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INAUGURAL LECTURE

"IN THE REALMS OF TELECOMMUNICATIONS, RELIABILITY AND QUALITY ENGINEERING"

By

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Ladies and Gentlemen

My Journey into the Engineering Profession

As a science student in the secondary school in those days, I found myself in the wilderness of possible professional careers. However, the only career that never came to my mind, and hence not under consideration, was Medicine because I could not, and can still not, be comfortable seeing fresh blood, even of animals, talk less of human blood. I always still remember the day I fainted in the accident ward of an orthopaedic hospital in 1982 on sighting an accident victim with bones protruding from his legs and covered with fresh blood. Indecision or lack of proper career guidance and counselling eventually found me in Electrical Engineering through an Hungarian Government scholarship scheme despite having admissions to study Forestry (University of Ibadan), Mechanical

Engineering (Ibadan Polytechnic), Land Surveying (University of Nigeria, Nsukka) and Mathematics (Makerere University in Uganda), all in the same year (1974) and all coming with scholarship/sponsorship. I eventually found myself studying Electrical Engineering (Telecommunications option) at the Budapest Technical University, Hungary.

On returning to Nigeria in 1980, I had my NYSC scheme in Kano and served with the Nigerian Army Electrical and Mechanical Engineers (NAEME) in the Bukavu Barracks. I thereafter took up academic appointment at the Federal Polytechnic, Ilaro, in February 1982 as a lecturer in the Department of Electrical Engineering. However, my urge to proceed for a PhD programme was thwarted by the Polytechnic's Staff Development Committee because, according to them, 'acquisition of doctorate degree is not the priority of the polytechnic'. Ironically, all the members of the Committee (all Deans), except one, were PhD holders. In 'annoyance', I decided to venture into Industrial Engineering by applying for sponsorship through the same Committee to pursue an MSc degree programme in the University of Ibadan; this was 'joyfully and speedily' approved by the same committee. This is a course I have never regretted venturing into because Industrial Engineering basically touches the border-line areas of all engineering disciplines, thereby exposing me to courses such as Quality Management, Operations Research, Manufacturing and Systems Engineering, Human Factors Engineering (Ergonomics), Reliability Engineering, Project Management and Value Engineering that have made me more versatile in the engineering profession. I have succeeded in producing textbooks in Engineering Economics and Reliability Engineering, in addition to those in Electrical Engineering. Therefore, as much as I am a Telecommunications Engineer, I am equally an Industrial Engineer and a Certified Management Consultant. To God be the Glory.

The Engineer as a Professional

An Engineer can be described as a professional who applies scientific knowledge, such as mathematics, physics, chemistry, biology and other specialised scientific courses to the optimum conversion of the resources of nature to the benefit of mankind. He/She is a professional because his/her basic satisfaction is in performing well, tasks he/she has been trained for, and is always striving to achieve the best standard possible in any circumstance. The resources of nature include raw materials which have to be converted to useful products with the help of man, materials, machines and money (4M). The expected benefits to mankind of engineering activities include safety, reliability, maintainability, availability and risk management (including risk identification, analysis and control).

Engineers are generally involved in planning, design (including subsystem and component design), construction, system operation and maintenance (O&M), research and development (R&D), consulting, manufacturing systems, project management, quality management (control & assurance), reliability, availability and maintainability (RAM), education, sales, etc. As a professional, an Engineer has a specialised body of knowledge received through a recognised training and should also be involved in continuous professional development (CPD). Most importantly, an Engineer should be covered by the codes of ethics and standards of the profession. Also, apart from technical responsibility, an Engineer has some social responsibilities for the environment in which he/she practises (Wikipedia, 2019).

Engineering Codes of Ethics

Tremendous progress in the areas of engineering, technology and science has resulted in new technologies, such as genetic engineering, biotechnology, nanotechnology and Artificial Intelligence (AI), all aided by Information Technology (IT). Some of the major challenges faced by Engineers today include collapse of engineering structures and natural disasters (e.g. earthquakes, tsunami, etc.), chemical leakage, oil spillage, plant explosion and fire accidents. In the face of all these, it is primarily the social responsibility of Engineers to ensure public safety by: protecting people (public safety, health and well-being); creating a better working environment; being proud of their profession; reporting those who flout codes and standards of the profession; encouraging others to report non-compliance; preventing and reporting conflicts of interest; building up public confidence; and being honest and of high integrity. Other ethical issues stipulated for an Engineer include healthy relationship with clients, competitors, contractors, employer and colleagues (Wikipedia, 2019). The purpose of engineering ethics, therefore, is to increase the moral judgment skill of the Engineer.

Engineering Training in Ethics and Social Responsibility

Engineering students, either by omission or commission, usually and wrongly take lightly (or even detest) any course that they consider as non-core engineering course, such as economics, history and philosophy of science, management and law. All these, and other social science courses are required, and therefore included in the engineering curricula, to be taught in order to make the students, who are the future engineers, realise their social responsibility to the public and environment in which they will eventually practise. Students detest these courses either because the courses are not properly taught or are taught at wrong times. Our engineering curricula may be a suspect and probably have to be re-designed by incorporating engineering ethics and social responsibility issues within relevant engineering core courses. For example, a course in electrical power generation should incorporate social responsibility issues in various power plants and supported by appropriate case studies (using e.g. video clips) of disasters that have been experienced. I always remember the video clip of the Tay Bridge collapse of 1879 as shown to us in the 100 level physics class in 1975 while treating resonance.

Reliability Engineering for Quality Products and Services

Every age or era in history has its own long list of technological horror stories in forms of accidents, failures and failed products. The rate of failures of engineering structures has however become a technological embarrassment to the concerned professionals, particularly engineers, whose major professional ethics is safety of the product while in operation. Some notable engineering failures in history that resulted from human errors are summarised in Table 1.

In addition to these and other disasters, collapse of buildings, bridges and telecommunications masts is the order of the day in Nigeria, and is on the increase. Also, millions of automobiles (vehicles) are being recalled worldwide, and on monthly basis, by various vehicle manufacturers due to one failure mode or another, some fatal. Recalls have to be made by notable automobile manufacturers in order to avoid serious litigations from individual victims or governments that care about the safety of their citizens. For example, Toyota had to agree to a settlement of above US$1 billion to resolve hundreds of lawsuits due to just acceleration problem in one of their vehicle brands; this excluded lawsuits instigated as a result of death.

Table 1: Some notable engineering failures

S/No.	Year	Description	Feature(s)
1	1876	Ashtabula River railroad disaster	• Derailment caused by failure of a bridge over the Ashtabula River about 300 m from the railroad station in northeastern Ohio • killed 92 people, including the gospel singer and hymn-writer Philip Bliss and his wife • the bridge had been improperly designed and inadequately inspected
2	1879	Tay Bridge disaster	• Collapsed as a train passed over it, killing all aboard • no explicit allowance for wind loading was made in the design • had other flaws in detailed design, maintenance, and quality control of castings
3	1907	Quebec Bridge collapse	• Road, rail and pedestrian bridge project that failed twice, at the cost of 88 lives, and took over 30 years to complete.
4	1919	Boston Molasses disaster	• A molasses tank exploded under pressure, killing 21 people • a 40-foot wave of molasses buckled the elevated railroad tracks, crushed buildings and inundated the neighbourhood • physics and neglect contributed to make the accident so horrific
5	1979	Three-mile Island accident	• A partial meltdown of reactor of the generating station in Pennsylvania, a

			• accident began with mechanical failures which allowed large amounts of radioactive gases and iodine into the environment • mechanical failures were compounded by initial failure of plant operators to recognize the situation due to inadequate training and human factors • Cleanup took 14 years, with a total clean-up cost of about $1 billion
6	1986	Chernobyl disaster	• A combination of reactor design and construction flaws caused an uncontrolled nuclear chain reaction in the nuclear plant, resulting in highly destructive steam explosion, killing two of the operating staff • Out of 134 firemen and station staff hospitalized with acute radiation syndrome, 28 died in the days to months afterward and about 14 suspected radiation-induced cancer deaths in the following 10 years
7	1986	Space Shuttle Challenger disaster	• The NASA Space Shuttle orbiter broke apart 73 seconds into its flight, killing all seven crew members • failure was caused by the failure of O-ring seals used in the joint that were not designed to handle the unusually cold conditions that existed at this launch

8	2003	Space Shuttle Columbia disaster	• Disintegrated during atmospheric entry, killing all seven crew members • a piece of foam insulation broke off from the Space Shuttle external tank and struck the left wing of the orbiter.
9	2013	Bangladesh building collapse	• A structural failure causing an 8-storey commercial building to collapse. • 1,134 people died, approximately 2,500 people injured and rescued • considered the deadliest structural failure accident in modern history
10	2019	Brazilian dam collapse	• The dam released a mudflow that advanced through the mine's offices, including a cafeteria during lunchtime, along with houses, farms, inns and roads downstream • 272 people died, of whom 256 were officially confirmed dead and 14 others are missing as their bodies have not been found.

Source: Wikipaedia (accessed 4/11/2019)

This brings us to the issues of quality and reliability of products and services. **Quality** is "the totality of all features and characteristics of a product or service that contribute to the satisfaction of a customer's needs" (Adediran, 2014). Such quality characteristics can be categorized as (Besterfield, 1986):

- Technological: e.g. physical dimensions (length, height, breadth), weight;

- Psychological: e.g. aesthetics, colour, interior decoration; and
- Time-oriented: e.g. reliability, maintainability, availability (Besterfield, 1985).

Reliability is, therefore, a time-oriented parameter of quality, and can be defined as "the **probability** that a component or **system** will perform its **prescribed duty** without **failure** for a given **time** when **operated correctly** in a **specified environment**" (Adediran, 2014). Quality Engineers suggest changes that permit a product to be produced within tolerance at a reasonable cost, while Reliability Engineers make recommendations that permit the product to function correctly for a longer period of time.

At this point, the question to ask is: Are all engineering failures traceable to Engineers? As much as engineering is a human endeavour, hence subject to human error, some engineering errors are however merely annoying, unacceptable and embarrassing, not only to the nation, but particularly to all the stakeholders in the design and implementation of such engineering systems.

Why do Engineering Systems Fail?

