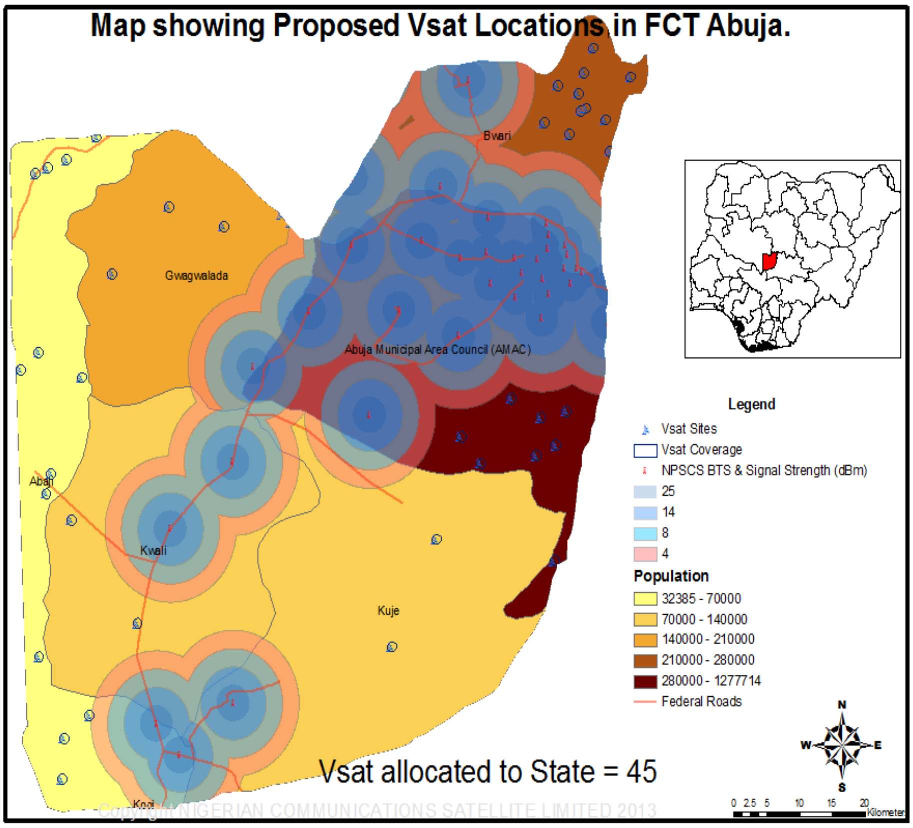


Figure 8.16: Showing coverage of NPSCS Network, Population distribution and VSAT requirements for financial inclusion of all in Abuja, Federal Capital Territory (FCT).

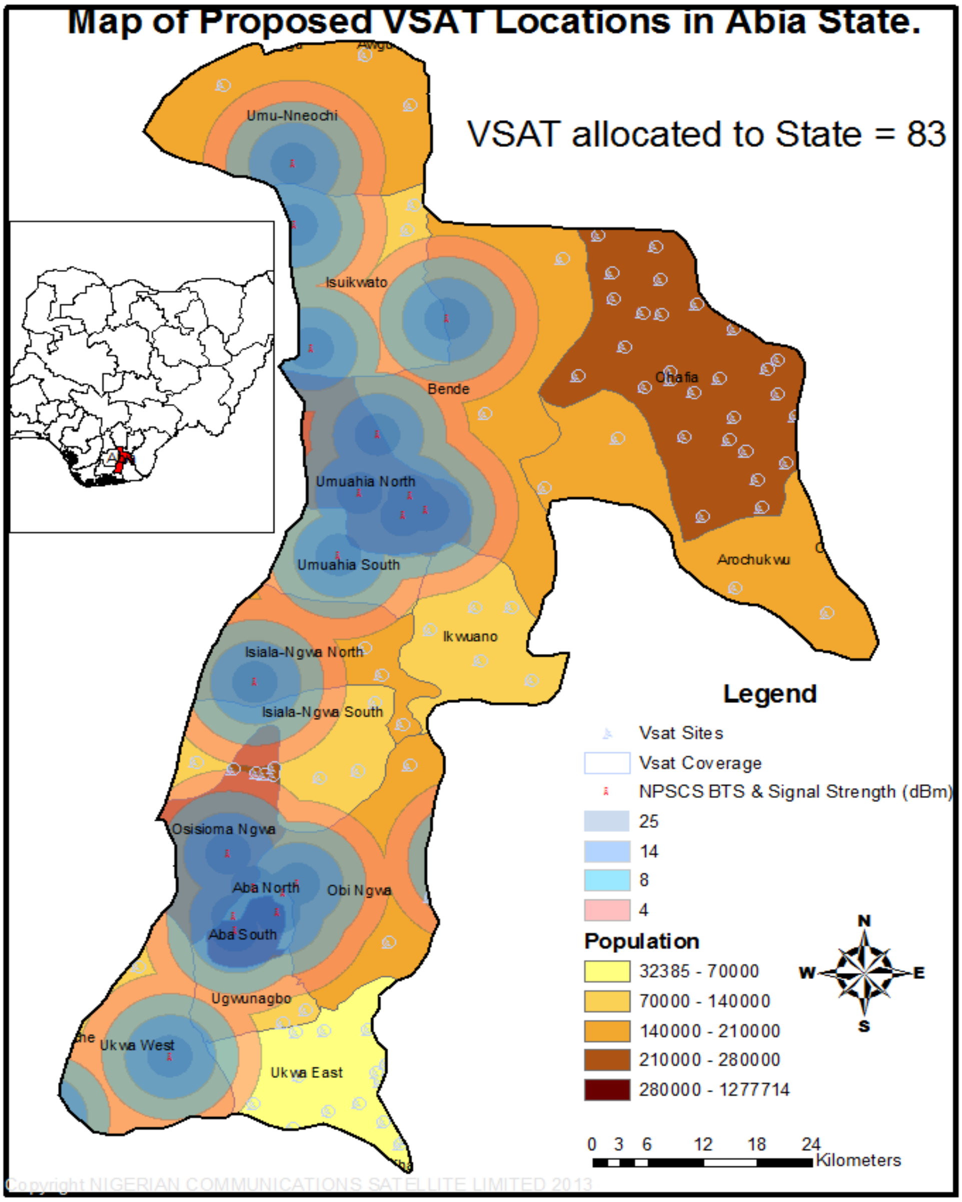


Figure 8.17: Showing coverage of NPSCS Network, Population distribution and VSAT requirements for financial inclusion of all in Abia State.

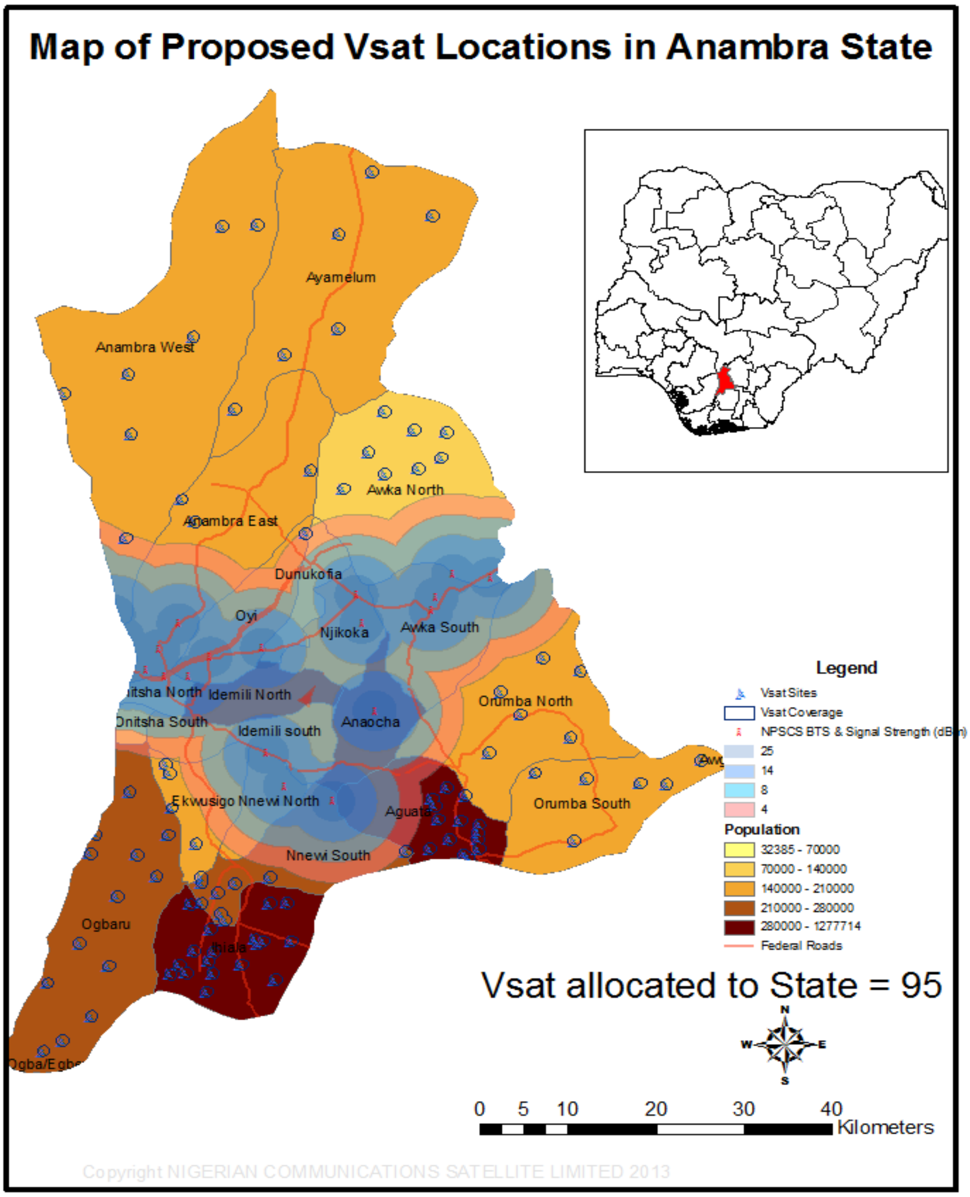


Figure 8.18: Showing coverage of NPSCS Network, Population distribution and VSAT requirements for financial inclusion of all in Anambra State.

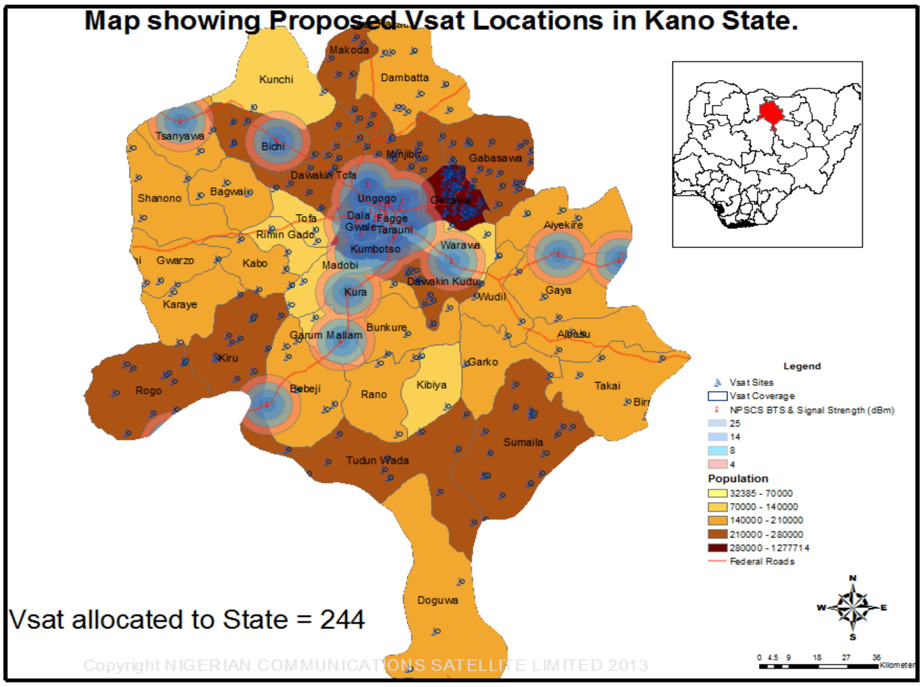


Figure 8.19: Showing coverage of NPSCS Network, Population distribution and VSAT requirements for financial inclusion of all in Kano State.

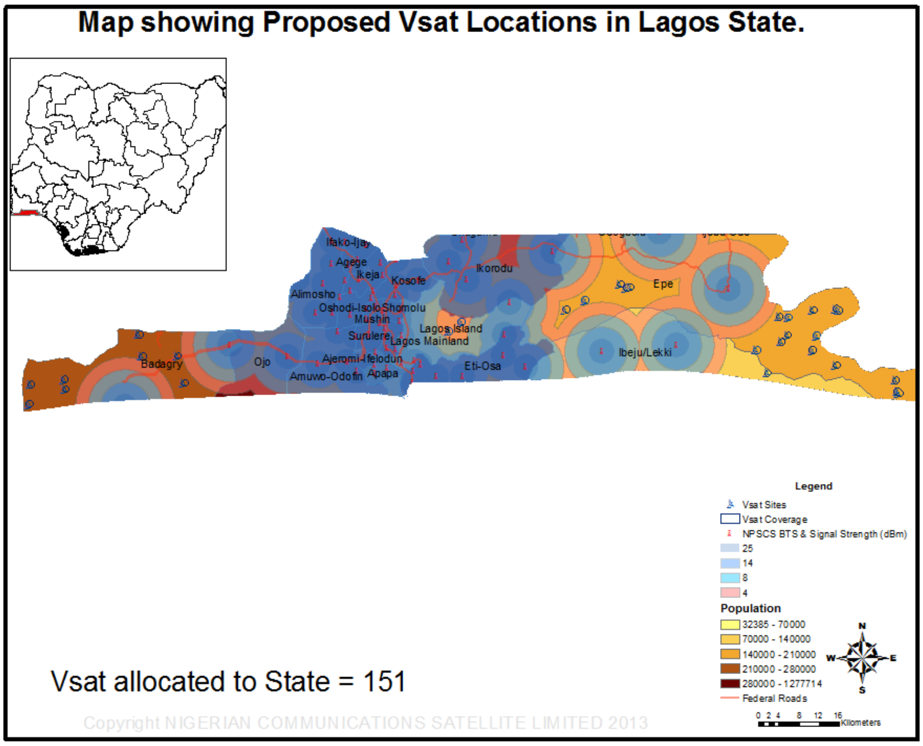


Figure 8.20: Showing coverage of NPSCS Network, Population distribution and VSAT requirements for financial inclusion of all in Lagos State.

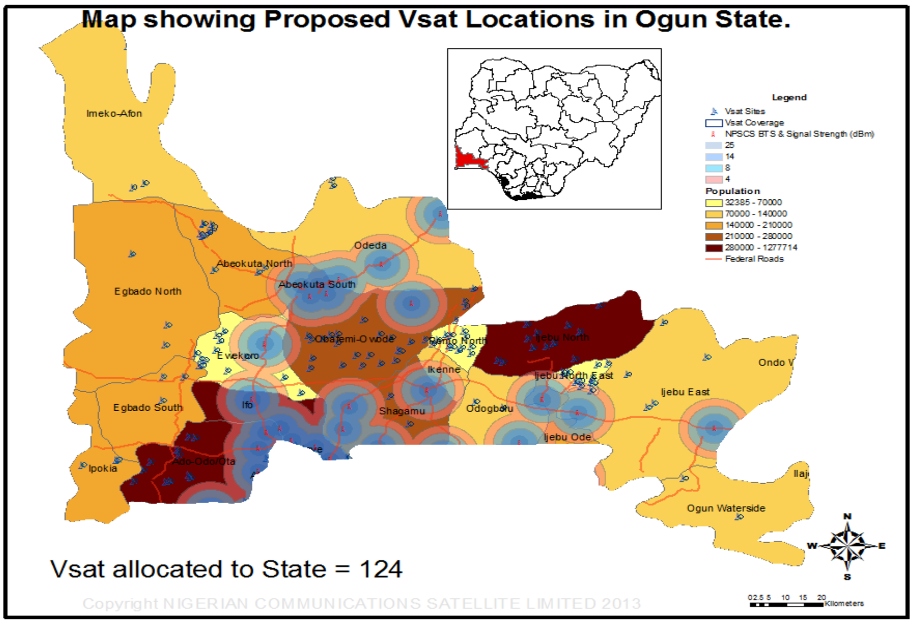


Figure 8.21: Showing coverage of NPSCS Network, Population distribution and VSAT requirements for financial inclusion of all in Ogun State.

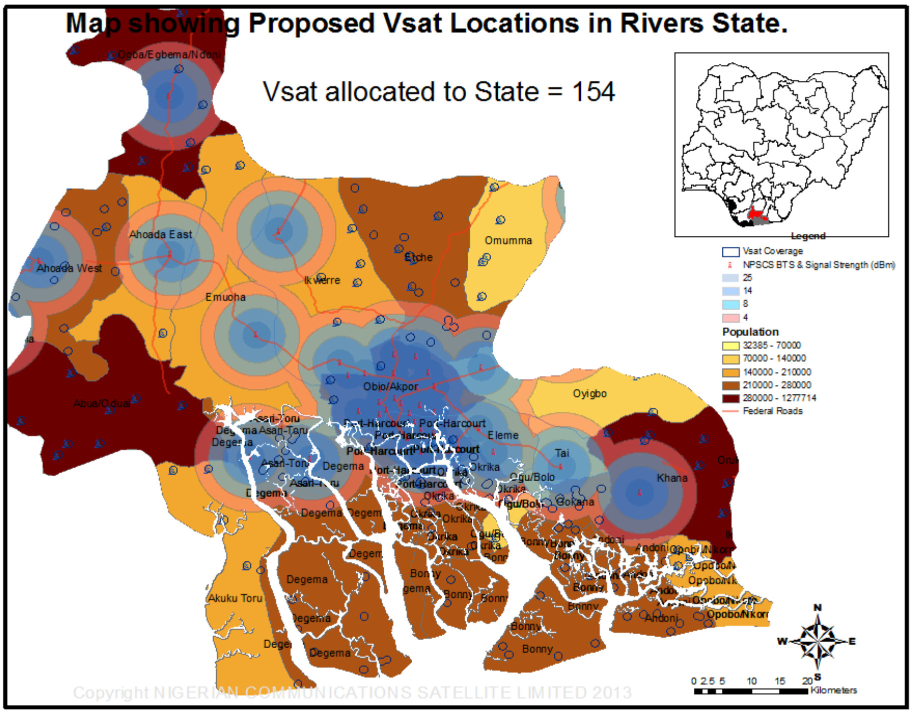


Figure 8.22: Showing coverage of NPSCS Network, Population distribution and VSAT requirements for financial inclusion of all in Rivers State.

Strategic nationwide projection and requirements for the remaining 30 states using VSAT terminals to complement the reach of the NPSCS terrestrial network amounts to about 2,804 VSAT terminals using the country's population distribution and the NPSCS network coverage in the first phase as provided in Appendix with figure E.1 to E.30.

