

# **ENHANCING PUBLIC SAFETY AND SECURITY OF CRITICAL NATIONAL INFRASTRUCTURE UTILIZING THE NIGERIAN SATELLITE AUGMENTATION SYSTEM (NSAS).**

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## **ABSTRACT**

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, 2011). 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, 17<sup>th</sup>, 1995. Improvement in accuracy for general transportation, especially in aviation, ushered in augmentation systems. The quest for performance focused on the ability to accurately transmit and keep time signals stable up to the picosecond level and even more in receivers and clock reference signals for 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, 2011).

The 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 is a Space Based Augmentation System meant to provide a Navigation Overlay Service (NOS) similar to the European Geostationary Navigation Overlay Service (EGNOS).

This paper describes the huge untapped potential that the hybrid satellite offers in the area of public safety, security of critical national infrastructure, aviation, maritime, defense, effectiveness of Location Based Services for Emergency and Crisis management amongst other applications; it thus fills a great gap in the augmentation systems for Africa.

Keywords: GNSS, GPS, Navigation, NIGCOMSAT-1R, NIIMP, NOS, NSAS, Public Safety, SBAS, Security

## **INTRODUCTION TO GLOBAL POSITION SYSTEM TECHNIQUE AND AUGMENTATION SYSTEM**

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, 17<sup>th</sup>, 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 2<sup>nd</sup> 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 even more for receivers and clock reference signals for space systems, especially in navigation satellites using high performance oscillators ranging from ultra-stable quartz crystals with ovenized control of high performance atomic circuits (Lawal & Chatwin, 2011).

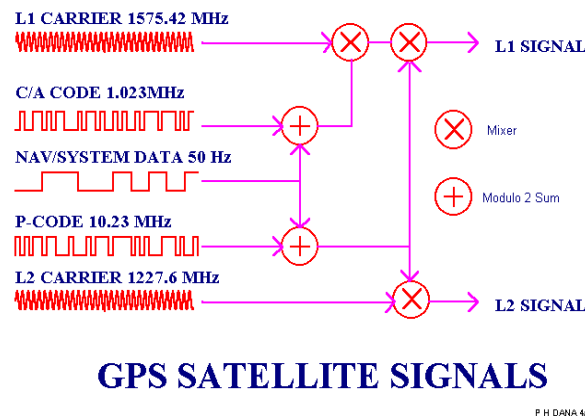
The Global Positioning System (GPS) is primarily a ranging system as it tries to find how far an object is from itself (satellite). Thus, GPS operates on the principle of trilateration, which refers to determination of an unknown point by measuring the lengths of the sides of the triangle between the 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 ( $c$ ) by 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, 2011).

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 1, 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 1: Composition of the signals from GPS satellites showing roles of Oscillators**  
**(Sourced from: Dana, 1999 with permission).**

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.

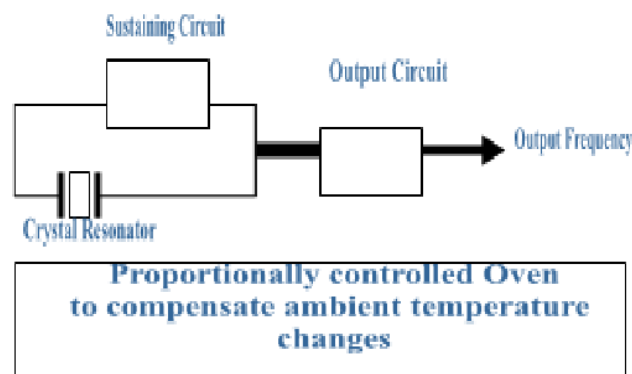
The most effective augmentation system, especially for coverage capability, is the Satellite-Based Augmentation System (SBAS), which involves the use of Geostationary Communication Satellites to transmit signals over a wide geographic area creating and contributing to the Global Navigation Satellite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

### **ROLES OF SPACE-BORNE OSCILLATORS FOR IMPROVED PERFORMANCE OF SATELLITE-BASED AUGMENTATION SYSTEM (SBAS).**

When using satellites for Navigation, time precision is the key determinant of accuracy in locating position, displacement and velocity. 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.