Figure 1 summarises the phases involved in the life cycle of an engineering product. An engineering system, nowadays, may be composed of either hardware alone, or software-controlled hardware. The hardware-related failure causes include: damaged hardware, badly designed hardware, and poor fit between system and organisation. Software-related failure causes include: poor development practices, poor testing, incorrect perceptions of system requirements, poor user interface, and poor/lack of documentation.

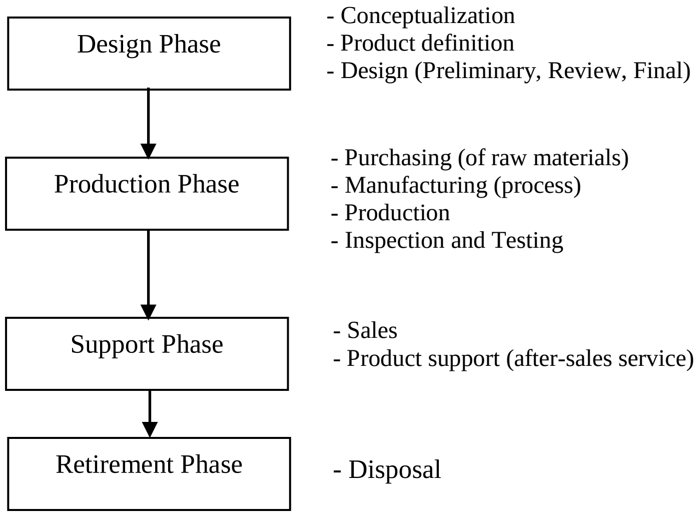


Figure l: Life-Cycle of a Product (Adediran, 2014)

As long as it is almost impossible to eliminate human involvement in design, construction, operation and maintenance of engineering systems, human reliability itself comes into play when considering engineering system failures. Human error may arise from: inadequate or lack of knowledge about the equipment and manufacturing/production process; poor judgment skills in handling the equipment; absence of correct quality management procedures and instructions (i.e. lack of standards); carelessness or inattention; and physical inability of the operator. Therefore, among the procedures for preventing/mitigating human error are: placing physical barriers to errors by not putting round shaft in square holes; displaying reminders such as photos of correct/incorrect results; use of automated equipment to detect errors; and standardising procedures such as performing same action on a family of parts. The norm therefore is: *Let the person making error suggest how the design should be in order to make error impossible*.

This brings us to the issue of the need for Reliability Engineering today, which according to Adediran (2014) includes:

- larger systems with large numbers of components;
- more complex functions to be performed (by a single system);
- competition among manufacturers;
- critical systems (e.g. power plants and telecom systems);
- public pressures on product performance and failure rate;
- systems used in increasingly hostile environments (of temperature, pressure, vibration, shock, humidity, terrain, etc.); and
- increasing number of reliability- and quality-related litigations arising from failed products.

Therefore, a process must be designed to ensure that the product performs to a required level of Reliability. The old reliability practice has focused on functionality, thus leaving out the key failure modes and failure rate of the product, key failure mechanisms in service environment, usable life of the product, availability, and rigorous testing. In quality engineering, including reliability engineering, the customer's needs assessment must be carried out. Prototyping, for example, of the product or service provides the design team with a 3-D object that can run through reliability tests or Quality Function Deployment (QFD) which provides a process for planning new or redesigned products or services. The current trend and emphasis in product/service design therefore is to Design for Reliability (DFR) through concurrent engineering, configuration design, appropriate component selection mechanism, verification and performance testing, and customer needs assessment. The role of the Reliability Function in an organisation, therefore, is to:

- improve product design through reliability analysis;
- assist marketing and advertising (e.g. on warranties);

- detect and prevent/mitigate product liability issues (with respect to safety and health hazards, product replacement); and
- assist manufacturing to: study impact of process parameters on product failure; compare alternative processes for their effect on reliability; determine preventive maintenance schedules and spare parts inventories; evaluate improvement in process reliability while using parallel process streams; enhance safety through understanding of equipment failure rates; and evaluate vendors more effectively (Adediran, 2014; HCL Technologies, 2007).

Every facet of an organisation can benefit from Reliability Engineering knowledge, especially to improve the effectiveness and efficiency of their functions.

My Contributions to Knowledge in Telecommunications

Mr. Vice Chancellor Sir, the word ‘telecommunications’ was coined from the Greek words ‘tele’ and ‘communicare’ which respectively mean ‘over a distance’ and ‘the ability to share’ (Goleniewski, 2002). Hence, telecommunications literally means ‘the sharing of information over a distance’. However, telecommunications today can be more comprehensively defined as ‘sharing of information over a distance with the aid of electrical devices’. Thus, in electrical engineering terms, **communication** refers to the sending, processing and reception of information using electrical means (Adediran, 2005a); the information or message to be sent, processed and received may take different forms: voice, picture, image, video, data, written message, etc. However, the message, irrespective of its original form, must be converted to an electrical signal. A **communication system**, therefore, is a technique or equipment that is used to send, process and receive messages. Telecommunications can therefore be achieved by the application of communication systems.

Radio Waves and the Electromagnetic Spectrum War

The electromagnetic (EM) spectrum is a scarce and limited natural resource because many new and emerging radio services and technologies (e.g. wireless LANs, 4G & 5G systems, radio frequency identification (RFID) systems, ultra wide band (UWB), software defined radio (SDR), cognitive radio, mesh networks, etc.) are scrambling to have access to it. Unfortunately, spectrum can neither be created nor produced and additional one can also not be created as is the case with industrial raw materials. It is also not a consumable resource. The traditional approach of allocating and assigning spectrum for use had been the administrative process which gave exclusive use to the spectrum. This approach lacked flexibility, with the licensee either using the spectrum for any purpose or warehousing/banking it. This deficiency led to the market-oriented approach whereby not only national governments are involved, but also private sector and non-governmental organisations. Four factors used or recommended by the International Telecommunications Union (ITU) in spectrum pricing are: cost of spectrum management (SM) function; revenues derived from licensees' use of the spectrum; provision of incentives for achieving SM, and the economic cost associated with the use of the spectrum by licensee. Thus, the spectrum charge is a fee that is based on SM costs comprising a licence fee and a royalty charge (Adediran, 2006; Idika & Adediran, 2008). Spectrum trading, together with spectrum liberalisation, has been a key to optimising and rationalising spectrum use, with constraints upon usage as set by the regulator (Nigeria Communications Commission or Nigeria Broadcasting Commission in Nigeria). Nigeria benefitted from spectrum sale in 2001 with the auctioning of the GSM licenses to MTN, Econet Wireless and MTel, thus raking in millions of dollars. Each of the operators paid US$285 million in 2001, while Globacom paid US$200 million in 2003 for its license (Adediran et al., 2005). Market-oriented mechanism, through spectrum trading, is therefore recommended as the best option to confer property rights on licensees, thus enabling innovative technology developments through third party arrangement (Adediran, 2006).

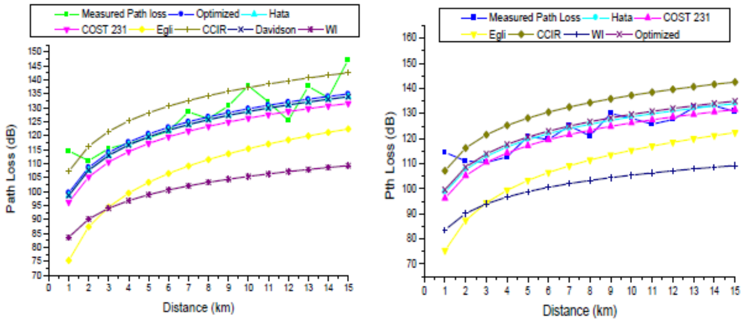
The following options are available to improve on the effective and efficient use of the spectrum: increasing capacity, increased spectrum sharing; band clearing/relocation; increased use of the license-exempt Industrial, Scientific and Medical (ISM) bands; extending the upper limit of the usable frequency; use of non-spectrum technologies; and use of property rights (Adediran, 2007).

Radio Wave Propagation and Path Loss

The fundamental principle in the design of any wireless system is the design of transmission strategy that will optimise the coverage and minimise interference. Understanding the behaviour of the radio propagation channel in an environment is essential for the success and deployment of any communications technology built to operate in such environment. In all frequency bands, signals undergo attenuation which increases with distance; this is referred to as **path loss**. Multiple signals may arrive at the receiver constructively or destructively; this will cause small variation of the signal or **multipath fading** which arises from reflection, refraction, diffraction and/or scattering of the signal due to the presence of physical objects in the environment.

Path loss propagation models are required in coverage planning and optimisation, and signal prediction, and are used for interference analysis to ensure coexistence of various services. Path loss models are applied in cellular environments, fixed wireless access systems and TV broadcast systems. They are used in our research works for the prediction of television coverage. Several empirical models have been proposed, such as the ITU-R P.1546-4 for predicting the radio coverage at VHF and UHF bands. Empirical models have been given attention for decades due to their accuracy and environmental compatibility. However, peculiarities of these models give rise to high prediction errors when deployed in a different environment other than the one initially built for.

Propagation measurements were conducted in Ilorin (longitude 4^{o} 36’ 25”E, latitude 8^{o} 25’ 55’’N) and its environs within Kwara State, Nigeria. Ilorin is a large city characterised by a complex terrain due to the presence of hills and valleys within the metropolis. Outside the metropolis, the routes are covered with thick vegetation. The altitude of the transmitter’s location is 403.7 m; the altitude can be as low as 150 m when driving within and outside the city. Six routes were covered during the measurement campaign. NTA Ilorin and Kwara TV transmitters were utilized. NTA transmits on channel 5 at 203.25 MHz while Kwara TV transmits on channel 35 at 583.25 MHz. During transmission, a dedicated spectrum analyzer was placed inside a vehicle and driven at an average speed of 40 km/h along the routes. Field strength was measured continuously and stored in an external drive for subsequent analysis. Total route length and number of points were 169 km and 314,914 respectively (Faruk *et al*., 2013 a&b, 2014). The measurement results were converted to path losses and were compared with path loss prediction of eight widely used empirical models. Least squares and linear iterative methods were employed to optimise the Davidson model. The predictions of the tuned model were compared with other models in terms of relative error, prediction error, mean error and skewness. Results of the simulations indicate that the optimised model gave smaller values for the considered metrics. In terms of skewness, the optimised model provided a significant improvement of about 54.5% and 86.8% respectively when compared with Davidson model and Hata model (see Figure 2).



