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2010

System Model for the Evaluation of Interference

“Cosite Analysis Model”

MSc Wireless Systems Engineering

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ABSTRACT

There is an increasing demand to solve the interference between wireless communication systems. This means in particular to antenna networks that placed near together such as radio mast as well at warship and airplane antenna. In this case the system may become limited by interference rather than anything else. One promising technology for radio station in interference-limited systems is Cosite Analysis Model (COSAM). This is technology allows both for reducing the space between antenna and reducing interference in the same time. As result, can reducing the proliferation of towers. The aim of this project is to introduce comprehensive case study about an integrate cosite system models for the evaluation of interference between antennas. Furthermore, since that the most important reason of interference is intermodulation (IM); this project introduces an intermodulation product interference detection and analysis tools. One of promising method which will use in this project is known as Method of Performing Antenna Cosite Analysis using Intermodulation Technique. The main power of this method is to analyze and detect all possible intermodulation products that could cause interference.

ACKNOWLEDGEMENT

I wish to express my deepest gratitude to everyone who has motivated me and/or supported me for the completion of this work and especially to Mr. Nick Riley for his precious time, constant support and indulgence in this work. I would also like to thank Dr.Ashag for his time and expert advice in the course of this project work.

Special thanks to my wife, my mother, sister, brother-in-law, others in the family and friends for supporting me in this pursuit.

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CHAPTER 1

Introduction and Motivation

1.0 Introduction

As telecommunication systems become more complex and more antennas are placed on the same structure the problem of interference becomes significant for the performance of the systems. Interference can occur in any radio system (For example Radio mast which used to install different antenna at same place faces serious interference challenges. Figure 1.1 below show the design structure of tower and antennas which may cause interference between antennas. Another area where interference is highly sighted as a potential safety and quality problem is the radio interference at airplanes and ships[1].

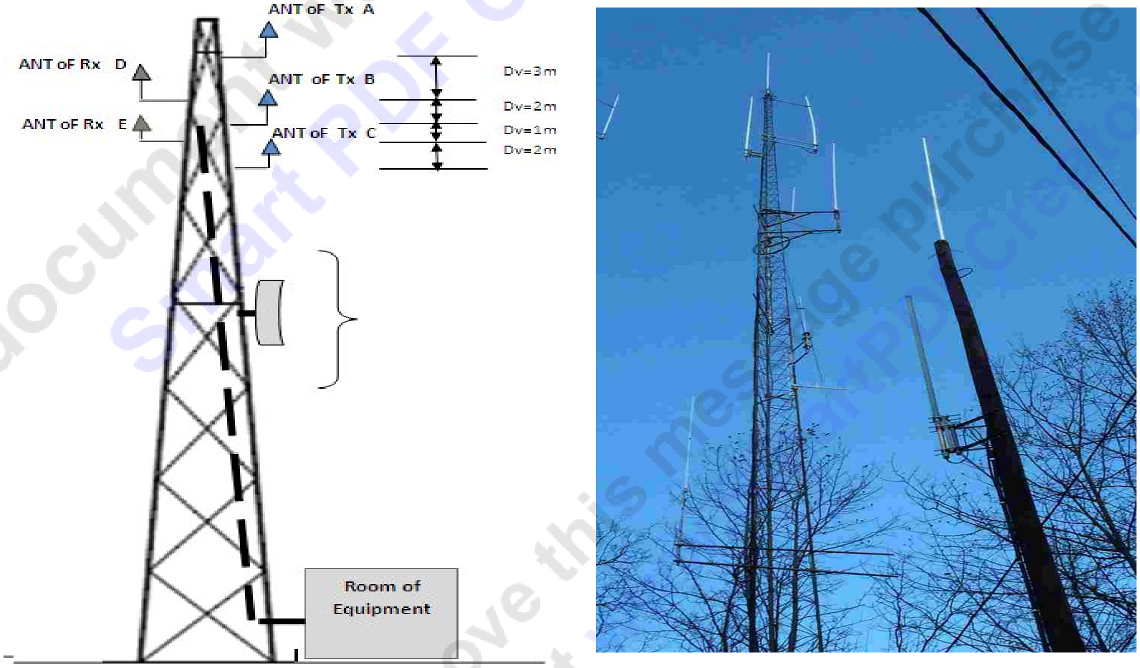

Figure (1.1) -Design structure of tower and antennas which may cause interference

The presence of a strong interfering signal in close proximity to highly sensitivity receiver poses a severe challenge to the radio-frequency Interference is generally known as cosite interference because it occurs at the same location as the victim receiver. The level of the interfering signal present at the input of receiver depends on factors such as the output power level of transmitter, antenna- antenna coupling (isolation), and any filter rejection in RF path. This high level of interference can cause a number of deleterious effects to occur such as receiver saturation, residual interference, transmitter wideband noise and intermodulation products. Intermodulation (**IM**) consider as one of the main source of interference [2].