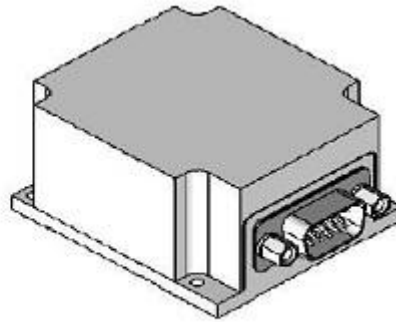
Generally and for the stringent requirements of stability, space-borne oscillators use customized ovenized controlled oscillators designed to suit the orbit and space environment in which they will be deployed; particularly in terms of radiation and temperature variations. Figure 2 shows a typical OCXO Block diagram, while Figure 3 shows the 10MHz Master oscillator used in the navigation payload of Nigerian Communications Satellite (NIGCOMSAT-1R).



**Figure 2: A Typical Ovenized Crystal Oscillator (OCXO) showing its Crystal Resonator and external circuits in a proportionally controlled oven to compensate ambient temperature changes.**



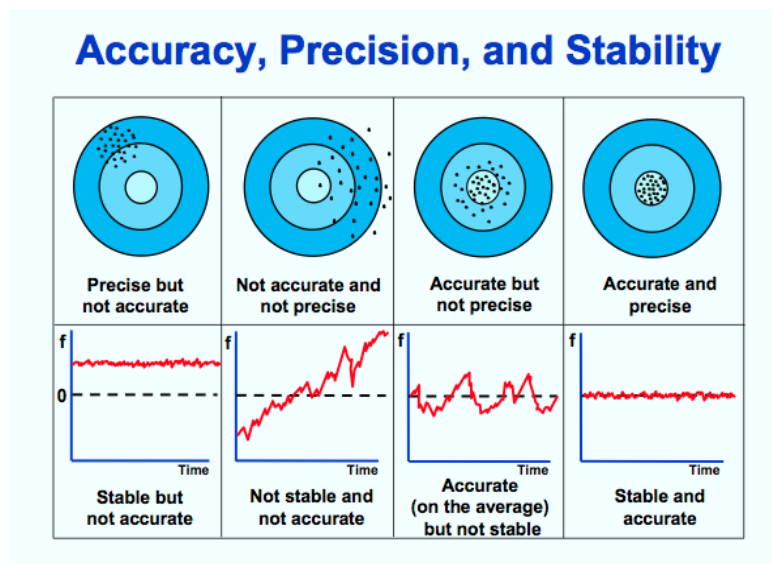
10MHz Master Oscillator



10MHz ultra stable crystal oscillator

**Figure 3: The 10MHz Master oscillator used in the navigation payload of the Nigerian Communications Satellite (NIGCOMSAT-1R).**

In the course of oscillation, oscillators 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 4 as the measured quantity, figure 4 (Vig, 2007; John, 1992).



**Figure 4: 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. (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).

## **NIGCOMSAT-1R AND THE NIGERIAN SATELLITE AUGMENTATION SYSTEM (NSAS).**

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 (GNSS). It was however de-orbited on the 10<sup>th</sup> 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, is the insurance replacement for the NIGCOMSAT-1 satellite and launched on 20<sup>th</sup> December, 2011. NIGCOMSAT-1R has an onboard Navigation payload.



**Figure 5: NIGCOMSAT-1R Spacecraft Project hoisted on Mechanical Ground Support Equipment (MGSE) in the Assembly, Integration and Test (AIT) Room.**

The NigComSat-1R Navigation (L-band) payload as illustrated in figure 6 is the Nigerian Space-Based Augmentation System (NSAS) meant to provide a Navigation Overlay Service (NOS) similar to the European Geostationary Navigation Overlay Service (EGNOS).