(a) (b)

Fig.2:Comparison of the Optimized Model with Measured Path Loss along (a) Route 1 with Measured Path Loss along (b) Route 2.

A similar exercise was carried out by Adediran *et al*. (2017) in the Osogbo environment in Osun State of Nigeria. Propagation path loss prediction model was developed for the study area using drive test technique in conjunction with six existing models. The authors have reported the development of a path loss prediction model that describes the signal attenuation characteristics between transmitting and receiving antennae as a function of the propagation distance and other parameters for the study area. The model is extensively useful and therefore recommended for conducting feasibility studies for signal prediction, coverage optimisation and interference analysis during the initial phase of network planning in the study area and other areas with similar environmental and propagation characteristics.

TV White Space and Spectrum Occupancy

TV white spaces are vacant, unused or interleaved frequencies located within the broadcast TV channels in the VHF/UHF range, which can be found between 54 MHz and 806 MHz. With the advent of digital switch-over, more spectrums will be freed as white space and, as such, there would be rapid development of wireless communication systems operating at VHF and UHF bands. Exploitation of these vacant channels has become a major challenge since the idea of cognitive radio (CR) technology, which aims to exploit the available TV white space, may not be guaranteed for deployment at the present stage. This called for alternative spectrum management models and techniques that would allow efficient utilisation of the TV white space, which could either be temporal (i.e. at the times when the primary service is switched off) or spatial (where low power and low-range wireless devices, or secondary users, in a strictly localized manner can utilise the white space without interfering with the TV transmission). In order to recover the spatial TV white space, signal prediction techniques are required to make a decision whether the location is white space or not; and the decision is based on a threshold, that is, if the received signal level at the position is greater than a certain value as described in the IEEE 802.22 draft.

The first step is to develop an empirical path loss model that could be used in predicting the presence of a primary user, PU, (TV signals in this case), both temporally and spatially, in order to extract the available spectrum holes that could accommodate a secondary user (SU). It is also necessary to investigate the effects of, for example, transmit power, transmitter height, operating frequency and the sensing threshold. Therefore, an algorithm that could predict the service contour and make decision on the availability of the white space was developed. The algorithm recovered the region outside the global no-talk zone of the primary user. Results of simulation showed that the amount of white space that could be recovered depended on the threshold rule applied. It was also found that the keep-out-distance varied as a function of the operating frequency and the propagation characteristics of the area (Nasir et al., 2013).

The simulation and algorithm development considered the ITU regulation of 41 dBu for service contour for digital TV (DTV) systems. The DTV coverage distance and the protection margins were calculated. Hata, COST 231, CCIR and the optimized models were considered. Three scenarios were considered when calculating the keep-out-distances for secondary operation: (1) evaluation of the effective DTV coverage, also known as the 1st coverage radius of the primary transmitter using the grade B contour; (2) when the 15.5 dB D/U (desired-to-undesired signal) ratio as additional protection margin Δ_1 is imposed; and (3) when FCC's -114 dBm sensing rule is applied for protection margin Δ_2. For computational convenience, the electric field strength unit (dBu) was converted to the signal power unit (dBm). Figure 3 depicts the primary user and secondary user DTV coverage and the protection margins.

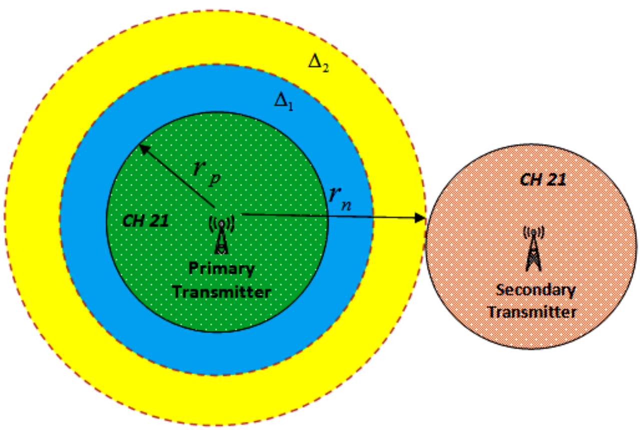


Fig.3: DTV Coverage and Protection Margins

The algorithm developed was able to recover the region outside the global no-talk zones of the primary user. Analysis of the result showed that more white space could be recovered when grade B contour was used as a reference threshold. However, the 15.5 D/U ratio provided extra protection margin for the primaries but would ultimately decrease the amount of white spaces (Faruk *et al*., 2013c; 2014)

Microwave Engineering and Satellite Communications

A communication satellite system consists of an electronic object put in space at some orbit to receive and transmit electromagnetic (EM) signals between it and the earth stations or similar satellite(s) in space. Two components of particular research interest to us are the waveguides used to convey the EM signal in the microwave region and the antenna feeds. The primary concern in waveguides is the multipaction phenomenon which can degrade the performance of the waveguide, while weight reduction is paramount in the case of the feed antenna.

Multipaction: Satellite-borne rectangular waveguide couplers operate in a high vacuum space environment and under high radio frequency (RF) power. Both conditions favour the initiation of multipactor breakdown/discharge. Multipaction (MP) is the resonant growth of secondary electron population in RF components with the possibility of an eventual electrical discharge, ultimately resulting to damage of on-board equipment, generation of excess heat which can lead to melting and cracking of components, increased noise generation, harmonic distortion, inter-modulation, and general degradation in link budget and power output performance of the satellite.

In an effort to suppress the initiation of multipaction, couplers expected to operate under vacuum and high RF power conditions are incorporated with extensive surface and geometry modifications by manufacturers. However, this suppression approach is rather expensive, in terms of both design cycle and test campaign. As a direct result of this challenge, the European Space Agency (ESA) awarded a contract titled “Multipactor and Corona Discharge: Simulation and Design in Microwave Components - AO-4026 ITT ESA”. The contract was devoted to the investigation of multipactor and corona effects in rectangular waveguide components, modelled as parallel plates, through the development of multipactor prediction software tools. The multipactor predictor was required to possess the capability to analyse, not only the electromagnetic response of microwave components, but also to determine the breakdown power of such structures with reasonable accuracy.

An important design, manufacturing and test consideration in systems utilising hollow waveguides operating at low gas pressures and high RF power levels is therefore the prevention of the multipactor breakdown phenomenon. Our studies (Akoma & Adediran, 2010; 2012, Akoma *et al*., 2012) in this area make use of a proposed multipactor prediction algorithm designed with apposite consideration for reflected electrons to predict possible breakdown power levels for rectangular waveguide couplers operating at the transverse electric (TE_{10}) propagation mode. The results of further analysis, using the algorithm, suggest that it is crucial to account properly for reflected electrons during a multipaction process investigation in order not to overlook subtle breakdown powers (Akoma and Adediran, 2013).

Feed Antenna Array: The antenna subsystems on majority of communication satellites, when fully deployed, utilise parabolic reflectors for their earthward beams. Over the past decades, the conventional feed for parabolic reflector antennas on-board satellites has been the horn since it provides the required directivity. One of the goals of the satellite antenna designer is to minimise the weight as much as possible without sacrificing the overall performance of the antenna. The problem here is the weight of the bulky horns which, in turn, affects the weight of the feed support structure and increases the overall weight of the satellite payload. Weight is also a strong factor that affects the overall cost of the launch campaign in space missions where mass and size limitations are extremely strict. Weight also affects the maneuverability and cost of station keeping for in-orbit satellites. There was therefore a need to attempt to solve this problem by giving consideration to patch antennas to replace the horns. Some of the principal advantages of patch antennas are light weight and low volume. The small size of patch antennas limits control of the pattern and one must therefore use arrays of patches since the desire is to control its pattern. In this area, a 4x1 patch antenna array was modelled to operate as feed for a parabolic dish antenna (*F/D*=0.36) operating in the C-band. Using CST MWS-2012 software, an analysis of the model was carried out (Ibigbami & Adediran, 2013).

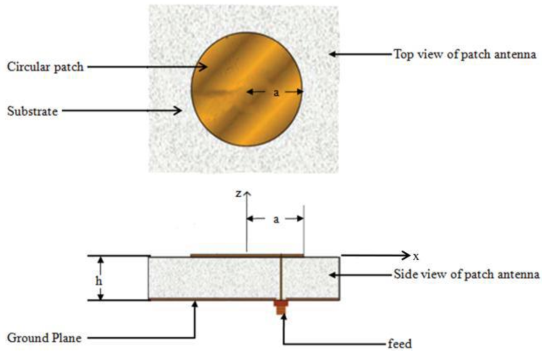


Fig. 4: Single Patch Antenna Structure

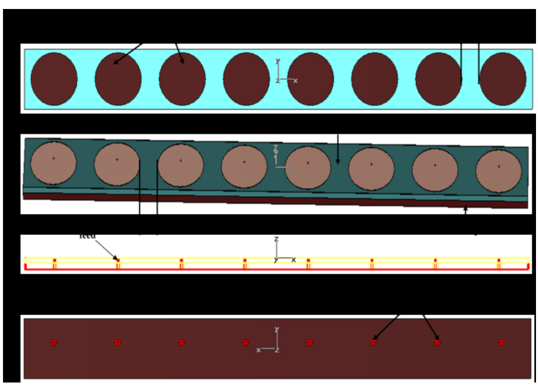


Fig. 5: 8x1 Patch Antenna Array

The design approach for the determination of the inter-element distance for best performance was based on the illumination efficiency rather than trial by error. The model was simulated and the results of the simulations were analyzed. At a given inter-element spacing, the achieved simulated efficiency, while keeping all the other efficiency components constant, was about 49%. This was very competitive when compared to the maximum of 55% that could be achieved with conventional feeds for the same *F/D* ratio of 0.36 (Wade, 2003).

In the simulation process, the beam width between the first nulls (FNBW) for patch antenna array feed was varied while keeping the normalised signal excitation amplitudes and phases of the array elements uniform and constant. This was achieved by varying the inter-element distance. Conventional feeds have a wide main lobe that maximises the illumination efficiency. The best efficiency occurred when the illumination energy was about 10 dB down at the edge of the dish. The array designs resulting from this approach were simulated and their RF performances analysed through the use of Personal Computer Aided Antenna Design (PCAAD 5.0) software which is a specialised tool for fast and accurate three-dimensional EM simulations of high frequency problems (Ibigbami & Adediran, 2013).