The total VSATs (3,700) is subject to the outcome of a survey to identify regions and locations with adequate and robust last mile infrastructure that will fulfill proof –of-concept user acceptance criteria and performance of table 8.1 With completion of the survey report, areas with good and robust 3rd and 4th generation GSM mobile network will be populated accordingly with a good number of the 88% of GPRS-based POS terminals as shown in figure 8.7 while the rest GPRS–based POS terminals are retrofitted with CDMA450 and Wifi Modules for the Hybrid NPSCS + NIGCOMSAT-1R solution. To ensure successful nationwide implementation, the second phase of the NPSCS network shall include an optical fiber transmission backbone as terrestrial metro-transmission such as Gigabit Passive Optical Network (GPON) and Ethernet Passive Optical Network (EPON) to support the huge data traffic transmission as the cashless policy gains nationwide acceptability while NIGCOMSAT 2 and 3 shall be High Throughput Satellite (HTS) to complement the 5Gbps capacity of NIGCOMSAT-1R.

8.5 Conclusion

NIGCOMSAT-1R is playing a strategic role as a critical ICT backbone infrastructure to drive the national ICT revolution in providing cost effective solutions and affordable access to meet the telecommunications and electronic services of the nation as well as providing revenue diversification for the nation.

The first phase in the Banking and Financial Service inclusion strategy has greatly improved e-payment performance and efficiency. The cashless service is already in Nigeria to stay and the combined hybrid communications satellite is already providing a more robust and resilient capacity for our banking industries enabling them to offer a more seamless services with easier, faster and more efficient banking transactions including online banking services.

The NPSCS network's sustainability has been secured by using excess capacity for the strategic commercial telecommunication needs of the state and its citizens as exemplified by Nigeria's Cashless policy pilot project for financial and digital inclusion. This effectively drives the universal access goals, without exclusivity, in a continent, which still remains the least wired in the world.

The success of Nigeria's information technology policy and other developing nations with little or no terrestrial infrastructure depends greatly on satellite communications and its supporting technologies to meet short and medium term plans. Satellite Communications have a competitive advantage as they complement the present sparsely distributed terrestrial links (fiber optic) and radio link extensions contributing to accelerated economic growth, secure communications for security agencies, socio-economic development and launchpad for all-inclusive participation in the global knowledge-based economy thus accelerating sustainable growth and development.

CHAPTER 9:Conclusions, Recommendations, Challenges &Limitations and Future Research Work

9.1 Conclusion

The success of information communications technology policy of emerging nations and economies with little or no terrestrial ICT infrastructure depends greatly on satellite communications and its supporting terrestrial wireless technologies to meet short and medium term plans. Satellite Communications have a competitive advantage as they complement the present sparsely distributed terrestrial links (fiber optic) and last-mile ICT infrastructure contributing to accelerated economic growth, secure communications for security agencies, socio-economic development and launchpad for participation in the global knowledge-based economy thus accelerating sustainable growth and development by leveraging on the adequate terabyte submarine optic fiber cable at the shores of African continent made possible with favorable and ambitious ICT de-regulation and business climate to enhance and promote private participation with strong independent regulatory mechanisms to ensure compliance to Government ICT frameworks (Lawal & Chatwin, 2011). The continuously increasing demand for services provided by geostationary satellites challenges satellite system design engineers to continue to evolve an enhanced satellite bus with advanced broad-band based communication payloads to support not just broad-band capabilities but also advanced payload capabilities incorporating on-board switching techniques, multi-frequency, multi-polarization and multi-spot beams and large geographical coverage area capability with reduced on-orbit cost per transponder, increased service capacity from a single orbital slot, frequency reuse techniques especially in the utilization of the upper region of the satellite spectrum i.e Ka Band and extended orbital life. The importance of optimizing the mass/volume ratio, optimal antenna layout technique with high power delivery are key factors in providing efficient and advanced leading-edge spacecraft missions supporting high capacity capability amongst other requirements as detailed in Chapter two. A global passive communication infrastructure remains an attractive method to meet market demand for telecommunications, broadcasting, navigational and other value-added services especially in areas with inadequate terrestrial telecommunication networks. The dramatic increase in satellite communications services and resources in recent times has been made possible through High Throughput Satellites (HTS).

ICT is a development enabler. The ICT development process, and a country’s transformation to becoming an information society, can be described using the following three-stage model and contexts:

Stage 1: ICT readiness (reflecting the level of networked infrastructure and access to ICTs);

Stage 2: ICT intensity (reflecting the level of use of ICTs in the society);

Stage 3: ICT impact (reflecting the result/outcome of efficient and effective ICT use)

The situational analysis of Information Communications Technology (ICT) infrastructure in Africa was thoroughly examined and identified through a feasibility survey, needs assessment with a strong need for passive Global Space-based ICT Infrastructure (Communications Satellite System and associated technologies) as a short and medium term measure to bridge the huge digital hiatus as detailed in chapter three. A suitably designed regional communications satellite was assembled and integrated with its systems and tested before being launched to significantly improve access to telecoms services in the Sub-Saharan region, especially in rural areas as a niche market as well as address other strategic needs of the region even beyond the African continent, as detailed in chapter four with verified key performance parameters.

The NIGCOMSAT-1R Communication satellite is a passive regional global ICT infrastructure and its supporting terrestrial wireless technologies has leveraged on the grossly under-utilized fibre-optic terabyte capacity at the shores of Africa, playing a critical role in delivering ICT readiness in terms of making Internet access available to unserved and underserved areas and acting as a signpost for the e-readiness of a knowledge-based economy to drive transformation as is evident from the questionnaire response from users and subscribers to Nigerian Communication Satellite services across six geo-political regions of Nigeria with different social status. The results confirmed satisfactory quality of experience (QoE) in service delivery with excellent pre-sales and post-sales service support.

NIGCOMSAT-1R is playing a strategic role as a critical ICT backbone infrastructure to drive the national ICT revolution in providing cost effective solutions and affordable access to meet the telecommunications and electronic services of the nation as well as providing revenue diversification for the nation .

The national public security communications system (NPSCS) has been deployed and provided on CDMA- EVDO-Rev. A technology using a Service-Oriented Architecture (SOA). A total IP technology with services such as Professional GoTa command and dispatch services in response to emergency situations, prioritized communications between high level users, high quality voice service and short messaging service, high speed data service for data and surveillance and live audio/video streaming, strong encryption technology to ensure system security, emergency alarm service for the general public for pre-emptive and reactive emergencies reporting to police, video surveillance service, video conference service, coalition emergency response service, police office e-service system, training and after sales support

Highlights of the solution provided by the project include security of the GoTa system, special trunked service to enable individual, group, emergency and broadcast calls as well as calls prioritization, wireless broadband data service, 3G service, low cost network with mature products as detailed in chapter six. In addition, all network equipment complied with national environmental protection standards and poses no danger to the citizens and the environment.

The system supports an integrated intelligence system with the capability to support operations for general security alarms, emergency alarms and alarm handling, and cooperative security systems such as surveillance, interception, information gathering, analysis, preplanning, etc. The Security Communications system allows for collection, management, analysis, fusion and interpretation of relevant information to commanders, operators to guide planning, resources deployment, tactical response and strategic planning as well as information sharing and symmetry between similar organizations and other relevant organizations.

The NPSCS Service Oriented Architecture (SOA) is built on IP/MPLS bearer service oriented architecture (SOA) to integrate with the Nigerian Communications Satellite (NIGCOMSAT-1R) as a backhaul complemented with microwave topology to provide an IP cloud all over the country and facilitate rapid availability of transmission infrastructure and connection everywhere in the country and along border areas until there is adequate terrestrial metro-transmission such as fiber optical transmission; Gigabit Passive Optical Network (GPON) and Ethernet Passive Optical Network (EPON) for the huge video transmission as more cameras are deployed in the second and third phase of the project to cover Abuja, Lagos and other big cities and hot spots for the whole nation. The long-term security communications system to complement the deployed 2,000 video surveillance system pilot project requires the deployment of fibre optic links in the third phase to support the huge video traffic transmission for entire coverage of the nation.

The Nigerian National Public Security Communication Network has impacted positively on the security of the nation with social benefits. The project is economically sustainable through utilization of the network for financial and digital inclusion, viable and critical for national security and as well as enhancing the overall total productivity factor of the nation.

The first phase in the Banking and Financial Service inclusion strategy has greatly improved e-payment performance and efficiency. The cashless service is already in Nigeria to stay and the combined hybrid solution of NIGCOMSAT-1R and the National Public Security Communications System (NPSCS) is already providing a more robust and resilient capacity for our banking industries enabling them to offer more seamless services with easier, faster and more reliable banking transactions including online banking services.

The NPSCS network’s sustainability has been secured by using excess capacity for the strategic commercial telecommunication needs of the state and its citizens as exemplified by Nigeria’s Cashless policy pilot project for financial and digital inclusion. This effectively drives the universal access goals, without exclusivity, in a continent, which still remains the least wired in the world. The utilization of scarce spectrum re-farmed from the single channel Walkie-Talkie analogue system of Public Security Services (PSS) demonstrates without compromise of how such a broadband-based security network model can effectively drive the universal access goals, without exclusivity, in a continent which still remains the least wired in the world.

The strategic business model as detailed in chapter 8 also helps resolve the challenge of spectrum regulatory authorities allocating appropriate radio spectrum to enable a broadband-based network for public safety and an emergency network as it is considered waste of scarce spectrum resource by commercial mobile operators and other stakeholders to dedicate radio spectrum for occasional transmission during emergency in the 21st century. Nigeria's Cashless policy pilot project is a proof-of-concept (POC) pilot driving financial and digital inclusion for all. A requirement for nationwide coverage of financial and digital inclusion without exclusivity has been defined exploiting the combined resources of NIGCOMSAT-1R and the NPSCS network system using the country's most recent population distribution profile. To ensure successful nationwide implementation, the second phase of the NPSCS network shall include an optical fiber transmission backbone as terrestrial metro-transmission such as Gigabit Passive Optical Network (GPON) and Ethernet Passive Optical Network (EPON) to support the huge data transmission traffic as the cashless policy gains nationwide acceptability while NIGCOMSAT 2 and 3 next fleet shall be High Throughput Satellites (HTS) to complement the 5Gbps capacity of NIGCOMSAT-1R.

Communications-disaster preparedness of nations especially in the continent of Africa, exploiting communication satellite systems complemented and supported by broad-band based terrestrial wireless technologies as the first line of action to facilitate reliable and timely disaster response remains an important necessity as a key factor for success in a crisis situation and emergency management in the face of incessant natural and man-made disasters in 21st century. The Coalition Emergency Response Sub-system (CERS) of the National Public Security Communications System (NPSCS) was designed to meet such emergency requirements as detailed in this research work with six emergency communication vehicles integrated into the NIGCOMSAT-1R communications satellite to provide triple-play mobile communications services in areas not covered terrestrially by the fixed Base Transceiver station as well as areas affected by disasters. With well-integrated satellite imagery, location-based services and navigation technologies, evacuation, fire outbreaks, location of the nearest hospitals, disaster relief guidance and routes to access: aid, evacuation centers, shelters, e-health services and makeshift medicare and medication centers are easily facilitated and symmetrically co-ordinated with various emergency response teams, government agencies, aid donors at local, national and international level. To improve the precision of location based services (LBS) and navigation system utilization, we examined thoroughly the critical role that Space-Borne Oscillators play in improving Performance of Satellite-Based Augmentation Systems, guidelines for selection of appropriate oscillators, system requirements, electrical analysis and performance requirements, qualification, test and validation of such performance requirements considering its criticality in ensuring frequency stability and stability of global time-based signals viz-a-viz positioning accuracy of location based services and navigation. Improvements in space-borne oscillators not only enhances the precision of Satellite Based Augmentation systems but the general performance of the system in terms of fast acquisition of navigation signals, lower power consumption, optimized spectrum utilization, improved error rates, longer service life, improved recalibration requirements, improved navigation capability, and improved defense application requirements in terms of target detection and tracking and jamming resistance.

NIGCOMSAT-1R is a hybrid communication satellite with a piggy-back payload for navigation. The externalized 10 MHz Ultra-Stable Crystal Oscillators in 3 X 4 hybrid array configuration was qualified, tested and validated for the effectiveness of Location Based Services and navigation services as verified by the In-orbit test results detailed in chapter five including utility for Emergency and Crisis management amongst other applications.

NIGCOMSAT-1R is similar to European Geostationary Navigation Overlay Service (EGNOS) providing Navigation Overlay Service (NOS) and African's nascent contribution to the Global Navigation Satellite System (GNSS).

Definition of broadband by African nations should be led by the telecommunications regulatory agencies and commissions based on each African country's needs assessment, demand and the industry statistics at their disposal. Broadband-based communications Satellites enabled by efficient technologies allows more throughput and supporting High Definition Television transmission of the Olympic Games to people around the globe. The NigComSat-1R satellite is a strategic continental ICT and Broadcast infrastructure provider in Sub-Saharan Africa with far reaching impacts in enhancing telecommunications, broadcasting, other value-added telecommunications services, real-time monitoring services and navigation in Africa as detailed in chapter seven including transforming Nigeria from just being a consumer of bandwidth to a provider as well as a content carrier/distributor in the broadcast sector as an alternative to Digital Terrestrial Television (DTT) as we move closer to the ITU deadline for Analogue Switch-Off (ASO).

Conclusively, NIGCOMSAT-1R communications Satellite complements and connects to the National Public Security and Communications System serving not just Public Security Service (PSS) and emergency needs but remains a corner stone for universal access goals in a continent that still remains the least wired and a business model demonstrator for allocation of appropriate radio spectrum to enable a broadband-based network for public safety and an emergency with optimal utilization for strategic commercial and national needs as exemplified by Nigeria's National cashless policy implementation on public security network.

9.2 Recommendations

- The ICT readiness of any nation is a function of the level of networked telecommunications infrastructure and a determinant for the 3As for universal access goals and digital inclusion. The 3As are:
    - Availability
    - Affordability
    - Accessibility
- Convergence in communications networks through integrated connectivities (Satellite, fiber optics, radio s etc) are required to optimize national public security and emergency networks especially in Africa, which still remains the least wired continent in the world.

- Appropriate Quality of Service (QoS) and Quality of Experience implementation and suppression of latency syndrome with appropriate technologies and differentiated class of users based on traffic engineering to avoid apathy and the perception that Communications Satellite cannot deliver broadband-based services.
- The need for safety and disaster preparedness of Communication Satellite Systems with redundant backup satellites, geographically separated backup ground stations with satellite control and network operations (Lawal & Chatwin, 2010b).
- Need to canvass for support for additional satellite position filings with the International Telecommunications Union (ITU) and spectrum allocation for global satellite communications within the African continent as a disadvantaged continent requiring space-based assets and resources to bridge the digital hiatus and at the same time the need for ITU to evolve new procedures that will discourage paper-based (satellites that are never launched) communication satellites; this generally hurts the multi-billion dollar communications satellite industry.
- Adoption and replacement of low data rate public security service (PSS) such as the Walkie-talkie and Push-to-Talk (PTT) systems, the analogue trunking multi-channel system, the TETRA and iDEN (integrated digital enhanced network) networks with newer emerging broadband-based terrestrial wireless technologies that supports higher data rate for video, map and data applications.
- 20th century bureaucracies are unable to handle 21st century disasters.
- Need for effectiveness of early warning systems to a wider audience and public awareness in realizing their vulnerability to disasters.
- Need for operational and organizational hierarchy and symmetry of

assembling emergency response teams through coordinated first response (CFR) of an integrated communication system.

- Need for sufficient terrestrial spectrum resource allocation for public safety and emergency communications network with a synergetic commercial model for commercial utilization without compromise to security of the network, while enhancing self-sustenance and maintenance of the network system.

9.3 Challenges and Limitations

There are a number of challenges in the communications satellite industry. Polluted skies with space debris comprising of manmade and natural sources pose a major concern to working spacecraft in different orbits as well as during launch operations enroute to the desired orbit. However, the U.S Space Surveillance Network tracks pieces of orbital debris that are greater than 10 centimeters in diameter on a routine basis while spacecraft manufacturers have taken a number of measures to reduce number of debris produced by spacecrafts for various missions. (Rudd, 1998; Thrash, 1999).

A powerful and newly built communications satellite can be reduced to shrapnel during launch as a result of launch failure (Gifford, 1997). If the launch vehicle successfully places the communications satellite into the desired orbit, in-orbit failure may occur due to either Solar power arrays or drive mechanism similar to the NIGCOMSAT-1 failure (NIGCOMSAT-1, 2005) or propulsion or other subsystem failure or anomaly. The Communications Satellite industry is surely a very risky business as emphasized by Gifford (1997) requiring insurance but with few brokers and underwriters willing to shoulder such high risks, thus a considerable premium is paid to the few satellite insurers that are out there.

Incessant failures of launch vehicles such as the late 1990s failures of first two Delta 3 missions, Three Titan 4S, Athena 2 missions amongst others caused an unprecedented backlog in the launch of commercial and non-commercial satellites similar to a re-run of the late 1950s, when rockets regularly veered off course and exploded into a ball of flames before attention to detail was mastered through high quality design, testing procedures, launch vehicle engineering etc. (Williamson, 1999).

Limitations of Communication Satellites systems are as follows:

- Capacity, throughput (bandwidth) and power are limited by number of transponders and available power on-board a Communications satellite.
- High propagation delay due to altitudes of satellites (36,000km away from earth surface), which results to latency of about 250msecs (earth-satellite-earth). The latency doubles to 500msec for a return path transmission affecting real-time communications.
- Orbital slots of COMSATs are limited and scarce resources offered on first come, first serve basis by ITU.

- Satellite resources and capacities are also limited by frequencies in Fixed Satellite Service (FSS) and Broadcast Satellite Service (BSS) range.
- Satellite Service Performance and quality of service (QoS) are easily affected by changes in weather e.g rain attenuation especially in Ku and Ka band range, non-clear sky (cloudy) conditions.

9.4 Future Research

High throughput satellites offer significant opportunities for the future; current 15kW systems can support data rates upto 140 Gb/s. Terabyte satellites require the development of key technologies, much of which is already emerging. Such as triple junction solar panels offering efficiencies upto 42%. 50 kW satellites will be able to deliver huge bandwidths facilitating global communication systems that will secure low cost high bandwidth to any location on the planet. The following future research directions are enabling technologies for highly optimized High Throughput Satellites as Global non-passive (active) ICT spaced-based Infrastructure:

- Flexible Reconfigurable Payload Technologies for High Throughput Satellites to Meet Future Business Needs by exploiting steerable antenna pointing mechanism (APM), periodic and aperiodic Direct Radiating Array (DRA) antennas, multi-port high power amplifiers, flexible channelization and routing using onboard routers, on-board processors, switches, digital signal processing capability and multi-feed per beam antenna technologies (Lawal and Chatwin, 2010a).
- Propagation delay-tolerant and secure virtual networks in real time by implementation of on-board routers and processors support routing of voice, video and data communications to multiple areas in one-hop.
- The Ka band ushering additional bandwidth to satellite operators and communications satellite industry through the use of new HTS systems. However, it is affected by atmospheric propagation effects and Fade mitigation techniques helped tremendously in signal fades originating from propagation effects. Improved modelling of propagation effects with meteorological database on a region by region basis will improve our knowledge of satellite systems behaviour and our ability to combat rain attenuation in real time to optimize link availability as well as enhanced availability estimations for definite service level agreements (SLAs).
- High Powered Ka band waveguides and Isolator technologies with improved power handling and matching capability operating without Multipaction, Passive Intermodulation (PIM), thermal breakdown or non-liner distortions and effects.
- Use of Micro-Electro-Mechanical systems (MEMs) with a drastic reduction in mass, volume and power requirement in radio frequency switches and filters for

channelization, multiplexing and demultiplexing of radio frequency signals of the repeater subsystem with enhanced RF performance and reduced insertion loss.

