Chapter One

Introduction

1.1 Background to the Study

The history of non-natural sources of electromagnetic radiation and fields is quite brief, spanning barely the last century. There are two types of non-natural sources of electromagnetic radiation or fields. The first category contains ionising radiation, which has a relatively high energy and can ionise matter particles. The existence of this type of radiation is mostly due to natural causes (the median yearly exposure dose is around 2.4 mSv)[1]. Non-natural sources of ionising radiation, such as technical gadgets that utilise various radioactive isotopes, are currently regarded as the most serious issues in public health protection.

The second category includes non-ionizing radiation of energy that is too weak to ionise matter particles. All techniques of producing, transmitting, and utilising electrical power are common sources of this type of radiation (high-voltage power lines, substations, motors, generators, industrial and domestic appliances, home wiring, etc.). Telecommunication systems (radio, television, internet, and Wi-Fi) and medical devices used for diagnosis or therapy are significant sources of electromagnetic radiation[2]. Nonionizing radiation is classified into four levels, according to the European Commission: static fields, Extremely Low Frequency fields (ELF fields), Intermediate Frequency fields (IF fields), and Radio Frequency fields (RF fields)[1].

Radiation of Radio Frequency Once emitted, RFR travels through space at the speed of light and oscillates during propagation. The frequency of a wave is determined by the number of oscillations it makes in one second[3]. Radiofrequency radiation is found in the nonionizing bands and spans a considerable portion of the electromagnetic spectrum. Its frequency spans from 10 kHz to 300 GHz, with 1 Hz equaling one oscillation every second. Different RFR frequencies are employed in various applications. AM radio transmission uses a frequency range of 540 to 1600 kHz, while FM radio uses a frequency range of 76 to 108 MHz. Cell phone technology operates on frequencies ranging from 800 MHz to 3 GHz. Some Wi-Fi applications and microwave cooking employ the RFR of 2450 MHz[4]. RFR intensity is commonly quantified and recorded in scientific literature in watts per square metre (W/m2), milliWatt per square centimetre (mW/cm2), or microwatts per square centimetre (W/cm2). All of these are energy interactions in space. However, biological impacts are determined by how much energy is absorbed in the body of a living organism, not just how much energy exists in space[5].

1.2 Statement of Research Problem

Airports required numerous hectares of land for operational activities. Hence, few airports are built in the metropolis and those airports (such as Lagos and Ibadan Airports) built on the outskirts of the city in the 80s are currently being hemmed in by urban and suburban developmental infrastructures such as Telecommunication base stations, Television and Radio stations. medical facilities such as X-Rays and Computerized Tomography (CT) scanners, nuclear power plants, research laboratories, manufacturing and construction companies, among other EMFs sources. These EMF based infrastructures are mostly kept far below 15 km step-back stipulated by NCC as Airport's setback.

However, the stray electric and magnetic fields from these EMFs sources do generate charged encroaching fields that could affect the health status of Airport professionals (which are being continuously subjected to EMF fields greater than ICNIRP recommendations over time / per unit time). Also, the fields interfere with the needed operation of the aircrafts' microprocessor memories and instruments, computers and controllers, causing trifling disorder in the flight deck display or, more seriously, shutdown the aircraft's engine. To investigate the level of electro-spatial encroachment and interference of the stray electric and magnetic fields around Ibadan airport's immediate environment, hence this study.

1.3 Aim and Objectives

The aim of the study is to investigate the impacts of electromagnetic interference and geo-spatial encroachment that emanated from the Electromagnetic Field (EMF) Based Infrastructures (EMF-BI) on Aircrafts and Airports' staff, within and around Ibadan Airport. After appraisal of necessary regulations and guidelines on operation of Radio-Frequency based devices in relation to airports domain, the following objectives are proposed for achieving the aim:

i. Evaluate the spatial existence of Electromagnetic Field (EMF) Based Infrastructures (EMF-BI) within and on 15 km setback of Ibadan Airport, using Satellite based technology.

ii. Measurement and numeric computation of electromagnetic field radiations (electric, magnetic and power flux density) from (i) at spatial range R of $0.5m \leq R \leq 2.0m$.

iii. Investigate electromagnetic interference and spatial encroachment of Radio Frequency (RF) waveforms (to be generated with MatLab software) using data from (ii) on Ibadan Airport.

iv. Comparatively analyze (a) results from (i) with the NCC regulations on EMF interference and electro-spatial encroachments generated from (ii) and (iii); (b) evaluate the compliance of International Commission for Non-Ionizing Radiation Protection (ICNIRP) standard on exposure of EMF to airport workers which would be obtained through questionnaires.

1.4 Research Questions

What tools would be required to determine the existence of Electromagnetic Radiation within 15 Km setback of Ibadan Airport?

What data or parameters are available for computation?

Is the existence of electromagnetic radiation within and outside of the setback injurious to staff and air assets?

1.5 Significance of the Study

As the aircraft of today are becoming increasingly more dependent on computerized or electronically controlled systems, the typically low power inputs and in some cases outputs of these systems are easily corrupted when unwanted induced electrical signals from stray electromagnetic fields find their way into otherwise isolated circuits. This could generate electromotive force that could ignite the thrust and total control of the aircraft. Consequently, the aircraft could be crashed and cause vital destruction to infrastructures that are not within legal set-back.

1.6 Scope of the Study

The research study would be conducted within Ibadan airport and her immediate environment at maximum spatial distance of 20 km to Ibadan Airport.

1.7 Limitations of the Study

The research study would be limited to permissible domain within Ibadan airport while interview and questionnaires would be conducted among approved professionals. Also, 20 km (maximum) total buffering would be conducted at 2 km spatial interval from the airport's fence to the 20th kilometer spatial locations around the airport buffer. The collection of data from EMF sources would only be limited to Industrial Sites, Hospitals with heavy microwave medical equipment, Telecommunications, AM and FM Base Stations masts and highly conspicuous EMF sources.

1.8 Definition of Terms

The definitions of some of the technical terms and abbreviations used in conducting this research are defined below:

EMF	Electro Magnetic Field
BI	Based Infrastructures
EMI	Electro Magnetic Interference
EME	Electro Magnetic Environment
ELF	Extremely Low Frequency
IF	Intermediate Frequency
RF	Radio Frequency
RFR	Radio Frequency Radiation
AM	Amplitude Modulated
FM	Frequency Modulated
TV	Television
HF	High Frequency
UHF	Ultra High Frequency
PCS	Personal Communication System

WLAN Wireless Local Area Network

ITU International Telecommunication Union

RR Radio Regulation

PABX Private Automatic Branch Exchange

Topology The way in which constituent parts are interrelated or arranged. "the topology of a computer network"

RFR Radio Frequency Radiation

ERP Effective Radiated Power

Tomography A technique for displaying a representation of a cross section through a human body or other solid object using X-rays or ultrasound.

Airport: An airport is an aerodrome with extended facilities, mostly for commercial air transport.

Avionics: Avionics are the electronic systems used on aircraft, artificial satellites, and spacecraft.

DECT: Digital Enhanced Cordless Telecommunications is a digital wireless technology.

EMI: Electromagnetic interference is the disruption of operation of an electronic device when it is in the vicinity of an electromagnetic field (EM field)

FAAN: Federal Airport Authority of Nigeria (FAAN) is a service organization statutorily charged to manage all Commercial Airports in Nigeria and provide service to both passenger and cargo airlines.

ICNIRP: ICNIRP is an International Commission on Non-Ionizing Radiation Protection

NCC: Nigerian Communications Commission, an independent National Regulatory Authority for the telecommunications industry in Nigeria.

PCS: Personal Communications Service (PCS) is a type of wireless mobile service with advanced coverage and that delivers services at a more personal level

PSTN: PSTN stands for public switched telephone network, or the traditional circuit-switched telephone network.

Radio Frequency Fields : A radio frequency field (RF field) is an alternating current which, when put through an antenna, generates an electromagnetic field for wireless broadcasting or communication by sending a current through an antenna.

Radio Frequency Radiation RFR Radiofrequency (RF) electromagnetic radiation (EMR) is the transfer of energy by radio waves. RF EMR lies in the frequency range between 100 kilohertz (kHz).

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1.9 Outline of the thesis

The Investigation of Electromagnetic Interference and Geo-Spatial Encroachment of Radio-Frequency Based Infrastructures around Ibadan Airport was borne out of the interest to find a lasting solution to the cause of perennial headache experienced by me and other personnel, usually when on active Service. The number of man hours lost or wasted was a serious concern that led to the selection of this topic when the opportunity presented itself. Consequently, the presence of electromagnetic radiation was established contrary to the ICNIRP recommended setback. Therefore there was need to further investigate encroachment of electromagnet radiation within and outside the prescribed setback limits set by WHO and ICNIRP.

Electromagnetic interference (EMI), often known as radio-frequency interference (RFI) when occurring in the radio frequency spectrum, is a disruption caused by an external source and affecting an electrical circuit through electromagnetic induction, electrostatic coupling, or conduction. The disturbance may damage the circuit's performance or perhaps cause it to fail. The consequences can range from an increase in mistake rate to total data loss in the case of a data path. EMI can be caused by both man-made and natural sources of fluctuating electrical currents and voltages, such as ignition systems, mobile phone cellular networks, lightning, solar flares, and auroras (northern/southern lights). AM radios are frequently affected by EMI. It can also affect mobile phones, FM radios, and televisions, as well as radio astronomy and atmospheric science observations.

Nigeria has approximately 28 airports. The Federal Airports Authority of Nigeria (FAAN) manages 23 out of them, including Ibadan Airport. Ibadan Airport serves Ibadan, the capital of the Nigerian state of Oyo. The airport is located in Alakia, Ibadan, between the Adegbaiji neighborhood and Iwo Road. The research work was conducted within the specified limits. While in use, mobile and cordless phones emit radiofrequency (RF) radiation. Due to the increasing use of the wireless technology, environmental exposure to RF radiation has been increasing. The ICNIRP is the non-governmental organization officially recognized by the WHO and the International Labor Organization (ILO) in the field of Non-Ionizing Radiation. These basic restrictions were established based on published biomedical studies and relative to the health effects of electromagnetic waves.

In the area of high frequencies, they are expressed in terms of Specific Absorption Rate (SAR) and the biological effects appear above 4 Watts per kilogram for the entire body (increase in body temperature of more than one degree) and above 100 watts per kilogram locally.

The scientific research methods of Computer Science include but not limited to Computer Modeling and Simulation, Theoretical and Experimental Computer Science.

A computer model is an abstract mathematic representations of a real-world event, system, behavior, or natural phenomenon. A computer model could be a translation of objects or phenomena from the real world into mathematical equations. Thus, it is designed to behave just like the real-life system. The more accurate the model, the closer it matches real-life. A model might be used:

i. To test a system without having to create the system for real (Building real-life systems can be expensive, and take a long time).

ii. To predict what might happen to a system in the future (An accurate model allows us to go forward in virtual time to see what the system will be doing in the future).

iii. To train people to use a system without putting them at risk (Learning to fly an airplane is very difficult and mistake will be made. In a real plane mistakes could be fatal!).

iv. To investigate a system in great detail (A model of a system can be zoomed in/out or rotated. Time can be stopped, rewound, etc.)

In line with this, problems must be designed to allow for the creation of a model dealing with; elements, relationships and operations between these elements, patterns and rules governing these relationships.

Chapter Two will review available literature on the subject , while in chapter Three, specific techniques for selecting data collection and analysis tools, and, collection and analyzes of data in order to uncover the impacts of electromagnetic interference from Electromagnetic Field (EMF) based Infrastructure on aircrafts, geo-spatial encroachment on airport and airlines operational activities would be discussed.

The result of the findings will be discussed in Chapter Four and the conclusion of the findings will be in Chapter Five.

1.9.1 Introduction

The history of non-natural sources of electromagnetic radiation and fields is quite brief, spanning barely the last century. There are two types of non-natural sources of electromagnetic radiation or fields. The first category contains ionising radiation, which has a relatively high energy and can ionise matter particles. The existence of this type of radiation is mostly due to natural causes (the median yearly exposure dose is around 2.4 mSv)[1]. Non-natural sources of ionizing radiation, such as technical gadgets that utilize various radioactive isotopes, are currently regarded as the most serious issues in public health protection.

The second category includes non-ionizing radiation of energy that is too weak to ionise matter particles. All techniques of producing, transmitting, and utilizing electrical power are common

sources of this type of radiation (high-voltage power lines, substations, motors, generators, industrial and domestic appliances, home wiring, etc.). Telecommunication systems (radio, television, internet, and Wi-Fi) and medical devices used for diagnosis or therapy are significant sources of electromagnetic radiation[2]. Nonionizing radiation is classified into four levels, according to the European Commission: static fields, Extremely Low Frequency fields (ELF fields), Intermediate Frequency fields (IF fields), and Radio Frequency fields (RF fields)[1].

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1.9.2 Sources of Radio-Frequencies Technology

Cell phone technology has evolved dramatically during the last two decades. Beginning in the mid-1980s, the initial wireless systems employed analogue transmissions in the 850-900 MHz range. Because the wavelengths were longer, infrastructure was required every 8 to 10 miles on average.

Then, in the late 1990s, came digital personal communications systems (PCS), which used higher frequencies, around 1900 GHz, and digitised transmissions. PCS systems, which use shorter wavelengths and stricter exposure limitations, necessitate infrastructure every 1 to 3 miles. Digital signals operate on a binary basis, simulating a wave that permits any frequency to be split in various ways, containing significantly more information than just speech messages[6].

Today's 3G network can transfer photographs and music and video immediately to the screen of a cell phone or iPod. To establish additional service for wireless Internet access, the new 4G systems digitise and recycle part of the older frequencies in the 700 to 875 MHz ranges. The 4G network does not require customers who wish to connect wirelessly to find a "hot spot," as private Wi-Fi systems do. Wi-Fi today employs a network of small antennae to provide coverage of a limited area of 100 feet (30 meters) or less in homes or businesses. Wi-Fi can also be used to construct a small wireless computer system at a school, which is known as a wireless local area network (WLANs). Wi-Fi can be made available to entire cities by installing antennas on utility poles[7]. Furthermore, large-scale Wi-Fi networks have faced growing criticism from residents concerned about health risks, who have legally prohibited such installations (Antenna Free Union). Small-scale Wi-Fi has also come under examination, with governments in France and across Europe banning such installations in libraries and schools on precautionary grounds[8].

1.9.3 Electromagnetic Interference

Electromagnetic interference (EMI), often known as radio-frequency interference (RFI) when occurring in the radio frequency spectrum, is a disruption caused by an external source and affecting an electrical circuit through electromagnetic induction, electrostatic coupling, or conduction. The disturbance may damage the circuit's performance or perhaps cause it to fail. These consequences can range from an increase in mistake rate to total data loss in the case of a data path.

EMI can be caused by both man-made and natural sources of fluctuating electrical currents and voltages, such as ignition systems, mobile phone cellular networks, lightning, solar flares, and auroras (northern/southern lights). AM radios are frequently affected by EMI. It can also affect mobile phones, FM radios, and televisions, as well as radio astronomy and atmospheric science observations. EMI can be purposely employed to jam radio signals, as in electronic warfare[9].

Electromagnetic interference is defined as "the effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radio communication system, manifested by performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy" in Article 1.166 of the International Telecommunication Union's (ITU) Radio Regulations. According to ITU RR (article 1), interference variations are classed as permissible interference, tolerable interference, and damaging interference[9]. EMI or RFI can also be classified as narrowband EMI or RFI, which often emerges from intended transmissions such as radio and TV stations or mobile phones, and broadband EMI or RFI, which is unintended radiation from sources such as electric power transmission lines. Conducted EMI is created by physical contact between conductors, as opposed to radiated EMI, which is caused by induction (without physical contact of the conductors). Electromagnetic disturbances in a conductor's EM field will no longer be confined to its surface, but will instead radiate away from it. This is true for all conductors, and mutual inductance between two emitted electromagnetic fields causes EMI[9].

In today's aircraft, digital electronics are significantly more frequent. Current aircraft automated flight controls are controlled by digital clocks, data buses, switching regulators, pulse width modulated power, and radio frequency transmitters on the one hand, and sensitive analogue and digital equipment on the other. Electromagnetic interference could cause a flight delay or jeopardise an aircraft's operation at 30,000 feet. There are numerous types of electromagnetic interference generators for aircraft (illustrated in Figure 1.1):

i. Radio frequency transmitters that can be mounted on the aircraft, such as high-frequency (HF) or very high frequency (VHF) communication links, or high-energy sources on the ground, such as our common frequency modulated (FM) radio or HF-VHF-UHF broadcast stations3 [shown in Figure 1.1 (a)].
ii. The 400-Hz electric and magnetic fields of the aircraft power line.
iii. The microprocessor timing and control clock signal circuits in computers and avionics (aircraft) that generate radio frequencies of one MHz or higher [shown in Figure 1.1 (b)].
iv. The aircraft power switching regulators which are used to interconvert electrical power.
v. Electrical switching transients caused by the activation and deactivation of aircraft lights, fans, and engines, as well as the functioning of control surfaces such as ailerons, slats, and flaps.
vi. Lightning and electrostatic discharges: These transients and electromagnetic waves may transfer into wiring and create "electromagnetic interference" to microcircuits inside electrical systems.

(a)

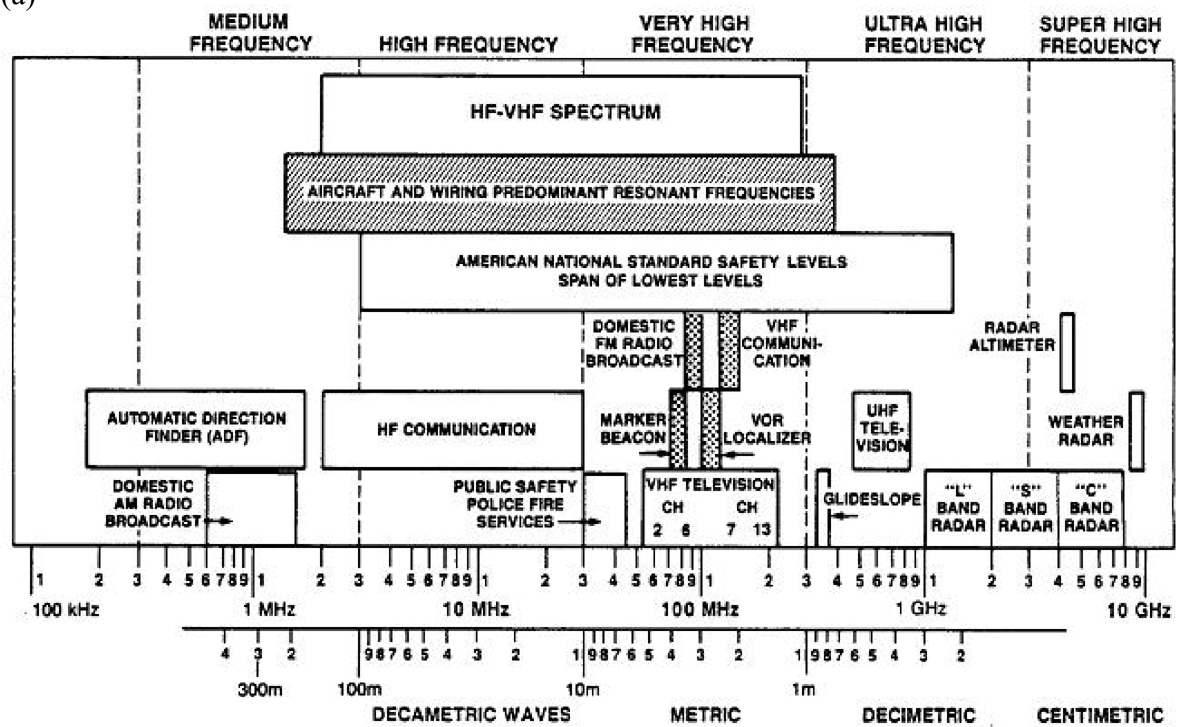


Figure 1.1: Radio Frequency Range[3].

equipment and avionics, possibly resulting in a minor glitch in a flight deck display or, more dangerously, engine shutdown[3].

Electrical wiring's conductive channels provide a path for electromagnetic interference to reach aeroplane avionics and signal inputs. When wiring is removed, electromagnetic interference almost completely disappears. The most critical factor in electromagnetic interference and electromagnetic compatibility is the wiring. The electromagnetic interference channel through the avionic equipment's metal casing or case is substantially less important. The electrical interface and link between avionic equipment is known as wiring. Its primary function is to transmit avionics signals, data, and information. However, in that capacity, it is frequently used to transport electromagnetic interference energy to other wires in a wire bundle. It also sprays or radiates like a sending antenna and receives radio frequency energy very efficiently like a receiving antenna[3].

1.9.4 The Aircraft Avionics

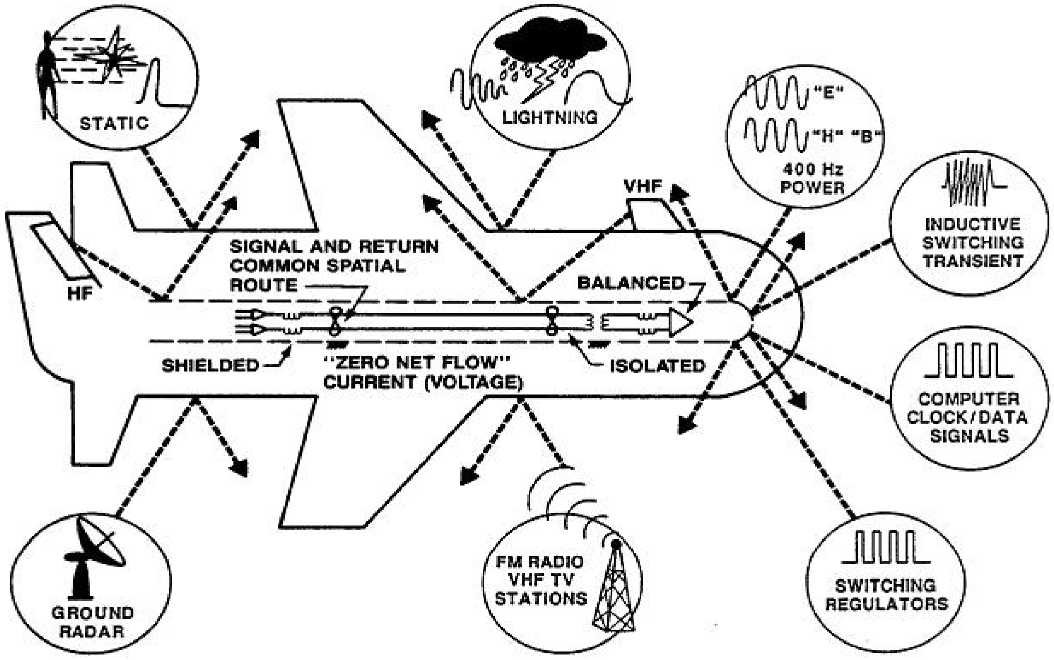
With the introduction of digital electronic technology in electrical and electronic systems, remarkable expansion of aviation system functionality and evolution of aircraft function automation have been possible. As a result, systems that use such technologies are increasingly being employed to implement aircraft functions. The Electromagnetic Environment (EME) is a sort of energy that is similar to the type of energy (electrical) used by electrical/electronic equipment to process and convey information. As a result, this environment poses a serious threat to the proper operation of systems that rely on such equipment. It is a frequent modal hazard capable of undermining fault-tolerant methods based on redundant electrical/electronic systems[2].

Level A digital systems perform functions that can affect the safe operation of an aircraft and rely on information (e.g., guidance, control, etc.) processed by electronic equipment. As a result, the EME threat to such systems may be seen as a threat to the airplane itself. Modern aircraft guidance and control systems are vulnerable to disruption from lightning and sources that emit RF at frequencies mostly between 1 and 500 MHz and produce aircraft internal field intensities of 5 to 200 V/m or greater. Internal field strengths larger than 200 V/m are often represented by periodic pulses with pulse lengths shorter than 10 s. Internal lightning-induced voltages and currents can vary from about 50 volts and 20 amps to more than 3000 volts and 5000 amps. The susceptibility of electrical/electronic systems to such an environment has been suspected as the source of "nuisance disconnects," "hard overs," and "upsets." This type of system upset, in general, occurs at far lower levels of EM field intensity than that which could induce component failure, leaves no trace, and is usually non-repeatable[3].

1.9.4.1 Electromagnetic Compatibility of an Aircraft Subsystem

"Zero net current flow in a shielded, balanced, isolated circuit" is the number one condition for an electromagnetic compatibility design program that will rule out electromagnetic interference problems. To put it another way, the signal and return wires should always be wired together using twisted pair, coaxial, or shielded pair cable. As a result, the aircraft fundamental structure is not used as the circuit's return path [(shown in Figure 1.2(a)]. This virtually eliminates the three entry points for electromagnetic interference: common mode impedance routes, magnetic field coupling, and electric field coupling. (When two circuits share a portion of the same e-path, common mode impedance conditions apply.)[2]. According to a recent estimate of aeroplane difficulties, the variability of the sources and their percentage composition are: power line electric and magnetic field coupling (30%), radio frequency fields (20%), transients (15%), and common mode impedance routes (10%) account for 75% of faults. Electromagnetic interference can arise in a variety of aircraft components [shown in Figure 1.2(b)]. Uncontrolled, it shows on passenger entertainment systems as radio tones, static, or 400-Hz hum. It can manifest as flight deck display distortion or illegibility, impeded data transmissions, computer memory loss, and even equipment shutdown.

(a)



(b)

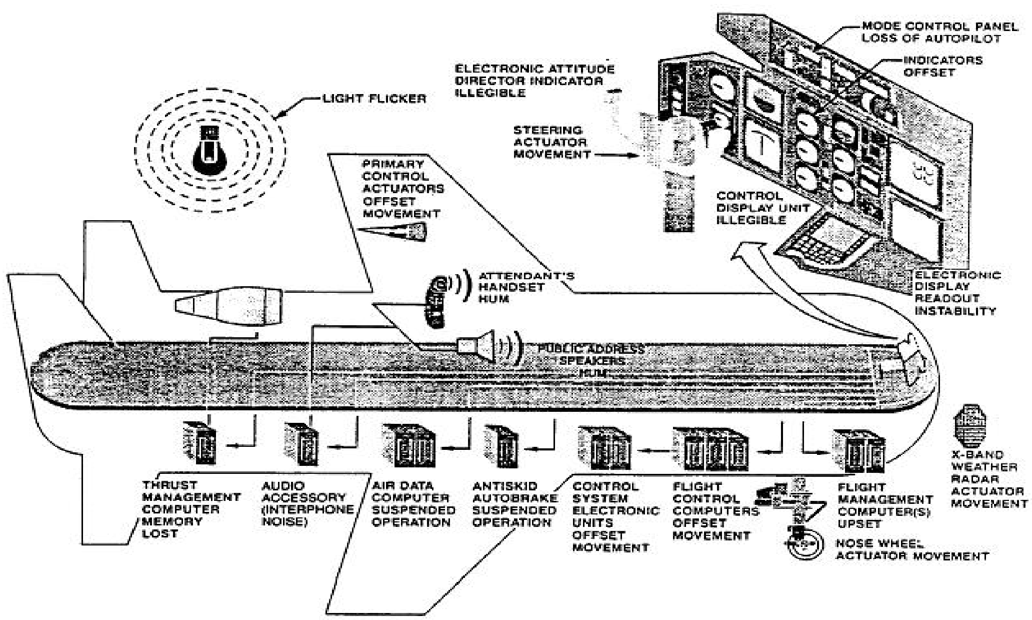


Figure 1.2: (a) Electromagnetic Interference Environment on Aircraft[3] and (b) Illustration of Electromagnetic Interference Effects[3]

Radio frequencies are becoming increasingly problematic. Memory loss may occur, and machine operation may be halted. Radio frequencies are becoming increasingly problematic. ' Every day, the primary radio frequency fields that interfere with the operation of avionic equipment fall into the HF-VHF radio frequency spectrum [shown in Figure 1.2 (b)]. The range of future planes may vary[3].

1.9.4.2 Airport and the Spatial RF Sources Around its Environment

An airport is made up of two basic parts: an airfield and terminals. A conventional airfield consists of a takeoff and landing runway as well as two (or one) parallel taxing lanes (taxiway). Runways are identified according to the direction they face (rounded magnetic azimuth in decimal)[4]. As a result, an aircraft utilising runway 09 would face east (90 degrees), whereas an aircraft using runway 27 (270 degrees), which is the same, would face west. The connecting lanes between the runway and the taxiing lanes are normally at an angle, allowing planes that have recently landed to vacate the runway quickly. Depending on the size of the plane, modern airport designs allow two or three departing choices per landing direction. A tiny aircraft will need less distance to brake than a large aircraft, allowing it to evacuate the runway quickly, freeing up important take off or landing slots[10].

Although there are many different terminal designs, the most of them fall into one of the following categories:

i. **Standard**: The linear orientation of terminals allows several planes to board passengers at the same time (through jet bridges) and is the most prevalent terminal design. This concept can be expanded to include piers or a number of concourses connected by underground corridors and internal transit systems. The extensive lateral movements of passengers and luggage between gates are a disadvantage of these designs. This is especially true for large hubs where passengers may have to walk for several minutes between gates (e.g., Chicago, Brussels, Minneapolis)[10].

ii Satellite: The satellite addresses the issue of terminal space shortages by allowing the storage of multiple planes on a smaller terminal surface. A hall or an underground passage connects the satellite to the rest of the airport (e.g., Charles de Gaulle, Dallas/Fort Worth Satellite Airport).

iii Shuttles: Some airports use shuttles, which allows them to reduce terminal size while increasing the number of flights that can be serviced. This, however, necessitates lengthier boarding times. Shuttles are frequently used at major airports where normal jet bridges support large flights and smaller domestic planes are parked on a pad and serviced by buses. In congested areas, shuttles can be employed to dump people, freeing up gates for boarding. Shuttles (haulers transporting air unit load devices) normally load and unload freight planes, hence the usage of shuttles in the design is common in air cargo operations[10].

1.9.5 Digital Enhanced Cordless Telecommunications

Cell phones and household cordless phones use comparable frequencies and a transmitter placed against the head. However, unlike previous domestic cordless phones, the modern digitally enhanced cordless technology (DECT) cordless domestic phones send a steady signal even when the phone is not in use. However, several DECT brands are available that disable transmission while the mobile units are docked. Digital Enhanced Cordless Telecommunications (DECTTM) is an ETSI standard for short-range cordless communications that may be customised for a variety of applications and utilised globally on license-free frequency allocations[11].

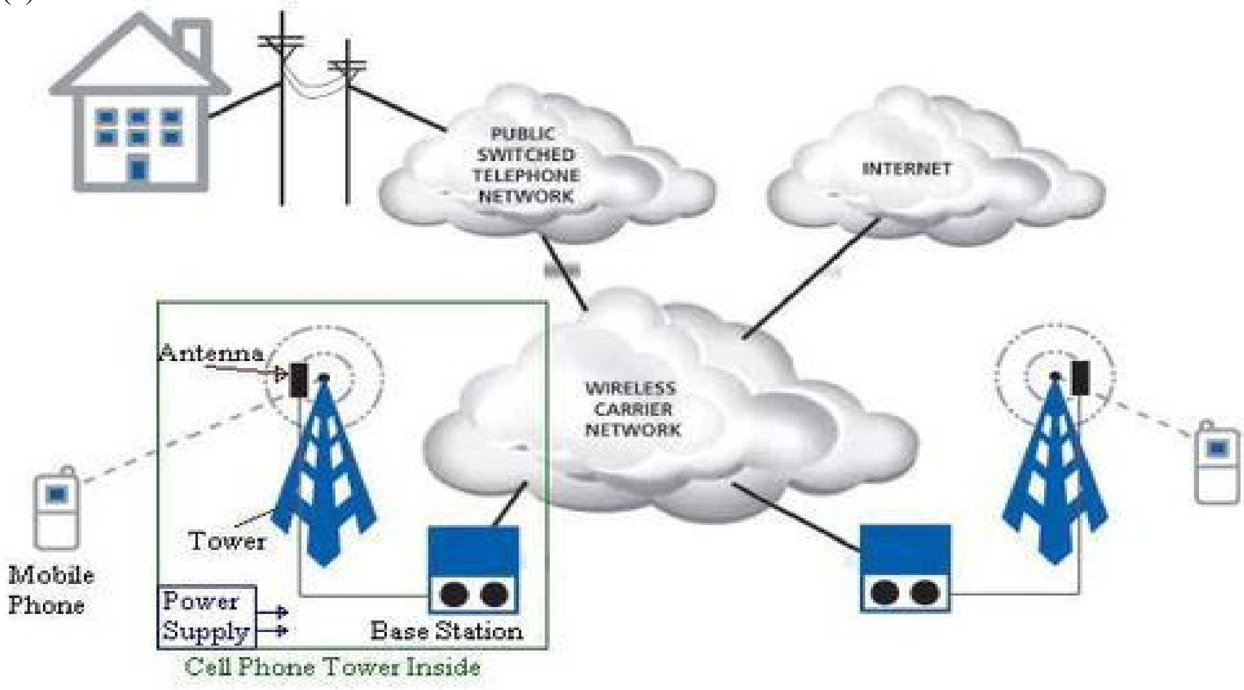
The total number of DECT devices created exceeds one billion, with an annual growth rate of more than 100 million units. DECT has a range of up to 500 metres and is suitable for voice (including PSTN and VoIP telephony), data, and networking applications. DECT is the industry leader in both the cordless home and enterprise PABX (Private Automatic Branch eXchange) markets. DECT Evolution was created to provide new functionality for high-end and professional audio system applications, such as those used in the PMSE industry, where audio streaming at high data speeds and low latency is critical. DECT-2020 is the most recent development, offering enhanced channel coding and Hybrid ARQ with incremental redundancy, allowing for quick re-transmission. The physical layer allows for quick connection adaption, broadcast and receiver diversity, and MIMO operations with up to eight streams. DECT-2020 addresses both star network topology, such as for URLLC use cases, and mesh network topology, such as for mMTC use[11].

1.9.5.1 Telecommunication Base Stations

When compared to many other commercial applications of radiofrequency energy, telecommunication base stations consist of cell towers, which are considered low-power installations. Wireless transmission for radio, television (TV), satellite communications, police and military radar, federal homeland security systems, emergency response networks, and a variety of other applications all emit Radio Frequency Radiation RFR, which can reach millions of watts of Effective Radiated Power (ERP). Cellular facilities, on the other hand, consume a few hundred watts of ERP per channel, depending on the application at hand and the number of service providers co-located at any one tower[11].

Despite the fact that the intensity of RFR reduces fast with distance from the emitting source, exposure to RFR from transmission towers is frequently of low intensity depending on one's vicinity. Living near a plant that will involve long-duration exposures, sometimes for years, at many hours per day may breach the statutory regulation on general public exposure to electromagnetic radiation[11]. Working at home or in the office can result in low-level 24 h exposures, and nighttime alone can result in 8 h continuous exposures. Figure 1.3 (a) represents basic cell phone tower components, whereas Figure 1.3 (b) depicts ICNIRP (2020) antenna field zones[12].

(a)



(b)

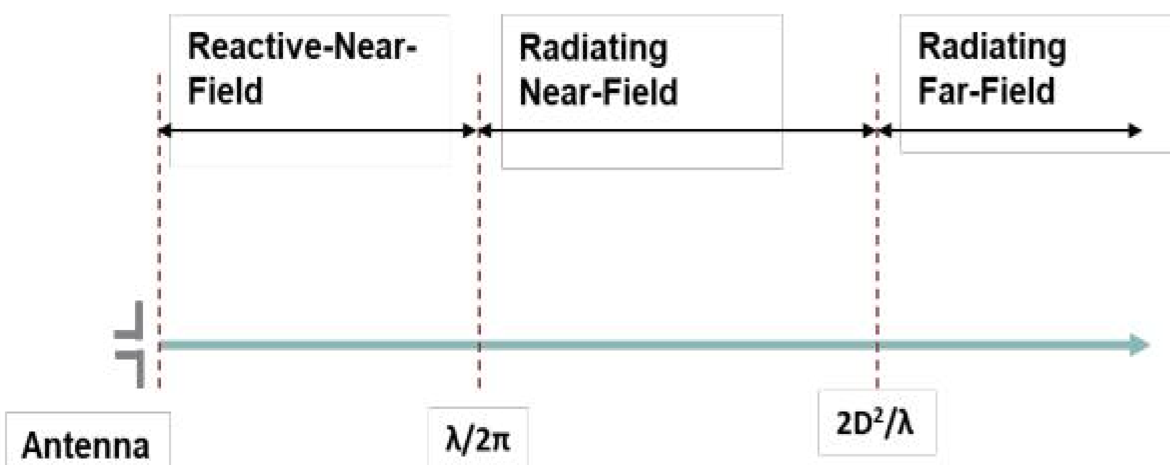


Figure 1.3: (a) Basic Cell Phone Tower Components and (b) ICNIRP Antenna Field Zones[11].

Basic cell phone tower components consist of elevated structure, equipment, antennas and utilities[12]. These components are discussed as follows:

i. **Cell Phone Tower Structure**: As stated below, there are various forms of tower structures. To elevate such buildings above ground level, adequate support must be supplied.

ii. **RF and Baseband Equipment**: The equipment is classified into two types: indoor and outdoor or roof mounted. Indoor equipment is often installed in a room. The indoor equipment is linked to the outdoor equipment or antenna using coaxial cable. Baseband information is converted by RF equipment into a format that can be sent or received by RF antennas. Baseband equipment interfaces with voice and data equipment. Baseband and RF devices are sometimes integrated and referred to as modems.

iii. **RF Antennas**: On the cell tower, each telecom carrier employs numerous antennas. Each site typically houses 3 to 18 antennas. The capacity of the subscribers is used to augment the antennas.

iv. **Other utilities**:The most important utilities are power supply, UPS (Uninterrupted power supply), and AC to DC rectifier, which are utilised to power electronic circuits and equipment. In the event of a power outage, a UPS is employed as a battery backup system.

Cell site interacts with the Public Switch Telephone Network PSTN for landline telephone, the PSDN for internet connectivity, and other cellular towers. Fiber optic cables, terrestrial microwave links, satellite links, and other means connect the cell tower location to other sites[11].

1.9.5.2 The Ibadan Airport

Nigeria has approximately 28 airports. The Federal Airports Authority of Nigeria (FAAN) manages 23 of them, including Ibadan Airport[13]. Ibadan Airport serves Ibadan, the capital of the Nigerian state of Oyo. The airport is located in Alakia, Ibadan, between the Adegbaiji neighbourhood and Iwo Road. Figure 1.4 (a) depicts typical airport components/terminal designs, whereas Figure 1.4 (b) depicts an aerial perspective of Ibadan airport.

(a)

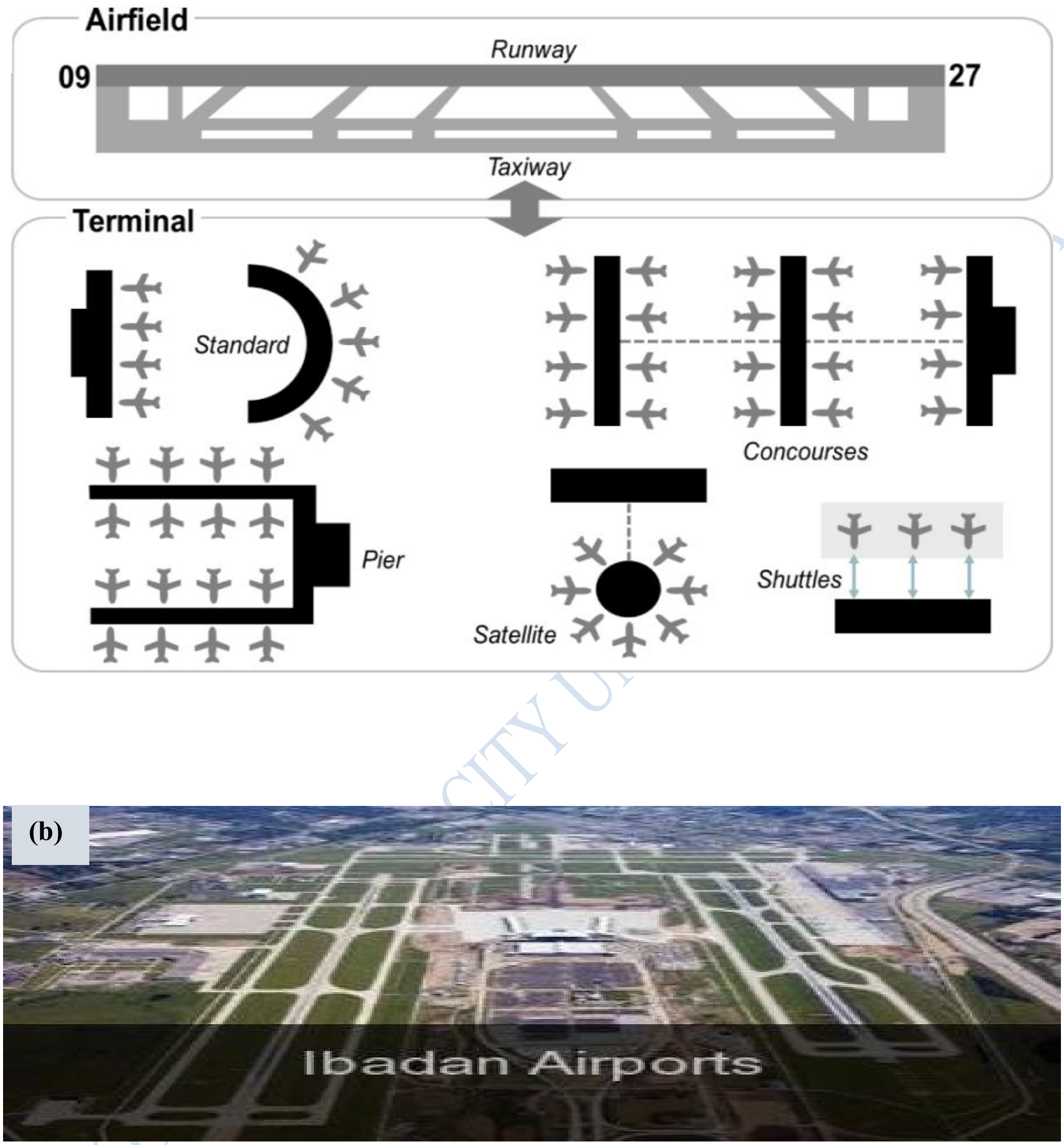


Figure 1.4: (a) Typical Airport Components and Terminal Configurations ; (b) Aerial Photograph of Ibadan Airport[14].