Further simulations were carried out on inter-element distances, d = 0. 5 cm and d = 1.35 cm to find out the effect on the radiation pattern presented by the 8x1 patch antenna array feed for the C-Band dish. The total efficiency for the antenna array was 0.91, radiation efficiency 0.99, and realized gain 11.57 dB. The antenna VSWR was less than 3.0 at all the 4 input ports for the chosen central frequency of 4 GHz. Also at this spacing, the total array length is 15 cm which satisfies the condition of reduced dimensions required for on-board satellite applications where mass and size limitations are extremely strict.

Look Angles: To optimise the performance of a satellite communications system, the directions of maximum gain of a satellite ground control station antenna (referred to as boresight) must be pointed directly at the satellite. And to ensure that the earth station antenna is aligned, two angles must be determined, the azimuth angle, *Az*, and the elevation angle, *El*, which are jointly referred to as the antenna look angles. Antenna look angles of a geostationary communications satellite provide the information required to ensure that the control station antenna is directed towards the satellite, more specifically to ensure that the main lobe of the antenna is aligned with the main lobe of the satellite's antenna, and to ensure that the largest amount of energy is captured from the satellite. Our work in this area describes, in detail, the mathematical modelling of antenna look angles of two models of satellite ground control station.

The mathematical model presented in our work is a good tool that can be used to determine look angles for pointing satellite ground control station antenna to true geostationary satellites. The real values of Abuja Satellite Ground Control Station and Nigeria Communication Satellite (Nigcomsat-1) were compared with the values obtained through modelling. The real values and those obtained through modelling are very close, indicating that the modelling can be used to determine the look angles of satellites moving in orbits (Akoma et al, 2010).

Power Line Communication (PLC) Systems

Power Line Communication (PLC) is a term used to identify technologies, equipment, applications and services aimed at providing end-users with communication means over existing electrical power lines. PLC technology has been around for many years since the power line carrier systems were being used for electric power transmission and distribution lines to carry digital data and voice. For example, voice transmission via power line carrier dates back to the 1920s. Power companies have also been using PLC to send control messages for their own internal applications. PLC technology could also let the electric power transmission companies open lucrative revenue streams through bundling of electricity supply with broadband telecommunication access by providing high speed and reliable communication traffic, including Internet access. PLC-based communication systems are attracting attention because PLC is a promising technology to deploy communication networks in remote places, taking advantage of the existing electrical infrastructure.

Our work in this area analysed the reliability of a typical power line communication system connected to the Nigerian national electricity grid for a period of eleven (11) years. A reliability block diagram (RBD) reduction technique was used to derive the reliability functions of phase-to-earth, phase-to-phase and inter-system PLC couplings. A comparative assessment was made on the reliability of the existing PLC in PHCN Osogbo-Jebba, Jebba-Shiroro and Inter-system networks. The mean time between failures (MTBF) for the existing communication networks in PHCN was obtained. The study showed the reliability of PLC systems to be a function of the coupling methods. Reliability figures for the phase-to-earth coupling connected to the Nigerian grid for the 11 years were found to be very low when compared to the expected reliability figures obtained using RBD model. Inter-system coupling has the highest reliability figures, followed by phase-to-phase and phase-to-earth in that order. This work proposed that, for improvement in reliability, phase-to-phase or inter-system were preferable coupling methods in PLC systems. The work has also shown that transmission line distance has little effect on the reliability figures of the PLC system; rather, most of transmission line failures are as a result of vandalism (Abdulkarim & Adediran, 2011).

Components importance analysis of the PLC system was also carried out using the Birnbaum's component importance techniques. A comparative analysis was made on the PHCN phase-to-phase and inter-system networks (Abubakar et al, 2011). The study showed the components' importance of the PLC systems to be a function of the coupling method employed. It was therefore recommended that the components or units of the system should be replaced with higher reliability ones in order to improve on the reliability of the existing PLC system in PHCN.

Modulation and Multiplexing Techniques

Various modulation techniques, both analogue and digital, have been applied in communication systems, starting from the simple amplitude modulation (AM) through shift-keying methods and to the more advanced complex digital schemes. Each modulation method has its own features, advantages and application areas. An attempt was made by Adediran and Reyaz (2003) to discuss and classify the important modulation techniques used in mobile communication systems by highlighting the attractiveness of individual modulation schemes using the figure of merit of the receiver, such as bit error rate (BER) for digital modulation schemes. In addition, the authors considered separately the spread spectrum (SS) technology as used in mobile communication systems (Reyaz & Adediran, 2003). The most important advantage of SS is its interference rejection capability.

Multiplexing is a way of accommodating many input sources of low capacity over a high capacity outgoing channel. Statistical Time Division Multiplexing (STDM) is a technique that allows the number of users to be multiplexed over the channel more than the channel can normally afford by normally exploiting unused time slots by the non-active users and allocating those slots for the active users. In this way STDM utilises channel bandwidth better than the traditional Time Division Multiplexing (TDM). In our work, the statistical multiplexer is first viewed as an M/M/1queuing system using the Markov chain model shown in Figure 4 and its performance measured by comparing analytical results to simulation results. The index used to determine the performance of the statistical multiplexer is the number of packets both in the system and in the queue. Comparison of analytical results was also done between M/M/1 and M/M/2 and also between M/M/1 and M/D/1 queue systems. At high utilisation values, M/M/2 performs better than M/M/1. M/D/1 also outperforms M/M/1.

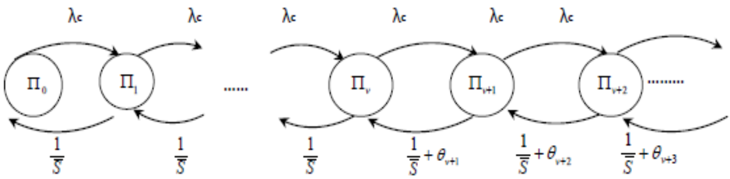


Fig.4: Markov chain model for

Simulations were done and data collected for the graphical plots of utilisation against buffer size in order to determine the efficiency of STDM. The performance of the statistical multiplexer was described by the number of packets in the system and in queue, average delay and buffer size. At low workload intensity (low utilization), an arriving packet meets low competition; hence, the multiplexer transmits packets infrequently. Therefore, because there is no much contention, the number of packets in the entire system is small. However, as the utilisation increases, there is more contention and, hence, more packets in the system. The multiplexer reaches saturation at a certain arrival rate, when the utilisation is very close to unity. If the link utilisation approaches 100%, delay approaches infinity.

Figure 5 compares the mean number of packets in queue versus utilisation for single server and 2-server queues. The single server reaches saturation when the utilisation is very close to 1 while the 2-server reaches saturation when the utilisation is close to 2, as expected. Simulation results to analyse the performance of the statistical multiplexer, when viewed as M/M/1 and M/M/k queue models, has also been presented in this study. Comparison was also done between the M/M/1 and M/D/1 models (Figure 6). Results confirm that increase in utilisation leads also to increase in the number of packets in the queue and in the system. These results also imply a corresponding increase in the buffer size and packet delay. Randomness (in service and arrival) is what causes queuing at buffers. Results show that queues and queuing delay increase dramatically as utilisation becomes greater than 90%. Comparison between the M/M/1 and M/D/1 reveals that M/D/1 outperforms M/M/1 to up to 50% at higher utilisation (Ajiboye & Adediran, 2010).

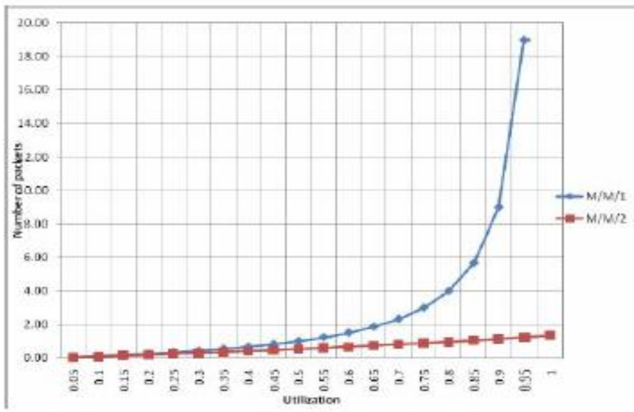


Fig.5: Mean Number of Packets in System versus Utilization for M/M/1 and M/M/2 Analytical Model

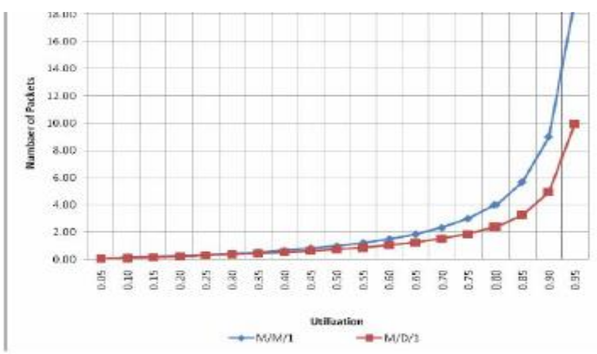


Fig.6: Mean Number of Packets versus Utilization for M/M/1 and M/D/1 Analytical Model

Universal Telecommunications Access

Rural telecommunication access has to do with provision of telecommunication infrastructure in rural communities for the purpose of connectivity within communities and with the rest of the world. There has been growing interest in how to provide universal telecommunication access in developing countries. The trend in digital divide between the rural and urban areas for developing countries reveals a growing gap, whereas efforts are being made by developed nations to close the gap. Hence, there is the need for the developing nations to follow suit in their pursuit of sustainable development. The rural communities in Africa, particularly in Nigeria, are strongly faced with many challenges which include extreme poverty, lack of social services and infrastructures, low level of education and health status, as well as unequal access to income opportunities. Despite the fact that telecommunications services in Nigeria could be traced back to 1851, the aforementioned factors, coupled with the difficult physical terrain in some cases, have made them lag behind the urban areas with regard to provision of telecommunications access.

