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Analyzing Interference on Aviation Instrument Landing System from Frequency Modulated Broadcasting Systems: the Case of Bole International Airport

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Declaration

I the undersigned, declare that this thesis is my original work ,has not been present for a degree in this or any other university ,and all sources of material used for the thesis have been fully acknowledged .

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Abstract

An Instrument Landing System (ILS) is a ground-based instrument approach system that provides precision guidance to aircrafts approaching and landing on a runway using combinations of radio signals. There are three components of ILS; namely, localizer (LOC), Glide slope (GP) and Distance Measuring Equipment (DME) or series of markers. LOC is used by the pilot to determine the location of the airplane relative to the centerline of the runway; GP provides the slope information (inclination angle) and DME distance from the beginning of the runway. Among the three ILS subsystems (components) this thesis focuses on LOC which is operating from 108.1 MHZ to 111.975 MHZ. This frequency range is prone to adjacent channel interference from Frequency Modulation (FM) broadcasting systems that are operating from 87.5MHZ to 108MHZ.

In the past few years there is an increase in number of FM broadcasting radio stations in Addis Ababa. FM broadcasting stations are likely to cause intermodulation interference to the ILS LOC, hence, posing a great risk to aircraft navigation safety. This thesis addresses interference of Addis Ababa Bole international airport RWY 25 ILS localizers and analyzes the interference mechanism.

The study accomplished through the establishment and implementation of models regarding the characterization of the transmitter and its signal, as well the definition of the aircraft approach path. Model development was done from the bases of field measurements of ILS LOC power level on a certain approach rout and then translates each parameter into defining the scenario. Furthermore, the assessments of interference were performed by using two criteria. One consisted on the raw analysis of the ratio between the LOC signal power and interfering signals power, and the other is based on an International Telecommunication Union (ITU) Recommendation. The results verified the non-existence of any harmful interference generated by Addis Ababa commercial FM broadcasting networks on ILS LOCs runway (RWY) 25 heading for the time being. However, the results also indicate that there is interference RWY 07, though it is not being operational for the time being.

Keywords: *ILS, Localizer, broadcasting, Interference, inter-modulation.*

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Acronyms

ANS: Air Navigation service

ANSP: Air Navigation service provider

CIR: Carrier to Interference Ratio

CNS: communication ,navication and serviellance

CSB: Carrier-plus Side Band

DDM: Difference in Depth of Modulation

DME: Distance measuring equipment

DSB-S: Double Side Band Suppressed Carrier

EMI: Electro Magnetic Interference

ERP: Effective Radiated Power

FAA : Federal Aviation Administration

FCC: Federal Communication Commission

FM : Frequency Modulated

GP: Glide path

GS: Glide Slope

HPBW: Half power beam width

25L /25R: Heading 25 Left / 25 Right

IM: Inner Marker

ILS: Instrument Landing System

IMD: Inter Modulation

ICAO: International Civil Aviation Organization

ITU: International Telecommunication Union

LOC: Localizer

LPD: Log Periodic Dipole

MDS: Minimum discernible signal

MM: Middle Marker

NM: nautical mile

OM: Outer Marker

PIR: Portable ILS/VOR Receiver

SBO: Side Band Only

VDA: Vertical Dipole Array

VHF: Very High frequency

VOR: VHF Omni-directional Range

VSWR: Voltage Standing Wave Ratio

Chapter1

Introduction

1.1 Background

Instrument Landing System (ILS) is a ground-based instrument approach system that provides precision guidance to an aircraft approaching and landing on a runway, using a combination of radio signals. ILS consists of three independent sub-systems the first one provides lateral guidance (localizer), the second providing vertical guidance (glide path) and the third one is a threshold distance measuring equipment (DME) or a series of markers. A modulation depth comparison of two radio signal that are amplitude modulated 150 HZ and 90 HZ beams radiated strategically from the localizer (LOC) and received by the ILS receiver in the aircraft provides course-line information (runway center-line) while a similar comparison from the glide path (GP) provides the slope information (inclination angle) and the round trip time of DME pulses determine the aircraft distance. Figure 1 shows aircraft final approach path together with all instrument landing system components. Thus according to the figure below localizer transmitter is located at the far end of runway, glide path transmitter is located at the side of runway and its projection angle is normally adjusted to 3 degrees above horizontal, so that it intersects the inner marker (IM), middle marker (MM) at about 180 feet and the outer marker (OM) at about 1,200 feet above the runway elevation.

Navigational aids must keep a certain degree of accuracy set by International Civil Aviation Organization (ICAO). Accuracy standards are enforced by flight inspection organizations which periodically check critical parameters using properly equipped aircrafts to calibrate and certify ILS precision **[1].** Therefore each ILS subsystem parameter signal parameters has to be with in standard tolerance**.**

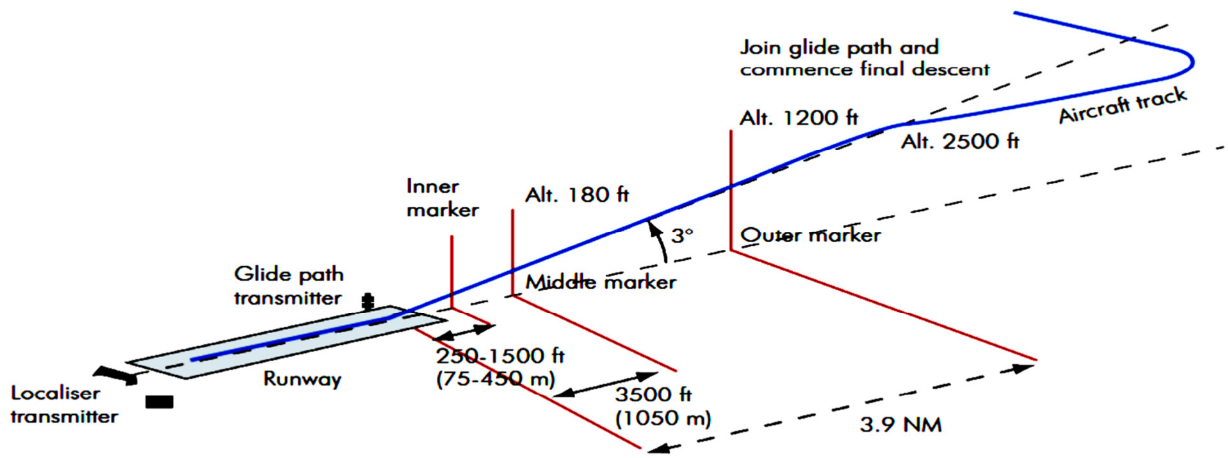


Figure 1 ILS System Configurations [2].

There are different ground-based radio navigation systems that are installed in Ethiopia which provide en-route and approach guidance for the pilots. Ethiopian Civil Aviation Authority (ECAA) is responsible for controlling, maintaining and flight check these ground radio aids to provide quality and precise Air Navigation service (ANS) throughout Ethiopian air space, which assist the aircraft positioning to its defined route. Air Navigation Service is one of the core section in Ethiopian Civil Aviation Authority that includes communication Navigation and Surveillance engineering (CNS). This section must comply with numerous quality standards, whether national or international. In a worldwide scale, the International Civil Aviation Organization is responsible for assessing and supervising the required standards for the provision of air navigation services **[3].** Since LOC is one of radio navigation aid and operating 108.1MHZ-111.975MHZ, ILS guidance quality is affected by interference due to different factors, but in this thesis interference due to sound FM broadcasting station is assessed. FM audio broadcasting stations transmit in the lower adjacent frequency band which is 87.5-108MHZ.Hence, there are number of FM audio transmitters in Addis Ababa which provide coverage throughout the town and adjacent regions. These are usually positioned on the top of hills, in order to strategically provide coverage to the surrounding regions with the minimum obstacles obstructing the view. The chosen locations without surrounding terrain or buildings obstructing the propagation of the signal also make the signal propagation into the airspace unobstructed, and this may cause interference in the signals used by aeronautical radio navigation systems.

The focus of this work is to assess whether FM audio broadcasting systems that are found in Addis Ababa have any impact in the quality of the ILS LOC maintained by ECAA. To that end, assessment of received power of both the wanted localizer and interfering FM broadcasting signals is conducted. Afterwards, two theoretical models were be used to assess if there is any interference caused to the LOC signal, the first one being an evaluation of the ratio between the wanted and interfering signals, and the second one being based on a recommendation from the International Telecommunication Union (ITU).

1.2 Statement of the Problem

ITU-R identifies FM broadcasting stations interference to ILS localizers as a widely recognized problem among user of aviation facility. In air born receivers that interference is more serious problem as it has the potential to make airplanes' deviate from their course line, especially during critical approach and landing phases. There is an increase probability of harmful interference due to growing of FM broadcasting stations. ITU identifies FM broadcasting interference in aeronautical navigation systems in to two categories [4]:

- Type A interference corresponds to the interference caused by FM broadcast emissions into the aeronautical frequency band.
- Type B interference is generated in the aeronautical receiver due to side effects of emissions outside of the aeronautical band.

FM broadcasting channels in Addis Ababa are growing in number. The FM broadcasting band extends from 87.5 to 108 MHZ which is adjacent to ILS localizer band that ranges from 108.1 to 111.95 MHZ. Thus, ILS LOC in Addis Ababa is susceptible to interference that originates from multiple FM broadcasting stations that are transmitting in a neighboring frequency bands. As ITU stated the interference level to aircraft receiver is non-negligible and the most sever at the final landing phase. It can make an ILS LOC deviation signal erratic and generate sound in its voice channel. Thus, impact of FM broadcasting systems on ILS LOC has to be continuously investigated due to the fact that the interference at the airport is harmful. Although interference due to sound broadcasting is widely studied in different countries to maximize aviation safety, no prior work is conducted in the case of the aviation system at Bole International Airport ILS LOC RWY 25L and RWY 25R guidance. Therefore, these thesis asses the interference of the growing FM broadcasting stations in Addis Ababa on ILS LOC RWY 25.

1.2.1 General Objective

The main goal of this work is to examine and quantify the effect of interference from FM sound broadcasting stations located in Addis Ababa on the ILS LOC signal along Bole International airport RWY 25 approach routes.

1.2.2 Specific objectives

The above general objective is achieved by performing the following specific objectives.

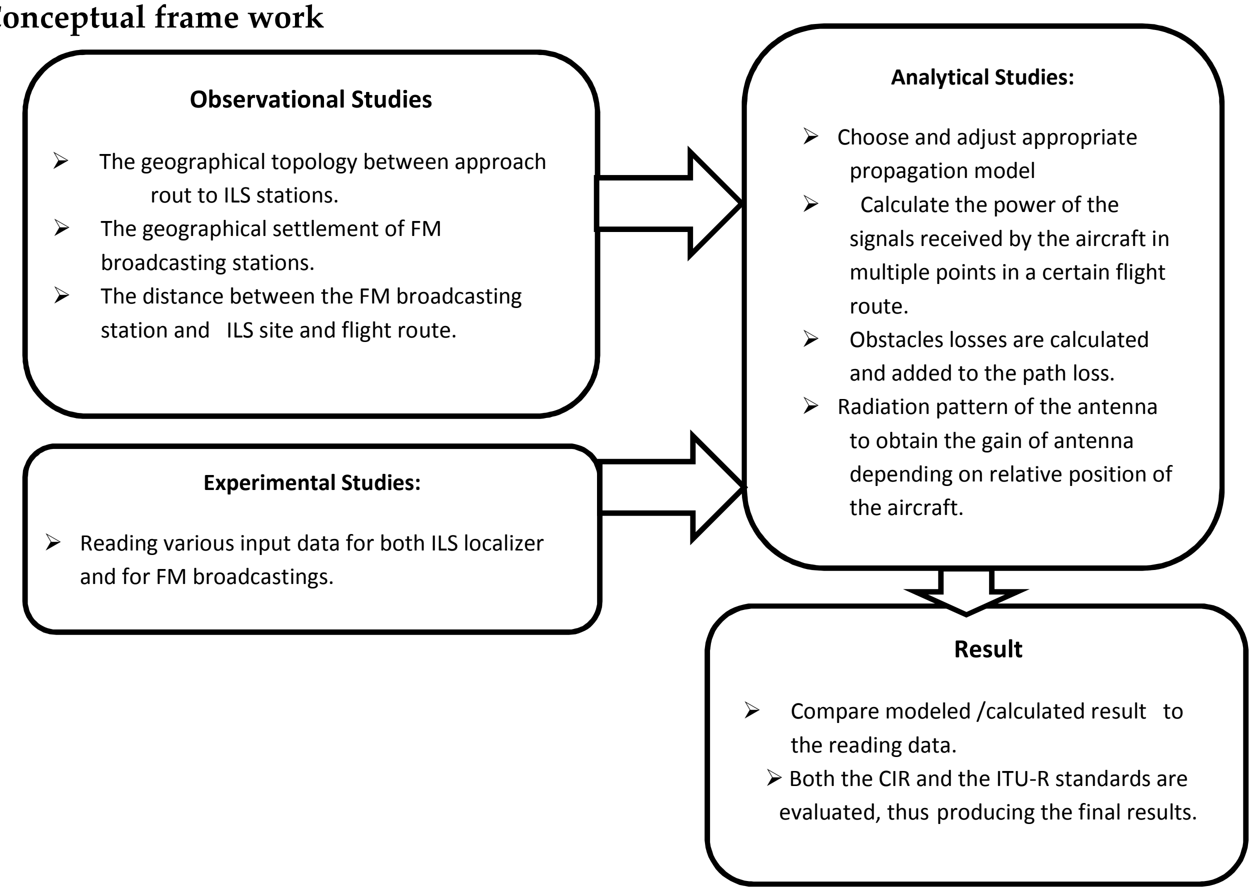
- Based on ILS localizer measured data, survey different propagation models that fit the measured data.
- Investigate theoretical propagation model that capture the level of interference from the FM broadcasting stations.
- Determine the carrier-to-interference ratio (CIR) on the ILS LOC by taking various assumptions and scenarios, and compare with ITU-R standards.
- Produce recommendations on how to mitigate the effect of additional upcoming FM stations installation on ILS localizer guidance.

1.3 Methodology

The case study area of this research is around Addis Ababa Bole International Airport on localizers RWY25L and RWY25R, hence, methods used to achieve the desired objectives of this thesis were done according to the following steps:

- Reading books, articles and other resources related to intermodulation interference from nearby FM broadcasting station on Instrument landing system localizer.
- Studying the geographical topology of the ILS localizer station and FM broadcasting systems with respect to Bole International Airport runway heading 25 approach routes.
- Gathering important data for the study such as; LOC field measurement data, both ILS LOC and FM broadcasting system equipment's technical data, geographical co-ordinates of the threshold that is beginning of the runway, the approach bearing, the total path distance, and the initial height of aircraft.
- By using MATLAB R2013a simulator model both ILS localizers and FM broadcasting systems power received by aircraft in multiple points of ILS 25 approach route by defining various scenarios.
- Finally the result was interpreted in terms of intermodulation interference power level at the receiver and conclusion was drawn on the result obtained.

Conceptual frame work



1.4 Literature Review

Research on interference between FM broadcasting and Aeronautical communication systems have been conducted by different people and organization among many.

The thesis which is titled "Impact of FM Broadcasting signals on Aeronautical Radio navigation" studied intermodulation interference on radio navigation system. The thesis assessed the transmissions VHF from 108-117.95 MHZ, and thus, the systems that presented to be relevant for the study included the VHF Omnidirectional Range and the Instrument Landing System Localizer [5].The thesis assed interference level of Portugal FM broadcasting stations on radio navigation. The assessment was established in accordance to selected VOR route by considering two different altitudes of aircraft and the approach route for ILS localizers in order to quantify the interference level.

This thesis focused on the interference generated due the intermodulation of multiple FM broadcasting station in Portugal and considers the impacts on each ILS and VOR station. The conclusion of this work was nonexistence of harmful interference generated by any commercial FM broadcasting station, but Lisbon Airport RWY 03 had sign of interference. The thesis mentioned that most interesting data missing that field measurements; this would present a validation of the theoretical models that were implemented.

"Interference Immunities of Aviation Receivers Due to FM Broadcast Transmissions" It is the journal of Federal Communications Commission research by Daniel J. Stanks. Ten aeronautical localizer receivers were tested to determine their susceptibility to intermodulation interference caused by combinations of two and three FM broadcast transmissions.

The tests were conducted in a manner to show how the intermodulation responses of the receivers varied with respect to changes in the desired ILS signal level. Finally the journal was interpreted results and concluded that, when two or three signals mix in a receiver a third order intermodulation product can be produced. If the signals are at equal levels and are kept equal as they are increased, the intermodu1ation product will increase three dB for every one dB increase in the signals causing the product [6]. If the frequency of a desired signal coincides with the frequency of intermodulation product interference occurs. Since intermodulation interference due to FM sound broadcasting study was conducted by generating the desired ILS LOC composite signal and two or three FM broadcasting signal inside the laboratory, it was good to determine the variation of Intermodulation power level in accordance with the variation of desired and undesired power. But the real environment between ILS LOC and FM broadcasting station with respect to the approaching aircraft position is not considered.

Another thesis is the Massachusetts Institute of Technology studied by William W. Zhou. The thesis mainly concerned with unsuccessful landings due to unwanted electromagnetic interference from nearby Frequency Modulated radio stations. The FM signals transmitted from station tower to receiver are considered as free-space transmission. Power levels of individual FM station signals present at the receiving terminal is calculated then relate the magnitude of the intermodulation product on the ILS localizer and correlate with the database of receiver test results. The thesis concerned with the probabilities of interference rather than the magnitudes of interference. Hence it uses the statistical approach rather than quantifying the interference level. In such case, instead of claiming interferences do not exist, the statistical model tells that there is smaller probability of interference [7].

International Civil Aviation Organization (ICAO) conducted research on aeronautical facilities interference which led to documentation of ICAO annex 10.These documents stipulate compatibility standards for different aeronautical communication systems. Among them it includes ILS LOC receiver shave 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 Maximum level at unwanted Frequency signal at receiver input as follows:

Table 1-1Maximum level at unwanted Frequency signal at receiver input

Frequency(MHz)	Maximum level of un wanted signal at receiver input (dBm)
88-102	+15
104	+10
106	+5
107.9	–10

1.5 Contributions of the Thesis

The contributions of this thesis are outlined as follows:

- Safety in aviation becomes a burning problem over many countries today. Aviation accidents may result in human injury or even death. Accident statistics based on ICAO (1997-2006) show that 51% of air accidents occur during final approach, landing and take-offs of an aircraft. Like others interference, effect of the growing Addis Ababa FM broadcasting station interference on Bole International Airport's ILS LOC RWY25L and RWY 25R was not yet studied. Therefore this thesis assessed intermodulation interference due to Addis Ababa FM sound broadcasting system and the impact in the quality of ILS localizers. Thus the study increase safety in our aviation.
- According to the result, for future installation of FM broadcasting stations, that minimizes the unnecessary cost to install either FM or ILS systems, hence the thesis recommends that has to be taken by ECAA and FM broadcasting regulatory body.
- In order to maximize safety the study of radio navigation aid interference has to be continuous. Hence, this thesis can contribute for further radio Navigation-aid interference study in Aviation industry.