According to the Federal Airport Authority of Nigeria (FAAN), it was commissioned in June 1982 by Joseph Wayas, a former Nigerian Senate President. On the field are the Ibadan VOR-DME (Ident: IBA) and the non-directional beacon (Ident: IN). The airport has a single terminal and a

2,400-metre-long runway. Overland Airways and Arik Air are airlines with scheduled flights into the terminal connecting passengers between Ibadan and Abuja, as well as a return flight between Abuja and Ibadan.

1.9.5.3 Regulations on Airport and Aircraft Operations

The transportation sector is an economy's lifeline. To a large part, an economy's growth and development are dependent on the expansion of its transportation sector. Roads and highways, trains, civil aviation, and water space are all part of the transportation industry. In terms of modal share, air space now ranks third and fourth in developed and developing countries for passenger movement and freight movement, respectively. In terms of passenger movement (passenger kilometre), air space comes in second to roads and railroads, while freight transportation (tone kilometre) comes in third to roads, trains, and water transport. Despite its relevance, monitoring government agencies' regulations and stipulations must not be abandoned.

1.9.5.4 Stipulations of National Communications Commission on Siting of Mast around Airport

According to the National Communications Commission NCC's 2009 guidelines, no communication masts or towers, regardless of height, shall be erected within 15 kilometres of any airport, or within the vicinity of helicopter pads and approaches, without prior approval and permits from the Nigerian Airspace Management Authority, NAMA5. Furthermore, under Section 9(1)(a), the maximum height for a telecommunications tower in commercial and industrial regions shall not exceed 150 metres unless the Commission is convinced that the greater height is necessary

i. will not be detrimental to public health, safety or general welfare.

ii. will not have negative effect on the neighbourhood.

iii. Is in conformity with the plan of the particular area and the general plan of the community.

iv. Will not impair compliance with any other applicable laws or guidelines[13].

Furthermore, new telecommunications facilities are permitted in residential areas, according to the 2009 legislation. It must, however, not exceed a height of 25 metres. All towers above 25 metres in height in residential zones must be erected at a minimum setback of 5 metres from the next demised property, excluding the fence. In addition, prior clearance from the Commission is required before erection. Furthermore, where the Commission grants permission to erect towers or masts taller than 150 metres, such towers or masts must be set back from the right-of-way of all controlled access, federal and state roadways designated as freeways by a minimum of 50 metres in order to provide unobstructed flight paths for helicopters. The mast location must have a parking/loading area, and any site that is 50 metres or fewer from a paved road must be paved[13].

1.9.6 Permit Requirements for Telecommunication Base Transceiver Stations

Before constructing a Communication Base Transceiver Station CBTS, certain approvals must be obtained. The Aviation Height Clearance permission (AHC) required by Section 13(b)(xvii) of the Civil Aviation Act 2006 must be obtained under the Federal Government authorization. It also enables the Nigerian Civil Aviation Authority, abbreviated "NCAA," under Section 30(3)(l) of the Civil Aviation Act 2006, to "*prohibit and restrict the installation of any structure, which is judged to endanger the safety of air navigation by virtue of its height or position*;"[13]. This describes the AHC's aim, which is to ensure that the tower or mast scheduled to be built would not pose any kind of threat to air navigation. The AHC is typically issued within 30 to 45 days and is renewed annually[13].

Furthermore, the Nigerian Airspace Management Agency (NAMA) requires all free-standing masts to be no taller than 150 metres. When a mast exceeds the specified height, it can only be installed with a NAMA clearance certificate. NAMA requires that all masts be lighted. Through the NESREA, the Federal Ministry of Environment also grants a permission known as an

Environmental Impact Statement and Certificate (EISC). The EISC is issued after more than 180 days, and it is renewed every three years if the CBTS is active. The EISC is given every five years in areas where it is not active. This is because, before issuing an EISC, NESREA will conduct an Environmental Impact Assessment (EIA), which will be performed by its qualified environmental auditors[13].

1.9.7 ICNIRP Guidelines on Exposure of Non-Ionizing Radiation Electromagnetic Field

The International Commission for Non-Ionizing Radiation Protection's (ICNIRP) updated international guidelines for exposure to radiofrequency electromagnetic fields (RF-EMFs) focus on elements of the guidelines that are most relevant for exposures from mobile communications network equipment and devices operating in the frequency range of 400 MHz to 300 GHz[12]. Quantitative RF-EMF levels for personal exposure are specified in the ICNIRP guidelines. Adherence to these thresholds is designed to safeguard persons from all substantiated health-harming consequences of radiofrequency EMF exposure. The amended ICNIRP guidelines maintain different limits for occupationally exposed individuals and members of the general public, with stricter restrictions for the latter.

Furthermore, regardless of exposure scenario, ICNIRP defines the foetus as a member of the general public and subject to general public restrictions[12]. According to the ICNIRP, there is no direct evidence that pregnant workers' occupational whole-body exposure may harm the foetus, and the decision to treat a pregnant worker as a member of the general population is conservative. According to the organisation, there are mitigating measures that can be considered in order to allow pregnant workers to enter regions where radiofrequency EMFs are at occupational exposure levels while not exceeding general public prohibitions. According to the ICNIRP, a pregnant worker can stay in an area at the occupational exposure limit level for 6 minutes within a 30-minute averaging interval, as long as the SAR averaged over 30 minutes (including this 6-minute interval) does not exceed the general public restrictions. Table 1.1 (a) represents the ICNIRP reference levels averaged over the entire body for a 30 minute temporal period, whereas Table 1.1 (b) depicts the ICNIRP (2020) reference levels for local exposure averaged over 6 minutes[12].

Table 1.1 (a): ICNIRP (2020) Reference Levels Averaged Over the Whole Body @ 30 Min Temporal[12].

Exposure scenario	Frequency range	Incident E-field Strength E_{inc} (V/m)	Incident H-field Strength H_{inc} (V/m)	Incident power density S_{inc} (W/m^2)
Occupational	> 400 – 2000MHz	$3f_m^{0.5}$	$0.008f_m^{0.5}$	$f_m/40$
General public	> 400 – 2000MHz	$1.375f_m^{0.5}$	$0.0037f_m^{0.5}$	$f_m/200$

Table 1.1 (b): ICNIRP (2020) Reference Levels For Local Exposure, Averaged Over 6 Min[12].

Exposure scenario	Frequency range	Incident E-field Strength E_{inc} (V/m)	Incident H-field Strength H_{inc} (V/m)	Incident power density S_{inc} (W/m^2)
Occupational	> 400 – 2000MHz	$3f_m^{0.5}$	$0.008f_m^{0.5}$	$0.29f_m^{0.86}$
General public	> 400 – 2000MHz	$1.375f_m^{0.5}$	$0.0037f_m^{0.5}$	$0.058f_m^{0.86}$

where $f_m$is frequency (MHz)of operation of the system

1.10

Airports required numerous hectares of land for operational activities. Hence, few airports are built in the metropolis and those airports (such as Lagos and Ibadan Airports) built on the outskirts of the city at 3early 80s are currently being hemmed in by urban and suburban developmental infrastructures such as Telecommunication base stations, Television and Radio stations. medical facilities such as X-Rays and Computerized Tomography (CT) scanners, nuclear power plants, research laboratories, manufacturing and construction companies, among other EMFs sources.

These EMF based infrastructures are mostly kept far below 15 km step-back stipulated by NCC as Airport's setback.

However, the stray electric and magnetic fields from these EMFs sources do generate charged encroaching fields that could affect the health status of Airport professionals (which are being continuously subjected to EMF fields greater than ICNIRP recommendations over time / per unit time). Also, the fields interfere with the needed operation of the aircrafts' microprocessor memories and instruments, computers and controllers, causing trifling disorder in the flight deck display or, more seriously, shutdown the aircraft's engine. To investigate the level of electro-spatial encroachment and interference of the stray electric and magnetic fields around Ibadan airport's immediate environment, hence this study.

1.11

The aim of the study is to investigate the impacts of electromagnetic interference and geo-spatial encroachment that emanated from the Electromagnetic Field (EMF) Based Infrastructures (EMF-BI) on Aircrafts and Airports' staff, within and around Ibadan Airport. After appraisal of necessary regulations and guidelines on operation of Radio-Frequency based devices in relation to airports domain, the following objectives are proposed for achieving the aim:

i. Evaluate the spatial existence of Electromagnetic Field (EMF) Based Infrastructures (EMF-BI) within and on 15 km setback of Ibadan Airport, using Satellite based technology.
ii. Measurement and numeric computation of electromagnetic field radiations (electric, magnetic and power flux density) from (i) at spatial range R of $0.5m \leq R \leq 2.0m$
iii. Investigate electromagnetic interference and spatial encroachment of Radio Frequency (RF) waveforms (to be generated with MatLab software) using data from (ii) on Ibadan Airport.

iv. Comparatively analyze (a) results from (i) with the NCC regulations on EMF interference and electro-spatial encroachments generated from (ii) and (iii); (b) evaluate the compliance of International Commission for Non-Ionizing Radiation Protection (ICNIRP) standard on exposure of EMF to airport workers which would be obtained through questionnaires.

1.12

As modern aeroplanes become more reliant on computerised or electronically controlled systems, their normally low power inputs and, in some situations, outputs are easily corrupted when undesired induced electrical impulses from stray electromagnetic fields find their way into otherwise isolated circuits. This might generate electromotive force, igniting the thrust and giving the aircraft complete control. As a result, the plane might crash and cause critical infrastructure damage with no legal repercussions.

Endnotes

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Chapter Two

Literature Review

2.1 Conceptual Review

Computer Science is a field of study that is concerned with theoretical and applied disciplines in the development and use of computers for information storage and processing, mathematics, logic, science, and many other areas[1]. Also, Computing is the systematic study of algorithmic processes that describe and transform information: their theory, analysis, design, efficiency, implementation, and application. The scientific research methods of Computer Science include but not limited to Computer Modeling and Simulation, Theoretical and Experimental Computer Science.

A computer model is an abstract mathematic representations of a real-world event, system, behavior, or natural phenomenon. A computer model could be a translation of objects or phenomena from the real world into mathematical equations. Thus, it is designed to behave just like the real-life system. The more accurate the model, the closer it matches real-life. A model might be used:

v. To test a system without having to create the system for real (Building real-life systems can be expensive, and take a long time).

vi. To predict what might happen to a system in the future (An accurate model allows us to go forward in virtual time to see what the system will be doing in the future).

vii. To train people to use a system without putting them at risk (Learning to fly an airplane is very difficult and mistake will be made. In a real plane mistakes could be fatal!).

viii. To investigate a system in great detail (A model of a system can be zoomed in/out or rotated. Time can be stopped, rewound, etc.)

In line with this, problems must be designed to allow for the creation of a model dealing with; elements, relationships and operations between these elements, patterns and rules governing these relationships. Two different types of models are deterministic (A model or simulation where no randomness is involved) and stochastic (A model or simulation that uses random numbers so that the system states and the output results are not exactly predictable from run to run). In addition, Computer Simulation enables investigations beyond current experimental capabilities, study phenomena that cannot be replicated in laboratories, guided by theory and experimental results (feedback loop) and, simulate phenomena and processes. Hence, the literature review and subsequently, the research methodology would be based on application of scientific models and experimental investigation using computer science research techniques and tools.

This rest of this chapter would focus on conceptual, theoretical and empirical reviews, summary of research gaps from the related literatures, and conceptual framework for the research study which would be based on the research gaps. The conceptual review discusses the following concepts in relation to the research objectives:

i. Electric charges, radiofrequency radiations and electromagnetic spectrum.

ii. Principle of electromagnetic interference and measurement of electromagnetic radiation.

iii. Basics of cell towers and other radio-frequency sources.

iv. Basic architectural structure of aircraft and layers of Earth's atmosphere.

Also, the theoretical review focused on the review of electromagnetic field theory, magnetic force on charged particles, etc. More so, the empirical review which intensively reviewed the publications of previous scholars in relation to the research aim and objectives of the research study appraised the following studies:

i. High intensity radiated field coupling into aircraft

ii. Perception of health risks of electromagnetic field by radiographers and airport security officers.

iii. Analysis of Risks in Aircraft Systems due to Electromagnetic Environmental Effects executed

iv. Electromagnetic Interference to Flight Navigation and Communication Systems:

Avionic systems contain numerous on-board and frequency-generating systems which include telemetry circuitry, frequency synthesizers, digital circuitry and switching electrical power supplies. A good grounding plan, shield termination and interconnects, proper wiring classification and harnessing, and shielding are the main means of controlling electromagnetic interference EMI from affecting the components of avionics system[1]. Many systems require shielding of enclosures and connec1tors, starting at 60dB and ranging up to more than 100dB. Methods for achieving such levels include; proper enclosure material, effective printed circuit board layout and design, ensuring resistance across enclosure continuities and properly terminating cable shields, among others[4].

2.1.1 Electric Charges and Radio-Frequency Radiations

The presence of moving or stationary electrical charges generate an electric field (E-field) between the charges. The oscillating or moving charges are called time-varying currents. If there is a current flowing, then there will be a magnetic field (H-field) generated. The direction of the magnetic field can be determined by the right-hand rule. Maxwell equations iterated that these moving charges (i.e., a current flow) will not only have a time-varying H-field, but will generate a time-varying E-field called electromagnetic. The E-field and H-field components of electromagnetic field are mutually dependent and are transverse to each other. However, electromagnetic field interference

EMI or potential EMI is unwanted energy that can disturb other nearby electronic devices, especially important with sensitive signal levels such as GPS and digital communications between systems[3].

Radiofrequency radiation covers a large segment of the electromagnetic spectrum and falls within the nonionizing bands. Its frequency ranges between 10 kHz to 300 GHz; 1 Hz = 1 oscillation per second; 1 kHz = 1000 Hz; 1 MHz = 1 000 000 Hz; and 1 GHz = 1 000 000 000 Hz. The intensity of RFR is generally measured and noted in scientific literature in watts per square meter (W/m^2); milliwatts per square centimetre (mW/cm^2), or microwatts per square centimetre ($\mu W/cm^2$). All are energy relationships that exist in space. However, biological effects depend on how much of the energy is absorbed in the body of a living organism, not just what exists in space.

Different frequencies of RFR are used in different applications. Some examples include the frequency range of 540 to 1600 kHz used in Amplitude Modulation AM radio transmission; and 76 to 108 MHz used for Frequency Modulation FM radio. Cell-phone technology uses frequencies between 800 MHz and 3 GHz. The RFR of 2450 MHz is used in some Wi-Fi applications and microwave system[2]. Currently, all the new telecommunications technologies are digitized and in developed countries like United State of America U.S.A., all TV is broadcast in 100% digital formats; Digital Television (DTV) and High Definition Television (HDTV). The old analog TV signals, primarily in the 700 MHz ranges, will now be recycled and relicensed for other applications to additional users, creating additional layers of ambient exposures[2].

2.1.2 The Electromagnetic Spectrum

Generally, the radio communication services within the Very Low Frequency VLF, Low Frequency LF, Medium Frequency MF, High Frequency HF, Very High Frequency VHF, Ultra High Frequency UHF, Super High Frequency SHF and Extreme High Frequency EHF frequency bands, are presently utilized to a limited extent for purposes of civil and commercial civil applications. The technology has been analogue and over the past years the use of the LF, MF and HF frequency bands decreased and this decrease seems to continue. However, the introduction of digital technologies and frequency adaptive systems of these bands has brought experience in revitalization[10]. Radio frequencies are considered to be that portion of the electromagnetic spectrum below the infrared frequencies. The daily application of radio waves ranges from VLF, LF, MF, HF, VHF, UHF, SHF and EHF bands. The uses include Internet application, Television, Mobile phones, remote sensing and GPS systems, door control system, wireless clocks, military radio such as police communication system, infrared controlled toys, among others. Due to dissimilar propagation properties of different frequencies traveling over the worlds' sphere, it is logical to assign separate spectrum allocations to different applications. MF and HF bands has been facing some decrease over the past years but a number of national operators are now using MF as well as HF bands for radio broadcasting[10].

It is expected that the development of a global digital standard (DRM) with higher quality and new markets and services will further support and accelerate the development of the Broadcasting Service in particular in the LF and MF bands but also in the slightly longer term in the HF bands. It may be expected that the digital technology within the broadcasting service could be adapted by other commercial radio communication services such as the Fixed and Mobile services and the Maritime Mobile service[10]. Electromagnetic fields are classified by frequency as tabulated in Table 2.1 with different bands and illustrated with different range of applications as shown in Figure 2.1[10]. However, the frequency allocations for auxiliary services may change from time to time as the needs of various services for radio frequencies change and as technology for equipment improves. The most common used frequency bands are AM/FM and Television stations[1]

Table 2.1: Radio Frequency Range and Application

S/N	Category of Frequency	Frequency Range	Wavelength	Name	Application
1	Radio Frequency	3kHz - 30kHz	100m -10 km	Very Low Frequency VLF	Beacon
2		30kHz - 300kHz	10 km – 1 km	Low Frequency LF	Marine communication
3		300kHz - 3MHz	1 km – 100 m	Medium Frequency MF	AM radio broadcast
4		3MHz - 30MHz	100 m – 10m	High Frequency HF	Shortwave broadcast
5		30MHz - 3000MHz	10 m – 1 m	Very High Frequency VHF	FM, Television
6		300MHz - 1GHz	100 cm – 10 cm	Ultra High Frequency UHF	Television, Microwave oven, Mobile Phones
7	Microwave Frequency	1GHz -2GHz	10 cm – 1 cm	L Band	Mobile Phones, Wireless LAN, Radar, GPS
8		2GHz - 4GHz	1 cm – 10 mm	S Band	Bluetooth
9		4GHz - 8GHz	10 mm – 1 mm	C Band	Satellite Communication, Cordless Telephone, Wi-Fi

Source: Adapted from [10].

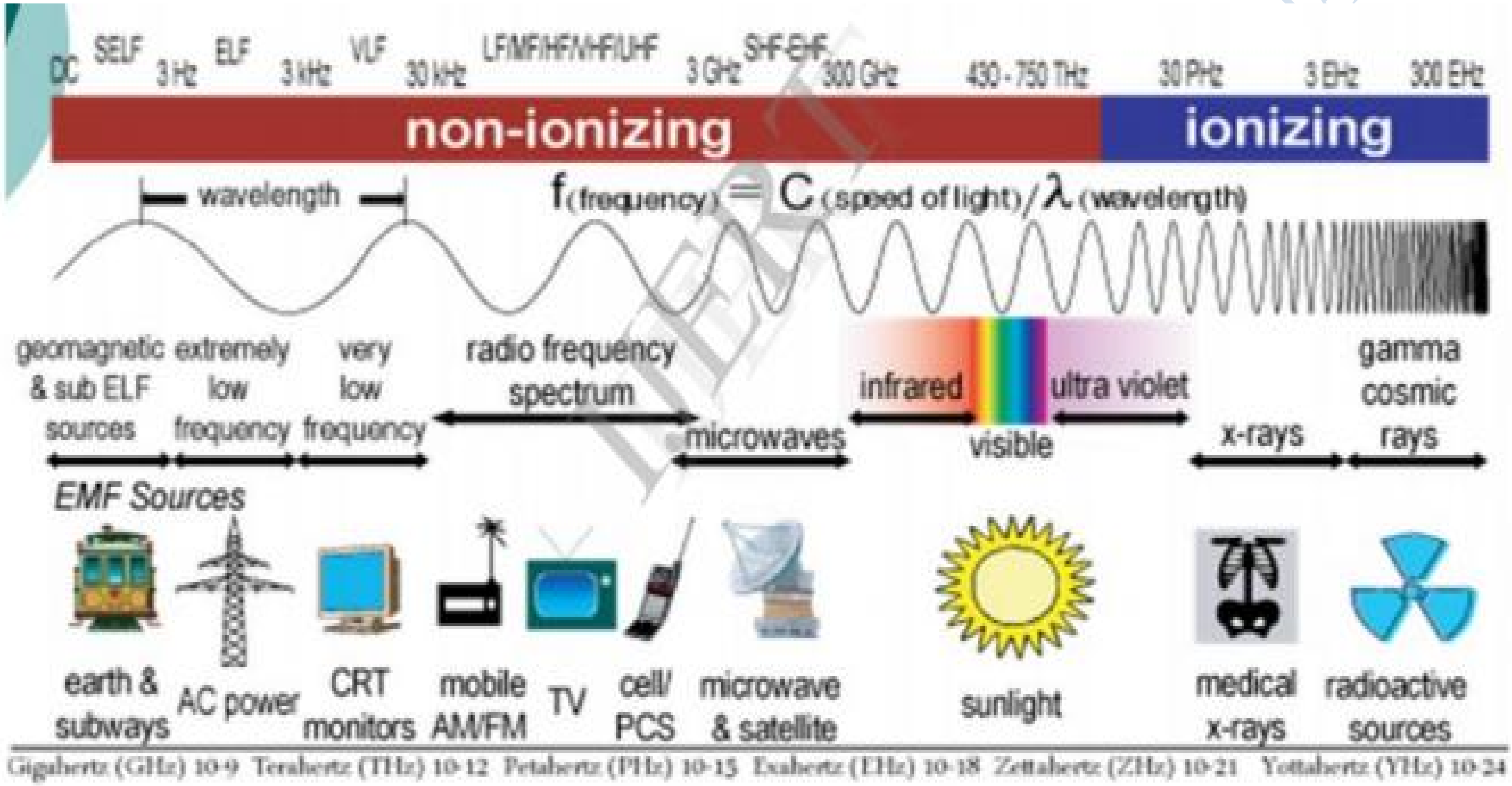


Figure 2.1: The Electromagnetic Spectrum and Its Application[5].

2.1.3 Electromagnetic Field

Electromagnetic radiation (EMR) consists of waves of the electromagnetic (EM) field, propagating through space, carrying electromagnetic radiant energy. It includes radio waves, microwaves, infrared, (visible) light, ultraviolet, X-rays, and gamma rays. All of these waves form part of the electromagnetic spectrum[4]. Classically, electromagnetic radiation consists of electromagnetic waves, which are synchronized oscillations of electric and magnetic fields. Electromagnetic radiation or electromagnetic waves are created due to periodic change of electric or magnetic field. Depending on how this periodic change occurs and the power generated, different wavelengths of electromagnetic spectrum are produced. In a vacuum, electromagnetic waves travel at the speed of light, commonly denoted by c[5].

In homogeneous, isotropic media, the oscillations of the two fields are perpendicular to each other and perpendicular to the direction of energy and wave propagation, forming a transverse wave. The wavefront of electromagnetic waves emitted from a point source (such as a light bulb) is a sphere. The position of an electromagnetic wave within the electromagnetic spectrum can be characterized by either its frequency of oscillation or its wavelength. Electromagnetic waves of different frequency are called by different names since they have different sources and effects on matter. In order of increasing frequency and decreasing wavelength these are: radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays and gamma rays[2].

Electromagnetic waves are emitted by electrically charged particles undergoing acceleration[3] and these waves can subsequently interact with other charged particles, exerting force on them. EM waves carry energy, momentum and angular momentum away from their source particle and can impart those quantities to matter with which they interact. Electromagnetic radiation is associated with those EM waves that are free to propagate themselves ("radiate") without the continuing influence of the moving charges that produced them, because they have achieved sufficient distance from those charges. Thus, EMR is sometimes referred to as the far field. In this language, the near field refers to EM fields near the charges and current that directly produced them, specifically electromagnetic induction and electrostatic induction phenomena[3]. The behaviour of the electromagnetic field can be divided into four different parts of a loop[7]:

i. the electric and magnetic fields are generated by moving electric charges,
ii. the electric and magnetic fields interact with each other,
iii. the electric and magnetic fields produce forces on electric charges and
iv. the electric charges move in space.

2.1.4 Principle of Electromagnetic Interference

Electromagnetic interference, or EMI, disrupts devices' sensitive internal mechanisms and prevents them from functioning properly. Three main causes of electromagnetic interference are;

1. **Natural EMI**: Natural phenomena around us can emit EMI in several ways. Precipitation such as a rainstorm or snowstorm carries electrical static. When vehicles and other electronics encounter this, they build up a charge and emit EMI. Beyond our world, stars and other nearby celestial bodies also emit natural EMI. Significant levels of solar radiation strike occasionally, while larger planets such as Jupiter emit appreciable EMI when they approach Earth. Many modern devices maintain their functionality when natural EMI is high, but this does impair older devices somewhat. Overall, engineers don't implement device shielding to mitigate natural EMI because it isn't a significant threat[6].

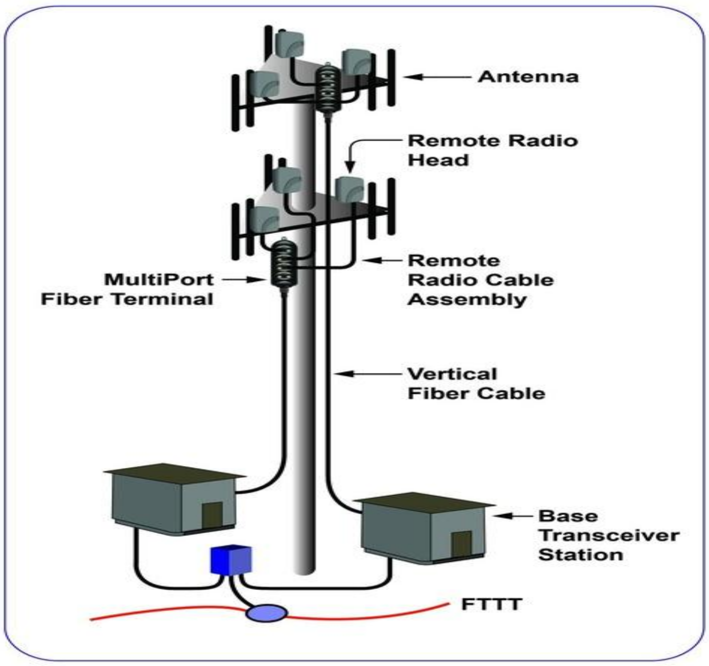
Human-Made EMI: The second type of EMI is human-made in the sense that manufactured devices and large-scale electrical systems emit interference. This encompasses every electronic assembly, from power lines to handheld devices. Any time these electronic assembly signals meet each other at the same frequency, they disrupt each other, depending on their relative strength. This is the major form of electromagnetic interference that shielding techniques such as vacuum metalizing limit. Because human-made EMI poses such a threat, some militaries intentionally weaponized it to inhibit enemy electronics[9].

Inherent EMI: The last of the three main causes of electromagnetic interference is inherent EMI. Inherent EMI is more difficult to remedy because it originates from the device itself. Essentially, devices' internal electrical systems interact with other internal features, even within a shield or conductive coating[9].

2.1.5 Basics of Cell Towers and Other Radio-Frequency Sources

Cell towers are considered low-power installations when compared to many other commercial uses of radiofrequency energy. Wireless transmission for radio, television (TV), satellite communications, police and military radar, federal homeland security systems, emergency response networks, and many other applications all emit Radio-Frequency Radiation RFR, sometimes at millions of watts of Effective Radiated Power (ERP). Cellular facilities, by contrast, use a few hundred watts of ERP per channel, depending on the use being called for at any given time and the number of service providers co-located at any given tower. No matter what the use, once emitted, travels through space at the speed of light and oscillates during propagation. The number of times the wave oscillates in one second determines its frequency[2]. Typical structural components of cell towers are shown in Fig. 2.2.

There is little difference between cell phones and the domestic cordless phones used today. Both use similar frequencies and involve a transmitter placed against the head. But the newer digitally enhanced cordless technology (DECT) cordless domestic phones transmit a constant signal even when the phone is not in use, unlike the older domestic cordless phones. But some DECT brands are available that stop transmission if the mobile units are placed in their docking station[3].



Cell phone tower (right) and combination cell phone and microwave tower (left).

Figure 2.2: Typical Structural Components of Cell Towers
Source: https://www.google.com/imgres

2.1.5.1 Specific Absorption Rate of Radiofrequency Radiation From Cell Tower

Specific Absorption Rate (SAR) is the term used to describe the absorption of radiofrequency radiation. SAR is the rate of energy that is actually absorbed by a unit of tissue and is generally expressed in watts per kilogram (W/kg) of tissue. The SAR measurements are averaged either over the whole body, or over a small volume of tissue, typically between 1 and 10 g of tissue. The SAR is used to quantify energy absorption to fields typically between 100 kHz and 10 GHz and encompasses RFR from devices such as cellular phones, MRI (magnetic resonance imaging) and other radiofrequency (RF) sources[3].

The Absorption of radio frequency radiation RFR depends on many factors including the transmission frequency and the power density, one's distance from the radiating source, and one's orientation toward the radiation of the system. Other factors include the size, shape, mineral and water content of an organism. Children absorb energy differently than adults because of differences in their anatomies and tissue composition. The bodies of children are developing, thus, children may be more susceptible to damage from cell phone radiation. For instance, radiation from a cell phone penetrates deeper into the head of children[3] and certain tissues of a child's head, e.g., the bone marrow and the eye, absorb significantly more energy than those in an adult head. The same can be presumed for proximity to towers, even though exposure will be lower from towers under most circumstances than from cell phones. This is because of the distance from the source. The transmitter is placed directly against the head during cell phone use whereas proximity to a cell tower will be an ambient exposure at a distance[3].

Specific absorption rates are more reliable determinant and index of RFR's biological effects than are power density, or the intensity of the field in space, because SARs reflect what is actually being absorbed rather than the energy in space. However, while SARs may be a more precise model, at least in theory, there were only a handful of animal studies that were used to determine the threshold values of SAR for the setting of human exposure guidelines Those values are still reflected in today's standards. It is presumed that by controlling the field strength from the transmitting source that SARs will automatically be controlled too, but this may not be true in all cases, especially with far-field exposures such as near cell or broadcast towers. Actual measurement of SARs is very difficult in real life so measurements of electric and magnetic fields are used as surrogates because they are easier to assess. In fact, it is impossible to conduct SAR measurements in living organisms so all values are inferred from dead animal measurements (thermography, calorimetry, etc.), phantom models, or computer simulation (FDTD).

In addition to average SARs, there are indications that biological effects may also depend on how energy is actually deposited in the body. Different propagation characteristics such as modulation, or different wave-forms and shapes, may have different effects on living systems. For example, the same amount of energy can be delivered to tissue continuously or in short pulses. Different biological effects may result depending on the type and duration of the exposure[3].

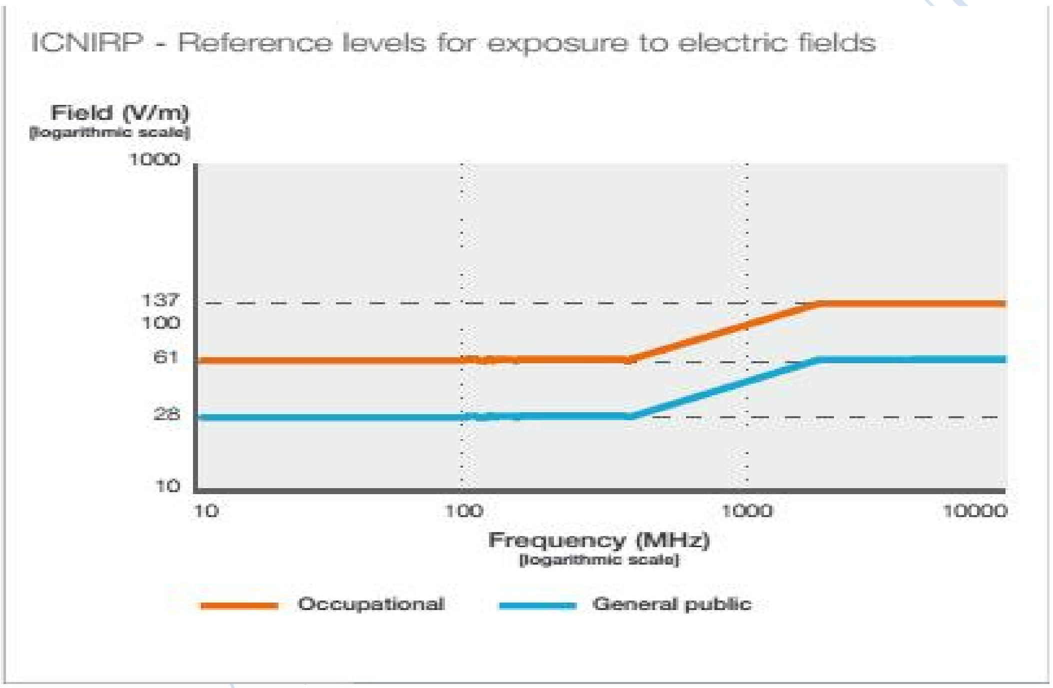
2.1.5.2 Techniques for Measurement of Electromagnetic Radiation

The use of wireless digital technology has grown rapidly during the last couple of decades[11]. To protect individuals from the potential health effects of radio waves, protection levels known as basic restrictions were recommended by the International Commission on Non-Ionizing Radiation Protection (ICNIRP)[12]. While in use, mobile and cordless phones emit radiofrequency (RF) radiation. Due to the increasing use of the wireless technology, environmental exposure to RF radiation has been increasing[13]. The ICNIRP is the non-governmental organization officially recognized by the WHO and the International Labor Organization (ILO) in the field of Non-Ionizing Radiation. These basic restrictions were established based on published biomedical studies and relative to the health effects of electromagnetic waves[13].

In the area of high frequencies, they are expressed in terms of Specific Absorption Rate (SAR) and the biological effects appear above 4 Watts per kilogram for the entire body (increase in body temperature of more than one degree) and above 100 watts per kilogram locally. The basic restrictions are set to account for uncertainties related to personal sensitivity, environmental conditions and diversity in the age and state of health of the populations concerned. The protection levels for workers were established at one tenth of these exposure levels producing an impact, and fifty times lower for the general public. For the general public, the basic restrictions thus require that the power absorbed per kilogram (SAR) be at 0.08 W/kg maximum for the entire body and 2W/kg maximum for 10 grams of tissue[13].

Given the complexity of measuring the SAR in situ, the ICNIRP (based on the studies carried out to find the relation between a plane wave power surface density and the power absorbed by an ellipsoid representing a human body) has defined reference levels deduced from basic restrictions and expressed in Volts per meter or Watts per square meter. Compliance with all the recommended reference levels will ensure that the basic restrictions are observed. These are illustrated in Figure 2.3. If the measured values are higher than the reference levels, this does not necessarily mean that the basic restrictions have been exceeded. In this case, check whether these levels of exposure are lower than the basic restrictions[13]. The electromagnetic radiation could be measured with aid of the following radiation meter, among others[11]:

1. **EME-Spy 200 Exposimeter:** The EME SPY 200 is a selective measuring device developed by MVG. It is specifically designed for electromagnetic field applications. This device is also a light-weight and portable security dosimeter. It continuously measures the amount of



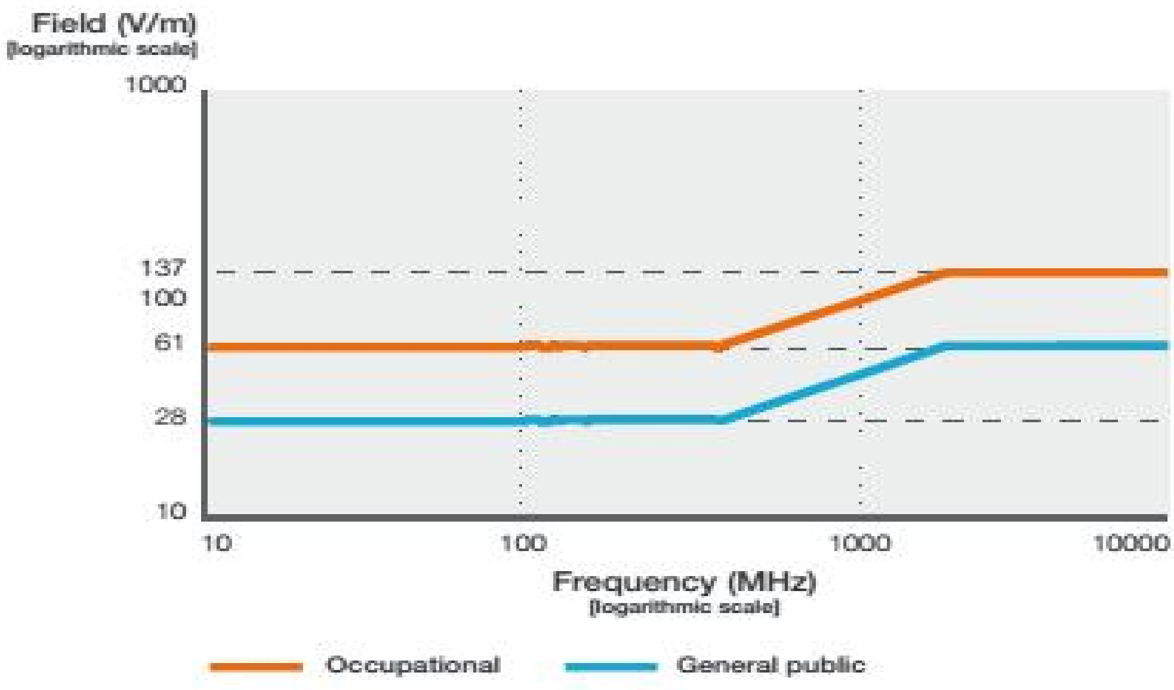


Figure 2.3: Illustration of ICNIRP Compliance Level
Source: (ICNIRP, 2021)

Table 2.2: Basic Parameters of Frequency for Exposimeters (According to Manufacturer Data)

Parameter	Type of exposimeter, manufacturer			
	ESM-140, Maschek (Germany)	EME SPY 121, Satimo (France)	EME SPY 140, Satimo (France)	EME SPY 200, Satimo (France)
Measurement range (V/m)	0.001–70	0.05–10	0.005–5	0.005–5
Frequency range (MHz)/number of subbands	(880–2500)/8	(88–2400)/12	(88–5850)/14	(88–5850)/20
Sampling rate	0.5–10 s	4–255 s	4–255 s	2-(3-, 4-)255 s(1)
Storage capacity (number of memory cells)	260000	12540	80000	80000
Dimensions (mm)	115 × 45 × 29	193 × 96 × 70	169 × 79 × 46	169 × 79 × 50
Weight (g)	87	450	400	440
Marker of events	Yes	Yes	Yes	Yes

exposure of the humans to an electromagnetic field. It comes with 20 selected frequency bands of 88 MHz up to 5850 MHz. As reference, it uses the ICNIRP level. Its features are enhanced with the real time kit[11].

2. **Broadband Probe**: Exposure to electromagnetic fields is generally measured using a probe and a receiver (Volt meter or power meter). An electromagnetic field probe is an "antenna" that has been optimized to measure exposure to electromagnetic fields. There are two types of probe for measuring exposure to electromagnetic fields: "broadband" probes and "frequency selective" probes[11].

   A broadband probe generally comprises a dipole and a diode connected directly between the two poles of the antenna. Using this type of probe, the voltage proportional to the field level is measured. The quality of this type of probe will therefore depend on its ability to provide the same voltage for the same field and regardless of the frequency (frequency is of course within the usage bandwidth) of the field to be measured. These "broadband" probes provide information on the level of exposure, but do not indicate the frequency of the field to which the user is exposed. They are mostly used in warning products (worker exposure meter) or for a quick measurement of compliance when measured levels remain low. This type of probe is defined by its isotropy, its bandwidth, its sensitivity, its measurement dynamic, its frequency flatness and its linearity[11].