Rural telecommunications access will contribute to many social and economic development in Nigeria, such as: local businesses experiencing lower communication costs and improved access to information about markets and commodity prices; potential growth in entrepreneurship, tourism, etc.; maximisation of establishment of new services such as Internet cafes; easier access to information on health, agriculture, security, distance education services, disaster warning; and access to job information, and closer contact with distant family members.

Provision of telecommunications access to the rural communities in Nigeria has, at various times, suffered setbacks. An exploratory study was conducted in 15 rural communities across four LGAs of Kwara State. These villages were chosen because they fell within the categories of rural definition provided by the Nigeria Population Commission. The villages considered have number of houses ranging from 10 to 40 with an average of 5 persons per home, and aged 18 years and above. Out of the 15 villages visited 11 have limited access to telephone service with poor quality of service. It was noted from the respondents that most times they have to climb trees or roof tops of their houses to make voice calls due to poor signal reception. Four villages with an average population of 350 people do not have access to any telephone service. Five villages were not connected to the electricity grid; 9 of the villages were connected but electricity supply was occasional and one village was connected to the national grid but no electricity supply. All the access roads to the villages were rough despite the closeness (< 3 km) of some villages to the LGA headquarters. Three villages did not have access to school while 12 had at least a primary school. In terms of basic ICT access such as computer centre, internet café, call centre and TV viewing centre, none of these could be found in any of the villages.

There are so many issues and challenges bedevilling telecom service provision to rural communities; these include (Nasir *et al*., 2017):

Literacy and Telecom Technology Awareness: The ability of these communities to participate in the current ICT-induced global knowledge economy; problems of poor computer literacy and lack of awareness of other telecommunication services beyond telephony; and feasibility and desirability of efforts to implement rural telecommunication networks

Security and Socio-political Challenges: Nigeria in recent times has witnessed an unprecedented level of insecurity; rural communities are not left out as Nigeria has consistently ranked low in the Global Peace Index [GPI, 2012]. Insecurity discourages investment because it increases the cost of doing business. Nigeria's insecurity situation has halted business operations during the periods of violence, caused outright closure of many telecom facilities, led to Telecom Service Providers (TSPs) relocating their telecom sites and depleted some communities due to migration, etc.

Economic Profile of Rural Communities: This allows description of feasibility of implementing a rural telecom access scheme in such a community; Important indices: average household income, type of economic activities, volume of economic activities and economic growth predictions; GNI per capita is about US$1,000 as compared with over US$12,000 for developed countries; Half of Nigeria's population living in the rural areas; Expected return on investment, ROI, for rural telecom to break even.

Infrastructure Deployment Cost: Rural communities in developing countries are characterised by: poor infrastructure development; poor access to electricity and good roads; remote geographical location and difficult terrain; unavailability of leasable real-estate; skyrocketing project cost; and telecoms service providers having to invest more money to deploy special technologies.

Financial Sustainability of Rural Telecom Access Schemes: One of the major inhibitors to the growth of rural telecoms is the huge initial investment involved in the provision of telecom (infrastructure). There is therefore the need to provide a steady flow of financial resource for the maintenance of telecom infrastructure and personnel. Deterrents such as multiple taxation and access to capital and lack of financial incentives should be provided. There is also the need for low interest rate on capital for rural telecom access projects and government subsidies on imported equipment.

NCC's Regulatory Challenges: NCC witnessed a flurry of activities in the telecommunications industry in its initial four years of existence; it has come a long way to become a responsible regulatory body recognised nationally and internationally. Some regulatory challenges include deregulation of the telecom sector, translating to, licensing several operators in order to rapidly meet demand, hence leading to a highly fragmented market that became difficult to regulate and complex to understand, thus tasking the ability of NCC.

In order to extend ICT access to the rural and remote communities in Africa, there is the need to consider available options. It is however important to note that geographical location of the villages and local terrain of the environment are major issues to be considered when deploying ICT equipment to provide access to the Internet in remote communities. Other factors such as government policies, sources of funding, sustainability of the deployed infrastructures and demography of the villages are also important as they could have tremendous effects on the whole system. Each option has its own unique approach to serving the rural communities and has its own advantages and shortcomings. Some options have been deployed in Nigeria and other neighbouring African countries while some are still in the developmental stages.

The following technology options for Rural Telecommunication Access are hereby recommended: (a) Digital Subscriber Line (DSL) technology; (b) Global System for Mobile communication (GSM) technology; (c) CDMA 450; (d) Satellite technologies; (e) Wireless LAN technologies (wifi hotspots); (f) Wireless MAN (WMAN) technologies; and (g) Television White Space (TVWS) technology, power line communication (PLC) system (Olayiwola et al, 2017).

Electromagnetic Interference (EMI)

Electromagnetic Interference (EMI) refers to any electromagnetic (EM) disturbance that interrupts, obstructs, degrades or limits the effective performance of a piece of electrical/electronic equipment, transmission channel, or other susceptible systems. It can occur in any part of the EM spectrum from frequencies of 0 Hz (d.c.) to 20 GHz or higher, but however most prevalent in the radio frequency (RF) region. EMI is one part of the EM environment which also consists of electromagnetic compatibility (EMC), electromagnetic vulnerability, emission control, precipitation static, radiation hazard, electromagnetic pulse, lightning, etc.

The history of EMI could be traced back to World War II when it was referred to as radio frequency interference (RFI) and when majority of the high-tech electronic systems started to operate erratically. And as digital logic devices were being developed later in the 1970s, EMI became an issue, particularly in personal computers, communication equipment, intelligent transportation systems, sophisticated avionics, etc. Therefore, in the mid- to late 1970s, the Federal Communications Commission (FCC) of the United States of America began to promulgate an emission standard for some EMI emitting equipment. Today, many other national, regional and international regulatory bodies have developed emission standards in the relevant areas of jurisdiction.

Effects of EMI are noticed in many of electronic equipment which may act either as the source, or as the victim, or both, of EM radiation. Some common noticeable examples of EMI are: TV screen showing dots or roving pictures when a nearby computer system is being operated; noisy sound from a radio receiver operating near motorized equipment (e.g. grinding machines); and lightning manifesting as noise in, particularly, AM radio receivers. These effects could be considered as minor disruptive disturbances caused by EMI. Various other, and more serious/hazardous effects of EMI had caused disruption in the operation of electronics on-board aircraft and have allegedly caused air disasters. Medical devices have also not been spared, particularly for people wearing pacemakers and other cardiac devices (Adediran *et al*., 2010).

Three entities are involved in the existence of electromagnetic interference, namely: Source, Victim, and Coupling Path. These are depicted in the EMI triangle in Figure 7.

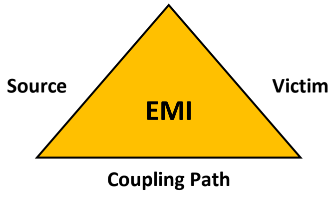


Fig. 7: The EMI triangle

Source: This is the actual 'emitter' of electromagnetic energy, either intentionally (e.g. hand-held radio transmitters) or unintentionally (e.g. power transformer). Other sources include vehicle ignition, mobile electronics, lightning, power transmission lines, and atmospheric emissions.

Victim: This is the device that is susceptible to EM energy emitted by the source. The level of EMI interference in the device depends on the immunity it has to reject the energy. Such victim can be a computer, TV system, radio receiver, medical devices, aircraft electronics, GPS, etc.

Coupling Path: This is the means or mechanism through which EM energy is transmitted between the Source and the Victim. The physical distance between the Source and the Victim and their orientation play significant roles. Some common coupling mechanisms are: conduction through electric current; radiation through EM field; capacitive coupling through electric field; and inductive coupling through magnetic field.

The methods used to protect against EMI or to limit EMI susceptibility is known as electromagnetic compatibility (EMC) controls. Electrical/electronic systems must therefore be designed to both avoid transmitting EMI and be affected by EMI. Some ways of protecting against EMI emissions and limiting EMI susceptibility are (Adediran, 2014):

(a) S*creening* by enclosing circuits and conductors in grounded and conductive boxes or by providing grounded conductive screens for cables, or by using twisted pair cable arrangement;

(b) *Filtering* out unwanted frequency from noise and transients or to power supply. Digital systems, in particular, must include noise filter at the PCB power input or near to each IC;

(c) *Isolation* by opto-couplers;

(d) *Careful design*, particularly with respect to circuit layout, packaging, etc;

(e) using *coding* method to software-driven systems;

(f) *Proper selection* of switches, relays and other make-or-break circuit components and possibly designing filter circuits around them;

(g) *Provision of balanced circuit impedances* (e.g. between power supplies and loads) to enhance self-cancelling of any noise pickup.

My Contributions in Quality Engineering and Electronic Waste

Electronic Waste

Mr. Vice Chancellor Sir, I ventured into the study of Electronic Waste (E-Waste) through an invitation by the Nigerian Institute of Environmental Engineers and the Ministry of Environment. Electrical and Electronics equipment have generally made life easy and convenient because of their efficiency and time saving in application. For example, communication systems and entertainment industry (music, radio, television, cameras, etc.) would have remained crude if not for the continuing development in electronic technology. However, electronic devices, in particular, become technologically obsolete in a matter of months as a result of continuous development of new models. This rapid technological growth leads to the high rate of production of electronic equipment. Some 20 to 50 million metric tonnes of E-Waste are generated worldwide every year. In the United States alone, 14 to 20 million personal computers are thrown out each year, with an annual increase of 3-5%. However, only some 13-18% are recycled. In the end, the disused equipment find their way into various directions, some ending up in landfills where they pose environmental and health hazards to humans, livestock and the soil. Some of these are incinerated, leading to environmental pollution from the fumes. The ‘surviving’ (now E-Waste) find their way into poor developing countries where, possibly out of ignorance, they are carelessly handled, hence posing a serious threat to human health, soil, livestock and drinking water. Common sources of E-waste can be categorized into: Small and Large Household appliances; IT and Telecommunication Equipment; Consumer electronic equipment; Lighting equipment; Electrical and Electronic Tools; Toys, Leisure and

Sports equipment; Medical devices; Monitoring and Control instruments; and Automatic dispensers.

The average life cycle (or obsolescence rate) of an equipment is the time span after which the item comes to its end of life. It is defined as:

Average life cycle = Active life + Passive Life + Storage time

where *Active life* is the number of years the equipment can be efficiently used; *Passive life* is the time period, after Active Life, when the equipment can be refurbished or reused; and *Storage time* is the time during which the equipment is stored and at repair shops before dismantling.