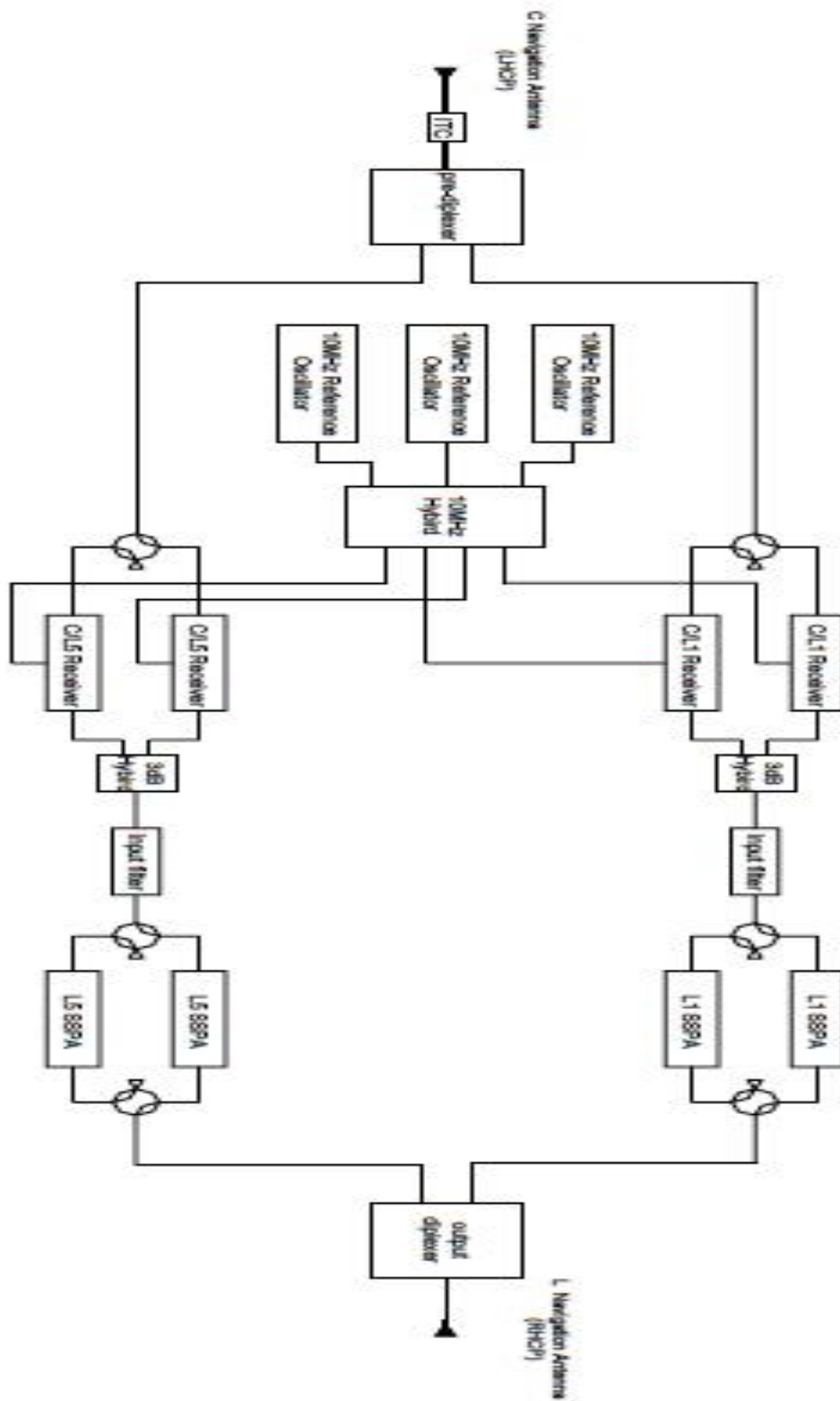


Figure 6: Illustrating the Navigation Payload of NIGCOMSAT-1R with externalized 10 MHz Master Oscillator in 3X 4 10MHz Hybrid Array Configuration.

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 as illustrated in figure 6.