- High packaging density of RF devices, switches and amplifiers with optimal mass/volume ratio as well as Use of radiation hardened Field Programmable Gate Array (FPGA) devices.
- Use of high temperature super conducting materials (HTS) for filters, input multiplexers (IMUX) , radiation hardened and advanced Monolithic Microwave Integrated Circuits (MMICs) using multi-layers, development of high power, temperature compensated cavity filters for output multiplexers (OMUX) etc.
- Research on high powered dual multiplexers offering significant improvements in size, mass and insertion loss with optimized channel filter for multi-beam communications satellite system architecture.
- Use and implementation of effective plasma (Electric) Thrusters in modern satellite bus (platform) in place of propellant and chemical-based system as propulsion subsystem lowering propellant mass requirements for the spacecraft mission constitutes between 55%-65% of the total mass of a most geostationary satellite spacecraft.
- Improved high performance battery technologies with improved depth of discharge, longer charge/discharge life cycle, minimal thermal and heat dissipation.
- Advanced on-board resource management with appropriate bandwidth on-demand (BoD) algorithm for advanced Multi-beam star/meshed Networks based on DVB-RCS2 in HTS Communications Satellite for optimal performance.
- Research work on low-cost commercial anti-interference and anti-jamming technical solutions to guarantee high level of quality of service in crisis areas and denial-of-service (DOS) territories exploiting multi-beam antenna (MBA), spatial processing, beam-shaping, diversity and beam forming technology on antenna sub-system, receivers; RF/Digital technique using frequency agile converter (FAC) on RF processing equipment including at Digital Signal Processing Level using Time Domain Adaptive filtering. Implementation of Digital Video Broadcasting Carrier Identification (DVB-CID) with global Unique identifier (GUI) as better way of identifying and locating non-malicious radio frequency interference (RFI) of digital satellite signals and thus lowering RFI events.
- Electronically controlled or hybrid solution of mechanics and electronics conformal phased-array antennas for mobile and airborne satellite communication systems with strict control of beamwidth, beam pointing accuracy and sidelobe performance.
- Future research studies to achieve Terabit/s geostationary satellite system through improving technologies at payload and platform level several multi-feed reflector antennas, optical feeder links and ground segment gateway stations.

- Design and implementation of HTS-based NIGCOMSAT 2 & 3 to complement and serve as a backup to NIGCOMSAT-1R operations, capacity and capability.
- Multi-band and versatile Communication Satellite terminal equipment i.e Ku/Ka Band equipment and devices.
- Design and implementation of optic-fiber backbone topology to complement the microwave and NIGCOMSAT-1R backbone topology in the second and third phase of NPSCS network.
- Research work on software-defined radio (SDR) GNSS receivers to ensure interoperability with global and regional GNSS systems and general performance of the system in terms of fast acquisition and detection of navigation signals, lower power consumption, optimized spectrum utilization, improved error rates, longer service life, improved navigation capability, improved defense application requirements in terms of target detection and tracking.
- Integration of variants of mobile communication satellite last-mile equipment models named "SATCOM CRISIS MANAGER" for Emergency Communication Preparedness of African Countries exploiting Communication Satellites as illustrated below in figure 9.1:

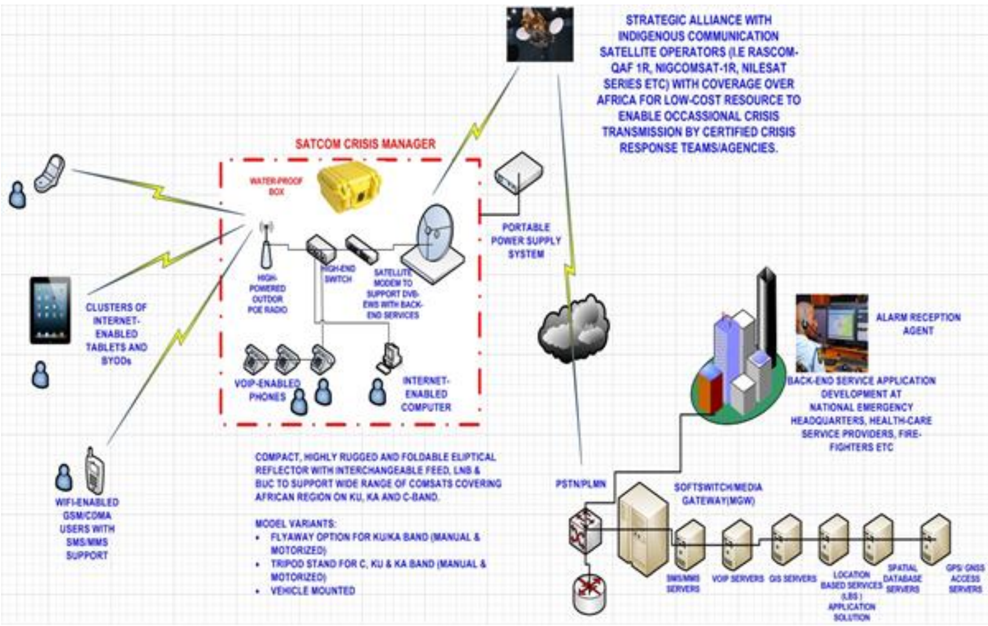


Figure 9.1:"SATCOM CRISIS MANAGER" for Emergency Communication Preparedness of African Countries exploiting Communication Satellites with terrestrial wireless technologies.

- Collaborative Research in Software-Defined Radios (SDR) and Cognitive Radios (CR) for Very Small Aperture Terminal (VSAT) hardware to promote seamless interoperability at different frequencies and with different communications satellites especially for the SATCOM CRISIS MANAGER.

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Appendices

Appendix A

1.0 **Ku Band Antenna and Payload Design with Gain and Loss Computations of NIGCOMSAT-1R.**

Frequency range

Down link 12.500～12.725GHz

Uplink 14.00～14.25Hz

Saturation Flux Density

-(77 + G/T) dBW/m^2 ~ -(97 + G/T) dBW/m^2

TWTA Output Power

150 Watts

Generally, repeater gain can be evaluated from the difference between input power and the output power. Given that input power and output power are represented by Pin and Pout respectively, the total gain in dB is given by:

Total gain (dB) = [Pout] – [Pin]

NB: In this thesis, brackets are used to denote decibel quantities using the basic power definition. In calculating repeater gain, the gain of the receiver, the gain of the power amplifier, input loss, middle loss and output loss are required. Figure A1.1 illustrates simply the sources of these gains and losses as analyzed from the block diagram of the Ku Band repeater in figure 4.1 of chapter 4 in the main text.

Please note that the lengths of the coaxial cables and waveguides in the diagram do not necessarily represent the actual proportions in the satellite-harness layout.

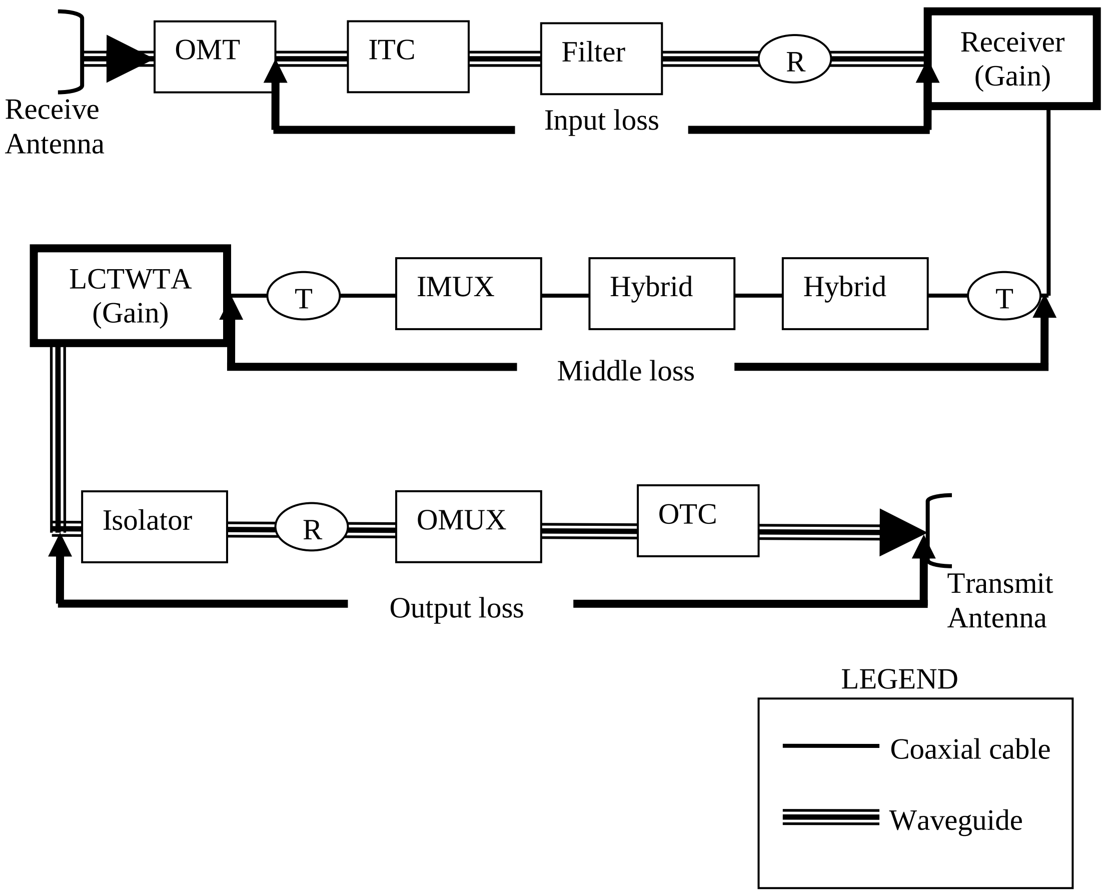

Figure A1.1: Diagram of Repeater loss path from Input to Output

Repeater input loss includes the loss of input test coupler, input filter, receiver input switcher and the connection waveguide.

The middle loss consists of the loss from the receiver output port to the power amplifier input port.

The output loss includes the loss of high power isolators, high power switches, OMUX, output test coupler (OTC) and the connection waveguides.

1.1 Input Loss and T Budget of Ku Band Repeater

The table A1.1 below gives a summary of the insertion losses of various repeater input equipment from which the total input loss and T budget of Ku band for NIGCOMSAT-1R is calculated. The insertion losses are inherited based on the DFH-4 Chinese Satellite bus for on System Noise Temperature (T) budget but with consideration to average ambient (environmental) temperature of Sub-Saharan Africa. The standard atmospheric temperature at mean sea level is 15 degrees Celsius according to the International Commission for Air Navigation (ICAN), and Sub-Saharan African atmospheric temperature at mean sea level was evaluated to be 17 degrees Celcius and thus 290K deduced for computations as thermal noise due to earth in Sub-Saharan region (Mustafa, n.d). The Chinese DFH-4 satellite bus is similar to other commercial high powered geostationary satellite bus's such as Spacebus 4000 of Alcatel Alenia Space, 702 Family of Boeing, 1300 Bus of Space Systems Loral, A2100 family of Lockheed Martin, E3000 Bus of EADS Astrium and the Express Series Satellite Bus of Russia (Lawal, 2009).

Table A1.1: NIGCOMSAT-1R Ku Band T Budget

S/N	**Units**	**Insertion loss (dB)**
1	Waveguide	0.4
2	Input Test Coupler	0.1
3	Input Pre-Filter	0.6
4	Waveguide	0.1
5	R switch	0.2
6	Waveguide	0.1
7	**Total Input loss**	**1.5**
8	10log290	**24.6**
9	Noise figure of receiver	**1.9**
10	**T (Noise Temperature)**	**1.5+24.6+1.9 = 28.0**
		28.0

Sub-Saharan Atmospheric Temperature at mean sea level as thermal noise due to earth= 290K

1.2 G/T Budget of Ku Band Repeater

To determine a suitable gain for the receiving antenna, GR, the equations relating GR, T, and G/T are as deduced below :

Generally speaking,

[G/T] = [GR] – [T] Eqn. A1.2.1

[GR] = [G/T] + [T] Eqn. A1.2.2

A tolerance margin is added to the specified G/T, thus:

[G/T] = [G/T]spec + [margin] Eqn.A1.2.3

Substituting equation A1.2.3 into equation A1.2.2 above gives:

[GR] = [G/T]spec + [margin] +[T] A1.2.4

Utilizing the spec values of G/T as provided in Table A1.2, The gains of the Ku Antennas are as follows:

Gain of Ku Receive Antenna

Beam 1(ECOWAS 1) Zone 1:

Let [margin] = 0dB

[GR] = 5.0 + 0.0 + 28 dB

[GR] = 33dB

Beam 1(ECOWAS 1) Zone 2:

Let [margin] = 0.6dB

[GR] = 4.0 + 0.6 + 28 dB

[GR] = 32.6dB

Beam 2 (ECOWAS 2):

Let [margin] = 0.1dB

[GR] = 1+ 0.1 + 28 dB

[GR] = 29.1dB

Beam 3(East Asia Beam) Zone 1:

Let [margin] = 0dB

[GR] = 6.5 + 0.0 + 28 dB

[GR] = 34.5dB

Beam 3 (East Asia Beam) Zone 2:

Let [margin] = 0.0dB

[GR] = 2.0 + 0.0 + 28 dB

[GR] = 30.0dB

With the T budget in Table A1.1, the expected G/T in dB/K is presented in Table A1.2.

Table A1.2: Summary of NIGCOMSAT-1R Ku Band G/T Budget

Beam	**G_R (dBi)**	**T (K)**	**G/T (dB/K)**	**G/Tspec (dB/K)**	**Margin (dB)**
1 (Zone 1)	33.0	28.0	5.0	5.0	0.0
1(Zone 2)	32.6	28.0	4.6	4.0	0.6
2	29.1	28.0	1.1	1	0.1

3 (Zone 1)	34.5	28.0	6.5	6.5	0.0
3 (Zone 1)	30.0	28.0	2.0	2.0	0.0

Summary of computed Ku Band G/T Budget for NIGCOMSAT-1R is presented in table A1.2.

1.3 Output Loss and Power Dissipation Budget of Ku Band Repeater

As stated earlier in section 1.0 & 1.1 and illustrated in figure A1.1, the output loss includes the loss of high power isolators, high power switches, OMUX, output test coupler (OTC) and the connection waveguides.

These losses are in decibel (dB), while the power dissipation equivalents are in Watts, W.

Equation for heat dissipation analysis is:

$Pdis = Pin - (Pin * 10^{(-IL/10)})$ Eqn A1.3.1

Or generally speaking,

$Pdis = Pin - Pout$ where $Pout = Pin * 10^{(-IL/10)}$ Eqn A1.3.2

Keys for the equation

Pdis = Power dissipated (W)

Pin = Input Power

Pout = Output Power

IL = Insertion Loss

For the thesis and typical of spacecraft design, the method below is used as it gives a good and better analytical approximate.

Pdis = Pin – Pout

Output power and dissipated power are deduced using eqn A1.3.2 with values of unit loss in table A.1.3.

Given that:

Pin (TWTA) = 150W

[Pin] = 10log150 = 21.76dB

[Loss] (Waveguide) = 0.1dB

Hence,

[Pout] = 21.76 – 0.1 =21.66dB

Pout (W) = $10^{(21.66/10)}$

Pout (W) = 146.55W

Therefore,

Pdis = Pin – Pout

Pdis = 150 – 146.55W

Pdis = 3.45W

For the next stage of power dissipation, the input power is the output power from the previous stage.

That is; Pin(stage 2) = Pout(stage 1) as illustrated in diagram of figure A1.2. Table A1.3 gives summary of Ku Band Output losses and power dissipation budget based on 150W TWTA power amplifier.

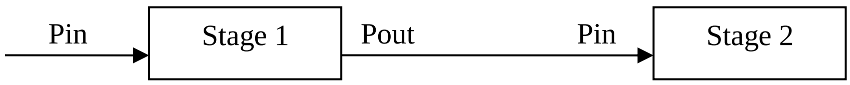

Figure A1.2: Illustration of Power Dissipation Analysis in Power Amplifiers

Pin (Isolator) =146.55W

[Pin] = 21.66dB

[Loss] (Isolator) = 0.15dB

[Pout] = 21.66 – 0.15 = 21.51dB

Hence,

Pout (W) = $10^{(21.51/10)}$

Pout (W) = 141.58W

Therefore,

Pdis = Pin – Pout

Pdis (W) = 146.55 – 141.58W

Pdis = 4.97W

Table A1.3: Summary of Ku band Output Losses and Power Dissipation Budget.

S/N	**Units**	**Loss (dB)**	**Power Dissipation (W)**
	LCTWTA output power (150W)		
1	Waveguide	0.1	3.45

2	Isolator	0.15	4.97
3	Waveguide	0.25	7.92
4	High power R switch	0.1	3.04
5	Waveguide	0.1	2.98
6	Multiplexer	0.95 (one channel)	25 (one channel)
7	Output Test Coupler	0.1 (one channel)	2.34 (one channel)
8	Waveguide	0.25 (channel)	5.61 (one channel)
	Total	**2.0**	

1.4 EIRP Budget of Ku Band Repeater of NIGCOMSAT-1R

Generally, the Equivalent Isotropic Radiated Power (EIRP) is determined by the sum in dB of the transmit power; PT, gain of transmit GT, and loss from passive components of the transmit chain. The loss is negated as seen in equation A1.4.1:

[EIRP] = [PT] + [GT] – [Losses]　　Eqn A1.4.1

From equation A1.4.1, the gain of the transmitting antenna can be easily calculated. Making GT the subject of the formula gives:

[GT] = [EIRP] – [PT] + [Losses]　　Eqn A1.4.2

The designed EIRP for the budget will be the specified EIRP, [EIRP] spec plus a tolerance margin.

[EIRP] = [EIRP]spec + [margin]　　Eqn A1.4.3

Therefore, substituting eqn A1.4.3 into eqn A1.4.2 gives

[GT] = [EIRP]spec +[margin] – [PT] + [Losses]　　Eqn A1.4.4

Gain of Ku Beams are deduced using eqn. A1.4.4 with specified EIRPs in Table A1.4, losses in table A1.4 etc.

Gain of Ku Beam Transmit Antenna

Let the [margin] = 0dB

Beam 1 (Zone 1):

[EIRP]spec = 53dBW

[EIRP] = 53 + 0 = 53dB

[GT] = 53 – 21.7 + 2 dB

[GT] = 33.3dB

Beam 1 (Zone 2):

[EIRP]spec = 52dBW

[EIRP] = 52 + 0.5= 52.5dB

[GT] = 52.5 – 21.7 + 2 dB

[GT] = 32.8dB

Beam 2:

[EIRP]spec = 48dBW

[EIRP] = 48.0+ 0.1 = 48.1dB

[GT] = 48.1 – 21.7 + 2 dB

[GT] = 28. 4dB

Beam 3 (Zone 1):

[EIRP]spec = 52dBW

[EIRP] = 52 + 0 = 52dB

[GT] = 52 – 21.7 + 2 dB

[GT] = 32.3dB

Beam 3 (Zone 2):

[EIRP]spec = 48dBW

[EIRP] = 48 + 0.0= 48dB

[GT] = 48 – 21.7 + 2 dB

[GT] = 38.3dB

Thus, summary of EIRP Budget of KU Band Repeater for NIGCOMSAT-1R is as presented in Table A1.4.

Table A1.4: Summary of EIRP Budget of Ku Band Repeater.

