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Review on Electromagnetic Interference and Compatibility in Aeronautical Radio communications Systems –Tanzania Case Study.

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Abstract

— Electromagnetic interference (EMI) in communication systems is one of the major challenges which face the communication sector and is mainly caused by unwanted signals which can be characterized as noise. Due to this during communication system design stages, implementation phase and operation of communication link Electromagnetic compatibility (EMC) measures are of great importance. EMC analysis provides important information for communication system designers, planners and operators which facilitate coexistence of different communication systems. In past few years there is an increase in number of Frequency Modulation (FM) broadcasting radio stations in Tanzania which operates in frequency band adjacent to aeronautical communication facilities. The FM broadcasting stations causes interference to the aeronautical radio-communication systems hence posing a great risk to aircraft navigation safety. This is mainly due to unavailability of guard band between the two systems and high power radiated by FM broadcasting stations. This paper addresses interference cases in Tanzania and analyzes the interference mechanism for each interference case. To facilitate this field measurement was conducted in Arusha, Iringa and Zanzibar and mitigation measures which will ensure compatibility are proposed. In paper we have proposed the use of corner plate antenna to mitigate interference caused by FM broadcasting systems.
Keywords: EMI, EMC, FM, Interference

1. Introduction

With liberalization of broadcasting sector in Tanzania the number of FM sound broadcasting stations have increased from 14 stations in year 2000 to 85 Radio stations in 2012 [1]. FM Radio equipment's utilize Radio Spectrum which is a form of oscillating electrical and magnetic energy capable of traversing space without the benefit of physical interconnections and is scarce resource. Radio spectrum starts from 9 kHz to 3 000 GHz and frequency band utilized by FM Radio systems is under category of Very High Frequency (VHF) which starts from 30MHz to 300MHz. According to International Telecommunication Union(ITU) Region I FM Broadcasting Radio stations have been assigned in VHF Band between 87.5MHz to 108 MHz Bandwidth assigned each for station is 400 KHz. Polarization of an FM signal may be horizontal, vertical or mixed with Frequency Modulation technique. Power level stipulated in broadcasting regulation is 1kW [6] and its propagation mode is by space waves. VHF band is also utilised by other communication services including Aeronautical communication services which are assigned in the frequencies from 108MHz to 136MHz. Aeronautical systems in this band include aeronautical radio navigation services (NAV) which are assigned in frequencies from 108 MHz to 116 MHz and aeronautical Radio-communication services (COM) in the frequency band 116-137 MHz [1].

Increase in usage of VHF spectrum by FM broadcasting stations, land mobile networks and Aeronautical systems, and consideration that there is no guard band to separate between these services pose to these systems and hence the need of mitigation measures and control which involve process for making design changes or adjustments of the signal or noise levels in order to achieve Electromagnetic Compatibility (EMC) are of greater importance [6].

Frequency spectrum is allocated by the ITU and assigned by national administrations which are usually government bodies, for example Tanzania Communications Regulatory Authority (TCRA) in Tanzania. These assignments in each country are based on the allocations established in the ITU radio regulation. Assignment of frequencies to airfields and other aeronautical locations is the responsibility of the national civil aviation authority like Tanzania Civil Aviation Authority (TCAA) and International Civil Aviation

Organization [10]

Based on ITU [6], Aeronautical services are classified as having Primary status hence has prime importance and must be protected from interference from other services while broadcasting services are of secondary status hence must avoid causing interference to any primary services and must shut down if requested.

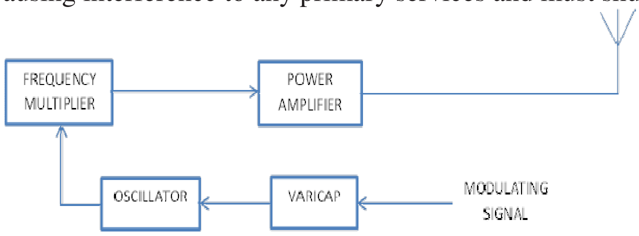

Figure 1: FM transmitter block diagram

2. Background and Literature Survey

Research on interference between FM broadcasting and Aeronautical communication systems have been conducted by different bodies among them include:

2.1 Protection Ratios

- ✓ Analysis conducted by Aeronautical Communication Panel (ACP) on the potential interference that can be caused by FM broadcasting transmitters to VHF Data Link (VDL) Mode 4 operating in the band 112-117.975 MHz On this analysis spurious emission suppression limits for FM broadcasting transmitters where developed in order to avoid interference. Likewise protection ratio for calculation of potential interference was developed [5].