The construction of new sites is expensive, and often presents new challenges. Specifically, the additional sites result in more signals that contribute to the rise in the spectrum noise floor and reduce the frequency re-use. Thus, the reduction of interference level emerges as one of the most viable solutions for the radio communication and service provider networks. As both wireless technologies emerge and the number of transmitter's increases there is an equivalent increase in interference. Radio system not only effect a hazard to service providers market share, but also threaten the very quality of voice and data transfer speed networks, service providers share, due to momentous interference with presented carrier signal[3].

For a single system installation, the analysis of interference is relatively simple because the equipment of site and the configuration of antenna can be restricted to attempted and examined set-ups. However, for multiple systems collected at share site, the scenarios are become more complex to predict and other than providing broad guidelines for collocation there is no choice but to implement the comprehensive interference intermodulation studies on a site by site basis. There is growing required realizing and analysis the problems in a combined manner since the number of collocated sites raise. **[4].**

1.1 Overview available software technique for evaluation of interference

There are numerous software's are used in order to satisfy the needs of the implementing organization of antennas interference. One of the earliest references to a shared location RF interference analysis software analysis was Cosite analysis Model (COSAM) published by ITT Research Institute, Electromagnetic Compatibility Analysis Center (ECAC), in 1970[5]. This was followed by the program, developed primarily for applications on board ships, in 1978 through the development of two software modules called the Design Communication Algorithm (DECAL)[6], and performance evaluation (Telecommunications) algorithm (PECAL)[7]. Other programs that are developed during this period on ships and included Shipboard Electromagnetic Compatibility (SEMCA), established by the General Electric Company, Atlantic Research[8], and Interference Prediction Model(IPM), developed by Leighton[9]. In 1989, Science Lab at the University of Kansas published a paper on the

Communication System Engineering Design System (CODES)[10]. CODE was software program shell written around the ECAC software, which consists of the graphical user interface, and database administrators and processor performance evaluation function [10].

Since 1970 up to now there are many shared RF interference software analysis were developed for the military or for commercial applications, but all of them depend on the same principle of Cosite Analysis Model (COSAM) interaction.

Although there are many new tools that exit nowadays to solve the interference between antenna such as UNIstar program, Comsite Profession program and TAP/Soft Wright[11], in this project I am going to explain another method to evaluate interference between antennas which called Method of Performing Antenna Cosite Analysis using Intermediation Technique[12].

1.2-Motivation

The need to address interference analysis is motivated by several features:

1. Number of service providers continues to grow, due to an increase in spectrum licenses auction in all parts of the world.
2. Tower owners try to collocate more carriers on the tower itself, in order to increase revenue. This phenomenon leads to more interference problems.
3. Tower Farms have become more common, especially when service providers strive for more coverage along the main roads as well as in densely populated areas
4. The interaction associated with interference for example intermodulation can cause grave security issues, particular at the time of crisis. Any interference in the signal associated with the government during the crisis can cause a huge impact on the security.
5. Health institution, by and great, carry on to be concerned that radio interference may hazard the safety of people.
6. The high cost associated with unresolved interference issues will contribute to the cost of radio cellular service for the end users.

Example A about the cost related to unresolved interference: It is estimated that the annual loss of income and engineering cost due to unresolved interference is in excess of $400,000 per site ($300,000 lost revenue due to dropped calls and $100,000 is the average engineering cost for troubleshooting). This number is predictable to raise much larger as further locations be liable to neighbor one another, extra collocation occurs on the same site, and more cellular penetration is achieve**[1].**

1.3 Objective of Project

Without good models for interference analysis, which is characterized by low performance, it is almost impossible to address the current needs and requirements. Consequently, methods and tools for interference detection, analysis, and resolution are necessary. One promising technology radio station in interference-limited systems is Cosite analysis model (COSAM). This is technology allows both for reducing the space between antenna and reducing interference in the same time. As result, can reducing the proliferation of towers. The aim of this project is to introduce review about an integrate cosite system models for the evaluation of interference between antennas. Furthermore, this project introduces an intermodulation product interference detection and analysis tool. The main power of this tool is to analyze and detect all possible intermodulation products that could cause interference.

1.4 Overview of Chapters

The second chapter introduces the basic idea of the radio frequency and radio interference and its structure. The third chapter provides case studies that illustrate the cosite analysis model. The fourth chapter provides basic principle about intermodulation and antenna isolation. The fifth chapter presents Performance of evaluation cosite interference using intermodulation technique. Chapter 6, the Conclusion, draws together the observations arising from cosit analysis model (COSM), and computation and analysis of intermodulation. It answers the following questions:

- How much spacing one really needs between antennas?
-what can be educated from Intermodulation technique using method of performing antenna cosite analysis?