3. **Frequency and Amplitude Based Measuring Probe:** The second type of probe, depending on the receiver topology used with it, provides information regarding the frequency and the amplitude of the measured field, as well as information on the level. They are incorporated into more refined compliance or information measuring products. They are defined by their

isotropy, their bandwidth, and their antenna gain or factor: the dynamic, sensitivity and linearity in this case are dependent on the receiver topology used with a given probe.

i. Isotropy: The isotropy characterizes the ability of the field measuring probe to always provide the same response to a given field level, regardless of the direction of arrival of this field or its polarizations. It is a parameter required by most of the current measurement standards. There is no single naturally isotropic antenna: for electromagnetic field probes, this isotropy is thus obtained by combining the radiation pattern of three elementary antennae (dipole or monopole) appropriately placed with respect to each other[11].

ii. Bandwidth: The performances of an electromagnetic field measurement probe vary according to the frequency of the field to be measured. They are thus defined to be used over a limited frequency range, known as the usage bandwidth.

iii. Sensitivity: The sensitivity of an electromagnetic field measurement probe or system is the minimum level of the field that can be measured with this tool. Dynamic: The dynamic of an electromagnetic field measurement probe or system is the difference between the maximum and minimum field that can be measured with this tool. It is generally expressed in dB. Frequency flatness: This parameter characterizes the quality of a broadband probe. It represents the variations of the measured E-field at a fixed frequency, when the level of the E-field is varied over the dynamic range of the probe[13].

iv. Linearity: This parameter characterizes the quality of a broadband probe. It represents the variations in the levels measured, with fixed frequency and making the level of the field measured over the probe's measuring range vary.

v. Antenna Gain and/or Factor: An antenna gain (respectively of an electromagnetic field measuring probe) characterizes its ability to emit (respectively receive) in a specified direction. It is generally expressed in dBi, taking as a reference an isotropic antenna, meaning a fictitious antenna that radiates uniformly in all directions. The gain of this antenna is thus 1, or 0 dBi (dBi for decibel-isotropic). The role of an electromagnetic field probe is to transform the

vi. recieved electromagnetic field level into RF power. The antenna factor is defined as the ratio of the electromagnetic field captured by this antenna to the voltage measured at the antenna terminals[13].

$$AF = \frac{E}{V_r} \quad 2.1$$

The antenna factor (expressed in dB) is linked to its gain by the following equation:

$$AF = 20 \log(F) - G - 29.78 \quad 2.2$$

In this equation, F is the frequency in MHz, and G is the gain in dBi. The power received by an antenna capturing an electromagnetic field can easily be found using the following formula:

$$P_r = 20 * \log(E) - AF + 13 \quad 2.3$$

In this equation, P_r is expressed in dBm, E in V/m and the antenna factor in dB[13].

2.1.6 Basic Architectural Structure of Aircraft

An aircraft is a device that is used for, or is intended to be used for, flight in the air. Major categories of aircraft are airplane, rotorcraft, glider, and lighter-than-air vehicles. Each of these may be divided further by major distinguishing features of the aircraft, such as airships and balloons. Both are lighter-than-air aircraft but have differentiating features and are operated differently. Aircraft structural members are designed to carry a load or to resist stress. In designing an aircraft, every square inch of wing and fuselage, every rib, spar, and even each metal fitting must be considered in relation to the physical characteristics of the material of which it is made. Every part of the aircraft must be planned to carry the load to be imposed upon it. The determination of such loads is called stress analysis[14].

2.1.6.1 Aircraft Construction Materials

i. Wood used in the Aircraft

Wood was among the first materials used to construct aircraft. Most of the airplanes built during World War I (WWI) were constructed of wood frames with fabric coverings. Wood was the material of choice for aircraft construction into the 1930s. Part of the reason was the slow development of strong, lightweight, metal aircraft structures and the lack of suitable corrosion-resistant materials for all-metal aircraft. Of all the requirements of wood in aircraft , the procurement of suitable, clear, straight grained lumber presents the, most important problem, and the suitability of species will be discussed primarily from this standpoint.

2.1.6.2 Aircraft Flight Control Systems

A properly designed airplane is stable and easily controlled during normal maneuvering, thus, an aircraft flight control systems consist of primary and secondary systems. The ailerons, elevator (or stabiliser), and rudder constitute the primary control system and are required to control an aircraft safely during flight. Wing flaps, leading edge devices, spoilers, and trim systems constitute the secondary control system and improve the performance characteristics of the airplane or relieve the pilot of excessive control forces. Aircraft control systems are carefully designed to provide adequate responsiveness to control inputs while allowing a natural feel. At low airspeeds, the controls usually feel soft and sluggish, and the aircraft responds slowly to control applications[14].

At higher airspeeds, the controls become increasingly firm and aircraft response is more rapid. Movement of any of the three primary flight control surfaces (ailerons, elevator or stabiliser, or rudder), changes the airflow and pressure distribution over and around the airfoil. These hanges affect the lift and drag produced by the airfoil/control surface combination, and allows a pilot to control the aircraft about its three axes of rotation. Design fwatures limit the amount of deflection of flight control surfaces. For example, control-stop mechanisms may be incorporated into the flight control linkages, or movement of the control column and/or rudder pedals may be

limited. The purpose of these design limits is to prevent the pilot from inadvertently over controlling and over stressing the aircraft during normal maneuvers[14]. This is depicted in Figure 2.2(a).

Other major components are:

v. **Ailerons**: Ailerons control roll about the longitudinal axis. The ailerons are attached to the outboard trailing edge of each wing and move in the opposite direction from each other. Ailerons are connected by cables, bell cranks, pulleys and/or push-pull tubes to a control wheel or control stick. Moving the control wheel or control stick to the right causes the right aileron to deflect upward and the left aileron to deflect downward. The upward deflection of the right aileron decreases the camber resulting in decreased lift on the right wing. The corresponding downward deflection of the left aileron increases the camber resulting in increased lift on the left wing. Thus, the increased lift on the left wing and the decreased lift on the right wing cause the airplane to roll to the right.

vi. **Adverse Yaw**: Since the downward deflected aileron produces more lift as evidenced by the wing raising, it also produces more drag. This added drag causes the wing to slow down slightly. This results in the aircraft yawing toward the wing which had experienced an increase in lift (and drag). From the pilot's perspective, the yaw is opposite the direction of the bank. The adverse yaw is a result of differential drag and the slight difference in the velocity of the left and right wings [Illustrated in Figure 2.4 (c)].

Adverse yaw becomes more pronounced at low airspeeds. At these slower airspeeds aerodynamic pressure on control surfaces are low and larger controls inputs are required to effectively maneuver the airplane. As a result, the increase in aileron deflection causes an increase in adverse yaw. The yaw is especially evident in aircraft with long wing spans. Application of rudder is used to counteract adverse yaw. The amount of rudder control required is greatest at low airspeeds, high angles of attack, and with large aileron deflect ions.

Like all control surfaces at lower airspeeds, the vertical stabilizer/rudder becomes less effective, and magnifies the control problems associated with adverse yaw.

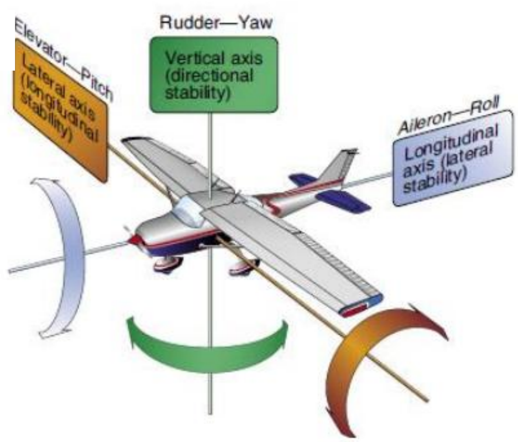
vii. **Differential Ailerons:** With differential ailerons, one aileron is raised a greater distance than the other aileron is lowered for a given movement of the control wheel or control stick. This produces an increase in drag on the descending wing. The greater drag results from deflecting the up aileron on the descending wing to a greater angle than the down aileron on the rising wing. While adverse yaw is reduced, it is not eliminated completely.

viii. **Frise-Type Ailerons:** With a frise-type aileron, when pressure is applied to the control wheel or control stick, the aileron that is being raised pivots on an offset hinge. This projects the leading edge of the aileron into the airflow and creates drag. It helps equalize the drag created by the lowered aileron on the opposite wing and reduces adverse yaw. The frise-type ailero also forms a slot so air flows smoothly over the lowered aileron, making it more effective at high angles of attack. Frise-type ailerons may also be designed to function differentially. Like the differential aileron, the frise-type aileron does not eliminate adverse yaw entirely. Coordinated rudder application is still needed wherever ailerons are applied.

ix. **Elevator:** The elevator controls pitch about the lateral axis. Like the ailerons on small aircraft, the elevator is connected to the control column in the flight deck by a series of mechanical linkages. Aft movement of the control column deflects the trailing edge of the elevator surface up. This is usually referred to as up "elevator." The up-elevator position decreases the camber of the elevator and creates a downward aerodynamic force, which is greater than the normal tail-down force that exists in straightand-level flight. The overall effect causes the tail of the aircraft to move down and the nose to pitch up (Shown in Fig. 2.4a).

The pitching moment occurs about the centre of gravity (CG). The strength of the pitching moment is determined by the distance between the CG and the horizontal tail surface, as well as by the aerodynamic effectiveness of the horizontal tail surface. Moving the control column forward has the opposite effect.

(a)



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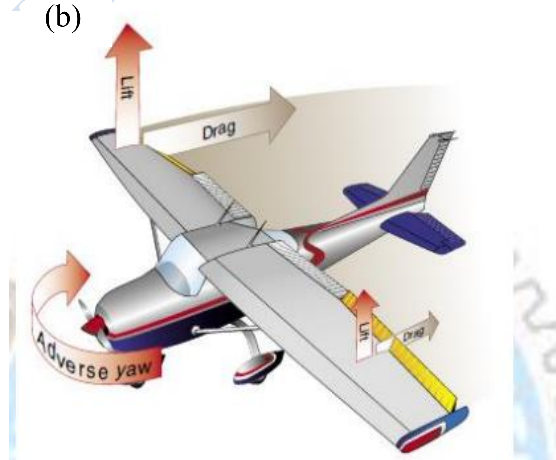

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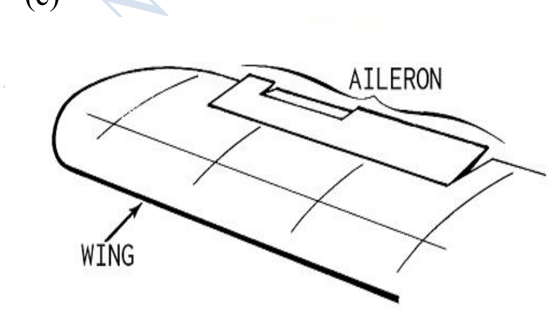
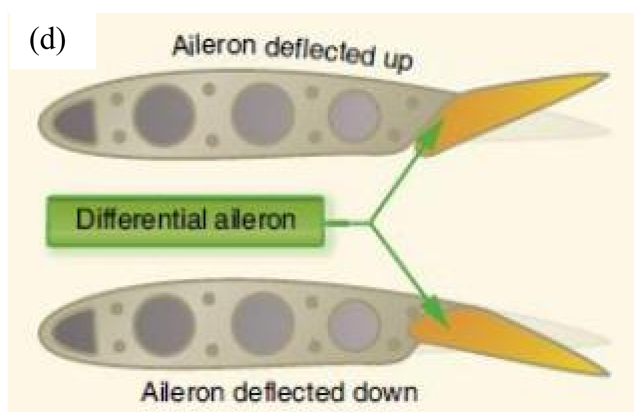


Aileron

(d)



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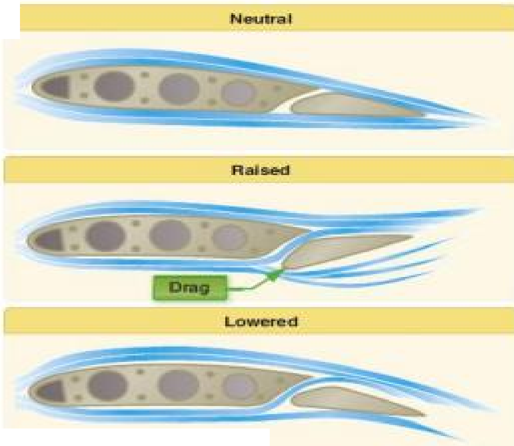


Frise-type ailerons

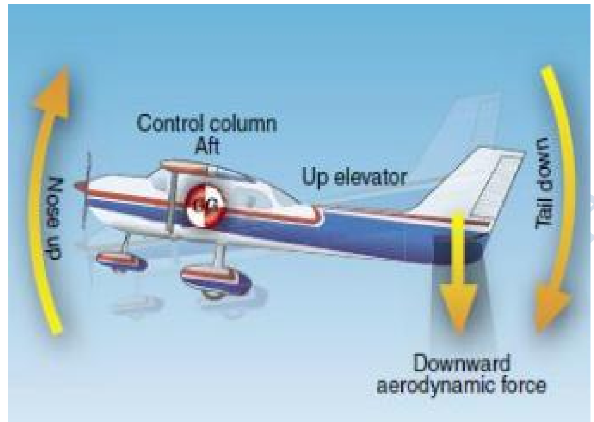


Figure 2.4: Airplane Controls, Movement, Axes of Rotation, and Type of Stability[14]

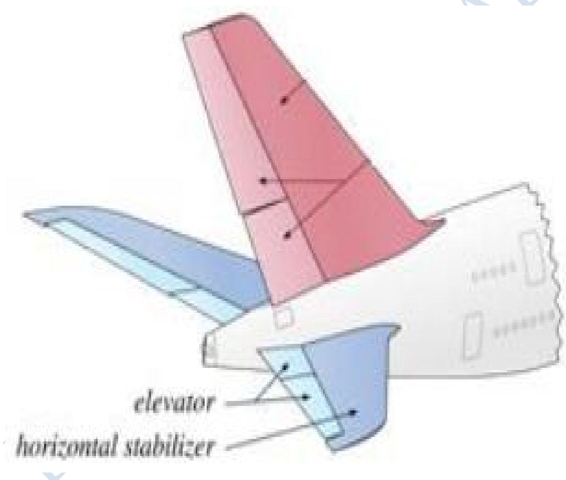
In this case, elevator camber increases, creating more lift (less tail-down force) on the horizontal stabilizer/elevator. This moves the tail upward and pitches the nose down. Again, the pitching moment occurs about the CG. As mentioned earlier in the coverage on stability, power, thrust line, and the position of the horizontal tail surfaces on the empennage are factors in elevator effectiveness controlling pitch. For example, the horizontal tail surfaces may be attached near the lower part of the vertical stabilizer, at the midpoint, or at the high point, as in the T -tail design

x. **T-Tail:** In a T-tail configuration, the elevator is above most of the effects of downwash from the propeller as well as airflow around the fuselage and/or wings during normal flight conditions. Operation of the elevators in this undisturbed air allows control movements that are consistent throughout most flight regimes. T-tail designs have become popular on many light and large aircraft, especially those with aft fuselage-mounted engines because the T-tail

xi. configuration removes the tail from the exhaust blast of the engines (Illustrated in Fig. 2.5).

xii. Seaplanes and amphibians often have T-tails in order to keep the horizontal surfaces as far from the water as possible. An additional benefit is reduced vibration and noise inside the aircraft. At slow speeds, the elevator on a T-tail aircraft must be moved through a larger number of degrees of travel to raise the nose a given amount than on a conventional-tail aircraft. This is because the conventional-tail aircraft has the downwash from the propeller pushing down on the tail to assist in raising the nose. Since controls on aircraft are rigged so that increasing control forces are required for increased control travel, the forces required to raise the nose of aT-tail aircraft are greater than those for a conventional-tail aircraft. Longitudinal stability of a trimmed aircraft is the same for both types of configuration, but the pilot must be aware that the required control forces are greater at slow speeds during takeoffs, landings, or stalls than for similar size aircraft equipped with conventional tails.

(a)



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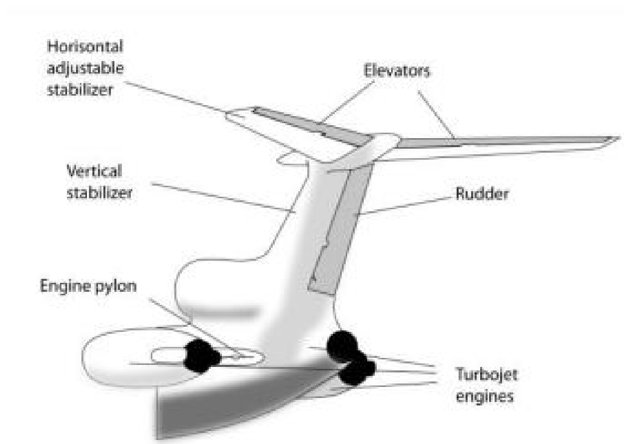
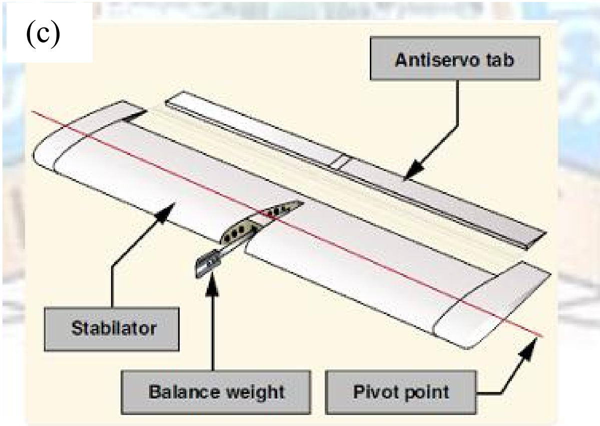




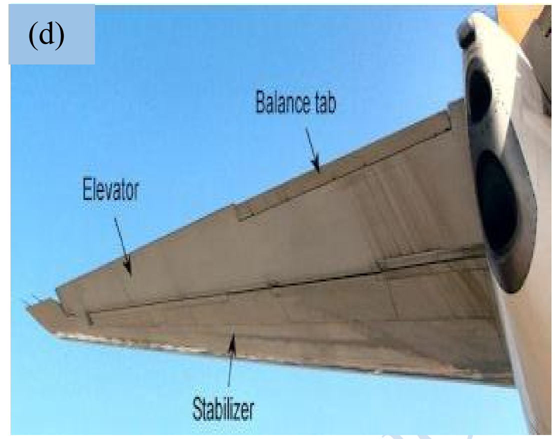


Figure 2.5: Airplane With (a) Elevator; (b and c) a T-Tail Design at a High Angle of Attack

T-tail airplanes also require additional design considerations to counter the problem of flutter. Since the weight of the horizontal surfaces is at the top of the vertical stabilizer, the moment arm created causes high loads on the vertical stabilizer which can result in flutter. Engineers must compensate for this by increasing the design stiffness of the vertical stabilizer, usually resulting in a weight penalty over conventional tail designs. When flying at a very high AOA with a low airspeed and an aft CG, the T-tail aircraft may be susceptible to a deep stall. In a deep stall, the airflow over the horizontal tail is blanketed by the disturbed airflow from the wings and fuselage. In these circumstances, elevator or stabilizer control could be diminished, making it difficult to recover from the stall. It should be noted that an aft CG is often a contributing factor in these incidents, since similar recovery problems are also found with conventional tail aircraft with an aft CG[14].

xiii. **Stabilizer:** A stabilizer (shown in Fig. 2.4) is essentially a one-piece horizontal stabilizer that pivots from a central hinge point. When the control column is pulled back, it raises the stabilizer's trailing edge, pulling the airplane's nose up. Pushing the control column forward lowers the trailing edge of the stabilizer and pitches the nose of the airplane down. Because stabilizers pivot around a central hinge point, they are extremely sensitive to control inputs and aerodynamic loads. Anti-servo tabs are incorporated on the trailing edge to decrease sensitivity. They deflect in the same direction as the stabilizer. These results in an increase in the force required to move the stabilizer, thus making it less prone to pilot -induced over controlling. In addition, a balance weight is usually incorporated in front of the main spar. The balance weight may project into the empennage or may be incorporated on the forward portion of the stabilizer tips [14].

Tables 2.3 (a): Secondary Control Mechanisms and their Respective Functions

Secondary/Auxiliary Flight Control Surfaces

Name	Location	Function
Flaps	Inboard trailing edge of wings	Extend the camber of the wing for greater lift and slower flight. Allows control at low speeds for short field takeoffs and landings
Trim Tabs	Trailing edge of primary flight control surfaces	Reduces the force needed to move a primary control surfaces
Balance Tabs	Trailing edge of primary flight control surface	Reduces the force needed to move a primary control surfaces
Anti-Balance Tabs	Trailing edge of primary flight control surface	Increases feel and effectiveness of primary control surface
Servo Tabs	Trailing edge of primary flight control surface	Assists or provides the force for moving a primary flight control
Spoilers	Upper and /or trailing edge of wings	Decreases (spoil) lift. Can augment aileron function
Slats	Mid to outboard leading edge of wings	Extend the camber of the wing for greater lift and slower flight. Allow control at low speed for short field takeoffs and landing
Slots	Outer leading edge of wings forward of aileron	Direct air over super surface of wings during high angle of attack. Lower stall speed and provides control during slow flight
Leading Edge Flap	Inboard leading edge of wings	Extend the cambers of the wings for greater lift and slower flight. Allow control at low speeds for short field takeoffs and landings

Tables 2.3(b): Flight Control Mechanism and the Effect
Secondary/Auxiliary Flight Control Surfaces

Name	Location	Activation	Effect
Trim	Opposite	Set by pilot from cockpit. Uses independent linkage	Statically balance the aircraft in flight. Allows "hands off" maintenance of flight condition
Balance	Opposite	Moves when pilot moves control surface. Coupled to control surface linkage	Aids pilot in overcoming the force needed to move the control surface
Servo	Opposite	Directly linked to flight control input device. Can be primary or backup means of control	Aerodynamically position control surfaces that requires too much force to move manually
Anti-Balance or Anti Servo	Same	Directly linked to flight control input device	Increases force needed by pilot to change flight control position. De-sensitizes flight control
Spring	Opposite	Located in line of direct linkage to servo tab. Springs assist when control forces becomes too high in high speed flight	Enables moving control surface when forces are high. Inactive during slow flight

2.1.7 Layers of Earth's Atmosphere

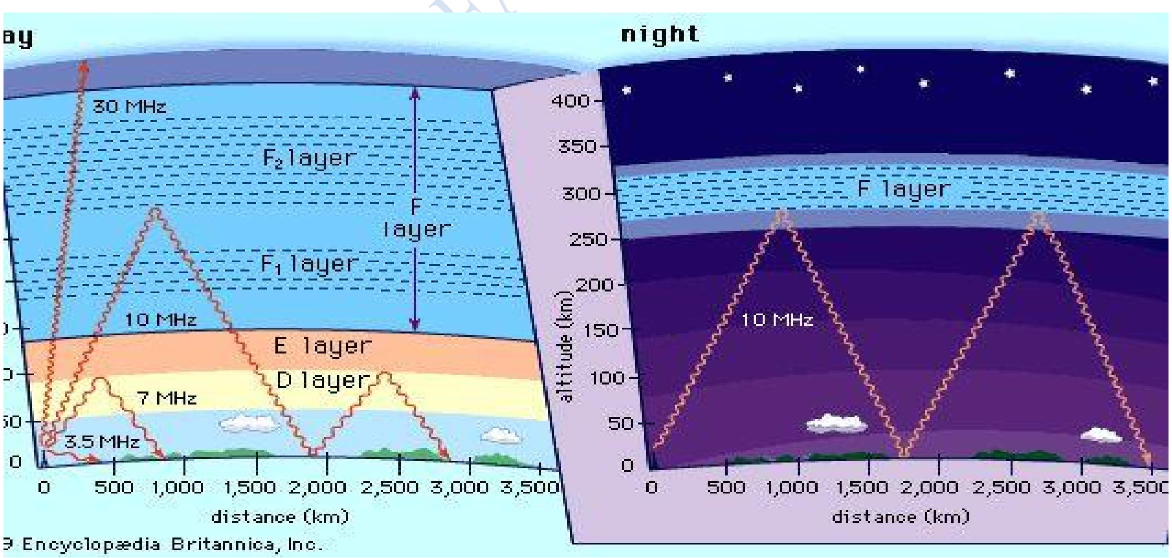
Earth's atmosphere has a series of layers, each with its own specific traits. Moving upward from ground level, these layers are named the troposphere, stratosphere, mesosphere, thermosphere and exosphere. The exosphere gradually fades away into the realm of interplanetary space.

1. **Troposphere:** The troposphere is the lowest layer of our atmosphere. Starting at ground level, it extends upward to about 10 km (6.2 miles or about 33,000 feet) above sea level. We humans live in the troposphere, and nearly all weather occurs in this lowest layer. Most clouds appear here, mainly because 99% of the water vapor in the atmosphere is found in the troposphere. Air pressure drops, and temperatures get colder, as you climb higher in the troposphere.

2. **Stratosphere:** The next layer up is called the stratosphere. The stratosphere extends from the top of the troposphere to about 50 km (31 miles) above the ground. The infamous ozone layer is found within the stratosphere. Ozone molecules in this layer absorb high-energy ultraviolet (UV) light from the Sun, converting the UV energy into heat. Unlike the troposphere, the stratosphere actually gets warmer the higher one goes. That trend of rising temperatures with altitude means that air in the stratosphere lacks the turbulence and updrafts of the troposphere beneath. Commercial passenger jets fly in the lower stratosphere, partly because this less-turbulent layer provides a smoother ride. The jet stream flows near the border between the troposphere and the stratosphere.

3. **Mesosphere:** Above the stratosphere is the mesosphere. It extends upward to a height of about 85 km (53 miles) above our planet. Most meteors burn up in the mesosphere. Unlike the stratosphere, temperatures once again grow colder as you rise up through the mesosphere. The coldest temperatures Earth's atmosphere, about -90° C (-130° F), are found near the top of this

(a)



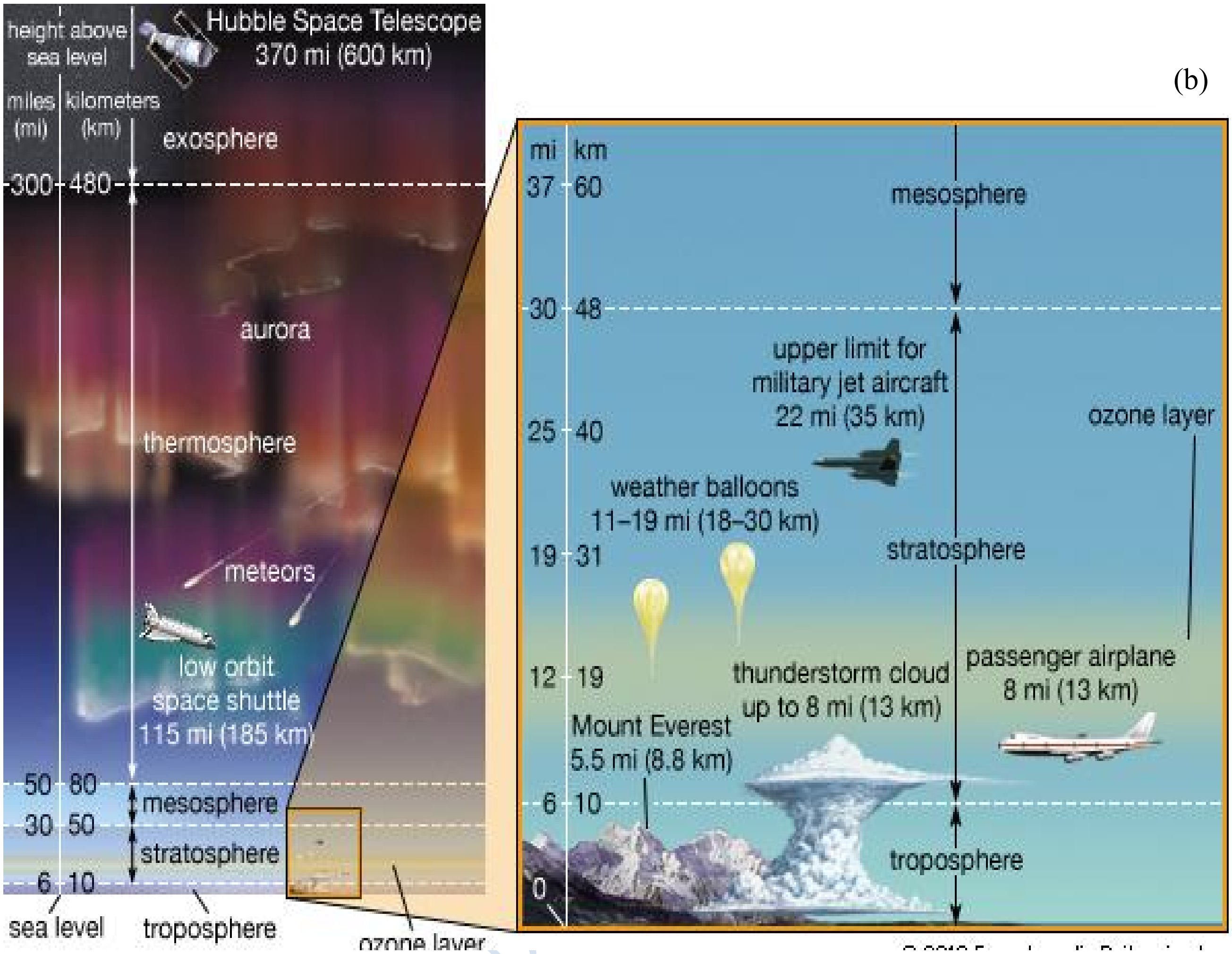


Figure 2.6: Atmospheric Layers
Source: (http://www.weather.gov.sg/learn_atmosphere)

layer. The air in the mesosphere is far too thin to breathe; air pressure at the bottom of the layer is well below 1% of the pressure at sea level, and continues dropping as you go higher.

Temperatures in the mesosphere decrease with altitude. Because there are few gas molecules in the mesosphere to absorb the Sun's radiation, the heat source is the stratosphere below. The mesosphere is extremely cold, especially at its top, about −90 degrees C (−130 degrees F). The air in the mesosphere has extremely low density: 99.9 percent of the mass of the atmosphere is below the mesosphere. As a result, air pressure is very low. A person traveling through the mesosphere would experience severe burns from ultraviolet light since the ozone layer which provides UV protection is in the stratosphere below. There would be almost no oxygen for breathing. Stranger yet, an unprotected traveler's blood would boil at normal body temperature because the pressure is so low.

4.**Thermosphere**: The layer of very rare air above the mesosphere is called the thermosphere. High-energy X-rays and UV radiation from the Sun are absorbed in the thermosphere, raising its temperature to hundreds or at times thousands of degrees. However, the air in this layer is so thin that it would feel freezing cold to us! In many ways, the thermosphere is more like outer space than a part of the atmosphere. Many satellites actually orbit Earth within the thermosphere. Variations in the amount of energy coming from the Sun exert a powerful influence on both the height of the top of this layer and the temperature within it. Because of this, the top of the thermosphere can be found anywhere between 500 and 1,000 km (311 to 621 miles) above the ground. Temperatures in the upper thermosphere can range from about 500° C (932° F) to 2,000° C (3,632° F) or higher. The aurora, the Northern Lights and Southern Lights, occur in the thermosphere.

5. **Exosphere**: Although some experts consider the thermosphere to be the uppermost layer of our atmosphere, others consider the exosphere to be the actual "final frontier" of Earth's gaseous envelope. As you might imagine, the "air" in the exosphere is very, very, very thin, making this layer even more space-like than the thermosphere. In fact, the air in the exosphere is constantly - though very gradually - "leaking" out of Earth's atmosphere into outer space. There is no clear-cut upper boundary where the exosphere finally fades away into space. Different definitions place the top of the exosphere somewhere between 100,000 km (62,000 miles) and 190,000 km (120,000 miles) above the surface of Earth. The latter value is about halfway to the Moon.

6. **Ionosphere**: The ionosphere is not a distinct layer like the others mentioned above. Instead, the ionosphere is a series of regions in parts of the mesosphere and thermosphere where high-energy

radiation from the Sun has knocked electrons loose from their parent atoms and molecules. The electrically charged atoms and molecules that are formed in this way are called ions, giving the ionosphere its name and endowing this region with some special properties[25].

The ionosphere is the area that is traditionally thought of as providing the means by which long distance communications can be made. It has a major effect on what are normally thought of as the short wave bands, providing a means by which signals appear to be reflected back to earth from layers high above the ground. The ionosphere has a high level of free electrons and ions - hence the name ionosphere. It is found that the level of electrons sharply increases at altitudes of around 30 km, but it is not until altitudes of around 60km are reached that the free electrons are sufficiently dense to significantly affect radio signals. The ionization occurs as a result of radiation, mainly from the sun, striking molecules of air with sufficient energy to release electrons and leave positive ions.

Obviously when ions and free electrons meet, then they are likely to recombine, so a state of dynamic equilibrium is set up, but the higher the level of radiation, the more electrons will be freed.

Much of the ionization is caused by ultraviolet light. As it reaches the higher reaches of the atmosphere it will be at its strongest, but as it hits molecules in their upper reaches where the air is very thin, it will ionise much of the gas. In doing this, the intensity of the radiation is reduced. At the lower levels of the ionosphere, the intensity of the ultraviolet light his much reduced and more penetrating radiation including x-rays and cosmic rays gives rise to much of the ionization. As a result of many factors it is found that the level of free electrons varies over the ionosphere and there are areas that affect radio signals more than others. These are often referred to as layers, but are possibly more correctly thought of a regions as they are quite indistinct in many respects. These layers are given designations D, E, and F1 and F2.[24]

2.1.7.1 Description of Ionospheric Regions

The ionospheric regions are the D region, E region and F region.

i. **D Region:** The D layer or D region is the lowest of the regions that affects radio signals. It exists at altitudes between about 60 and 90 km. It is present during the day when radiation is being received from the sun, but because of the density of molecules at this altitude, free electrons and ions quickly recombine after sunset when there is no radiation to retain the ionization levels. The main effect of the D region is to attenuate signals that pass through it, although the level of attenuation decreases with increasing frequency. Accordingly, its effects are very obvious on the medium wave broadcast band - during the day when the D region is present, few signals are heard beyond that provided by ground wave coverage. At night when the region is not present, signals are reflected from higher layers and signals are heard from much further afield [24].

ii. ***E Region:*** Above the D region, the next region is the E region or E layer. This exists at an altitude of between 100 and 125 km. The main effect of this region is to reflect radio signals although they still undergo some attenuation. In view of its altitude and the density of the air, electrons and positive ions recombine relatively quickly. This means that after sunset when the source of radiation is removed, the layer reduces in strength very considerably although some residual ionisation does remain[24].

iii. ***F Region:*** The F region or F layer is higher than both the D and E regions and it the most important region for long distance HF communications. During the day it often splits into two regions known as the F_1 and F_2 regions, the F_1 layer being the lower of the two. At night these two regions merge as a result of the reduction in level of radiation to give one region called the F region. The altitudes of the F regions vary considerably. Time of day, season and the state of the sun all have major effects on the F region. Typical summer altitudes for the F_1 region may be approximately 300 km with the F_2 layer at about 400 km or even higher. Winter figures may see the

iv. altitudes reduced to about 200 km and 300 km. Night time altitudes may be around 250 to 300 km[24]. Like the D and E regions, the level of ionization for the F region falls at night, but in view of the much lower air density, the ions and electrons combine much more slowly and the F layer decays much more slowly. As a result, it is able to support radio communications at night, although changes are experienced because of the lessening of the ionization levels.

2.1.8 Remote Sensing and Geographical Information Systems' Application Softwares

Remote sensing can be broadly defined as the collection and interpretation of information about an object, area, or event without being in physical contact with the object. Aircraft and satellites are the common platforms for remote sensing of the earth and its natural resources. Aerial photography in the visible portion of the electromagnetic wavelength was the original form of remote sensing but technological developments has enabled the acquisition of information at other wavelengths including near infrared, thermal infrared and microwave. Collection of information over a large numbers of wavelength bands is referred to as multispectral or hyperspectral data. The development and deployment of manned and unmanned satellites has enhanced the collection of remotely sensed data and offers an inexpensive way to obtain information over large areas. The capacity of remote sensing to identify and monitor land surfaces and environmental conditions has expanded greatly over the last few years and remotely sensed data will be an essential tool in natural resource management[33].

Remote sensing involves the measurement of energy in many parts of the electromagnetic (EM) spectrum. The major regions of interest in satellite sensing are visible light, reflected and emitted infrared, and the microwave regions. The measurement of this radiation takes place in what are known as spectral bands. A spectral band is defined as a discrete interval of the EM spectrum. For example the wavelength range of 0.4µm to 0.5µm (µm = 10^{-6} m) is one spectral band. Satellite sensors have been designed to measure responses within particular spectral bands to enable the discrimination of the

major Earth surface materials. Scientists will choose a particular spectral band for data collection depending on what they wish to examine. The design of satellite sensors is based on the absorption characteristics of Earth surface materials across all the measurable parts in the EM spectrum[33].

In remote sensing, a detector measures the electromagnetic (EM) radiation that is reflected back from the Earth's surface materials. These measurements can help to distinguish the type of land covering. Soil, water and vegetation have clearly different patterns of reflectance and absorption over different wavelengths. The reflectance of radiation from one type of surface material, such as soil, varies over the range of wavelengths in the EM spectrum. This is known as the spectral signature of the material. All Earth surface features, including minerals, vegetation, dry soil, water, and snow, have unique spectral reflectance signatures[33].

2.1.8.1 Resolution of Satellite Imagery

Most remote sensing images are composed of a matrix of picture elements, or pixels, which are the smallest units of an image. Image pixels are normally square and represent a certain area on an image. It is important to distinguish between pixel sizeand spatial resolution - they are not interchangeable. If a sensor has a spatial resolution of 20 metres and an image from that sensor is displayed at full resolution, each pixel represents an area of 20m x 20m on the ground. In this case, the pixel size as 1shown in Fig.2.7

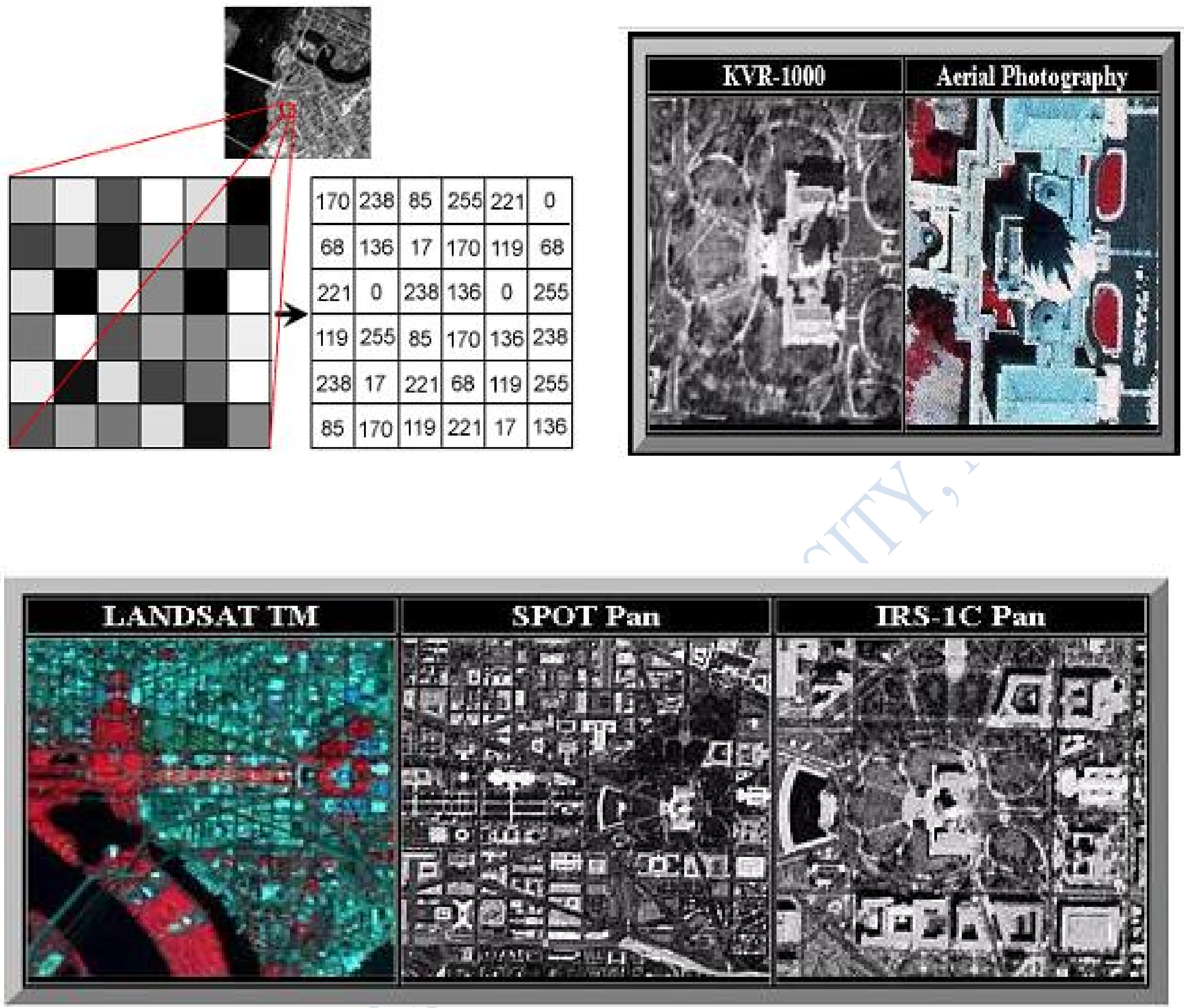


Figure 2.7: Illustration of Satellite Imageries Resolution

and resolution are the same. However, it is possible to display an image with a pixel size different than the resolution. Many posters of satellite images of the Earth have their pixels averaged to represent larger areas, although the original spatial resolution of the sensor that collected the imagery remains the same. A photograph can be represented and displayed in a digital format by subdividing the image into small equal-sized and shaped areas, called picture elements or pixels, and representing the brightness of each area with a numeric value or digital number[35].