1.6 Scope/Limitations

The case study area of this research was Addis Ababa Bole International Airport where different radio navigation aid navigation aids provides guidance for approach and landing aircrafts. Hence the scope of this work was assess the interference of Addis Ababa FM broadcasting system on ILS LOC RWY 25 guidance and evaluate according to different stated standards. Propagation model designed from the bases of field measurement is realistic approach in order to compute intermodulation interference on the aircraft receiver. But the limitation of this work was missing FM broadcasting station field measurement along approach flight route.

Systems Overview

2.1 Instrument Landing system

The ILS is a navigation aid used internationally to facilitate approach and landing. It is comprised of a localizer (LLZ or LOC), a glide path/Glide Slope (GP/ GS) and a series of marker beacons that includes an outer and middle marker and, in special cases, an inner marker. Each group generates radio signals independently and simultaneously.

The localizer operates in the frequency range of 108.1 to 111.975 MHz and generates a lateral guidance plane which permits the pilot to select a left/right approach course from a distance of about 25 nautical miles (NM) which is 46km from the runway threshold. The array radiates a horizontally polarized, composite field pattern modulated with 90HZ and 150 Hz within the frequency band as illustrated by Figure 2. If the pilot deviates to the left of the guidance plane, the 90 Hz modulation signal will predominate causing the cockpit indicator to show a fly right indication. If the pilot deviates to the right, the 150 Hz modulation signal will predominate causing the cockpit indicator to show a fly left indication [8].

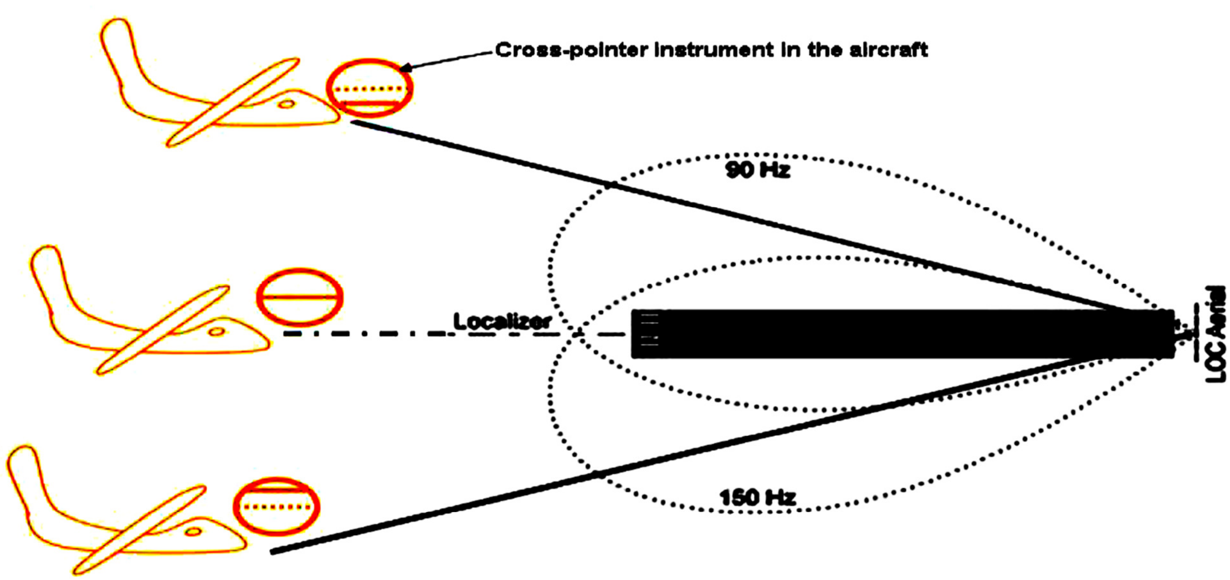


Figure 2 : Principle of ILS localizer [9].

This ILS localizer composite signal identifies the "course plane" that is the vertical the plane which intersects runway along extended runway center line up to the coverage of LOC signal which is produced by a transmitter and antenna system, which can be a dual frequency (2F) system or a single frequency (1F) system. Dual frequency (2F) system is a localizer system in which coverage is achieved by the use of two independent radiation field patterns spaced on separate carrier frequencies within the particular localizer VHF channel; and single frequency (1F) system in which coverage is achieved by the use of only single radiation field.

The localizer signal is obtainable up to a distance of up to 25 nautical miles (46 km) for a sector of ±10°, and it is obtainable up to a distance of ≥ 17 nautical miles (31 km) for a sector of ±35° relative to the course line and the LLZ-antenna. The detail of ILS localizer will be explains in next sections. The second ILS subsystem is the glide slope (GP); it operates within the ultra-high frequency (UHF) band from 329.15 MHz to 335MHz. The glide path radiates its signal only in the direction of the localizer front course which is situated on the same side of the localizer as the runway. The glide slope frequency is usually paired with the localizer frequency, when pilot enters only the localizer frequency in the aircraft instruments at the same time glide path frequency is tuned. The radiation from the UHF glide path antenna system produce a composite field pattern which is amplitude modulated by a 90 Hz and a 150 Hz tone. The pattern shall be arranged to provide a straight line descent path in the vertical plane containing the center line of the runway, with the 150 Hz tone predominating below the path and the 90 Hz tone predominating above the path.

The other ILS components are a series of Marker Beacons. The Marker Beacons (MB) corresponds to a maximum of three beacons spread along the extended runway front-course. All of these beacons are composed of directional antennas sending the signal vertically, making the form of an inverted cone. The Outer Marker (OM) is placed 7.2km from the threshold and the Middle Marker (MM) located around 1050m. Some aerodromes have an Inner Marker (IM) that is placed around 60 m from the runway. The markers send signals in the 75 MHz band, and as the plane enters in the inverted cone defining the beacons’ line of sight, the receiver differentiates between the different beacons and displays in which region the airplane is located. Some aerodromes have a Distance Measuring Equipment (DME) associated with the ILS, located near the landing runway, being used instead of the marker beacons to provide the distance information. The DME is typically calibrated to give the distance relative to either the touchdown or the threshold of the runway, instead to the location of the DME equipment [10].

2.1.1 ILS Categories

The ILS classification is determines the course quality and safety/integrity level as required by Annex 10. In addition, it is proposed to review the list of values for the landing Category attributes of Final Leg and Taxi Holding Position. According to ICAO Annex 10, Volume 1, ILS installations are characterized by a "facility performance" classification code which has 3 alphanumerical characters.

Facility Performance Category I (CAT I):

- A precision instrument approach and landing with a decision height not lower than 60m and with either a visibility not less than 800 m or a runway visual range not less than 550 m.

Facility Performance Category II (CAT II):

- A precision instrument approach and landing with a decision height lower than 60 m (200 ft) but not lower than 30 m (100 ft), and a runway visual range not less than 350 m.

Facility Performance Category III (CAT III):

- The most precise ILS equipment, requiring special airborne equipment to fully grasp the functionality of the system. The CAT III approach is divided in three subcategories.

CAT IIIA: A precision instrument approach and landing with:

- A decision height lower than 30 m (100 ft), or no decision height; and
- A runway visual range not less than 200 m.

CAT IIIB: A precision instrument approach and landing with:

- A decision height lower than 15 m (50 ft)
- A runway visual range less than 200 m but not less than 50 m.

CAT IIIC: It is intended for operations with no decision height and no RVR limitations, thus provides guidance information from the coverage limit of the facility to, and along, the surface of the runway.

Inside the Bole airport there are two parallel runways namely Runway heading 25 Left (RWY25L) and Runway heading 25 Right (RWY 25R). These runways are equipped with full ILS system, thus both are CAT I ILS that provides guidance information from the coverage limit of the facility up to the decision height of 60 m.

2.1.2 Localizer Transmitter

Localizer system composed of the transmitter rack, antenna array with reflector screen and monitor system. An antenna array of a dual frequency LOC system transmits the course and the clearance signals, and it is normally defined by its total number of elements.

Localizer transmission is 108.1 MHZ to 111.975MHZ. Normally the antenna is installed in multi element arrays perpendicular to the desired approach course, which is normally the extended runway center line. The antenna array includes an RF distribution unit, RF coaxial cable to and from each antenna, an RF combining unit, and monitor combining network. The RF distribution unit provides for a specific amplitude and phase distribution to each antenna, which varies with the desired signal in space characteristics of each antenna array. All current localizer system utilizes integral monitoring where a combined sample of the radiated signal from each antenna is used to characterize the signal in space. Categories II &III type systems may use a "far-field" monitor, which provides additional monitoring of the signal in space [11].

Figure 3 describes the characteristic of LOC within certain sectors, and in relation to the runway centerline, are as follows DDM 0 exists when the approach direction corresponds exactly to the runway Centre line. DDM 15.5% characterizes the course sector selected such that the boundary at the level of the runway threshold is 107 m to the left and right of the runway with respect to the center line. These points are also known as width points.

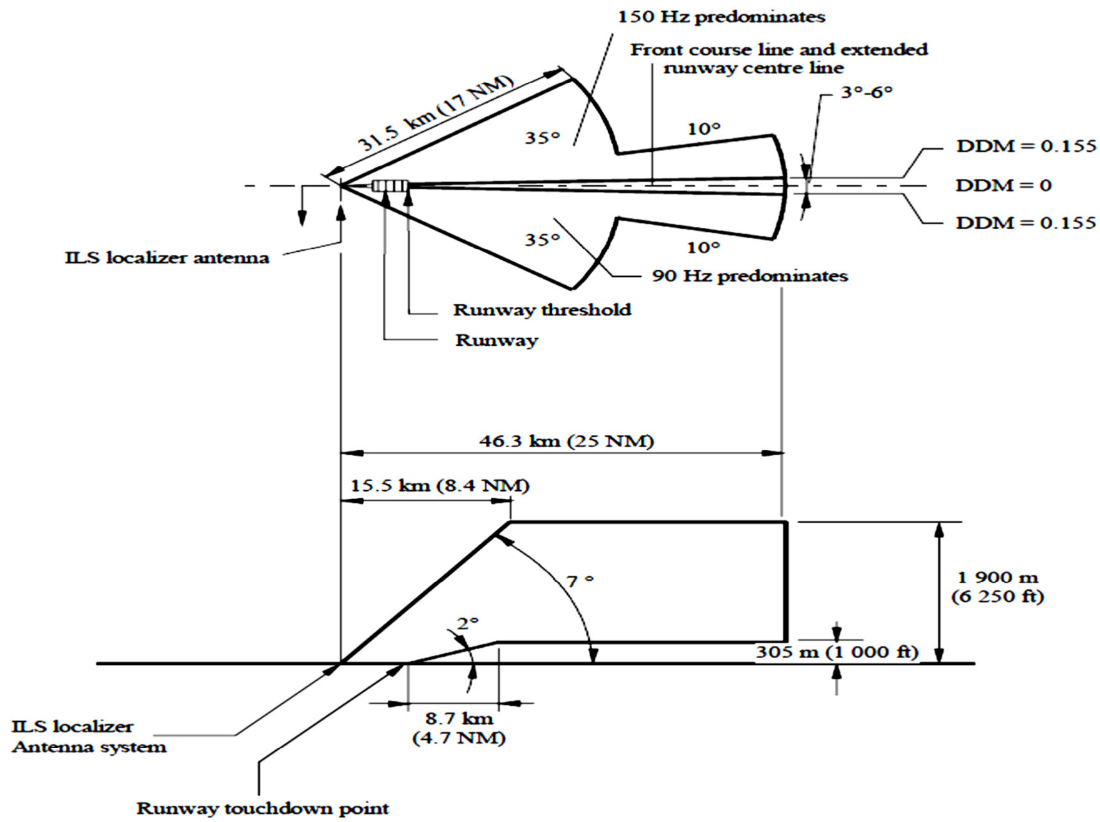


Figure 3: ITU-R SM.1009-1: Typical ILS localizer front course [3].

Hence, the above figure illustrates the two courses and clearance signals transmit the same information but have different purposes. The course signals' radiation pattern corresponds to lobes with a longer range that radiate up to 10º deviation of the extended runway centerline with a coverage range up to 25 NM. On the other hand, clearance signals are used for a shorter but broader range, covering azimuth angles within 10º and 35º from the extended runway centerline, reaching up to 17 NM. The coverage range of these signals may be reduced; depending on the topographical features of the terrain, down to 18 and 10 NM respectively Focusing on the vertical propagation, an ILS LOC must cover the region situated between 2 and 7º vertically for ground distances lower than 4.7 NM.

2.1.3 Localizer Antenna Array

The localizer antenna radiates RF signals to provide final approach azimuth navigation information to landing aircraft. Each antenna in the array is a broadband log-periodic dipole (LPD) antenna with seven parallel, horizontally polarized dipoles that are fed from a common balanced transmission line. The transmission line is excited to produce a traveling wave that progresses from the front toward the rear of the antenna structure. The amount of RF energy extracted from the passing traveling wave and radiated by a given dipole depends upon the electrical length of that particular dipole at the operating frequency. Frequency independent performance is obtained from the log-periodic radiating structure by virtue of the fact that the dipole lengths and positions along the balanced transmission line feeder are arranged so that the function of the resonant element is transferred smoothly along the structure, from one dipole radiator to another, as the operating frequency changes. The polarity of the drive signals applied to the alternate dipoles along the balanced transmission line feeder are transposed to achieve a concentration of radiated RF energy toward the front of the structure, even though the wave on the balanced transmission line progresses toward the rear. This transposition is accomplished by connecting the dipole radiators to the feeder line so that the alternate dipoles come out of the line in opposite directions. There are different elements of log periodic localizer antenna, for this particular study THLES 420 ILS fourteen LPD broadband localizer antenna array is considered. The array receives the course and clearance CSB and SBO distributed antenna array and radiates the signals for lateral guidance of a landing aircraft. An antenna array of a dual frequency LOC system transmits the course and the clearance signals, and it is normally defined by its total number of elements. In some arrays, it is defined by the number of elements transmitting the course and clearance signals, i.e., a 14/10 Localizer Array corresponds to all 14 elements radiating course signals and the center 10 transmitting clearance signals. The maximum output power of these signals rounds 25 W. Localize RWY 25L is dual frequency and it has course and clearance transmitter but for RWY 25R is single frequency localizer, it has only course transmitter [12].

2.1.4 Airborne ILS Receiver

The signal is received onboard of an aircraft by onboard localizer receiver. A simplified block scheme of on board receiver of localizer's signals is displayed in Figure 4. ILS localizer signal is received by the receiver antenna and extracted by the demodulator. The output of demodulator splits to three, one is to audio amplifier which is ILS identification tone

1020HZ and the others to each 90HZ filter and 150HZ filters. Hence, the tone output of the localizer receiver is separated into 90-hertz and 150-hertz components by band pass filters and after being rectified the two voltages are applied to the vertical needle of the cross pointer indicator.

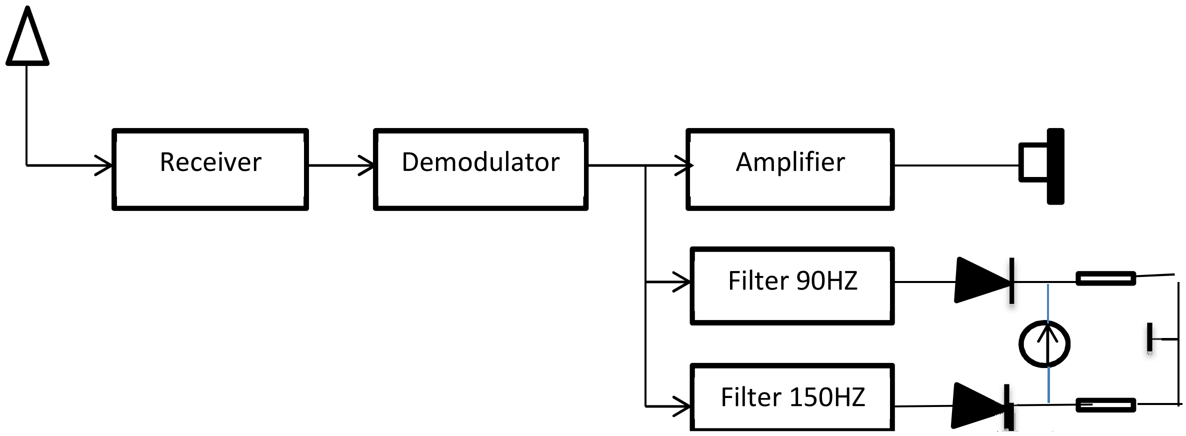


Figure 4: Block scheme of onboard localizer receiver [13].

According to ICAO annex 10 vol 1 Localizer receiver design should provide correct operation in the following environment:

i. The desired signal exceeds an undesired co-channel by 20 dB or more;
ii. An undesired signal, 50 kHz removed from the desired signal, exceeds the desired signal by up to 34 dB.
iii. An undesired signal, 100 kHz removed from the desired signal, exceeds the desired signal by up to 46 dB;
iv. An undesired signal, 150 kHz or further removed from the desired signal, exceeds the desired signal by up to 50 dB.

The level of an ILS signal varies throughout its service volume but previous work examining interference immunities of aviation receivers primarily considered the case where the received /ILS signal is assumed to be constant at the minimum desired level -89 dBm at the ILS receiver's antenna terminal. The level of an ILS signal varies throughout its service volume but previous work examining interference immunities of aviation receivers primarily considered the case where the received ILS signal is assumed to be constant at the minimum desired level (-89 dBm at the ILS receiver's antenna terminal).

2.2 FM Broadcasting

In 1984, the worldwide standards for FM broadcasting were defined in an international agreement made by ITU. These standards define, amongst others, the frequency spectrum characteristics and the installation procedures regarding co-channel and even air navigation radio navigation interference.

The frequency allocations for each broadcast station vary from region to region as to optimize the band and avoid interference. The installation of the stations is carefully studied in order to provide an optimal coverage for the least cost and also to avoid co-channel interference [15]

Since the aim of radio broadcasting is to inform and to entertain the people. Consequently, the properties of the human hearing have to be taken into regard when the quality parameters of the radio broadcasting systems and that of the receivers are specified. In monophonic broadcasting a single audio baseband signal is used to modulate a carrier; this signal originates from a single studio microphone. If more than one microphone is used, their outputs are mixed to generate a single signal. FM broadcasting was originally monophonic, and the Federal Communication Commission (FCC) standards were established for mono. The FCC standards of transmission bandwidth of 200 kHz with maximum frequency deviation of Δf = 75 kHz. Stereo uses two microphones or two groups of microphones to generate a left signal L(t) and a right signal R(t). These signals are to be fed into two identical speakers at the receiving end. With proper speaker positioning, the result is a more accurate reproduction of the soundstage than is possible with mono.

By the time engineers had figured out how to do stereo FM, mono FM had been around a long time and there were millions of mono receivers in use. Instead of changing the standards and forcing everyone to buy new stereo receivers, the FCC required that any proposed stereo scheme would have to be compatible with mono in the sense that any standard mono FM receiver would be able, without modification, to receive a mono version of a stereo transmission. Furthermore, the stereo signal is required to stay within the200kHz transmission bandwidth limitation.

