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Investigation of measured received power from FM broadcasting radios-A case of Tanzania

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Abstract
Aeronautical ground to air Very High Frequency Communication (COM) systems is among communication safety services in aircraft which safeguard life and property and is the main voice communication between pilots of aircraft and control tower. These systems have been facing interference from Frequency Modulation (FM) broadcasting radio stations. With increase in number of FM radio stations in Tanzania these interferences case increases hence pause for immediate measure to mitigate interferences. This paper compares the received signal level at Designated Operational Coverage of COM facilities with established minimum threshold level and there after comparison of empirical radio propagation models against measured data. It was observed that the signal level from FM broadcasting radios were strong enough to cause interference. Hence concluded corner reflector antenna has to be used as interference mitigation technique so as to lower the FM broadcasting power level reaching aeronautical communication facilities.
Keywords: FM, VHF, COM, propagation and Transmission Loss.

1. Introduction

As the number of FM broadcasting radio signal in Tanzania increase, interference cases to Aeronautical VHF ground to air communication have increased too [1]. Electromagnetic interference energy from FM broadcasting stations reaches victim aeronautical systems receivers by two primary mechanisms which are radiation and conduction [2]. Radiation have subdivided into two further categories which are direct radiation in which interfering FM broadcasting transmitter radiates electromagnetic energy using the same frequency as the interfered aeronautical communications system[3] and third order intermodulation products radiations in which one or more strong interfering signals on certain frequencies related to the one which an aeronautical system is operating cause interference effects to aeronautical communication systems. For induction electromagnetic interfering energy from FM broadcasting transmitters get induced into aeronautical systems when the two systems are placed close to each other hence Radio Frequency currents can be induced in its lengths [3, 4].

With consideration of importance and necessity of aeronautical communication facilities as safety services with primary status compared to broadcasting services which fall under secondary status[5] mitigation measures to alleviate interference are of prime importance.

2. Literature review

2.2.1 Third Order Intermodulation Products

FM broadcasting radio third order intermodulation products occur when two or more separate frequencies exist together in a non-linear device hence sum and difference frequencies are also produced in addition to the harmonics. Three types of intermodulation products which originates from FM broadcasting radio systems include

- ✓ single channel intermodulation in which the wanted signal is distorted by virtue of non-linearity in the transmitter
- ✓ inter transmitter intermodulation in which one or more transmitters on a same site produce intermodulation products either within the transmitters themselves or within a non-linear component on site to produce intermodulation products and
- ✓ intermodulation due to passive circuits: where transmitters share the same radiating element and intermodulation occurs due to non-linearity’s of passive circuits [6].

Intermodulation also may get generated in aeronautical system receiver as a result of the receiver being driven into non-linearity by high power from FM 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. [3].

Intermodulation products of two frequencies f1 and f2 and their orders of intermodulation products are shown in Table 1:

Table 1: Intermodulation products of two frequencies

Intermodulation Order	Intermodulation Products	Intermodulation Products
1st Order	f_1	f_2
2nd Order	f_1+f_2	f_2-f_1
3rd Order	$2f_1+f_2$, $2f_1-f_2$	2f2-f1, 2f2+f1
4th Order	2f1+2f2	2f2-2f1
5th Order	3f1-2f1, 3f1+2f2	3f2-2f1, 3f2+2f2

2.2.2 Protection Ratio

There are two established principles for protection of desired signal within Designated Operational Coverage (DOC) of COM facilities;

i. The first principle calculates the actual field strength of desired and undesired signal at the COM receiver antenna. On the basis of the established Desired to Undesired signal D/U ratio, the maximum signal level of the undesired (interfering) signal determines in turn the maximum level of the interfering signal, before the interference becomes harmful[7].
ii. The second principle uses the minimum field strength at the COM receiver antenna. The stipulated protection ratio is between 14 to 20 dB between desired signal and undesired signal In this the standard set for DOC is electric field strength of 75 dBμV which is equivalent to (-82 dBm). With consideration of 20dB margin interfering has to be lower than -102dBm [8].