Images where only large features are visible are said to have coarse or low resolution. In fine or high resolution images, small objects can be detected. Military sensors for example, are designed to view as much detail as possible, and therefore have very fine resolution. Commercial satellites provide imagery with resolutions varying from a few metres to several kilometres. Generally speaking, the finer the resolution, the less total ground area can be seen[35]. Basic resolutions of satellite are:

i. **Spatial Resolution:** The spatial resolution (also known as ground resolution) is the ground area imaged for the instantaneous field of view (IFOV) of the sensing device. Spatial resolution may also be described as the ground surface area that forms one pixel in the satellite image. The IFOV or ground resolution of the Landsat Thematic Mapper (TM)sensor, for example, is 30 m. The ground resolution of weather satellite sensors isoften larger than a square kilometer. There are satellites that collect data at less than one meter ground resolution but these are classified military satellites or very expensive commercial systems.

ii. **Temporal Resolution:** Temporal resolution is a measure of the repeat cycle or frequency with which a sensor revisits the same part of the Earth's surface. The frequency will vary from several times per day, for a typical weather satellite,to 8—20 times a year for a moderate ground resolution satellite, such as Landsat TM. The frequency characteristics will be determined by the design of the satellite sensor and its orbit pattern.

iii. **Spectral Resolution**: The spectral resolution of a sensor system is the number and width of spectral bands in the sensing device. The simplest form of spectral resolution is a sensor with one band only, which senses visible light. An image from this sensor would be similar in appearance to a black and white photograph from an aircraft. A sensor with three spectral bands in the visible region of the EM spectrum would collect similar information to that of the human vision system. The Landsat TM sensor has seven spectral bands located in the visible and near to mid infrared parts of the spectrum. Other typical satellites are: GOES -5 spectral bands 1 - 41 km spatial resolution Geostationary; NOAA AVHRR -5 spectral bands, 1.1 km spatial resolution and 1day

iv. repeat cycle; Landsat TM -7 spectral bands, 30m spatial resolution, 16 day repeat cycle; MODIS- Multi- spectral bands of 250-1000m spatial resolution (band dependent), 1day repeat cycle; IKONOS - 4 spectral Bands, 4m spatial resolution and 5 day repeat cycle. A panchromatic image consists of only one band. Itis usually displayed as a grey scale image, i.e. the displayed brightness of a particular pixel is proportional to the pixel digital number which is related to the intensity of solar radiation reflected by the targets in the pixel and detected by the detector. Thus, a panchromatic image may be similarly interpreted as a black-and-white aerial photograph of the area, though at a lower resolution. Also, multispectral and hyperspectral images consists of several bands of data. For visual display, each band of the image may be displayed one band at a time as a grey scale image, or in combination of three bands at a time as a color composite image. Interpretation of a multispectral color composite image will require the knowledge of the spectral reflectance signature of the targets in the scene as illustrated in Figure 2.4 (a) and (b).

2.1.8.2 Geographical Information System

A Geographic Information System (GIS)is a computer-assisted system for handling spatial information. GIS software can be considered as a collection of software programs to acquire, store, analyze, and display information. The input data can be maps, charts, spreadsheets, or pictures. The GIS software can analyze these data using image processing and statistical procedures. Data can be grouped together and displayed as overlays. Overlays could be information such as soil type, topography, crop type, crop yield, pest levels, irrigation, and management information. Figure 2.4 shows a categorized aerial photograph overlaid with soil information using GIS software.

Relationships can be examined and new data sets produced by combining a number of overlays. These data sets can be combined with models and decision support systems to construct a powerful management tool. For example, we could assess how far a field was from roads or nonagricultural crops. This information could be important in pest infestation or in planning chemical application. We could also examine crop yield relationship to soil type or other factors as show in Figure 2.4(b). A number of GIS software packages are now commercially available. Spatial data for the GIS is often collected using GPS equipment but another source of spatial information is aerial and satellite imagery[33].

2.1.8.3 Spectral Reflectance Signature

When solar radiation hits a target surface, it may be transmitted, absorbed or reflected. Different materials reflect and absorb differently at different wavelengths. The reflectance spectrum of a material is a plot of the fraction of radiation reflected as a function of the incident wavelength and serves as a unique signature for the material. In principle, a material can be identified from its spectral reflectance signature if the sensing system has sufficient spectral resolution to distinguish its spectrum from those of other materials. This premise provides the basis for multispectral remote sensing. The reflectance of clear wateris generally low. However, the reflectance is maximum at the blue end of the spectrum and decreases as wavelength increases. Hence, water appears dark bluish to the visible eye. Turbid water has some sediment suspension that increases the reflectance in the red end of the spectrum and would be brownish in appearance. The reflectance of bare soil generally depends

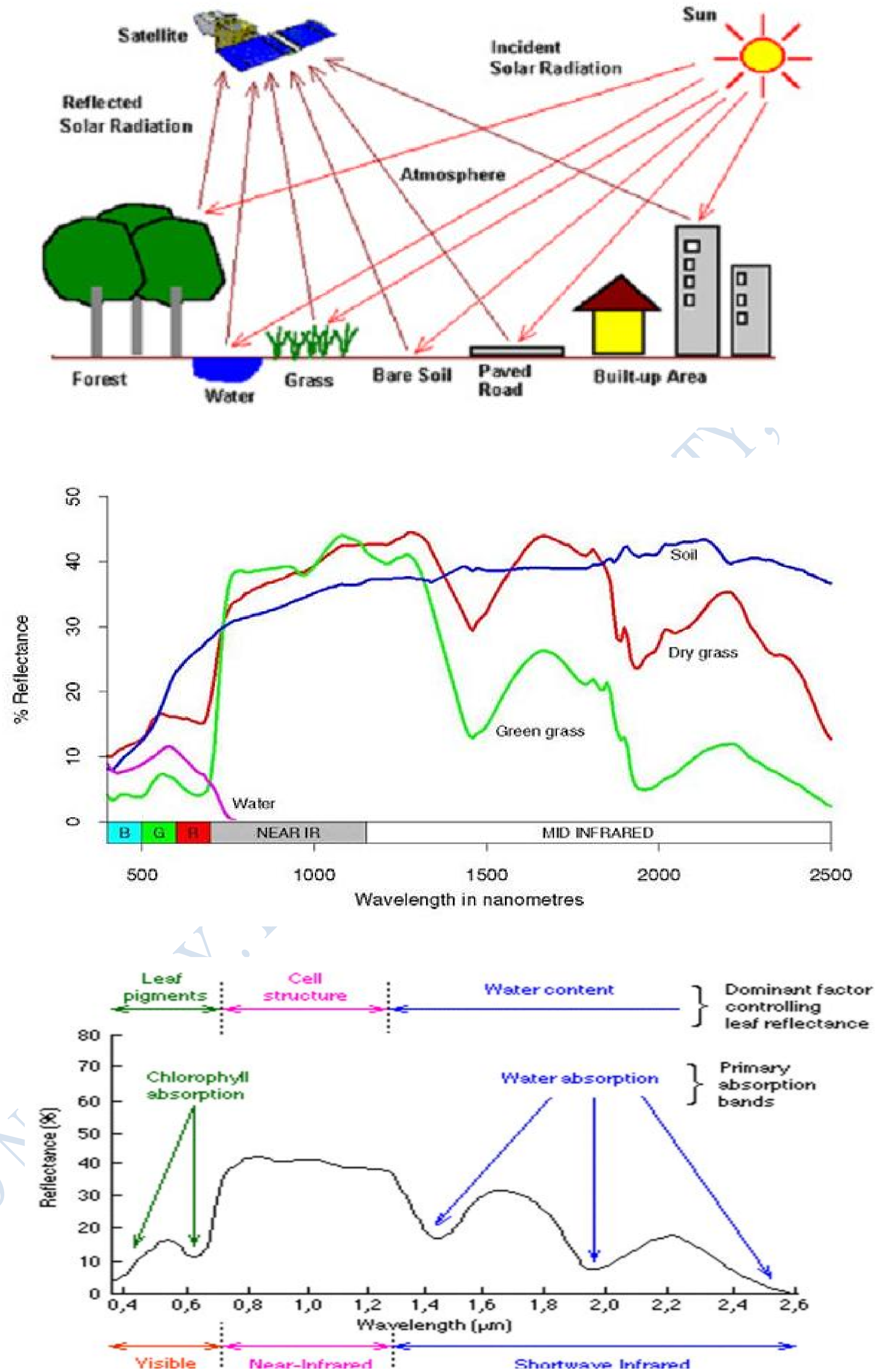


Figure 2.8: Spectral Signatures of Natural and Human-Made Materials; (a) - (c)

on its composition. In the example shown in Figure 2.8, the reflectance increases monotonically with increasing wavelength. Hence, it should appear yellowish-red to the eye.

Vegetation has a unique spectral signature that enables it to be distinguished readily from other types of land cover in an optical/near-infrared image. The reflectance is low in both the blue and red regions of the spectrum, due to absorption by chlorophyll for photosynthesis. It has a peak at the green region. In the near infrared (NIR)region, the reflectance is much higher than that in the visible band due to the cellular structure in the leaves. Hence, vegetation can be identified by the high NIR but generally low visible reflectance. This property has been used in early reconnaissance missions during war times for "camouflage detection".

The shape of the reflectance spectrum can be used for identification of vegetation type. For example, the reflectance spectra of dry grass and green grass in the previous figures can be distinguished although they exhibit the generally characteristics of high NIR but low visible reflectance. Dry grass has higher reflectance in the visible region but lower reflectance in the NIR region. For the same vegetation type, the reflectance spectrum also depends on other factors such as the leaf moisture content and health of the plants. These properties enable vegetation condition o be monitored using remotely sensed images.

2.1.8.4 Global Positioning System

The Global Positioning System (GPS) is a satellite based system that gives real time three dimensional (3D) latitude, longitude, and height information at sub-meter accuracy. The system was developed by the United States military in the late 1970's to give troops accurate and navigational information. A GPS receiver (typical types illustrated in Figure 2.9)calculates its position on earth from radio signals broadcast by satellites orbiting the earth. There are currently twenty-four GPS satellites in this system.

GPS equipment is capable of measuring a position to within centimeters but the accuracy suffers due

to

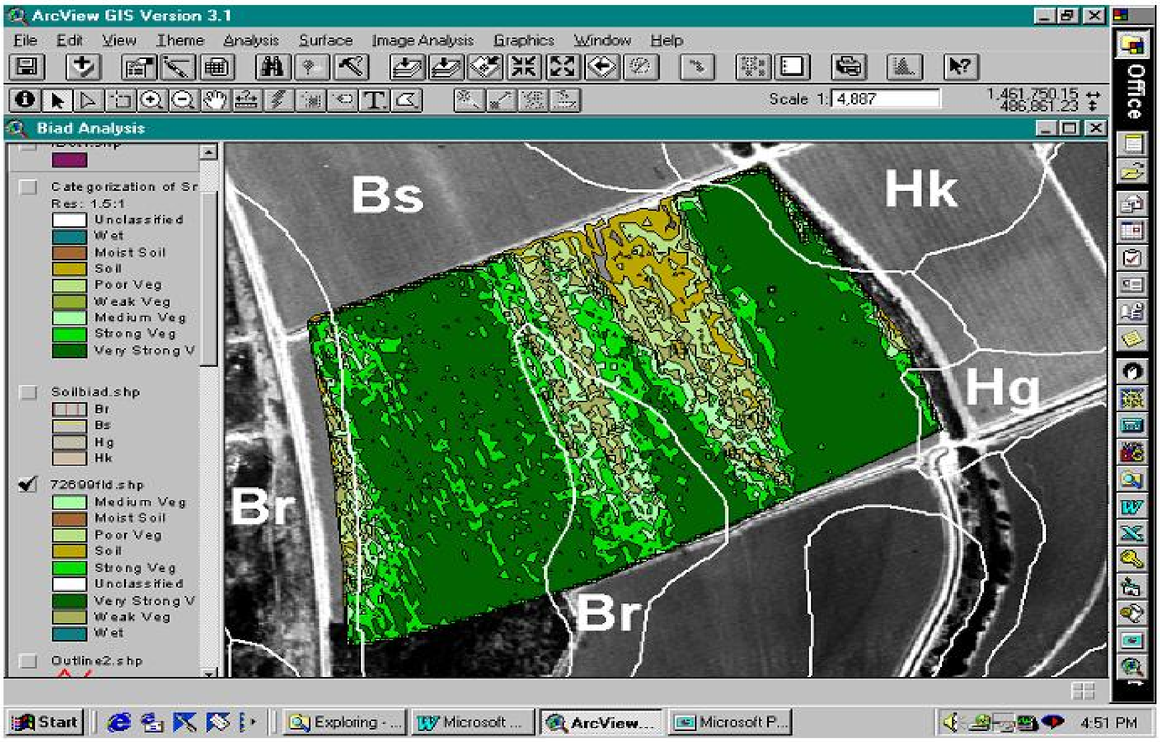


Figure 2.9 (a): A Categorized Aerial Photograph Overlaid With Soil Information Using GIS Software

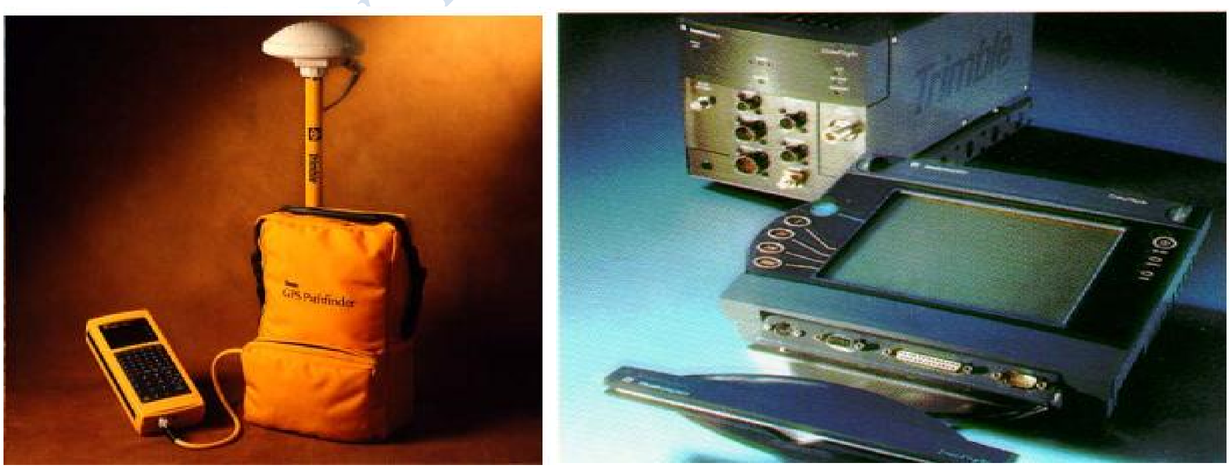


Figure 2.9(b): Examples of GPS Equipment

errors in the satellite signals. Errors in the signal can be caused by atmospheric interference, proximity of mountains, trees, or tall buildings.

The government can also introduce errors in the signal for security purposes. This intentional degradation of the satellite signals is known as selective availability. The accuracy of the position information can be improved by using differential GPS. In differential GPS, one receiver is mounted in a stationary position, usually at the farm office, while the other is on the tractor or harvesting equipment. The stationary receiver calculates the error and transmits the necessary correction to the mobile receiver.

GPS equipment suitable for precision agricultural cost several thousands dollars. Less expensive equipment is becoming available but the accuracy and capability is reduced.

2.1.8.5 Geographic Information System (GIS) Softwares

Geographic information system (GIS) software encompasses a broad range of applications, all of which involve the use of some combination of digital maps and georeferenced data. GIS software can extend the reach of businesses of any size in industries like marketing, healthcare, insurance, manufacturing, and more. Thanks to indispensable capabilities like GPS tracking, topography, historical geographical analysis, spatial data mining, and web mapping, GIS applications allow for better data visualization and pattern and trend interpretation. GIS software can be sorted into different categories. Below is a list of notable GIS software applicationscategories[34].

i. **ArcGIS:** ArcGIS from ESRI is one of the world's most famous GIS software products. Due to its power and advanced functionality, the software is often used by larger enterprises in a variety of industries, such as transportation, public utilities and construction. The ArcGIS online platform is fully cloud-based. As it's delivered as a SaaS product, it can be used at anytime and anywhere by hundreds of users in your organization. This allows users to have live access to all of the data created by the GIS mapping software. ArcGIS gives you everything you need to work with geodata to make maps, share your work with others and collaborate on projects, as well as take advantage of its powerful data analysis features to make sense of the data you've collected in the field. One of the main advantages of using ArcGIS is that the software lets you easily create your own maps.

ii. **Mapline Overview:** This GIS software is designed to build maps for the entirety of your business's operations from a single city to across the globe. Simply add or import locations from a Microsoft Excel spreadsheet to have Mapline flesh out your market, no matter its size. Build a visual representation of your company data with ease, and customize it with plenty of presentation options. Personalize each location with labels and pins for quick comprehension, or use custom images to differentiate each spot. Use colors or create heat maps to plot out each territory your company visits, and layer them to better understand your routes. Other functions include filtering visible locations and measuring distances, along with a handy route tool.

iii. **Maptitude Overview:** Maptitude is GIS software that utilizes demographic and geospatial data to help you grow your business. This user-friendly platform can be used to visualize various spreadsheets and databases with its geographic analysis tools. Maptitude allowsing of patterns and identify new business opportunities, and to see how the geographical data plays day-to-day operations. Some of the top features of Maptitude include the heat map, route planner, custom territory builder, demographic estimates, drive time calculators, route planners, and the Create-a-Map Wizard. Maptitude's powerful database capabilities can connect data to an existing map layer, pin and label any relevant data, and locate features with detailed geocoding[35].

Others GIS softwares are IDRISI Taiga 16.05, GRASS GIS originally developed by the U.S. Army Corps of Engineers;SAGA GIS – System for Automated Geoscientific Analysis- a hybrid GIS software; Quantum GIS – QGIS is an Open Source GIS that runs on Linux, Unix, Mac OS X, and

Windows; MapWindow GIS – Free, open source GIS desktop application and programming component and ILWIS – ILWIS (Integrated Land and Water Information System) integrates image, vector and thematic data[34].

2.2 Theoretical Review

The theoretical review covers the theories on the basic principles of the research subject mostly electromagnetic theorems and the related. Thus, the review of Electromagnetic Field Theory is presented among others.

2.2.1 Review of Electromagnetic Field Theory

Charge is the ultimate source of the electric field and has SI base units of coulomb (C). An important source of charge is the electron, whose charge is defined to be negative. However, the term "charge" generally refers to a large number of charge carriers of various types, and whose relative net charge may be either positive or negative. Distributions of charge may alternatively be expressed in terms of line charge density ρ_l (C/m), surface charge density ρ_s (C/m^2), or volume charge density ρ_v (C/m^3). Electric current describes the net motion of charge. Current is expressed in SI base units of amperes (A) and may alternatively be quantified in terms of surface current density J_s (A/m) or volume current density J (A/m^2).

The electric field may be interpreted in terms of energy or flux. The energy interpretation of the electric field is referred to as electric field intensity E (SI base units of N/C or V/m), and is related to the energy associated with charge and forces between charges. But, the electric potential (SI base units of V) over a path C is given by

$$V = -\int_c E \cdot dl \text{ b} \qquad 2.4$$

The principle of independence of path means thatonly the endpoints of C in Equation 1.1, and no other details of C , matter. This leads to the finding that the electrostatic field is conservative; i.e.,

$$\oint_c E \cdot dl = 0 \qquad 2.5$$

This is referred to as Kirchoff's voltage law for electrostatics. The inverse of Equation 1.1 is

$$E = -\nabla V \qquad 2.6$$

That is, the electric field intensity points in the direction in which the potential is most rapidly decreasing, and the magnitude is equal to the rate of change in that direction. The flux interpretation of the electric field is referred to as electric flux density D (SI base units of C/m^2), and quantifies the effect of charge as a flow emanating from the charge.

Gauss' law for electric fields states that the electric flux through a closed surface is equal to the enclosed charge Qencl; i.e.,

$$\oint_s D \cdot ds = Q_{encl} \qquad (2.7)$$

Within a material region, the electric flux density D is expressed as;

$$D = \epsilon E \qquad (2.8a)$$

where ϵ is the permittivity of the material. In free space, ϵ_o is equal to 8.854×10^{-12} F/m. It is often convenient to quantify the permittivity of material in terms of the unitless relative permittivity

$$\epsilon_r \triangleq \epsilon/\epsilon_o \qquad (2.8b)$$

Both E and D are useful as they lead to distinct an independent boundary conditions at the boundary between dissimilar material regions. Let us refer to these regions as Regions 1 and 2, having fields (E1, D1) and (E2, D2), respectively. Given a vector $\overline{n}$ perpendicular to the boundary and pointing into Region 1, we find;

$$\overline{n} \times [E_1 - E_2] = 0 \qquad (2.9)$$

i.e., the tangential component of the electric field is continuous across a boundary, and

$$\overline{n} \cdot [D_1 - D_2] = \rho_s \qquad (2.10)$$

i.e., any discontinuity in the normal component of the electric field must be supported by a surface charge distribution on the boundary.

Like the electric field, the magnetic field may be quantified in terms of energy or flux. The flux interpretation of the magnetic field is referred to as magnetic flux density **B** having SI base units of Wb/m^2), and quantifies the field as a flow associated with, but not emanating from, the source of the field. The magnetic flux Φ (SI base units of Wb) is this flow measured through a specified surface. Gauss' law for magnetic fields states that:

$$\oint_s B \cdot ds = 0 \qquad (2.11)$$

i.e., the magnetic flux through a closed surface is zero. Comparison to Equation 1.4 leads to the conclusion that the source of the magnetic field cannot be localized; i.e., there is no "magnetic charge" analogous to electric charge. Equation 1.9 also leads to the conclusion that magnetic field linesform closed loops.

The energy interpretation of the magnetic field is referred to as magnetic field intensity H (SI base units

of A/m), and is related to the energy associated with sources of the magnetic field. Ampere's law for magnetostatics states that;

$$\oint_s H \cdot dI = I_{encl} \qquad (2.12)$$

where I_{encl} is the current flowing past any open surface bounded by C . Within a homogeneous material region, magnetic flux density ***B*** is expressed as;

$$\boldsymbol{B} = \mu H \qquad (2.13)$$

where μ is the permeability (SI base units of H/m) of the material. In free space, μ is equal to

$$\mu_0 \triangleq 4\pi \times 10^{-7} \text{ H/m}. \qquad (2.14)$$

It is often convenient to quantify the permeability of material in terms of the unitless relative permeability $\mu_r \triangleq \mu/\mu_0$. Both **B** and **H** are useful as they lead to distinct and independent boundary

conditions at the boundaries between dissimilar material regions. Let these regions be referred to as Regions 1 and 2, having fields(B1, H1) and (B2, H2), respectively. Given a vector $\overline{n}$ perpendicular to the boundary and pointing into Region 1, the resultant field could be expressed as:

$$\overline{n} \cdot [\boldsymbol{B}_1 - \boldsymbol{B}_2] = 0 \qquad (2.15)$$

i.e., the normal component of the magnetic field is continuous across a boundary, and

$$\overline{n} \times [\boldsymbol{H}_1 - \boldsymbol{H}_2] = 0 \qquad (2.16)$$

i.e., any discontinuity in the tangential component of the magnetic field must be supported by current on the boundary[21].

2.2.2 Magnetic Force on Charged Particles

A charged particle in motion inside a magnetic field experiences a force $\boldsymbol{F}$ at right angle to its velocity, with a magnitude proportional to the charge q (C), the velocity $\boldsymbol{v}$ (m/s), and the magnetic flux density $\boldsymbol{B}$. The complete expression is given by the cross product

$$\boldsymbol{F} = q\boldsymbol{v} \times \boldsymbol{B}. \qquad (2.17)$$

The charged particle will be deflected when it passes through the lines of magnetic field,

because magnetic field created by the mobile charged particle will react with the magnetic field through which it is moving. If the field $\boldsymbol{B}$ is uniform throughout a region and the particle has an initial velocity normal to the field, the path of the particle is a circle. Equating the magnitude of the force $\boldsymbol{F}$ and centrifugal force (mv^2/r) on the particle, the radius r (m) of the particle's path is expressed as

$$r = \frac{mv}{qB}. \quad (2.18)$$

In the presence of fields $\boldsymbol{E}$ and $\boldsymbol{B}$, the force $\boldsymbol{F}$ on the charge as described by Lorentz force $[q(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B})]$, can be expressed with Newton's equation of motion as

$$\boldsymbol{F} = m\frac{d\boldsymbol{v}}{dt} = q(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B}). \quad (2.19)$$

The force $\boldsymbol{F}$ will increase the kinetic energy of the charge at a rate that is equal to the rate of work done by the Lorentz force on the charge[21].

2.2.3 Field Distances of RF Antenna and Incident Radiation

The radiation characteristics of an antenna vary with distance from the antenna. For instance, at large distances (referred to as the far-field region) some radiation characteristics are independent of distance, e.g. the gain is constant as the distance increases. On the other hand, at distances closer to the antenna (near-field region), the gain changes with distance. When two antennas are in the far-field of each other, the activation of one antenna has no effect on the performance characteristics (e.g., impedance, radiation pattern) of the other antenna. Conversely, when the antennas are in the near-field of each other, the activation of one antenna could modify the performance characteristics of the other antenna[26].

For low-gain types of antennas (monopole, dipole, whip, rubber ducky), a common minimum value for the distance to the far-field region is four wavelengths. For directive types of antennas (e.g., Yagi-Uda), the distance to the far-field region may be calculated using the following equation[26]:

$$D_{FF} = \frac{2 \cdot D_{ant}^2}{\lambda} \quad 2.20$$

where D_{FF} = distance to the far-field region (meter), D_{ant} = largest dimension of the antenna (meter)

λ = wavelength at the system's frequency (meter)

Moreover, an electromagnetic wave consists of an electric field (E-field) and a magnetic field (H-field). In general, the E-field and the H-field are perpendicular to each other and to the direction (the ray path) that the wave is traveling. The intensity of either field is referred to as field strength, where the intensity of the E-field is measured in volts per meter (V/m) and the intensity of the H-field is measured in amperes (amps) per meter (A/m). The E-field and the H-field together carry power, where

the power flow through space is called the power density, which is measured in watts per square meter (W/m^2) [26].

2.2.4 Effective Isotropic Radiated Power and Power Density of RF Antenna

Consider a transmitting source in free space, radiating a total power P_t (Watts) uniformly in all directions as shown in Figure 2.6. At a distance $R(m)$ from the hypothetical isotropic source transmitting RF power P_t (W), the flux density F crossing the surface of the sphere with radius R is given as:

$$F = \frac{P_t}{4\pi R^2} \quad (Watt/m^2) \tag{2.20}$$

But, real antenna has a gain $G(\theta)$ defined as the ratio of power per unit solid angle radiated in a direction θ to the average power radiated per unit solid angle given as:

$$G(\theta) = \frac{P(\theta)}{\frac{P_o}{4\pi}} \quad (Watt/m^2), \tag{2.21}$$

where $G(\theta) = Gain\ of\ the\ antenna\ at\ an\ angle\ \theta.$

$P(\theta) = power\ radiated\ per\ unit\ solid\ angle\ by\ the\ antenna.$

$P_o =\ total\ power\ radiated\ by\ the\ antenna.$

The reference for angle θ is the direction in which maximum power is radiated, often called ***Boresight Directivity*** of the antenna. The gain of the antenna is then the value of $G(\theta)$ at angle $\theta = 0°$. For a transmitter with output P_t watts driving a lossless antenna with Gain G_t , the flux density in the direction of the antenna's boresight at distance $R(m)$ is;

$$F = \frac{P_t G_t}{4\pi R^2} \quad (W/m^2) \qquad (2.22)$$

The product $P_t G_t$is called ***Effective Isotropically Radiated Power EIRP***.

$\therefore Effective\ Isotropically\ Radiated\ Power\ (EIRP) = P_t \cdot G_t \qquad (3a)$

If we had an ideal receiving antenna with an aperture area of A(m^2) as shown in Figure 2, we would collect power P_r given by:

$$P_r = F \times A \quad (Watts) \qquad (2.22a)$$

However, practical antenna will have losses due to absorption and reflection. This reduction in efficiency is described by using an ***Effective Aperture Area A_e*** slated as:

$$A_e = \eta_A \cdot A_r \qquad (2.22b)$$

where η_A – Antenna aperture efficiency and A_r *is Aperture Area of receiving Antenna.*

η_A accounts for all the losses between the incident wavefront and the antenna output port which include;

- Illumination efficiency related to the energy distribution produced by the feed across the aperture,
- Spillover, blockage, phase errors and diffraction effects,
- Polarization and mismatch issues (Illustrated in Figure 3)

Putting equation (1) into (4), P_r becomes;

$$P_r = \frac{P_t A}{4\pi R^2} \quad (W) \qquad (2.23)$$

Thus, the power received by real antenna with a physical receiving area A_r and effective aperture area A_e (m^2) is:

$$P_r = \frac{P_t G_t A_e}{4\pi R^2} \quad (W) \qquad (2.24)$$

where P_r is Power received by real antenna, P_t is Output power of transmitter, P_t is Output power of transmitter , G_t is Gain of Transmitter and A_e *is* Effective Aperture Area.

Note: Equation (2.24) is independent of frequency if G_t and A_e are constant within a given band; the power received by an earth station depends only on the:

- *Effective Isotropically Radiated Power EIRP* of the satellite,
- the effective *Area of the earth station antenna* and
- the distance R from the earth station antenna to the Satellite.

A fundamental relationship in antenna theory is that the gain G_t and area A_e of an antenna are related by:

$$G_r = \frac{4\pi A_e}{\lambda^2} \qquad (2.25)$$

where λ is wavelength (m) at the frequency of operation. Putting (2.24) into (2.25), we would have equation 2.26.

$$P_r = \frac{P_t G_t G_r}{(4\pi R/\lambda)^2} \quad (W) \qquad (2.26)$$

Equation (2.26) is known as ***Link Equation*** and its essential in the calculation of power received in any radio link. The term $(4\pi R/\lambda)^2$is known the *Path Loss* L_p i.e.

$$Path\ Loss\ L_p = \left[\frac{4\pi R}{\lambda}\right]^2 \qquad (2.27)$$

L_p is not a loss in the sense of power being absorbed, it accounts for the way energy spreads out as electromagnetic wave travels away from a transmitting source in three-dimensional space. Collecting the various factors, equation (2.27) can be expressed as;

$$Power\ Received\ P_r = \frac{EIRP \times Receiving\ Antenna\ Gain(G_r)}{Path\ Loss\ (L_p)} \qquad (2.28a)$$

In decibel terms, equation (10a) can be expressed as;

$$P_r = EIRP + G_r - L_p \quad (dBW) \qquad (2.28b)$$

$$where \quad EIRP = 10log_{10}(P_t G_t) \quad (dBW)$$

$$G_r = 10log_{10}(4\pi A_e/\lambda^2) \quad (dB)$$

$$L_p = 10log_{10}\{(4\pi R/\lambda)^2\} = 20log_{10}\{(4\pi R/\lambda)\} \quad (dB)$$

Equation (2.28b) represents an idealized case in which there are no additional losses in the link. To account for losses in the atmosphere due to attenuation by oxygen, water vapor and rain, losses in the antenna at each end of the link and reduction in antenna due to mis-pointing; system margin is added. Hence, equation (10b) can be expressed as:

$$P_r = EIRP + G_r - L_p - L_a - L_{ta} - L_{ra} \quad (dBW) \qquad (2.29)$$

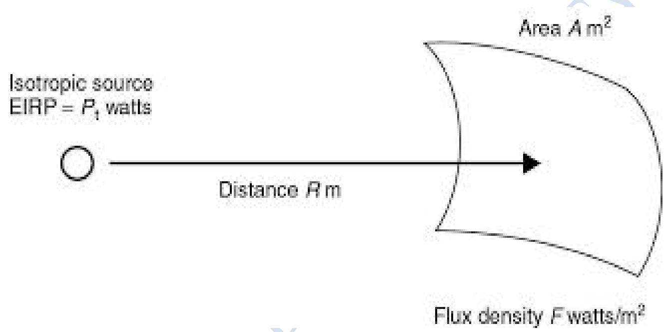


Figure 2.10 a: Flux Density Produced by an Isotropic Source[27].

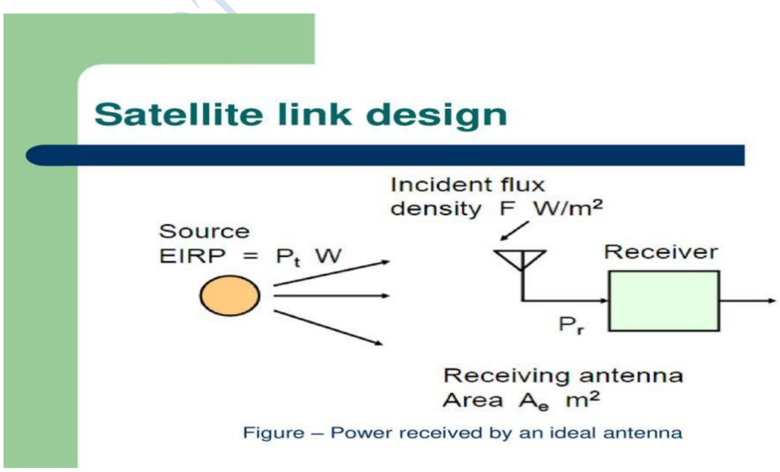


Figure 2.10 b: Power Received by an Ideal Antenna with Area A(m^2)[27].

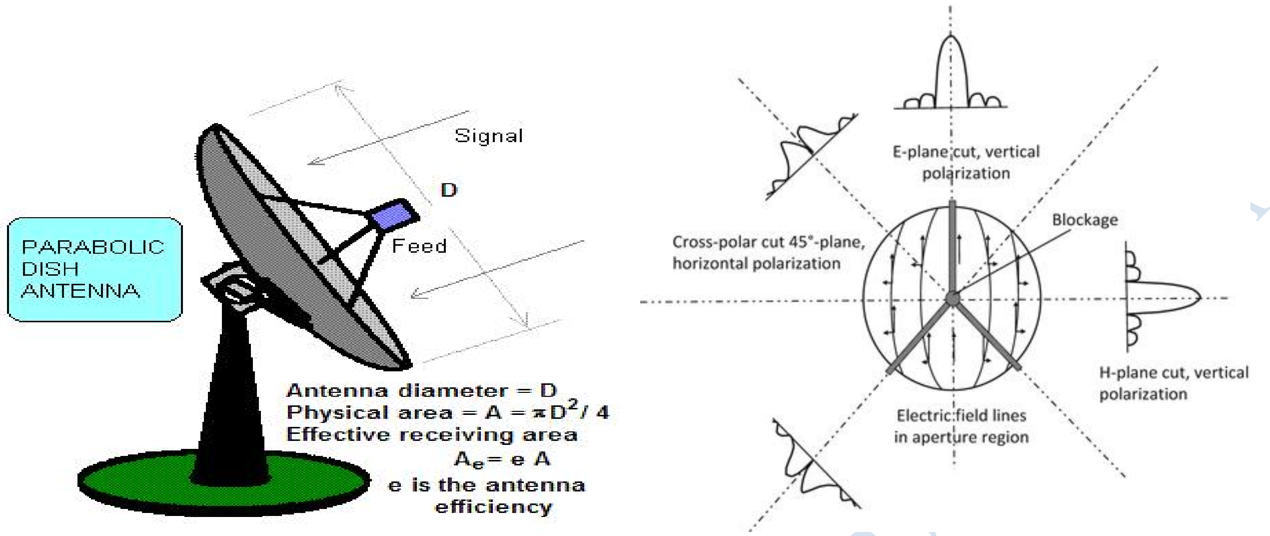


Figure 2.10 c: Illustration of Typical RF Antenna components and Polarization Waveforms[27].

where L_a = Attenuation in atmosphere.

L_{ta} = Losses associated with transmitting antenna.

L_{ra} = Losses associated with receiving antenna.

2.2.5 Electric and Magnetic Field Strengths

Given a value for the power density incident on a point, the intensity of the electric field may be computed using the following equation:

$$E = \sqrt{120\,\pi s} \qquad (2.30)$$

where

E =root-mean-square (rms) E-field strength (V/m)

s = power density (W/m^2)

120π (~377) = impedance of free space (dimensionless)

Given a value for the power density incident on the point, the intensity of the magnetic field may be computed using the following equation:

$$H = \sqrt{\frac{s}{120\,\pi}} \tag{2.31}$$

where H = root-mean-square (rms), H-field strength (A/m) and all other terms were defined previously.

In general, when two antennas are within line-of-sight of each other, and in the far-field of each other, the level of received power is related to the free-space propagation loss. This loss assumes the EM wave radiated by a transmit antenna spreads spherically. In the absence of a detailed propagation model, the free-space propagation loss may be used to provide an estimate of the loss. The free-space propagation loss along the straight-line path between two antennas may be calculated using the following equation:

$$L_{FS} = 20 \log \frac{\lambda}{4\pi D} \tag{2.32}$$

where L_{FS} = free-space propagation loss (dB), Free-space propagation losses do not include any additional diffraction and reflection losses (e.g., reflection, multipath, refraction) along the ray path, λ = wavelength at the receive frequency (m) and D = distance between antennas (m).

2.3 Empirical Review

This section appraised previous researches on encroachment of airport by radio frequency (RF) sources and other infrastructures. The empirical review to be discussed including the following research publications; electromagnetic interference with aircraft systems, effects of living near an Airport, High intensity radiated field coupling into Aircraft researched in which scientific Method of Moment (MoM) was utilized in 2014,

2.3.1 Electromagnetic Interference with Aircraft Systems

Navigation systems of aircraft are particularly vulnerable for two reasons, they have parts devised to detect and act on signals coming from `outside' and the radio-based systems are particularly susceptible to low levels of interference. Aircraft control systems are located entirely within the aircraft and are shielded from absolutely any signals not coming from one of their own devices; they are also not radio-based, but are based entirely on electrical signals conducted through wires as are most computer networks (in the future, maybe also light signals conducted through glass-fibre cables). Navigation avionics, on the other hand, must have some designed sensitivity to environmental radio signals in order to perform their function.

The antennas of radio-based avionics may be affected by electromagnetic field intensities of only microvolts per meter. But being outside the aircraft, the antennas get some protective attenuation from the fuselage of radiation originating inside the aircraft. Non-radio systems generally have higher signal levels, and so are less susceptible to low levels of interference. The hull of a metal aircraft forms an effective electromagnetic boundary between the outside and the inside of an aircraft. Electromagnetic signals find it hard to get in, or to get out. That is why the navigation and radio antennae on an aircraft need to be placed outside the aircraft hull. But while outside they must be sensitive, the navigation electronics inside the hull can be in principle just as well and securely shielded as control avionics, because there is no reason at all for navigation systems to be sensitive to electromagnetic signals coming from inside the aircraft -- indeed, very good reasons for these systems to be very insensitive, namely, that there are lots of other electronics working there as well.

2.3.1.1 The Regulatory Environment

US Federal Aviation Regulation 91.21 prohibits the use of any portable electronic devices on board aircraft, with the exception of voice recorders, hearing aids, heart pacemakers, shavers, and any other device that the operator of the aircraft has determined will not cause interference with the navigation or communication systems of its aircraft: (a) Except as provided in paragraph (b) of this section, no person may operate, nor may any operator or pilot in command of an aircraft allow the operation of, any portable electronic device on any of the following U.S.-registered civil aircraft:

i. Aircraft operated by a holder of an air carrier operating certificate or an operating certificate; or

ii. Any other aircraft while it is operated under IFR.

Paragraph (a) of the section does not apply to Portable voice recorders, hearing aids, Heart pacemakers, Electric shavers or any other portable electronic device that the operator of the aircraft has determined will not cause interference with the navigation or communication system of the aircraft on which it is to be used. In the case of an aircraft operated by the holder of an air carrier operating certificate or an operating certificate, the determination required by paragraph (b)(5) of the section shall be made by that operator of the aircraft on which the particular device is to be used. In the case of other aircraft, the determination may be made by the pilot in command or other operator of the aircraft.

The regulation puts the responsibility firmly on an individual airline to determine that there is no interference. However, as Nordwall points out, `Compact consumer electronic devices have proliferated in numbers that defy cataloguing, let alone testing.' The question is what would constitute an appropriate `determination of no interference'. In contrast to the US Federal Aviation Regulations, the International Civial Aviation Organisation (ICAO) has no regulations relating to portable electronics [20]. US airlines implement a general ban on using any portable electronic devices (PEDs) below 10,000ft.

According to former FAA associate administrator for regulation and certification, Tony Broderick, this action was first initiated by Northwest Airlines, and other airlines quickly followed suit. Broderick notes that the use of PEDs during takeoff and landing phases is to be discouraged anyway, not only because of possible consequences of EMI but also to encourage passengers to pay attention to the cabin crew in case an emergency should arise during these critical phases of flight (Bro97) (a

commercial aircraft is below 10,000ft usually only during the takeoff and landing phases of flight, and according to the Boeing statistics, 20.9% of all fatal accidents to jet aircraft have happened during takeoff and initial climb, and 46.6% during initial and final approach and landing (Boe96)). Broderick also believes that the FAA, in cooperation with the industry, will need to determine if there is indeed a problem with PEDs on board aircraft, and that it will soon become commonplace to have PEDs on board that are doing things (for example, transmitting) that their owners aren't really aware of [20].

2.3.2 Effects of Living Near an Airport

According to Clean Air Solution, accessed from posted on August 16, 2017 by Camfilusa, the study have found that people living near an airport can experience a higher rate of respiratory problems due to elevated airplane emissions that contain hazardous contaminants and studies have found that living near an airport could be hazardous to your health[21].