**Table 1: Downlink Frequency and Polarization of NIGCOMSAT-1R L-Band Payload.**

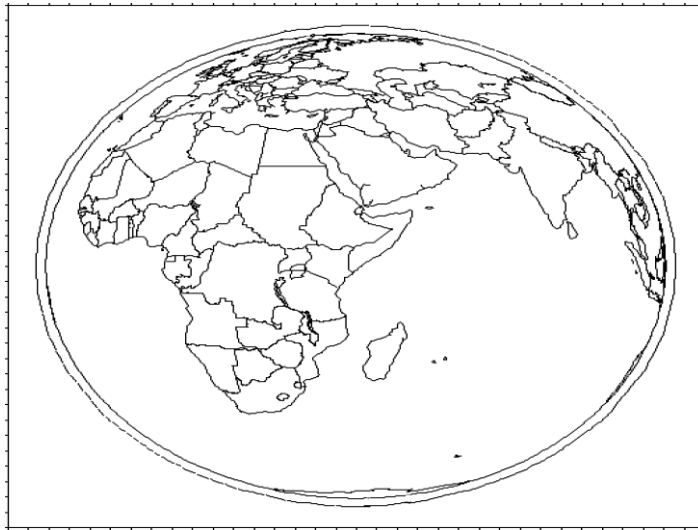
Channel	Frequency (MHz)	Polarization	Bandwidth (MHz)
L1-Downlink	1575.42	RHCP	4
L5-Downlink	1176.45	RHCP	20

The beam from the downlink L-band navigation antenna is global, ensuring that NigComSat-1R is capable of broadcasting to its coverage area while the GEO ranging signals and Satellite Based Augmentation System (SBAS) signals through the L1 and L5 frequencies are as shown in Table 1. The In-Orbit Test (IOT) was used to validate the functional capability of the navigation payload and its readiness for function and applications.

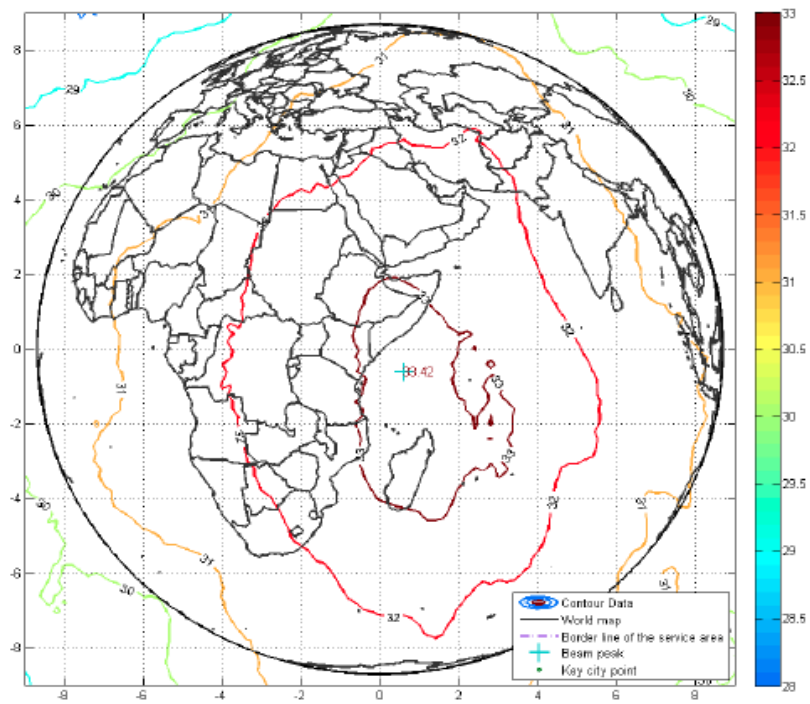
The system augments the Global Navigation Satellite System (GNSS) over Europe and Africa. Recognizing the important advance of dual user frequencies over the single L1 frequency capabilities of previous GNSS, the planned system produces an additional civil signal on the L5 frequency broadcasting Safety-of-Life signals on both the L1 and L5 frequencies as planned with Galileo systems and thus 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 the 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 of the C-band as illustrated in figure 7. The navigation payload down converts the C-band signals to L-band, L1 and L5, and retransmits these signals globally to users in its coverage areas as shown in figure 8 and 9 respectively. 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 (Lawal, 2014).