- ✓ International Civil Aviation Organization (ICAO) conducted research on aeronautical facilities interference which led to documentation of ICAO annex 10. This documents stipulates compatibility standards for different aeronautical communication systems Among them include COM receivers have to provide satisfactory performance in the presence of two signals; third-order intermodulation products caused by VHF FM broadcast signals having levels at the receiver input of –5 dBm and also shall not be desensitized in the presence of VHF FM broadcast signals having levels at the receiver input of –5 dBm [6].

- ✓ ITU also have produced a recommendation document which provide guidelines on compatibility criteria and assessment methods between FM broadcasting stations in the band between 87.5 MHz to 108 MHz to Instrument Landing Systems (ILS), VHF Omni-directional Radio Range (VOR) and aircraft ground to air communications systems (COM) operating in adjacent band from 108 MHz to 136 MHz, this work further developed the minimum field strength to be protected throughout the designated operational coverage of ILS and VOR as shown in Table 1 and Table 2 which depict spurious emissions limits [7].

Table 1: Minimum field strength to be protected throughout DOC

s/n	Aeronautical Facility	Field Strength
1	ILS localizer front course	32 dB(µV/m) (40µV/m
2	ILS localizer back course	32 dB(µV/m)
3	VOR	39dB(µV/m)(90 µV/m)
4	COM	38 dB(µV/m) 75 µV/m)

Table 2: Spurious Emission Limits

s/n	Transmitter Frequency	Power < 25 W	Power > 25 W
1	Below 30 MHz	-60dB	-60 dB
2	30-235 MHz	-40dB	-60 dB
3	235- 960 MHz	-40dB	-60dB
4	960 MHz-17.3 GHz	-	-50 dB

2.2 Sources of Electromagnetic Interference

EMI in communication systems is mainly caused by unwanted voltages or current which affect the performance of communication system [9] and manifested as noise. Different sources of EMI have been identified but mainly can be categorized into two which are due to natural sources like lightning, electrostatic discharge, atmospheric effects, sunspot activity, and reflections from the rough Earth surface or man-made sources such as industrial activity, high tension electric cables, radar, high power broadcasting transmitters[8].

As both FM broadcasting radios and aeronautical systems use analogue modulation techniques, Signal to Noise Ratio (SNR) value is high between transmitter and receiver. SNR represent the ratio of received wanted signal strength over the noise which is unwanted signal strength and in analogue modulation communication systems is used for assessing the quality of communication in communication path. EMI can be characterized as noise in communication path. Hence can be taken as Additive White Gaussian Noise (AWGN) which is statistically random noise in the wide frequency range with constant spectral density sources this can be due to thermal noise which is caused by resistivity of a conductor to the flow of electrons and depends on temperature, shot noise which is due to variation of current flow [9].

Thermal Noise exists in every communication system and mathematically can be represented as:

$$P = kTB \qquad (1)$$

P – Noise Power [W]
k - Boltzmann constant 1.38×10^{-23} $m^2 Kg\, s^{-2} K^{-1}$
T - Temperature in [K],
B - Frequency bandwidth in [Hz].

While Shot Noise can be represented mathematically as:
I_n, in Ampere [A] is defined as

$$I_n = \sqrt{2qI_{DC}B} \qquad (2)$$

Where
q - Charge of the electron 1.6·10–19C,
I_{DC} is a DC bias current in the electric circuit, and B is the frequency bandwidth in [Hz].