$$Pd - Pu = \frac{D}{U} \quad (1)$$

Where;

P_d= power of the undesired signal at the receiver (dBW)
P_u= power of the desired signal at the receiver (dBW)
D/U= Protection ratio (dB)

2.2.3 Radio Propagation Models

Propagation of radio waves involves mechanism such as reflection which occurs when radio wave propagation in one medium impinges upon another medium with different electromagnetics properties, scattering when radio waves hits a rough surface or an object which is having a size much smaller than the signal wave length and diffraction which is caused by bending of propagating radio waves when encounter obstacles. VHF signal propagate by using space waves when travelling from transmitter to the receiver[9].

Table 2: Frequencies Bands and propagation mode

Frequency Band	Frequency Range	Propagation Mode
Extremely Low Frequency	Less than 3 KHz	Ground wave
Very Low Frequency	3KHz-30 KHz	Earth/ Ionosphere guided wave
Low Frequency	30KHz-300 KHz	Ground wave
Medium Frequency	300KHz -3 MHz	Ground and Sky wave
High Frequency	3MHz – 30 MHz	Sky wave
Very High Frequency	30 MHz-300MHz	Space wave
Ultra High Frequency	300 MHz- 3000MHz	Space wave
Super High Frequency	3GHz-30 GHz	Space wave
Extremely High Frequency	30 GHz – 300GHz	Space wave

For prediction of propagation of radio signal in different terrain environments different radio propagation modals have been developed. Radio propagation models are mathematical formulation which characterises propagation of radio waves as a function of power, frequency, distance and other link conditions[10]. These models are useful during planning of frequencies by communication regulators since assist to predict coverage and probability of interference at a given distance from the transmitter.Henceforth prediction of path loss is significant element in designing communication system[11]. A reliable propagation model calculates the path loss with small standard deviation. Propagation models are divided into empirical and deterministic models. [12] checked suitability of Free space propagation model, Hata Okumura path loss model, Okumura model and Extended COST- 231 Hata for predicting propagation of FM broadcasting signals in North India and concluded that Extended COST- 231 Hata Model was the best in predicting broadcasting signals. The same result was obtained in hilly areas of Nigeria [13].

In this paper three empirical model which free space attenuation model, two ray reflection model and Egli model have been discussed and compared against the measured data.

i. Free Space Path loss model

Free-space propagation model is used to predict received signal strength when the path between the transmitter and the receiver is a clear and unobstructed line-of-sight[12]. The ideal antenna propagation radiates in all directions from transmitting source and propagating to an infinite distance with no degradation. Attenuation occurs due to spreading of power over greater areas [4].

Henceforth the resulting power density P_d is calculated using equation

$$P_d = \frac{P_t}{4\pi d^2} \tag{2}$$

Where;

P_t is the transmitted power

P_d is power at distance d from antenna.

As the signal propagates from the antenna, it experiences a reduction in intensity and the amount of power received depends on the effective capture area of the receiving antenna. The power received P_r for a given power density is calculated as

$$P_r = P_d \times A_e \tag{3}$$

Where Ae is the effective antenna aperture and is given by equation

$$A_e = \frac{\lambda^2}{4\pi} \tag{4}$$

Where

λ is the signal wavelength of propagated signal.

The amount of power captured by the antenna at the certain distance d, thus depends on power density and also on the effective capture aperture of the antenna. Combining equations (1) and (3) into (2), we have the power received to be as expressed as

$$P_r = P_t \left[\frac{\lambda}{4\pi d} \right]^2 \tag{5}$$

The free space path loss Lp is given as Pt / Pr and can represented in terms of frequency rather than wavelength of signals, we can make the substitution λ= c/f to get the free space path loss as shown in equation 5

$$Lp = \left[\frac{4\pi}{c} \right]^2 d^2 f^2 \tag{6}$$

Where

c and f are the speed of light and operating frequency respectively.