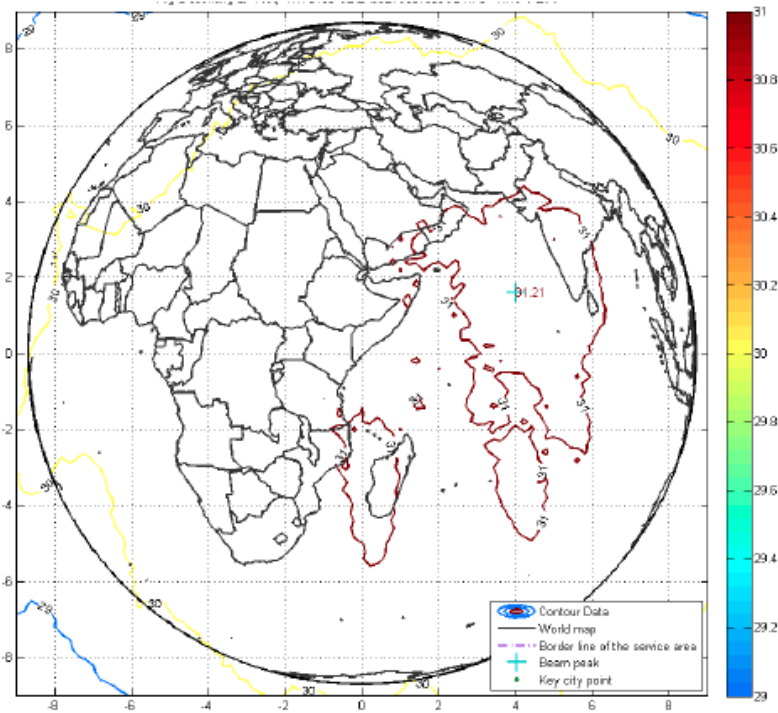




**Figure 7: The uplink coverage beam of NIGCOMSAT-1R Geo-Navigation Satellite using C-Band Navigation Antenna.**



**Figure 8: The Downlink coverage beam (L1-Band) of NIGCOMSAT-1R Geo-Navigation Satellite using Dual L-Band Helix Antenna.**



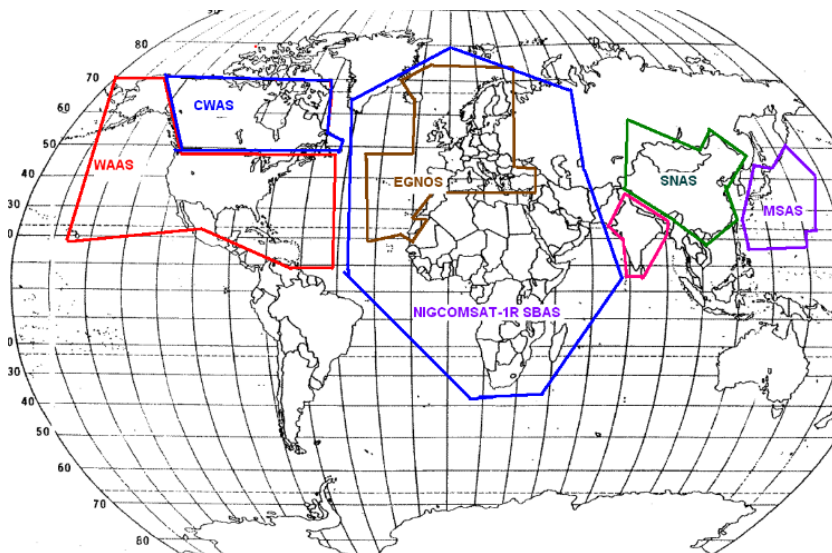
**Figure 9: The Downlink coverage beam (L5-Band) of NIGCOMSAT-1R Geo-Navigation Satellite using Dual L-Band Helix Antenna.**

Global Navigation Satellite System's (GNSS) without augmentation, whether GPS, GLONASS, GALILEO or BEIDOU - are not type approved for critical and demanding sectors that involve safety of life (SOL) such as aviation, maritime and professional applications. They also lack real-time monitoring and application with dynamic positioning systems except for the newer generation with modernized technology. Thus, augmented systems are meant to provide integrity, availability, accuracy, continuity and fleet management capability.