In developed countries, passive life and storage life are virtually non-existent; hence, the average life cycle of electronic equipment is generally the same as the Active life. Unfortunately, the passive and disposal times are taken care of by the developing countries to which the equipment are transported and where second-hand market exists for them. Nigeria, like almost all other African countries, has a thriving market for these electronic junks as a result of lack of financial capacity to buy/manufacture new and modern ones and, most importantly, hunger for information and global IT relevance in order to bridge the digital divide. Hence, African countries become the latest destination for this 'digital dump' since many Asian countries have come up with legislation that bans uncontrolled importation of certain categories of used Electrical and Electronics equipment. It must be emphasised that such trade is unfair to developing countries because of the inherent dangers that E-Waste poses to the environment, humans, livestock, soil and the ecosystem, though the electronic products may contain some reusable and valuable materials. The cathode ray tube (CRT) of a TV set or computer monitor, for example, contains lead, antimony, phosphorous, etc. in some proportions, while circuit boards in different electronic products contain lead, beryllium, antimony and brominated flame retardant (BFR). Other toxic substances contained in various electronic items include selenium, antimony trioxide, cadmium, cobalt, manganese, bromine and barium, amongst many others.

Apart from the hazardous effects on humans, E-Waste also leaches the soil due to the presence of mercury, cadmium, lead and phosphorus in it. E-Waste can also cause uncontrolled fire risk, leading to toxic fumes. In addition, uncontrolled burning, disassembly and disposal of E-Waste can cause a variety of environmental problems such as groundwater contamination, atmospheric pollution, and occupational and safety effects among those directly or indirectly involved in the processing of E-Waste. It is worrisome that a lot of Nigerians are unaware of the dangers inherent in careless handling of E-Waste. It is common to see both young and old scavengers rummaging through solid waste heaps at dumpsites without caring about the health implications of such dangerous means of livelihood. It is therefore pertinent to consider alternative ways of managing E-Waste, particularly in healthier and safer ways, the focal point of which is recovery, reusing and recycling (3Rs).

Nigeria's efforts in E-Waste Management have not been encouragingly serious, even with the existence of sizeable number of government agencies that could be directly or indirectly involved in E-Waste management. Among these are Federal Environmental Protection Agency (FEPA), National Environmental Standards and Regulations Enforcement Agency (NESREA), National Emergency Management Agency (NEMA), National Space Research and Development Agency (NASRDA) and Nigeria Customs Service (NCS). Though there is an institutional framework in place, its effect is yet to be felt. Therefore, to effectively address the issues surrounding E-Waste management in Nigeria, a number of challenges must equally be addressed. For example, there is no legislation to control the flow of used consumer electronic products; used electronic products are not regarded as contraband by the Nigeria Customs Service as long as appropriate duties and taxes are collected on them; there is no public awareness on the inherent dangers of handling E-Waste, which is regarded as a business opportunity, except for smelting of scrap metals; there are no E-Waste recycling facilities in the country; and there is poor (if any) corporate social responsibility on the part of industries on E-Waste.

An attempt was made by NESREA in 2009 by sponsoring an international conference on E-Waste control tagged 'The Abuja Platform on E-Waste'. Also, the first international E-Waste Summit in Nigeria was held from 24th to 25th February 2011 in Lagos with the theme 'Regulation and Management of E-Waste in Nigeria'. This was the first Summit of its kind in Nigeria and probably in Africa following the International Conference on E-Waste Control held by NESREA in 2009. The conference called on the Federal Government to encourage and enforce collection, recovery, re-use and recycling (3R) of E-Waste. Figure 8 shows the identified stakeholders in E-Waste generation and management and whose concerted, coordinated and committed efforts would be required in effective and efficient management of E-Waste.

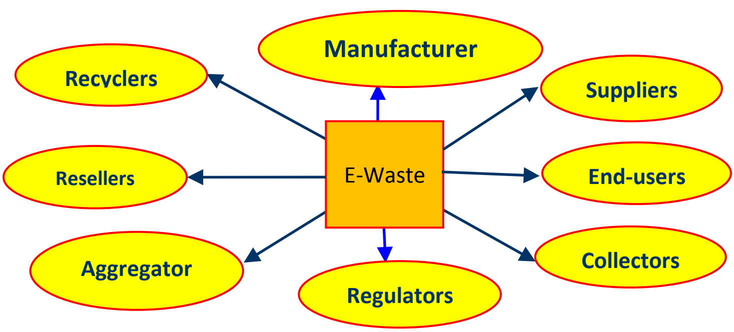


Fig.8: Stakeholders in E-waste generation and management (Adediran & Abdulkarim, 2012)

Basically, everyone is a stakeholder in the generation of E-Waste as consumer, seller, producer, importer, etc. Therefore, effective and efficient management of E-Waste concerns everyone who must play their roles in order to make the environment safe and healthy. The NESREA intervention in Nigeria is therefore a welcome development.

Recovery of Zn, MnO and Mn from Spent Zn-C Dry Cells

The Zn-C dry cell is an electrochemical energy source that converts chemical energy into electrical energy. It contains Zn container as the negative plate, carbon rod as the positive plate and moisture of MnO_2 and ground carbon as the electrolyte. The cell is generally used in portable transistorised radio receivers, flash-lights, electric bells, etc.

Hydrometallurgical recycling process was used to recover zinc and manganese dioxide from the spent cell. The process, which involved electroplating of zinc and oxidation of manganese dioxide, allowed easy separation of the components. The design was able to produce 10 kg/day of MnO_2 and zinc, made up of 538 kg of MnO_2 and 4.62 kg of zinc. The process was also used to recover mercury, nickel and iron, all at an annual production cost of N3,088,775 for a total production of 3000 kg per year, and giving a gain margin of N1,651,105 (Eterigho & Adediran, 2001). In a similar vein, the Zn-C dry cell also provided manganese through hydrometallurgical process. The spent cells were pre-treated and subjected to hydrometallurgical process (grinding, leaching, alkalination, etc.) which allowed for easy separation of the various components of the cells. Manganese was produced from the extracted manganese dioxide by passing hydrogen gas over it. From the process, 5.38 kg/day of manganese was recovered at an estimated annual production cost of N1,255,811 and at an annual profit of N1,987,189, hence making the process commercially viable (Eterigho & Adediran, 2004).

Electrochemical Power Sources: The lead-acid battery

A typical automobile lead-acid battery element is a basic electrochemical system consisting of a positive electrode (cathode) of lead oxide (PbO_2) paste applied to a grid, a negative electrode (anode) of spongy lead, and an electrolyte of aqueous sulphuric acid (H_2SO_4). Adjacent positive and negative electrodes are insulated from each other by insertion of separators in-between them. Certain numbers of these elements are connected together in series or parallel, the number depending on the required voltage/current level (Bullock, 1994; Adediran, 2001).

A lead-acid battery put into use can prematurely fail to perform its intended functions as a result of either manufacturing defect or service-related defect. Manufacturing defects come from: improper composition of grid leading to corrosion and active mass shedding; lack of adequate process control at the various stages of production; and improper placement of separators. Service-related defects can arise from: filling the battery with wrong electrolyte either in composition or purity; overcharging the battery, leading to oxidation of the grid, buckled plates and chunky shredding; and undercharging leading to buckled plates (Adediran, 1999). Reliability analysis carried out using failure mode and effect analysis (FMEA) showed the results summarized in Table 2.

Battery failure data were obtained from a lead-acid manufacturing company based on the failed batteries during operation and subsequently returned to the company under existing warranty agreement. Altogether, 18,157 batteries of various designs and capacity ratings were returned during the period under review. Out of these, 10,574 (or 58.24%) were identified to have failed as a result of some manufacturing/processing errors while the remaining 7,583 (or 41.76%) failed prematurely due to in-service-related problems. The manufacturing defects were categorized into 13 groups and frequency of occurrence of each defect-group determined. Tables 3 and 4 summarise the results.

Lead contributes 90% by weight of a lead-acid battery, while local annual demand for the product was put at about 18,000 metric tonnes. However, no appreciable local production of lead has been recorded to date, hence the need for local battery manufacturers to import it or recycle spent batteries to recover the lead content. Apart from lead, most of the remaining raw materials

Table 2: Summary of Manufacturing and Service-related Defects of Lead-acid Batteries

Item/ Component	Failure Mode	Local Failure Effects	System Failure Effects	Symptom	Rectification/ Corrective Action
Grid	○ Grid corrosion	○ Grid growth ○ Internal short circuit ○ Loss of contact between grid and active mass	○ Bending of battery lid ○ Explosion ○ Container leakage	○ Initial weight increase	○ Flexible grid feet ○ Avoidance of impurities
Positive active mass	○ Sulphation between active mass and grid interface ○ Sulphation of active mass ○ Mass softening	○ Reduction in electrical conducti-vity ○ Capacity reduction ○ Electrical isolation of PbO2 particles	○ Premature capacity loss	○ Expansion of electrolyte ○ Decrease in electrolyte density	○ Use of Sb-free grid ○ Automatic change of charging regime ○ Improvement in grid design ○ Adequate control of paste and pasting process
Separators	○ Short-circuiting of positive and negative plate ○ Sediment short-circuit	○ Separator shorts ○ Capacity loss	○ Premature capacity loss	○ Micro-shorts ○ Separator leakage	
Electr	○ Dry-out	○ Poor	○ Premature	○ Separator	○ Avoid

olyte	○ Thermal run away	contact between paste and separator ○ Increase in internal resistance	capacity loss ○ Limitation of life span	contraction ○ Overcharging	severe charging regime and high temperature ○ Avoid close packing of batteries
Container	○ Cracking	○ Electrolyte leakage ○ Bending of lid	○ Leakage ○ Battery explosion	○ Electrolyte leakage ○ Pressure build-up	○ Avoid high operation temperature