2.2.1 FM Transmitters

The transmitter is shown in Figure 5. Note that the left and right signals are first band limited to 15 kHz. The oscillator at fp = 19 kHz provides a pilot carrier, which will eliminate the need for a local oscillator at the receiver. The frequency Double gives f_{sc} = 38 kHz;

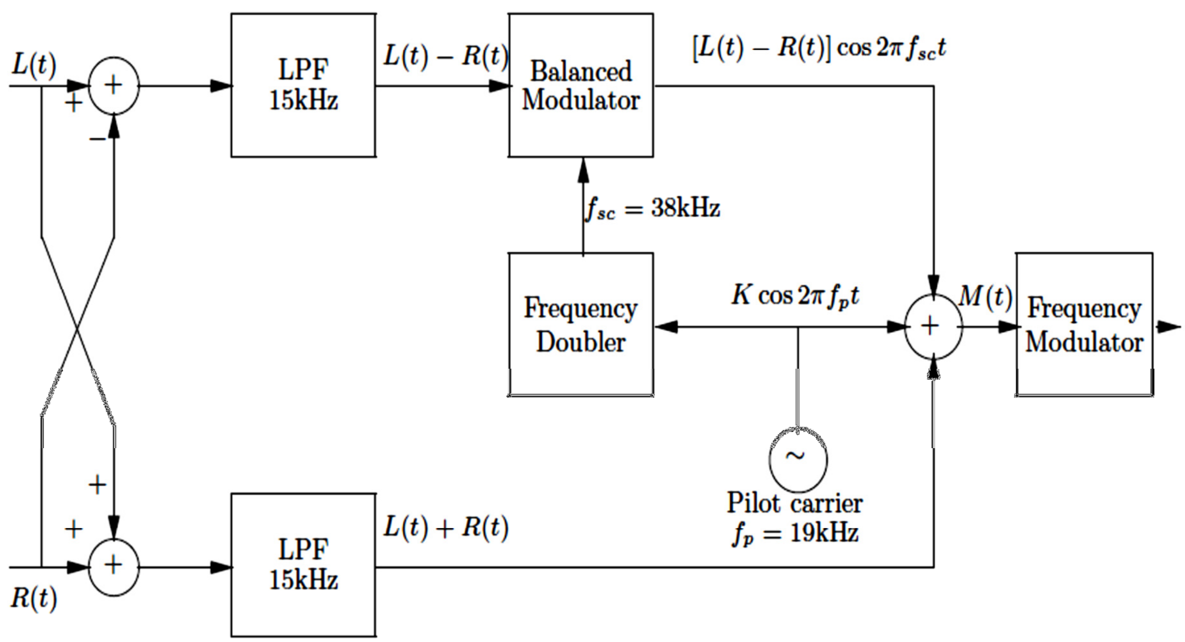


Figure 5: Stereo Transmitter [16]

This is called the subcarrier. The signal $L(t) - R(t)$ is applied to a balanced modulator; i.e.,$L - R$ is used to generate a Double Sideband Suppressed Carrier (DSB-SC) modulation of the subcarrier. The signal M(t),

Which is used to produce the transmitted FM signal, consists of three parts: L + R, the Modulation of the sub carrier by $L - R$, and the pilot carrier.

$$M(t) = [L(t) + R(t)] + [L(t) - R(t)]\cos 2\pi f_{sc} t + K \cos 2\pi f_p t \qquad (2.1)$$

The constant K determines the level of the pilot carrier relative to the other message signals in M.

A typical spectrum is shown in Figure 5. It is known that, the maximum frequency deviation is set by the FCC to be $\Delta f = 75kHz$. For monophonic transmission, a baseband $B = 15\ kHz$results in a deviation ratio of

$$D = \frac{75}{15} = 5 \qquad (2.2)$$

The transmission bandwidth then is

$$BFM = 2(D + 1)B = 2 * 6 * 15 = 180kHz \qquad (2.3)$$

Where; BFM is transmission band width of FM, D is deviation ratio and B is baseband signal bandwidth.

According to Carson's Rule, the validity of which is questionable when D = 5, but it gives us an idea of the bandwidth). For stereo transmission, the baseband signal M(t) has bandwidth 53kHz (see Figure 6), resulting in a much lower deviation ratio.

$$D = \frac{75}{53} = 1.42 \qquad (2.4)$$

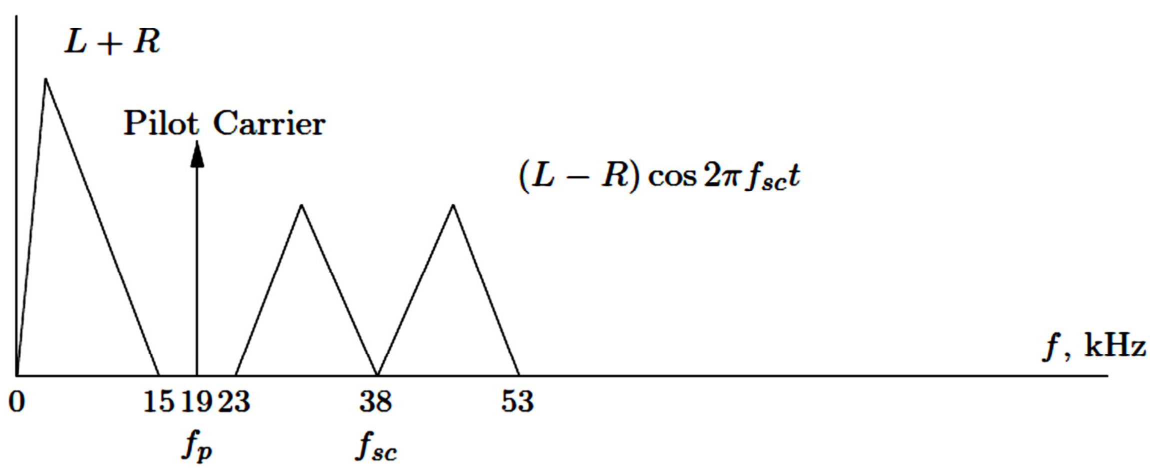


Figure 6 : Spectrum of M(t) [16]

The bandwidth using Carson's Rule despite its drawbacks:

$BFM = 2 * 2.42 * 53 = 256.5kHz$:... (2.5)

Equation (2.5) proves the stereo transmission bandwidth exceeds the 200 kHz limit; hence for stereo transmission, Δf must be reduced. Note that in stereo transmission, we have a small deviation ratio D; i.e., stereo FM must be essentially narrowband FM, and so we sacrifice the tremendous gain in output SNR that is possible with wideband FM. The main reason FM sounds better than AM is that the baseband signal bandwidth in FM is 15 kHz, while in AM it is only 5kHz (remember that the AM transmission bandwidth is restricted to 10kHz).

2.2.2 FM Broadcasting Antenna

Most of the broadcasting stations have Omni-directional antennas to cover the surrounding region. There are also installations in which highly directional antennas are positioned pointing to various directions to cover more efficiently the targeted areas by using antennas with higher gains. But most of the time FM broadcasting uses Vertical Dipole Array type antenna. The transmitting power of FM broadcasting stations is defined by their Effective Radiated Power (ERP), which corresponds to the power obtained in the direction of the main lobe; include both the loss and gain of the system. The height of a communication tower is typically around 60m, although it can be over 100m. There is numerous FM antenna type commercially available with differing characteristics.

2.3 Electromagnetic Interference

In general Electromagnetic interference (EMI), also called radio-frequency interference (RFI) when in the radio frequency spectrum, is a disturbance generated by an external source that affects an electrical circuit by electromagnetic induction, electrostatic coupling, or conduction. The disturbance may degrade the performance of the circuit or even stop it from functioning. There are three basic types of interference: radio frequency interference (RFI), electrical interference and intermodulation. The paper concerns on intermodulation interference due to FM broadcasting system on ILS LOC.

2.3.1 Inter-modulation Interference

Intermodulation (IM) or intermodulation interference is a frequency conversion process that occurs when two or more signals pass through a non-linear system or devices/components with in a system. The essential result of process is that energy contained in the input signal of non-linear system is transformed at its output in to a set of frequency components at the original frequency plus additional components at new frequencies that were not contained in the input.

Interference due to intermodulation is caused by strong signals which are generally near that of the wireless frequency. Instead, these strong signals overload some circuit in the wireless receiver, causing the circuit to internally generate harmonics of the strong signals. These harmonics then combine, or mix, in the receiver to create a new frequency that was not present at the receiver input. The newly-created frequency, called an "intermodulation product," then interferes with the wireless system in much the same way as other sources of interference.

There are three main points where the intermodulation can potentially occur:

- Final stages of transmitters, due to nonlinearities in power amplification circuits;
- Front-ends of receivers, due to nonlinearities in mixers and RF circuits.
- Nonlinear materials and nonlinear metal contacts, such as poor or corroded contacts in coaxial cables, waveguides, connectors, couplers, fences, steel structures and towers.

In general Inter-modulation occurs as a result of receiver being driven into non-linearity. The thesis studies inter-modulation interference on ILS localizer due to Addis Ababas' FM broadcasting systems [17].

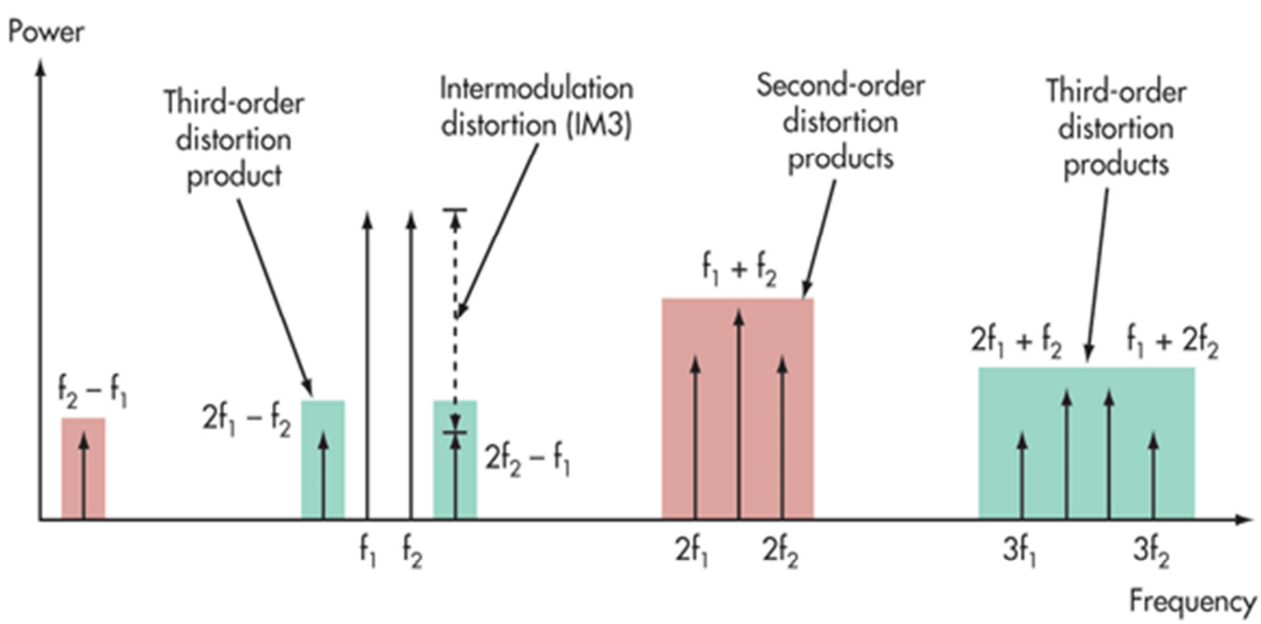


Figure 7: Intermodulation distortion (IMD) is the amplitude modulation of signals [18]

For the inter-modulation to occur, at least two signals need to be present. And the harmonics are linear combinations of input frequencies. For example, if the input of a nonlinear device contains two frequencies f_1 and f_2,then the second order inter-modulation components occur at $f_1 + f_2$and $f_1 - f_2$,the third-order inter-modulation components occur at $2f_1+f_2$, $2f_1 - f_2$, $2f_2 + f_1$and$2f_2 - f_1$.

If the non-linearity were stronger, it would have an output containing the following potential interference carrier:

2f1-f2,2f2-f1	third order products
3f1-2f2,3f2-2f1	fifth order products
4f1-3f2,4f2-3f1	seventh order products

With respect to the original tone at f1 and f2, the third-order components are closest, the fifth orders are the next closest and the seventh-orders are furthest. The pattern continues for device of increasing non-linearity severity.

Even if all the interfering frequencies lie out of the receiver pass band, their inter-modulation components can fall right at the desired frequency. The proximity of FM broadcasting frequencies to ILS localizer band makes localizer receiver susceptible to FM-generated inter-modulation interference.

Thus inter-modulation occurs as a result of the airborne receiver being driven into non-linearity by a high-power broadcast signal outside the aeronautical band. This distortion could serve to erroneously increase the magnitude of either at the carrier frequency + 150 Hz or at the carrier frequency + 90 Hz. If these increases are small, they can degrade signal integrity and cause false guidance being provided to the pilot/autopilot. If large, these increases can disrupt operation by causing the ILS receiver to alarm and stop providing service all together.

2.3.2 ITU-R interference Classification on Aeronautical System

The meaning of electromagnetic interference, also radio-frequency interference according to the International Telecommunication Union's (ITU) Radio Regulations (RR) – 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 any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy. ITU justify that the FM broadcasting interference in aeronautical radio navigation systems by dividing its effects in two categories [4].

Type A interference

Type A interference caused by un wanted emission in to aeronautical to the frequency band from one or more broadcasting transmitter. Type A interference is also sub divided in to Type A1 and Type A2.

A single transmitter may generate spurious emissions or several broadcasting transmitters may produce inter-modulation components in the aeronautical frequency bands; this is termed type A1 interference. On the other side a broadcasting signal may include non-negligible components in aeronautical bands; this interference mechanism is termed as type A2 interference. In practice arise only from broadcasting transmitter having frequency near to 108MHz and will only interfere with ILS localizer and VOR.

Type B interference

In contrast Type B interference is generated in the aeronautical receiver due to side effects of emissions outside of the aeronautical band. Type B interference is sub-divided in to two that are Type B1 and Type B2**.** In the case of type B1 interference Inter-modulation may be generated in an aeronautical receiver as a result of the receiver being driven into non-linearity by broadcasting signals outside the aeronautical band. In order to occur this type of interference, at least two broadcasting signals need to be present and they must have a frequency relationship which, in a non-linear process, can produce an inter-modulation product within the wanted RF channel in use. On the other hand if the signal strength of the FM broadcast signal(s) at the input of the receiver is too high, it can also cause saturation of the front end, resulting in the desensitization of the receiver, this is termed as type B2 interference.

Chapter 3

Propagation model Development

Mathematical radio propagation model is mathematical formulation for the characterization of radio wave propagation as a function of frequency, distance and other factors. In this section the propagation model development is described for both ILS localizer and the broadcasting station with different assumption.

3.1 ILS Localizer Propagation Model

A model is usually developed to predict the behavior of propagation for a link under certain constraints. Since variations due to path loss and shadowing occur over relatively large distances, this variation is sometimes referred to as large-scale propagation effects. Variation due to multipath occurs over very short distances, on the order of the signal wavelength, so these variations are sometimes referred to as small-scale propagation effects but the study considers only large scale propagation.

Localizer antenna arrays radiate directional composite signal with minimum coverage of 25NM. The antenna arrays are always installed at the approach end of the runway therefore its signal propagation is considered as line-of-site. Thus the signal propagation is considered as free-space propagation. The free space power received by a receiver antenna which is separated from a radiating transmitter antenna distance d_s, is given by free space equation. The most appropriate propagation model for our aeronautical environment is the free space propagation model. Another assumption is since LOC is landing aid the transmission distances on the earth are small enough so as not to be affected by the earth's curvature, thus flat earth model is used to calculate transmission loss for the ILS localizer system. The system is operating in VHF band the so, factors such as the atmosphere and rain are not taken into account, that their impact caused is too small to be taken into consideration so that for a first approximation, radio rays could be considered to be straight lines above the earth.

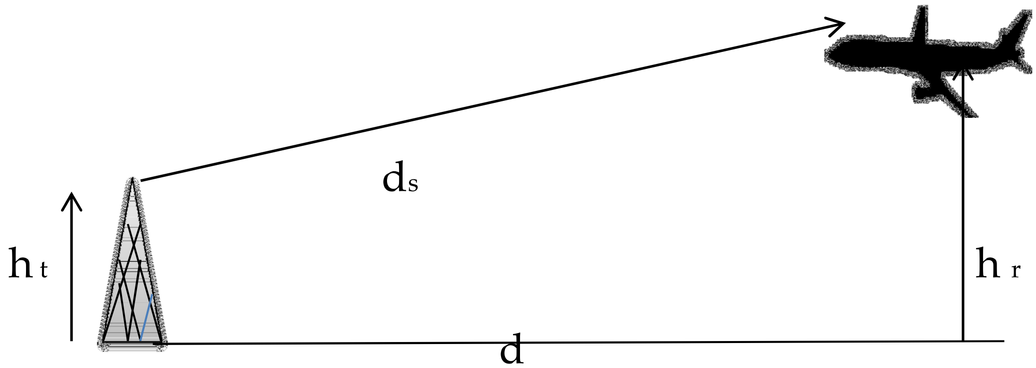


Figure 8: Free Space Transmission Link System

Where; h_t is height of transmitter h_r is height of receiver, d and d_s are ground distance and slant distance between transmitter and receiver respectively.

3.1.1 Localizer system parameter

ILS localizer propagation modeled according system parameters on THALES 421 ILS ground equipment which is installed at Bole international airport for RWY 25L, Thus the technical specification of THALES 421 ILS LOC are listed in the table 3.1, Carrier power refers to the carrier power delivered to the terminals of the carrier antenna, and antenna gain refers to the main lobe free space gain of the carrier antenna with reference to an isotropic radiator. ILS localizer use horizontally polarized antennas.

Table 3.1 technical parameter of ILS localizer system

Localizer LPD Antenna Characteristics	**LOC LPD Antenna Parameter level**
Antenna type	14 element LPD
Carrier power	25W
Input VSWR	1.2:1 maximum
Gain	10 dB
Front-to-back ratio	Approximately 26 dB
Input Impedance	50 ohms
Horizontal coverage	±35°
Vertical coverage	Up to 7°
Polarization	Horizontal

Localizer signal parameters has to measure by Portable ILS VOR Receiver (PIR) on the ground and flight check by special flight inspection system equipped aircraft in order to determine the main signal parameters in space are with in either Federal Aviation Administration (FAA) and /or ICAO standard. Hence, for this particular study transmitter and antenna parameters and flight calibration data are used for modeling the signal power level at the receiver end.