2.3 Electromagnetic Interference Mechanisms

Electromagnetic energy from the source of interference reaches the victim receiver in two primary mechanisms which are radiation and conduction. Electromagnetic interference mechanism by radiation is further divided into; direct radiation in which interfering communication equipment radiates electromagnetic energy using the same frequency as the interfered aeronautical communications system. and third order intermodulation products radiations in which one or more strong interfering signals on certain frequencies related to the one to which an aeronautical system is operating cause interference effects to aeronautical communication systems. Likewise intermodulation may also be generated in aeronautical system receiver as a result of the receiver being driven into non-linearity by high power broadcasting signals outside the aeronautical band. For this interference to occur two or more broadcasting signals which have frequency relationship which, in a non-linear process, can produce an intermodulation product within the wanted RF channel in use by the aeronautical receiver

2.4 Electromagnetic Interference Mitigation Measures and Techniques

In order to facilitate mitigation of interference in communication systems a number of techniques and measures have been proposed. Mitigation techniques vary for different services and systems according to the nature of interference, interference source and interference mechanism hence not all of the techniques are suitable in all cases. ITU produced a recommendation for protection of safety services from unwanted emissions in this document a number of mitigation measures have been stipulated including;

- ✓ Improving radio frequency selectivity in-order to reduce unwanted signals outside of the tuned bandwidth and provide good adjacent channel rejection performance.
- ✓ Beam down-tilt so as to reduce interfering signal and also increase penetration.
- ✓ Modification of antenna pattern which is much facilitated by corner reflectors and directional antennas which when used direct a signal to the intended area of interest hence minimizing interference to outside the service area.
- ✓ Deployment of electronic Radio Frequency filters such as notch filter and band pass filters [8].

3. State of the Art

FM broadcasting band have been in high demand an electromagnetic interference in aeronautical VHF ground to air communication systems have been repetitively as shown in this section

3.1 Frequency Assignment

Auction, beauty contest and first come first saved are three major spectrum allocation techniques which are used by regulatory authorities and government agencies responsible for allocation and assignment of frequency spectrum. In Tanzania assignment of frequency is based on first come first saved method. VHF FM frequency band is among the highly utilised frequency band in Tanzania and due to that FM broadcasting stations frequencies of Dar es Salaam, Arusha, Mbeya, Iringa and Mwanza service areas have been exhausted [20]. Assignment of frequencies to FM Broadcasting Radio Stations follows ITU Geneva 84 convention where parameters considered for granting of license include Bandwidth, Transmitter power, Transmitter stability, modulation, and antenna gain. Frequency reuse in VHF band is done after 100 kilometers. In Tanzania regions with many FM Radio stations include Dar- es- Salaam followed by Arusha, Mwanza, Mbeya and Iringa [10]

FM sound broadcasting transmitter use frequency modulation technique in which carrier frequency is changed by a modulating signal. The frequency of the modulated signal can be written as

$$s(\mathrm{t}) = \mathrm{A}(\cos \mathrm{wt} + \mathrm{k}\sin \mathrm{wt}) \qquad (3)$$

Where:

S (t) - the frequency of modulated signal
k- Modulation index
A - Amplitude of the signal
w - Angular velocity

3.2 Aeronautical Interference cases

Number of interferences on VHF Aeronautical communication systems in Tanzania has been repetitively reported to TCRA by TCAA in the period from 2010 to 2013, these include:

3.2.1 Arusha

Aeronautical frequency 118.4 MHz in Arusha have been interfered repeatedly since 2010 to 2014. This interference was affecting the control tower and air borne communication. Investigation of source of interference found it to be caused by FM broadcasting radio which was located at latitude 10˚43'32.16" S longitude 35˚41'07.77" E and altitude: 1,563 above mean sea level more than 10 kilometers from the airport. Resolution made was to reduce power of FM broadcasting station and installation of cavity filter [13].

3.2.2 Kilimanjaro

Interference at Kilimanjaro International Airport Interference on frequency 121.2 MHz, this interference was experienced as background noises heard by the control tower which obstruct communications between pilot and control tower. Interference source was identified to be due to illegal land mobile radio which operated with the same frequency as the control tower frequency. Mechanism for RF coupling was by direct radiation [13].