The free space path loss equation can be represented in logarithmic

$$Lp = 32.5 + 20\log_{10} d + 20\log_{10} f \tag{7}$$

Where by frequency f is in MHz and distance d in kilometre

In free space Electric field strength can be calculated by equation;

$$E_{fs} = \frac{\sqrt{30 P_t G_t}}{d} \tag{8}$$

Where

E_{fs} = Electric field in free space

Pt= power transmitted

Gt= Gain of the transmitter

D = distance from transmitter

ii. Two Ray Ground Reflection Model

In this model the total received power at the receiver is taken to be summation of power from two different paths which are direct path between transmitter and receiver second path is obtained by one ground reflection of the signal wave in between transmitter and receiver. This model also considers the height of location of receiver & transmitter with respect to the ground[14].

Mathematical formula for calculating received power at a distance d, is given as:

$$P_r = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4 L} \quad (9)$$

Where;
Pr= Received power of the transmitter at distance d
Pt= Power transmitted by the transmitter
Gt= Gain of the transmitter
Gr= Gain of the receiver
ht= Height of the transmitter
hr= Height of the receiver
L= System loss
D= separation distance between transmitter and receiver

iii. Egli Model

Egli model also is among the empirical model which is used to predict propagation losses taking into account the effect of the terrain, when both the transmitting and the receiving antenna are located relatively close to the ground. This model gives more accurate prediction of path loss when compared to the free space model. The Egli model is based on measured path losses and converted into the following mathematical model and provides an alternative generic method to predict propagation losses when the antennas are close to the ground and includes an empirical frequency dependent correction for frequencies greater than 30 MHz

Mathematically power received at the receiver antenna is given by equation:

$$P_r = P_t + G_t + G_r - L_r - L_p - 40\log \mathrm{D} + 20\log H_t + 20\log H_r + 20\log 40 - 20\log f \quad (10)$$

Where;
Pr= Received power of the transmitter at distance d
Pt= Power transmitted by the transmitter
Gt= Gain of the transmitter
Gr= Gain of the receiver
Ht= Height of the transmitter
Hr= Height of the receiver
Lr= Receiver cable loss
L_{pol}=System loss due to polarization
D= separation distance between transmitter and receiver

iv. Shadowing Model

This model considers logarithmic relationship between transmitted power and received power at a certain distance. It involves a normalized random variable which accounts for path loss in different environment.

Power received at distance d can be computed by considering relationship with received power at reference distance d0 as shown in the following equation:

$$P_d = P_{d0} \left(\frac{d0}{d} \right)^{\sigma} \quad (11)$$

In decibel

$$P_d = P_{d0} + \sigma 10 \log_{10} \left(\frac{d}{d0} \right) \quad (12)$$

Where;
Pd= Power received at distance d
Pd0= Power received at reference distance d0
σ = path loss exponent

For this paper Free Space model have been considered
Some typical values of path loss exponent are shown in table 3

Table 3: Path loss exponent values for different environment

Environment	Path loss Exponent Value
Free Space	2
Shadowed urban	3-5
Urban Area Cellular radio	2.7-3.5
In building line of sight	1.6-1.8
Obstructed in building	4-6
Obstructed in factories	2-3

3. Materials and Methods

Field measurements were conducted in Arusha and Iringa town and data collection exercise involved measurement of electric field strength and power levels from all broadcasting radio stations in Arusha and Iringa. Comparison between measured data and minimum thresholds levels were conducted for those stations which were located in the same transmission tower and their out of band emission was found to be present in aeronautical frequency.

i. Transmission Site

In Arusha broadcasting stations have installed their transmitters at the themi hill site, height of transmission tower was found to be 62 metre and the tower is located at Latitude 03º22ˈ33.38ˈˈ Longitude 36º40ˈ39.26ˈˈ Altitude 1365. Aeronautical ground to air communication facilities use 118.4 MHz frequency and have been installed at the control tower of Arusha airport which is located at latitude 03º22ˈ06ˈS and longitude 36º37ˈ29.40ˈˈ this area at altitude of 1361 m above sea level and Electric field strength of COM system measured was 91.77 dBμV.