3.1.2 Frequency Spectrum

Signals are represented only by their transmitting bandwidth. According to ICAO annex 10 volume one, localizer operates in the band 108.1 MHz to 111.975 MHZ. Where a single radio frequency carrier is used, the frequency tolerance shall not exceed plus or minus 0.005 per cent. Where two radio frequency carriers are used, the frequency tolerance shall not exceed 0.002 per cent and the nominal band occupied by the carriers shall be symmetrical about the assigned frequency. As ICAO standard the frequency separation between the carriers shall not be less than 5 kHz nor more than 14 kHz. For THALES 421 dual frequency localizer frequency spectrum is depicted on Figure 9 below;

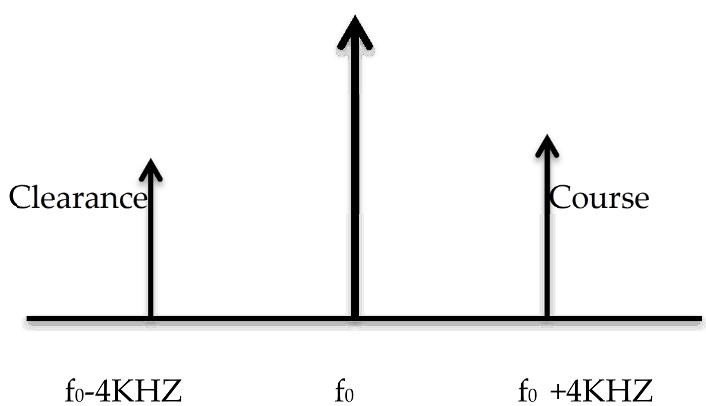


Figure 9 : Dual Frequency Spectrum for ILS LOC

As we have seen from the Figure 9, $_0$ is center frequency; course/clearance carrier difference is 8KHZ. One should denote that the course and clearance signals would have to be implemented differently, due to their different radiation patterns. The course signal is transmitted with an offset of +4 kHz and the clearance signal is transmitted with an offset -4kHz from LOC center frequency. It is true that frequency affects the values of the path and obstacle losses, but since the maximum deviation relative to the carrier in these systems is around 4 kHz.

3.1.3 Received power and System Loss Calculation

An aircraft representing the receiving terminal, ILS represents a desired navigational-aid transmitting facility, and FM transmitting facility represents un-desired. All three are aligned along a great circle path, and for simplicity assumed to be above a smooth flat surface.

In order to determine the propagation model one has to determine the geographical topology between the transmitting and receiving system, the radiation pattern of both ILS LOC and FM broadcasting, and general aeronautical localizer receiver which is an aircraft position and characteristics.

ITU states the localizer composite signal is radiated 2 degree above the surface of the runway and 7 degree vertical coverage which is illustrated chapter in 2 Figure 3. Thus elevation of Addis Ababa bole international runway 25L/25R threshold and the highest peak within 10 NM radiuses is 2317m and 2467m respectively. From final landing phase up to touch down one can analyze using partygoer's theorem and evaluate the maximum elevation in front of the localizer antenna.

Assuming no polarization mismatch loss and no obstruction between the transmitting and the receiving antennas, the free space power received by a receiver antenna which is separated from a radiating transmitter antenna by a distance d_s, is given by: [19]

$$\boldsymbol{P_r}\ (\mathbf{d}_s) = \frac{\boldsymbol{PtGtGr\lambda^2}}{(\boldsymbol{4\pi})^2 \boldsymbol{ds}\ \boldsymbol{K_{hill}}} \qquad (3.1)$$

Where:- $Pr(d_s)$: Received power in watt,

P_t: Transmitted power in watt

G_t : Transmit antenna gain

G_r: Receive antenna gain

$\boldsymbol{\lambda}$: Transmitted signal wave length in meter

d_s: Slant distance between transmitter and receiver in kilometer

$Khill$: Corrective factor for hilly region

Thus, slant distance between transmitter and receiver is given by:

$$ds=\sqrt{\boldsymbol{d^2} + (\boldsymbol{hr} - \boldsymbol{ht})^2} \qquad (3.2)$$

Where: ds is slant distance from transmitter to receiver, $\boldsymbol{d}$ is horizontal distance from transmitter to receiver,hr is height of receiver and ht is height of transmitter

The gain of the antenna is related to its effective aperture area A_e, is given by

$$G = \frac{4\pi Ae}{\lambda^2} \qquad (3.3)$$

The effective aperture A_e is related to the physical size of the antenna, and $\boldsymbol{\lambda}$ is related to the carrier frequency by,

$$\boldsymbol{\lambda} = \frac{\boldsymbol{c}}{\boldsymbol{f}} \qquad (3.3)$$

Where f is carrier frequency in Hertz and C is the speed of light given in meters per seconds. The values for P_t and P_r must be expressed in the same units; G_r and G_t are dimensionless quantities.

The path loss, which represents signal attenuation as a positive quantity measured in dB, is defined as the difference (in dB) between the effective transmitted power and the received power, and may or may not include the effect of the antenna gains. The path loss for the free space model when antenna gains are included is given by,

$$\text{Lf} = 10\log_{10}[\frac{\lambda}{4\pi ds}]^2 \qquad (3.4)$$

Since the ILS signal measuring equipment that is the flight inspection system analyses the ILS received power in the aircraft instead of in dBw or dBm it measures power density of LOC (dBW/m^2) thus substituting equation (3.3) into equation (3.4):

$$\text{Lf} = 10\log_{10}[\frac{c}{4f\pi ds}]^2 \qquad (3.5)$$

The distance of aircraft is measured in accordance with runway threshold in nautical mile (NM) unit thus one nautical miles is equivalent to 1852 meters thus the path loss equation becomes:[7]

$$L_f= 10\log_{10}[\frac{161987}{4f\pi ds}]^2 \qquad (3.6)$$

161987 is Velocity of light in NM/sec, f is MHZ and d_s is nautical mile.

Two ray Model was tested for this study, two-ray is the simplest ray-tracing model model, which accurately describes signal propagation when there is one direct path between the transmitter and receiver and one reflected path. This model characterizes signal propagation in isolated areas with few reflectors.

$$pr(dBm) = Pt(dBm) + 10\log(Gl) + 20\log(ht\ hr) - 40\log(d) \qquad (3.7)$$

Where: $Pt\ is\ transmit\ power,\ \sqrt{Gl} = \sqrt{Ga + Gb}$ is the product of transmit and receive antenna field radiation patterns in the LOS direction, $ht\ and\ hr$ transmitter and receiver height, d is the distance between transmitter and receiver [19].

Similarly received power density P_D (dBW/m^2) for the case of an isotropic antenna may be computed in the following manner [1]

$$PD = \Pr(ds) - 10\log\frac{\lambda^2}{4\pi} \qquad (3.8)$$

Where: PD=power density in (dBW/m^2)

Pr(d_s)= Received power dBW

λ = wavelength in metres.

When the ILS localizer signal propagation is modeled one has to be considering the receiver position. Therefore the flight routes for this particular study were the approach flight route of Bole International Airport runway 25 (RWY 25).

The approach should be defined by the runway heading angle, starting point of the approach, initial altitude, and descent angle in percentage. In order to model the aircraft's position at approaches flight routes. The approach distance D_{path} and the altitude H_i are given by: [20]

$$Dpath[m] = \frac{Hinital[m] - Hfinal[m]}{tan\ \alpha} \qquad (3.9)$$

Similarly

$$Hi[m] = Hinital[m] \text{-Di[m] tan } \alpha \qquad (3.10)$$

Where; $H_{initial}$: Approach initial height above mean sea level (MSL).

H_{final} : Airport runway height above MSL.

α : Descent angle.

H_i : Height in a point of the approach.

D_i : Relative distance in a point to the end of the approach.

3.1.4 Radiation Pattern

Localizer array radiates RF energy generated by the subsystem course and clearance transmitters and produces a VHF signal-in-space that contains modulation information. The array radiates a course frequency signal that consists of two different VHF signals; carrier-plus sideband (CSB) and sideband-only (SBO).

The CSB signal consists of a VHF carrier that is amplitude modulated to equal depths by the two audio navigational tones, 90 and 150 Hz. The SBO signal consists of a double-sideband, suppressed carrier signal that is modulated by the absolute value of the 90-150 Hz signal. The antenna array also radiates a clearance signal that is modulated like the course signal but offset from the course carrier by a fixed frequency of 8 kHz. Both CSB signals are also modulated by a keyed 1020-Hz identification tone. [12]

a. **CSB pattern:** - The CSB pattern for both course and clearance is generated by pairs of radiating antennas. Each pair of antennas is fed with equal-amplitude and in-phase signals. Radiated signal level decreases away from the runway centerline and, eventually, the radiated signal nulls at a certain angle. The location of a null depends upon the spacing between antennas of the pair. The CSB pattern is tailored by using the following parameters; spacing of the antennas, number of pairs of elements, and amplitude distribution among pairs of antennas.

   SBO Pattern:- The composite SBO pattern for both course and clearance is generated by pairs of radiating antennas. The signals fed to each pair of antennas are equal in amplitude but are 180 degrees out-of-phase. A pair of antennas fed in this manner produces a signal with a null on the runway centerline. Signal level increases away from the centerline and eventually reaches a maximum level, then starts to decrease. The angle at which the maximum signal is realized depends on the spacing between antennas. When the SBO signals are added to the CSB signals in space, an RF signal is produced that has a difference between the depth of 90-Hz modulation and the depth of 150-Hz modulation. The greater the relative SBO signal level is with respect to the CSB signal level, the greater the difference is in depth of modulation. When there are no SBO signals in space, such as on the runway centerline, there is no difference in depth of modulation (0 DDM).

For the antenna system, one considers the radiation pattern of the course CSB signal, since it corresponds to the signal received by the aircraft at longer distances.

The main concern of the modeling is the main lobe of the course signal, since the analyzed signal is inside of the section covered by it. The array radiation pattern is given by Thales 421 localizer .It is necessary to characterize the elements composing the antenna system. In [21], a simple model for the radiation pattern of an LPDA by doing an approximation to a dipole is presented.

The horizontal normalized gain of a dipole is given by:

$$Garray = Gant * AF \qquad (3.11)$$

Where;

$Garray$: Gain of the array

$Gant$: Gain of the array antenna element

AF = array factor

The amplitude and phase of the AF can be controlled in uniform arrays by properly selecting the relative phase ø between the $elements. In\ non$ uniform arrays the amplitude as well as the phase can be used to control the information distribution of the total array factor. Thus for N elements of array the array factor is calculated by: [22]

$$AF(e^{j\emptyset} - 1) = -1 + e^{-jN\phi} \qquad (3.12)$$

The reference point is the physical center of the array, the array factor of the above equation becomes:

$$AF = {}^{\sin N\emptyset/2}\!/_{\sin \emptyset/2} \qquad (3.13)$$

Since THALES 421 manual describes the spacing between the arrays is with a reference of physical center line of the runway which is the center of the array, therefore equation (3.13) is valid for this system.

Table 3.2 - 14-element LPDA course CSB characteristics [12]

Antenna no.	Distance from center line[m]	Course CSB	
		Electrical current ratio [a_q]	Phase [^{0}]
1L	0.819	0.8535	0
2L	2.959	1.0000	0
3L	5.359	0.7751	0
4L	7.746	0.4443	0
5L	10.159	0.2219	0
6L	12.560	0.0344	0
7L	15.113	0.0000	0
1R	0.819	0.8535	0
2R	2.959	1.0000	0
3R	5.359	0.7751	0
4R	7.746	0.4443	0
5R	10.159	0.2219	0
6R	12.560	0.0344	0
7R	15.113	0.0000	0

3.2 FM Broadcasting Stations Propagation Model

To begin with, one can formulate the exact path of electromagnetic wave propagation between the FM transmission towers and the receivers located on the landing aircraft; one has to study the geographical topology between transmitter which is the broadcasting station and airborne receiver. The variable in any given FM transmission system are many. They include factors such as antenna height versus ERP, antenna gain versus transmitter power, Fresnel zone, polarization site location and topography among others. In this thesis examine the intermodulation power that reaches at the approaching aircraft receiver considering the above factors.

Mount Furi is one of the highest pick where most Addis Ababa FM broadcasting antennas are installed. According to the collected data from FM broadcasting station the elevation of this mountain is 2839 meter which is higher than the elevation of Bole international airport runway, therefore one can select frees-pace propagation model in order to determine the power reached at the receiver end. However, measurements have shown that free-space propagation predictions may lead to a significant over estimation in a case where both the transmitting and receiving antennas are at low heights (for example, less than 150 m) above the ground, but in this case the receiver altitude is more than the minimum requirement. In this particular study the receiver is above 150 m above the ground.

3.2.1 FM Broadcasting Stations parameters

FM radio broadcasting stations are operating in the very high frequency (VHF) range, which is adjacent to the ILS localizer frequency. According to the statistics of broadcasting agency document there are 15 number of FM broadcasting station in Addis Ababa. Among Addis Ababa broadcasting stations thirteen FM broadcasting stations antennas are mounted at Furi [23]. VDA is considered as broadcasting antenna which is a realistic approach and horizontal omnidirectional characteristics. Most FM station tilt down their antenna to cover the terminals located at the ground more efficiently, this also implies that the effect of FM on airspace is reduced as compared to the non- tilted one. But the sample data of Addis Ababa FM broadcasting station shows that the antennas are non-tilted. Since the propagation model is studied based on the following sample three FM broadcasting stations data where their frequency are more adjacent to the ILS localizer frequency. VDA is considered as non-tilted and horizontal omnidirectional characteristics.

The sample data are collected from three FM broadcasting stations that are more adjacent to ILS localizer frequency. The parameters that are necessary for FM signal modeling is listed in table 3.3. Shown below:

Table 3.3 FM broad casting radio transmitter and antenna parameter

	The Exact value FM station parameters		
Transmitter and antenna parameters	**Ethio FM 107.8**	**Afro-FM 105.3**	**Sheger FM102.1**
Antenna type	Omni-directional	Gambro	Dipole
No. of antenna array	6	6	6
Transmitted power(ERP)	3kw	2Kw/3kw	2KW
Input VSWR	1.3:1	xx	1.5:1
Antenna Gain	6dB	5.05dB	7.5dB
BW	±75KHZ	200KHZ	±75KHZ
Input Impedance	50 ohm	50 ohm	50 ohm
coverage	150km	150 KM	150 KM
Height of mast	60m	60m	54m
Transmitter model	Harris 3kw	Eddy stone	Harris Z2

3.2.2 FM Broadcasting System Frequency Spectrum

The frequency allocations for each broadcast station vary from region to region as to optimize the band and avoid interference. The installation of the stations is carefully studied in order to provide an optimal coverage for the least cost and also to avoid co-channel interference.

In 1984, the worldwide standards for FM broadcasting were defined in an international agreement made by ITU. These standards define, amongst others, the frequency spectrum characteristics and the installation procedures regarding co-channel and even radio navigation interference [24]. In Ethiopia, the RF allocation of FM broadcasting throughout the country is controlled by Ethiopian Broadcasting Authority which is the federal media regulatory in Ethiopia.

FM broadcasting is operated with a spectrum from 87.5MHZ up to 108MHZ. When considering an emission of an FM audio broadcasting, one should evaluate what kind of signal and which components are being transmitted. A mono signal only needs up to 15 kHz of audio bandwidth, and the 200 kHz allocated bandwidth allows for a 75 kHz carrier frequency deviation plus guard bands for reducing interference. For stereo signals, the audio bandwidth is 53 kHz, which entails that, for the same carrier frequency deviation, it is more prone to interfere with adjacent channels. In out-of-band emission limits for FM transmitters, when considering a carrier with 200 kHz bandwidth, are presented [25].

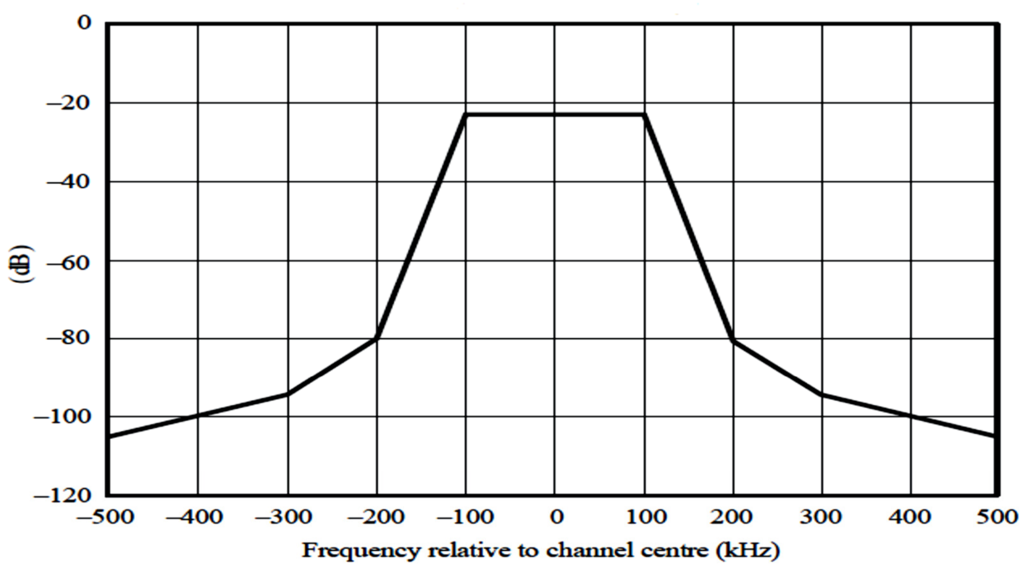


Figure 10 : Out-of-band transmission mask for FM broadcasting transmitters [25]

3.2.3 FM Broadcasting Radiation Pattern and Power Level

Broadcasting antennas are typically located at a high altitude, since it typically implies a larger coverage range. And there are different types of FM broadcasting antenna According to the sample Addis Ababa FM broadcasting station data the height of a communication tower is around 60 and the antenna types are different. Thus most FM broadcasting stations have Omni-directional antenna to cover the contagious region. But there is directional antenna to cover more efficient direction such as log periodic antenna. Hence, this study considers that vertical Dipole Array (VDA) which have Omni-directional characteristics. All antennas are Depending on the transmitting power and its location, a broadcast station is able to cover up tens of kilo meters. The Effective Radiated Power (ERP) of a commercial FM broadcasting station can go over 100 kW, depending on the desirable coverage range. FM broadcasting stations, one must take into account that the power output is not constant throughout the considered band, being given by:

$$Ptfm[dB] = Ptmax[dB] - At[dB] \tag{3.14}$$

Where: $\mathbf{P_{tfm}}$: power of the signal transmitted by the FM broadcasting station.

$\mathbf{P_{tmax}}$: maximum transmitted power of the FM broadcasting station.

A_t : transmit antenna gain.