3.2.3 Mbeya

Ground to Air communication frequency 119.3 MHz was reported to be interfered repetitively from 2010 to December 2013. These communication systems were installed at kaluwe hill which is situated at latitude 8˚51'19.07" S, longitude 33˚25'14.63" E and altitude: 2,643 m above mean sea level in Mbeya city. The site also shared with three FM Radio stations. Measurements were conducted by using Spectrum Analyser at power Amplifier RF monitoring output for each transmitter at the site. Measurement results show FM Radios were emitting spurious emissions above emissions levels stipulated in regulation. Compatibility measure taken was to reduce transmission power for all broadcasting Radio which were located at the same transmission site with aeronautical facilities [12].

3.2.4 Zanzibar

Interference on frequency 121.2 MHz was experienced by pilots at 2000 feet height above the ground when they approach airport for landing and also during take-off. This interference which occurred in December 2012 obstructed communication between pilot and control tower. Identification of source of interference was done by taking measurement of power received for all FM broadcasting radios licensed for Zanzibar service are. These measurements where conducted in two different points near to airport. Five radio stations which were found to have highest received signal level were visited. This interference was resolved by aforesaid Radio station to reduce power levels [12]

3.2.5 Songea

Interference of Aeronautical frequency in Songea airport frequency 119.3 MHz, this interference was affecting the control tower communication. Investigation of source of interference found it to be caused by FM broadcasting radio which was co-located at the same transmission site Matogoro which is located at latitude 10˚43'32.16" S longitude 35˚41'07.77" E and altitude: 1,563 above mean sea level both two systems were located in Tanzania Telecommunication Company Limited tower. Resolution made was to reduce power of FM broadcasting station and installation of cavity filter [12].

3.2.6 Dar es Salaam

Ground to air voice communication frequency for Dar es Salaam International Airport was suffering from noises which caused poor communication between pilots and control tower in November 2013. After frequency monitoring in Dar es Salaam source of interference was identified to be originating in Makongo transmission site area where four FM broadcasting stations pass through one combiner and use same antenna. These radio stations were generating out of band emissions and this interference was ended after every radio station install own antenna instead of using combiner [13]

3.2.7 Dodoma

In Dodoma affected COM frequency was 119.2 MHz used for ground to air voice communication Interference from signal leakage from cable television modulator was identified in Dodoma airport. Measurement made by Spectrum analyzer show the modulator was using the same COM frequency. Interference mechanism was by direct radiation and resolution made was to change frequency used by the cable television modulator [12].

3.2.8 Iringa

Interference was reported from Iringa airport in Iringa. Affected frequency was COM frequency 118.1 MHz used for ground to air voice communication. Measurements were conducted by spectrum analyzer within Iringa town. By demodulating the signal at interfered frequency three FM broadcasting stations were heard. All three radio stations were located at Nyamafifi hill 7˚45'50.72" S, 35˚42'58.55" E, Altitude: 1,769 m above mean sea level. After switching off broadcasting radio one after the other it was observed that broadcasting radio station with frequency 103.6 MHz was transmitting RF signals of the other two FM radios which have frequencies 98.6 MHz and 93.5 MHz respectively. Compatibility measures undertaken were power level reduction and installation of filters [13].

4. Antenna Characteristics

Antenna is part of radio communication system devices which is used for radiating and receiving electromagnetic energy. Due to this proper antenna design, installation and other parameters are of great importance in solving EMI in communications systems. There are different types of antenna such as monopole, dipole, corner reflector, yagi, log periodic FM broadcasting stations mostly use dipole and folded dipole antenna systems. This system usually consist in collinear arrays realized by a stack of equally spaced vertical dipoles fed with currents having the same amplitude and phase which are equipped with dipole antennas. Dipole antenna consists of two identical rod conductors, with the signal from the transmitter applied between the two halves of the antenna [24]. As EMI mitigation measure antenna properties has to be modified. Among properties to be modified include:

4.1 Antenna Radiation

Antenna radiation pattern refers to variation of the power radiated by an antenna with regard to distance from the antenna [18].