One air quality study found that neighborhoods as far as 10 miles away from Los Angeles International Airport (LAX) are contaminated with high levels of ultrafine particles that can easily be swallowed or inhaled. These particles are hazardous to human health because they can penetrate in to the lungs and into breathing passages and worsen asthma symptoms, as well as lead to decreased lung function and impair cognitive ability in children. Researchers have known for years that the exhaust from aircraft contains ultrafine particles that are harmful to human health. But a growing body of studies is finding that far from just being contained within a small area, airport pollution can spread much further out than previously thought, and cause real health problems in residential areas where people are unaware of the risk. This is an issue that affects everyone concerned about the quality of air where they live.

2.3.2.1 Facts about Airport Pollution

To fully understand this issue, it's important to detail some airport pollution facts. According to the Los Angeles Times, aircraft exhaust is the main source of airport pollution at major urban areas in the U.S. The reason is that scorching exhaust vapor from airplanes creates ultrafine particles, which can worsen lung and heart conditions, aggravate bronchitis and emphysema, and even lead to blocked arteries[1].

These ultrafine particles are, "less than one-thousandth the width of a human hair [and] they can go deep in the lungs, make their way into the bloodstream and spread to the brain, heart and other critical organs. While emissions of slightly larger exhaust particles are regulated, ultrafine particles are not."Therefore, the majority of airborne pollutants generated by aircraft exhaust are not regulated by the U.S. Environmental Protection Agency (EPA), which is of great concern, because of the number of major airports throughout the U.S.Another source of concern is the LAX study, which found that neighborhoods as far as 10 miles away from the airport had elevated particle levels due to airport emissions. And the level of pollution at LAX was equivalent to the emissions generated by nearly 500 vehicles stalled in freeway traffic every day.

What's worse is that researchers have also detected other harmful pollutants in and around airports, such as nitrogen oxide which creates smog and black carbon. A major component of soot found in engine exhaust and it's not just major airports that are a risk because the American Chemical Society reported that emissions from regional airports were "significantly elevated when compared to background pollution levels[21]."

2.3.2.2 Controlling Airport Related Pollution

Given these facts, controlling airport related pollution is vital to preventing the health problems caused by the dispersion of ultrafine particles into the atmosphere. Some airports have acted on their own and implemented new policies in an effort to reduce emission levels. According to Enviro Aero, some airports provide electric power and air supplies at terminal gates, which allows pilots to turn off auxiliary power in aircrafts, "reducing fuel burn and pollutants[3]. Other airports have tried to shrink the amount of time that airplanes taxi on the runway waiting for a gate to open.

In addition, some airports have begun tackling the problem of emissions generated by vehicles used on the tarmac. They are exploring the effectiveness of alternative fuels, including liquid petroleum gas and compressed natural gas that have less harmful emissions than diesel and gasoline. "Lowering the rate of pollution at airports is a difficult task," stated Kevin Wood, Camfil USA Vice President Sales & Marketing. "It will require a change of mindset by airport officials in terms of how they manage aircraft on the runway. For example, an airport in Minnesota now requires airplanes to remain at cruising altitude for a longer period of time before they approach the airport. As a result, planes burn less fuel and emit less carbon dioxide. And as mentioned earlier, this isn't just an issue for airports but is vital for people living near an airport who are being harmed by the level of pollution generated by planes that take off and land each day. If you live near an airport, you can take steps to help improve the quality of the air you breathe.

- First, recognize that you spend most of your time indoors because indoor air is more quality Second, invest in an air purifier that is rated to remove gas and particle pollution from the air.

- Third, make sure that you install air filters in your HVAC system that can trap the common pollutants generated by airport emissions[22].

2.3.3 High Intensity Radiated Field Coupling into Aircraft

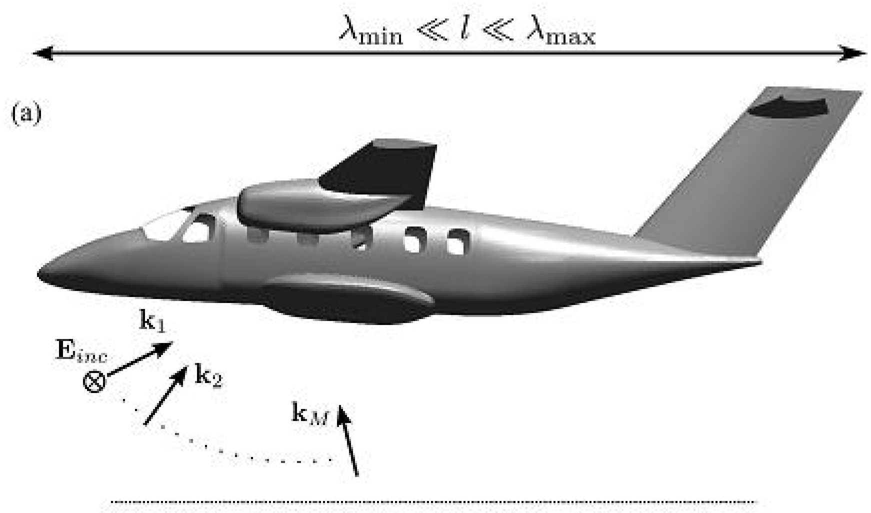
The analysis of high intensity radiated field coupling into Aircraft using the Method of Moments (MoM) was carried out by in 2014[28]. The research study pointed out that the recent development in aeronautical industry brought a massive substitution of classic flight instrumentation by electronic equipment. This trend is extended from big transport aircraft down to general aviation and small aircraft making it more vulnerable to its electromagnetic environment than classic airborne equipment. The most fundamental components of the normal electromagnetic (EM) environment, lightning, and high intensity radiated fields (HIRF) are met in a regular flight service with a given probability. Due to that, aircraft must be certified according to special regulations[29]. Strong and variable external EM fields may penetrate into the fuselage and the internal wiring installations. These installations, when stressed by the field, become sources of interfering and possibly destructive voltages and currents may endanger vulnerable airborne equipment as illustrated in Figure 2.5 (c). Therefore, the internal EM environment has to be carefully examined not only at the stage of an aircraft certification, but also at an early stage of the aircraft design. The numerical EMC analysis of aircraft is a challenging task for various reasons. Aircraft structures are usually highly complex, including many geometrical details, different materials, and complex internal wiring connecting plenty of electronic devices. Considering a typical frequency range up to 18 GHz [1], the electrical size of an aircraft becomes large and as a consequence, analyzing such a structure may quickly exceed conventional computational resources when using full-wave solvers such as finite-difference time-domain (FDTD), the finite-elements method (FEM), or the method of moments (MoM).

In the MOM aperture, problems were solved for rectangular structures applying dyadic Green's function. In this study, arbitrarily-shaped enclosures involving arbitrarily-shaped apertures were analyzed using MoM. Also, the accuracy of conventional Integral Equations (IEs) prevents the

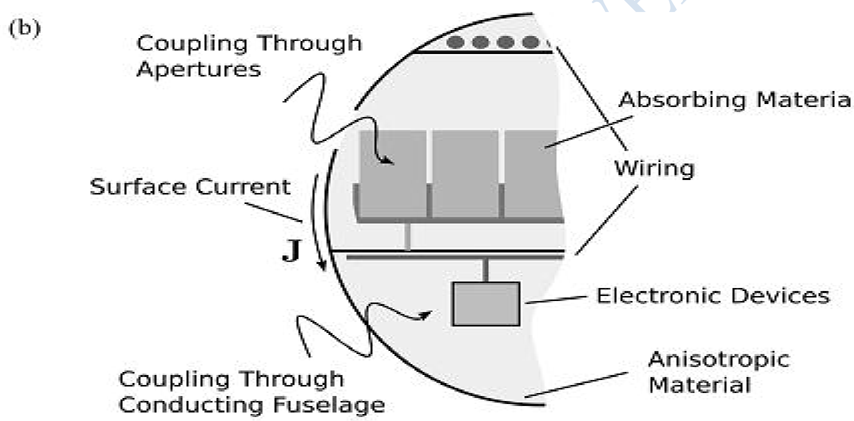
computation of field penetration through apertures. Here, we analyze the limitation of conventional MoM approaches for aperture problems and present an accurate IE based on this analysis. To accelerate the solution of the resulting matrix equation, a solution scheme is developed, which exploits the particular matrix structure. In order to analyze the accuracy and applicability of the introduced IE, numerical results are compared to measurements for a generic aircraft object. Following the insights gained for the generic aircraft object, a real-life aircraft is investigated numerically and experimentally with focus on model-to-hardware correlation. In both applications, the test establishment and execution follows the HIRF certification guideline, e. g., to be in accordance to practical requirements[29]. Various modeling aspects required for a meaningful numerical simulation are discussed and their impact on the correlation to measurements is analyzed in order to indicate the range of deviations typically observed when comparing experimental and numerical results.

The results obtained from the research methodologies are as follows: For aperture coupling analysis of Perfect Electric Conducting (PEC) objects, the electric field integral equation (EFIE) was typically used. It relates the scattered electric field produced by a surface current J to the incident field E_{inc} on the surface of the body. This is modelled as:

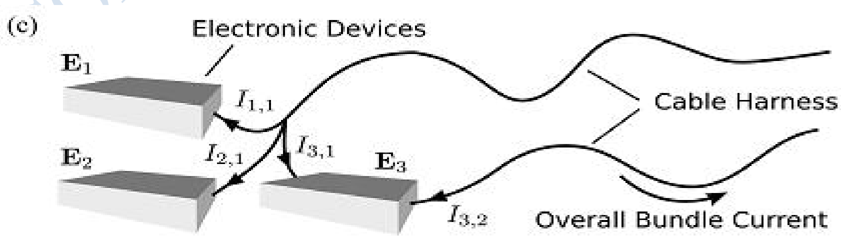
$$\hat{n} \times [E_{inc} + E(J)] = 0 \qquad (2.33)$$



$[Small = (I \ll 10\,kHz \ll \lambda_{max})$ and $Large = (I \gg 10\,kHz \gg \lambda_{max})$



Aircraft cross section coupled with external field



Cable bundle with Induced Current I and Electric Field E

Figure 2.11: Varying Electrical Values in Aircraft[28].

with $\hat{n}$ being the normal vector of the surface. In order to solve the EFIE for arbitrary-shaped bodies, an approximated surface current J_{num} is described in terms of N basis functions b_j and associated weighting coefficients a_j :

$$J_{num} = \sum_{j=1}^{N} a_j b_j(r) \; = J \acute{+} \Delta J \approx J \qquad (2.34)$$

Since this expansion is an approximation to the physical current, an error term ΔJ was introduced. By applying appropriate testing functions, which ensure the particular boundary condition of (1), the EFIE is transferred into a matrix equation. It is usually solved by algebraic techniques such as the lower-upper (LU) decomposition. Solving problems with a large number of unknowns is often accomplished using,

e. g., the MLFMA [3]. The total electric field E computed with MoM consists of a physical portion and an erroneous portion caused by numerical approximations, following (2):

$$E = E_{inc} + E(\text{J}) + E(\Delta\text{J}) \qquad (2.35)$$

For most aperture coupling problems, the internal field magnitude is orders of magnitude smaller than the external field. In case of numerical analysis, the impact of erroneous currents will dominate the internal fields and hence the accuracy limitation of MoM codes prevents the analysis of aperture problems for which the internal field magnitude is in the range of the MoM accuracy.In this study, two electric aperture currents were considered. The electric field on the PEC boundaries is described in analogy to by the set of equations[28].

$$\hat{n} \times [E_{inc} + E(\text{J}_e, \text{J}_e^a)] = 0, \;\; on\, S^+ \qquad (2.36a)$$

$$\hat{n} \times [E(\text{J}_i, \text{J}_i^a)] = 0, \;\; on\, S^- \qquad (2.36b)$$

The tangential electric and magnetic fields on the aperture have to be continuous according to:

$$\hat{n} \times [E_{inc} + E(\text{J}_i, \text{J}_i^a)] \;\; = \;\; \hat{n} \times [E(\text{J}_e, \text{J}_e^a)] \qquad (2.37b)$$

$$\hat{n} \times [H_{inc} + H(\text{J}_i, \text{J}_i^a)] \;\; = \;\; \hat{n} \times [H(\text{J}_e, \text{J}_e^a)] \qquad (2.37b)$$

The resulting integral equation is referred to as double layer integral equation (DLIE). To solve the DLIE numerically, it is discretized analogously to the EFIE using RWG basis functions and appropriate testing functions.

A virtual prototype of a small reciprocating single-engine four-seater EVEKTORVUT100 Cobra was investigated numerically and experimentally by the team. The dimensional drawing and material diversity of theVUT100 are shown in Figure 6. The fundamental cavity mode appears at around 65MHz. In the following, this frequency distinguishes between low-, mid-, and high-frequency range. In order to investigate the model-to-hardware correlation, MoM results are contrasted with results gained by the finite integration technique (FIT). For numerical investigations of real- life objects, parameter studies as outlined here are advisable especially for sensitive areas[28].

The model used for the numerical analysis of the aircraft's electromagnetic behavior was created in three main steps. The first of them is related with the proper geometrical modeling using a standard quality CAD geometry and its conversion into a simulation model using a preprocessor/mesher. The second one includes the modeling of complex material parts, geometrical dimensions, material diversity and illustration of field excitation for the considered aircraft model EVEKTOR VUT100. ULTEM is a thermos softening plastic. Crosses indicate the location of test points for evaluating the surface current (MC1, MC2, MC3) and electric field (AR1, AR2). The direction of field incidence is θ=80 And φ=45 composites. The last step encompasses simplifications that are inevitable for the simulation, e. g., the definitions of the electromagnetic source, the aircrafts surrounding in the lab or idealization of detectors and other equipment used during a real measurement.

From the material point of view, the aircraft was divided into four groups representing their main electrical characteristics. For FIT, the metallic parts were approximated by PEC. Proper material representations of the other material groups have been derived from measurements and approximated via convenient material models. The nonconductive materials like unprotected glass fiber composite were defined by the firstorder Debye dispersion model. Composite materials with highly conductive parts were approximated using a transfer impedance approach. In case of MoM, metallic and protected structure parts have been modeled by PEC and the unprotected glass-fiber parts have simply been neglected[28]. To obtain the individual radiated environment according to[29], the low-level swept field (LLSF) method is applied. The measurement of cable currents and surface currents is split into two parts, the DCI and low-level swept current (LLSC) method.

I. **10 kHz–20 MHz (Low-Frequency Range)**: The first setup under consideration concerns the surface current density on the fuselage of the aircraft. The aircraft is excited by DCI with 1 W forward power. The DCI current loop is terminated with 50Ω and the numerical excitation is a voltage generator with 1 V and 50Ω internal resistance, providing a certain forward power. In order to assure exactly 1 W forward power, the results have been scaled accordingly.

II. **0 – 400 MHz (Mid-Frequency Range)**: This test procedure follows the LLSC technique, where the aircraft is illuminated by an antenna and the surface currents are measured as response. In the simulation, the excitation has been modeled by a plane wave and by a fully discretized log-periodic antenna. Here, only the antenna which was used up to 220 MHz has been simulated. The conductive ground was part of the model. To assure a well-defined electric field reference for all frequencies, a clear reference point has been chosen. The electric reference field was recorded in 2.2 m height and 3 m distance from the antenna tip (angle of incidence θ=90) without the aircraft being present. This procedure were performed in the numerical setup for plane wave excitation and antenna excitation. All results (surface currents, internal fields) were scaled to the recorded electric reference field[28].

III. 100 MHz–18 GHz (40 GHz) (High-Frequency Range): The excitation of the last test setup is in accordance to the LLSF technique. Here, internal fields, arising from the excitation by an external antenna are measured. Due to limited computer resources, the largest frequency considered here is 1 GHz. Two numerical models have been used for the simulations: a grid valid up to 400 MHz, and a grid valid up 1 GHz. In both cases, the minimum and maximum cell size was $1/90\lambda$ and $1/10\lambda$, respectively. In the case of MoM, MLFMA has been applied for frequencies above 400 MHz[28].

From their findings, the research team shown that the conventional mixed potential electric field integral equation may lead to inaccurate results regarding the field penetration through aircraft apertures. An alternative integral equation is introduced which splits the computational domain into an interior and an exterior domain, improving the results for aperture problems. To analyze the accuracy and the range of applicability for these integral equations, a generic aircraft structure was investigated, both numerically and experimentally. Hence, various modeling aspects required for a meaningful simulation of aircraft were discussed. Following these observations, a real aircraft is analyzed in a broad frequency range from 10 kHz to 1 GHz by the team. It is demonstrated that accurate numerical techniques are as important as modeling and appropriate simplification of the considered structures[28].

Research Gap**:** The main influencing factors like environment factor, material diversity of the aircraft, geometrical uncertainties as well as sensor, source of electromagnetic field, and object modeling, could not be modelled and quantified accurately.

2.3.4 Perception of Health Risks of EM Field by Radiographers and Airport Security Officers

In a research carried out and cross sectional analysis on the perception of health risks of electromagnetic fields by Magnetic Resonance Imaging (MRI) radiographers and airport security officers compared to the general Dutch working population. The team pointed out that in the last decade, increased in usage of mobile phone and the subsequent increase in number of mobile phone base stations has led to a raise in concerns about health effects of EMF among citizens. Studies on adverse health effects of extreme low frequencies and of radiofrequencies, such as the development of brain tumors and childhood leukemia in the long-term, and short-term health effects, like headache sand dizziness which showed scientific controversy. Littleis known about how the working population perceives the health risk of different EMF sources, in particular those working with specific EMF-

emitting equipment. The study showed that during clinical imaging MRI workers can be exposed to magnetic fields exceeding the guidelines of the EU-Directive 2004/40/EC.

Hence, the team attempted to find answers to the following questions: Do the occupational groups differ on perceived risk of and feelings towards EMF in general and of different EMF sources, and if so to what extent?; What is the relationship between negative and positive feeling with perceived risk of EMF in general and of different EMF sources of the occupational groups?; Do the occupational groups differ on health concerns with respect to EMF and different EMF sources, and if so to what extent?

The research group utilized three groups: Group 1 consisted of people of the general Dutch working population; group 2 consisted of airport security officers who regularly work with a source of EMF with field strengths far below EMF exposure limits (metal detector); and group 3 consisted of MRI radiographers who regularly work with a source of EMF with field strengths close to EMF exposure limits (MRI equipment). The working population was approached via an invitation in an online consumer panel (20,000 members, ISO 20252 and ISO 26362). The panel consisted of a representative sample of the adult Dutch population. To ensure that the sample is an accurate representation of the population, the sample was stratified on demographic features (age, gender, educational level and area of residence).

The security officers were recruited via a security company at Schiphol/Amsterdam airport. They were approached in their break by one of the researchers. They were asked to participate in an anonymous, online study on EMF sources in daily life and at work. In exchange for their e-mail address they received a small incentive, which resulted in 217 officers signing up. MRI radiographers were recruited via a call from the Dutch Society for Medical Imaging and Radiotherapy (NVMBR) through an advertisement in their monthly journal and through contact by a NVMBR representative in most

Dutch hospitals. The call described that the study was about the use of EMF in daily life and at work. MRI radiographers were asked to send their email address. To this call 344 MRI radiographers from 36 hospitals responded.

Both security officers and MRI radiographers who had signed up received an e-mail with a link to the questionnaire. They received a first reminder after a week and a second one after two weeks. The response rate of the security officers was 49%. The response rate of the MRI radiographers was 56%. The security officers received, additionally to the small incentive they got for their email address, company points after filling out the questionnaire, which they could exchange for gifts. The MRI radiographers received a small incentive

Hence, eight different EMF sources were selected by the researchers based on their different properties. Three types were used: domestic, occupational, and environmental. Domestic sources included commonly used equipment, namely a mobile phone, a microwave oven, and a cordless phone (DECT). Occupational sources included the MRI and a metal detector. Environmental sources included a GSM base station, a UMTS base station and power lines. Both UMTS and GSM base station were included while previous focus group interviews (data not published) showed that people were more concerned about the new UMTS base station, than the older GSM base station. To compare these three types of EMF sources, a group mean of risk perception was calculated for the domestic sources and the environmental sources. Risk perception of a DECT, a microwave oven, and a mobile phone were summed into domestic source (a= 0.88). Risk perception of power lines, a GSM base station, and an UMTS base station were summed up for environmental source (a= .93). The metal detector and the

MRI were not combined for the occupational source, since too many differences in risk perception were expected between these two sources. Thus, analyses of variances were conducted to compare the three occupational groups on risk perception, and, negative and positive feeling of Electromagnetic Field EMF in general.

From their result, the group characteristics demonstrate some differences between the groups. MRI radiographers are usually higher educated women, while the security officers are younger and their educational level mainly medium.

i. No strong significant correlations were found within the general working population between educational level and the variables perceived risk of EMF in general and of different EMF sources and feelings towards EMF in general and of different EMF sources ($-0.17 < r^2 > 0.15$). Therefore, we can presume that the found differences between the occupational groups were not related to the difference in educational level between the groups.
ii. Perceived risk of and feelings towards EMF in general and of different EMF Sources**:** Table 2 shows risk perception of and feelings towards EMF in general and of different EMF sources of the three groups. Analyses of variance showed that MRI radiographers felt significantly more positive and less negative about EMF and had a lower perceived risk of EMF than the general working population and security officers.

   The MRI radiographers rated all sources of EMF as being significantly less hazardous for health (risk perception) than the other two groups, including their own occupational source, the MRI equipment. Security officers rated almost all sources of EMF more hazardous than the other two groups, including their own occupational source, the metal detector. The largest differences between the three groups in feelings towards the different EMF sources was found for the occupational sources. MRI radiographers were most positive about the MRI equipment and significantly more than the other two groups. We also found that security officers were significantly more positive about the metal detector than the working population, but at the same time, they were also significantly more negative about the metal detector than the other two groups.

There were also differences in the risk perception of different types of EMF sources. Repeated measure analysis of variance showed an overall effect of sources ($F(3,858) = 6.97$; $p < .01$) with all sources differing significantly from each other and with the metal detector having the lowest rating on perceived risk and environmental sources the highest. Domestic sources were overall rated significantly less hazardous for health than environmental sources.

iii. Relationships between perceived risk of and feelings towards EMF in general and of different EMF sources. The security officers did not differ in perceived risk of EMF from the general working population, but felt significantly less negative and less positive about EMF in general. Negative feeling correlated in all three groups significantly with perceived risk (general working population: $r = 0.61$; security officers: $r = 0.36$; MRI radiographers: $r = 0.44$, $p < .05$). With the exception of the security officers ($r = -0.12$, $p = 0.240$), positive feeling and risk perception of EMF had a significantly negative correlation in the general working population ($r = -0.50$, $p < 0.05$) and a weak but significant negative correlation in the MRI radiographers group ($r = -0.28$, $p <0 .05$). Fisher's r to z transformation showed that for the general working population there was a stronger positive correlation between risk perception and negative feeling than for the MRI radiographers ($z = 3.10$, $p < .01$) and the security officers ($z = 2.82$, $p < .01$). Also, a stronger negative correlation between risk perception and positive feeling was found for general working population compared to the MRI radiographers ($z = -3.12$, $p < 0.01$) and the security officers ($z = -4.00$, $p < 0.01$)

iv. Concerns about Health Effects of EMF**:** 68% of all the participants believed that EMF could cause a disease and 76% believed it could cause physical complaints. There were no significant differences between beliefs about a disease and beliefs about developing physical complaints (see Table 4), with the exception of the MRI radiographers. Pearson chi-square tests showed that significantly more MRI radiographers believed that people could get physical complaints from EMF compared to the working population and security officers.

Also, a lower percentage of the MRI radiographers had the opinion that over 10,000 Dutch people a year physical complaints due to EMF compared to the other 2 groups. Analysis of variance showed that security officers rated the chances of getting a disease themselves as significantly higher than the general working population and the MRI radiographers, and the chances of getting physical complaints themselves significantly higher than MRI workers.

From the findings, this study shows that not all occupational groups have the same risk perception of EMF and EMF sources. The MRI radiographers rated EMF and different EMF sources as less hazardous for health than did the general working population and the security officers. Ratings of the security officers did not differ much from the general working population. In line with earlier studies, all three groups rated the less voluntary and less controllable environmental sources as a higher risk for health than the more voluntary and more controllable domestic sources. Negative feeling towards EMF were associated with a higher perceived risk. Additionally, more than two third of the participants believed that EMF could cause adverse health effects.

The limitations of this study are:

i. Presentation of cross-sectional data by the study and which cannot show the dynamic relationships between the variables. Therefore, only descriptive analyses were performed, demonstrating differences between the occupational groups.

ii. The precise occupations of the general Dutch working population are unknown. We excluded participants who reported working with devices close to EMF exposure limits, but whether they work with other EMF sources, and of what category, is not known. Therefore, this group serves primarily as a control group to compare with the two specific occupational groups.

iii. Also, the exact dose and duration of EMF exposure per individual within the specific occupational groups is not known. However, it seems unlikely that these individual differences in exposure would affect the differences in perceived health risks between occupational groups to a large extent.

2.3.5 Electromagnetic Interference to Flight Navigation and Communication Systems

The Electromagnetic Interference to Flight Navigation and Communication Systems: New Strategies in the Age of Wireless[44].

The author iterated that since 1920's, radio technologies have faithfully and continually enabled the ever-expanding need for aerospace vehicle navigation and communication capability[44]. Likewise, the need for reliable, secure communication, navigation and surveillance (CNS) and air traffic management (ATM) for aerospace vehicles has continually driven improvements in radio technology. As aviation has become more dependent upon radio for CNS, the effects of EMI have become ever more important. Since the 1920's, with few exceptions, radio spectrum for aeronautical radio services has been coordinated and protected by law, so as to minimize the potential of EMI from other radio services.

2.3.5.1 Airplane Coupling Path Measurements

Figure 2.6(a) illustrates typical radio receiver interference coupling paths and Figure 2.6(c) shows a setup for conducting Interference Path Loss (IPL) measurements. IPL is defined as the measurement of the radiated field coupling between passenger cabin locations and aircraft communication and navigation receivers, via their antennas. The setup shows a tracking source is used to provide RF power to the transmit antenna, and a spectrum analyzer is used to measure the signal received by the aircraft antenna. The frequency-coupled spectrum analyzer and tracking source pair allows for

frequency sweeps, resulting in more thorough measurements and reduced test time. Swept CW was preferred over discrete frequency measurement, according to RTCA/DO-233. A pair of test cables is used to connect the instruments to the aircraft antenna cable and to the transmit antenna. An optional amplifier may be needed to increase the signal strength depending upon the capability of the tracking source and the path loss level. A preamplifier may be needed in the receive path near the spectrum analyzer for increased dynamic range. This preamplifier may be internal to the spectrum analyzer.

2.3.5.2 EMI Detection and Shielding for Aviation Safety

Until recently, it was generally assumed that Electromagnetic Interference EMI situations that occur on commercial airplanes would be caused unintentionally. Today's increased awareness of global terrorism, and the expanding media coverage of EMI weapons, makes it more likely that EMI weapons may be used against airplanes. On February 25, 1998, the U. S. Congress held a Joint Economic Committee Hearing on Radio Frequency Weapons and Proliferation. In one of the recorded statements, Dr. R. Alan Kehs of the Army Research Lab asked a profound question: "At what point do common civilian electronic devices become weapons?"[31]

The first reported measurements of electromagnetic shielding of commercial airplane apertures to prevent Portable Electronic Device (PED) coupling to aircraft radio systems was performed by Veda Incorporated, under contract to the FAA[34]. A median shielding effectiveness of 26 to 35dB was reported when covering all port and starboard windows with aluminum foil and tape. It was observed that shielding all the windows resulted in more variation of field levels inside the passenger cabin (ie. "stronger modal structure"). Veda also experimented with using 2-inch foil tape to partially cover aircraft windows. Over 10dB of additional shielding was reported when using only one strip of 2-inch tape. Various combinations of aluminum tape and alternating window coverage were examined. The

report did not reveal the dependency of shielding effectiveness on particular RF bands however. In August 1996, RTCA Special Committee-177 recommended "Government and industry should pursue research into the design and feasibility of using devices designed to detect emissions that produce

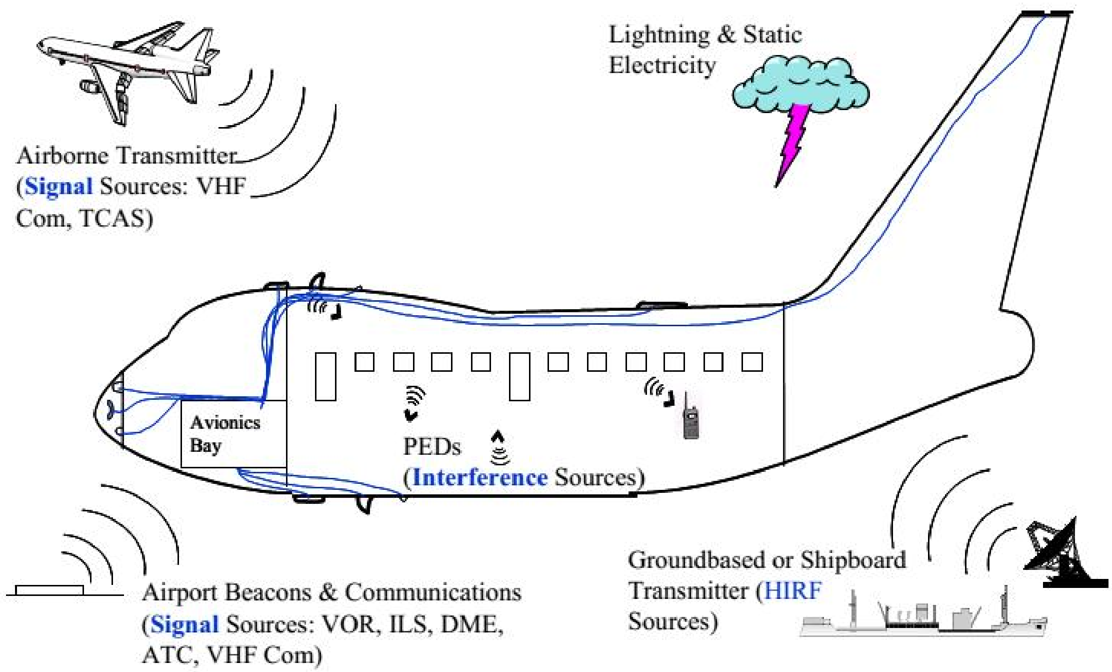


Figure 2.12a: Illustration of Electromagnetic Threats to Aircraft Systems

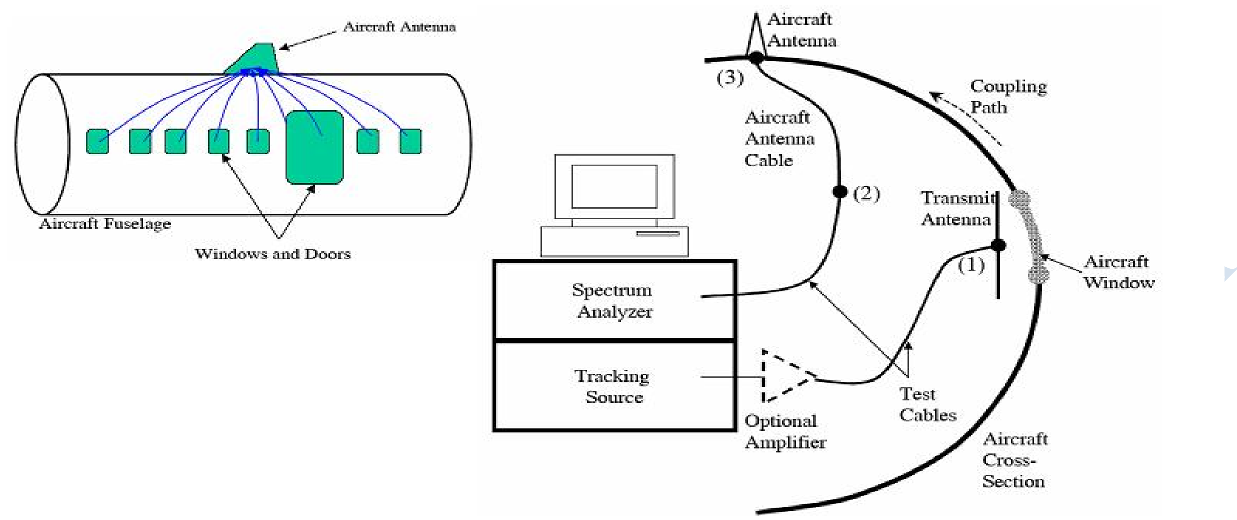


Figure 2.12 b. A Typical Radio Receiver Interference Coupling Path For a Top Mounted Aircraft Antenna.

electromagnetic interference from PEDs within aircraft cabins". Soon after publication of the RTCA/DO-233 report, the FAA entered into a Small Business Innovative Research (SBIR) contract with Megawave Corporation (Boylston, Massachusetts) and Embry Riddle Aeronautical University (ERAU, Daytona Beach, Florida) to design a system for the detection and localization of potentially harmful radiation from PEDs carried onboard aircraft. The system was designed to monitor the radio spectrum from 50 to 2000 MHz, with up to 64 sensors distributed throughout the passenger cabin of an airplane. Unfortunately, funding and sponsorship of the system dissolved before a proto type could be built. To date, the Mega wave/ERAU design remains the most comprehensive approach for a PED detection system. Details of the design were presented at the 1998 Digital Avionics Systems Conference[32].

Aside from a system designed exclusively for installation on aircraft, other PED detection options have become available since the RTCA/DO-233 recommendation. Holaday Industries (now a part of ETS-Lindgren) markets a Cell Alert system for detection and alerting of wireless phones that may be activated in the hospital environment, but are unauthorized. Cellbusters.com, in Phoenix, Arizona, manufactures the Cellbuster, which appears similar to the Cell Alert, and is marketed for use in power plants, airports, medical clinics, computer rooms, transportation operations, industrial plants, control rooms, laboratories, financial institutions, courthouses, government buildings, legal offices, embassies, and defense facilities. Details may be found at http://www.cellbusters.com. Channel Business Services, of Hamburg Germany, markets the Mobifinder mobile phone detector, for use in airplanes, airports, hospitals, doctor's offices, medical laboratories, fuel depots and gas stations, and other security areas.

Alitalia Airlines has evaluated the Mobifinder as a tool for the chief cabin attendant on some flights in 1998, and found that it was often difficult to identify the exact location of the unauthorized transmitter. The Alitalia evaluation team recommended that multiple Mobifinder units be used to increase the likelihood of threat localization, to heighten passenger awareness to the potential hazards of wireless phones, and to aid the flight crews in resolving suspected EMI events. Other PED detection products are also likely to be (or become) available. Narda East (L3 Communications), in Hauppauge, New York has advertised the portable AirGuard® PED sensor, for detecting PED emissions that may be present in aircraft communication/navigation frequency bands, and has demonstrated a prototype unit at NASA LaRC. The Narda approach is subtly different from the other approaches because it focuses on excessive PED emissions in aircraft frequency bands, rather than detecting specific T-PED frequencies that have been designated as unauthorized for use onboard airplanes. This significant difference was identified in the Mega wave /ERAU study, and acknowledged to be of significant design concern for an operational system to provide a high probability of detecting potentially harmful PED signals, while not burdening flight crews with false alarms. The most difficult issues relating to the detection of unauthorized PEDs are less technical than financial and operational. Any piece of electronic equipment an airline designates for use onboard their aircraft must be certified for flight worthiness according to FAA regulations. Certification may add significant cost over the base price of the equipment. Also, airplanes can only generate revenue when they are carrying passengers. Thus, an installed PED detection system is subject to the additional cost of lost revenues during its installation time. Once the technical issues and certification requirements for a PED detection system have been resolved, flight crew training and enforcement policies must be developed to address situations when potentially harmful PEDs are being used by passengers. In addition, it is nearly

impossible to ensure that passenger mobile phones will not bypass the onboard picocell and transmit (at maximum power output) to a terrestrial base station.

2.3.6 Spurious Radiated Emission Measurements from T-PEDs

In the Spring of 2001, NASA LaRC entered into an Interagency Agreement with the FAA and teamed with the University of Oklahoma Wireless EMC Center to develop a radiated emission measurement process for CDMA (IS-95) and GSM (ETSI GSM 11.22) wireless phones[44]. Spurious radiated emissions were characterized from devices tested in both semi-anechoic and reverberation chambers, in terms of effective isotropic radiated power. Eight representative handsets (4 GSM, 4 CDMA) were commanded to operate while varying their radio transmitter parameters (power, modulation, etc.) as illustrated in Figure 2.7.

The NASA report provided a detailed description of the measurement process and resulting data, which may subsequently be used by others as a basis of consistent evaluation for cellular/PCS phones, Bluetooth, IEEE802.11b, IEEE802.11a, FRS/GMRS radios, and other portable transmitters. Aircraft interference path loss (IPL) and navigation radio interference threshold data from numerous reference documents, standards, and NASA partnerships were compiled. Using this data, a preliminary risk assessment was provided for CDMA and GSM wireless phone interference to aircraft localizer, Glideslope, VOR, and GPS radio receivers on typical transport airplanes. The report identified where existing data for device emissions, IPL, and navigation radio interference thresholds needs to be extended for an accurate risk assessment for wireless transmitters in aircraft.

2.4 Summary of Gaps in Literature Reviewed

Airports and its domain are mostly restricted from human activities due to likely perceived danger that external activities may pose on the operational health of the aircrafts. However, the information from the literatures reviewed shows that electromagnetic interference with aircraft systems and air pollution caused by aircraft systems are already issues in aviation. The summary of gaps from the reviews are:

1. **Electromagnetic Interference with Aircraft Systems:** In contrast to the US Federal Aviation Regulations, the International Civial Aviation Organization (ICAO) has no regulations relating to portable electronics [20] despite the facts that:

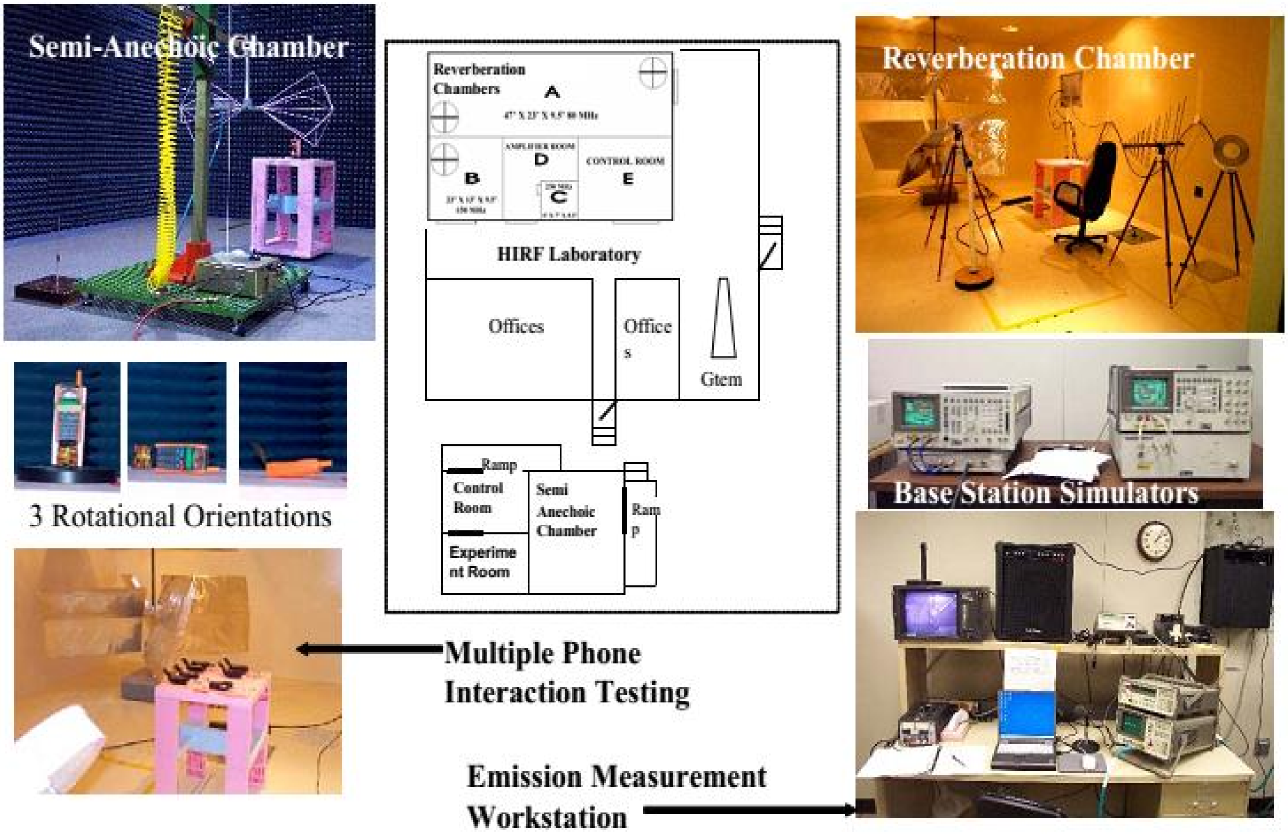


Figure 2.13: NASA Langley Research Center Hirf Laboratory Setups for Measuring Spurious Radiated Emissions from Cdma, GSM and Other Mobile Phones and Peds

a. Navigation systems of aircraft have parts devised to detect and act on signals coming from `outside', and the radio-based systems are particularly susceptible to low levels of interference.

b. US Federal Aviation Regulation 91.21 prohibits the use of any portable electronic devices on board aircraft, with the exception of voice recorders, hearing aids, heart pacemakers, shavers, and any other device that the operator of the aircraft has determined will not cause interference with the navigation or communication systems of its aircraft:

c. US airlines implement a general ban on using any portable electronic devices (PEDs) below 10,000ft.