3.3 Interference Model

When considering ILS LOC systems it uses very specific frequencies to provide critical guidance to aircrafts. In general, from an ILS localizer receiver point of view, FM broadcasting transmission can be regarded as noise due to the ability to convert inters modulation frequency. In the case of ILS LOC, it corresponds to frequency shifts of navigation tones 90 and 150 HZ. The paper models the intermodulation interference that are created at the output receiver under influence of intensive unwanted signals at the receiver input due to non-linearity of an amplitude response of the receiver. On the other hand specifically there are establishment of the procedures to analyze the impact of interference on the localizer receiver, accompanied by a thorough study of the various interference mechanisms and the presentation of the various criteria. Presently, there are two official models for ILS localizer and VOR receivers developed, which are used to calculate the impact of the interference caused by FM Broadcasting: one was agreed at a meeting of Task Group 12/1 in Montreal in 1992 (Montreal receivers), and the other was published in Annex 10 in 1998, presenting better interference immunity criteria [1].

3.3.1 General Receiver Intermodulation Model

Intermodulation distortion (IMD) is a popular measure of the linearity of amplifiers, gain blocks, mixers, and other RF components. The second and third-order intercept points (IP2 and IP3) are figures of merit for these specifications and allow distortion products to be computed for various signal amplitudes.

In order to model intermodulation interference level one has to consider the non-linear property of receiver amplifier .Thus Actual amplifier behavior requires more terms to describe: [26]

$$V_{out} = A_v V_{in} + B{V_{in}}^2 + C{V_{in}}^3 + \cdots \qquad (3.15)$$

This representation is simply a Taylor Series representation of the non-linear function:

$$V_{out} = f(V_{in}) \qquad (3.16)$$

But, as V_{in} gets large, the values $B{V_{in}}^2$v and $C{V_{in}}^3$ will get large. In that case, the terms $B{V_{in}}^2$ v and $C{V_{in}}^3$will become significant. As a result, the output will not simply be a larger version of the input. The output will instead be distorted a phenomenon known as inter-modulation interference. Say the input to the amplifier is sinusoidal, with magnitude 'a'

$$V_{in} = \mathrm{a}\cos wt \qquad (3.17)$$

When we substitute eq.(3.17) in to eq.(3.15)

$$V_{out} = \mathrm{B}a^2\, cos^2 wt + Ca^3\, cos^3 wt + \cdots$$

Using our knowledge of trigonometry, we can determine the result of the second term of the output Taylor series.

$$V_{out} = B\frac{a^2}{2} + B\frac{a^2}{2}\cos 2wt + C\frac{a^3}{2}\cos wt + C\frac{a^3}{2}\cos 3wt + \cdots \qquad (3.18)$$

From equation (3.18) one can observes that harmonics of 2wt and 3wt. These harmonics are called second and third-order product.

To understand why intermodulation distortion can be a problem in aeronautical receiver problem, we need to consider the power of the output signals.

$${p_1}^{out} = \mathrm{A}^2{}_v p_{in} = Gp_{in} \qquad \text{1 st-order output power} \qquad (3.19)$$

$${p_2}^{out} = \frac{B^2}{4} p_{in} = G_2\, {p_{in}}^2 \qquad \text{2nd-order output power} \qquad (3.20)$$

$$p_3^{out} = \frac{C^3}{16} p_{in} = G_3\, p_{in}^{\ 3} \qquad \text{3rd-order output power} \qquad (3.21)$$

Where G is the equipment gain:

Unlike G, the values G_2 and G_3 are not coefficients (i.e., not unit less). The value G_2 obviously has units of inverse power (e.g., mW^{-1} or W^{-1}), while G_3 has units of inverse power squared (e.g., mW^{-2} or W^{-2}).

Therefore the general formula for third order intermodulation components of power level either two frequency or three frequency is given by: [27]

-Two incoming signals at the input, at frequencies f1 and f2 correspondingly 3rd order inter-modulation power level P_{IMP}, based on intercept points IP3 is given by:

$$P_{IMP}[dBm] = 3(P_{ein} + G) - 2 * IP3 \qquad (3.22)$$

-Three incoming signals at the input of receiver, at frequencies f1, f2, and f3 correspondingly 3rd order intermodulation power level is

$$P_{IM}[dBm] = 3(P_{ein} + G) - 2 * IP3 + 6 \qquad (3.23)$$

Where : P_{IMP}=Third order intermodulation power at(dBm)

$P_{ein=}$ received broadcasting power level (dBm)

G = Receiver the gain (dB)

IP3=third order intercept point of receiver

Third order intermodulation power at the output of the receiver is calculated by

$$P_{i0} = P_{IM} - G \qquad (3.24)$$

In order to distinguish the resistance of a receiver to intermodulation (IMD), a standardized figure of merit called third-order intercept point (IP3) of receiver is used. A receiver with higher intercept point presents better immunity to IMD. IP3 is considered at the front end of the receiver, which means it already considers the non-linearity of all the components inside the instrument, including the amplifier and the band-pass filter. The value of IP3 is highly dependent on the individual characteristics of a receiver and not all of them contain this information concerning IMD. Most commercial manufacturers specify IP3 for their devices. According to NSA dynamic receiver study typical receiver has an IP3 of around +30 dBm. In this study, this value is considered for the aeronautical receiver [28].

3.3.2 ITU-R Model for Receiver Intermodulation Analysis

This thesis is studying performance of the aeronautical localizer receiver becomes unacceptably degraded due Addis Ababa FM broadcasting stations transmission according to Montreal ILS localizer criteria and ICAO annex 10 criteria. ITU-Recommendation specifies test procedures for determining the interference immunity characteristics of ICAO Annex 10 ILS localizer receiver and Montreal ILS localizer receiver whether Type A, and B interference degraded from nearby broadcasting stations.

ICAO states in general type A and B interferences on January 1998, the ILS localizer receiving system shall have immunity to interference from two-signal, third-order intermodulation products caused by FM broadcast signals is as follows. When two VHF FM sound broadcasting signals reach to receiver, third-order intermodulation will be occurred at the front end of receiver. This third order signal can similar to the desired ILS localizer frequency that makes harmful interference on ILS operation ,thus Annex 10 vol 1 gives guidance for different broadcasting ranges. For frequency range 107.7 – 108.0 MHz VHF FM sound broadcasting signals the following formula is used [1].

$$2 * P_{fm1} + P_{fm2} \leq 0 \qquad (3.25)$$

For frequency below 107.7 MHz VHF FM sound broadcasting signals the following formula is used:

$$2 * P_{fm1} + P_{fm2} 3 * [24 - 20\log \Delta f / 0.4] \leq 0 \qquad (3.26)$$

Where P_{fm1} and P_{fm2} are the levels (dBm) of the two VHF FM sound broadcasting signals at the ILS localizer receiver input , Δf = 108.1 – f1, and f1 is the frequency of P_{fm1}, the VHF FM sound broadcasting signal closer to 108.1 MHz.

A. Montreal ILS localizer and VOR receivers

Montreal aeronautical receivers an ILS localizer or VOR receiver characteristics where agreed at the 1992 meeting of Task Group 12/1 in Montreal. Whose characteristics are defined by the equations specified below: [4]

Type A interference

In general Type A interference is caused by unwanted emissions into the aeronautical band from one or more VHF FM broadcasting transmitters

a) For a broadcasting signal in the band 87.5-108.0 MHz:

$$P_{rfm} = E_{fm} - 118 - Ls - L(f) - La \quad (3.27)$$

Where; P_{rfm} : broadcasting signal level (dBm) at the input to the aeronautical receiver

E_{fm} : field strength (dB(μV/m)) of the broadcasting signal

Ls : signal splitter loss of 3.5 dB

L(f) : antenna system frequency-dependent loss at broadcasting frequency f (MHz) of 1.2 dB per MHz below 108 MHz

La : antenna system fixed loss of 9 dB.

b) For an aeronautical signal and a Type A1 signal in the band 108-118 MHz:

$$P_{ra} = E_a - 118 + L_s - L_a \quad (3.28)$$

Where: P_{ra} =signal level (dBm) at the input to the aeronautical receiver

E_a =field strength (dB(μV/m)) of the aeronautical or Type A1 signal.

Type B interference

Type B interference is that generated in an aeronautical receiver resulting from broadcasting transmissions on frequencies outside the aeronautical band. Intermodulation may be generated in an aeronautical receiver as a result of the receiver being driven into non-linearity by broadcasting signals outside the aeronautical band; this is termed Type B1 interference. One of the broadcasting signals must be of sufficient amplitude to drive the receiver into regions of non-linearity but interference may then be produced even though the other signal(s) may be of significantly lower amplitude. For B1 interference third-order intermodulation products are considered; they take the form of:

$$\left.\begin{array}{ll} f_{intermod} = 2f_{fm1} + f_{fm2} & \text{Two-signal case} \\ f_{intermod} = f_{fm1} + f_{fm2} - f_{fm3} & \text{Three –signal case} \end{array}\right\} \quad (3.29)$$

Where: $f_{intermod}$: intermodulation product frequency (MHz).

f_{fm1},f_{fm2} and f_{fm3} are broadcasting frequency, where f_{fm1}>f_{fm2}> f_{fm3}

According to Montreal ILS localizer receiver convention ITU –R states that formula that testes ILS localizer and VOR receivers exhibiting B1 interference, the following formulas should be used to assess potential incompatibilities [4].

a) Two-signal case: Montreal receiver

$$\left.\begin{array}{l} f(x) = 2\{P_{fm1} - 28\log\{\max(1.0; flo - f1))\}\} + \\ P_{fm2} - 20\log\{\max(1.0; flo - f2)\} + K + Lc > 0 \end{array}\right\} \quad (3.\ 30)$$

b) Three-signal case: Montreal receiver

$$\left.\begin{array}{l} P_{fm1} - 28LOG\{\max(1.0; flo - f1)\} + P_{fm2} \\ -28\log\{\max(1.0; flo - f2)\} + P_{fm3} \\ -28\log\{\max(1.0; flo - f3)\} + k + 6 - Lc > 0 \end{array}\right\} \quad (3.31)$$

Where : P_{fm1}, P_{fm2} *and* P_{fm3} are broadcasting signal levels (dBm) at the input to the aeronautical receiver for broadcasting frequenciesf1, f2 and f3 respectively; flo aeronautical frequency (MHz); f1, f2, f3 are broadcasting frequencies (MHz) f1 ≥ f2 > f3; the value of K = 140 and Lc =correction factor (dB) to account for changes in the ILS localizer.

For the above formula one can use correction factor Lc for Type B1 interference immunity resulting from changes in wanted signal levels. Thus correction factor may be applied for ILS localizer two and three-signal cases:

$$Lc = P_{rlo} - P_{ref} \quad (3.32)$$

where: Lc = correction factor (dB) to account for changes in the wanted signal level

P_{rlo} = wanted signal level (dBm) at the input to the aeronautical receiver

P_{ref} =reference level (dBm) of the wanted signal at the input to the aeronautical receiver for the Type B1 interference immunity formula, it is –89 dBm for LOC

For an assessment of Type B2 of the Montreal approach interference, the following empirical formula may be used to determine the maximum level of a broadcasting signal at the input to the airborne ILS localizer or VOR receiver to avoid potential interference:

$$P_{rfm} = -20 + \frac{20\log\ max(0.4; flo - f_{fm})}{0.4} \qquad (3.33)$$

Where: P_{rfm} is maximum level (dBm) of the broadcasting signal at the input to the aeronautical localizer receiver; f_{fm} broadcasting frequency (MHz) and flo aeronautical localizer frequency (MHz).

B.ICAO Annex 10 1998 ILS localizer and VOR receivers

For Type A1 and A2 interference both ICAO Annex 10 1998 ILS localizer and VOR receivers Montreal aeronautical receivers an ILS localizer or VOR receiver whose criteria is the same as it is explained Montreal aeronautical receivers an ILS localizer or VOR receiver part the difference is on Type B interference.

Type B interference

Hence ILS LOC and VOR receivers exhibiting poor immunity to Type B1 interference, the Following formulas should be used to assess potential incompatibilities. A potential is identified when the relevant formula is satisfied.

a. Two-signal case:

$$\left.\begin{aligned} f(x) = \ & 2\{P_{fm1} - 28\log\left\{\max\frac{(0.4\ ;108.1 - f1)}{0.4}\right)\}\} + \\ & P_{fm2} - 20\log\left\{\max\frac{(0.4;108.1 - f2)}{0.4}\right\} + K + Lc + S > 0 \end{aligned}\right\} \qquad (3.\ 34)$$

b. Three-signal case:

$$\left.\begin{aligned} & P_{fm1} - 28LOG\left\{\max\frac{(0.4;108.1 - f1)}{0.4}\right\} + P_{fm2} \\ & -28\log\left\{\max\frac{(o.4;108.1 - f2)}{0.4}\right\} + P_{fm3} \\ & -28\log\left\{\frac{\max(0.4;108.1 - f3)}{0.4}\right\} + k + 6 - Lc + S > 0 \end{aligned}\right\} \qquad (3.35)$$

Where : P_{fm1}, P_{fm2} *and* P_{fm3} are broadcasting signal levels (dBm) at the input to the aeronautical receiver for broadcasting frequenciesf1, f2 and f3 respectively; f1, f2, f3 are broadcasting frequencies (MHz) f1 ≥ f2 > f3; the value of K = 78 for ILS localizer and Lc =correction factor (dB) to account for changes in the ILS localizer ; S=3 dB margin to take into account of the fact that the ICAO Annex 10 1998 receiver immunity criteria equations do not provide comprehensive compatibility assessment formulae.

For an assessment of Type B2 of the Montreal approach interference, the following empirical formula may be used to determine the maximum level of a broadcasting signal at the input to the airborne ILS localizer or VOR receiver to avoid potential interference:

$$P_{rfm} = min\{15; -10 + \frac{20log\max(0.4;108.1 - f_{fm})}{0.4} + Lc + S\} \quad (3.36)$$

Where: P_{rfm} is maximum level (dBm) of the broadcasting signal at the input to the aeronautical localizer receiver; f_{fm} broadcasting frequency (MHz).

After modeling the desired ILS localizer, undesired intermodulation interference due to FM broadcasting at the aircraft .The next step is analyzing the models using different scenarios and assumptions.

Chapter 4

Model Analysis and Results

Model analysis is done on measured the desired instrument landing system localizer signal which is flight inspection data (signal in space) for ILS RWY 25 and the analytical model of undesired broadcasting signal .The analysis is done using Google Earth for observational study, analytically and finally the real measured flight inspection data is used. The geographical study of both the desired and undesired signal with respect to air born receiver was one key factor for this particular study. Thus Figure 11 is taken from Google earth which describes the location of FM transmitting antenna for this specific study which is hill rock Furi, the position of the receiver point where interference analysis is started, location of ILS LOC antenna and runway threshold.

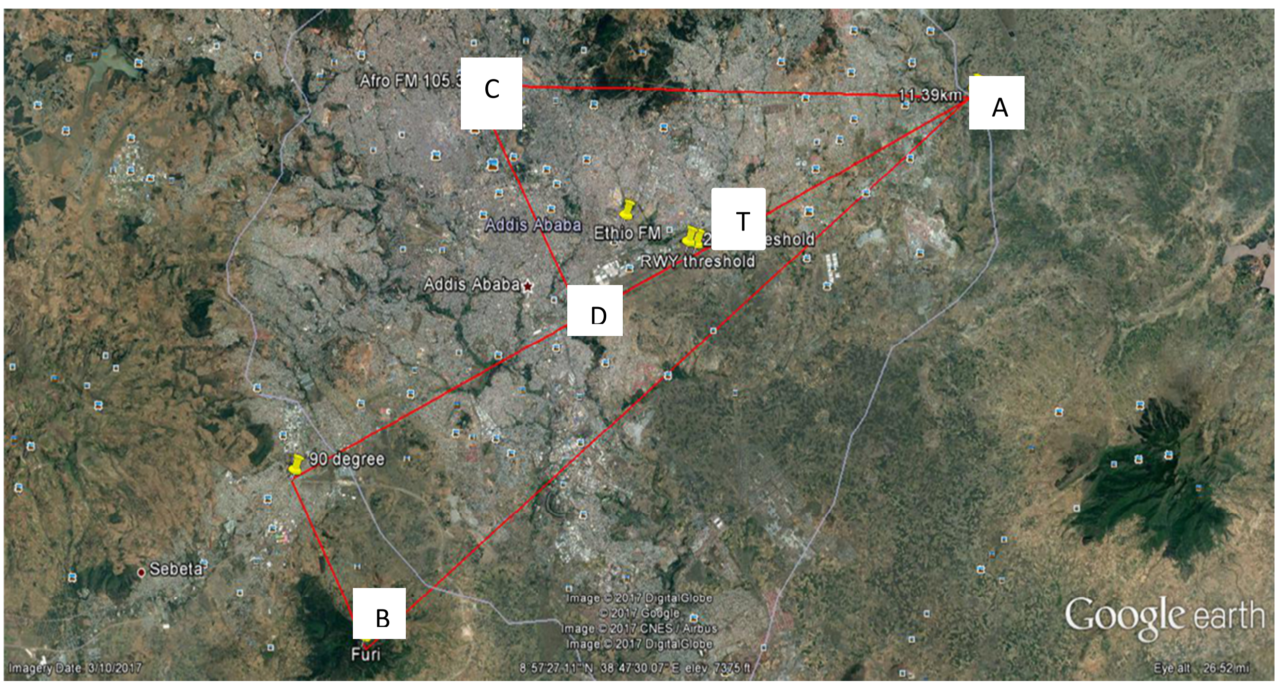


Figure 11: Location of Desired and Undesired Transmitters [from Google Earth]

However the minimum signal coverage of localizer is around 25 nautical miles, for this particular study it starts 10 nautical miles to runway threshold. Therefore model analysis of initial aircraft distance is taken 12NM because of the fact that after 10 NM the coverage become outside Addis Ababa for that reason the effect of FM signal power become degraded. After establishments of propagation model CIR, ICAO and ITU-R standards for ILS localizer receiving system were tested from two-signal and three signals, third-order inter-modulation products caused by VHF FM broadcasting systems.

From figure 11 Point ‘A ‘is receiver beginning point where the starting point for interference analysis along approach rout RWY 25L, point ‘A ‘to point ‘T ‘is considered as a final approach rout according to Google earth which is around 10 NM form runway threshold point which is point ‘T’. Point ‘B’ is mount Furi where most of broadcasting antennas are installed, point ’C’ the Afro-FM antenna location which is the most nearer antenna to the approach route and finally ‘D’ is the location of LOC RWY 25L antenna. Hence, in addition to different factor geographical study is one input during the development of propagation model. The major concern of modeling received power at the receiver end is to develop improved path loss prediction model which can produce consistent prediction result. For that reason determining and applying correction factor for propagation model by comparing between predicted and measured signal power from the transmitter has to be done. Therefore different propagation models were verified by using the following general model analysis method.