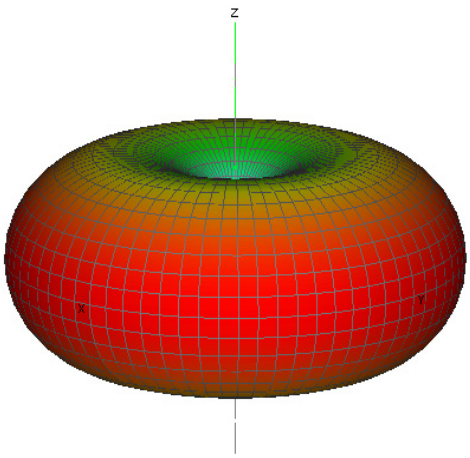

Figure 2: Dipole Antenna Radiation Pattern

4.2 Directivity

Directivity is another property of an antenna which facilitates mitigation of electromagnetic interference since it determines the concentration of radiated power in a particular direction. Directivity is the ratio of radiation intensity in a particular direction from the antenna to the average radiation intensity. Mathematically, the directivity can be represented as:

$$D(\theta, \Phi) = \frac{U(\theta, \Phi)}{U_{avg}} = \frac{4\Pi\, U(\theta, \Phi)}{P_{rad}} \qquad (4)$$

Where by:
D – Directivity
U – Power radiated in specific direction
P_{rad} – Power radiated from the antenna

4.3 Antenna Gain

Likewise gain of antenna is also characteristic of antenna to be taken care for EMI analysis. Gain of antenna is the ratio of antenna radiated power at a given point to the power at that point when isotropic antenna was used. Isotropic antenna is a reference ideal antenna which radiates power equally in all direction. For transmitting antenna gain describes how an antenna converts input power into radio waves in a given direction while in receivers side antenna gain describes how the antenna converts radio waves received from a specified direction into electrical power. As EMI mitigation measure increasing/decreasing gain of antenna will increase/decreasing the Effective Isotropic Radiated Power (EIRP) hence facilitate in varying electric field strength [18].

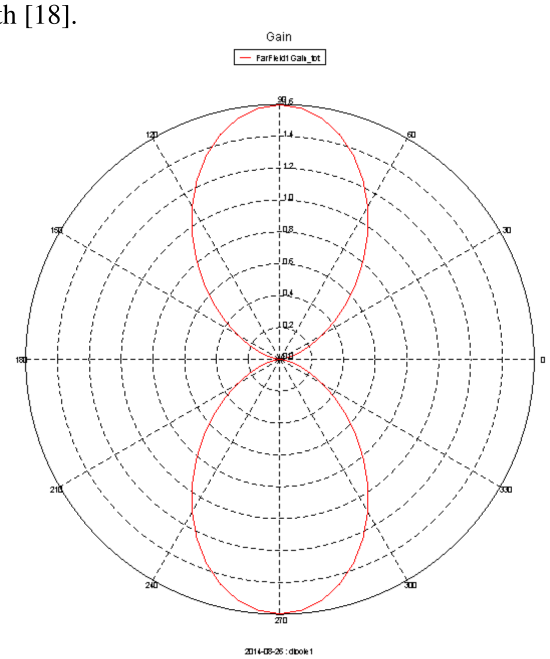

Figure 3: Dipole Antenna Gain

4.4 Polarization

Polarization of an antenna describes the orientation of the electric field of the radiated wave with reference to ground. There are different types of antenna polarization such as vertical, horizontal circular and mixed polarization. Polarization of simple antenna such as dipole antenna can be easily determined by the physical structure of the antenna. Dipole antenna will have vertically polarization when mounted vertically, and a horizontally polarization when mounted horizontally [18].

4.5 Impedance Matching and Voltage Standing Wave Ratio

Antenna input impedance is the ratio of the Voltage (V) to current (I) flowing at pairs of the terminal for efficient transfer of RF energy impedance of the transmitter, transmission line which connect transmitter to the antenna and that of the antenna must have same value hence being matched. Typical input impedance used in communication systems are 50 ohms, 75 ohms and 120 ohms. When two systems which have different input impedance are connected to each other impedance matching circuits known as balun are then required to match the two systems [16]. When there is impedance mismatch in communication system Voltage Standing Wave Ratio (VSWR) appear in a link. VSWR is a measure that numerically describes how well the antenna is impedance matched to the radio or transmission line which is connected to. VSWR is a function of the reflection coefficient, which describes the power reflected back from the antenna to the transmitter. An ideal transmission line would have an SWR of 1:1, which implies all power generated by transmitter is dissipated by the antenna [18].