S/N	Beam	LCTWTA Power (dB)	G_T (dBi)	Loss (dB)	EIRP (dBW)	EIRPspec (dBW)	Margin (dBW)
1	1 (Zone 1)	21.7	33.3	2.0	53.0	53.0	0.0

2	1 (Zone 2)	21.7	32.8	2.0	52.5	52.0	0.5
3	2	21.7	28.4	2.0	48.1	48.0	0.1
4	3 (Zone 1)	21.7	32.3	2.0	52.0	52.0	0.0
5	3 (Zone 2)	21.7	28.3	2.0	48.0	48.0	0.0

1.5 Gain Budget of Ku Band Repeater

The power, $P_{R,}$ delivered to a matched receiver is the power flux density, Ψ or Saturated Flux Density (SFD), multiplied by the effective aperture, of the receiving antenna, A_{eff}, which is given by the equation A.1.5.1:

P_R = SFD * A_{eff} A1.5.1

$A_{eff} = G_R * (4\pi /\lambda^2)^{-1}$ A1.5.2

Hence with substitution of eqn A1.5.2 into eqn A1.5.1

P_R = SFD * $G_R * (4\pi /\lambda^2)^{-1}$ A1.5.3

Where,

$G_{R\,=}$ gain of receiving antenna (minimum)

λ = wavelength of uplink signal in meters (m)

$\lambda^2/4\pi$ = effective area of an isotropic antenna

Re-writing equation A1.5.3 in dB format:

$[P_R] = [SFD] + [G_R] - [4\pi /\lambda^2]$ dBW A1.5.4

Converting to dBm gives,

$[P_R] = [SFD] + [G_R] - [4\pi /\lambda^2] + 30$ dBm A1.5.5

Ku band uplink frequency range requirement is 14.0 ~ 14.25 GHz. In evaluating P_R therefore, the least frequency is used so as to provide a reasonable design margin.

$c = f * \lambda$

Therefore,

$\lambda = c/f$

$c = 3 \times 10^8$m/s

$f = 14.0$GHz $= 14 \times 10^9$Hz

$\lambda = 0.021$m

Thus,

$(4\pi /\lambda^2)^{-1} = 3.66 \times 10^{-5}\text{m}^2$

$[4\pi/\lambda^2] = 44.3$dBW

The requirement specified different G/T values for beam 1 and beam 2. To get the value of the Ψ or SFD needed for our calculation, the least G/T will be used so as to ensure enough margins. Hence, if the least G/T gives an acceptable repeater gain, it can be concluded that the higher G/T values will do the same.

Thus, from the specified SFD range of section A1.0

[SFD] = - (74 + G/T) ~ - (80 + G/T)

[SFD] = - (74 + 1.0) ~ - (80 + 1.0)

[SFD] = -75 ~ -81 dBW/m^2

Using eqn A1.5.5

$[P_R] = [SFD] + [G_R] - [4\pi/\lambda^2] + 30$ dBm

$[P_R]$ = (-75 ~ -81) + 30.75 – 44.4 + 30 dBm

$[P_R]$ = -60.45 ~ -66.45dBm

Table A1.5: Summary of Ku Band Gain Budget for NIGCOMSAT-1R

S/N	**Item**	**Gain (dB)**	**Power (dBm)**
1	G/T (dB/K)	Beam 1 = 4.0 Beam 2 = 1.0	
2	SFD (dBW/m2)	-(77 + G/T) ~ -(97 + G/T)	
3	[4π/λ2] (dB/m2)	44.3	
4	G_R (dBi)	29.0	
5	**Input power (dBm)**		SFD+G_R-(4π/λ2) **-63.3~ -83.30**
6	Input loss (dB)	-1.5	-64.80 ~ -84.80
7	Receiver gain (dB)	62	-2.8 ~ -22.8
8	Cable loss /middle loss (dB)	-19.44	-22.24 ~ -42.24
9	LCTWTA gain (dB)	78.2-84.2	51.76
10	Output loss (dB)	-2.0	
11	**Output power (dBm)**		**49.76**
	Total gain (dB)	Output power – Input power 49.76– (-63 ~ -83)	**112.76 ~ 132.76**

Based on table A1.5, the value of the repeater gain is between **112.76 dBm to 132.76 dBm.**

Appendix B

2.0 C Band Antenna and Payload Design with Gain and Loss Computations of NIGCOMSAT-1R

Frequency range

Down link 3.400～3.600GHz

Uplink 6.425～6.625Hz

Saturation Flux Density

-(78.5 + G/T) dBW/m^2 ~ -(98.5 + G/T) dBW/m^2

TWTA Output Power

60 Watts

2.1 Input Loss and T Budget of C Band Repeater

The table B2.1 below gives a summary of the insertion losses of various repeater input equipment from which the total input loss and T budget of C band for NIGCOMSAT-1R is calculated. The insertion losses are inherited based on DFH-4 Chinese Satellite bus for on System Noise Temperature (T) budget but with consideration to average ambient (environmental) temperature of Sub-Saharan Africa. The standard atmospheric temperature at mean sea level is 15 degrees celcius according to the International Commission for Air Navigation (ICAN), and Sub-Saharan African atmospheric temperature at mean sea level was evaluated to be 17 degrees Celcius and thus 290K deduced for computations as thermal noise due to earth at Sub-Saharan region (Mustafa, n.d).

Table B2.1: NIGCOMSAT-1R Ku Band T Budget

S/N	Units	Insertion loss (dB)
1	Waveguide	0.3
2	Input Test Coupler	0.1
3	Input Pre-Filter	0.6
4	Waveguide	0.1
5	R switch	0.2
6	Waveguide	0.2
7	**Total Input loss**	**1.5**
8	10log290	**24.6**
9	Noise figure of receiver	**1.8**
10	**T (Noise Temperature)**	**1.5+24.6+1.8 = 27.9**
		27.9

Sub-Saharan Atmospheric Temperature at mean sea level as thermal noise due to earth = 290K

2.2 G/T Budget of C Band Repeater

To determine a suitable gain for the receiving antenna, G_R, the equation relating G_R, T, and G/T are as deduced below (Lawal, 2009):

Generally speaking,

$[G/T] = [G_R] – [T]$ Eqn.B2.2.1

$[G_R] = [G/T] + [T]$ Eqn.B2.2.2

A tolerance margin is added to the specified G/T, thus:

$[G/T] = [G/T]spec + [margin]$ Eqn. B2.2.3

Substituting equation B2.2.3 into equationB2.2.2 above gives:

$[G_R] = [G/T]spec + [margin] +[T]$ Eqn.B2.2.4

Utilizing Eqn. B2.2.4 with specified values of G/T in dB/K of table B2.2. The gains of the C-Band Receive Antenna are as below and results in Table B2.2:

Gain of C Receive Antenna

Beam 1(ECOWAS 1) Zone 1:
Let [margin] = 0.1dB
$[G_R] = 1.0 + 0.1 + 27.9$ dB
$[G_R] = 29$dB

Beam 1(ECOWAS 1) Zone 2:
Let [margin] = 0.1dB
$[G_R] = -5.0 + 0.1 + 27.9$ dB
$[G_R] = 23.0$dB
With the T-budget in table B2.1, the expected G/T in dB/K is presented in Table B2.2

Table B2.2: Summary of NIGCOMSAT-1R C Band G/T Budget

Beam	**G_R (dBi)**	**T (K)**	**G/T (dB/K)**	**G/Tspec (dB/K)**	**Margin (dB)**
1 (Zone 1)	29.0	27.9	1.1	1.0	0.1
1(Zone 2)	23	27.9	-4.9	-5.0	0.1

Summary of computed C Band G/T Budget for NIGCOMSAT-1 is presented in table B2.2.

2.3 Output Loss and Power Dissipation Budget of C Band Repeater

As stated earlier in section 1.0 & 1.1 and illustrated in figure A1.1 of Appendix A, the output loss includes the loss of high power isolators, high power switches, OMUX, output test coupler (OTC) and the connection waveguides.
These losses are in decibel (dB), while the power dissipation equivalents are in Watts, W.

Equation for heat dissipation analysis is:

$P_{dis} = P_{in} - (P_{in} * 10^{(-IL/10)})$ EqnB2.3.1

Or generally speaking,
$P_{dis} = P_{in} - P_{out}$ where Pout = Pin * $10^{(-IL/10)}$ EqnB2.3.2

Keys for the equation
P_{dis} = Power dissipated (W)
P_{in} = Input Power
P_{out} = Output Power
IL = Insertion Loss

For the thesis and typical of spacecraft design, the method below is used as it gives a good and better analytical approximate.
$P_{dis} = P_{in} - P_{out}$

Output power and dissipated power are deduced using eqn B2.3.2 with values of unit loss in Table B2.3

Given that:
P_{in} (TWTA) = 60W
[P_{in}] = 10log60 = 17.78dB
[Loss] (coaxial cable) = 0.2dB
Hence,
[P_{out}] = 17.78 – 0.2 =17.58dB
P_{out} (W) = $10^{(17.58/10)}$
P_{out} (W) = 57.28W
Therefore,
$P_{dis} = P_{in} - P_{out}$
P_{dis} = 60 – 57.27W
P_{dis} = 2.7W
P_{in} (Isolator) =57.27W
[P_{in}] = 17.58dB
[Loss] (Isolator) = 0.25dB
[P_{out}] = 17.58 – 0.25 = 17.33dB
Hence,
P_{out} (W) = $10^{(17.33/10)}$
P_{out} (W) = 54.08W

Therefore,

$P_{dis} = P_{in} - P_{out}$

P_{dis} (W) = 57.27 – 54.08W

P_{dis} = 3.2W

For the next stage of power dissipation, the input power is the output power from the previous stage.

That is; P_{in}(stage 2) = P_{out}(stage 1) as illustrated in diagram of figure A1.2 of Appendix A. Table 2.3 gives summary of C Band Output losses and power dissipation budget based on 60W TWTA power amplifier.

Table B2.3: Summary of C Band Output Losses and Power Dissipation Budget.

S/N	**Units**	**Loss (dB)**	**Power Dissipation (W)**
	LCTWTA output power (60W)		
1	Coaxial Cable	0.2	2.7
2	Isolator	0.25	3.2
3	Coaxial Cable	0.3	3.6
4	High power T switch	0.2	2.3
5	Coaxial Cable	0.25	2.7
6	Multiplexer + Harmonic Filter	0.65 (single channel)	6.3 (single channel)
7	Waveguide Circulator	0.1 (single channel)	0.9 (single channel)
8	Output Test Coupler	0.05 (single channel)	0.4 (single channel)
9	Waveguide	0.2 (single channel)	1.7 (single channel)
	Total	**2.2**	

2.4 EIRP Budget of C Band Repeater of NIGCOMSAT-1R

Generally, the Equivalent Isotropic Radiated Power (EIRP) is determined by the sum in dB of the transmit power; P_T, gain of transmit G_T, and loss from passive components of the transmit chain. The loss is negated as seen in equation B2.4.1:

$[EIRP] = [P_T] + [G_T] - [Losses]$ Eqn B2.4.1

From equation B2.4.1, the gain of the transmitting antenna can be easily calculated. Making G_T the subject of the formula gives:

$[G_T] = [EIRP] - [P_T] + [Losses]$ Eqn B2.4.2

The designed EIRP for the budget will be the specified EIRP, [EIRP]spec plus a tolerance margin.

$[EIRP] = [EIRP]_{spec} + [margin]$ Eqn B2.4.3

Therefore, substituting eqn B2.4.3 into eqn B2.4.2 gives

$[G_T] = [EIRP]_{spec} + [margin] – [P_T] + [Losses]$ Eqn B2.4.4

Gain of C Beam is deduced using eqn.B2.4.4 with specified EIRPs in Table B2.4

Gain of C Beam Transmit Antenna

Let the [margin] = 0.5dB

Beam 1 (Zone 1):

$[EIRP]_{spec}$ = 41dBW

[EIRP] = 41 + 0.5 = 41.5dB

$[G_T]$ = 41.5 – 17.7 + 2.2 dB

$[G_T]$ = 26dB

Beam 1 (Zone 2):

$[EIRP]_{spec}$ = 35dBW

[EIRP] = 35 + 0.5= 35.5dB

$[G_T]$ = 35.5 – 17.7 + 2.2 dB

$[G_T]$ = 20dB

Thus, summary of EIRP Budget of C Band Repeater for NIGCOMSAT-1R is as presented in Table B2.4.

Table B2.4: Summary of EIRP Budget of C Band Repeater.

S/N	Beam	LCTWTA Power (dB)	G_T (dBi)	Loss (dB)	EIRP (dBW)	EIRPspec (dBW)	Margin (dBW)
1	1 (zone 1)	17.7	26	2.2	41.5	41	0.5
2	1 (Zone 2)	17.7	20	2.2	35.5	35	0.5

2.5 Gain Budget of C Band Repeater

The power, P_R, delivered to a matched receiver is the power flux density, Ψ or Saturated Flux Density (SFD), multiplied by the effective aperture, of the receiving antenna, A_{eff}, which is given by the equation B2.5.1:

$P_R = SFD * A_{eff}$ Eqn B2.5.1

$A_{eff} = G_R * (4\pi /\lambda^2)^{-1}$ Eqn B2.5.2

Hence with substitution of eqnB 2.5.2 into eqn B2.5.1

$P_R = SFD * G_R * (4\pi /\lambda^2)^{-1}$ Eqn B2.5.3

Where,

G_R = gain of receiving antenna (minimum)

λ = wavelength of uplink signal in meters (m)

$\lambda^2/4\pi$ = effective area of an isotropic antenna

Re-writing equation 2.5.3 in dB format:

$[P_R] = [SFD] + [G_R] - [4\pi/\lambda^2]$ dBW Eqn B2.5.4

Converting to dBm gives,

$[P_R] = [SFD] + [G_R] - [4\pi/\lambda^2] + 30$ dBm Eqn B2.5.5

C band uplink frequency range requirement is 6.425 ~ 6.625 GHz. In evaluating P_R therefore, the least frequency is used so as to provide a reasonable design margin.

$c = f * \lambda$

Therefore,

$\lambda = c/f$

$c = 3 \times 10^8$m/s

$f = 6.425$GHz $= 6.425 \times 10^9$Hz

$\lambda = 0.047$m

Thus,

$(4\pi/\lambda^2)^{-1} = 1.73 \times 10^{-4}$m^2

$[4\pi/\lambda^2] = 37.7$dBW

The requirement specified different G/T values for beam 1 (zone1) and beam 1 (zone 2). To get the value of the Ψ or SFD needed for our calculation, the least G/T will be used so as to ensure enough margins. Hence, if the least G/T gives an acceptable repeater gain, it can be concluded that the higher G/T values will do the same.

Thus, from the specified SFD range of section B2.0

[SFD] = - (78.5 + G/T) ~ - (98.5+ G/T)

[SFD] = - (78.5 + (-5.0)) ~ - (98.5 + (-5.0))

[SFD] = -73.5 ~ -93.5 dBW/m^2

Using Eqn B2.5.5

$[P_R] = [SFD] + [G_R] - [4\pi/\lambda^2] + 30$ dBm

$[P_R]$ = (-73.5 ~ -93.5) + 23 – 37.7 + 30 dBm

$[P_R]$ = -58.2 ~ -78.2dBm

Table B2.5: Summary of C Band Gain Budget for NIGCOMSAT-1R

S/N	Item	Gain (dB)	Power (dBm)
1	G/T (dB/K)	Beam 1 = 1.0 Beam 2 = -5.0	
2	SFD (dBW/m^2)	-(78.5 + G/T) ~ -(98.5 + G/T)	
3	$[4\pi/\lambda^2]$ (dB/m^2)	37.7	
4	G_R (dBi)	23.0	
5	**Input power (dBm)**		SFD+G_R-($4\pi/\lambda^2$) **-58.2~ -78.2**

6	Input loss (dB)	-1.5	-59.7 ~ -79.7
7	Receiver gain (dB)	60	-0.3 ~ -19.7
8	Cable loss /middle loss (dB)	-14.52	-14.22 ~ -34.22
9	LCTWTA gain (dB)	62-82	47.78
10	Output loss (dB)	-2.2	
11	**Output power (dBm)**		**45.58**
	Total gain (dB)	Output power – Input power 45.58– (-58.2 ~ -78.2)	**103.78 ~ 123.78**

Based on table B2.5, the value of the repeater gain is between **103.78dBm to 123.78dBm.**

Appendix C

3.0 Ka Band Antenna and Payload Design with Gain and Loss Computations of NIGCOMSAT-1R

Frequency range

Down link 19.000～20.200GHz
Uplink 28.800～30.000Hz

Saturation Flux Density

-(63 + G/T) dBW/m^2 ~ -(83 + G/T) dBW/m^2

TWTA Output Power

70 Watts for both Trunking and Broadcasting

3.1 Input Loss and T Budget of Ka Band Repeater

The table C3.1 below gives a summary of the insertion losses of various repeater input equipment from which the total input loss and T budget of Ka Band for NIGCOMSAT-1R is calculated. The insertion losses are inherited based on DFH-4 Chinese Satellite bus for on System Noise Temperature (T) budget but with consideration to average ambient (environmental) temperature of Sub-Saharan Africa.

Table C3.1: NIGCOMSAT-1R Ka Band T Budget

S/N	Units	Insertion loss (dB)
1	Waveguide	0.6
2	Input Test Coupler	0.2
3	Input Pre-Filter	0.5
4	Waveguide	0.2
5	R switch (C Switch)	0.3
6	Waveguide (cable)	0.2
7	**Total Input loss**	**2.0**
8	10log290	**24.6**
9	Noise figure of receiver	**2.6**
10	**T (Noise Temperature)**	**2.0+24.6+2.6 = 27.9**
		29.2

Sub-Saharan Atmospheric Temperature at mean sea level as thermal noise due to earth = 290K

3.2 G/T Budget of Ka Band Repeater

To determine a suitable gain for the receiving antenna, G_R, the equation relating G_R, T, and G/T are as deduced below:

Generally speaking,
$[G/T] = [G_R] - [T]$ Eqn C3.2.1
$[G_R] = [G/T] + [T]$ Eqn C3.2.2

A tolerance margin is added to the specified G/T, thus:

$[G/T] = [G/T]spec + [margin]$ Eqn C3.2.3

Substituting equation C3.2.3 into equation C3.2.2 above gives:

$[G_R] = [G/T]spec + [margin] + [T]$ Eqn C3.2.4

Utilizing the spec values of G/T in dB/K as provided in Table C3.2, the gains of the Ka Antennas are as follows :

Gain of Ka Antenna

Trunking Beam (Europe):
Let [margin] = 0.1dB
$[G_R]$ = 9.0 + 0.1 + 29.2 dB
$[G_R]$ = 38.3dB

Trunking Beam (South Africa)):
Let [margin] = 0.1dB
$[G_R]$ = 9.0 + 0.1 + 29.2 dB
$[G_R]$ = 38.3dB

Trunking Beam (Nigeria):
Let [margin] = 0.8dB
$[G_R]$ = 9.0 + 0.8 + 29.2 dB
$[G_R]$ = 39dB

Broadcast Beam (Nigeria):
Let [margin] = 0.8dB
$[G_R]$ = 9.0 + 0.8 + 29.2 dB
$[G_R]$ = 39dB

With the T-budget in Table C3.1, the expected G/T in DB/K is represented in Table C3.2.

Table C3.2: Summary of NIGCOMSAT-1 Ka Band G/T Budget

Beam	G_R (dBi)	T (K)	G/T (dB/K)	G/T_{spec} (dB/K)	Margin (dB)
Trunking Beam (Europe)	38.3	29.2	9.1	9.0	0.1
Trunking Beam (South Africa)	38.3	29.2	9.1	9.0	0.1
Trunking Beam	39	29.2	9.8	9	0.8

(Nigeria)					
Broadcast Beam	39	29.2	9.8	9	0.8

Summary of computed Ka Band G/T Budget for NIGCOMSAT-1R is presented in table C3.2.