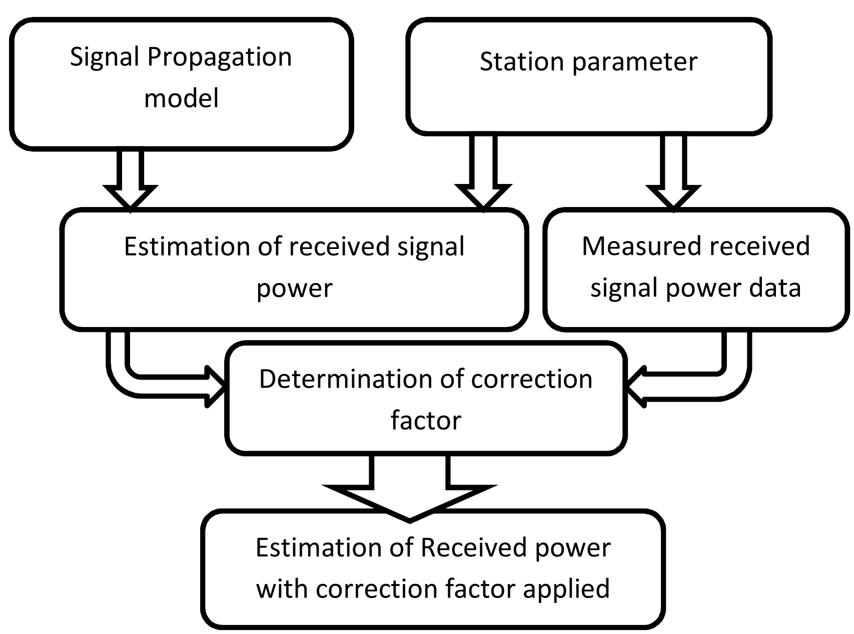


Figure 12 : Propagation Model design lay out

The above propagation model design as shown in figure 12 designates mathematical model that was expressed in chapter three .Input to design appropriate propagation model were selecting signal propagation model and station distance from either from localizer station or FM broadcasting station for wanted and unwanted transmission respectively; geographical location (coordinates); transmitter frequency; transmitter power; transmit antenna peak gain; transmit antenna horizontal and vertical patterns; Transmit antenna height; losses; receiver height; receiver antenna gain. The transmitter and receiver antenna radiation patterns are has to be considered to estimate received power to that end correction factor was determined form these estimated and actual received power level in a certain approach route. The measured signal for this particular study is taken from year 2017 G.C localizer flight inspection data. Two scenarios are studied; one is when the flight inspection aircraft is approaching with constant altitude to the localizer station or runway threshold and the other when the flight inspection aircraft is approaching with a certain angle [29]. Finally the measured and estimated received signal power as a function of the distances for the different propagation models is conducted at a certain approach route.

The correction factor is the mathematical adjustment that is to be applied to the estimated received signal power values for the propagation model that has the highest correlation coefficient and lowest MSE with measured received signal power values. This adjustment is to account for the deviation between the measured and estimated received signal power values. After applying the correction factor one has to check whether the estimated model approaches to the measured one or not. Therefore Mean Square Error (MSE) computed using expression.

Measures the average of the squares of the errors, where the errors show the difference between the estimated and the measured received signal power [30].

$$\mathrm{MSE} = \frac{1}{N}\sum_{i=1}^{N}[{P_{r,i}}^{E} - {P_{r,i}}^{M}]^2 \qquad (4.1)$$

Where ${P_{r,i}}^{E}$, ${P_{r,i}}^{M}$ and N are ; the i-th estimated received signal power; the i-th measured received signal power and number of sample. The larger the value of MSE, the further away the estimation is from the measured data values.

4.1 ILS Localizer Model Analysis

Landing is one of the most delicate maneuvers that a pilot has to perform, and ECAA is responsible for providing quality and precise ground support instruments to approaching aircrafts. To that end, there are two ILSs installed in Addis Ababa Bole international airport, ECAA's Communication Navigation and Surveillance Engineering department is being responsible for them. Table 4.1 lists describe the location of the ILS LOCs and their characteristics. The identified runway corresponds to the landing runway in which the ILS LOC is installed, and this number corresponds to the approximate tenth of the bearing of the landing approach in degrees.

This thesis addresses Category I (CAT I) Landing System (ILS) localizer interference prediction from nearby FM broadcasting station.

Table 4.1 Bole International Airport Runway geographical location and magnetic heading

Runway ID	Latitude [°]	Longitude [°]	Elevation [m]	Frequency [MHz]	P_t[W]	Azimuth [°]
RWY 25L	8 58 51.78N	38 48 48.50	2303	111.5MZ	25	252
RWY 25R	8 58 56.6N	38 48 40.30	2308	110.3MHZ	15	252

Besides the information regarding the transmitting equipment, this study must also take the surrounding terrain into account that is the geographical topology of the approach end. However the two runways that are parallel to each other, runways are modeled with constant elevation. The chosen distance corresponds to the maximum horizontal coverage range of the ILS LOC. One considered that the surrounding of the runway does not have obstacles affecting for ILS LOC signal propagation, hence, that its maximum range is extended to 25 NM (around 46.3 km).But for this study the analysis is done only the final landing phase.

Therefore the geographical topology between the ILS localizer antenna which is installed at Bole international airport runway and the Airborne receiver (test point on the approach rout 10nmi is determined form Google earth as shown below:

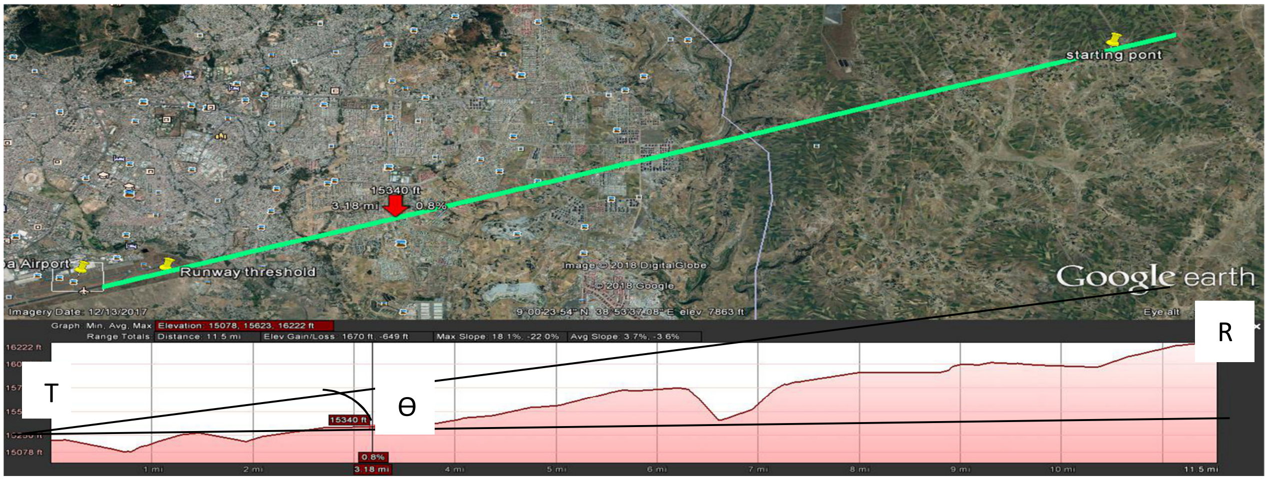


Figure 13: Elevation profile 25L up to 10 nmi [from Google Earth]

The localizer composite signal is radiated 2 degree above the surface of the runway and 7 degree vertical coverage. Thus from the figure 13 point 'T' is 2308m the lowest elevation with in 10NM which is the elevation of runway threshold and point 'R' is 2467m it is the highest elevation within 10 NM/18.5 km radius that is the final landing phase. One can analyze using partygoer's theorem and evaluate the maximum elevation in order to determine the appropriate propagation model. [4] For localizer propagation model the curve fitting technique were used.

Depend on two scenarios power received at the aircraft receiver were modeled by using MATLAB R2013a. One, the receiver moved at a constant altitude through approach route, the other consists of an approach maneuver, to analyze the variation of the ILS and FM broadcasting signals along the extended runway center line. These two scenarios are used to evaluate the ILS LOC which are the one installed in Bole international Airport, and the path depicted previously in Figure 13.

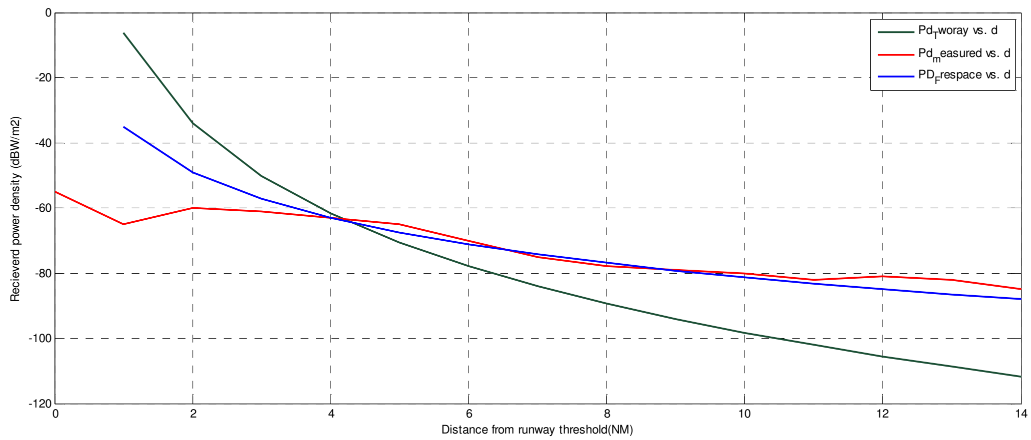


Figure 14 : ILS LOC Measured and Free space and two ray Modeled power with 1500 ft.

Localizer propagation model is done based on flight check measurement by using ECAA Flight Inspection System (FIS). Measurement is done inside calibration aircraft by activating the measuring device namely automatic flight inspection system (AFIS) during appropriate fight maneuver and then the real time computer /system starts to measure the localizer signal parameters in with the aircraft position. According to Figure 14 free space model power density approaches to the actual measured power density as compared to Two- ray model.

In this thesis two types of measurements were used in order to analyze the final intermodulation level at the airborne localizer receiver.

The first measurement was taken the aircraft follows the procedure 15NM at 1500ft altitude and approach to runway up to threshold maintaining constant altitude along runway center line. The other is threshold approach which is the aircraft approaches with a certain angle α along the extended runway center line, for this particular case the approach angle α is 2.3 degree. Thus for this measurement the power density of ILS localizer was measured from 2500ft starting from 10 NM up to run way threshold. From these measurements appropriate mathematical propagation model were designed, curve fitting technique is used [27]. For this particular thesis the free space model together with appropriate correction factors has better approaches to the measured one. The considered initial height corresponds to the first point where one procedure was started, being relative to the elevation of the runway track.

This is due to the fact that these scenarios are used to analyses the limits of the ILS LOC's coverage range.

4.2 FM broadcasting model analysis

Regarding interfering terminals, there are **15** of FM sound broadcasting stations in Addis Ababa. The scenarios are evaluated considering no obstacles between the FM stations and the receiver, hence considering the free space propagation model.

Table 4.2 Addis Ababa FM broadcasting stations [32]

FM ID number	FM broadcasting station name	Transmitting frequency (MHZ)	Transmitter location
01	Zami radio	90.7	Furi
02	Fiteh radio	91.1	Furi
03	Ethiopia national radio	93.2	Furi
04	Ahadu radio	94.3	Furi
05	FM 96.3	96.3	Furi
06	FM Addis	97.1	Furi
07	Fana FM	98.1	Furi
08	AAU community	99.4	AAU
09	civil service radio	100.5	Civil Service University
10	Besrat FM	101.1	Furi
11	Sheger FM	102.1	Furi
12	Abay FM	102.9	Furi
13	EBC FM	104.7	Furi
14	Afro FM	105.3	Addis Ababa
15	Ethio FM	107.8	Furi

Each FM station that is installed at Furi considered as line of sight with the receiver. Since broadcasting antennas are typically located at a high altitude, therefore it typically implies a larger coverage range. The ID number of broadcasting station is assigned for only this study that simplifies the study data analysis.

Accordingly, of Google Maps is used, which determines the terrain height of various points along a path between two terminals and distance. The Google Maps was adjusted to include the location of most FM broadcasting stations and the approach points of the flight path, in order to easily choose the geographical coordinates of the transmitter and the receiver. Thus Figure 15 defines that the geographical topology between the broadcasting antenna location and the receiver test point, thus point is ‘F’ mount Furi where most Addis Ababa FM broadcasting antennas are installed .The geographical coordinated of this hillock is 08^0 52’ 59’’N, 38041’11”E elevation2839m. When we compare the elevation of Furi and Bole international airport Furi has higher elevation. Therefore FM broadcasting signal propagation is modeled as free space model. Point ‘E’ indicates receiver test point which is 40 km from Furi and 11NM from runway threshold. Assume that the broadcasting antenna is isotopic radiator.

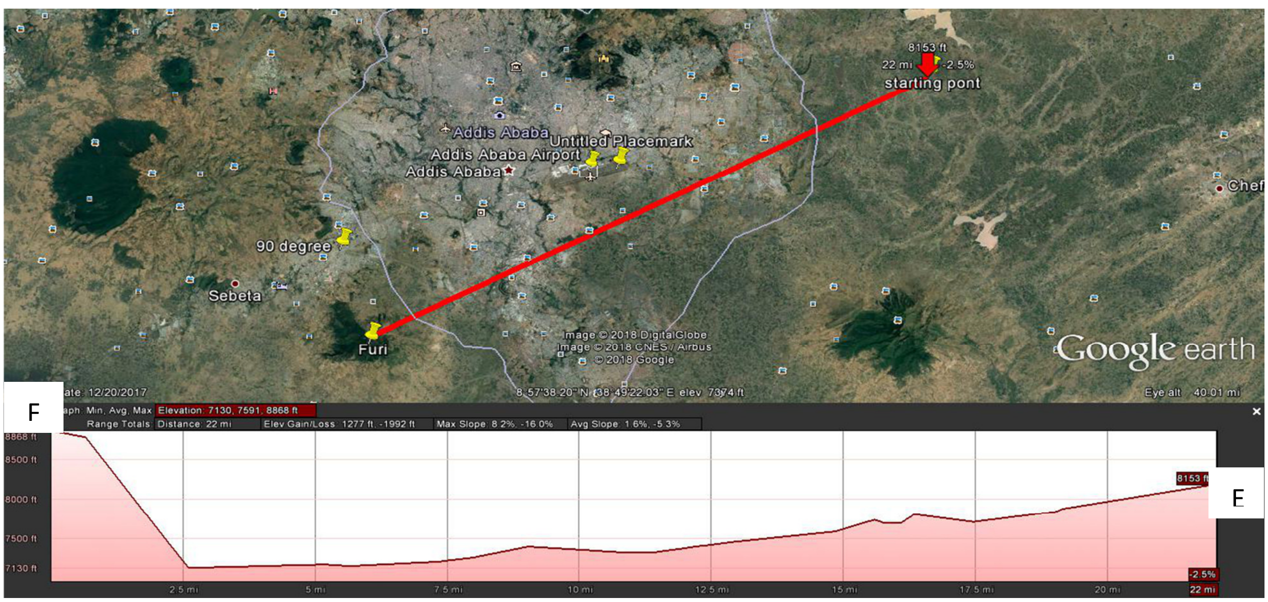


Figure 15 : Terrain profile from Mount Furi up to approach route [from Google earth]

The horizontal propagation from FM broadcasting antennas normally considered omni-directional radiation. There are also installations in which highly directional antennas are positioned pointing to various directions to cover more efficiently the targeted areas by using antennas with higher gains, e.g., a Yagi-Uda antenna or an LPDA. Nevertheless most broadcasting stations have omnidirectional antennas to cover the surrounding region. Thus for this particular study signal propagation were designed according to omnidirectional radiation patterns and non-tilt vertical dipole array is considered. The following MATLAB R2013a plot as shown in figure 16 illustrates free space model for Ethio FM and Sheger FM broadcasting system.

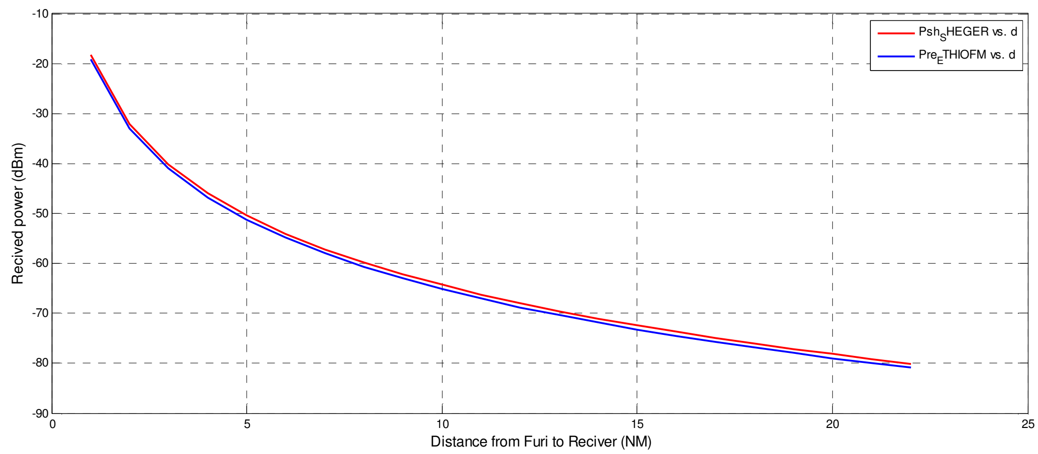


Figure 16: FM broadcasting free space model

According to sample FM broadcasting station data, most broadcasting station antenna type is non-tilted Vertical Dipole Array (VDA). It presents a realistic approach to a broadcasting antenna and its horizontal omnidirectional characteristics make it a good model to be applied in the simulator. Although Mount Furi is 22NM from the beginning of test point, the analysis was done after 10 NM from Furi (FM broadcasting station) to test point. The FM signal received power increases as the aircraft approaches up on the FM station location, hitting its peak in the nearest position.

4.3 Intermodulation analysis

A common performance measure of radio communication systems is the carrier-to-interference ratio (CIR). When co-channel or inter-channel interference is present,(CIR) or signal- to-interference ratio (SIR) is an important receiver parameter that characterizes the degree of system performance deterioration. According to equation (3.19) when the Broadcasting transmitted power is increased by one dB the third order intermodulation power increases by 3dB thus the rate is too much.

The thesis assesses third order intermodulation level at ILS localizer receiver, whether the interference level is harmful or not relating ITU-R and CIR. For ITU-R analyses of intermodulation level using two localizer receiver models were used one is ICAO Annex 10 ILS localizer receiver and the other Montreal ILS localizer receiver standards. Every third order intermodulation product with calculated power lower than the sensitivity of the receiver is excluded from the following CIR analysis. In the case of aeronautical ILS localizer receiver thus needed so that carrier-to-co-channel interference ratio (CIR) can be maintained within a tolerable bound. For deferent types of intermodulation interference ITU-R stated correction and protection ratio in Table 4.3, thus A1 and A2interference, the protection ratios for both categories of receivers are the same and are given in Table below. Similarly for B1 interference, several equations are given in chapter three that are equation (3.33), (3.34) and (3.35), depending on the type of inter-modulation product and the category of receivers. These equations contain a frequency offset correction term that is also given in Table 4.3.