Source: Adediran, 1998; Adediran *et al*., 2000

Table 3: Summary of Manufacturing Defects of Lead-acid Batteries

S/No.	Manufacturing Defects	Frequency of Occurrence
1	Poor plate fusing	19.24
2	Plate scissoring	18.82
3	Active mass shedding	9.13
4	Cell disconnected	15.73
5	Bent feet short	9.10
6	Paste lumps	8.24
7	Broken pillar	5.55
8	Distorted frame	4.52
9	Separator misalignment	2.98
10	Lead run	2.34
11	Separator damage	2.10
12	Bad connector burning	1.85
13	Reverse assembly	0.40

Source: Adediran, 2007

Table 4: Summary of Service-related Defects

S/NO.	Service-related Defects	Frequency of Occurrence
1	No electrolyte	53.17
2	Undercharge	23.56
3	Active mass shedding	11.55
4	Overcharge	1.48
5	Container damage	1.43
6	Miscellaneous defects	8.81

Source: Adediran *et al*., 1998b

are being imported, thus resulting in high production cost and, hence, high product price. There is abundance of the raw materials content of lead-acid batteries in Nigeria. All that is needed are the concerted efforts of all relevant stakeholders, governments and manufacturers in particular, to prospect for the raw materials and process them to the battery-grade level through adequate investment in industrial R&D and promotion of small and medium scale enterprises (SMSEs). Producing the component parts and commercially processing the raw materials are also recommended (Adediran & Khan, 1998a; 2001)

Widespread use of lead-acid batteries takes a toll on the environment. Batteries disposed of in municipal landfills and trash incinerators can disperse significant amounts of heavy metals and other toxic substances into the air and water. Therefore, battery waste prevention and recycling strategies are essential. The disposal of batteries has become an ever-increasing topic of discussion in the developed countries due to the presence of heavy metals such as mercury, lead, and cadmium in those batteries. In addition, the chemical composition of the electrolyte is also harmful to the environment if not properly disposed of or managed. In response to these concerns, there has been an increase in battery collection programmes and legislation controlling the production and disposal of batteries in developed countries. With the continuing growth in urbanisation and private vehicle ownership, particularly within newly industrialised countries, the steady increase in demand for automotive batteries is likely to continue, guaranteeing an international demand for lead (McColl, 1994).

There is no specific battery legislation in Nigeria mandating battery manufacturers, and major importers to put adequate measures in place for collecting spent lead-acid batteries or educating the consumers on the safe method of disposal after its useful life and environmental degradation if improperly disposed. Rather, spent lead-acid batteries are being managed in an unorganized method similar to what obtains in other developing countries. The battery scavengers move from house to house to collect the spent batteries. Majority of them buy large quantities of spent batteries from the battery technicians and transport them to scrap battery dealers who store the batteries until reasonable quantities can be accumulated for sale to the secondary smelters for breaking and recycling. Reasonable numbers of spent batteries are seen along the corridors, lawns, and in garages which eventually get dumped in the trash containers.

Our study shows that neither the companies producing lead-acid batteries nor the battery distributors inform the end-users about environmental risks and health hazards in improperly disposing lead-acid battery. The companies producing lead-acid batteries in Nigeria seem to be comfortable with the current environmental policy since it gives them the opportunities to operate freely and make maximum profit without any take-back commitment (Adediran et al, 2010).

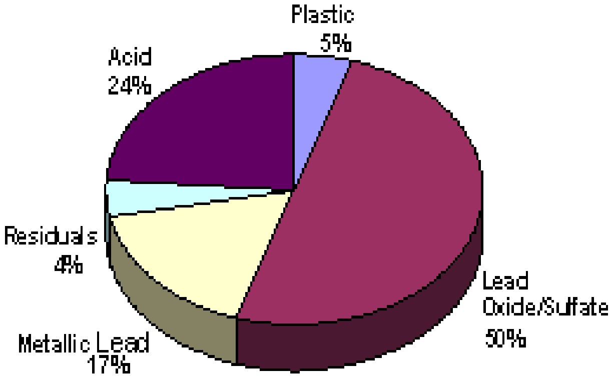


Fig.9: Constituents of Lead-Acid Batteries Percentage Weight

Table 4: Metal Concentrations in Lead-acid Batteries

Metal	**Concentration (mg/l)**
Particulate lead	60 – 240
Lead (dissolved)	1 to 6
Arsenic	1 to 6
Antimony	20 – 175
Zinc	1 - 13.5
Tin	1 to 6
Calcium	5 to 20
Iron	20 – 150

Source: Environment Canada, 1993

The legislation regulating hazardous waste through the establishment of Federal Ministry of Environment (FME) appears very appropriate, but the enforcement is not there; attention is rather focused on oil spillage and toxic waste discharges. There is no local or state law that strongly drives proper disposal of spent lead-acid batteries in Nigeria. Amongst the shortcomings are lack of accurate record of number of registered vehicles, tonnage of lead-acid batteries imported to Nigeria, improper disposal of lead-acid batteries, lack of adequate record of tonnage of lead-acid batteries manufactured annually, and seeming lack of full government participation in funding recycling plants in Nigeria (Adediran, 2001).

On the basis of the findings of this study, the following recommendations will be useful. Government should have regulations on lead-acid batteries. It may be of help to look at other countries' battery legislations with the plan to have a suitable battery recycling plant or battery waste management. Government can use the result of this research to select the preferred spent lead-acid battery collection centres. Also, manufacturers and importers who supply batteries, must be made to pay a prepaid disposal fee that could be used to finance collection, transportation and recycling of batteries; as well as to ascertain extent of provision of information, particularly for promotion of return of batteries. Retailers of lead-acid batteries should also be compelled to post a written notice indicating that spent lead-acid batteries are accepted for collection at the approved collection centres for recycling. Compulsory obligation should be in place for consumers to return all spent lead-acid batteries and for dealers to take back any spent battery. Government should establish separate collection targets for all spent lead-acid batteries in the community market. Finally, recycle ability should be a leading concern to battery producers and dealers.

Conclusion

- Engineers have the social responsibilities to the environment in which they practise and are covered by professional codes of ethics and standards in order to increase their skill of moral judgement.
- The rate of failures of engineering systems has become a technological embarrassment, particularly to engineers whose major professional ethics is safety.

- Electromagnetic or radio frequency spectrum is a scarce and limited natural resource with emerging technologies scrambling to have access to it. As much as Nigeria does not have problem of limited accessibility to the spectrum, there is every need by the spectrum regulators to still ensure it is optimally and rationally used in order to avoid interference of services.
- Power line communication (PLC) technology is a lucrative opportunity for electricity utility companies to ‘bundle’ electricity supply with broadband telecom access via high speed and reliable telecom traffic, particularly in remote places, taking advantage of already existing electrical installation.
- Telecom access can contribute immensely to socio-economic development of rural and remote areas. However, rural and remote communities in Nigeria lag behind the urban areas with regard to provision of telecom access due to peculiar challenges such as poverty, low level of education and health status, difficult physical terrain, amongst many others.
- Electronic Waste has been a source of concern to developing countries because of the health hazards it poses to the environment; and, no serious efforts are being made to control the situation in Nigeria.
- There is abundance of industrial raw materials for the production of electrical and electronics goods. However, these raw materials have to be exploited and value added to them to bring them to the level of industrial usage.

Recommendations

- Engineering training at all levels should include codes of ethics of engineering profession in order for future engineers to realise early in their careers the social and technical responsibilities to the environment in which they will eventually practise after graduation.
- Products and services should be designed for Reliability through application of concurrent engineering, configuration

engineering, appropriate selection mechanism; and reliability principles should be applied in every facet of an organisation in order to improve the efficiency and effectiveness of their function.

- Nigeria should come up with a spectrum management model that will not only generate revenue for the country but also obey international regulations in line with ITU recommendations on electromagnetic interference.
- Government should provide enabling environment for medium and small scale enterprises (MSMEs) so that they can add value to the abundant raw materials and process them to industry use grade.
- Government should, through all relevant agencies, legislate against uncontrolled dumping of electronic waste in Nigeria.

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References

Abdulkarim A., **Adediran Y.A.** and Olufeagba B.J. (2011): *Components Reliability Ranking of Power Line Communication System in PHCN.*Nigerian Journal of Technological Development, University of Ilorin, Vol. 8 No. 2.

Abdulkarim A. and **Adediran Y.A** (2011): *Reliability Analysis of PLC Networks: Case Study of Power Holding Company Nigeria*. NSE Technical Transactions, Vol.46, No.4 (October – December), pp 88-96.

Adediran Y.A. (1996): *Total Quality Management in Engineering Product Design*; Proceedings of the Annual National Conference of College of Engineering, Kadpoly, Vol. 3, No. 1 pp. 27-30.

Adediran Y.A. (1998): *Analysis of Service Defects of Lead/Acid Batteries*, Proceedings of the National Engineering Conference Series, Kadpoly, Vol.5, No.1, pp. 138-141.

Adediran Y.A. (1999): Quality *Management Issues Involved in Nigeria Manufactured Products*. Proceedings of the First National Engineering Design Conference “DESIGN 99”, Sheraton Hotel and Towers, Abuja, September 26-29, 1999.

Adediran Y.A. (2001): *Review of Technological Advances in Lead/acid Battery Productio*n; Journal of Science, Technology and Mathematics Education, Vol. 4(1), April 2001, pp 121 - 128.

Adediran Y.A. (2005a): *Telecommunications: Principles and System*s; Second Edition; FINOM Associates; January 2005, 230 pages. (Second Edition).

Adediran Y.A. (2005b): *Universal Access for Communities in Rural and Remote Areas*; Proc. of the International Conference in Engineering 2005, 23-26 May, Lagos Nigeria, pp 84-92.

Adediran Y.A. (2006): *Economics of Radio Frequency Spectrum Management*. Nigerian Journal of Engineering Management, Vol. 7, no 3, pp13-17.

Adediran Y.A. (2007): *Spectrum Management Improvement Techniques*; Nigerian Journal of Engineering Management; Vol. 8, No 3, pp 5-9.

Adediran Y. A. (2014): *Introduction to Reliability Engineering.* FINOM Associates, Minna; April 2014. 222 pages.

Adediran Y.A. and Abdulkarim A. (2012): Challenges of Electronic Waste Management in Nigeria.International Journal of Advances in Engineering & Technology (IJAET), Vol. 4, Issue 1, July Edition, pp.640-648.

Adediran Y.A., Babatunde A. A. & Khan R.H (2000): *Analysis of Manufacturing Defects of Lead/Acid Batteries - A case study*; Journal of the Institution of Production Engineers, Vol. 5, No. 1, pp 3-9.