Parameters for two broadcasting stations in Arusha town which were found to have out of band emission in COM frequency were as stipulated in Table 3

Table 4: Transmission parameters for 105.7 MHz and 93.0 MHz broadcasting stations

Parameter	Station1	Station 2
Transmitter Power	1000 W	1000 W
Transmitter Frequency	105.7 MHz	93.0 MHz
Transmitting Antenna Gain	8.5 dBi	6 dBi
Antenna Type	Dipole	Dipole
Cable Loss	0.2 dB	0.2 dB
Tower Height	62 m	62 m

Figure1: 105.7MHz Transmitter

Figure 2: 93.0 MHz Transmitter

In Iringa FM broadcasting radio stations were located at Nyamafifi hill situated at 7˚45'50.72" S, 35˚42'58.55" E, Altitude: 1,769m above mean sea level

iii. Measurement Devices

For electric field strength measurement Rhode and Schwarz Spectrum Analyser was used while spatial information was collected by from ROMES software which has GPS Receiver attachment.

Figure 3: Spectrum Analyser

Figure 4: Monitoring Vehicle

iv. Measurement Routes

Three different routes were selected for measurement exercise in Arusha town include;
Route 1 from themi hill to njiro road passing nanenane, and tanesco,
Route 2 from themi hill to kisongo passing along sokoine road and Arusha airport
Route 3 from themi hill to moshono passing maasai camp
These routes were selected based on environment

4. Results and Analysis

4.1 Source of interference in Arusha

Field measurements depict intermodulation products from FM broadcasting radio stations to be the source of interference to COM systems

In Arusha interfered aeronautical frequency was 118.4 MHz by using spectrum analyser interfering signal level was observed to be above minimum threshold level of -102dBm. Further analysis of observed signals showed there was third order intermodulation product relationship which is given by

$$IM = 2f1 - f2 \qquad (13)$$

Where $f_1 > f_2$

f_1= 105.7MHz, $f_{2=}$ 93.0 MHz

4.2 Sources of interference in Iringa

For the case of Iringa interference, interfered frequency was 118.1 MHz, analysis of interference shows that three FM broadcasting radio station intermodulation and produce effect in aeronautical frequency.

$$IM = f_1 + f_2 - f_3 \quad (14)$$

Where

$f_1>f_2>f_3$

f1= 104.9 MHz, f2= 103.6MHz, f3= 90.4MHz

4.3 Simulation Result

Matlab simulation of measured received power levels data against empirical path loss models for two radios in Arusha are shown in figure 1 and figure 2

The comparison between the observed and predicted path loss models has been done by using Normalized Mean Mean Square Error and show that Egli model can be used to predict power level of broadcasting FM stations.

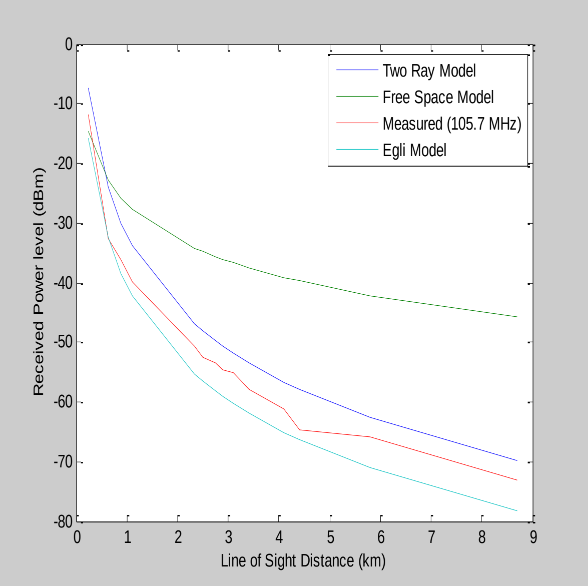

Figure 5: Received Power level (dBm) from 105.7 MHz vs Line of Sight Distance (Km)