3.3 Output Loss and Power Dissipation Budget of Ka Band Repeater

As stated earlier in section A1.0 & A1.1 and illustrated in figure A1.1 of Appendix A, the output loss includes the loss of high power isolators, high power switches, OMUX, output test coupler (OTC) and the connection waveguides.
These losses are in decibel (dB), while the power dissipation equivalents are in Watts, W.

Equation for heat dissipation analysis is:

$P_{dis} = P_{in} – (P_{in} * 10^{(-IL/10)})$ Eqn C3.3.1

Or generally speaking,
$P_{dis} = P_{in} – P_{out}$ where $P_{out} = P_{in} * 10^{(-IL/10)}$ Eqn C3.3.2

Keys for the equation
P_{dis} = Power dissipated (W)
P_{in} = Input Power
P_{out} = Output Power
IL = Insertion Loss

For the thesis and typical of spacecraft design, the method below is used as it gives a good and better analytical approximate.
$P_{dis} = P_{in} – P_{out}$
Output power and dissipated power are deduced using eqn C3.3.2 bwith values of unit loss in table C3.3.

Given that:
P_{in} (TWTA) = 70W
$[P_{in}]$ = 10log70 = 18.45dB
[Loss] (Waveguide) = 0.15dB
Hence,
$[P_{out}]$ = 18.45 – 0.15 =18.3dB
P_{out} (W) = $10^{(18.3/10)}$
P_{out} (W) = 67.61W
Therefore,
$P_{dis} = P_{in} – P_{out}$
P_{dis} = 70 – 67.61W
P_{dis} = 2.39W=2.4W

P_{in} (Isolator) =67.61W

$[P_{in}]$ = 18.3dB

[Loss] (Isolator) = 0.25dB

$[P_{out}]$ = 18.3 – 0.25 = 18.05dB

Hence,

P_{out} (W) = $10^{(18.05/10)}$

P_{out} (W) = 63.83W

Therefore,

$P_{dis} = P_{in} - P_{out}$

P_{dis} (W) = 67.61 – 63.83W

P_{dis} = 3.78W

For the next stage of power dissipation, the input power is the output power from the previous stage.

That is; P_{in}(stage 2) = P_{out}(stage 1) as illustrated in diagram of figure A1.2 of Appendix A. Table C3.3 gives summary of Ka Band Output losses and power dissipation budget based on 70W TWTA power amplifiers.

Table C3.3: Summary of Ka Band Output Losses and Power Dissipation Budget.

S/N	**Units**	**Loss (dB)**	**Power Dissipation (W)**
	LCTWTA output power (70W)		
1	Waveguide	0.15	2.4
2	Isolator	0.25	3.8
3	Waveguide	0.35	5.1
4	High power R switch	0.2	2.7
5	Waveguide	0.2	2.5
6	Multiplexer	0.9 (single channel)	10.1 (single channel)
7	Output Test Coupler	0.15 (single channel)	1.5 (single channel)
8	Waveguide	0.3 (single channel)	2.8 (single channel)
	Total	**2.5**	

3.4 EIRP Budget of Ka Band Repeater of NIGCOMSAT-1R

Generally, the Equivalent Isotropic Radiated Power (EIRP) is determined by the sum in dB of the transmit power; P_T, gain of transmit G_T, and loss from passive components of the transmit chain. The loss is negated as seen in equation C3.4.1:

$[EIRP] = [P_T] + [G_T] - [Losses]$ Eqn C3.4.1

From equation C3.4.1, the gain of the transmitting antenna can be easily calculated. Making G_T the subject of the formula gives:

$[G_T] = [EIRP] – [P_T] + [Losses]$ Eqn C3.4.2

The designed EIRP for the budget will be the specified EIRP, $[EIRP]_{spec}$ plus a tolerance margin.

$[EIRP] = [EIRP]_{spec} + [margin]$ Eqn C3.4.3
Therefore, substituting eqn C3.4.3 into eqn C3.4.2 gives
$[G_T] = [EIRP]_{spec} +[margin] – [P_T] + [Losses]$ Eqn C3.4.4
Gains of Ka beams are deduced using Eqn. C3.4.4 with specified EIRP values in Table C3.4, losses in table C3.4 etc.

Gain of Ka Beam Antenna

Let the [margin] = 0.5dB

European Spot Beam:
$[EIRP]_{spec} = 52dBW$
$[EIRP] = 52 + 0.5 = 52.5dB$
$[G_T] = 52.5 – 18.4 + 2.5$ dB
$[G_T] = 36.6dB$

South African Spot Beam:
$[EIRP]_{spec} = 52dBW$
$[EIRP] = 52 + 0.5 = 52.5dB$
$[G_T] = 52.5 – 18.4 + 2.5$ dB
$[G_T] = 36.6dB$

Nigerian Spot Beam:
$[EIRP]_{spec} = 52dBW$
$[EIRP] = 52 + 1.4 = 53.4dB$
$[G_T] = 53.4 – 18.4 + 2.5$ dB
$[G_T] = 37.5dB$

Broadcast Spot Beam:
$[EIRP]_{spec} = 52dBW$
$[EIRP] = 52 + 0 = 52dB$
$[G_T] = 52 – 18.4 + 2.5$ dB
$[G_T] = 36.1dB$

Thus, summary of EIRP Budget of Ka Band Repeater for NIGCOMSAT-1R is as presented in Table C3.4.

Table C3.4: Summary of EIRP Budget of Ka Band Repeater.

S/N	Beam	LCTWTA Power (dB)	G_T (dBi)	Loss (dB)	EIRP (dBW)	EIRPspec (dBW)	Margin (dBW)
1	European Beam	18.4 (70W)	36.6	2.5	52.5	52	0.5
2	South African Beam	18.4 (70W)	36.6	2.5	52.5	52	0.5
3.	Nigerian Beam	18.4 (70W)	37.5	2.5	53.4	52	1.4
4	Broadcast Beam	18.4 (70W)	36.1	2.5	52	52	0

3.5 Gain Budget of Ka Band Repeater

The power, $P_{R,}$ delivered to a matched receiver is the power flux density, Ψ or Saturated Flux Density (SFD), multiplied by the effective aperture, of the receiving antenna, A_{eff}, which is given by the equation C3.5.1:

$$P_R = SFD * A_{eff} \qquad C3.5.1$$

$$A_{eff} = G_R * (4\pi /\lambda^2)^{-1} \qquad C3.5.2$$

Hence with substitution of eqn C3.5.2 into eqn C3.5.1

$$P_R = SFD * G_R * (4\pi /\lambda^2)^{-1} \qquad C3.5.3$$

Where,
$G_R =$ gain of receiving antenna (minimum)
λ = wavelength of uplink signal in meters (m)
$\lambda^2/4\pi$ = effective area of an isotropic antenna

Re-writing equation C3.5.3 in dB format:

$$[P_R] = [SFD] + [G_R] - [4\pi /\lambda^2] \text{ dBW} \qquad C3.5.4$$

Converting to dBm gives,

$$[P_R] = [SFD] + [G_R] - [4\pi /\lambda^2] + 30 \text{ dBm} \qquad C3.5.5$$

Ka band uplink frequency range requirement is 28.800 ~ 30.000 GHz. In evaluating P_R therefore, the least frequency is used so as to provide a reasonable design margin.
$c = f * \lambda$
Therefore,
$\lambda = c/f$
$c = 3 \times 10^8$m/s
$f = 28.8$GHz $= 28.8 \times 10^9$Hz
$\lambda = 0.010$m
Thus,
$(4\pi /\lambda^2)^{-1} = 8.634 \times 10^{-6}\text{m}^2$
$[4\pi /\lambda^2] = 50.8$dBW

Thus, from the specified SFD range of section C3.0

$[SFD] = -(63 + G/T) \sim -(83 + G/T)$
$[SFD] = -(63 + 12) \sim -(83 + 12)$
$[SFD] = -75 \sim -95\ dBW/m^2$

$[P_R] = [SFD] + [G_R] - [4\pi/\lambda^2] + 30\ dBm$
$[P_R] = (-75 \sim -95) + 42 – 50.8 + 30\ dBm$
$[P_R] = -53.8 \sim -73.8 dBm$

Table C3.5: Summary of Ka Band Gain Budget for NIGCOMSAT-1R

S/N	**Item**	**Gain (dB)**	**Power (dBm)**
1	G/T (dB/K)	12.0	
2	SFD (dBW/m^2)	-(63 + G/T) ~ -(83 + G/T)	
3	[$4\pi/\lambda^2$] (dB/m^2)	50.8	
4	G_R (dBi)	42.0	
5	**Input power (dBm)**		$SFD+G_R-(4\pi/\lambda^2)$ **-53.8~ -73.8**
6	Input loss (dB)	-2.0	**-55.8~ -75.8**
7	Receiver gain (dB)	56	0.2 ~ -19.8
8	Cable loss /middle loss (dB)	-19.7	-19.5 ~ -39.5
9	LCTWTA gain (dB)	66.5-86.5 (Trunking) 67.9-87.9 (Broadcasting)	47 (Trunking) 48.4 (Broadcast)
10	Output loss (dB)	-2.5	
11	**Output power (dBm)**		**44.5 (Trunking)** **45.9 (Broadcast)**
	Total gain (dB)	Output power – Input power 44.5– (-53.8 ~ -73.8) 45.9– (-53.8 ~ -73.8)	**98.3 ~ 118.3 (Trunking)** **99.7 ~ 119.7 (Broadcast)**

Based on table C3.5, the value of the repeater gain is between **98.3dBm to 118.3dBm** for trunking while the value of the repeater gain is between **99.7dBm to 119.7dBm** for Broadcast.

Appendix D

4.0 L Band (Navigation) Antenna and Payload Design with Gain and Loss Computations of NIGCOMSAT-1R

Frequency range

Down link 1166.45～1577.42MHz

Uplink 6629.45～6700.42MHz

Saturation Flux Density

-80 dBW/m^2 ~ -96 dBW/m^2

SSPA Output Power

45 Watts for L5 and 62Watts for L1

4.1 Input Loss and T Budget of Navigation Band Repeater

The table D4.1 below gives a summary of the insertion losses of various repeater input equipment from which the total input loss and T budget of L- Band for NIGCOMSAT-1R is calculated. The insertion losses are inherited based on DFH-4 Chinese Satellite bus for on System Noise Temperature (T) budget but with consideration to average ambient (environmental) temperature of Sub-Saharan Africa.

Table D4.1: NIGCOMSAT-1R Navigation Band T Budget

S/N	Units	Insertion loss (dB)
1	Waveguide	0.2
2	Input Test Coupler	0.1
3	Input Pre-Filter	0.7
4	Waveguide	0.1
5	R switch	0.2
6	Waveguide (cable)	0.2
7	**Total Input loss**	**1.5**
8	10log290	**24.6**
9	Noise figure of receiver	**1.8**
10	**T (Noise Temperature)**	**1.5+24.6+1.8 = 27.9**
		27.9

Sub-Saharan Atmospheric Temperature at mean sea level as thermal noise due to earth = 290K

4.2 G/T Budget of Navigation Band Repeater

To determine a suitable gain for the receiving antenna, G_R, the equation relating G_R, T, and G/T are as deduced below :

Generally speaking,

$[G/T] = [G_R] – [T]$ Eqn D4.2.1

$[G_R] = [G/T] + [T]$ Eqn D4.2.2

A tolerance margin is added to the specified G/T, thus:

$[G/T] = [G/T]spec + [margin]$ Eqn D4.2.3

Substituting equation D4.2.3 into equation D4.2.2 above gives:

$[G_R] = [G/T]spec + [margin] +[T]$ Eqn D4.2.4

Utilizing the spec values of G/T in dB/K as provided in Table D.4.2, the gain of the L-Band Antenna is as follows:

Gain of L Band Receive Antenna

Navigation Beam

Let [margin] = 0.6dB

$[G_R] = -12.0 + 0.6 + 27.9$ dB

$[G_R] = 16.5$dB

With the T-budget table in Table D4.1, the expected G/T in dB/K is presented in Table D4.2.

Table D4.2: Summary of NIGCOMSAT-1R L Band G/T Budget

Beam	**G_R (dBi)**	**T (K)**	**G/T (dB/K)**	**G/T_{spec} (dB/K)**	**Margin (dB)**
Navigation	16.5	27.9	-11.4	-12.0	0.6

Summary of computed L Band G/T Budget for NIGCOMSAT-1R is presented in table D4.2.

4.3 Output Loss and Power Dissipation Budget of L Band Repeater

As stated earlier in section A1.0 & A1.1 and illustrated in figure A1.1 of Appendix A, the output loss includes the loss of high power isolators, high power switches, OMUX, output test coupler (OTC) and the connection waveguides.

These losses are in decibel (dB), while the power dissipation equivalents are in Watts, W.

Equation for heat dissipation analysis is:

$P_{dis} = P_{in} – (P_{in} * 10^{(-IL/10)})$ Eqn D4.3.1

Or generally speaking,

$P_{dis} = P_{in} – P_{out}$ where $P_{out}= P_{in} * 10^{(-IL/10)}$ Eqn D4.3.2

Keys for the equation

P_{dis} = Power dissipated (W)

P_{in} = Input Power

P_{out} = Output Power

IL = Insertion Loss

For the thesis and typical of spacecraft design, the method below is used as it gives a good and better analytical approximate.

$$P_{dis} = P_{in} – P_{out}$$

Output power and dissipated power are deduced using eqn D4.3.2 with values of unit loss in Table D4.3

Given that:
Pin (SSPA) = 45W (L5)
[Pin] = 10log45 = 16.53dB
[Loss] (Cable) = 0.25dB
Hence,
[Pout] = 16.53 – 0.25 =16.25dB
Pout (W) = $10^{(16.25/10)}$
Pout (W) = 42.17W
Therefore,
Pdis = Pin – Pout
Pdis = 45 – 42.17W
Pdis = 2.7W

Similarly, Pin (SSPA) = 62W (L1)
[Pin] = 10log62 = 17.92dB
[Loss] (Cable) = 0.25dB
Hence,
[Pout] = 17.92 – 0.25 =17.67dB
Pout (W) = $10^{(17.67/10)}$
Pout (W) = 58.48W
Therefore,
Pdis = Pin – Pout
Pdis = 62 – 58.28W
Pdis = 3.7W

For the next stage of power dissipation, the input power is the output power from the previous stage.

That is; P_{in}(stage 2) = P_{out}(stage 1) as illustrated in diagram of figure A1.2 of Appendix A. Table D4.3 and D4.4 gives summary of L Band Output losses and power dissipation budget based on 45W and 62W Solid State Power Amplifier (SSPA) respectively for corresponding L5 and L1 channels.

Table D4.3: Summary of Output Losses and Power Dissipation Budget of L5 Channel

S/N	Units	Loss (dB)	Power Dissipation (W)
	SSPA output power (45W)		
1	Coaxial Cable	0.25	2.7
4	High power C switch	0.3	2.8
5	Coaxial Cable	0.3	2.6
6	Multiplexer	0.6 (single channel)	4.8 (single channel)
9	Coaxial Cable	0.45 (single channel)	3.2 (single channel)
	Total	**1.9**	

Table D4.4: Summary of Output Losses and Power Dissipation Budget of L1 Channel

S/N	Units	Loss (dB)	Power Dissipation (W)
	SSPA output power (62W)		
1	Coaxial Cable	0.25	3.7
4	High power C switch	0.3	2.8
5	Coaxial Cable	0.3	2.6
6	Multiplexer	0.6 (single channel)	6.6 (single channel)
9	Coaxial Cable	0.45 (single channel)	4.4 (single channel)
	Total	**1.9**	

4.4 EIRP Budget of L (Navigation) Band Repeater of NIGCOMSAT-1R

Generally, the Equivalent Isotropic Radiated Power (EIRP) is determined by the sum in dB of the transmit power; P_T, gain of transmit G_T, and loss from passive components of the transmit chain. The loss is negated as seen in equation D4.4.1:

$$[EIRP] = [P_T] + [G_T] - [Losses] \qquad \text{Eqn D4.4.1}$$

From equation D4.4.1, the gain of the transmitting antenna can be easily calculated. Making G_T the subject of the formula gives:

$$[G_T] = [EIRP] - [P_T] + [Losses] \qquad \text{Eqn D4.4.2}$$

The designed EIRP for the budget will be the specified EIRP, $[EIRP]_{spec}$ plus a tolerance margin.

$$[EIRP] = [EIRP]_{spec} + [margin] \qquad \text{Eqn D4.4.3}$$

Therefore, substituting eqn D4.4.3 into eqn D4.4.2 gives

$$[G_T] = [EIRP]_{spec} + [margin] - [P_T] + [Losses] \qquad \text{Eqn D4.4.4}$$

Gains of L band beams are deduced using Eqn D.4.4.4 with specified EIRP values in table D4.4, losses in Table D4.4 etc.

Gain of L1 & L5 Band Beam Antenna

Let the [margin] = 1.4dB

The Antenna Beams:

$[EIRP]_{spec}$ = 28.1dBW and 26.2dBW for L1 and L5 respectively

$[G_T]$ = 28.1 +1.4-17.9 +1.9 for L5 and

$[G_T]$ = 26.2 +1.4-16.5 +1.9 for L1

$[G_T]$ = 13.5dB for L5 and

$[G_T]$ = 13dB for L1.

Thus, summary of EIRP Budget of L Band Repeater for NIGCOMSAT-1R is as presented in Table C4.5.

Table D4.5: Summary of EIRP Budget of L Band Repeater.

S/N	Beam	LCTWTA Power (dB)	G_T (dBi)	Loss (dB)	EIRP (dBW)	EIRPspec (dBW)	Margin (dBW)
1	L1	17.9	13.5	1.9	29.5	28.1	1.4
2	L5	16.5	13	1.9	27.6	26.2	1.4

4.5 Gain Budget of L (Navigation) Band Repeater

The power, P_R, delivered to a matched receiver is the power flux density, Ψ or Saturated Flux Density (SFD), multiplied by the effective aperture, of the receiving antenna, A_{eff}, which is given by the equation D4.5.1:

$P_R = SFD * A_{eff}$ Eqn D4.5.1

$A_{eff} = G_R * (4\pi/\lambda^2)^{-1}$ Eqn D4.5.2

Hence with substitution of eqn D4.5.2 into eqn D4.5.1

$P_R = SFD * G_R * (4\pi/\lambda^2)^{-1}$ Eqn D4.5.3

Where,

G_R = gain of receiving antenna (minimum)

λ = wavelength of uplink signal in meters (m)

$\lambda^2/4\pi$ = effective area of an isotropic antenna

Re-writing equation D4.5.3 in dB format:

$[P_R] = [SFD] + [G_R] - [4\pi/\lambda^2]$ dBW Eqn D4.5.4

Converting to dBm gives,

$[P_R] = [SFD] + [G_R] - [4\pi/\lambda^2] + 30$ dBm Eqn D4.5.5

L band uplink frequency range requirement is 6629.45 ~ 6700.42 MHz. In evaluating P_R therefore, the least frequency is used so as to provide a reasonable design margin.