CHAPTER 2

Background about Radio Frequency and Radio Interference

2.0-Introduction

Radio use electromagnetic wave to extend the range of human communication. The radio system uses propagation of electromagnetic waves through space, to send information. Being an electromagnetic wave, the radio frequency (RF) wave has the same properties as visible light. The RF wave is, however, of a much lower frequency and so longer wavelength. The shorter waves in the electromagnetic spectrum have the highest frequency and the longer waves the lowest.

As the main aim of project is to deal with how can mitigation interference between antennas, many factors will contribute and evaluate such as tower or mast of antenna, transceiver device and radio interference. Hence, this chapter will be broken into 4 parts: **Part 1** deals with mast of antenna and transmitter station. **Part 2** deal with the fundamental of radio technology. **Part 3** deals with electromagnetic interference and electromagnetic compatibility. **Part 4** deal with radio frequency interference.

2.1- Radio Mast and Transmitter Station

Any structure designed to hold the antenna for communication and broadcasting such as mobile and television is typically called Radio Mast or Tower. They are among the tallest man-made structures. The cost of a mast or tower is very expansive proportional to the square of its height. Transmitter station is referring to terrestrial infrastructure for transmitting radio frequency signal. This station may be use for wireless communication, broadcasting, microwave link and mobile telephone **[13].**

Most AM radio transmitters are high-power equipment. Because of the relatively low frequency they use, they **don't need to be located in high places.** They may broadcast in LW (long wave), MW (mid wave) or SW (short wave). Since SW stations are assigned for very long distance communication (via reflections from atmospheric layers).

TV and FM (frequency modulated) radio transmitter stations as well as transceiver stations are almost **always built on top of tower**. A single station may have many transmitters both for TV and FM broadcasting. In some cases each transmitter has an antenna system. If two or more antenna systems have to be used, higher frequency antennas are mounted higher on the antenna mast.

Problem faces the tower design at lower distance:

This section explains why we install the antenna of VHF and may GSM system at the higher tower instead of using building or small tower **[14]**.

Firstly, Reflection of the radio wave against the building edge (vertical direction) and block of visibility (horizontal direction).When installing the base station on the building, the service area may not be assured due to block of visibility in vertical direction by building edge or block of visibility in horizontal direction by obstacles such as water tower or penthouse. **Secondly**, Intrusion to the Fresnel Zone by Obstacles such as Building- Along the propagation path from the base station to the terminal, the Fresnel zone may be intruded by buildings around the zone, preventing good communication**.**

How to Solve Problems

<u>Make antenna installation position higher</u>

Install the antenna at the high position as much as possible, to prevent block of visibility in the vertical direction around radio station and intrusion to the Fresnel zone.

Although antennas install at higher tower brought a lot of benefit, the cost of tower which build at higher distance is very expansive. Consequently, the best way to do it’s to install antenna as much as we can at the top of mast. But this will generate many interference between antenna special at higher frequency. So, to overcome this problem it is important to use a specialized program for the structural analysis of antenna, checking, interference and management of space between antennas. In this project the cosite analysis model will used as one of software program to evaluate the distance between antenna and mitigation interference **[15].**

2.2-Fundamental of Radio Systems

All RF systems consist of two key elements: a transmitter and a receiver. As the names imply, a transmitter transmits a signal to a receiver, which listens for the signal. RF systems include a transmitter to send the radio signal and a receiver to receive it. The system includes a set of rules that define how the transmitter and receiver communicate. A rule set can simply specify that the transmitter must communicate with the receiver at a specific frequency. More complicated rule sets define not only the frequency, but the time when the transmitter and receiver communicate, how "loud" they can talk, the "language" they speak, and what to do if they can't "hear" one another **[16].**

Since that the radio interference is very complicated process, in this section I am going to start by introduce the basic principle of receiver (superheterodyne receiver) before discuss the procedure of interference.

A radio receiver consists of the following: radio frequency (RF) section, An RF-to-IF converter (mixer), intermediate frequency (IF) section, and Demodulator and Audio amplifier.

In radio communication systems, the transmitted signal is very weak when it reaches the receiver, particularly when it has travelled over a long distance. The signal has also picked up noise of various kinds. Receivers must provide the sensitivity and selectivity that permit full recovery of the original signal. The radio receiver best suited to this task is known as the superheterodyne receiver as shown in figure (2.1) **[17].**