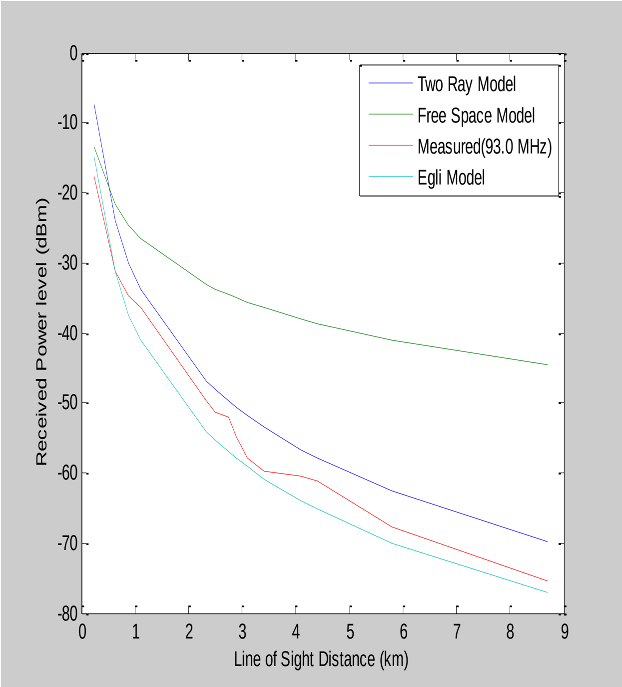

Figure 6: Receive Power Level (dBm) from 93 MHz Radio vs Line of Sight Distance

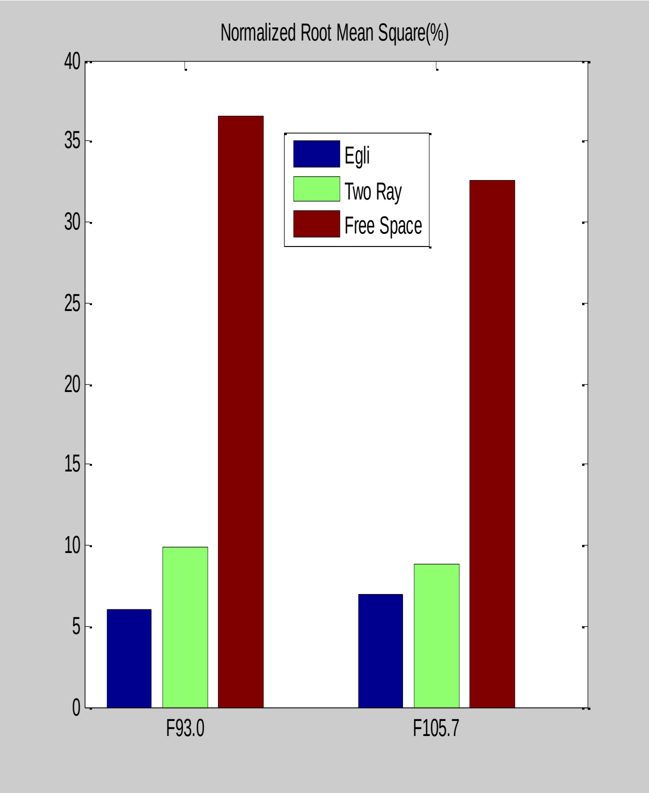

Figure 7: Normalized Root Mean Square

5. Conclusion

This paper has focused on comparing measured level of FM broadcasting signal reaching COM facilities with established protection ratios. The minimum threshold levels established by ICAO and those of FCC result show that the level of signal was above recommended standard hence pose a need for interference mitigation technique which will facilitate in lowering FM broadcasting radios signal power level reaching aeronautical facilities.

Future work to be done in order to mitigate interference is design of Corner reflector antenna due to its good front to back radiation pattern which is the ratio of the maximum directivity of an antenna to its directivity in the rearward direction which will reduce FM broadcasting signal level in direction of aeronautical ground to air VHF facilities.

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