$c = f * \lambda$

Therefore,

$\lambda = c/f$

$c = 3 \times 10^8$m/s

$f = 6629.45$MHz $= 6.62945 \times 10^9$Hz

$\lambda = 0.045$m

Thus,

$(4\pi /\lambda^2)^{-1} = 1.6296 \times 10^{-4}$m^2

$[4\pi /\lambda^2] = 37.9$dBW

[SFD] = -80 ~ -96 dBW/m^2 as specified in section D4.0,

$[P_R] = [SFD] + [G_R] - [4\pi /\lambda^2] + 30$ dBm

$[P_R] = (-80 \sim -96) + 16.5 – 38 + 30$ dBm

$[P_R] = -71.5 \sim -87.5$dBm

Table D4.6: Summary of L Band Gain Budget for NIGCOMSAT-1R

S/N	Item	Gain (dB)	Power (dBm)
1	G/T (dB/K)	-10	
2	SFD (dBW/m^2)	-80 ~ -96	
3	$[4\pi/\lambda^2]$ (dB/m^2)	38	
4	G_R (dBi)	16.5	
5	**Input power (dBm)**		SFD+G_R-$(4\pi/\lambda^2)$ **-71.5~ -87.5**
6	Input loss (dB)	-1.5	-73 ~ -89
7	Receiver gain (dB)	63 ~ 79	-10
8	Cable loss (dB)	-13.6	-23.6
9	SSPA gain (dB)	71.5 (L1) 70.1 (L5)	47.9 (L1) 46.5 (L5)
10	Output loss (dB)	-1.9	
11	**Output power (dBm)**		46.0 (L1) 44.6 (L5)
	Total gain (dB)	Output power – Input power 46.1– (-71.3 ~ -87.3) 44.6– (-71.3 ~ -87.3)	**117.3 ~ 133.3 (L1)** **115.9 ~ 131.9 (L5)**

Based on table D4.6, the value of the repeater gain for L1 and L5 are between **117.3dBm to 133.3dBm** and **115.9dBm and 131.9dBm** respectively.

Appendix E

Coverages of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion in 30 others States of Nigeria ranging from Adamawa, E1 to Zamfara State, E30 Respectively.

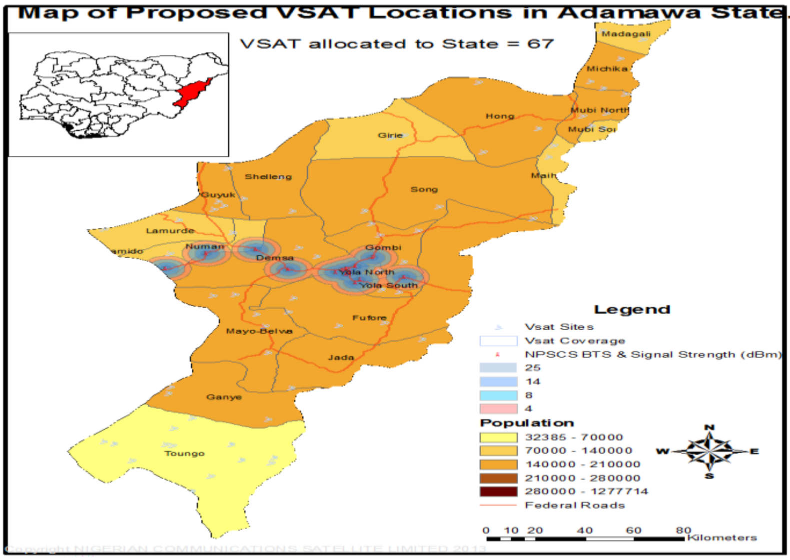

Figure E.1:Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Adamawa State.

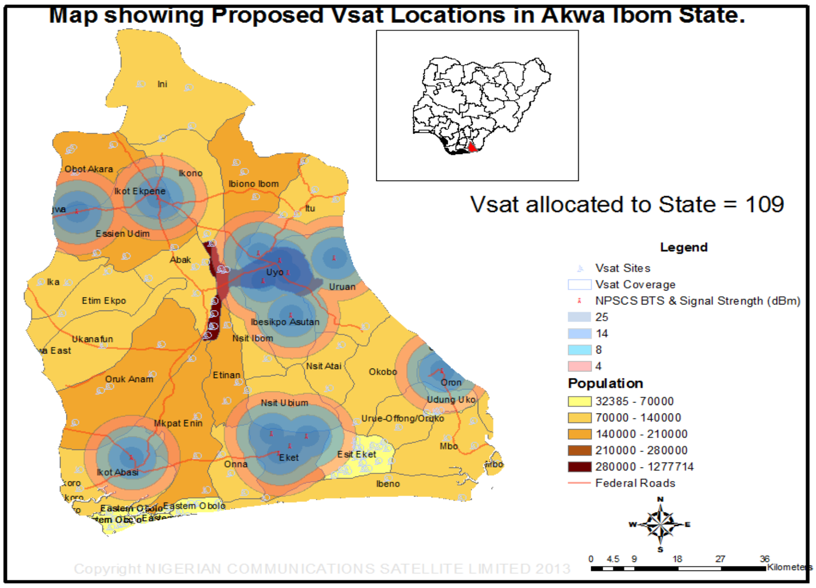

Figure E.2: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Akwa Ibom State.

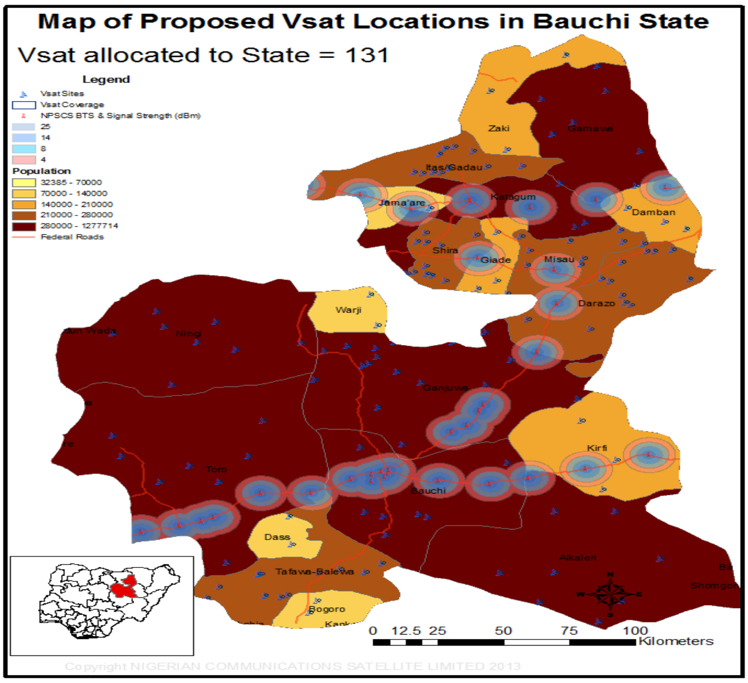

Figure E.3: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Bauchi State.

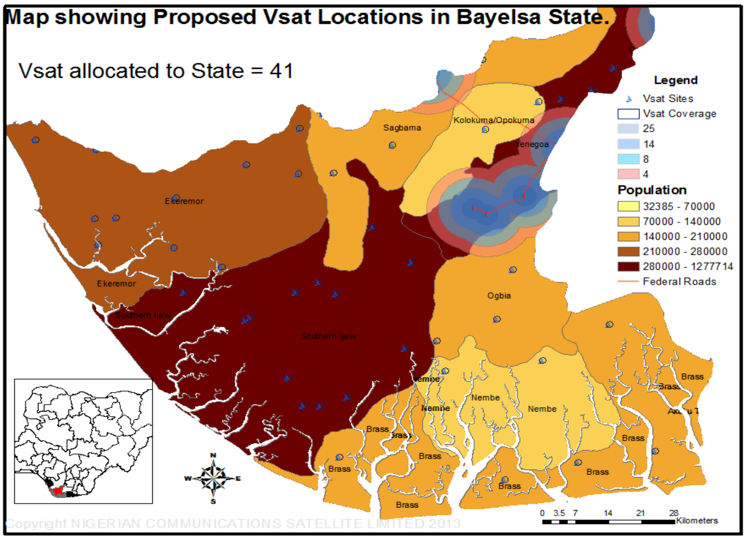

Figure E.4: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Bayelsa State.

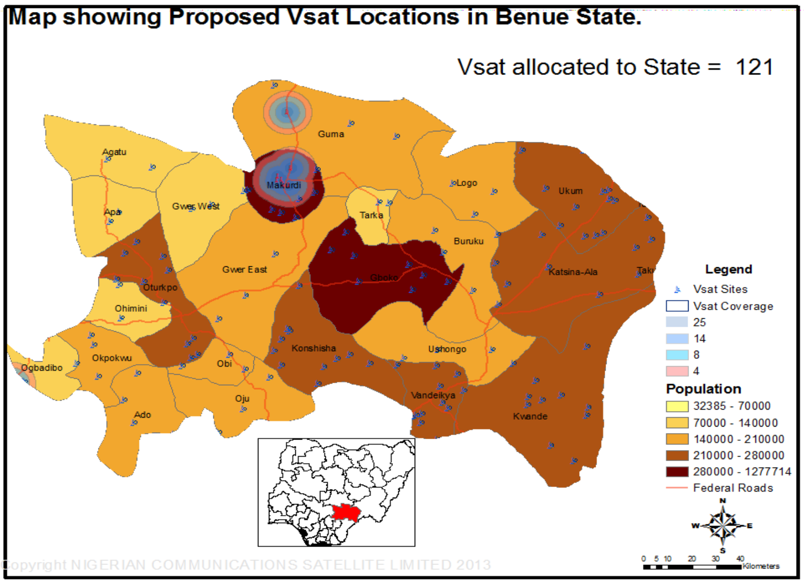

Figure E.5: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Benue State.

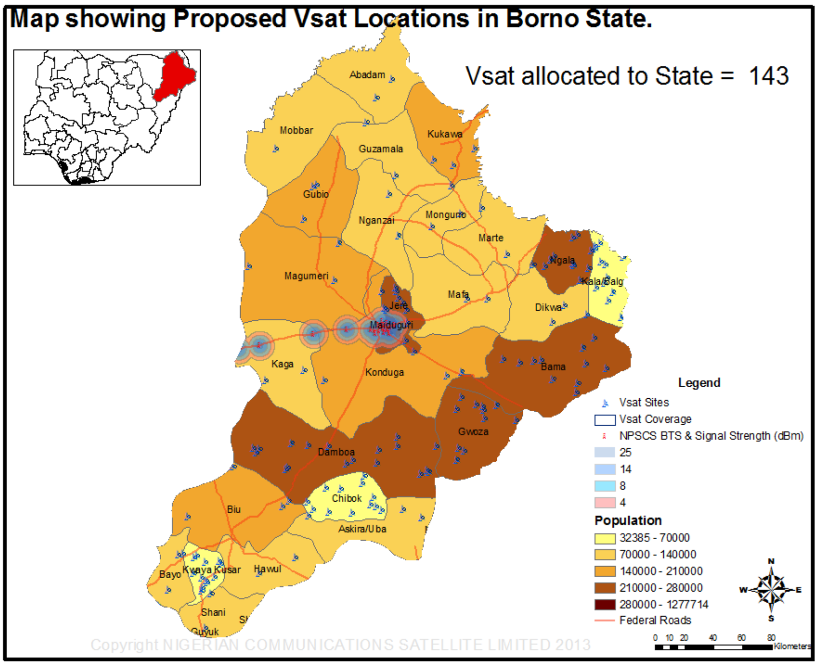

Figure E.6: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Bornu State.

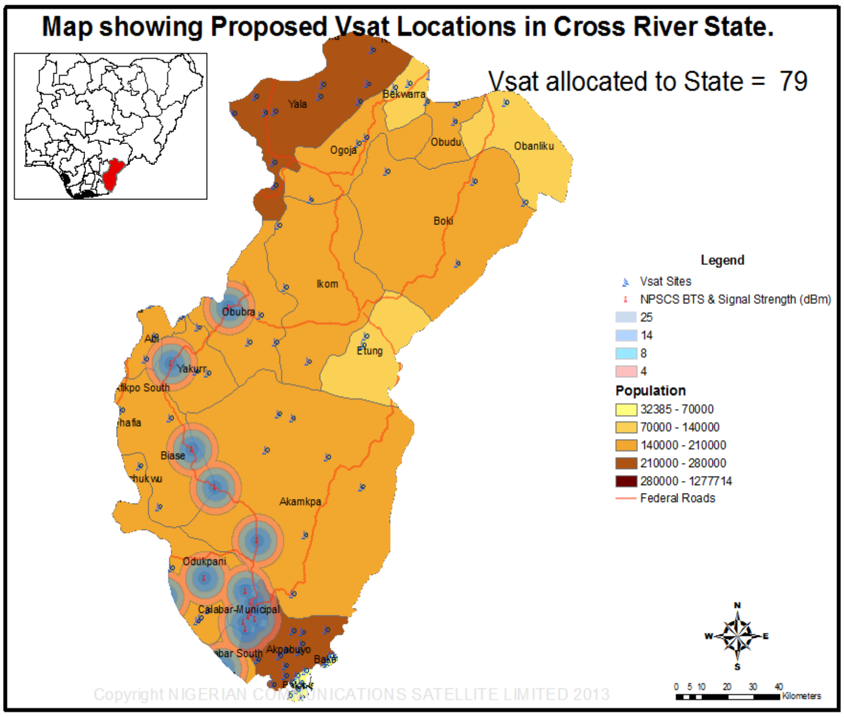

Figure E.7: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Cross River State.

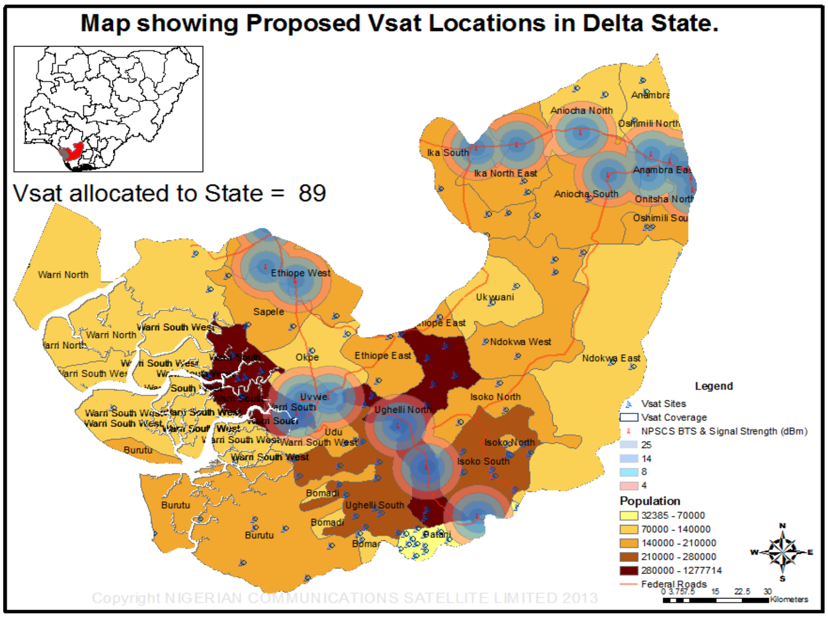

Figure E.8: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Delta State.

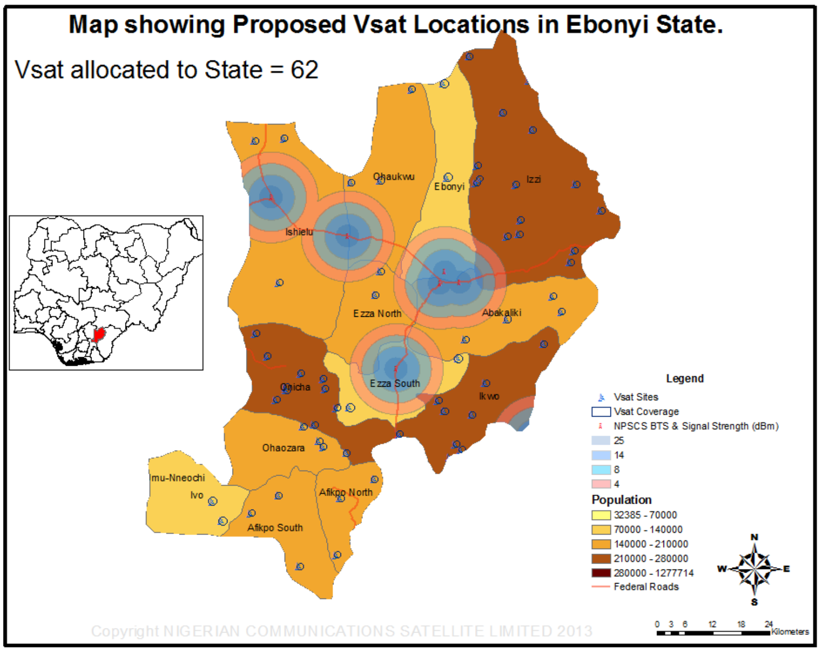

Figure E.9: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Ebonyi State.

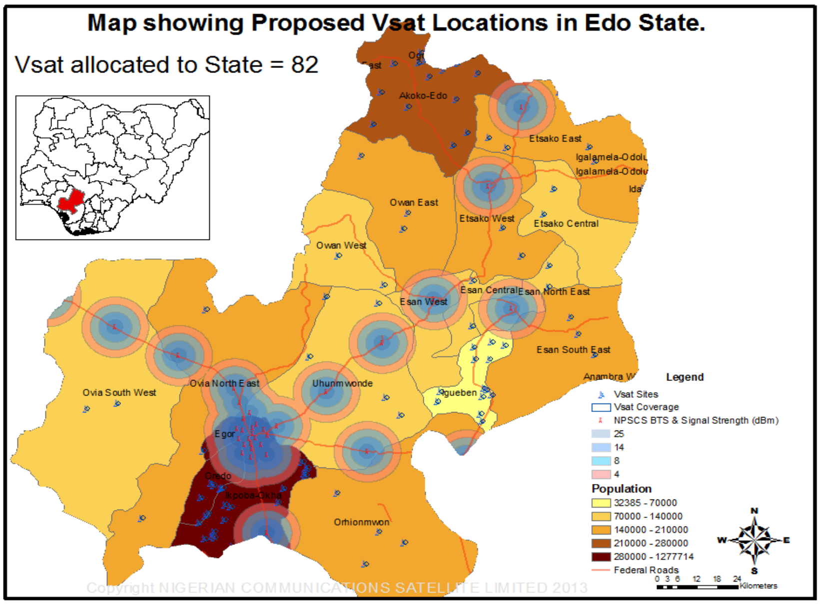

Figure E.10: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Edo State.

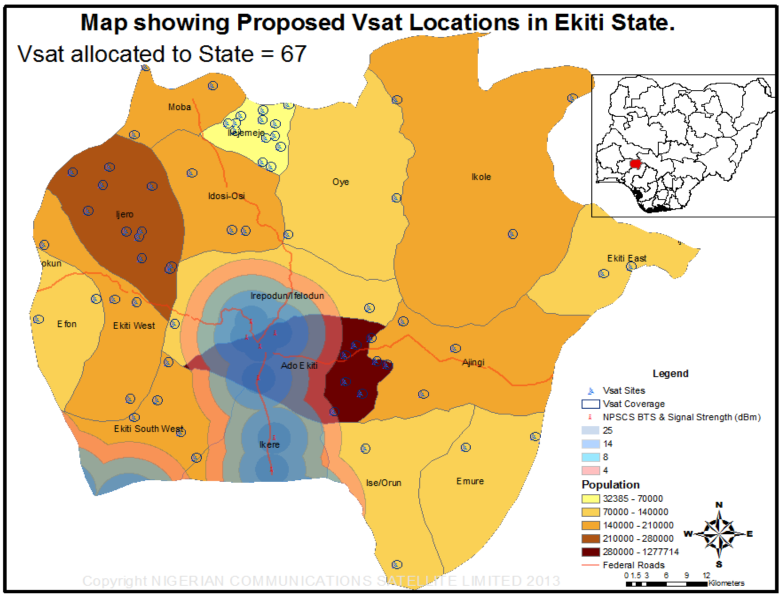

Figure E.11: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Ekiti State.