Table 4.3 ITU-R IS.1009-1 Recommendations for VOR/ILS LOC Protection Ratios

Frequency difference between wanted signal and unwanted signal or intermodulation product. (kHz)	**A1 Interference Protection Ratio (dB)**	**A2 Interference Protection Ratio (dB)**	**B1 Interference Correction Term (Montreal receivers)**	**B1 Interference Correction Term (ICAO ANNEX 10 receivers)**
0	14	NA	0	0
50	7	NA	2	2
100	-4	NA	8	8
150	-19	-41	16	11
200	-38	-50	26	NA
250	NA	-59	NA	NA
300	NA	-68	NA	NA

If the frequency difference between the desired localizer signal and the undesired FM broadcasting frequency has to be within the boundary of Table 4.3, then one can determine the compatibility assessments for type A1, type A2 and Type B1 .That demine whether the interference level in aeronautical receiver in a certain approach route is harmful or not. Accordingly the analysis is done for both ILS localizer runway 25L and 25R. Among Addis Ababa FM broadcasting, Ethio FM its transmitting frequency 107.8 MHZ is the most adjacent as compared to other FM broadcasting station for the two Bole International Airport ILS localizer channel frequency. Hence the frequency difference between Ethio-FM and localizer RWY 25 L and localizer RWY 25 R is 3.7 MHZ and 2.5 MHZ respectively.

4.3.1 Carrier to Interference Ratio

In order to determine the interference level at aeronautical localizer receiver one has put the standard threshold level of the receiver and the zones affected by intermodulation interference and relevant necessary geographical separation between interfering transmitters and receivers should be determined. An interference threshold is the minimum power level of an interfering signal that causes an unacceptable degradation in localizer receiver performance. The ideal ILS 25L approach rout is taken from Goggle Earth as shown in Figure.17. The identified runway either LOC RWY 25L or LOC RWY 25R corresponds to the landing runway in which the ILS LOC is installed. For this study there are two runway in Bole International Airport and each runway has its own ILS LOC. Runway number 25 is the landing approach corresponding of bearing 252 °, which implies that the azimuth of ILS localizer in opposite direction 072°. Thus the indication of runway is approach bearing for localizer azimuth. The exact angle must be known from approach chart which is attached at appendix A.

Figure 17 : Bole International Airport Approach Route [from Google earth]

This approach route has to be protected from dangerous interference and also aircraft receiver has to qualify the minimum standard to immune interference therefore from previous study aircraft receiver's sensitivity varies between p_{rmin} -96 and -113 dBm, and the desired signal exceeds an undesired co-channel by 20 dB or more; Besides these values, the receiver is also characterized by Gr= 2 dB and FN = 6 dB. One also considers that $P_{r,min}$ = -113 dBm for all scenarios, so that the receiver most vulnerable to interference is assessed [5].

On other hand by considering the bandwidths of the ILS LOC one can obtain an estimation of the, noise floor. Thus noise floor used as the threshold due to noise is lower than the sensitivity of the receiver.

The maximum sensitivity of a receiver is determined by the amount of noise internally generated in the receiver (primarily the first stage) and its bandwidth. It is the basic sensitivity figure, as any signal weaker than this will be masked by the noise. Another term one may encounter is minimum discernible signal (MDS) sensitivity. MDS is commonly defined in two ways. MDS is also defined as the value of the noise floor and is used interchangeably with that term. Where MDS is used in this technical note, it is equal to the noise floor [28].

$$Noise\ Flor = NF + 10\log BW - 174 \qquad (4.2)$$

Where; NF: noise figure

BW: bandwidth in Hz

-174: the noise floor (-174 dBm@2900K)

Using the above formula, the estimation of their, Noise floor being -128.98 dBm which is lower than the ILS LOC receiver sensitivity.

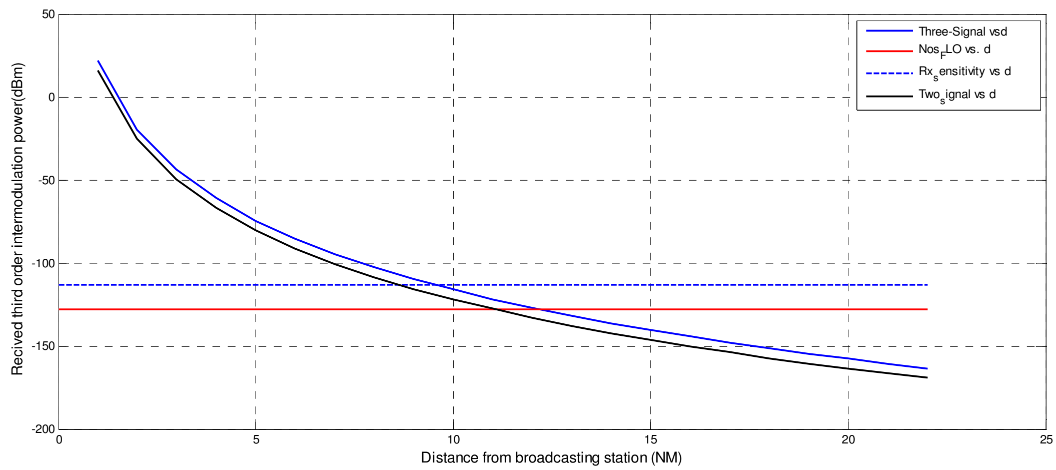


Figure 18 : 3rd intermodulation power level and Thresholds vs. Distance

There are two threshold levels that determine the receiver sensitivity as shown in Figure 18. One is general receiver noise floor, which is maximum sensitivity of a receiver that determines the amount of noise internally generated in the receiver. It is calculated from the noise figure and BW of the receiver .Therefore any desired signal weaker than this will be affected by the noise. The second receiver threshold is ILS localizer minimum signal strength which stated in ICAO annex 10. As compared to two thresholds the ICAO annex 10 standard thresholds is more preferable for analysis due to the fact that in order to interfere the desired signal the undesired signal has to reach -113 dBm. For this study the threshold level is taken -113 dBm. Thus from figure 18 the calculated inter-modulation power level become equal at distance 12 NM to noise floor and at 9 NM to standard ILS localizer receiver sensitivity. Generally speaking before 9 NM the intermodulation power is greater than the noise floor it can affects the aeronautical receiver in the aircraft. After 9NM from broadcasting station the power level of intermodulation power is less than the standard threshold, hence the intermodulation product is not affect aeronautical localizer receiver. Fig 18 describes the 3rd order intermodulation power level form Furi up to the binging of receiver test point. Since most FM broadcasting antennas are mounted at Furi ,hence this hillock is found behind ILS localizer station and 10nmi form ILS approach end of runway threshold .To make realistic approach the only considered intermodulation power level was after 10nmi up to receiver test point ,which is from 10nmi up to 22nmi from Furi. Model for intermodulation product for two signal and three signal case varies between [-114 -160] dBm and [-119 -170] dBm respectively, which is below the minimum signal level of ILS localizer receiver threshold. When the aircraft approaches to the runway at the same time it approaches to the broadcasting antenna too; According to MATLAB R2013a plot the intermodulation power increased when the aircraft approaches to runway threshold.

4.3.2 International Telecommunication Union (ITU)

Recommendation ITU-R Compatibility Between the Sound-Broadcasting Service in the Band of about 87.5-108 MHz and the Aeronautical Services in the Band 108-137 MHz contains recommendations for interference suppression of FM broadcast signals by VHF AM aeronautical receivers. This recommendation specifies criteria for compatibility between FM broadcast service and aeronautical services. It identifies four interference mechanisms as follows, and gives criteria for each. This recommendation specifies criteria for compatibility between FM broadcast service and aeronautical services. It identifies four interference mechanisms as follows, and gives criteria for each. Type A1 which is Spurious emissions caused by one or more broadcasting transmissions, Type A2,Out-of-band and similar emissions close to the transmitting frequency caused by broadcasting signals ,Type B1 Intermodulation generated as a result of a receiver being driven into non-linearity by broadcasting signals, and Type B2 desensitization caused by one or more broadcasting transmissions.

Refereeing ITU-R Interference assessment criteria – Montreal ILS localizer and Annex 10 localizer receiver described by table (4.3), for frequency the difference of the desired localizer and undesired FM broadcasting protection ratio is specified for each types of interferences, Type A1 interference need not be considered for frequency differences greater than 200 KHZ. Type A2 interference need not be considered for frequency differences greater than 300 kHz. Similarly Type B1 interference need not be considered for frequency differences greater than 200 KHZ.

To study Type B2 interference both of the Montreal and the ICAO Annex 10 receivers present a good approach. Equation (3.32) and (3.35) presents the maximum acceptable FM broadcasting signal at the input of aeronautical ILS LOC receiver. But Montreal receivers present better immunity criteria to Type B2 interference. Therefore, when considering the maximum allowed value of an input FM broadcast signal, the lowest value should be the one considered.

The other method of ITU-R intermodulation interference analysis is based on the broadcasting frequency with respect to the distance to test point of radio navigation station.

Table 4.4 Distance between a test point of radio navigation station and broadcasting station [33].

Effective radiated power of broadcasting station		**FM Broadcasting Stations Frequency In (MHZ)**						
		<100	**102**	**104**	**105**	**106**	**107**	**107.9**
dBW	**KW**	**Distance (Km)**						
55	300	125	210	400	500	500	500	500
50	100	75	120	230	340	500	500	500
45	30	40	56	125	190	310	500	500
40	10	25	40	70	105	180	380	500
35	3	20	20	40	60	95	210	500
30	1	20	20	25	35	55	120	370
25	0.30	20	20	20	20	30	65	200
20	0.10	20	20	20	20	20	40	115
≤15	≤0.03	20	20	20	20	20	20	65

Table 4 .5 gives separation distance between a broadcasting station with a given ERP and frequency a test point of an aeronautical navigation station .Therefore beyond this standard the aeronautical service is affected by the broadcasting station. Accordingly ILS localizer is one of aeronautical navigational aid therefore the above standard has to be satisfied in order to avoid harm full interference within service volume. For the case study distance of two broadcasting station location is analyzed. The first one is the distance between mount Furi where most FM broadcasting antenna installed and the test point. Using Google Earth the distance between Furi and the beginning of test point through RWY 25 final approach rout is around 40 km.

4.4 Results

This thesis was studying, analyzing and quantifying intermodulation interference level due to FM sound broadcasting station on Bole international airports ILS localizers operation. It begins by reading various input data and converting it into parameters defining the scenario. It also intended to evaluate various scenarios, to quantify the interference of ILS LOC due to intermodulation of FM systems, it verify if there is any relevant alarm on the final approach route. Finally analyze the intermodulation level by using various criteria proposed by ITU-R and ICAO.

In order to stretch to the final result the thesis follows the following phases; the first phase was determining Aeronautical ILS localizer and FM sound broadcasting signal parameters. Both the desired and undesired signal parameters are necessary for propagation model design.

Scenario definition is the second phase, that two scenarios are defined in order to analyses the interference on the ILS approach route. The first scenario was, when an aircraft carries out ILS approaches inbound from 15 NM up to runway threshold on LOC course line by maintaining constant altitude which is 1500ft.The second scenario was when an aircraft carries out ILS approaches inbound from 10 NM up to runway threshold on LOC course line in a certain angle which is 2.3 degree decent angle rather than on the Glide Slope. Information regarding the evaluated approach path contain coordinate of runway threshold, approach bearing, the total path distance and initial height.

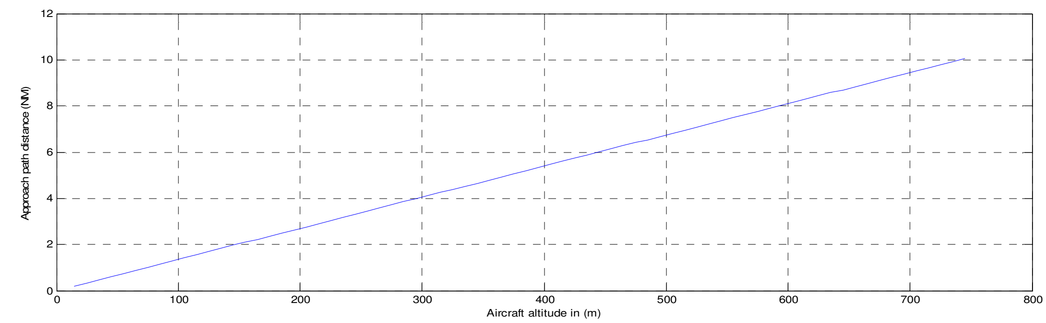


Figure 19 Path Distance from threshold versus altitude of aircraft

Approach path for the second scenario, where the aircraft approaches at 2.3 degree along approach the path is determined as a function of initial and final aircraft altitude as stated by equation (3.8) and equation (3.9). Figure 19 describes the approach $\boldsymbol{Dpath}$ of the receiver where initial altitude of aircraft is 762m and final altitude is the surface of the runway.

After deciding which scenario is going to be evaluated the corresponding link budget is calculated for both LOC and FM broadcasting station which is the third phase. In this phase different propagation models are tested according to the geographical settlement of broadcasting and localizer station in accordance with the approach routes. Thus two propagation model is tested namely the Free space propagation model and two ray model for both systems .Since measured data for ILS localizer is available, thus the free space propagation model was fittest one for the actual measured data as shown in figure below.

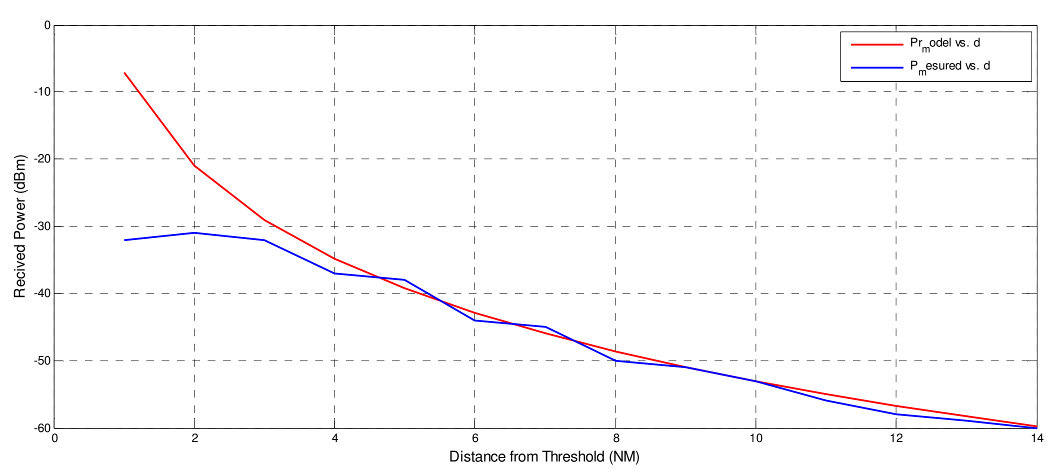


Figure 20 : ILS LOC received power from RWY Threshold to 14nmi with 1500 ft

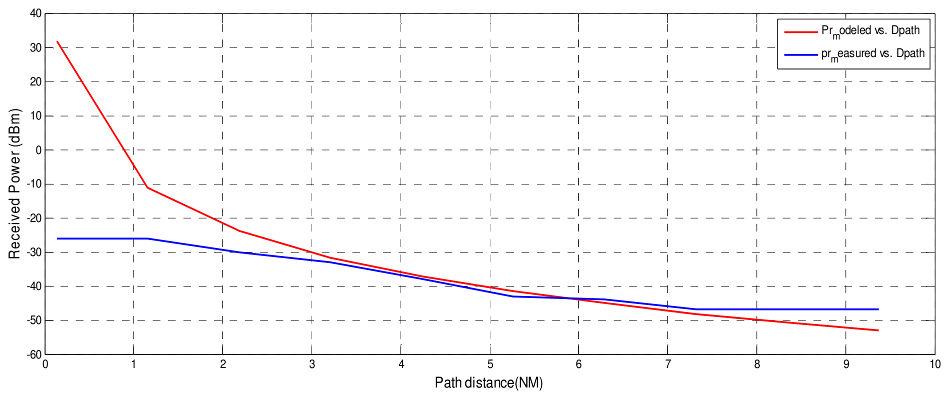


Figure 21: ILS LOC Received power at 2.3° angle decent

From FM broadcasting parameter the third order intermodulation power at reaches at the aircraft receiver terminal is modeled using the FM transmitting parameters. Thus by using equation (3.19) up to equation (3.23)

After modeling the desired and undesired signal the next step become putting standard receiver thresholds it is mention in section 4.3.1. After putting those standards one can assess the interference level by applying the defined scenarios. Two different functions are created to assess the effect of the interference that Addis Ababa FM stations cause on Bole International Airport ILS LOCs signal; the first one is one is based on the receiver's CIR and second one was verification of ITU-R standards in accordance with intermodulation product that was generated from FM broadcasting systems[4].

A. Carrier to Interference Ratio (CIR)

There are different parameters that determines receiver characteristics one is $(C/I)_{min}$ tis parameter is depending on terrain profile, position of azimuth, transmitted power, the gain of transmit and receiving antenna, the height of transmitter and receiver, frequency difference and flight route and altitude. Thus signal to interference ratio result for two cases as shown below in figure 22 and 23.

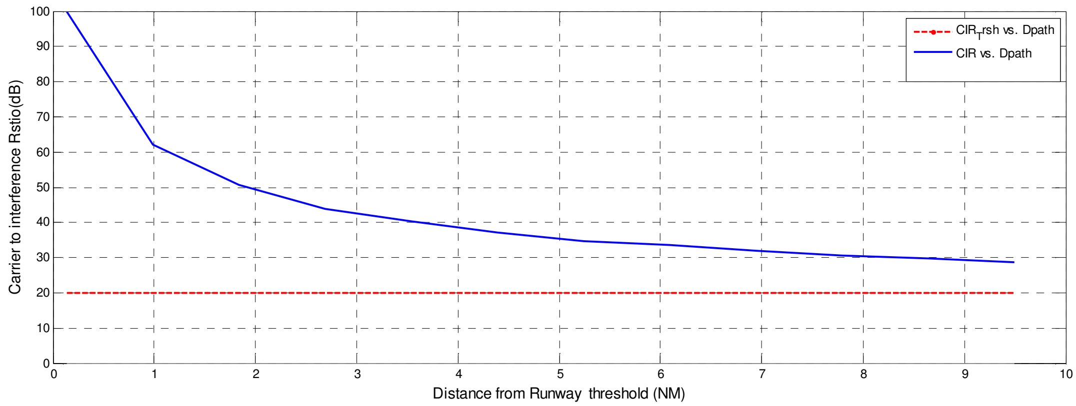


Figure 22 : Carrier to interference Ratio with descent angle 2.3°

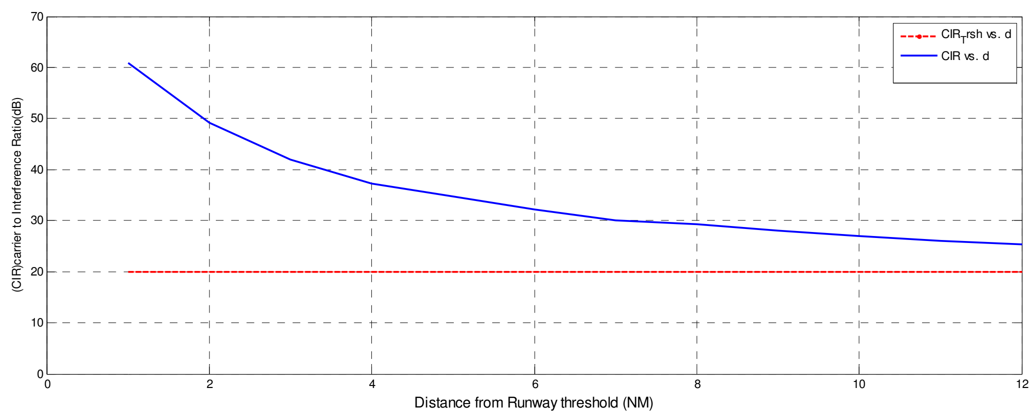


Figure 23: carrier to interference Ratio at constant 1500 ft altitude

From the above CIR results consider Fig 22 and Fig 23 the carrier to interference ratio threshold is 20dB thus the value varies from [90 30] dB for scenario where the receiver approaches with constant altitude and [60 25] dB the scenario where a receiver approaches where a certain angle . The above result verified that there is no sign of interference at Bole International Airport RWY 25 approach route.