2. High Intensity Radiated Field Coupling into Aircraft: Effects of electromagnetic field on aircraft investigated by Schroder utilized mathematical computer based models. Fast solution techniques using Multilevel Fast Multipole Algorithm (MLFMA) was introduced to speed-up the

MoM solution procedure and to reduce the required memory[30]. Although large problems up to 10 unknowns were solved using MLFMA and the geometrical complexity of real life aircraft leads to ill-conditioned system matrices, preventing the solution in a moderate time. To overcome this issue, appropriate preconditioners were developed. Furthermore, computing the response to exciting fields with varying angles of incidence requires the application of sophisticated acceleration techniques[31]. To account for complex materials, the development of material models to numerical codes is essential[32].

Despite these approaches, the main influencing factors like environment factor, material diversity of the aircraft, geometrical uncertainties as well as sensor, source of electromagnetic field, and object modeling, could not be modelled and quantified accurately. Hence, the study focused on the accuracy of MoM simulations regarding real-life aircraft and this could not be actualized for real life scenario.

3. Electromagnetic Interference to Flight Navigation and Communication Systems: Experiments conducted on interference to flight navigation and communication systems using airplane coupling path measurement indicated that EMI effects from lightning, electrostatic discharge and high intensity radiated fields (HIRF) from radars and broadcast transmitters could not be thoroughly utilized as research indicator in the experiments. Also, research on EMI detection and shielding for aviation safety indicated that current mobile phone manufacturers have demonstrated picocell systems to RTCA SC-202 and EUROCAE WG-58 that could be considered to be mobile phone detection and mitigation systems. Such systems have the benefit of being able to command the participating handsets to transmit at minimum power, thus possible reducing EMI risk. Unfortunately, regulatory guidelines make it difficult to design such a system that will work with all the mobile phone technologies (i.e. CDMA, GSM, PCS, PDC, 3G, EDGE, etc.) used by passengers on a typical airplane flight.

4. Spurious Radiated Emission Measurements from T-PEDs:

Some of the limitations on this experiment indicated that none of the four CDMA and four GSM wireless handsets tested would individually be likely to interfere with aircraft VOR, LOC, GS, or GPS navigation radios. Others are:

i. If a CDMA or GSM wireless handset radiated spurious signals equal to the maximum allowable FCC limits, it would result in large NEGATIVE safety margins, even when considering "reasonable minimum" radio receiver interference thresholds.

ii. Intermittent spurious radiated emissions would sometimes increase up to 10 dB when touching the keypad, touching the antenna, or retracting the antenna on the test handsets. However, when compared to the highest emission levels in all operating modes, these manipulations resulted in only a 3-dB increase for the highest emission levels. Also, GPS- and DME-band emissions occur, due to intermodulation between GSM and other wireless handset types, when the handsets were placed in close proximity to one another.

iii. Other combinations of common passenger transmitters could potentially produce intermodulation products in aircraft communication and navigation radio-frequency bands.

iv. FCC does not restrict airborne use of PCS wireless handsets. FCC limits for spurious radiated emissions for PCS handsets are the same as for cellular handsets. However, only cellular handsets are restricted from airborne operation by the FCC[44].

i. Repeatedly turning the handset power ON-OFF caused the most significant changes in the spurious radiated spectrum.

5. Perception of Health Risks of EM Field by Radiographers and Airport Security Officers

The limitations of this study are presentation of cross-sectional data by the study and which cannot show the dynamic relationships between the research variables in real life context. Therefore, only

descriptive analyses were performed, demonstrating differences between the occupational groups. Also, the exact dose and duration of EMF exposure per individual within the specific occupational groups is not known. However, it seems unlikely that these individual differences in exposure would affect the differences in perceived risk and health concerns between occupational groups to a large extent.

In addition, the precise occupations of the general Dutch working population are unknown, thus exclusion of participants who reported working with devices close to EMF exposure limits was executed. But whether they work with other EMF sources, and of what category, is not known. Therefore, this group serves primarily as a control group to compare with the two specific occupational groups in the research study.

6. Effects of Living Near an Airport

The study by Clean Air Solution have found that people living near an airport can experience a higher rate of respiratory problems due to elevated airplane emissions that contain hazardous contaminants[21] and studies have found that living near an airport could be hazardous to health[21].

Given these facts, controlling airport related pollution is vital to preventing the health problems caused by the dispersion of ultrafine particles into the atmosphere. Some airports have acted on their own and implemented new policies in an effort to reduce emission levels. According to Enviro Aero, some airports provide electric power and air supplies at terminal gates, which allows pilots to turn off auxiliary power in aircrafts, "reducing fuel burn and pollutants[3]. Other airports have tried to shrink the amount of time that airplanes taxi on the runway waiting for a gate to open. But, the research does not generate any framework that would make these to be legalized and standardized for airports operations.

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Chapter Three

Methodology

3.1 Research Approach

In this chapter, specific techniques for selecting data collection and analysis tools, and, collection and analyzes of data in order to uncover the impacts of electromagnetic interference from Electromagnetic Field (EMF) based Infrastructure on aircrafts, geo-spatial encroachment on airport and airlines operational activities would be discussed. The Electromagnetic Field (EMF) based Infrastructures considered include but not limited to Telecommunication Base Stations (TBS), AM and FM Radio Stations, Television (TV) Station, Electrical Transformers (ETs), Industrial EMF (I-EMF) Based-Infrastructure, Clinic/Hospital (H-EMF) Based-Generators (CRFG), among others, within and around Ibadan Airport. The research methodology would provide strategies for evaluating geo-spatial encroachment of Electromagnetic Field (EMF) based Infrastructures within and around Ibadan Airport using Satellite based technology at varied buffers, evaluate the level of the electric, magnetic and power flux density radiation from the Electromagnetic Field (IMF) based Infrastructures during the active hours of the airport.

The results generated from the operation discussed above would be investigated using EMF based data modeled in MATLAB application software. Also, the data would be comparatively analyzed using stipulation by International Commission for Non-Ionizing Radiation Protection (ICNIRP) and National Communications Commission on electromagnetic field interference and electro-spatial encroachments around Airport. The approaches used for conducting the research and evaluation of research subjects basically are; quantitative, qualitative, and mixed methods. These were utilized to ensure that the aim of this research is achieved. The quantitative method involved acquisition of satellite imagery for the study area, selection of appropriate instrumentation systems for measuring; radio-frequency radiations, geo-spatial locations of Electromagnetic Field (IMF) based Infrastructures

and analysis of the data generated using ARCGIS Geographical Information System's Application Software and MATLAB.

In addition, the qualitative technique involved generation of responses from the staff working in airport domain. The questionnaires and oral interactions were centered on effect of EMF radiations; experienced by the staff, noticed on aircraft operations and discovered on other electronic systems used for daily operations within the airport. However, the mixed research technique was used where instrumentation systems and questionnaires were possible to be utilized simultaneously for generation of data. This allows the research study to build on the relationship and strength that exists between quantitative and qualitative research approaches and allows the impact of electromagnetic field radiation that is being researched upon to be better investigated. Figure 3.1 shows the Ibadan Airport while Figure 3.2 shows the utilization and flow of research techniques.

3.2 System Design

The system design for the research study involved the process of defining the features utilized for selection of satellite imagery and instrumentation system for generation, processing and interpretation of data; for realization of aim and objectives of the study. The system design facilitated details on how area of research study was digitally obtained using satellite imagery, processing of electromagnetic field data and application of appropriate electromagnetic radiation model for computation of interference on aircrafts. Also, system design aided the concepts through which the questionnaires and oral questions for the staff working around airport domain were developed. Thus, the system designs facilitated the skillful subdivision of the entire processes and phenomena required for the research into meaningful and intelligible subcomponents.

3.2.1 The Study Area

The study area is Ibadan airport which is located at latitude 7.36222 N, longitude 3.97833E and elevation of 220 m. The Ibadan airport is a public airport operationally control by Federal Airports Authority of Nigeria (FAAN). The Airport commissioned in June, 1982 by the former Senate President, Joseph Wayas is located at Alakia, which is between Adegbaiji community and Iwo Road[4].

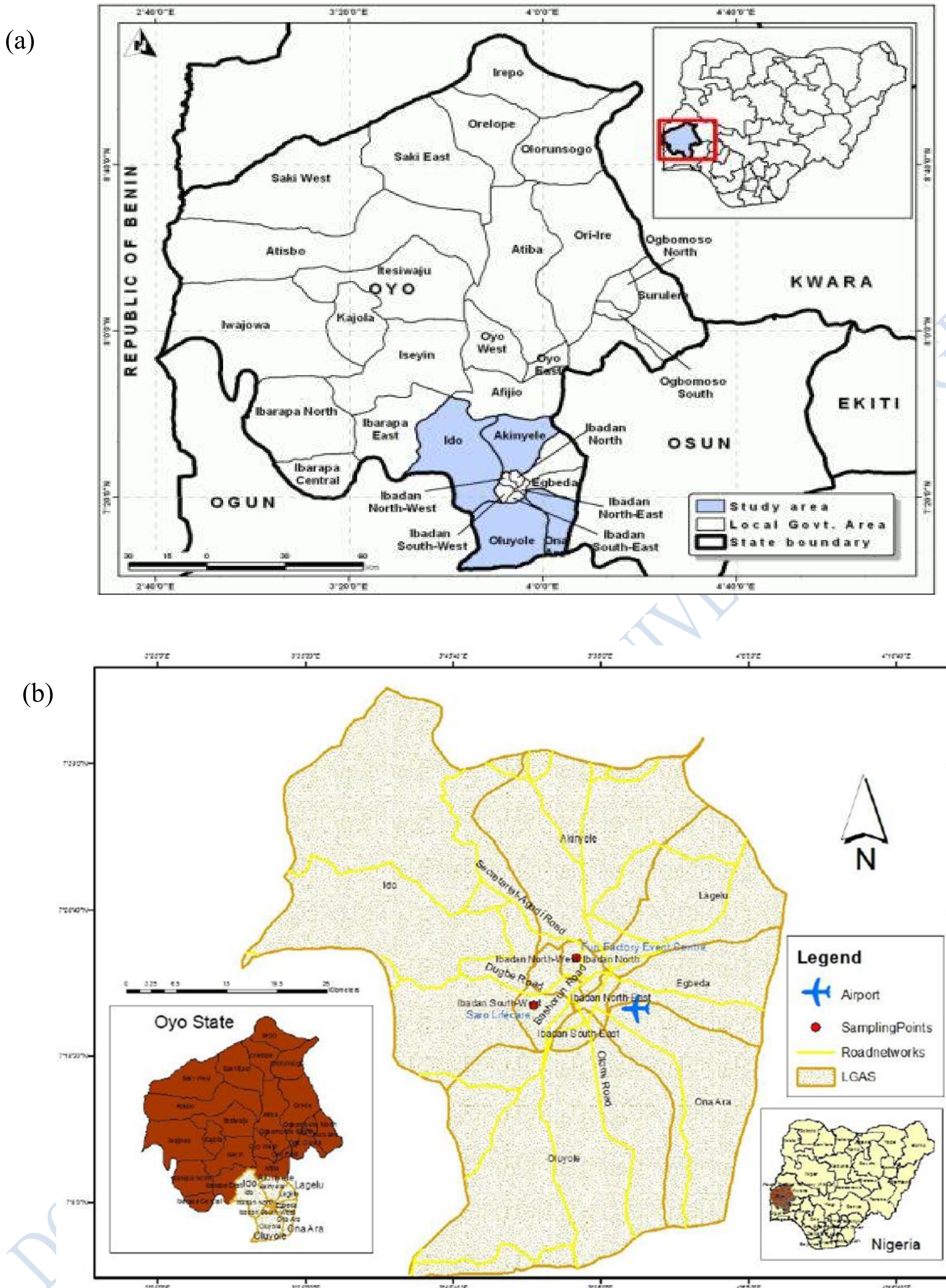


Figure 3.1: (a) Map of Oyo state and (b) Location of Ibadan Airport.

Source: [5] Tijani Saliu, Oluyemi E. Ayodele, Olabanji I. Oluremi, Adeniji A. Oluwole, 2018, Journal of Environment Pollution and Human Health. 2018, 6(4), pp.126-137.

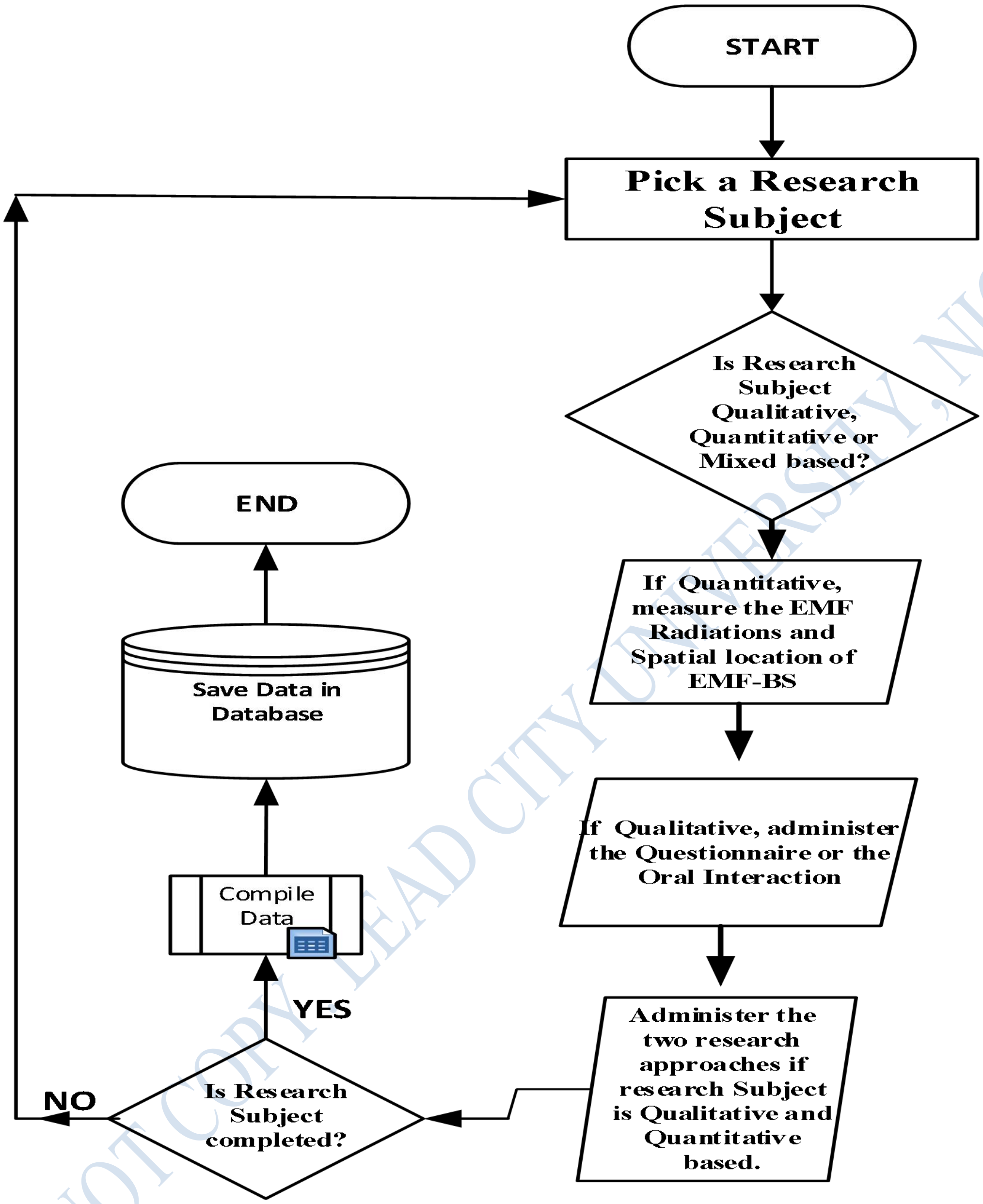


Figure 3.2: Flowchart showing the utilization and flow of research technique

3.3 Requirements Specification

The requirements specification considered for the research methodology are;

- Sourcing of Satellite Imagery for the Study Area.
- Selection of Application Software for Field Guide and Location of EMF based Infrastructures.
- Specification and Selection of GPS Receiver.
- Configuration of Radio-Frequency Meter and Radiation Standards.

3.3.1 Acquisition and Sources of Satellite Imagery for the Study Area

The satellite imagery for the study area was sourced from Google Earth[6]. Although, several other sources were considered. Among these are World Imagery, USGS Earth Explorer, Sentinel Open Access Hub, NASA Earthdata Search, NOAA Data and Access Viewer[7]. Google Earth is a free downloadable program that was install on the Windows of the processing laptop computer. The program requires very little space on the hard drive because the images are stored on Google's servers and streamed to the computer upon demand. The features that facilitated its selection as source of imagery for the research are: high-resolution and availability of multiple resolutions, recent images for most locations, easy and safe to download/install, easily browsable, useable on desktop, tablet or phone and easy to use. Typical Satellite imagery proposed and downloaded from Google Earth, utilized for field guide and location of Radio-Frequency Generator (RFG) is shown in Figure 3.3.

3.3.2 Application Software for Field Guide and Location of RFGs

Avenza Maps application software for Android phones is selected for field guide and location of Radio-Frequency Generators (RFGs) on the field. This is because Avenza Maps is a powerful app for Android and iOS devices that provides a variety of tools for use with georeferenced maps both online and offline. It allows maps to be imported from personal source, or downloaded from Avenza Map

Store, which currently contains over 500,000 maps across the world. When the Avenza Maps app is opened, the default screen is known as the 'Maps List'. This displays any maps that someone had downloaded

Figure 3.3a: Samples of Satellite Imagery **Source:** Google Earth, 24th February, 2021

Figure 3.3b: Ibadan Metropolis for Location of EMF-BS. **Source:** Google Earth, 24th February, 2021

or imported as well as various icons and tabs for navigating around the app. By default, maps are categorized based on whether they are Map Store maps or imported maps. Users without a subscription (Unlimited Import or Pro) are restricted to 3 imported maps at a time. All users are allowed an unlimited number of Map Store maps.

3.3.2.1 Map View and Toolbar in Avenza Apps

When map is selected from the Maps List, the map opens displaying the Map View. The Map View allows the App user to view his/her location, add placemarks, record tracks, as well as several other functionalities. The Maps List provides access to any maps that user have downloaded or imported onto processing device. The map's title, publisher, distance and direction from the user's current location are displayed. In place of distance and direction, user might see "On map" displayed, which signifies that the user is currently located within the extent/coverage of that map. Additionally, the list also indicates whether a map is part of a collection and if it was obtained from the Avenza Maps Store or imported from another source. User can add and manage maps from here. This is illustrated in Figure 3.4 (a) and Figure 3.4(b) shows typical RFGs location with the aid of the guide around airport domain . Avenza Maps currently supports the following map formats:

i. GeoPDF (.pdf) and Geospatial PDF (.pdf) - A PDF embedded with geographic information.
ii. GeoTIFF (.tiff, .tif) - A GeoTIFF is a TIFF file embedded with geographic information.
iii. JPG (.jpg) - a JPG is an image file that must be packaged with a TFW in a ZIP file.
iv. Avenza Maps File (.avenzamaps, .pdfmaps) - A format used to import multiple custom maps at once (such as for a folder or map collection).
v. Custom Scheme (avenzamaps://, pdfmaps://) - Creates a clickable link that can be shared via email, messaging, etc. and will automatically prompt Avenza Maps to open when clicked.

At the airport domain and its environment, the Avenza App is utilized for the location of RFGs and also served as guide for determining the domain within which data is to be selected.

(a)

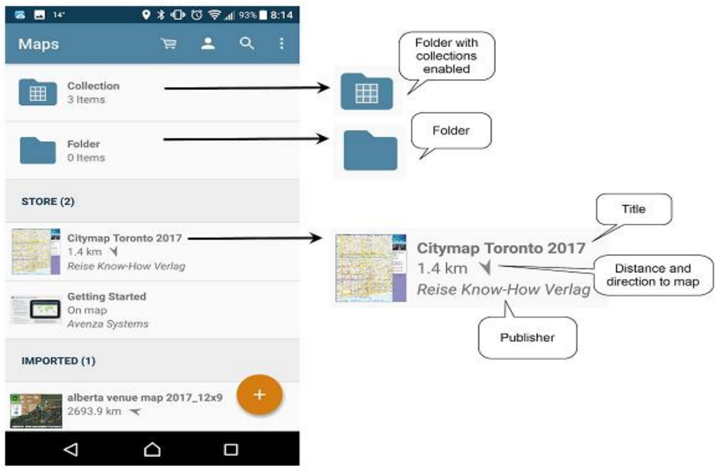


Figure 3.4a: Avenza Map List for Android;

Source: Avenza Maps Field Guide, 2022; https://ucanr.edu/sites/forestry/files/321982.pdf

(b)

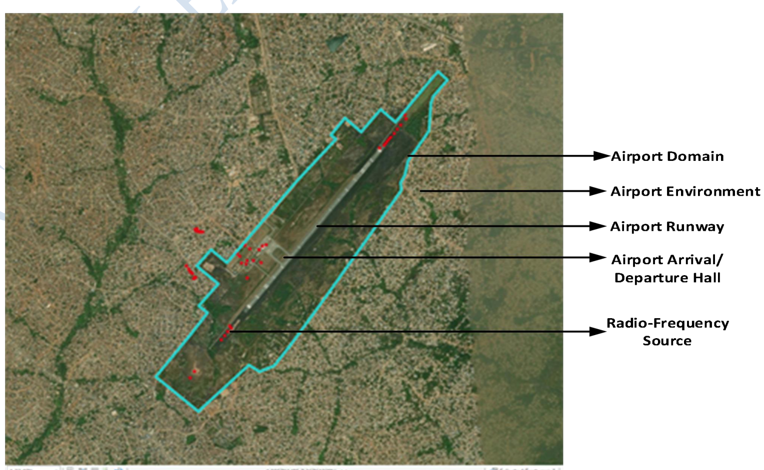


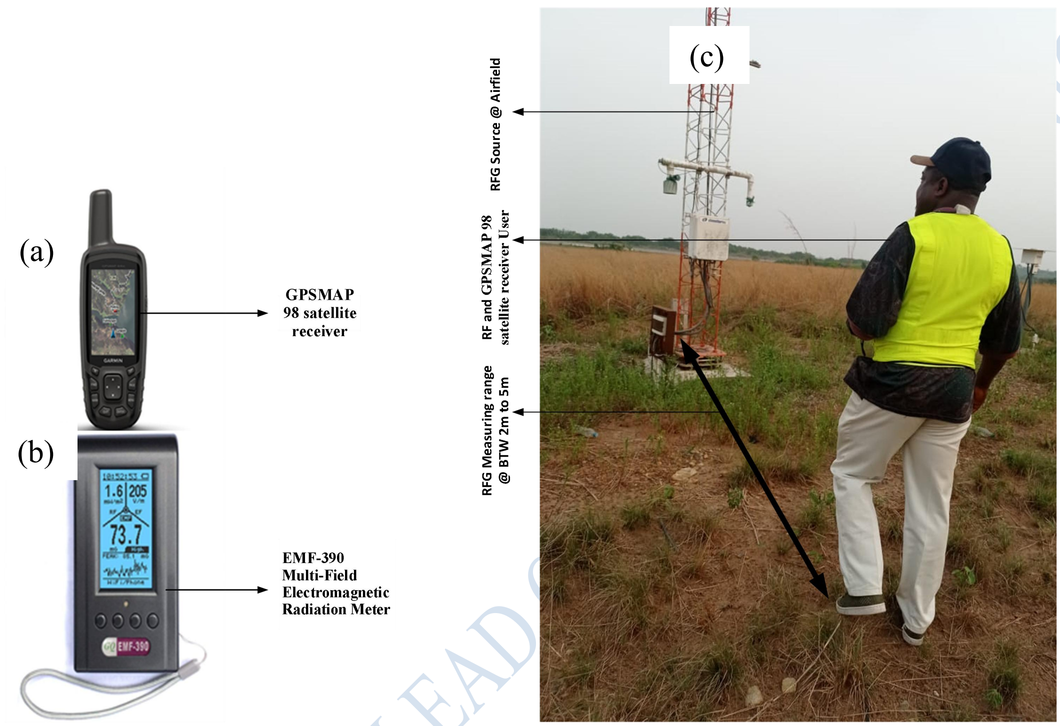
Figure 3.4b: Avenza Map Application on Airport Domain Source: Field work, 2022.

3.3.3 Specification and Selection of GPS Receiver

GPSMAP 98 satellite receiver was proposed and selected for the collection of Radio-Frequency Generators' (RFGs) locations within and around the Airport domain. The new GPSMAP handheld navigator features a 2.6" sunlight-readable screen, a high-sensitivity GPS, Expanded Internal Memory of size 4GB, pair with optional ANT+ sensors, such as heart rate monitor, temperature sensor, speed/cadence, which could be used to control VIRB action camera. The GPSMAP 98 satellite receiver is GLONASS based with a quad helix antenna for superior reception. The rugged and waterproof GPSMAP receiver comes with barometric altimeter, 3-axis compass and a preloaded Recreational Map. It wirelessly connects to smartphone to allow Live Tracking and Smart Notification. With its quad helix antenna and high-sensitivity, GPS and GLONASS receiver,

GPSMAP 98 locates users' position quickly and precisely and maintains its location even in thick forest and deep valleys.

The handheld based satellite receiver has a comprehensive set of navigation features and it has a built-in 3-axis tilt-compensated electronic compass, which shows the heading of the receiver even when you're standing still, without holding it level. Its barometric altimeter tracks changes in pressure to pinpoint users' altitude. To guarantee great readability under any condition GPSMAP 98 has a brilliant 2,6'' sunlight-readable colour screen and is easy to operate with any kind of gloves in a shaky, cold or wet environment because it relies on a button based user interface. Also, to guarantee convenience and maximum freedom on the go, the dual battery system allows the use of a battery pack for convenient charging in the device or conventional AA batteries. Fully charged the GPSMAP 98 lasts up to 16 hours which gives sufficient power reserve on a day trip in case of unexpected holdups. In addition, the spatial distance L of RFGs and measurement of radiation from the RFGs sources was proposed at $1.0\ m \leq L \leq 3.0\ m$. The picture of the GPSMAP 98 satellite receiver utilized for the filed work is shown in Figure 3.5(a), the EMF field meter is shown in Figure 3.5(b) while Figure 3.5 (c) and (d) show the utilization of the meters. These meters were utilized to obtain the GPS points and radiations.



Source: https://www.amazon.com/Garmin   Source: Field work. 2022.

Figure 3.5: (a) GPSMAP 98 Satellite Receiver; (b) RF Field Meter (c) Application's Range of Meters;

Source: Field work, 2022

Figure 3.5: (d) Meters Application @ Airport Luggage Scanning unit and (e) @ Runway environment

3.3.4 Configuration of Radio-Frequency Meter and Radiation Standards

The configuration of RF meter [shown in Figure 3.5 (b)] proposed and selected for the research study is Advanced GQ EMF-390 Multi-Field Electromagnetic Radiation 3-in-1 EMF ELF RF meter. It can be used for measuring radiation from 5G Cell Tower, Wifi Signal Detector of RF up to 10GHz with Data Logger and 2.5Ghz Spectrum Analyzer [9]. The GQ EMF-390 advanced multi-function digital EMF ELF meter is designed and developed by GQ Electronics, USA. It is a portable and convenient device. It can be used in the general-purpose test, detection, and other scientific applications. Such as Power Line, WiFi, Cell phone, 2G/3G/4G/5G Cell tower (low-medium band), Microwave, Smart Meter, etc. The device integrated features include three-axis Electromagnetic Fields, Electric Field, Radio Frequency (up to 10Ghz), and a bonus feature RF Spectrum Power Analyzer(five bands up to 2.504Ghz) [9.].

The EMF-390 RF meter has built-in flash memory for data logging and it can log the real-time data every second. The meter can identify/recognize the RF source from EMF/RF measured, such as Power Line, WiFi/Cell phone, Cell tower, Microwave, etc. It also comes with a built-in audible and visual alarm. It can be used for EMF, ELF, EF, RF detection and monitoring both indoor and outdoor, as well as in other similar environments. The unique GQ RF Browser feature visualizes the RF radiation precisely on the screen. With RF Browser, the user is able to see high-speed RF signals, such as Smart meter, cell phone transmission, estimates Digital RF transmission data in bytes, and RF power spectral histogram. The EMF-390 RF Browser is the ultra-fast response RF detector. It can detect 5G signal as fast as 250nS (nanosecond) digital RF pulses. The meter has installed multiple sensors to ensure maximum scale/range measurement and highest accuracy. With open communication protocol, the user could send commands to the system to get all data remotely. This allows the device to be easily integrated into any other system. More so. the device is equipped with a USB port, utilized for communication, and external power supply/charging of internal rechargeable 3.7V battery.

3.3.4.1 Radiation Standards for Comparative Analysis of Measured Radiations

The standards on exposure of electromagnetic radiations on human being considered for comparative analysis of measured signal radiations are:

i. Standards by the International Commission on Non-Ionizing Radiation Protection (ICNIRP).
ii. National Council on Radiation Protection (NCRP) for civilian exposures (referred to as uncontrolled environments).
iii. The International Electricians and Electronics Engineers (IEEE) for professional exposures; referred to as controlled environments. (U.S. FCC 1997).
iv. International Commission on Non-Ionizing Radiation Protection (ICNIRP). *Statement on the "Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz)"*, 2009.
v. Institute of Electrical and Electronics Engineers (IEEE). *IEEE standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 kHz to 300 GHz*, IEEE Std C95.1, 2015.
vi. 15 km setback to Airport's airfield by Nigeria Communication Commissions NCC.

Among the standards stated above, ICNIRP standard (iv) and NCC standard (vi) were proposed for comparative analysis of data obtained from the field.

3.3.5 Investigation of Electromagnetic Interference and Encroachment on Ibadan Airport

Radio signal interference causes wireless clients and access points especially users inside aircrafts to hold off transmitting, which causes delay and reduced throughput. As a result, interference lasting for longer periods of time (referred to as duty cycle) will cause more damage to the signal, and interference present for shorter periods of time may have less impact on the signal[10]. The resulting decrease in performance caused by interference can make browsing websites and downloading files

sluggish and severely limit the number of active voice users. In cases where interfering signals are strong enough, the wireless clients from in the aircraft might not be able to access the WLAN within the aircraft system at all time for an indefinite period of time.

Moreover, the electromagnetic radiation consists of an electric field (E-field) and a magnetic field (H-field) and the E-field and the H-field together carry power called power density (W/m^2) that flows through space. Hence, considering the power density P_t component of the electromagnetic field and flux density F component of P_t radiated from the EMF-BI sources, the interference power received on or in the aircraft (at the point of landing) between the RFG source and the aircraft (at distance R) could be expressed as (discussed in chapter two):

$$P_r = \frac{P_t G_t}{4\pi R^2} \qquad Equation(3.1a)$$

$$F = \frac{P_t}{4\pi R^2} \quad (W/m^2) \qquad Equation\ (3.1b)$$

where P_r = Received power density at the airfield.

F = Received flux density at the airfield

P_t = Transmitted power density (mW/m^2) from the EMF-based sources.

G_t = Transmitter antenna gain (near-field or far-field) (dBm).

R = distance from the antenna to the point of interest (m) at the airfield.

Exposure of personnel to hazardous radiation is tiered based upon frequency. All of the following assume an external, sinusoidal-based, electromagnetic field in a controlled environment. A controlled environment is defined as "an area that is accessible to those who are aware of the potential for exposure as a concomitant of employment, to individuals cognizant of exposure and potential adverse effects, or where exposure is the incidental result of passage through areas posted with warnings, or where the environment is not accessible to the general public and those individuals having access are aware of the potential for adverse effects. Thus, the limits on exposure of electromagnetic radiations for occupational/controlled areas inside the airport considered for investigation is illustrated in Table 3.1.

Table 3.1: Research Limits on Exposure of Electromagnetic Radiations

S/N	Operational Frequency f (MHz)	Maximum RMS Electric Field Strength (V/m)	Maximum RMS Magnetic Field Strength (A/m)	Average Maximum Power Density (mW/cm^2)	Average Time Duration (Minutes)
1	0.3 - 3.0	614	1.63	-	6
2	3.0 – 30	1842/f	4.89/f	-	6
3	30 – 300	61.4	0.163	-	6
4	300 – 1500	-	-	f/300	6
5	1500 - 100000	-	-	5	6

3.3.6 Design of Questionnaire for Airport Officials

The composition of the questionnaire was centered on conformity of ICNIRP standard and NCC regulations (in relation to sitting of infrastructures inside and around the airport). Other core factors considered were stated below and the design of the questionnaire is shown in appendix C.

i. Awareness of 15 km setback to airfield by NCC at the airport.

ii. Seeking and obtaining approval from Nigerian Airspace Management Authority, NAMA in accordance to NCC regulations.

iii. Payment of fee before acquisition of such Land and Periodic payment on such land.

iv. Questions on International Commission for Non-Ionizing Radiation Protection (ICNIRP).

v. Operational time and working conditions of staff working within the domain of electromagnetic field around the airport.

vi. Health challenges previously experienced by staff working within the domain of electromagnetic field around the airport.

3.3.6.1 Design of Questionnaire's Results Collation Form

Based on concepts mentioned in session 3.3.6 and the objective of evaluating the compliance of International Commission for Non-Ionizing Radiation Protection (ICNIRP) standard on exposure of EMF to airport workers, twenty-three questions were generated for the field work. The collation form for the responses was designed using Excel application software. This is depicted in Table 3.2.

3.4 Research Methods

Measuring the electromagnetic field is essential to check that exposure levels respect the regulatory limits established in the country, and thus ensure the safety of individuals exposed, whether members of the general public or workers. For individuals who work in proximity to high frequency emmiters, the measurement ensures that the emitter is switched off when the intervention takes place and/or that the electromagnetic fields are well below the recommended levels[2]. Hence, the following research methods would be thoroughly discussed.

3.4.1 Ground-Trothing of EMF-based Infrastructures via GPS Satellite Receiver

The spatial position of Electromagnetic Field (EMF) based Infrastructures were located with aid of the Avenza Map application software on which the satellite imagery of the Ibadan environment has been downloaded. During the field work, the GPS receiver meter was utilized to obtain the spatial locations of the EMF sources. This comprises of the altitude, latitude and longitude of such RFG. Also, the radiated power $\boldsymbol{P_r}$, **E** and **H** components of the electromagnetic radiation from the RFG sources were measured with the aid of Advanced GQ EMF-390 Multi-Field Electromagnetic Radiation meter. The measurement was done at the range of $1.0\ m \leq Range \leq 3.0\ m$.

3.4.2 Processing of Field Data using ArcGIS Application Software

ArcGIS is an application software that serves as Geographical Information System processing tool through which spatial-temporal related data could be processed. A geographic information system (GIS) lets users visualize, question, analyze, and interpret geographical data to help them understand and

Table 3.2: Questionnaire's Results Collation Form

S/N	Questions on Electromagnetic Fields' Impacts	RESPONDENTS' VIEW		RESPONDENTS' VIEW		RESPONDENTS' VIEW		RESPONDENTS' VIEW		RESPONDENTS' VIEW	
		OPTION A	TOTAL RESPONSES	OPTION B	TOTAL RESPONSES	OPTION C	TOTAL RESPONSES	OPTION D	TOTAL RESPONSES	OPTION E	TOTAL RESPONSES
1	Have you experienced any of the following health conditions due to RF Exposure?	Headache, skin rashes and / or sleep disruption		Dizziness, nausea or / and fatigue.		Disruptions of normal blood sugar levels.		Joint and muscle pains		None of the above	
2	Have you experienced any of the following chronic health conditions due to RF Exposure?	Cancers e.g. breast cancer, leukemia and/or brain tumors.		Neurological diseases such as Alzheimer's disease.		Amyotrophic Lateral Sclerosis (ALS) also known as Lou Gehrig's disease.		Malignant brain tumors and acoustic neuromas.		None of the above	
3	Have you experienced any of the following mental/internal organs health based conditions due to RF Exposure?	Cardiac problems and/ or Ringing in the ears ,		Memory and concentration problems		Asthma and worsening of inflammatory conditions.		Digestive problems and/or immune dysfunction		None of the above	
4	How often did you go for medical checkup?	Once in a Year.		Once in six months		Quarterly in a Year		Monthly		None of the above	

problem-solve relationships, patterns, and trends. ArcGIS offers unique capabilities and flexible licensing for applying location-based analytics to research studies and practices. It provides greater insights using contextual tools to visualize and analyze data that could be collaborated and share via maps, apps, dashboards and reports[11]. The software is selected due to the following features:

- With ArcGIS, the data collected was easily crowdsourced, stored, accessed, and processed efficiently and securely. It also allows the integration of the data stored in the computer systems and geo-enable any data from any source.
- ArcGIS gives you everything requires to manage and extract answers from imagery and remotely sensed data. It includes imagery tools and workflows for visualization and analysis, and access to the world's largest imagery collection.
- Aids spatial analysis of data using set of analytical methods and spatial algorithms. Use location as the connective thread to uncover hidden patterns, improve predictive modeling, and create a competitive edge. Thus, leverage the power of spatial analysis and data science on demand and at required scale.
- Aids Mapping that helps spot spatial patterns in collected data. Maps also break down barriers and facilitate collaboration. ArcGIS gives the ability to create, use, and share maps on devices.

ArcGIS is a family of client software, server software, and online geographic information system (GIS) services developed and maintained by Esri. ArcGIS was first released in 1999 and originally was released as ARC/INFO, a command line based GIS system for manipulating data. ARC/INFO was later merged into ArcGIS Desktop, which was eventually superseded by ArcGIS Pro in 2015. ArcGIS Pro works in 2D and 3D for cartography and visualization, and includes Artificial Intelligence (AI)[5.] Esri also provides server side ArcGIS software for web maps, known as ArcGIS Server.

3.4.2.1 Mapping of Landuse Change and Encroachments Around Ibadan Airport

The rate of encroachment by the public/personal infrastructures on the airport domain were investigated by buffering the acquired satellite imagery at 1 km spatial distances to the airport domain on ArcGIS application software illustrated in Figure 3.6. The study was carried out to investigate the landuse change and dynamics around the airport. The Landsat images (with 30 m spatial resolution) covering the study area were obtained from the Global Land Cover Facility using the online archive at Earth Explorer (https:// earthexplorer.usgs.gov/) for the years 1987 and 2022. Then, airport's satellite imagery was buffered on the processing software up to 10 km square and the landuse change was mapped using Landsat multispectral imageries.

The study area covers a single scene of Landsat image with path 191 and rows 055 under the reference datum's WRS (world reference system). Landsat TM (Thematic Mapper) image with the scene id – LT51910551987009XXX03 was acquired on January 09, 1987, and the Landsat OLI (Operational Land Imager) with scene id – LC81910552022025LGN00 acquired on January 25, 2022, are used for the landuse and land cover mapping and change detection during the 35 years. According to the USGS (2004) report on LULC classification, the combination of bands in Landsat TM and OLI images is effectively suitable for extracting various LULC features, especially from the builtup area. For example, the band combination of band 4, band 3 and band 2 of the TM image distinctly produced features like water bodies, settlements, and vegetated areas, similar to band 5, band 4 and band 3 of the OLI image. The three bands were combined in Erdas Imagine Software.

Several image classification techniques and algorithms have been developed extensively for landuse and land cover analysis worldwide. However, each method is developed and reviewed for its advantages and disadvantages based on its algorithm, iteration, and processing software. For example, algorithm-based classification methods like support vector machine (SVM), artificial neural network (ANN), Maximum Likelihood Classifier (MLC), fuzzy analysis, segmentation and clustering. Among

them, the MLC technique depends on a combination of ground samples and personal experience with the study area and is strictly used in the field observed training samples of the natural ground surface; thus, the MLC classification technique is selected for analysis of the preprocessed medium resolution image to extract the LULC feature in the study area.

Maximum likelihood classification assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class. Each pixel was assigned to the class with the highest probability (the maximum likelihood). The pixel remains unclassified if the highest probability is smaller than the specified threshold. The likelihood function was calculated for each pixel using equation 4.2 (Richards, 2013);

$$D = In(a_c) - [0.5 \cdot In(|COV_c|)] - \left[0.5 \cdot (\mathrm{X} - \mathrm{M}_c) \cdot T \cdot \left(COV_c{}^{-1}\right) \cdot (\mathrm{X} - \mathrm{M}_c)\right] \qquad Equation\ (3.2)$$

where D = weighted distance (likelihood).

c = a particular class

X = measurement vector of the candidate pixel

M_c = mean vector of the sample of class c

$a_c =$ percent probability that any candidate pixel is a member of class c (defaults to 1.0, or is entered from a priori knowledge)

$COV_c =$ covariance matrix of the pixels in the sample of class c

$|COV_c|$ = determinant of $COV_c =$ (matrix algebra)

$COV_c{}^{-1}$ = inverse of *Cov*c (matrix algebra)

In = natural logarithm function

$T =$ transposition function (matrix algebra)

The image classification was done in Erdas Imaging software to derive landuse classes, including Builtup, Forest, Shrubland, Cultivation, and Waterbody. The accuracy assessment was conducted using 120 randomly selected samples, deriving the kappa coefficient and classification accuracy for the 1987 and 2022 classified images.

Change detection assessment of land features provides information sources for monitoring the trend of changes in an area over time. This study performs the change detection analysis on the classified images from 1987 and 2022 in Idrisi software. Change detection matrix executes geometrically referenced pixel of a particular feature class in the classified image of 1987 and the corresponding pixels of the feature class in the classified image of 2022 to identify the differences in per pixel units within a particular feature class as well as the group of pixels of the same feature classes [17]. The comparative analysis of feature classes allows estimating differences in the area and perimeter of the landuse classes.