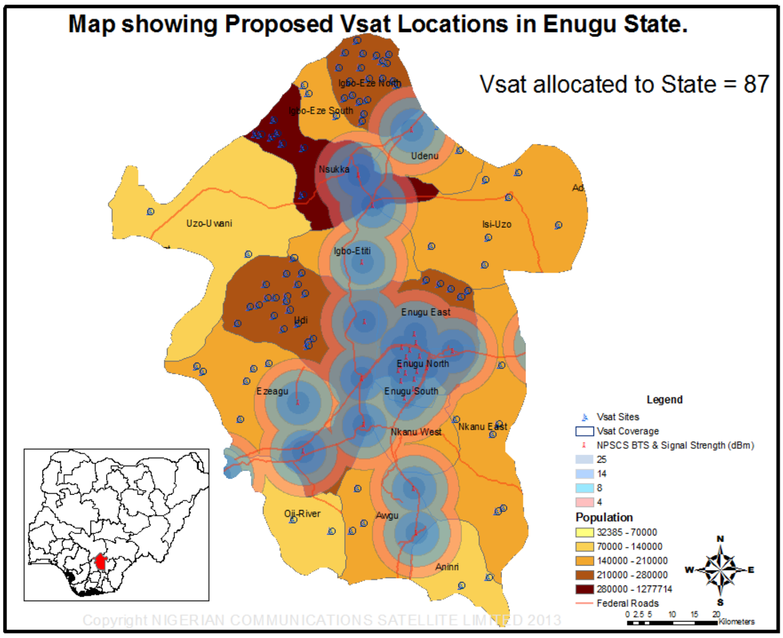

Figure E.12: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Enugu State.

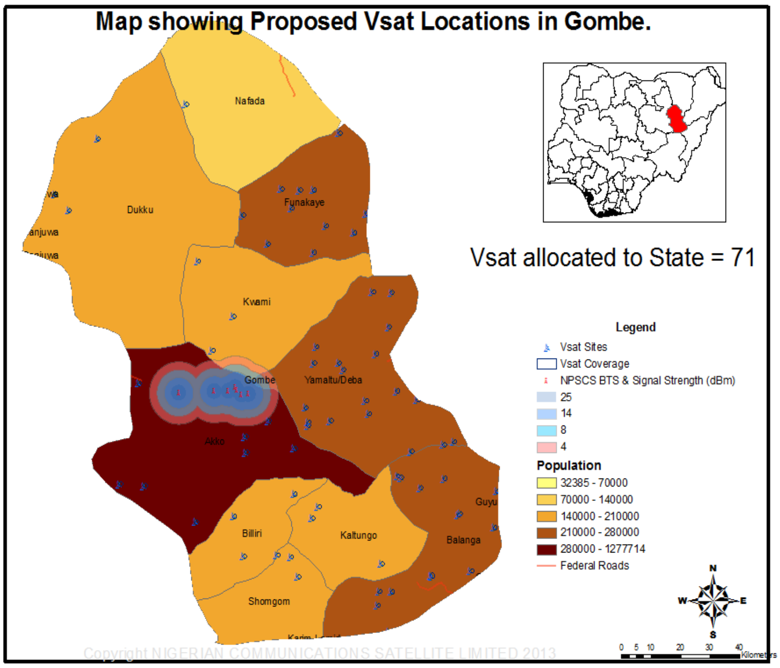

Figure E.13: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Gombe State.

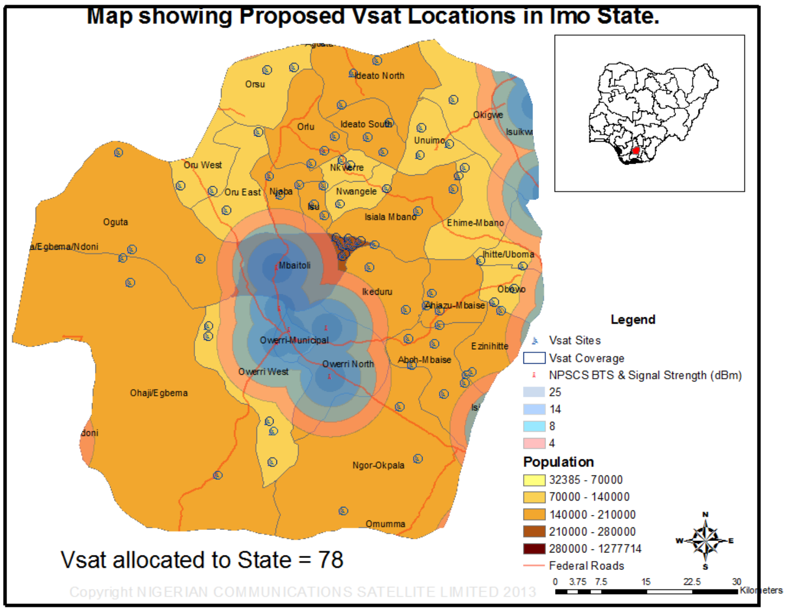

Figure E.14: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Imo State.

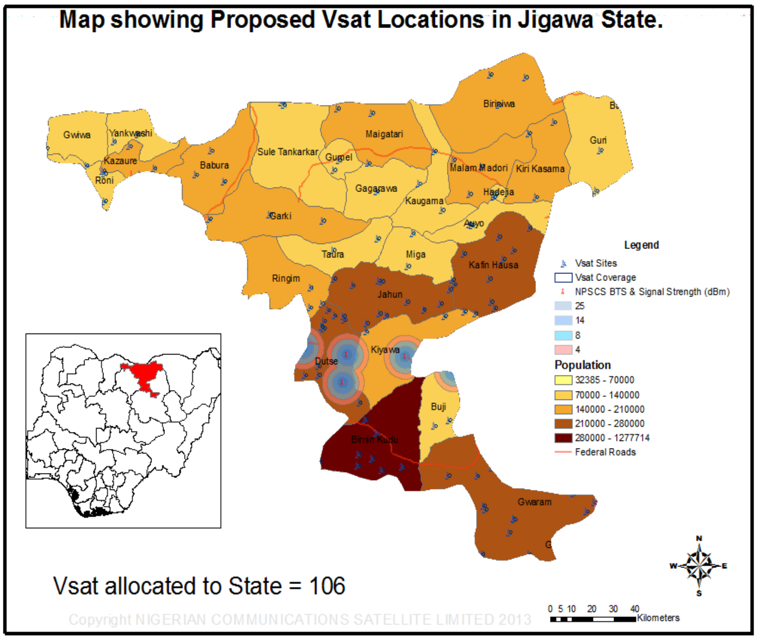

Figure E.15: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Jigawa State.

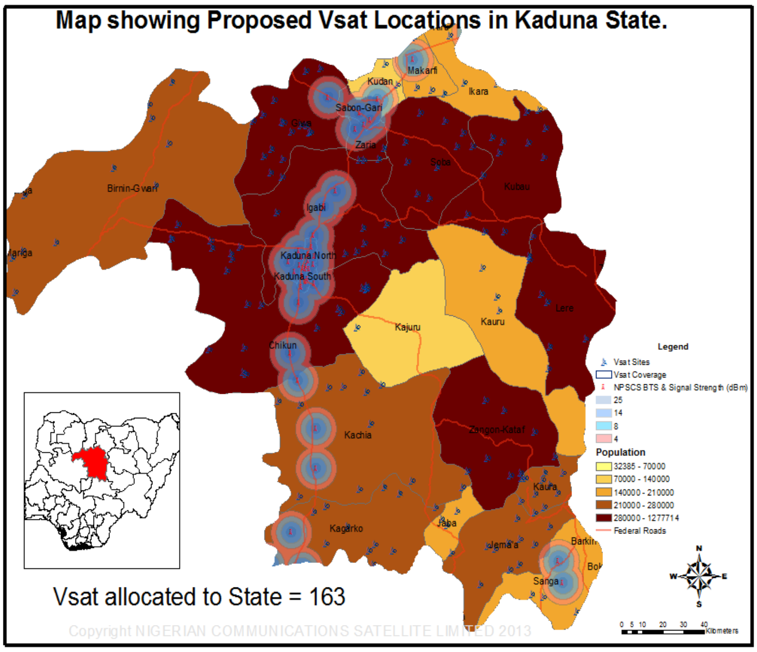

Figure E.16: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Kaduna State.

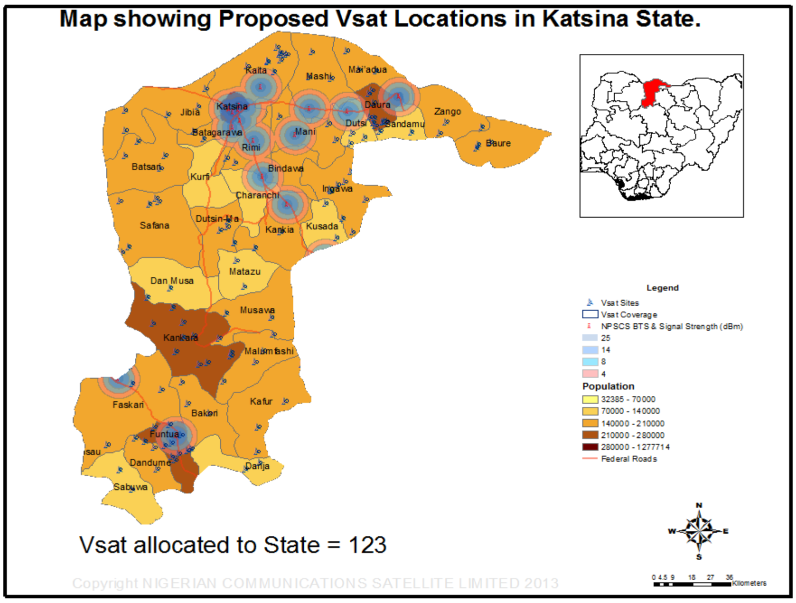

Figure E.17: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Katsina State.

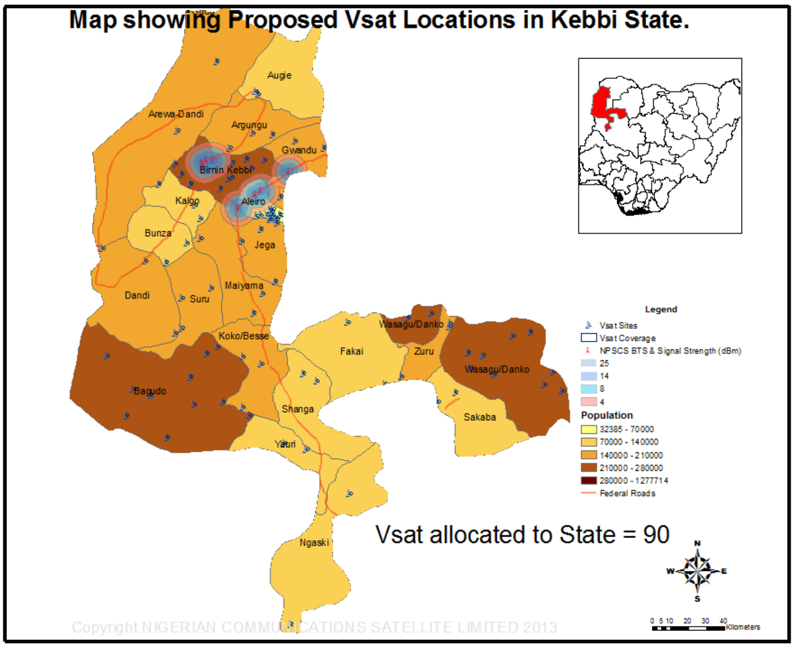

Figure E.18: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Kebbi State.

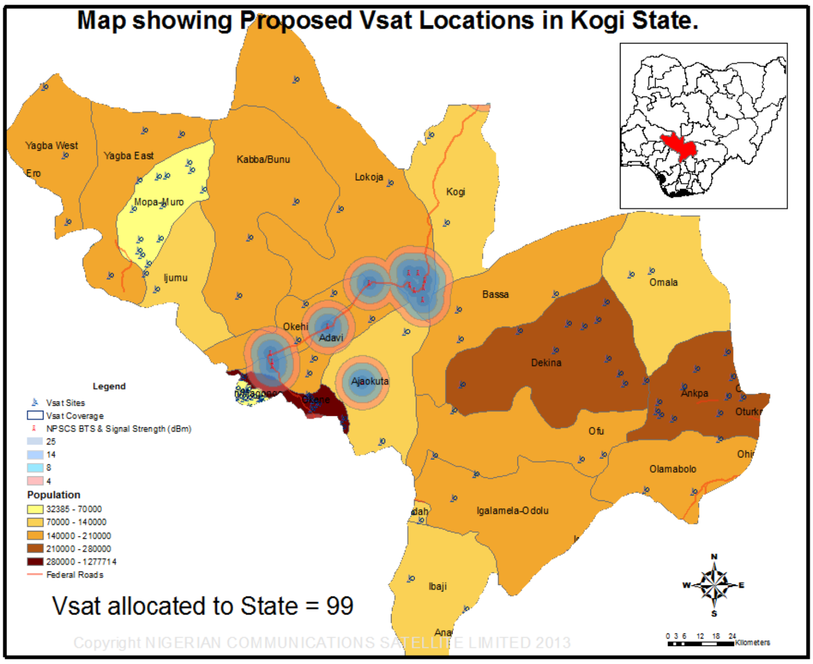

Figure E.19: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Kogi State.

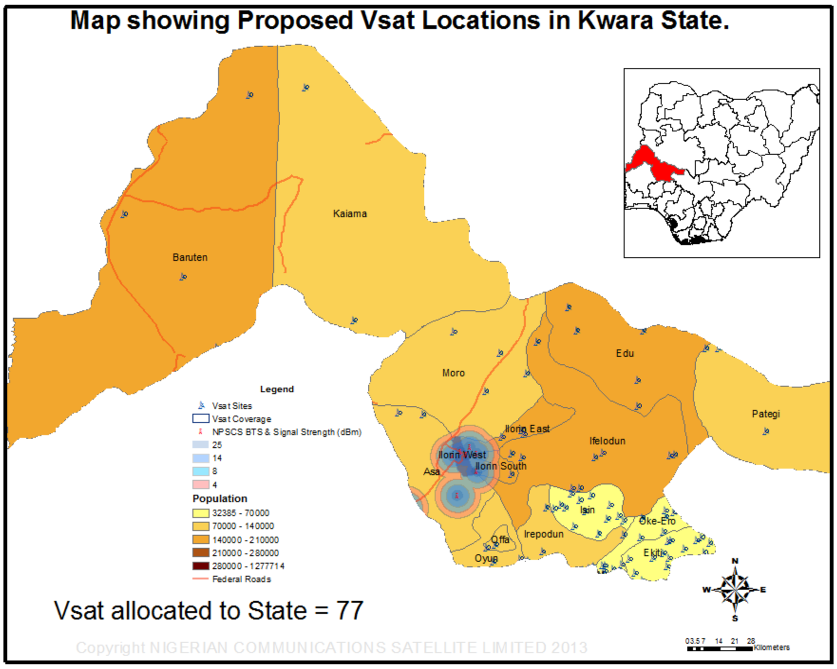

Figure E.20: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Kwara State.

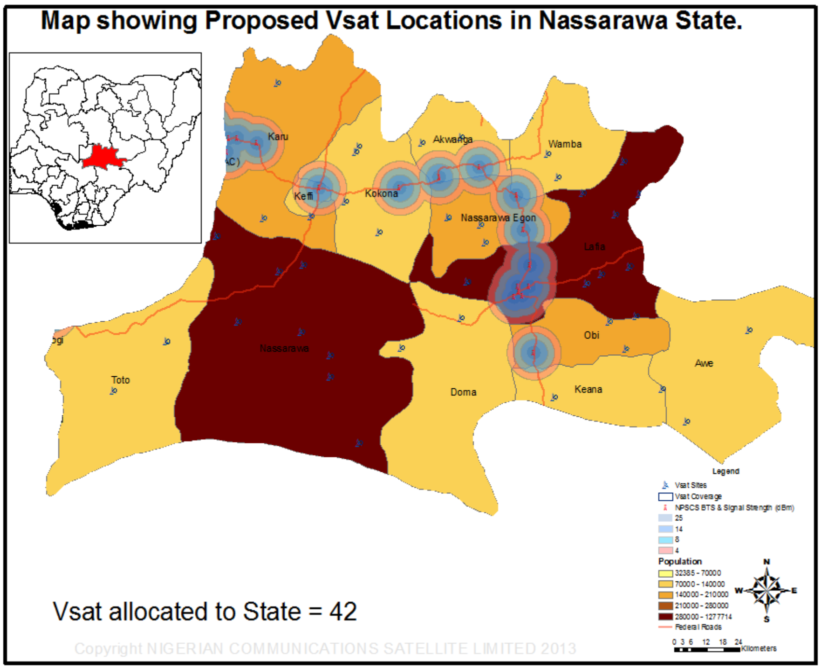

Figure E.21: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Nasarawa State.

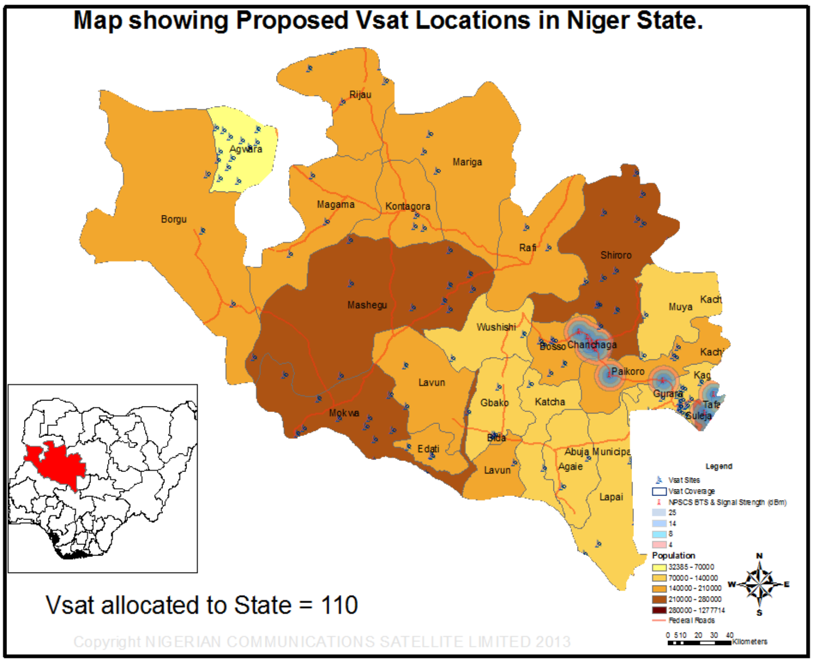

Figure E.22: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Niger State.