Satellite-Based Augmentation Systems (SBAS) using Geostationary Communication Satellites are ubiquitous and cover a wide area compared to localized Ground-Based Augmentation System (GBAS). 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. Figure 10 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 other African countries including the oceans to extend NIGCOMSAT-1R coverage.



**Figure 10: 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 have initial operational capability (IOC) i.e EGNOS of Europe, GAGAN of India, SNAS of China and MSAS of Japan.

## **BENEFITS, APPLICATIONS AND DERIVABLE SERVICES FROM NIGERIAN SATELLITE AUGMENTATION SYSTEM**

The Nigerian Satellite Augmentation System is incomplete without the complementary ground infrastructure for the Required Navigation Performance (RNP) in aviation, maritime and other critical sectors of the economy to help fill the great gap in Africa as regards augmentation systems. This was reiterated in the course of identification of strategic priority projects under ICT working group of National Integrated Infrastructure Master Plan (NIIMP) and was included under satellite and ground infrastructure expansion as a key priority project for the 2014-2018 portfolio infrastructure spend. (NIIMP Final presentation, July, 2013). With the necessary ground-related infrastructure such as Data Processing Center, Reference stations, User Terminal & Signal Simulation Unit and integration with Ground Uplink Station at NIGCOMSAT-1R Master Ground Station, the navigational capability and capacity of the space-based asset will be exploited for: enhanced productivity, enhanced security of assets and public safety, traffic management, pipeline monitoring, national strategic infrastructure, geographic information systems, agriculture in a mixed of controlled and free market.

### **Identified Primary Target (Customers and Economic buyers)**

- I. Car Users, Fleet Management outlets, Cargo Companies, Postal Agencies etc
- II. Indigenous Car Manufacturers for factory built Anti-theft devices and Navigators
- III. Vehicle Security Companies
- IV. Insurance Companies
- V. Armed Forces, Paramilitary organizations and Security agencies
- VI. Energy and Communications Company for utility Synchronization

- VII. Aviation
- VIII. Maritime, Sea and River Transport
- IX. Railroads
- X. Geographic Information System Companies
- XI. Geodesy and Cartography
- XII. Emergency Agencies i.e NEMA, Fire fighters, FRSC etc.

#### **Identified Secondary Users**

- I. Scientific Research
- II. Tourism
- III. Environmental Protection and Characterization
- IV. Public safety in Buildings and structural monitoring and construction such as bridges etc

Below are key areas of applications and services derivable from the Nigerian Satellite Augmentation System (NSAS):

##### ***A. Defence and Surveillance Applications by Military for Territorial Protection.***

With the required precision and timing of the navigation payload, the system is fit for application on land, air and sea during military operations and/or normal routine surveillance.

The navigation payload improves greatly the highly accurate position, velocity and time information and thus allowing 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. It 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. Naval and civilian ships are better monitored with NSAS considering the precision and real-time vessel management facilities.

##### ***B. Emergency & Recovery Services***

Natural disasters have become part of our existence; hence adequate preparation must be made for immediate recovery and future planning. With well-integrated satellite imagery and navigation technology, evacuation of disaster victims can 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 of emergency preparedness and management (Lawal & Chatwin, 2014).

##### ***C. Transportation***

From land to sea and air, safe navigation continues to generate concern and there needs to be an appropriate solution.

*i. 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. Figure 11 shows vehicle and fleet management telematic equipment compatible with NSAS. The rail system is best managed via support of Automatic Train Control (ATC), which among others things can be used to monitor goods from the different geopolitical ends on the nation.



**Figure 11: Vehicle and Fleet Management Telematic Equipment.**

*ii. Maritime:* Ocean, coastal, port approach and port maneuvers, under all weather conditions are better achieved under a space-based navigation system as NSAS exploiting the L1 & L5

transponders of NIGCOMSAT-1R Navigation payload. The satellite system will also provide precise navigation along inland waterways, inland ports, surveys and other maritime activities.