3.4.2.2 Spatial Encroachment of Radio-Frequency Based Infrastructures

The encroachment into the airport was mapped using historical imageries on the google earth pro application as depicted in Figure 3.6 (a and b). Google Earth (GE) was officially launched by Google in 2005 as a "geobrowser", providing tools required to monitor, measure, analyze, evaluate, and model Earth observation data [14.] The timeline tool in GE was used to view the area's historical images. The oldest high-resolution image was collected in 2003. Built structures within 1 km of the airport runway were extracted into saved places for 2003 and 2021. The saved place was exported as km^2 for both

years. The proximity analysis was done using multiple rings buffering of 200 m, and the statistics of the buildings inside each ring were extracted.

Subsequently, the building density was created using the Inverse Distance Weighted average tool, a deterministic approach for multivariate interpolation using a known distributed collection of points [15]. Using equation 4.3 (a), a weighted average of the values present at the known points was used to determine the values allocated to the unknown location/point. This was numerically evaluated using equation 4.3 (b).

$$IDW = \frac{\sum_{i=1}^{n} \frac{w_i}{d_i}}{\sum_{i=1}^{n} \frac{1}{d_i}} \qquad Equation\ (3.3a)$$

where IDW (Inverse Distance Weighted) is the estimated value at an unknown point

n is the number of points

w_i is the value at location i

d_i is the distance from location i to the unknown location

$$R = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} \qquad Equation\ (3.3b)$$

where R is the range between the entering point of aircraft at airfield (spatial point 1) and location of the EMF-BI around airport (spatial point 2)

$x, y\ and\ z$ are coordinates of the spatial point.

The codes for generating results using $Equation\ (4.3b)$ is depicted in appendix A while the snippet is

```
'run the calculations using the formulae for range
dblRange = Sqr((dblX * dblX) + (dblY * dblY) + (dblZ * dblZ))
'display result on the User Interface
lblRange.Caption = Str(dblRange)
End Sub
```

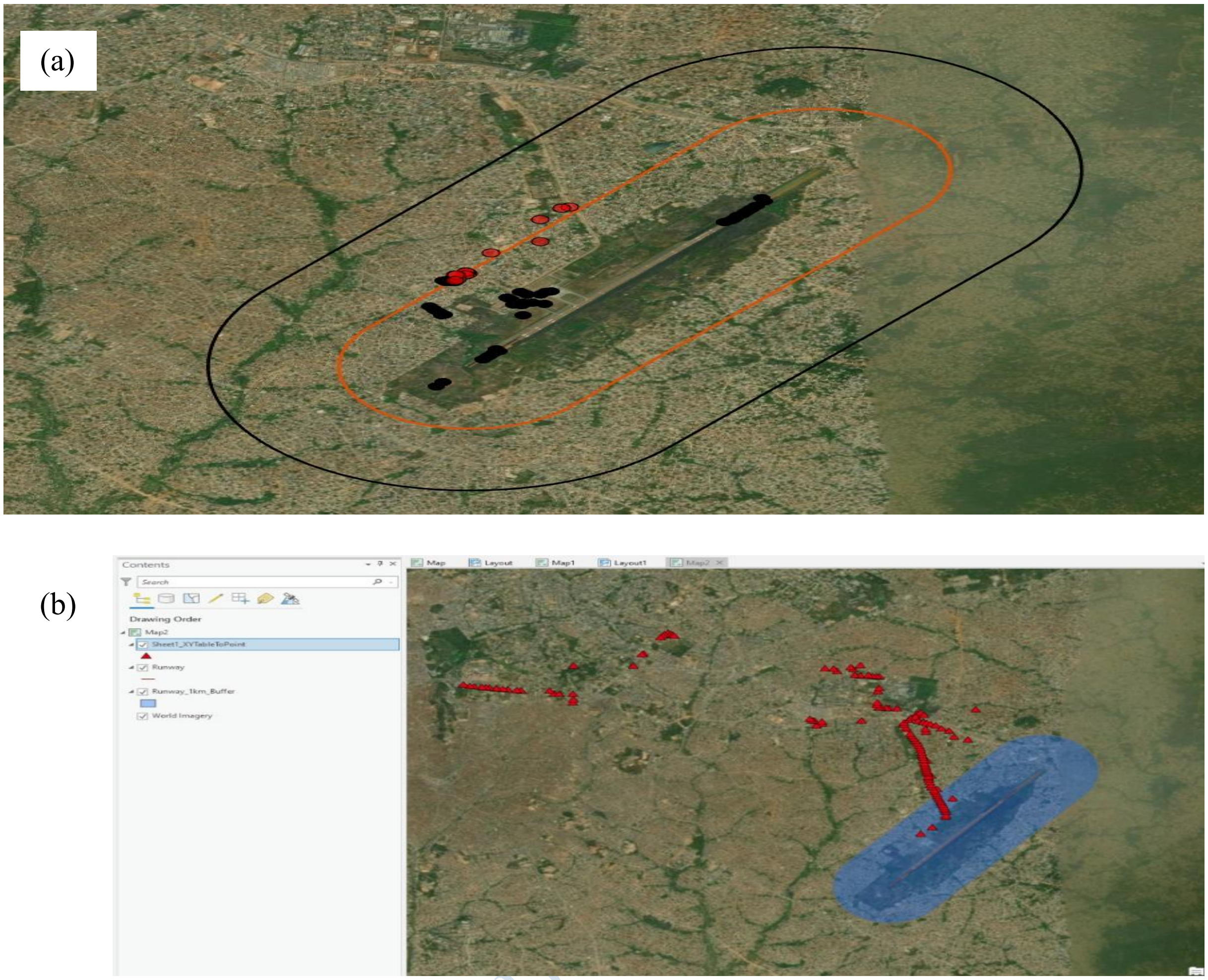


Figure 3.6: (a) Imagery of Ibadan Airport and Environs (b) Processing of Imagery in GIS Apps.

3.4.3 Generation of Interference Wwaveforms Using EMF Based Data

MATLAB, which stands for MATrix LABoratory, is a state-of-the-art mathematical software package, which is used extensively in both academia and industry. It is an interactive program for numerical computation and data visualization, which along with its programming capabilities provides a very useful tool for almost all areas of science and engineering[13]. The most basic data structure in MATLAB is the matrix: a two-dimensional, rectangularly shaped data structure capable of storing multiple elements of data in an easily accessible format. These data elements can be numbers, characters, logical states of true or false, or even other MATLAB structure types. MATLAB uses these two-dimensional matrices to store single numbers and linear series of numbers as well. In these cases, the dimensions are 1-by-1 and 1-by-n respectively, where n is the length of the numeric series. MATLAB also supports data structures that have more than two dimensions. These data structures are referred to as arrays in the MATLAB documentation[12].

MATLAB is chosen as data processing application software for processing RF interference due to its scientific and technical data processing capabilities which include the following, among others:

- It aids computation of vectors and matrices.
- Allows generation of plots and waveforms using basic trigonometric/other functions.
- Aids programming of non-inbuilt functions

The electromagnetic components consisting of electric field **E**, magnetic field **H** and electromagnetic power density **P** collected from the RFGs sources were developed into plots and waveforms. These are then utilized for comparative analysis with ICNIRP regulations and guidelines.

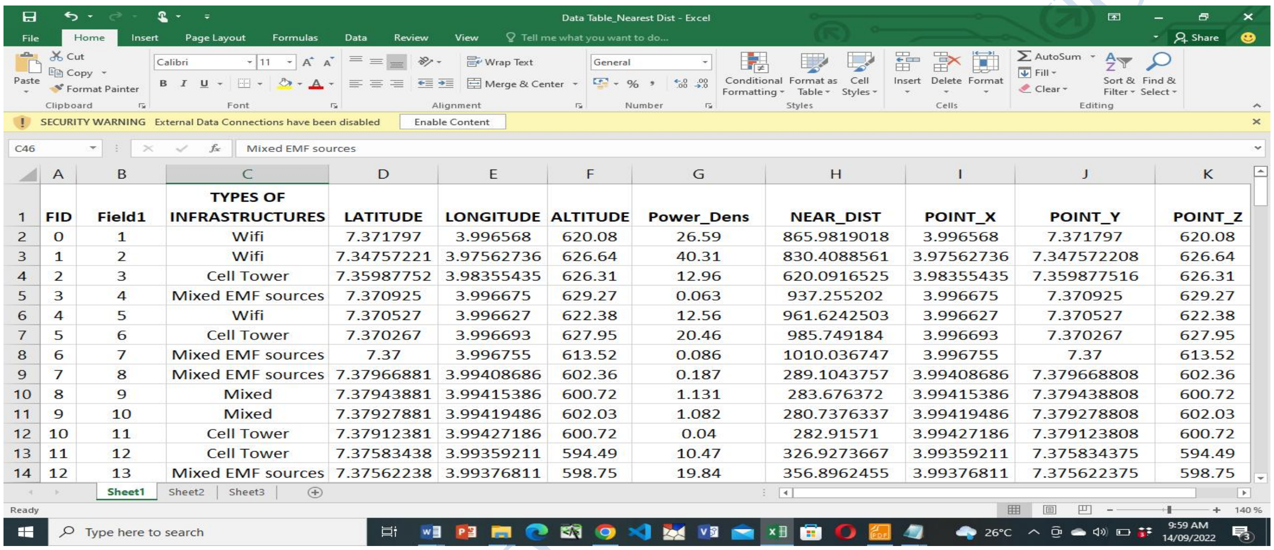
3.4.3.1 Comparative Analysis of EMF-BI and Questionnaire based Data

The electric field **E**, magnetic field **H** and electromagnetic power density **P** data collated from the field work were imported into MATLAB application software after pre-processing in Excel data processing software. These data were later compared with ICNIRP regulations on maximum and range of electromagnetic field in which workers around airport must not exceed per period of time. The snapshot of the data in excel environment is shown in Figure 3.7 while the results generated would be presented and discussed in chapter four.

3.4.4 Programming of EMF Radiations Data for Interference Waveforms

The generation of Electromagnetic Fields interference waveforms using the distance between the EMF-based infrastructure and landing point of aircraft on the airfield were generated in

Excel/MATLAB application software. This was initially computed in excel application software (as depicted in Figure 3.7) before been imported to MATLAB software.



	A	B	C	D	E	F	G	H	I	J	K
1	FID	Field1	TYPES OF INFRASTRUCTURES	LATITUDE	LONGITUDE	ALTITUDE	Power_Dens	NEAR_DIST	POINT_X	POINT_Y	POINT_Z
2	0	1	Wifi	7.371797	3.996568	620.08	26.59	865.9819018	3.996568	7.371797	620.08
3	1	2	Wifi	7.34757221	3.97562736	626.64	40.31	830.4088561	3.97562736	7.347572208	626.64
4	2	3	Cell Tower	7.35987752	3.98355435	626.31	12.96	620.0916525	3.98355435	7.359877516	626.31
5	3	4	Mixed EMF sources	7.370925	3.996675	629.27	0.063	937.255202	3.996675	7.370925	629.27
6	4	5	Wifi	7.370527	3.996627	622.38	12.56	961.6242503	3.996627	7.370527	622.38
7	5	6	Cell Tower	7.370267	3.996693	627.95	20.46	985.749184	3.996693	7.370267	627.95
8	6	7	Mixed EMF sources	7.37	3.996755	613.52	0.086	1010.036747	3.996755	7.37	613.52
9	7	8	Mixed EMF sources	7.37966881	3.99408686	602.36	0.187	289.1043757	3.99408686	7.379668808	602.36
10	8	9	Mixed	7.37943881	3.99415386	600.72	1.131	283.676372	3.99415386	7.379438808	600.72
11	9	10	Mixed	7.37927881	3.99419486	602.03	1.082	280.7376337	3.99419486	7.379278808	602.03
12	10	11	Cell Tower	7.37912381	3.99427186	600.72	0.04	282.91571	3.99427186	7.379123808	600.72
13	11	12	Cell Tower	7.37583438	3.99359211	594.49	10.47	326.9273667	3.99359211	7.375834375	594.49
14	12	13	Mixed EMF sources	7.37562238	3.99376811	598.75	19.84	356.8962455	3.99376811	7.375622375	598.75

Figure 3.7: The Snapshot of Electromagnetic Data in Excel environment

For easier numeric computation of the electromagnetic radiations of the EMF-BI, equation $Equation\ (4.1b)$ was utilized. This is because $Equation\ (4.1a)$ would require that the transmitter's antenna gain G_t for all EMF based infrastructures spatially located around the setback of the airport be known before the power density could be determined. The codes for generating the radiation using $Equation\ (4.1b)$ is depicted in appendix A while the snippet is;

```
'run the calculations using the formulae for flux
dblFlux = dblPower / (4 * (22 / 7) * dblDistance * dblDistance)
'display result on the User Interface
lblFlux.Caption = Str(dblFlux)
End Sub
```

3.4.5 Distribution of Questionnaires to Airport Officials

Questionnaires were randomly distributed among major crews that do operate and being frequently exposed to electromagnetic field from Radio-Frequency Based Infrastructures (RF-BI) within the Airport. These crews are the Operators of EMF based Infrastructures, Aircrafts' Operation and

Maintenance Crew (AOMC) and Airfield Control Staff (ACS). Moreover, the operators of EMF-BI within the Airports are Airport staff that operates devices such as the Electromagnetic Luggage Scanning Machines, Operators at the Airport's Control Tower, among others. While the Aircraft's Maintenance AOMC consists of the Pilots, Aircraft Maintenance Engineers (AME) and Aircrafts' Components Supplier (ACS); the Airfield Control Staff (ACS) is a crew that spatially direct the movement of the Aircraft by giving appropriate control signals to the pilot at take-off and packing.

Hence, one hundred questionnaires were distributed using the following percentages:

i. Operators of EMF based Infrastructures within Airport - 30%.
ii. Aircrafts' Operation and Maintenance Crew (AOMC) – 40%.
iii. Airfield Control Staff (ACS) – 30%.

3.5 Ethical Approval

Airport is a highly sensitive and secured environment. Movement within the Airport and its immediate environment are restricted. Thus, official permission was sorted through letter of introduction stating my Aim and objectives about the research study from the Department/my Supervisor to the Airport Management. The management subsequently gave ethical approval whose softcopy is attached in appendix D and the workflow for all the aforementioned procedures is shown in Figure 3.8,

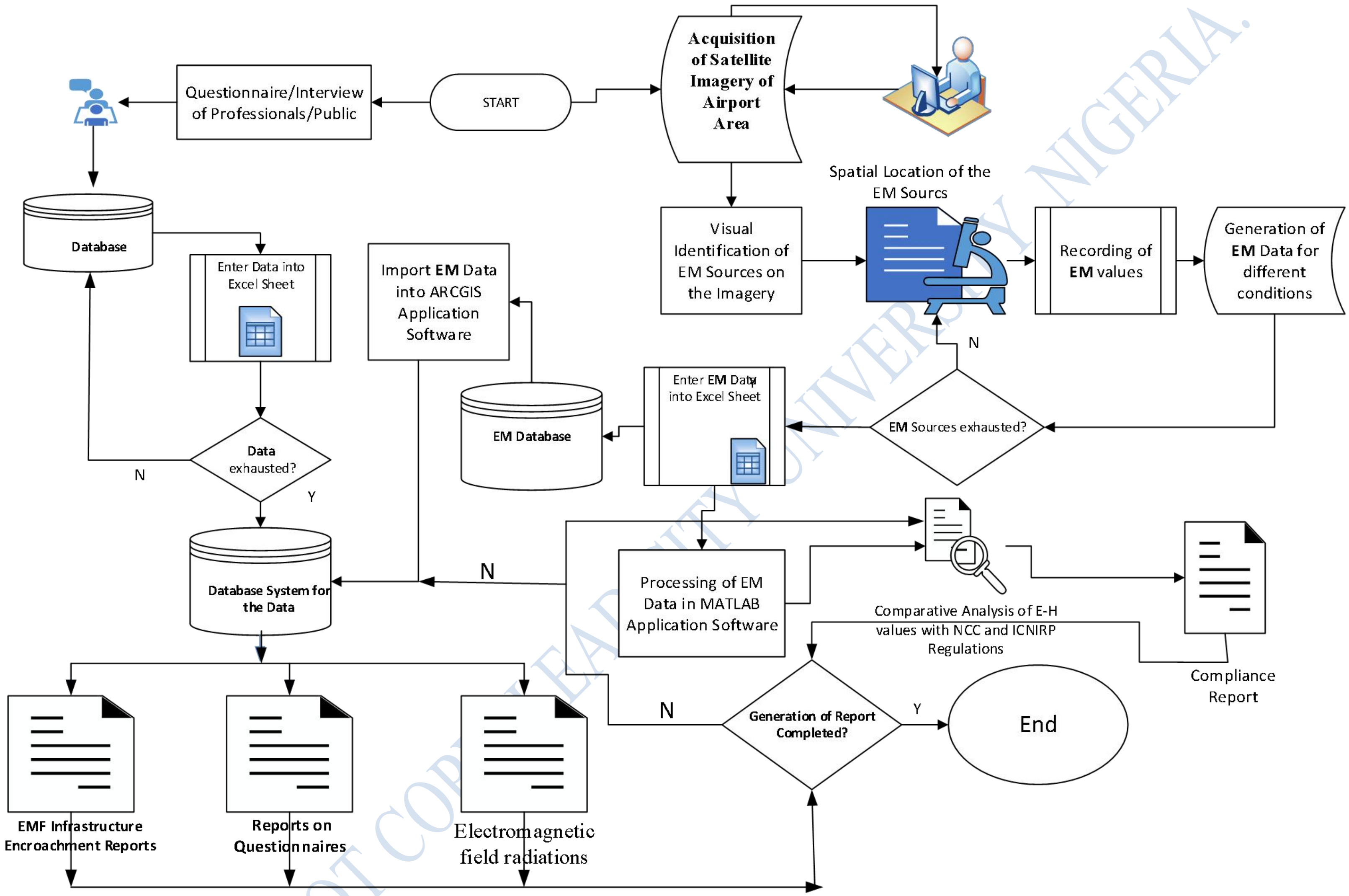


Figure 3.8: Flowchart for Research Procedures

Endnotes

[1.]R. Hess. *Electromagnetic Environment* (EME), accessed from http:// www.davi.Wsavionics /The Avionics Handbook_Cap_25.pdf 2020

[2.] EME Spy Evolution 2019, accessed from https://www.radiansa.com/datasheets/EME_SP.

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Chapter Four

Results and Discussion of Findings

4.1 Results

The landing of the first aircraft in 1925 provided the British imperial government a view of their possibility of citing airfields in Nigeria. An officer of the Air Ministry in London came to Nigeria in 1930 to access the feasibility of establishing landing grounds in Nigeria [3]. Before this, the Royal Air Force had consistently landed on the grounds in Kano and Maiduguri carrying mails from England to the northern protectorate for onward transmission to the colony of Lagos. The Imperial Airways began flight into Nigeria in 1935. The Air Ministry in London identified Azare, Bauchi, Bida, Benin Kebbi, Biu, Brass, Bussa, Gboko, Gusau and Katsina as potential airport sites. The task to build the stated airports was given to the Public Works Department[2]. This assignment was what aided the building of most Airport in Nigeria including Muritala Mohammad Airport and Ibadan Airport.

Implementation of the objectives proposed in chapter one and research methodologies discussed in chapter three facilitated the generation of expected results. Hence, the results generated during the research study are:

i. Current status of the setback around Ibadan Airport.
ii. Spatial and quantitative information on Electromagnetic Field (EMF) based Infrastructures around Ibadan Airport.
iii. Mapping of landuse change and encroachments around Ibadan Airport.
iv. Results from the questionnaires on the impacts of electromagnetic field on airport's workers within and around Ibadan airport.
v. Implementation status of INCIRP Regulations on Ibadan Airport.

4.1.1 Current Status of the Setback around Ibadan Airport

In accordance to the 2009 guidelines of the National Communications Commission NCC, no communication masts or towers, regardless of its height, shall be erected within 15 kilometers of any airport[1]. In line with this regulation, the information generated on the processed high resolution satellite imagery of Ibadan Airport in ArcGIS application software as indicated in Figure 4.1 indicated that even at spatial distance $R,\ 1km \leq R \leq 2km$ buffering from the airport fence, numerous infrastructures were noted. These infrastructures include EMF based infrastructures, buildings and other infrastructures as shown in Figure 4.2.

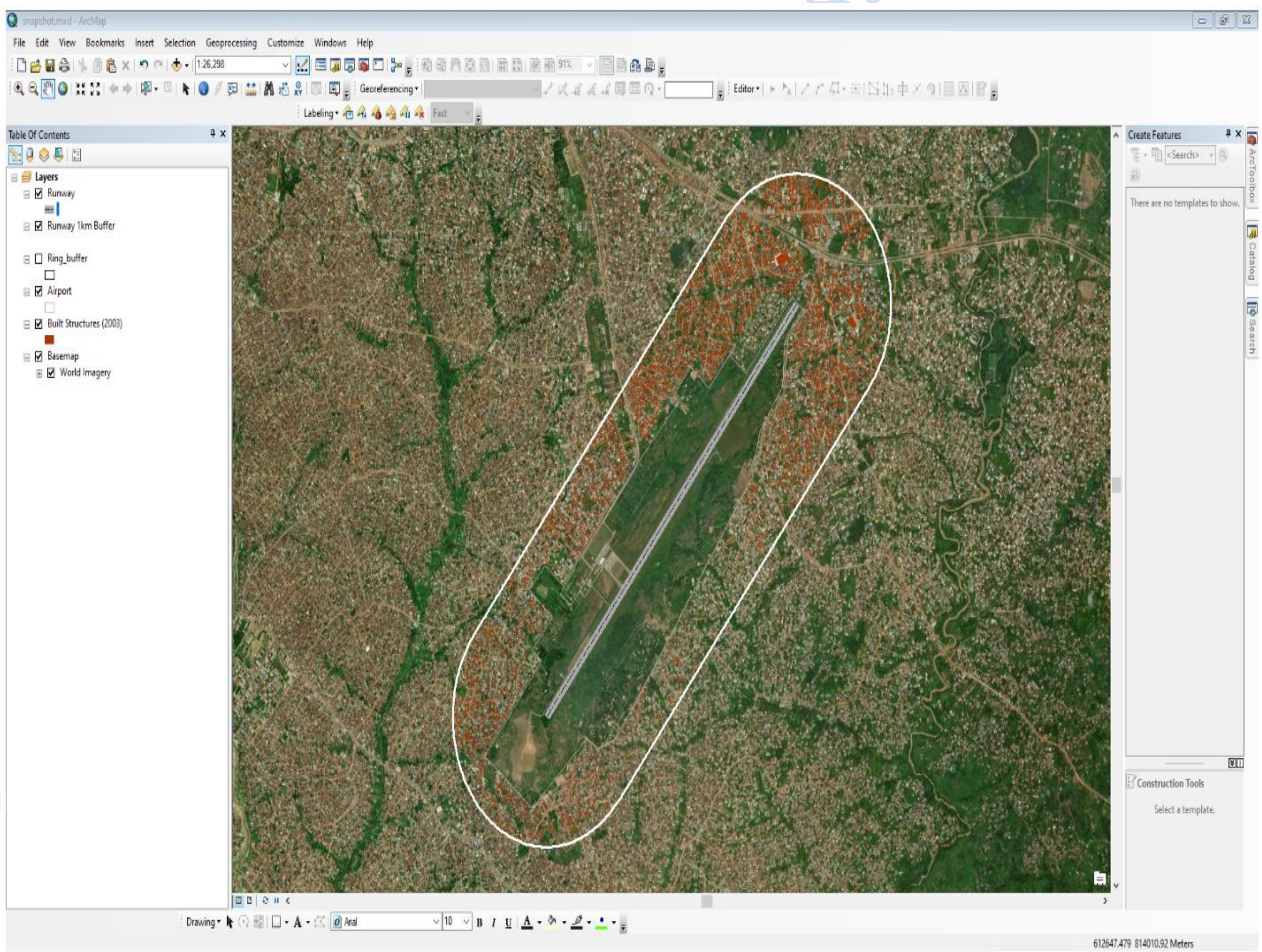

Figure 4.1: Snapshot of ARCGIS Software showing Infrastructures on Airport's Setback

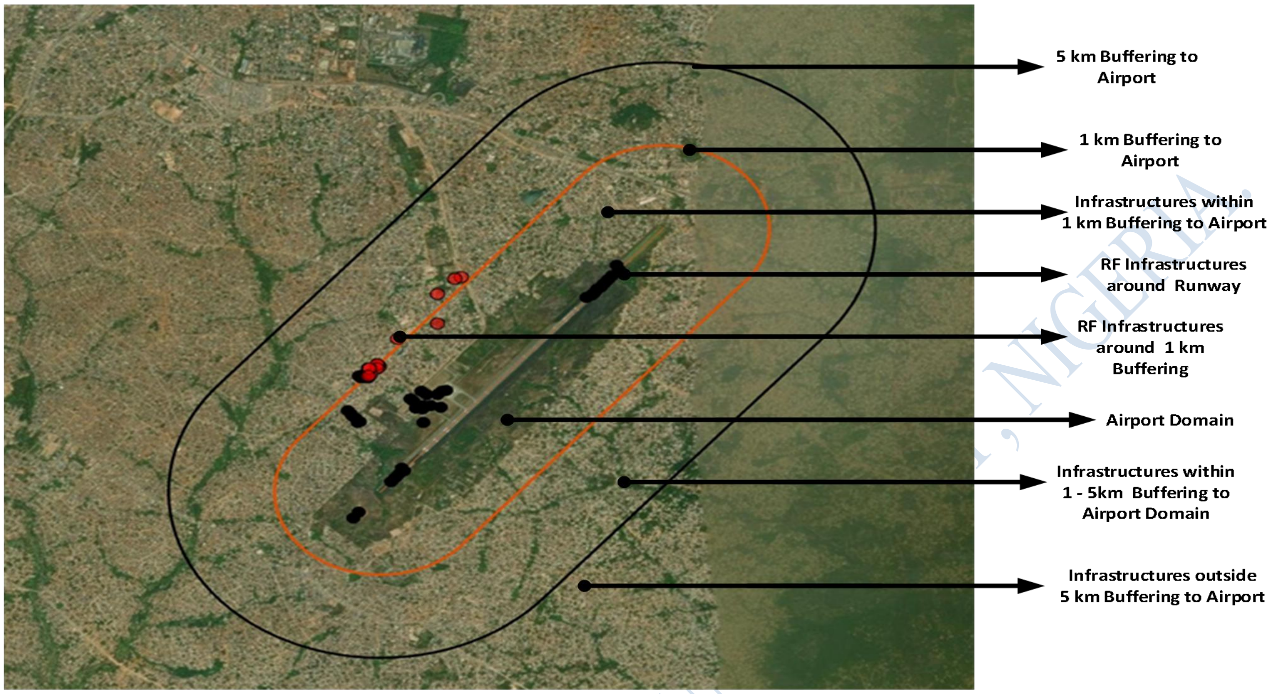

Figure 4.2: Satellite Imagery Showing Non-Compliance Infrastructures Around Ibadan Airport

These were confirmed during the field work of the research study and Plates 4.1 shows samples of infrastructures located within and around Airport domain as illustrated in Figure 4.2. Also, information generated on EMF based infrastructures at $1km \leq R \leq 5km$ buffering to the Airport (satellite based output) is compiled in Table 4.1 while comparative report for built structures within 200 m stepwise buffer from the airport runway for 2003 and 2022 is shown in .

Electrical Transformer on Airport Setback Communication Repeater within Airport

Figure 4.3: EMF Based Infrastructures Around and within Ibadan Airport (Field Report, 2022**)**

Table 4.1: Infrastructures on Airport setback @ Spatial distance 1km ≤ R ≤ 5km

S/N	Types Of Infrastructure	Estimated Quantity	Nearest Spatial Distance	Estimated Infrastructures @ 1km² Spatial Area
1	Housing units	13,000+	150 m	101
2	Shopping Mall	05	1000 m	02
3	Workshops	10	100 m	03
4	Schools	10	250 m	02
5	Corporate Company/Offices	03	500 m	01
6	Farms	20	100 m	05
7	Hotels	20	500 m	04
8	Estate	03	350 m	01
9	Banks	06	1500 m	01
10	GIM Centres	01	1000 m	01
11	Churches	10	250 m	02

Source: Field Report. 2022.

Table 4.2: Statistics Result for Built Structures within 200 m buffer from the Airport Runway

SN	Distance to Runway (m)	Number of Structures in 2003	Number of Structures in 2022
1	200	128	258
2	400	615	1093
3	600	1594	3036
4	800	3348	6711
5	1000	5240	10854

Source: Field Report. 2022.

4.1.2 Information Generated on Electromagnetic Field (IMF) based Infrastructures

Spatial and quantitative information on Electromagnetic Field (EMF) based Infrastructures within and around Ibadan Airport were obtained through the satellite imagery, Global Position Satellite (GPS) receiver and EMF field meter. Thus, one hundred and forty-seven datasets were collected and sample of the datasets is shown in Table 4.3 while the detail results are depicted in appendix E.

Table 4.3: Radiation from EMF based Infrastructures within and around Ibadan Airport

S/N	Name of RF Sources	Spatial Locations of RF Sources			Electromagnetic Radiation Detected		
		Latitude	Longitude	Altitude	Electric Field **E** (V/m)	Magnetic Field **H** (mG)	Power Density (mW/m^2)
1	Runway 22 localizer Xmer	7.37431	3.98786	729	0.015	0.004	0.986
2	22 Localizer Transmitter	7.37389	3.98798	725	0.019	0.003	2.612
3	Localizer Indicator	7.37325	3.98741	723	0.008	0.007	0.124
21	Control Tower	7.35999	3.97	750	0.028	0.002	12.6
22	Comms Antenna 3	7.36074	3.97324	758	0.034	0.076	10.7
23	Departure Hall	7.36061	3.97286	772	17.251	0.129	12.21
26	Weather Station	7.3591	3.9719	399	0.056	0.003	0.022
30	Cooperative Building	7.35909	3.97123	770	0.091	0.014	0.129
31	Transformer Unit	7.35955	3.97046	780	0.035	0.088	1.721
32	Feeder Pillar	7.35985	3.97019	772	0.019	0.003	0.908
36	Ayedun Mast by Airport	7.36209	3.96657	580	0.079	0.035	1.825
37	56 Ayedun Commty Zone2	7.36209	3.96626	760	0.006	0.016	5.354
46	8 Inu ewe	7.35721	3.9656	739	0.019	0.003	14.96
47	Abundant Model School Inu	7.35773	3.96548	730	0.008	0.007	11.13

	Ewe						
52	Cell Tower	7.36296	3.97252	230	0.01	0.000	5.231
53	Cell Tower	7.37409	3.97512	234	0.00	0.00	2.510
116	Power Line	7.39119	3.97058	233	31	0.25	0.037
151	Wifi/Phone	7.40405	3.95727	244	41	0.02	20.62
152	Broadcasting Tower	7.40769	3.92835	228	55	0.02	12.24
153	Broadcasting Tower	7.41224	3.93169	241	0.00	0.00	0.103

Source: Field Report. 2022.

The EMF based infrastructures accessed within and around the Airport include but not limited to WiFi transmitters, cell towers, electrical transformers, multiple sources of EMFs (Mixed), Frequency Modulation (FM) radio stations, Television stations, Communication Antenna, Localizer Antenna, Industrial Generator House, Feeder pillar, Weather Station, Schools, encroaching community, among others.

4.1.2.1 Spatial Distance of RF based Sources and Flux Density at Airfield Landing Point

The Inverse Distance Weighted (IDW) model expressed in equation 3.3 (a) was utilized to obtain the distance between the RF based sources and the entering point of aircraft at airfield. The model is incorporated in ARCGIS application software and it thus facilitated the computation. Moreover, equation 3.3(b) was used to obtain the range R between the entering point of aircraft at airfield and location of the EMF based infrastructure around airport (spatial point 2) where the

location and/or certainty of an RF source is not clear on satellite imagery. The minimum, maximum and average spatial distances R are 0.161561986 m, 1015.806314 m and 616.0426776 m respectively; while the minimum, maximum, average and total flux density measured are $3.54233 \times 10^{-12}\ W/m^2$, 0.021048083 W/m^2, 0.000167837 W/m^2 and 0.024504134 W/m^2, respectively. Other samples of the values are composed in Table 4.4 while appendix F shows the details of other values.

Table 4.4: Power/Flux Densities and Nearest Distances of RF Sources to Airport's Airfield

S/N	RF Infrastructures	Power Density (Pt) (W)	Nearest Distance (R) (m)	Flux Density (F) (W/m^2)
129	Cell Tower	2.513	337.5239244	1.75539E-09
130	Mixed	1.825	969.4182902	1.54536E-10
24	Weather Station	71.270	931.6844378	6.53370E-09
132	Mixed	5.783	986.1469095	4.73217E-10
133	Cell Tower	3.613	1011.889207	2.80797E-10
134	Wifi/Phone	3.193	849.8155418	3.51836E-10

Source:Field Report, 2022**.**

4.1.2.2 Spatial Variations of Encroaching EMF Radiations around the Airport's Runway

The electromagnetic radiations within and around Ibadan Airport varies spatially with numerous electromagnetic field based infrastructures towards the aircrafts' landing area. At the major part of the Airport environment as shown on the EM variation map in Figure 4.2, some EM radiations with the power flux density range of 0.15 to 150.86 $mW\ per\ m^2$ (deep green colour) were mostly noticed. Between $3^0$59'0" E and $7^0$22'0" E spatial area, radiation with flux density within the range of 150.87 and 301.57 $mW\ per\ m^2$ (light cream colour) were observed encroaching the runway from the take-off and landing points. More so, EM radiations with flux density between

the range of 452.28 to 602.98 $mW\ per\ m^2$ were engulfed in 602.98 to 753.68 $mW\ per\ m^2$ EM radiations (white colour) along and towards the take-off areas of the airfield.

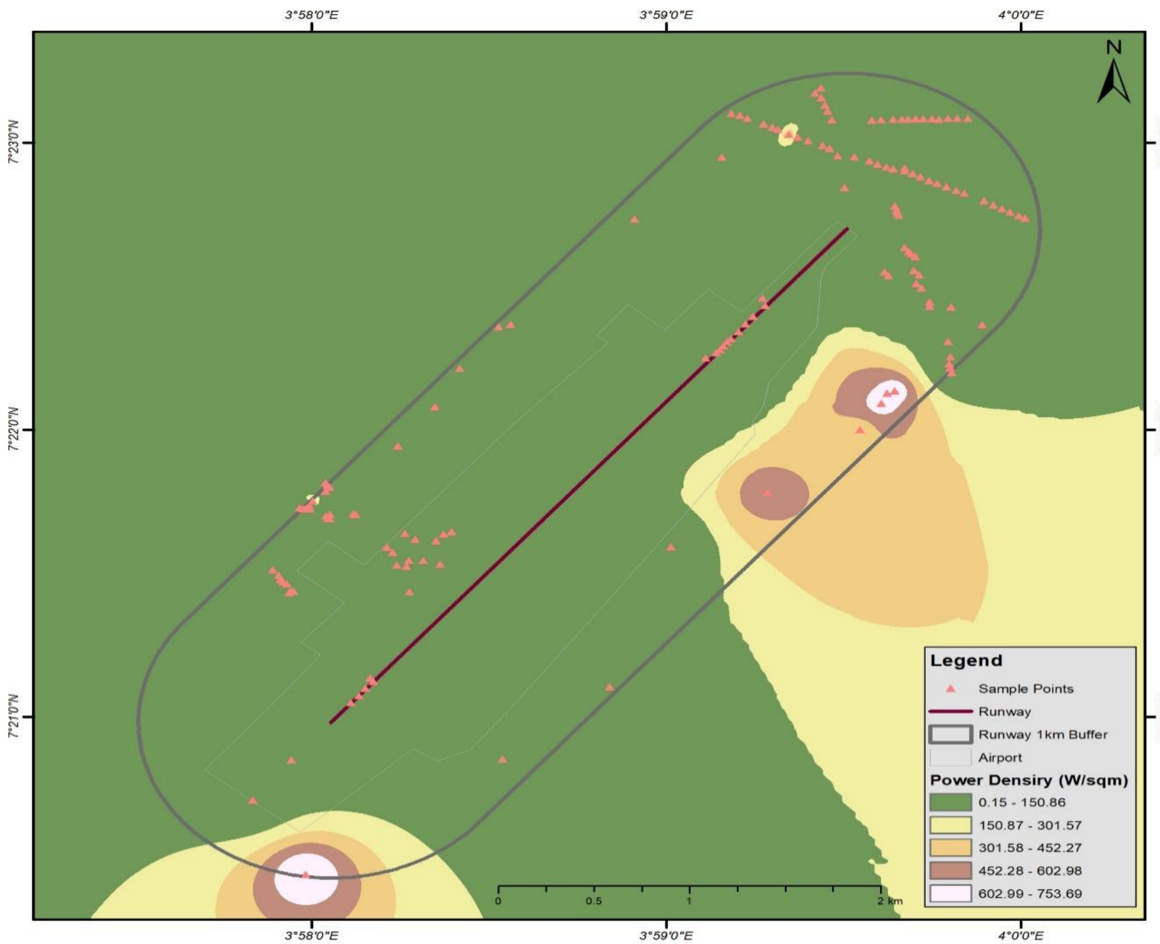

Figure 4.4: Encroaching EMF radiations around the Airport (Field Report, 2022)

4.1.2.3 Mapping of Landuse Change and Spatial Encroachments around Ibadan Airport

The results on encroachment into the airport was generated by mapping the satellite imageries from the google earth pro application[4]. The timeline tool in Google Earth (GE) was used to view the area's historical images. The oldest high-resolution image was collected in 2003. The 2007 imagery is comparatively illustrated with 2022 map of the study area as depicted in Figure 4.3.

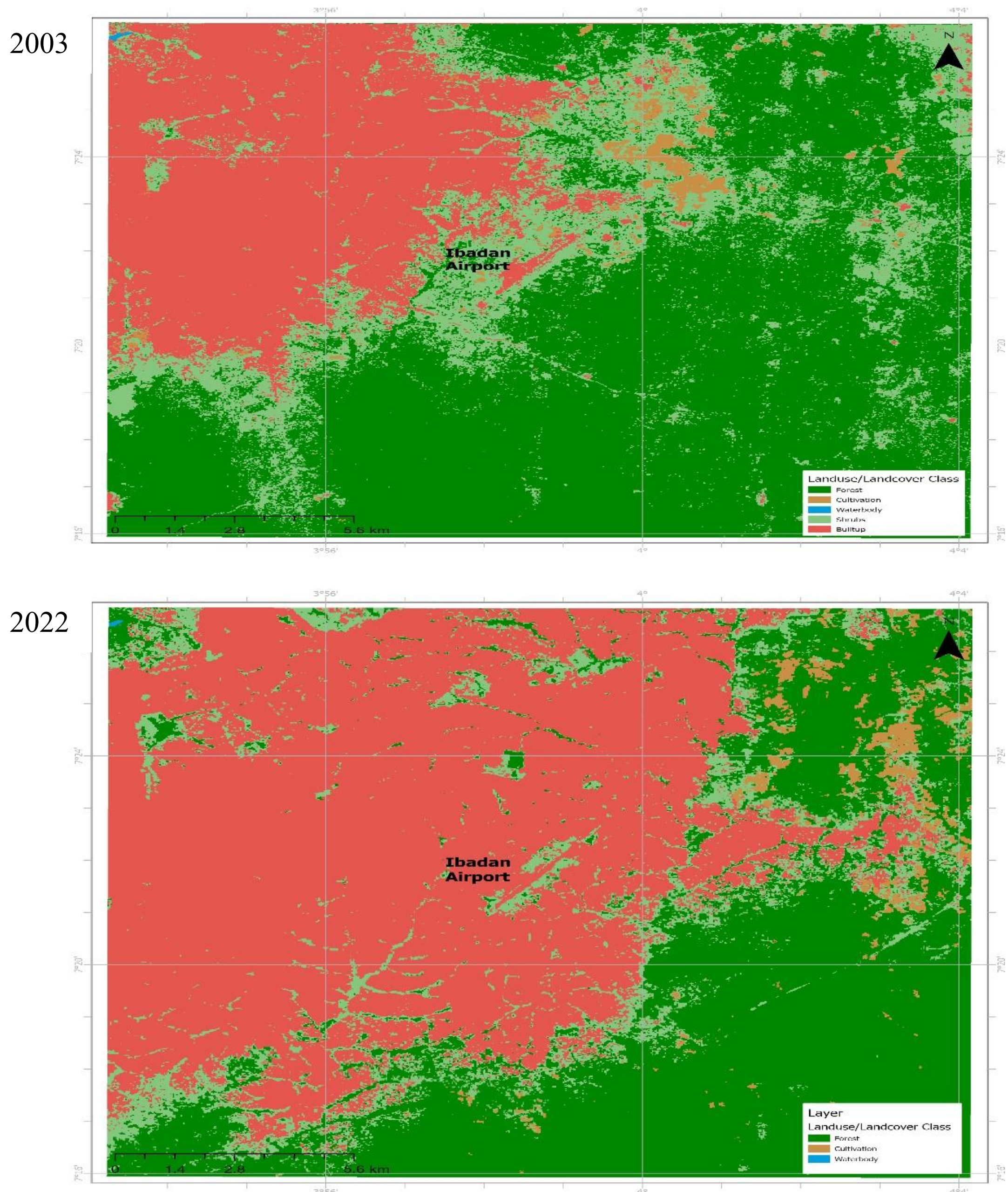

Figure 4.5: Satellite Imageries for Landuse Dynamics of the Study Area (2007 and 2022)

More so, built structures within 1 km of the airport runway were extracted into saved places for 2003 and 2021. The saved place was exported as km^2 for both years. The satellite imageries depicting the landuse dynamics with other classes of features for the area is shown in Figure 4.4 while Figure 4.5 shows the comparative analysis of the built structures for 2003 and 2022.