$$VSWR = \frac{1 + \Gamma}{1 - \Gamma} \qquad (5)$$

Where by Γ stands for reflection coefficient which is calculated by formula

$$\Gamma = \frac{Z - Z_0}{Z + Z_0} \qquad (6)$$

In which: Z= load impedance
Z_0= characteristic impedance of the line

5. Observation and Discussion

5.1 Nature of interference in Tanzania

On literature review, site visit and TCRA reports it was observed that ground to air communication equipment's are the mostly interfered aeronautical communication facility. This interference distress either the ground station at control tower or the airborne device installed in aircraft or interference can be in both two systems. The effects of interference to aircraft receivers vary with the aircraft location, altitude and inter-modulation and spurious emission conditions. Also depend on the make and model of the receiver which dictate the receiver selectivity, sensitivity and spurious rejection.

Further from TCRA report most of interference scenarios which occurred was caused by radiations from FM broadcasting radio stations and by considering mechanisms for electromagnetic interference energy transfer from the source to the victim receiver, third order inter-modulation product interference mechanism in which one or more strong interfering signals on certain frequencies related to the one to which an aeronautical system is operating cause interference effects is the mostly causing interference.

5.2 Signal Measurement

Due to abruptly significant change of magnitude of communication signal power; logarithmic scales are mostly utilized in which power of a signal is normally expressed in decibel (dB):

$$P(\mathrm{dBW}) = 10\log \mathrm{P(W)} \qquad (7)$$

Likewise communication signal Voltage can be represented in dB as:

$$\mathrm{v(dBV)} = 20\log \mathrm{v(V)} \qquad (8)$$

Henceforth the electric field strength of signal transmitted by communication system can be calculated at any distance by the equation:

$$E = 76.9 + P - 20\log d \qquad (9)$$

Where:

E: field strength (dB (μV/m)) of the (unwanted) FM broadcasting transmission *i*
P: maximum e.r.p (dBW) of the broadcasting station
d: distance between the broadcasting station and the aeronautical receiver

5.3: Aeronautical ground to Air facility

Aeronautical ground to air communication system deploy monopole antenna which consist of straight rod-shaped conductor, often mounted perpendicularly over some type of conductive surface, called a ground plane. The signal source is applied at the lower of the antenna and the ground plane. The monopole is a resonant antenna; the rod functions as a resonator for radio waves, with oscillating standing waves of voltage and current along its length. Therefore the length of the antenna is determined by the wavelength of the radio waves it is used with. The most common form is the quarter-wave monopole, in which the antenna is approximately 1/4 of a wavelength of the radio waves [18].

6. Conclusion and Future Work

6.1 Conclusion

After analysis of different sources of electromagnetic interferences, FM broadcasting radio station have been observed to be the main source of interference to aeronautical communication systems in Tanzania. Mechanism which transfers electromagnetic energy to victim aeronautical receiver from the FM broadcasting transmitter as the source is through third order intermodulation product. Different migration measures and techniques which have been suggested by ITU, on this research we have proposed the use of corner plate antenna to mitigate interference caused by FM broadcasting systems. Corner reflector antenna have good front to back ratio which will facilitate in decreasing amount of interfering signal power reaching aeronautical facilities. This has been proposed due to considerations made on the nature of interference which have been observed to be caused third order intermodulation products from FM broadcasting radios. This will be done so as ensure aeronautical communication systems operate in its intended operational environment without suffering unacceptable degradation and without causing un-intentional degradation to the environment.

6.2 Future Work

Work to be done include analysis of the measured data and comparing with minimum threshold levels, also establishing radio propagation model which predict propagation of FM broadcasting radio signal. After that design of corner plate antenna which will be used as a mitigation measure due to its good forward to back ratio radiation pattern compared to dipole antenna which are used by FM broadcasting radio stations will follow. Simulation of this antenna radiation will be compared with the minimum threshold values which have been set as limit in order to arrive to the conclusion and give possible recommendations to mitigate interference.

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