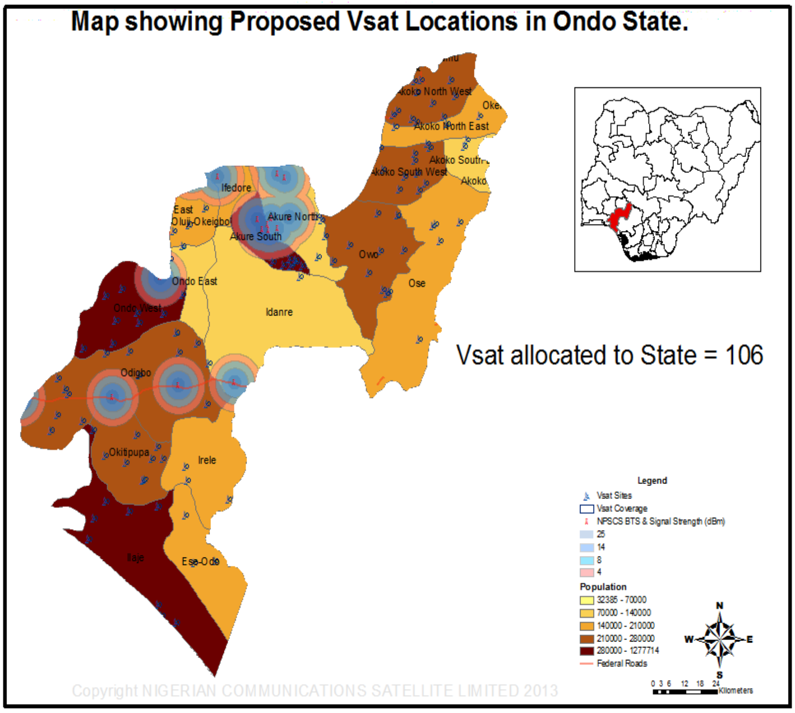

Figure E.23: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Ondo State.

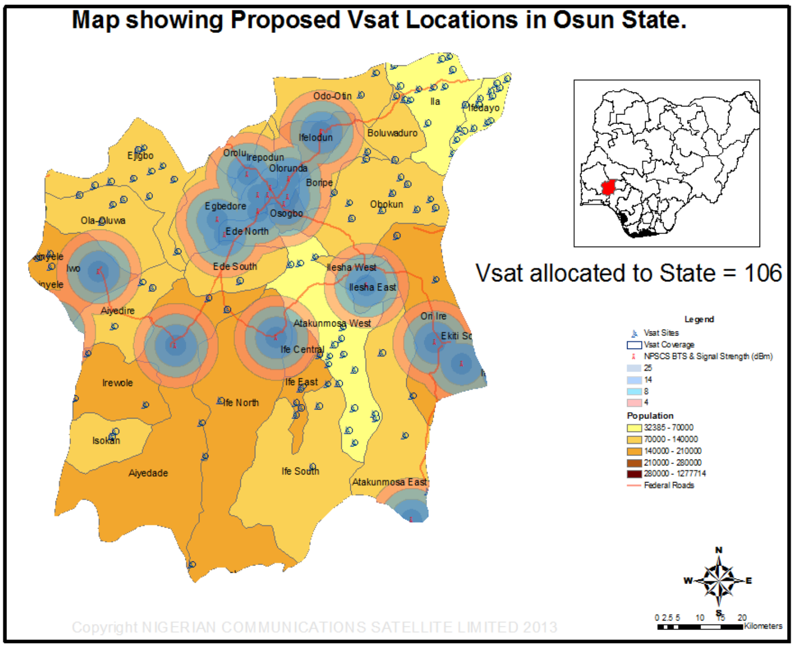

Figure E.24: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Osun State.

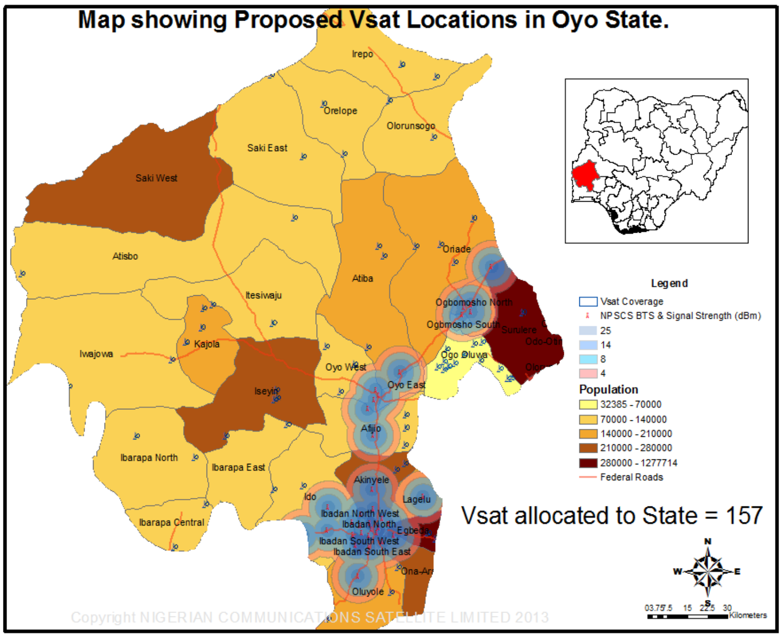

Figure E.25: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Oyo State.

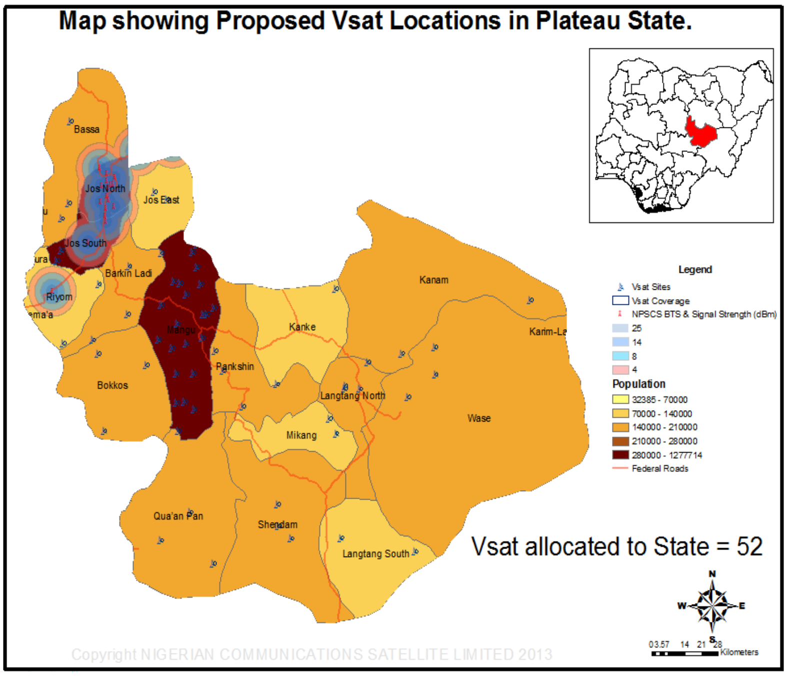

Figure E.26: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Plateau State.

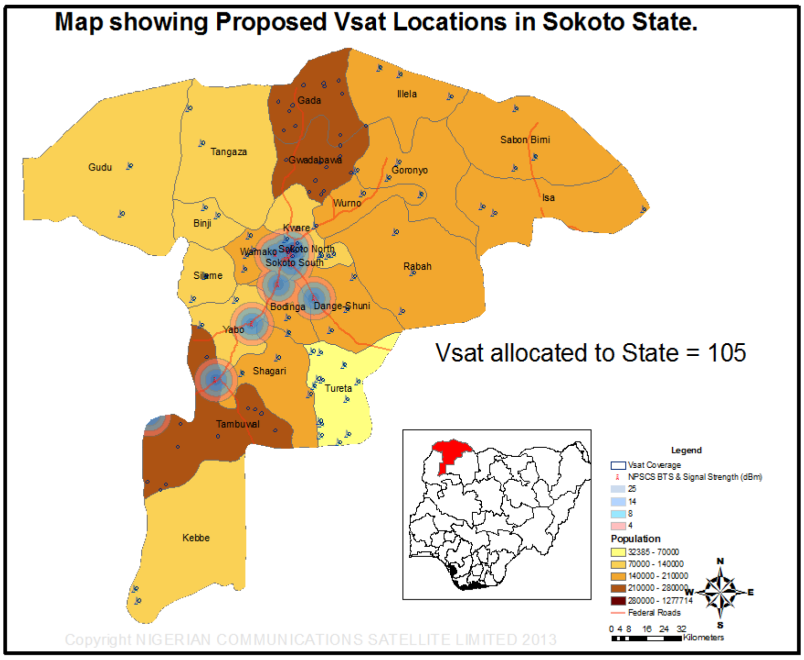

Figure E.27: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Sokoto State.

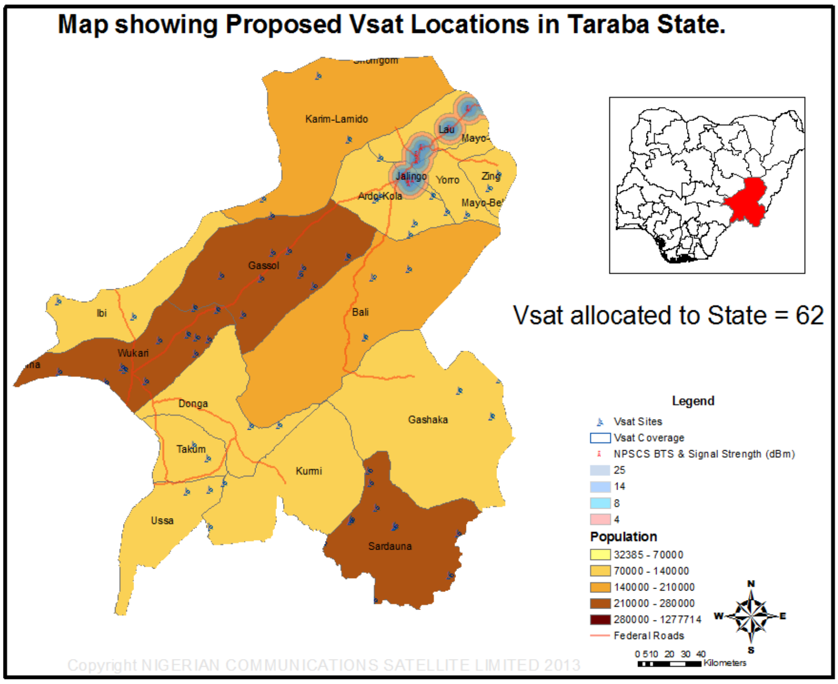

Figure E.28: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Taraba State.

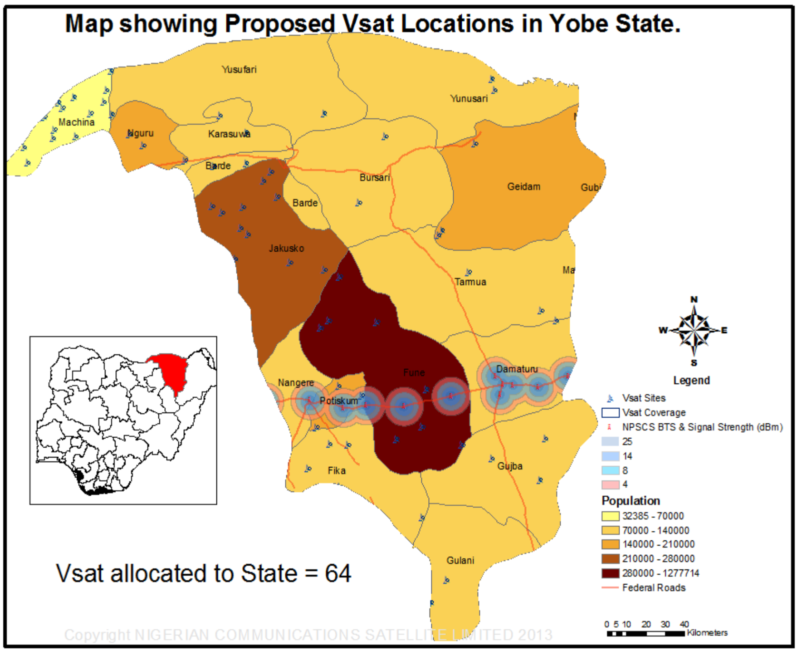

Figure E.29: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Yobe State.

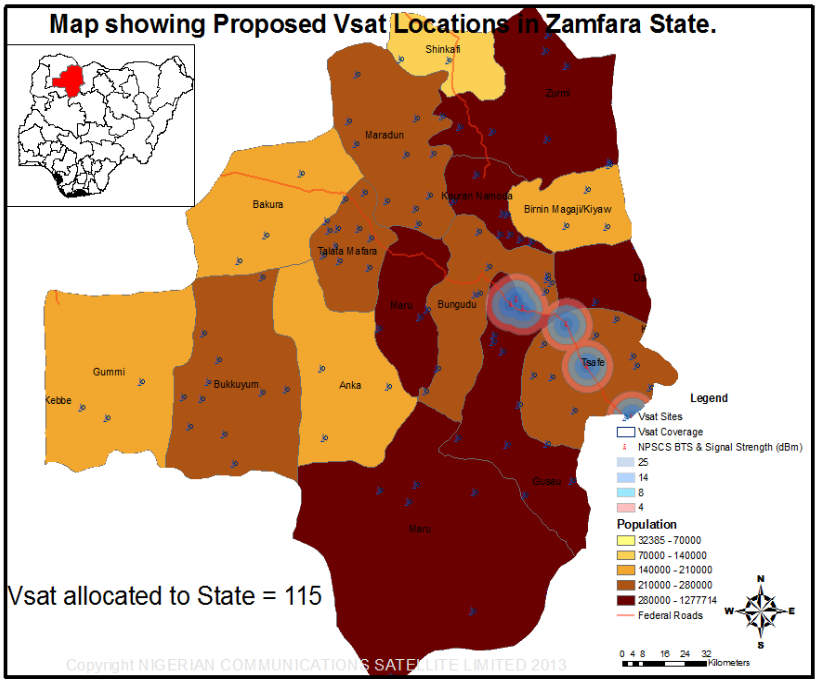

Figure E.30: Coverage of NPSCS Network, Population Distribution and VSAT Requirements for Financial Inclusion of all in Zamfara State.

Appendix F

List of Publications and Successful Launch of Communications Satellite (NIGCOMSAT-1R) during DPhil Programme.

Lawal, L.S., & Chatwin, C.R. (2011). Essential Parameters of Space-Borne Oscillators That Ensures Performance of Satellite-Based Augmentation System. Proceedings of *3rd IEEE International Conference on Science and Technology, ICAST,* (pp42-50). Abuja-Nigeria. doi: 10.1109/ICASTech.2011.6145156.

Lawal, L.S., & Chatwin, C.R. (2011). Optimization of Mass Volume ratio of Spacecraft Structure for Advanced and High Powered Communication Satellites, Proceedings of *10th International Information and Telecommunication Technologies conference,* Florianopolis, Santa Catarina Island, Brazil.

Lawal, L.S., & Chatwin, C.R. (2012). The Future of Wireless Communications in Africa. *International Conference on Wireless Network and Information System. Future Wireless Networks and Information Systems,* Lecture Notes in Electrical Engineering, Springer Link, 143, 243-251. doi: 10.1007/978-3-642-27323-0_31.

Lawal, L.S., & Chatwin, C.R. (2012). Advanced High Power Subsystem for Geostationary Satellites. *IEEE Computer Society, The Association of Computing Machinery Digital Library*. 4, 138-142. *ISBN: 978-0-7695-4703-9*

Lawal, L.S., & Chatwin, C.R. (2012). Advanced High Power Systems for Geostationary Satellites. Proceedings of 2012 *2nd International Conference on Electric Information and Control Engineering, ICEICE, 04,* (pp138-142), Lushan,China. Doi:10.1109/ICEICE.2012.1164.

Lawal, L.S., & Chatwin, C.R. (2012). Antenna System Layout in High Capacity Geostationary Communication Satellites. *Antennas and Propagation in Wireless Communications, IEEE APWC 2012 Topical Conference, (pp1012-1015),* Capetown, South Africa. *doi: 10.1109/APWC.2012.6324983.*

Lawal, L.S., Ahmed-Rufai, T., Chatwin, C.R., & Young, R.C.D. (2013). Delivery of Broadband Services to Sub-Saharan Africa via Nigerian Communications Satellite. *International Journal of Information and Computer Science (IJICS).* 2(5), 77-88.

Lawal, L.S., Ahmed-Rufai, T., Inuwa, D.A., & Chatwin, C.R., (n.d.). The Unique Role of Communications Satellites in addressing the Rapid Socio-Economic Development of Nigeria. (Unpublished)

Lawal, L.S., & Chatwin, C.R. (2013). Nigerian Communication Satellite (NIGCOMSAT-1R) Ka-band System", *19th Ka and Broadband Communications, Navigation and Earth Observation Conference and 31st AIAA International Communications Satellite Systems Conference (ICSSC),* Florence-Italy. Retrieved from http://www.kaconf.org/#

Lawal, L.S., Ahmed-Rufai, T., & Chatwin, C.R., (2013). Communication Satellite Alternative to Digital Terrestrial Television. *Proceedings* of *2nd IEEE International Conference on Emerging and Sustainable Technologies for Power and ICT in a Developing Society,* Owerri, Nigeria. Retrieved from http://www.nigercon.info/#!

Lawal, L.S., Ahmed-Rufai, T., Chatwin, C.R., & Liu, R. (2013). The role of Communication Satellites in Public Management, Education, Governance and Business in Nigeria. *Human Resource Management Research Journal, 3(5),178-187.* doi: 10.5923/j.hrmr.20130305.02. Retrieved from http://article.sapub.org/10.5923.j.hrmr.20130305.02.html

Lawal, L.S., Ahmed-Rufai, T., Chatwin, C.R., & Liu, R. (2013). The role of Communication Satellites in Public Management, Education, Governance and Business in Nigeria. Proceedings of *International conference on Electronics Engineering, Advanced Communications and Information Technology, EEACIT, Kuala Lumpur- Malaysia. Retrieved from http://www.eeacit.com/*

Lawal, L.S & Chatwin, C.R. (2014). Emergency Communication Preparedness in Africa Exploiting Communication Satellites. *Global Space Applications Conference (GLAC) by International Astronautical Federation (IAF) and United Nations Educational, Scientific and Cultural Organization (UNESCO)* on 2-4 June, 2014 at UNESCO HQ, Paris, France. Retrieved from http://www.iafastro.org/wp-content/uploads/2014/04/GLAC_FP_FINAL_May201428_online_2.pdf

Chatwin, C.R, Lawal, L.S, Young, R.C.D & Birch, P. (2014). Satellite & Fibre Communications: A Solution for Africa. *Conference paper proceeding of the Institution of Engineering and technology (IET)* at Crawley, Hawth, UK on 3rd June, 2014.

Lawal, L.S & Chatwin, C.R. (2014). Bridging The Digital Hiatus via Communications Satellite Broadband. *The World Engineering Conference 2014 on Sustainable Infrastructure (WECSI 2014) by World Federation of Engineering Organizations (WFEO) in association with the Nigerian Society of Engineers (NSE)* at the International Conference Centre, Abuja, Nigeria on November, 2-7, 2014.

(Abstract Accepted and Paper submitted for the Journal).

Lawal, L.S, & Chatwin, C.R. (2014) African Rural Financial and Digital Inclusion exploiting Nigerian Communications Satellite, *The 1st University Meets Microfinance (UMM) Workshop in Africa with conference theme; ACCELERATING INNOVATIVE RURAL FINANCE IN AFRICA at Ougadougou Burkina Faso, 1st-5th December, 2014.*

(Abstract and Paper submitted for the International Workshop and Conference).

Successful Launch of over $250 Million Nigerian Communications Satellite Replacement project (NIGCOMSAT-1R)as project team member with design contributions especially on service coverage and L-Bank Piggyback payload on the 20th of December, 2011 with enhanced performance as evident in In-Orbit Test (IOT) results and efficient satellite service delivery.