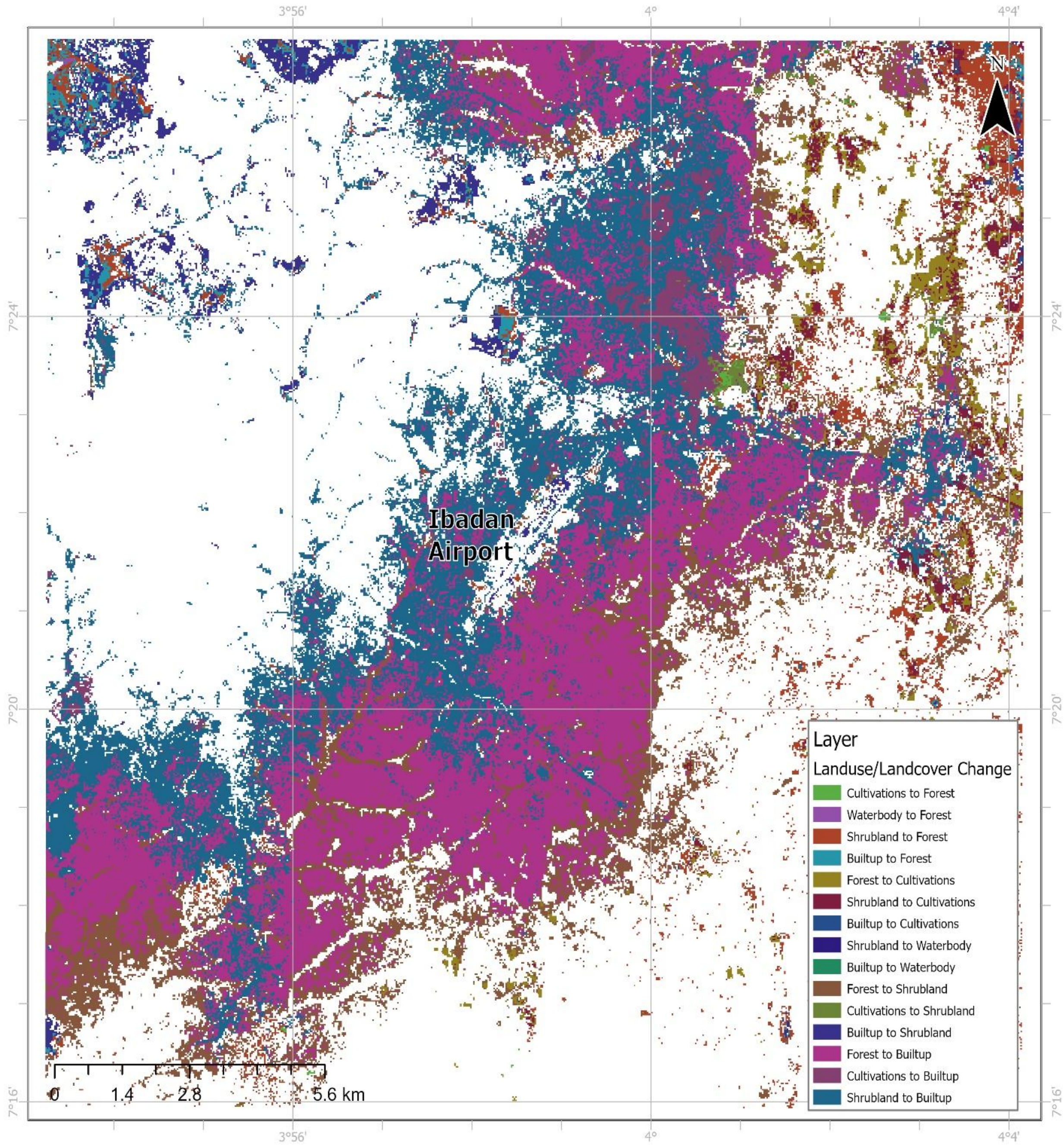

Figure 4.6: Land Use Dynamics with Other Classes of Features (Source: Field Report, 2022)

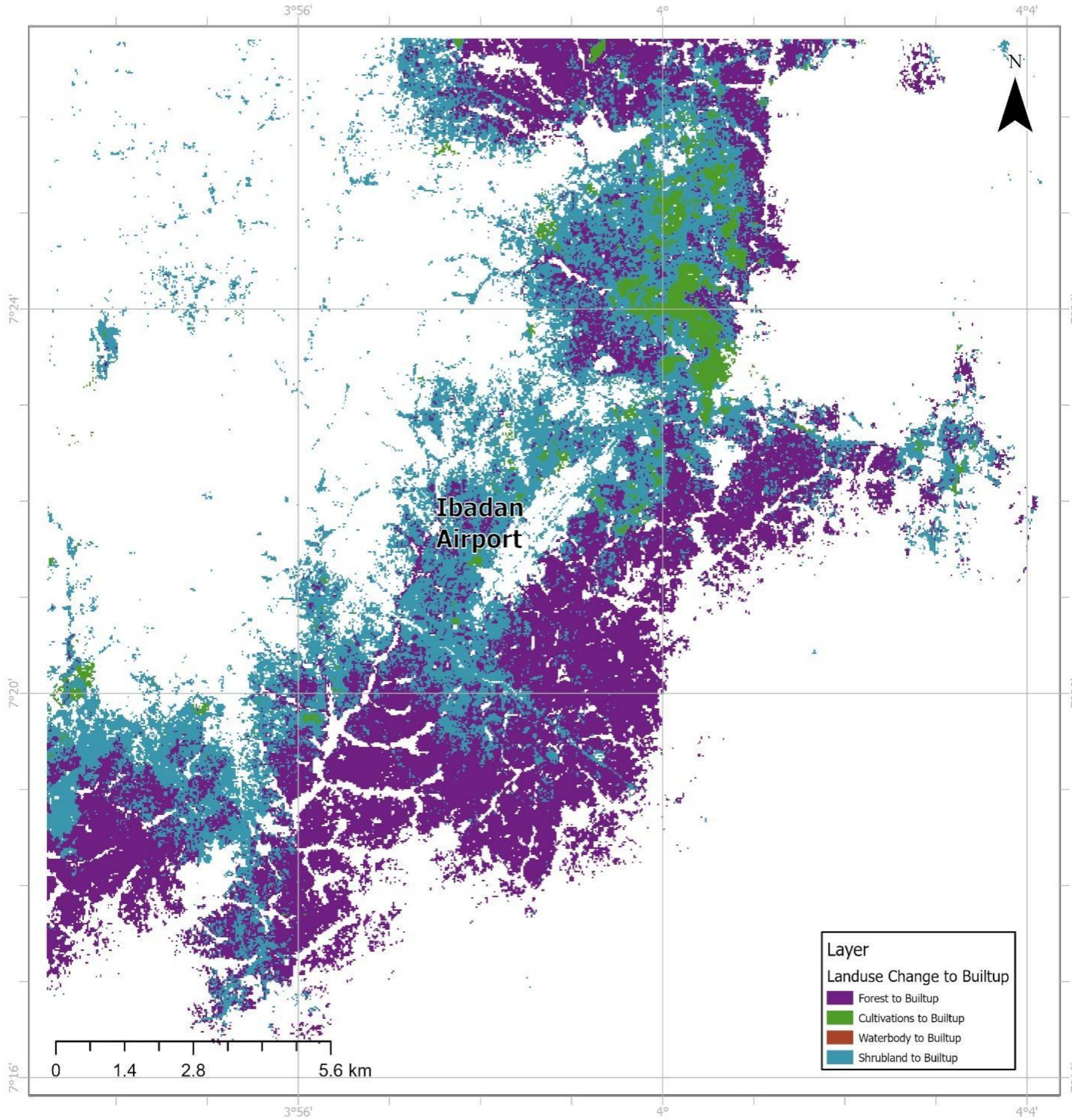

Figure 4.7: Land use/Land cover Change from 1987 to 2022 (Source: Field Report, 2022)

In addition, the proximity analysis was done using multiple rings buffering of 200 m, and the statistics of the buildings inside each ring were extracted. The building density was created using the Inverse Distance Weighted average tool, a deterministic approach for multivariate interpolation using a known distributed collection of points. Using equation 3.3 (a), a weighted average of the values present at the known points was used to determine the values allocated to the unknown location/point [7,11]. Figure 4.5 shows the results of the proximity analysis while the density of the structures is shown in Figure 4.6.

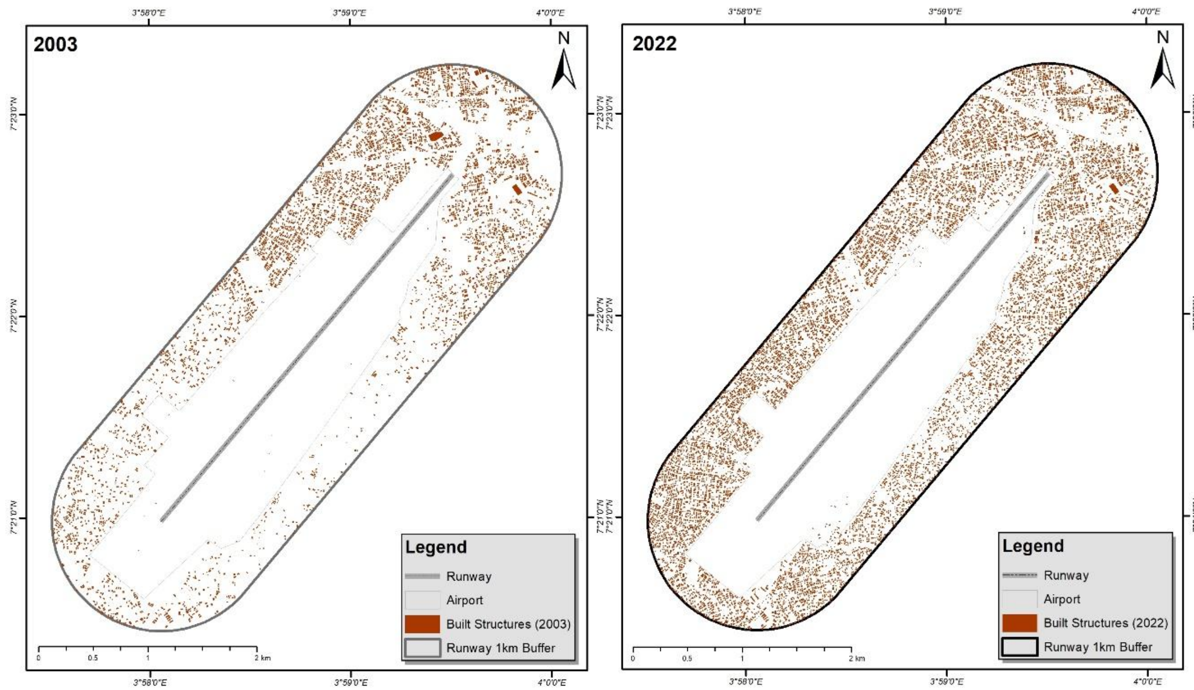

Figure 4.8: Built Structures Within 1 km of the Airport Runway for 2003 and 2022

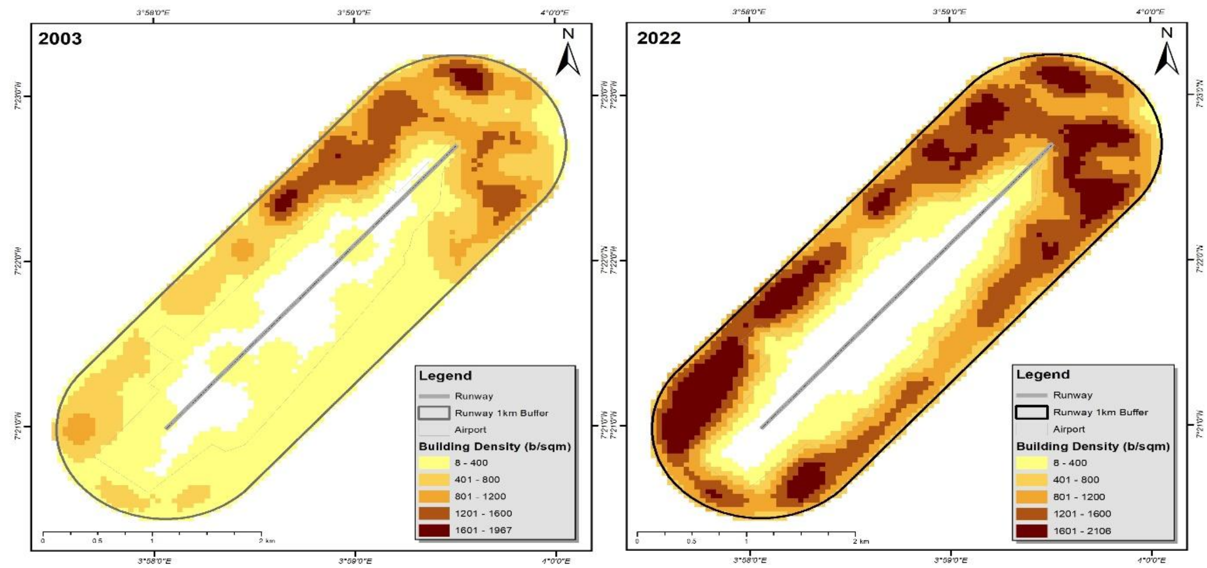

Figure 4.9 : Density of the Built Structures within 1 km distance around the Runway

4.1.3 Questionnaires' Report showing the Impacts of EM field on Airport's Workers

The results from the one hundred questionnaires distributed among the three major categories of Airports workers stated in section 3.4.5 of Chapter Three were extracted and tabulated as shown in Table 4.5. From the table, some respondents responded to all the questions, while neutrality of responses were observed on some questions. However, 80% of the respondents for Question nine which centered on sitting approval for the location of EMF based infrastructures around Airport stated that they collected approval from National Airport Management Agency (NAMA) while 90% remained neutral on operation of such EMF based infrastructures from NAMA.

Table 4.5: Results from the Questionnaires on the Impacts of EM field on Airport's Workers

QUESTION'S TAG	OPTION A TOTAL RESPONSES	OPTION B TOTAL RESPONSES	OPTION C TOTAL RESPONSES	OPTION D TOTAL RESPONSES	OPTION E TOTAL RESPONSES	NEUTRAL RESPONSES	TOTAL RESPONSES PER QUESTION
1	2	1	0	0	97	0	100
2	1	0	0	0	99	0	100
3	0	0	0	0	100	0	100
4	100	0	0	0	0	0	100
5	98	0	0	1	1	0	100
6	78	2	0	0	20	0	100
7	45	27	16	0	0	0	100
8	55	1	15	0	17	12	100
9	48	31	0	1	0	20	100
10	11	0	11	65	0	13	100
11	0	0	10	0	0	90	100
12	17	6	55	1	1	23	100
13	16	3	29	32	0	20	100
14	1	2	2	84	0	11	100
15	1	1	1	85	1	11	100
16	2	69	2	10	0	17	100
17	1	1	0	86	2	10	100
18	26	21	43	0	0	10	100
19	2	0	0	0	79	19	100
20	0	34	18	36	1	11	100
21	32	58	0	0	0	10	100
22	0	58	15	0	17	10	100

Source: Field Report, 2022

4.2 Discussion of Findings

The research study aimed and investigated the impacts of electromagnetic interference and geo-spatial encroachment of EMF based infrastructures on Aircrafts and Airports' staff, within and around Ibadan Airport. Based on stated objectives, following findings is discussed.

- Spatial existence of EMF generators within and on 15 km setback of Ibadan Airport.
- Analysis of numeric values of computed electromagnetic field radiations.

- Power Density Radiations and encroachment of RF Sources.
- Spatial variability of EMF waveforms within and around Ibadan Airport.
- Analysis of Questionnaires' Results based on Impacts of EM field.
- Comparative analyze of results with the NCC regulations on EMF interference.
- Evaluation of compliance using ICNIRP standard on EMF exposure to airport workers.

4.2.1 Spatial existence of EMF based Infrastructures within 15 km setback of Ibadan Airport

The sharp practices due to deregulation policy in aviation industry reported by Umezurike I.S. and Adamson D.G. [10] where qualitative research technique was utilized in June 2020 could facilitate building of infrastructures at close range of about 1000m on Airport's setback, as compiled by this research study[14]. The spatial variability of these structures are illustrated in figure 4.8.

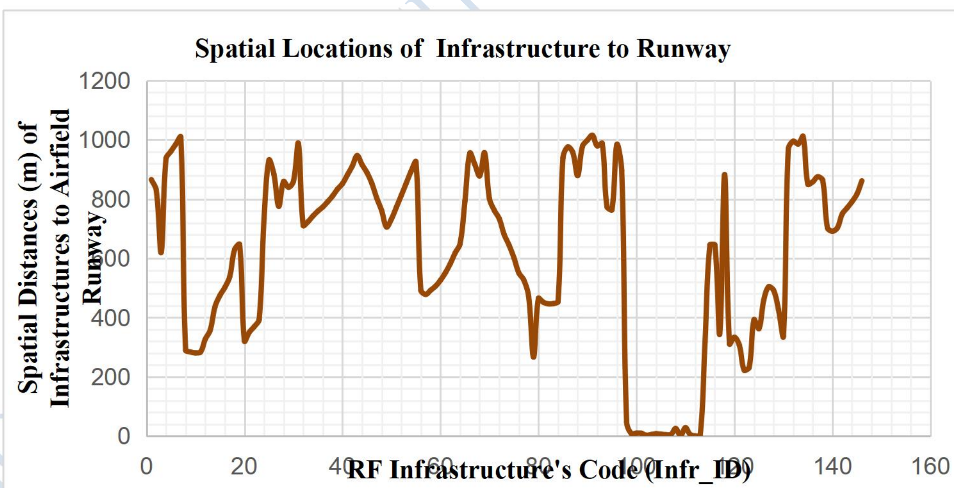

Figure 4.10: Graphical Analysis of Infrastructures around Airport

As illustrated in Figure 4.8, some infrastructures are sharing boundary with the fence of the Airport at spatial location of less than 1.0 m (0.161561986 m). The infrastructure at this location is Localizer Transformer with Infrastructural Identification Code (Infra_Code) of 110. Also, six major classes of RF infrastructures and their quantitative analysis is shown in Table 4.6; with mixed EMF sources having the largest value of total power density (i.e. 3037.681 mW/m^2)

Table 4.6: Quantitative Analysis of RF Infrastructures within and around Ibadan Airport

S/N	Types of Infrastructure	Quantity	Minimum Power Density (mW/m^2)	Maximum Power Density (mW/m^2)	Total Power Density (mW/m^2)	Nearest Distance (m) to Airfield's Runway (Minimum)	Nearest Distance(m) to Airfield's Runway (Maximum)
1	Power Lines	20	0.043	752.7	957.85	345.2026999	925.8790304
2	RF Infrastructures within the Airport	32	0.022 (Weather Station)	14.19 (Plus 25m)	125.324	0.161561985915 (50 m away from Antenna	882.8631391 (Control Tower)
3	WiFi Radiations	22	0.026	418.9	1718.968	492.2962806	988.7435157
4	Cell/Communication Towers	27	0.04 (Infr_Code 11)	71.269999 (Infr_Code 25)	390.467	282.915709956 (Infr_Code 11)	985.749183958 (Infr_Code 11)
5	Communities / Schools/Power Transformer	10	0.3061 (Infr_Code 142)	14.96 (Infr_Code 141)	81.0076	337.523924353999 (Infr_Code 130)	1011.88920694 (Infr_Code 134)
6	Mixed EMF sources	27	0.063 (Infr_Code 142)	696.80 (Infr_Code 28)	3037.681	266.631636365 (Infr_Code 130)	1015.806314 (Infr_Code 91)

Based on the analysis of the satellite imageries of the study area in ArcGIS, the trends of growth of infrastructures around airport domain which are sited on the Airport's setback between 2003 and 2011, especially housing structures had increased more than 50%. This is illustrated with chat in Figure 4.10. To prevent previous occurrence of multiple casualties as seen between 1941 and 2013 where 123 aircrafts had crashed[13], safety and regulations in Nigerian airspace must be maintained.

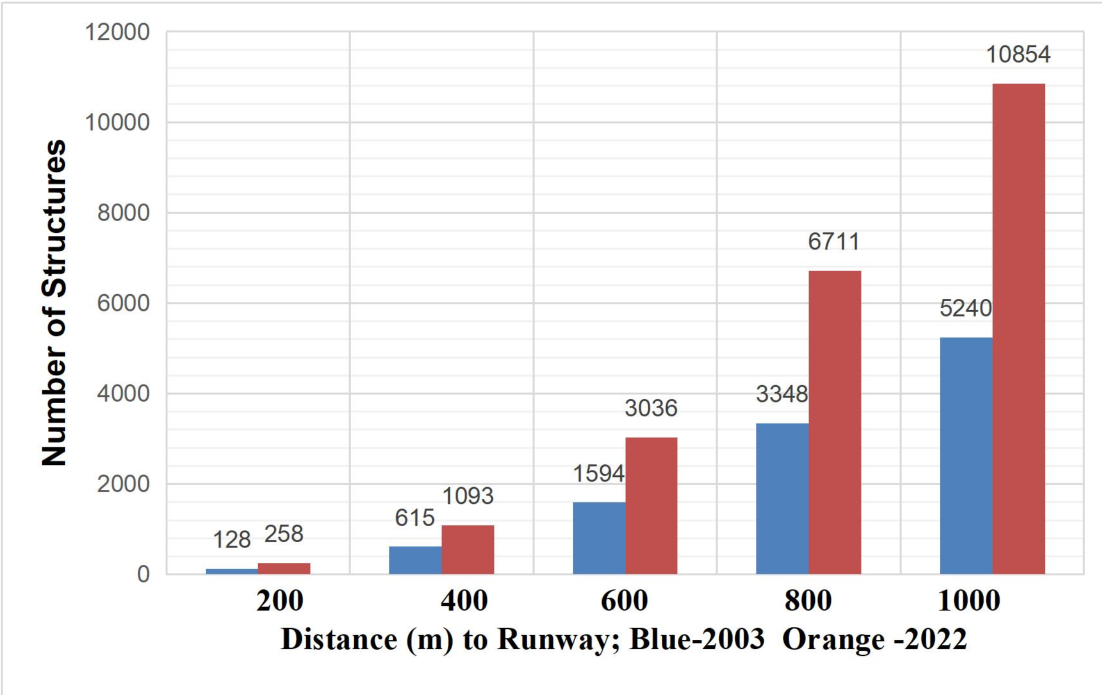

Figure 4.11: Comparison of Built Structures around Ibadan Airport
Source: Field report, 2022

4.2.2 Analysis of Numeric Values of Computed Electromagnetic Field Radiations

The numeric values of the computed electromagnetic EMF field radiations measured and the electromagnetic flux densities computed has minimum, maximum and average values of $3.54233 \times 10^{-09} mW per\ m^2$, $21.048083\ mW per\ m^2$ and $0.167837\ mW per\ m^2$, respectively. These were discovered at minimum, maximum and average spatial distances of $0.161561986\ m$, $1015.806314\ m\ (\cong 1.01581\ km)\ and\ 616.0426776\ m$ to the airport's airfield[14] . However, the total sum of radiations as reflected through encroaching EMF radiations around the Airport in Figure 4.2 has a numeric value of $24.504134\ mW per\ m^2$.

4.2.3 Power Density Radiations and Encroachment of RF Sources

The resultant radiation of 24.504134 $mW per\ m^2$ stated in session 4.2.2 is produced from RF sources that are installed on the set-back of the airport. These sources include FM Radio Station antenna, Television broadcasting station antenna, cellular communication base station antenna[14], among others. All these infrastructures are structurally located at spatial locations of less than 2.0 km (far below 5.0 km stipulation of NCC) and they serve as sources of transmitting stray electromagnetic to the aircraft around the airport. But, Alejandro, *et.al*., reflected that the propagation of radio signals in a TV broadcasting system is affected by the interactions of the electromagnetic wave with the propagating medium, causing various sorts of effects that need to be considered in system evaluation, network planning, and broadcast service operation[15]. These effects do affect the operation of aircraft digital control panel.

In addition, the two main architectures for terrestrial broadcast networks commonly used depending on transmit power levels and transmit antenna heights are also part of the RF sources as tabulated in appendix E. These are the traditional High-Power High-Tower (HPHT) network, which consists of elevated transmitting sites that have Effective Radiated Power (ERP) values in the range of dozens of kW with; transmitting antenna heights typically range from 150 m to 300 m. On the other hand, Low-Power Low-Tower (LPLT) networks that have typical transmitting antenna heights of up to 40m and ERP of a few kW. All these structures aided generation of encroaching electromagnetic radiation[15].

4.2.4 Spatial Variability of EMF Radiations Within and Around Ibadan Airport

An antenna is the portion of a radio system that can take radio energy from a transmission line and radiate it into space in a predictable pattern, and receive radio energy from open space and feed it back down a transmission line. The radiant flux as a function of the distance from the transmitting antenna varies according to the inverse-square law, since that describes the geometrical divergence of the transmitted wave. For a given incoming flux, the power acquired by a receiving antenna is proportional to its effective area. The power supplied to the antenna terminals which is not radiated is converted into heat. This is usually through loss resistance in the antenna's conductors, or loss between the reflector and feed horn of a parabolic antenna[16].

When the body system of an aircraft acts as antenna due to spatial variability of EMF radiations with high flux density[14] of 24.504134 $mW per\ m^2$ encroaching the airfield and the runway, the non-radiated power could be converted to heat energy. This could affect the digital systems of the aircraft. The spatial variability of the electromagnetic field within and around Ibadan Airport obtained during the days mostly between 10 am and 2pm is illustrated in Figure 4.9.

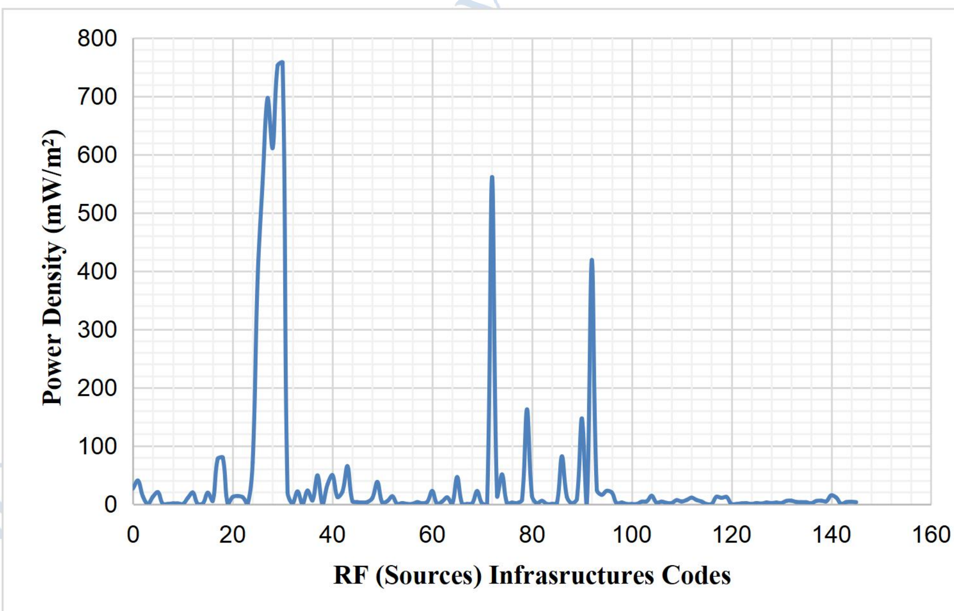

Figure 4.12: Spatial Variability of Electromagnetic Power Density
Source: Field work, 2022

In addition, the computed flux densities from the RF based infrastructures to the Airfield's runway within and around the Airport ranges in picoWatt per m^2 (5.70709E-12) to mWatt per m^2 (24,054 mW/m^2). Meanwhile, the magnitude of the resultant flux density at the field runway is computed as 29.008267 mWatt per m^2. The trend of the computed flux densities is shown in Figure 4.10.

4.2.5 Variability of Electric and Magnetic Field around the Study Area

The values of electric and magnetic field measured from the RF based infrastructures within and around Ibadan Airport varied spatially and temporally. Out of the 181 datasets obtained for radiated electromagnetic field, 90 datasets showed 0 v/m of electric field at different spatial locations. Moreover, 80 datasets reflected a range values of 0.1 V/m to 10.0 V/m while other values of electric field which are scantly scattered between 20 V/m and 60 V/m were measured around the cell towers. Within the Airport, the departure hall located at latitude 7.36061 N, longitude 3.97286 E and altitude of 772m has electric value of 17.251V/m and the highest peak value of 74.0 V/m was observed from static electromagnetic radiation from an Aircraft at latitude 7.40001 N, longitude 3.89964 E and altitude 220m. The variability of the electric field from all RF based infrastructures sighted is shown in Figure 4.10 while Table 4.9 shows values of static electric charges recorded from other Aircraft.

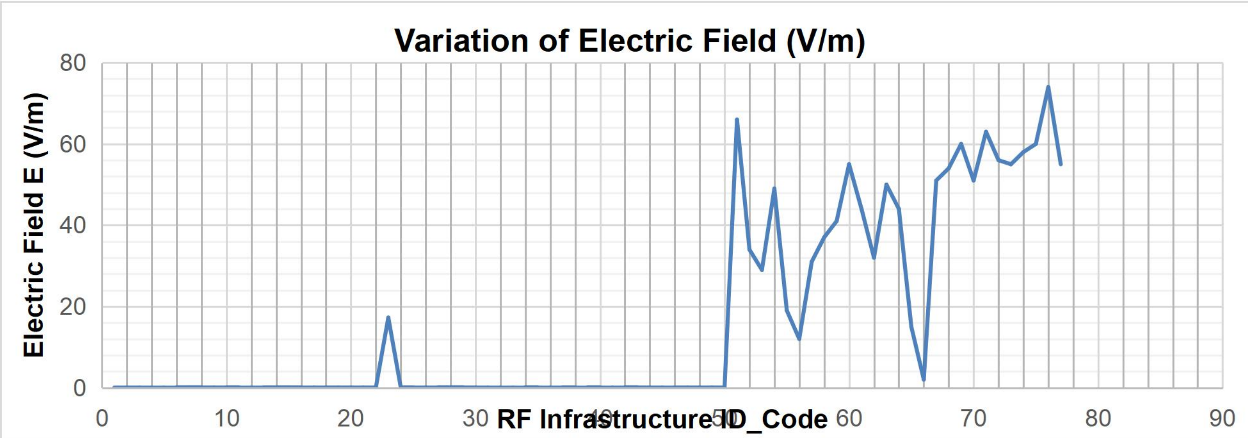

Figure 4.13: Variability of Electric Field Radiation at the Study Area

Source: Field work, 2022

Table 4.7: Static Electric Field Recorded Around Aircrafts

RF INFR_ID Code	Name of RF Sources	Spatial Locations Of RF Sources			Electromagnetic Radiation Detected		
		Latitude N	**Longitude E**	**Altitude (m)**	**Electric Field E (V/m)**	**Magnetic Field H (mG)**	**Power Density (mW/m^2)**
170	Static	7.3986	3.90811	212	51	0.00	2.495
171	Static	7.39879	3.90666	217	54	0.00	1.581
172	Static	7.39892	3.90592	218	60	0.00	5.391
173	Static	7.39906	3.90489	214	51	0.00	10.47
174	Static	7.39921	3.90376	208	63	0.00	7.811
175	Static	7.39927	3.90321	205	56	0.00	9.767
176	Static	7.39937	3.90257	201	55	0.00	43.20
177	Static	7.39953	3.90134	198	58	0.00	5.607
178	Static	7.39963	3.90067	198	60	0.00	9.693
179	Static	7.40001	3.89964	220	74	0.00	4.918

Source: Field work, 2022

4.2.6 Analysis of Questionnaires' Results based on Impacts of EMF Radiation

The twenty questions for the field questionnaire which were computed for Operators of EMF based Infrastructures, Aircrafts' Operation and Maintenance Crew (AOMC) and Airfield Control Staff (ACS) who work within the Airport were classified into five sections/classes during compilation and analysis of results. These sections are;

i. Awareness on electromagnetic (EMF) radiation vis-a-viz; types, sources, period of exposure by workers, effects on workers, interference effects on Aircraft system, accident of Aircrafts linked/traced to EMF and interference effects of EMF on Aircraft passengers, among others

ii. Medical Checkup of Airport's workers and treatment/ methods of preventing ill-health and ailments caused or suspected to be caused by EMF.

iii. Awareness on Health Regulations/Regulators for Airport workers; supply and types of protection utilized against EMF radiation.

iv. Criteria for siting Airport's land; acquisition and land ownership of Airport's set-back.

4.2.6.1 Electromagnetic Radiation Awareness and Impacts

Despite the awareness campaign on likely effects of electromagnetic radiation (by ICNIRP and World Health Organization, among others), regulation on period of interaction and prevention strategies recommended for workers within and around the EMF radiation sources, the output of the questionnaires from this research study indicate that: 83% of the respondents are aware of what EMF radiation is about but they have never experience common illness such as headache, dizziness and fatigue, and sleep disruption due to EMF. From this set of workers, 69% respondents indicated that radar and altimeter equipments are only source of EMF radiation known to them but 6% are aware of X- Rays and Gama- Rays radiation from some equipments on board Aircrafts. Moreover, all the respondents (100%) responded that they have not experienced internal organ ailment, 99% confirmed not having chronic health like Cancers, leukemia and/or brain tumors but 86% of the pilots responses indicated that they do have all of the; periodic Headache and Dizziness(1%) , Nausea and or fatigue (1%), Joint and muscle pain (1%)];which could be traced to exposure of EMF radiation from the aircraft and at the Airport.

However, 55% of the respondents claimed to do work for 12 hours per day despite the 6 minutes' maximum continuous exposure per period, recommended by ICNIRP. Other responses are tabulated in Table 4.9 using most positive responses and least positive responses on EMF impacts of radiation. In addition, investigation on awareness on damages caused by EMF

radiation to avionics equipment, 36% chose all of the above option which entail really occur, not being informed and classified information for aircrew and engineers; while, 18% said that such information is exclusively for aircrew and Engineers and research subject on frequency of Aircrafts accidents traceable to EMF indicated 79% respondents indicated that none of the; biannual periodic or more, period of six months to two years and period of four weeks to six months.

The responses from the aforementioned is in line with results from the research study conducted by Camfil. According to the research on Clean Air Solution conducted by Camfil USA, 2017, accessed from https://catalog.camfil.us, posted on August 16, 2017 by Camfilusa, the study found that people living near an airport can experience a higher rate of respiratory problems due to elevated airplane emissions that contain hazardous contaminants and studies have found that living near an airport could be hazardous to health[12].

4.2.6.2 Evaluation of Compliance Using ICNIRP Standard on EMF Exposure to Airport Workers

The research study generated that 78% of the respondents who are airport workers are not aware at all of what ICNIRP regulations state about EMF radiation on airport officials. Also, the following facts were obtained

i. Laws on siting of RF infrastructures within and around the airport: 45% does not have the knowledge on this, 27% mentioned they were taught during aviation training and 16% said they know it independently because they belong to non-aircrew trade.

ii. Awareness of the 15 Km setback before an Airfield: 55% have No knowledge at all; 16% was taught during training; 15% said they know it independently because they belong to non-aircrew trade; 12% were neutral

iii. Approval for the location of RF based infrastructure around the airport by Agencies: 48% chose Nigeria Airport Authority, (NAA); 31% chose Nigeria Air Force Authority (NAFA); 1% chosen NAA and NAFA; 20% were silence about it.

iv. Supply and types of protection utilize against EMF radiation: 16% of the respondents said they do provide EMF based protective wear; 3% chose Anti-radiation and/or anti-G-Suit wears wereprovided; 29% mention being given flying suit; 32% mentioned being

v. given EMF based protective wear, 0% never given Anti-radiation, anti-G-Suit wears and flying suit, 20% were neutral/silence.

Despite the aforementioned responses, question on periodic checkup for EMF Radiations recorded that 100% of the respondents do medical checkup once in a year while special method for EMF based health mitigation indicated that 85% of the respondents do; alternates duties/working days, being given and drinks milks after 12 hours of operation and issuing/acquisition of unscheduled Leave Pass but 11% were neutral. These precautions are in line with output of James Y. Lee and George J. Collins, 2017. The crew investigated the Risk Analysis of Electromagnetic Environmental Effects in Aircraft Systems using mathematical modelling. The team applied the Standard Risk Model to EM environmental hazards analysis and mitigation in aircraft and confirmed that EM energy interacted with aircraft [11], thus airport workers and passengers

4.2.6.3 Analysis of Results Using NCC Regulations on Setback Around Airport

The information generated on setback around the Airport are as follows:

i. Acquisition of Land containing sources(s) of RF around the airport: 11 % of the respondents said it was acquired through rentage from acclaimed Land owner, 0% claimed they bought from acclaimed owner; 11% claimed they Leased the Land from Airport Authority; 65% claimed they Leased the Land from Local or/and State Authorities; 13% were neutral about it.

ii. Airport's Agency that give Acquisition Certificate on Setback (Land): 0% claimed NAMA; 10% claimed NAFA; 90% remained silence.

iii. Criteria for siting land for Airport: 14% chose it has to be close to town, 84% chose land must be far from town with min of 6 km stretched surface land and the environment must not have very high tall building, 2% are not aware of any criteria.

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Chapter Five

Conclusion

5.1 Summary of Research Findings

An aircraft is a device that is used for flight in the air. At the ends of an aircraft trip, the Airport provides change of mode from the air to ground, thus, serves as point of connectivity between air and ground. The Aircraft has avionic system which contain numerous on-board and frequency-generating sub-systems, radio frequency transmitters, sensitive digital instrumentation sub-systems, automated flight control, among others. The aforementioned are susceptible to stray electromagnetic interference which could cause a flight delay or endanger the operation of an aircraft at 30,000 feet in space.

However, Airports required numerous hectares of land for operational activities. Meanwhile, few Airports such as Lagos and Ibadan Airports which were built on the outskirts of the city few decades ago are currently being hemmed in by Sub-urban Developmental Infrastructures (SDI) which are mostly Radio-Frequency based Infrastructures (RFI). These infrastructures are mostly kept far below 15 km step-back stipulated by Nigerian Communications Commission (NCC) and the stray electromagnetic (EMF) fields from RFI do generates charged encroaching field, subjecting Airport workers to EMF values that are much higher than recommendations by International Commission for Protection Against Non-Ionizing Radiation (ICNIRP). Hence, the research study investigated the level of spatial encroachment of RFI and electromagnetic interference from RFI within and around Ibadan Airport. The results generated would be useful for the effective management of Airport's landed and radiofrequency based infrastructures; as well as creates awareness on exposure of EMF radiations.

5.2 Conclusion

This research study investigated the spatial encroachment and electromagnetic interference from radiofrequency based infrastructures within and around Ibadan Airport. The study utilized digital electromagnetic meter, Global Positioning Satellite (GPS) receiver, satellite imageries of the study area and Geographical Information System (GIS) application software, among other satellite based technology. The results from the study showed that built structures are increasing geometrically on the setback of the Airport since 2003 to date and the minimum, maximum and average spatial distances of infrastructures to Airport's airfield are 0.161561986 m, 1015.806314 m and 616.0426776 m respectively. Also, radiofrequency infrastructures (RFI) such Communication and Cellular base station, electrical power infrastructures, among others were sited. The EMF radiations from RFI to airfield have minimum, maximum, average and flux density of $3.54233 \times 10^{-12} W/m^2$, 21.048083 mW/m^2, 0.167837 mW/m^2 and 24.504134 mW/m^2, respectively; and static electric field between 17.251V/m and 74.0 V/m were recorded around the Aircrafts. In conclusion, the qualitative output of this study indicates that most of the Airport's staff do work for 6 to 12 hours in the EMF domain previously reported.

5.3 Recommendations

Based on the findings from this study, it is recommended that the Department via the University management should present this report to the Airport Management Authority, Ibadan for onward awareness of the research discoveries. Also, the department in collaboration with Nigeria Air Force should develop a proposal on the research subject for other Airports that are infrastructural based encroached. This could be presented to Nigeria Airport Management Authority (NAMA) for onward sponsorship and execution.

5.4 Contributions to Knowledge

The research study generated electro-spatial information on electromagnetic interference within and around Ibadan Airport. Also, the status of the Airport set-back was evaluated using geo-spatial technology. The outputs of the study would be useful by Airport Management Authority for managing the trend of encroaching electromagnetic fields, structural development and location of RF based infrastructures around the Airport. Also, the results of the study would serve as input in policy development for management of Airport by concerned authorities such as NCC, NESREA and Air Force Authority.

5.5 Area(s) for Further Research

The study recommends that further electromagnetic based investigation should be carried out at various temporal and spatial domains of the Airport. The suggested and recommended researches are;

i. Investigation of EMF radiations during the festival seasons should be proposed to Airport Management Authority because of the large number of influx of EMF from RF infrastructures within (also contributed by customer's personal digital systems) and around the Airports. The results will aid adequate management of EMF influx in the Airport.

ii. Assessment of EMF radiations within the packing slot of the Aircrafts. The research is important due to high values of static electric charges recorded during the research.

iii. Temporal investigation of awareness on EMF radiations and adherence to ICNIRP regulations within the Airport using qualitative scientific approach.

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