B. ITU-R Interference assessment result

MATLAB R2013a simulator those 15 Addis Ababa FM broadcasting stations are assessed the possible 3rd order intermodulation product. The assessment is done using ITU-R equation (3.28) and MATLAB R2013a calculates the possible intermodulation product. Either two signal intermodulation or three signal 3rd order intermodulation assessment was conducted considering all FM broadcasting station. Consequently the assessment result tells that three signals and two signals 3rd order intermodulation product frequency coincides with ILS 25L and 25R localizer frequency. The following MATLAB result shows 3rd order intermodulation products that concede with ILS localizer operating frequency.

```
%Three signal intermodulation
IM150301=f15+f03-f01 %110.3
IM141106=f14+f11-f06 %110.3
IM131004=f13+f10-f04 %111.5
IM140803=f14+f08-f03 %111.5
IM140904=f14+f09-f04 %111.5
IM130501=f13+f05-f01 %110.3
IM120701=f12+f07-f01 %110.3
IM110902=f11+f09-f02 %111.5
%two signal intermodulation
IM1204= 2*f12-f04 %111.5
IM1514= 2*f15-f14 %110.3
IM1001= 2*f10-f01 %111.5
IM0901= 2*f09-f01 %110.3
```

The above result shows for three signal intermodulation frequency test , IM150301 means when the FM broadcasting station ID 15, ID 03 and ID 01 diversified at the receiver they produce 3rd order intermodulation frequency which coincides ILS LOC 25 R frequency which is 110.3 MHZ. Similarly for two signal 3rd order intermodulation IM1204 means FM broadcasting station ID 12, ID 04 produced intermodulation frequency which coincides ILS LOC 25L 111.5 MHZ frequency. Therefore form the above result among 15 broadcasting station 11 FM broadcasting stations produce either two or three signal 3rd order intermodulation frequency which coincides with either ILS LOC RWY 25R or ILS LOC 25L. Therefore according to ITU-R Type A1 and A2 interference is considered when the frequency difference between broadcasting and ILS LOC is according to table 4.3 that presents the protection ratios which should be attended for the various differences of frequency between the intermodulation product and the wanted signal .ITU-R states for both Montreal and ICAO Annex 10 receivers should be greater than 200 KHZ and 300 kHz. Thus for this particular study the most adjacent broadcasting station that is FM with ID number 15 which is Ethio-FM with broadcasting frequency 107.8MHZ for both ILS LOC 25L and 25R, hence, the frequency difference is 2.7MHZ and 2.5 MHZ respectively. Therefore type A1 interference is not accounted for a difference higher than 200 kHz. Type A2 and Type B1 interference are neglected for a frequency difference between the wanted signal and the broadcasting signal carrier higher than 300 KHZ.

Since when the RF section of an aeronautical receiver is subjected to overload by one or more broadcasting transmissions; this is termed Type B2 interference. Therefore ITU-R Recommendation SM.1009-1 detailed in Subsection 3.2.6 Type B2 potential interference, no allowance for the level of the aeronautical signal is made and thus the minimum values of 32dB(μV/m) for ILS is used. Hence for this particular study using MATLAB R2013a the simulator calculates each FM broadcasting station effect by using Montreal receiver's immunity criteria. Thus the result shows maximum value is 9.15dB (μV/m) than the standard that states ITU–R there is no sign of Type B2 interferences.

Chapter 5

Conclusion and Future work

5.1 Conclusion

The main purpose of this study is to assess and quantify the intermodulation interference level from Addis Ababa FM broadcasting station by establishing different scenario through the development of signal propagation model .Hence the study achieves its general and specific objectives.

In this study flat earth propagation model is used and this is explained due to short distance which is 14NM model and the low height of the aircraft relative to the ground, which generates a minimum caused by destructive interference. The model is done using two scenarios. For model development the ILS LOC, there was measured ILS LOC signal power at receiver end for both scenarios, but in the case of FM broadcasting there was limitation of measurements. Among different propagation model free space model with appropriate correction factor is realistic approach at the far field region which is also termed as fraunhofer region. Since Bole International airport's both localizers are Category one, where the guidance is up to around 1NM.Therefor localizer models fit to the practical measured values for both defined scenarios.

In general for individual receivers, the level of the undesired frequencies necessary to produce the interference criterion appears to be a function of the frequency product and not to be dependent upon the exact frequencies of the desired and undesired signals. From this study, when two or three signals mix in a receiver a third orders intermodulation product can be produced that is demonstrated by MATLAB R2013a considering all 15 Addis Ababa FM broadcastings. If the frequency of intermodulation product coincides with frequency of a desired signal and the power level is above ILS LOC receiver threshold the intermodulation interference occurs.

Their asssement is evaluated using two using to criterias thewhich is standard CIR and that shows there is no sign of interference on Bole International Airports ILS ocalizers 25L and 25R. Inorder to asses interference the study uses two internationally modelled ILS LOC reciver which was agreed at a meeting of Task Group 12/1 in Montreal in 1992 Monterial reciver model and ICAO anex 10 reciver model published in Annex 10 in 1998 are used. According to both standards the assesement shows both ILS LOC 25L and 25R guidance are clear from harmful interference.

According to this study the most important factors that the interference potential from FM broadcasting to ILS LOC is acombination of; broadcating transmitter power, separation distance from the airport, Frequency separation between ILS Localizer and broadcasting and geographical topology. Accordingly ITU-R staes on table 4.4 the frquency versus distance table inorder protect ILS LOC guidance safe from interfernce. Before additionl FM broadcasting icenced for the vicinity of Addis Ababa, the Regulatory body has to consider the above mentioned factors.

Each receiver has a value of that guarantees minimum carrier to interference ratio for proper functioning of the equipment without damaging the link. According to this study when the broadcasting power is increased by 1dB the intermodulation power is increased by 3dB which is to much rate to interfere ILS LOC operation .From the study if the broadcasting power increases by 1 dB on the second secenario CIR at distance 12 and 11 nmi will approaches to the minimum CIR that makes interefrence at the ILS LOC. In worst case If the broadcasting power inceased by 2dB, the result of CIR becomes lower that implies the interference level deviates ILS LOC guidance operation.

Culrently there is no sign of interference that disturbs Bole International Airport LOCs guidance that affects the landing aircraft safty. But for the future inorder to mantain LOC guidance safty the regulatory body takes care for the growing Addis Ababa FM broadcasting station power and Geographical location from the airport. Therefore the thesis recommends that, Ethiopian broadcast Authority who gives licence for FM broadcasting stations has to take measures according to listed factor before licenced the broadcasting station.

5.2 Future work

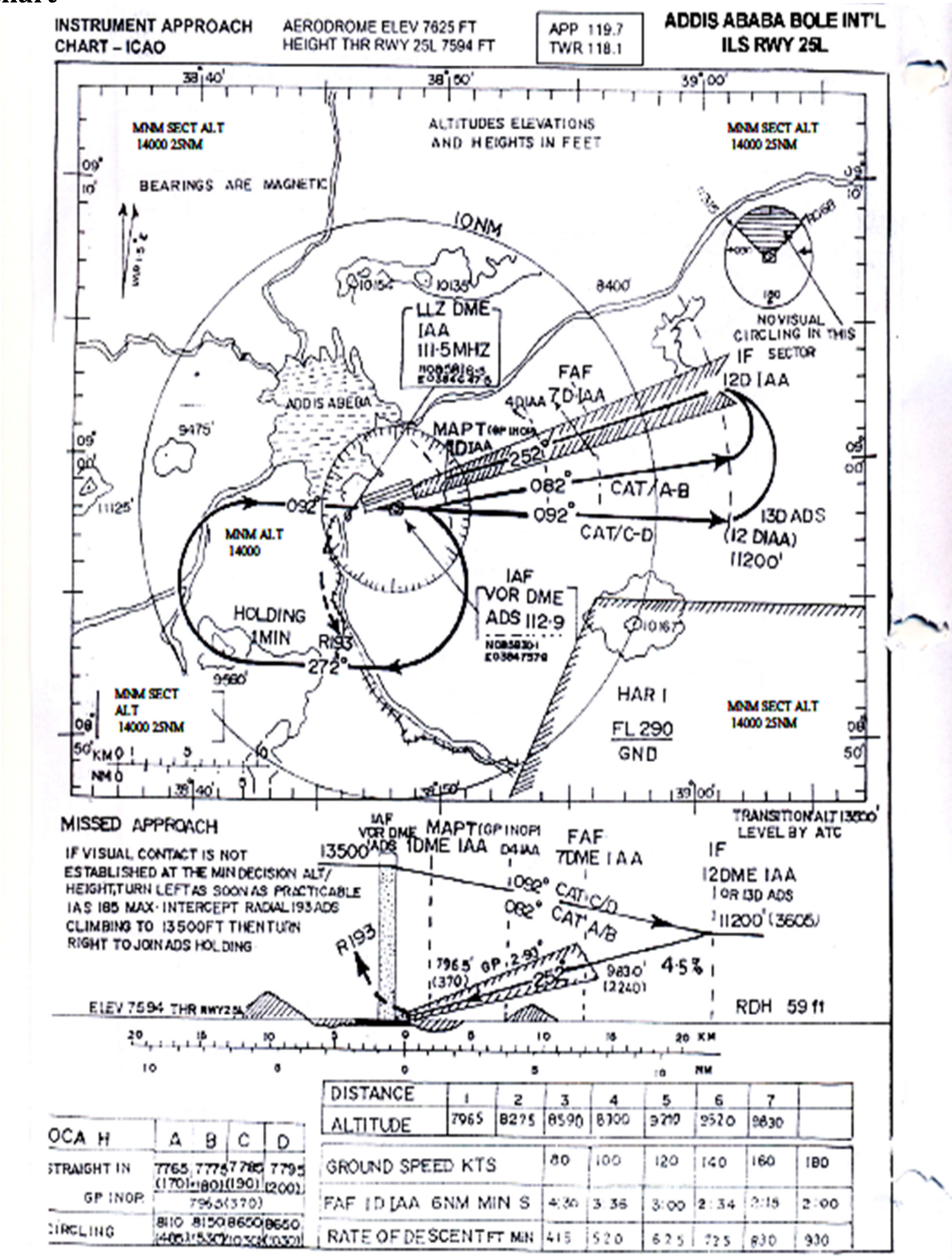
Regarding the study it assesed Bole Interenational Airport ILS localizer interference due to the growing Addis Ababa FM broadcasting system, recommendation of future work is proceeing further investigation /study on the bases of this paper.The only field measurement is done on ILS localizer systems inorder to model the received power at the approach path. But for the case of FM, the model uses Google earth inorder to determine geographical topology between the approach route and broadcasting transmitter.This thesis does not include FM broadcasting field measurement, for future work one can measure the FM signals along Bole international airport approach route in order to model FM broadcasting stations transmitted signal at the reciver end.

For this study data was collected form only three sample broadcastig station, therefore further works can extend the data source from more than three broadcasting station in order to model intermodulation power at receiver end.

Finally safty in aviation industry's number one priority, it costs many peopole life and very expensive equipment,Hence there are different CNS system that provides airnavigation service which are available in Bole International Airport. keeping our Aviation safety, interference effect on each CNS system has to be studed.

Since ILS gives precision guidance for an aircraft, pilot prefere this system on landing maneuvers rather than other landing systems and pocedures. Especially CAT III gidance is up to runway touch down that makes ILS prefereble. Thus ILS installation is better on both runway side that is applicale in several countries. But in Bole international airport only RWY25 heading has ILS guidance.According to this study ILS guidance on RWY 07 side is difficult, due to the reson that aircraft approches overhead FM antennas with low altitude.Accordingly intermodulation interference becomes incerase when the aircraft approching Bole international airport, that is at the same time it approches FM broadcasting station. For the time being there is no ILS on ruway 07 side, but for future installation RWY 07 side,ILS localizer gidance affected by 3rd order intermodulation inerference from broadcasting station.

Appendix A: Bole International Airport ILS RWY 25L Instrument approach chart



Appendix B: Bole International Airport ILS RWY 25R Instrument approach chart

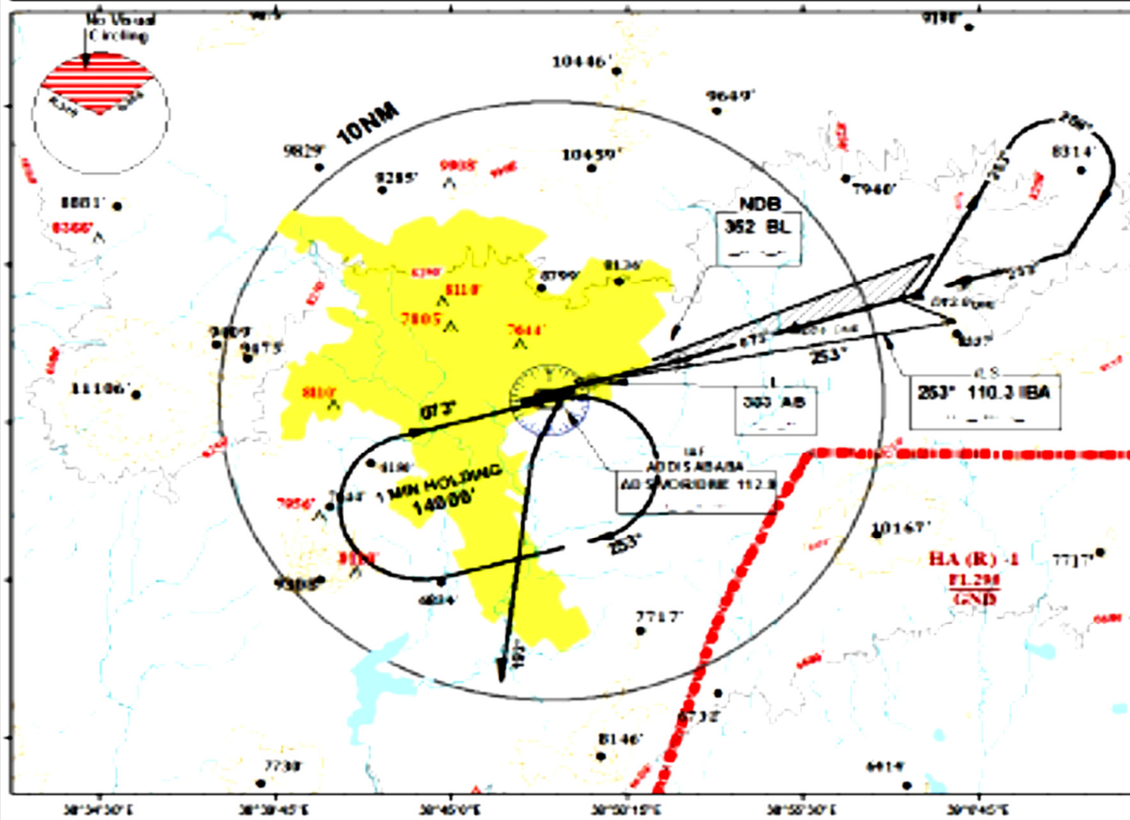
AIP ETHIOPIA

AD2-HAAB-34
10 DEC 15

INSTRUMENT APPROACH CHART-ICAO	ADDIS ABABA/BOLE INT'L AIRPORT ILS RWY 25R

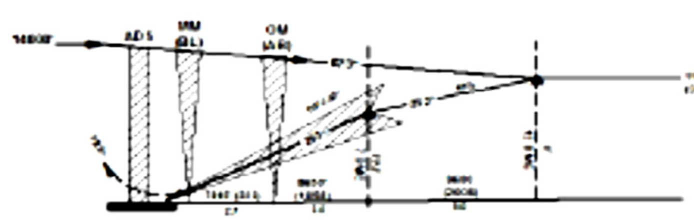
Bole Approach	BOLE Tower	BOLE Ground	
119.7	118.1	121.9	14,000'
LOC	Final Apch Crs 253°	AD Elevation 7625'	Trans level: By ATC
AM	GS OM 8650' (1058')	THR Elevation 7592'	Trans alt: 14000'
110.3	BEARINGS ARE MAGNETIC		MSA 25NM ADS VOR/DME

MISSED APCH: Turn LEFT as soon as practicable (MAX 185 KT) to intercept R-193 ADS climbing to 14000', then turn RIGHT to join VOR holding.



Scale: 1:250,000

OCA /H		A	B	C	D
Straight in Apch	CAT I	7766' (171)	7776' (180)	7785' (190)	7795' (200)
	GP INOP	7840' (248)			
Circling		8110' (485)	8150' (530)	8650' (1030)	



	KTS	80	100	120	140	160	180
FAP MM 5.66 NM	min:sec	04:15	03:24	02:50	02:26	02:07	01:53
Rate of Descent	ft/min	418	522	627	731	835	940

CIVIL AVIATION AUTHORITY
Addis Ababa

Amendment 02/15

APPENDIX C: 40 ILS channel frequency (adopted from Annex 10 Vol.1)

NO	Localizer	Glide path		NO.	Localizer	Glide path
1	108.1	334.7		21	110.1	334.4
2	108.15	334.55		22	110.15	334.25
3	108.3	334.1		23	110.3	335.0
4	108.35	333.95		24	110.35	329.85
5	108.5	329.9		25	110.5	329.6
6	108.55	330.75		26	110.55	329.45
7	108.7	330.5		27	110.7	330.2
8	108.75	330.35		28	110.75	330.05
9	108.9	329. 3		29	110.9	320. 8
10	108.95	334.15		30	110.95	330.65
11	109.1	331.4		31	111.1	331.7
12	109.15	331.25		32	111.15	331.55
13	109.3	332.0		33	111.3	332.3
14	109.35	331.85		34	111.35	332.15
15	109.5	332.6		35	111.5	332.9
16	109.55	332.45		36	111.55	332.75
17	109.7	333.2		37	111.7	333.5
18	109.75	333.05		38	111.75	333.35
19	109.9	323. 8		39	111.9	331.1
20	109.95	333.65		40	111.95	330.95

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