Adediran Y.A. & Khan R.H. (1998a): *Local Sourcing of Raw Materials for Lead/Acid Battery Production*; RMRDC Newsletter, Vol.8, No.1, pp 5-8.

Adediran Y.A. & Khan R. H. (1998b): Technological Aspects of Lead/Acid Battery Development. Proc. of the 2nd National Conference of the Nigerian Institution of Production Engineers, Benin; 21st – 24th July.

Adediran Y.A. & Khan R. H. (2001): *On Increasing Local Raw Materials Content of Lead-Acid Battery*. Journal of Engineering & Industrial Applications, Vol. 1, No. 4 pp 148-151.

Adediran Y.A, R. H. Khan and A. A. Babatunde (2007): *Failure Mode and Effect Analysis (FMEA) of Lead-Acid Battery*; Nigerian Journal of Engineering Research and Development; Vol 6, No 4, pp 11-18.

Adediran Y.A, H. Lasisi and O.B. Okedere (2017): *Interference Management Techniques in Cellular Networks: A Review*. Cogent Engineering, Cogent OA, UK, DOI: http://dx.org/10.1080/23311916.2017.1294133 pp 1-10.

Adediran Y.A, Ogundele D. A, & Akoma Henry E. C. A. (2010): *Electromagnetic Interference: Causes, Effects and Mitigation*. International Conference Proceedings of the Environmental Division of the Nigerian Society of Engineers, 9th-11th November, Abuja.

Adediran Y.A, Usman A. U. and Onyedibe B. N. (2005): *Nigeria's Telecommunications Industry in the New Millennium: Problems, Challenges and Prospects*; Proc. of 6th Annual Engineering Conference, Minna, Nigeria, 15-17 June 2005, pp 84-93.

Adediran Y.A. and Reyaz T. (2003): *A Comparative Analysis of Modulation Techniques in Mobile Communication Systems*. Proc. Of the Conference on Global System for Mobile Communications in Nigeria; Olabisi Onabanjo University, Ago-Iwoye; Sept. 3-5. pp 38-44.

Adediran Y.A, Shorinwa J. A, & Uhunmwangho R. (2010): *Spent Lead-Acid Battery Management: Nigeria as a Case Study*. International Journal of Pure and Applied Science, vol. 3, No. 1, pp 102-107.

Ajiboye Johnson A. and **Adediran Y.A.** (2010):.*Performance Analysis of Statistical Time Division Multiplexing (STDM) Systems*. Leonardo Electronic Journal of Practices and Technologies (LEJPT), Issue 16 (January-June), 2010 (9).

Akoma E.C.A. and **Adediran Y.A.** (2013): *Effect of Electron Reflection in Multipaction Prediction for TE_{10} Mode Rectangular Waveguide Couplers*. International Review of Physics (IREPHY), Vol. 7, No. 6, December, pp 400-406.

Akoma Henry E. C. A., **Adediran** Y.A., Onu O Spencer, Agboola A. O., Ogundele D. A., Iliya S. Z. and Aiyeola S.Y. (2012): *DC Magnetic Field Suppression Model for Multipactor Microwave Breakdown in Rectangular Waveguide Geometries.*The IUP Journal of Electrical & Electronics Engineering, Vol. V, No. 4, pp. 39-49, October 2012.

Akoma H.E.C.A. and **Adediran Y.A.** (2012): *Influence of Reflected Electrons on MultipactorPrediction for Rectangular Waveguides*. Cyber Journals: Multidisciplinary Journals in Science and Technology, Journal of Selected Areas in Telecommunications (JSAT), August Edition, pp17-22.

Akoma Henry E. C.A, Agboola O, Ogundele D.A, & **Adediran Y.A**. (2010): *Mathematical Modelling of Antenna Look Angles of Geostationary Communications Satellite using Two Models of Control Stations.*3rd International Conference on Advanced Computer Theory and Engineering (ICACTE 2010), China, pp V4-97 – V4-101.

Ayeni A. A., N. Faruk, N.T. Surajudeen-Bakinde, R.A. Okanlawon & **Y. A. Adediran** (2015): *Spatial Spectrum Utilization Efficiency Metric for Spectrum Sharing System. International Journal of Digital Information and Wireless Communications*, vol 5 No. 1, pp44-51.

Besterfield Dale H. (1986): *Quality Control*. 2ND Edition, Prentice-Hall, 358pp.

Bullock K. R. (1994): *Lead/acid Batteries*. Journal of Power Sources, vol 51, no. 1, pp1-17.

Eterigho E.J. and **Adediran Y.A.** (2001): *Recovery of Zinc and Carbon from spent Dry Cells*. Journal of Science, Technology and Mathematics Education, 4(1), April 2001, pp 103 -111.

Eterigho E. J. & **Adediran Y.A.** (2004): *Spent Zn-C Dry Cells as a Source of Manganese*; Nigerian Journal of Engineering Research and Development, Vol. 4, no 4, pp 54-57.

Faruk N., Ayeni A.A. and **Y.A. Adediran** (2013a): *Characterization of Propagation Path Loss at VHF and UHF Bands for Ilorin City, Nigeria.* Nigerian Journal of Technology (NIJOTECH), Vol. 52, No.2, July, pp 253-265. (IF 2.10). Available at http://nijotech.com/index.php/nijotech/article/view/656.

Faruk N., A. Ayeni, and **Y.A. Adediran** (2013b): *On the Study of Empirical Path Loss Models for Accurate Prediction of TV Signal for Secondary Users*.Progress In Electromagnetics Research (PIER B), Vol. 49, 155-176. (*Scopus*,IF5.29) .

Faruk N., Ayeni A. A. and **Adediran Y.A**. (2013c): *DTV coverage and protection contour estimation for spatial white space*. Proc. of IEEE Nigercon Conference on Emerging and Sustainable Technologies for Power and ICT, IEEE, Owerri, 14-16 November 2013.Available on http://ieeexplore.ieee.org/...D6715643

Faruk N., S-Bakinde N. T., Kolade O., Adeseko A. A. &**Adediran Y. A.** (2014): *DTV Protection Regions for Spectrum Sharing.*The Journal of Engineering, IET UK. 12th August 2014. doi: 10.1049/joe.2014.0192

Goleniewski L. (2002): *Telecommunications Essentials – The Complete Guide Global Guide Source for Communications Fundamentals, Data Networking and the Internet, and Next-Generation Networks*, Pearson Education Inc., 582pp.

HCL Technologies (2007): *Reliability Engineering Trends, Srategies and Best Practices*.

Ibigbami N.O. and **Adediran Y.A.** (2011): *Performance Analysis of a Patch Antenna Array Feed for a Satellite C-Band Dish Antenna*. Cyber Journals: Journal of Selected Areas in Telecommunications (JSAT), November, pp.24-30. Available online at www.cyberjournals.com/Papers/Nov2011/05.pdf.

Ibigbami O.N. and **Adediran Y.A.** (2013): *Patch Antenna Array Feed Design for a Dish Antenna*. International Journal on Communications Antenna and Propagation (I.Re.C.A.P.), Vol. 3, No. 5, October, pp 249-254.

Idika Ocha and **Adediran Y.A.** (2008): *Spectrum Management.* Published by the Digital Bridge Institute, Abuja. 137pp.

Iliya S.Z., **Y.A. Adediran**, T.A. Rahman, A.Y. Abdulrahman, H. Uledi and O. Elijah (2013): *Comparison between MATLAB and CST Simulated Results of Helical Antenna Implementation for Ku-band Application.*Cyber Journals: Multidisciplinary Journals in Science and Technology, Journal of Selected Areas in Telecommunications (JSAT), March Edition, Vol. 3, Issue 3, pp1-6.

McColl K. G. (1994): *Regulatory Trends in the Battery Industry.* Journal of Power Sources, vol 48, no 1-2, pp29-36.

Nasir Faruk N., Adeseko A. Ayeni and **Yinusa A. Adediran** (2013): Impact of Empirical Path Loss Models on Spatial TV White Space Utilization. European Scientific Journal, Special Edition, Vol. 4, December. Available at http://eujournal.org/index.php/esj/article/viewFile/2511/2384

Nasir Faruk, Olayiwola Wasiu Bello, Jaiye F. Opadiji &**Yinusa A. Adediran** (2017): Socio-Economic Challenges Of Rural Telecommunication Access Schemes In Nigeria. *An International Journal of Information and Communication Technology (ICT),* Vol. 4 No. 1, pp 194-217.

Nasir Faruk, **Yinusa Adediran**, Adeseko Ayeni, Nazmat Surajudeen-Bakinde, Olayiwola Bello, Olabanji Kolade (2015): *Geospatial Approach to Quantifying TV White Space in Nigeria in the UHF Band.*" JNIT: Journal of Next Generation Information Technology, Vol. 6, No. 4, pp. 1 ~ 13. http://www.globalcis.org/jnit/ppl/JNIT365PPL.pdf

Ogundele D. A, Akoma Henry E. C. A, & **Adediran Y.A.** (2010): *Matlab@ Analysis of the DC Magnetic Fields Multipactor Suppression Model for Rectangular Waveguides.*3rd International Conference on Advanced Computer Theory and Engineering (ICACTE 2010), China, pp V4-236 –V4-240.

Olayiwola Wasiu Bello, Jaiyeola Femi Opadiji, Nasir Faruk and **Yinusa Ademola Adediran (2016):** *Opportunities for Universal Telecommunication Access in Rural Communities: A Case Study of 15 Rural Villages in Nigeria's Kwara State*. The African Journal of Information and Communication (AJIC), Issue 17, pp 139-163.

Reyaz T. and **Adediran Y.A.** (2003): *Spread Spectrum Application in Mobile Communication Systems.* Proc. Of the Conference on Global System for Mobile Communications in Nigeria; Olabisi Onabanjo University, Ago-Iwoye; Sept. 3-5. pp 45-48.

Wade P. (2003): *Parabolic Dish Antennas*; The W1GHZ Online Microwave Antenna, Shirley, MA pp. 1-25, 2003.

Wikipedia (2019): *Engineering Ethics.* Available at en.wikipedia.org/wiki/Engineering_ethics Accessed 3/12/2019.