*iii. 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

#### ***D. Land Surveying (Mapping)***

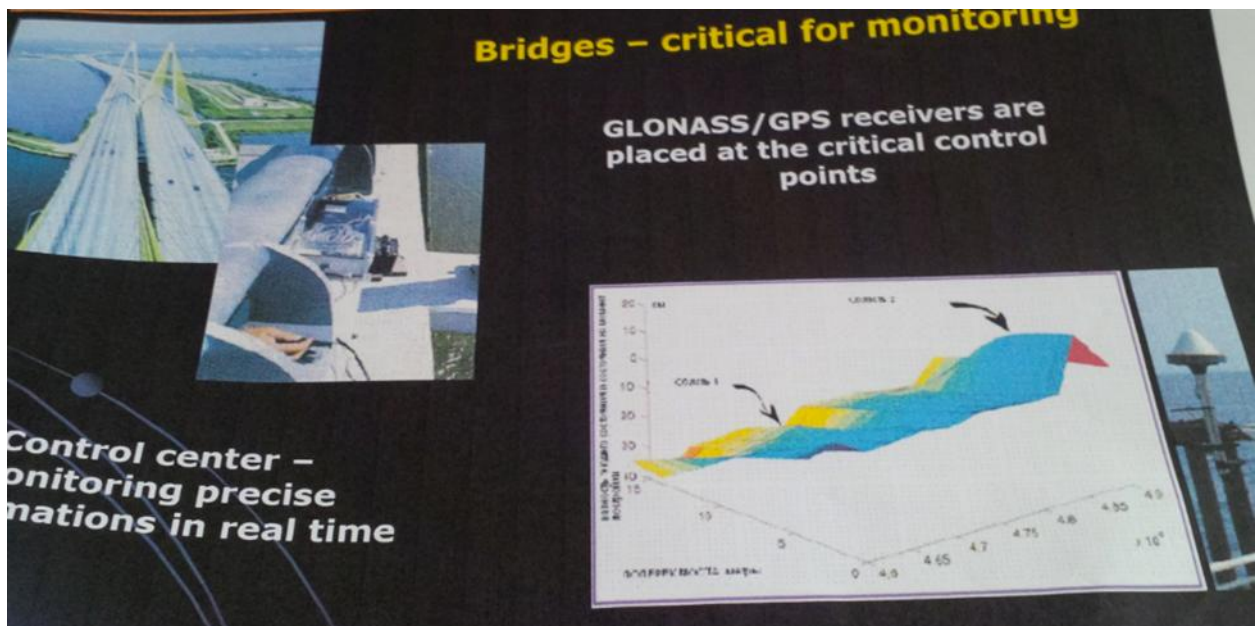
Precision mapping and land surveying today can better be done through a satellite positioning system to one millimeter (1mm) accuracy. Precision equipment like hand-held GNSS device and stations has replaced the old theodolite technology used for land survey and mapping.

#### ***E. 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 the fertility of agricultural soil & fields, the movement of the aquatic food supply can be monitored for a precision harvest etc.

#### ***F: Utility Management, Construction, Buildings and Bridges exploiting Remote Asset Management Solution.***

Heavy-duty equipment, facilities and infrastructure such as buildings and bridges could be monitored using the navigation system for their safety, human location etc from remote control centers using real-time alarm system for human and public safety and to help prevent intruders and mismanagement. Figure 12 shows GPS receivers at critical control points of a bridge to monitor their safety from trended graphs over time.



**Figure 12: GPS receivers at critical control points of a bridge to monitor public safety of the infrastructure from trended graph over time**

## CONCLUSION

The Nigerian Satellite Augmentation System provides Africa's contribution to the Global Navigation Satellite System (GNSS) exploiting 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 systems, increases the number of satellites in different orbital planes reducing 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 the 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. Target customers shall first be: car users, fleet management, cargo and postal agencies, car manufacturers, Vehicle anti-theft security companies, Military and Paramilitary organizations etc all are in the first phase of the operational plans for the West African and African sub region to meet short term objectives, sustainable requirements and addressing free market needs, operations and capital expenditure for value-added services and other benefits. It will facilitate an enabling environment for investment, enhanced productivity for economic growth, development, employment generation and wealth creation with enhanced public safety and security of critical national infrastructure.



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