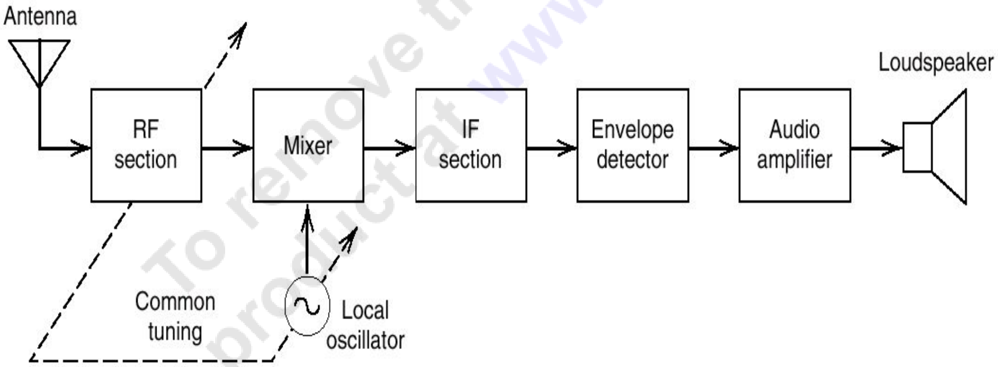

Figure (2.1)-block diagram of superheterodyne receiver

(Source from www.electronics-radio.com)

Points on superheterodyne receiver

Superheterodyne receiver is used to convert all incoming signal to a lower frequency, this known as the medium-frequency (IF), which single set of amplifier is used to provide a constant level of sensitivity and selectivity. Gain and selectivity are obtained in the IF amplifiers. The main key of the circuit is the mixer, which works like a simple amplitude modulator to produce sum and different frequencies. The output of signal mixed with LO.

Sensitivity and selectivity: sensitivity of a receiver is the ability of receiver to capture weak signals, is a function of overall gain, the factor by that is an input signal is multiplied to produce an output signal. The sensitivity is better, since the gain is high. Additional, the receiver which has good selectivity will be able to isolate the desired signal and eliminate undesired signal. The selectivity is improved by adding stage of amplification, after and before the modulator. For instant, Tuned Radio Frequency (TRF).

Tuned Radio Frequency (TRF): in the tuned radio frequency (TRF) receiver sensitivity is improved by adding a number of stages of RF amplification between the antenna and the detectors, followed by stages amplify the sound. The major trouble with the reception is to follow the TRF circuits tuned. Another problem with the tuned RF Receiver is which selectivity varies with frequency.

RF amplifier: the antenna picks up the weak radio signal and feeds it to the amplifier. Provide some initial gain, selectivity and is sometimes called the determinants of preconditions. Pick up desired station by tuning filter to right frequency band.

Mixer: The local oscillator is made tuneable so that its frequency can be attuned over a comparatively wide range. Mixers allow two inputs: The signal to be translated to another frequency is applied to one input, and the sine wave from a local oscillator is applied to the other input. Frequency of the local oscillator used for translation from RF to IF is:

$$f_{LO} = f_c + f_{IF} \quad \text{(up-conversion)} \quad \text{or}$$

$$f_{LO} = f_c - f_{IF} \quad \text{(down-conversion)}$$

$$\textit{Tuning ratio} = f_{LO,\,max} \,/\, f_{LO,\,min}$$

IF Amplifiers: The primary objective in the design of an IF stage is to obtain good selectivity. Narrow-band selectivity is best obtained at lower frequencies. The output of the mixer is an

IF signal containing the same modulation that appeared on the input RF signal. The signal is amplified by one or more IF amplifier stages and most of the gain are obtained in these stages. Selective tuned circuits provide fixed selectivity.

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Demodulators: The highly amplified IF signal is finally applied to the demodulator, which recovers the original modulating information. The output of the demodulator is then usually fed to an audio amplifier. Future advantages may be gained by using double superheterodyne receivers, by using two stage of mixing: Filter at first IF reduce the frequency image problem and filter at second IF has precise audio bandwidth **[17].**

2.3- Electromagnetic Interference (EMI)

Electromagnetic Interference or EMI has been defined as the "degradation of the performance of a piece of equipment, transmission channel, or system caused by an electromagnetic disturbance". EMI can occur throughout the EM spectrum from 0 Hz to 20 GHz or higher frequencies. However, EMI problems are most common in the RF frequencies. In other word, Electromagnetic Interference (EMI) is electromagnetic energy that harmfully affects the performance of electrical/electronic equipment by creating undesirable responses. The interference sources may be external or internal to the electrical or electronic equipment and they may propagate by radiation or conduction. This discipline includes Radio Frequency Interference (RFI), the term which was originally used to describe most electrical interference**[18]**.

2.4-Classification of Electromagnetic Interference

EMI include the following:

Susceptibility: The extent to which equipment is upset by emission generated by another equipment of other electromagnetic phenomenon. **Emission**: the extent to which equipment generates undesired signals (noise) that has the potential to upset equipment.

With respect to compliance with specification applicable to typical digital products, emission is divided into conducted emission and radiated emission .Similarly, susceptibility is divided into radio frequency interference (RFI) and electrostatic discharge (EDS). The various subclasses of EMI are illustrated in **Figure 2.1**.

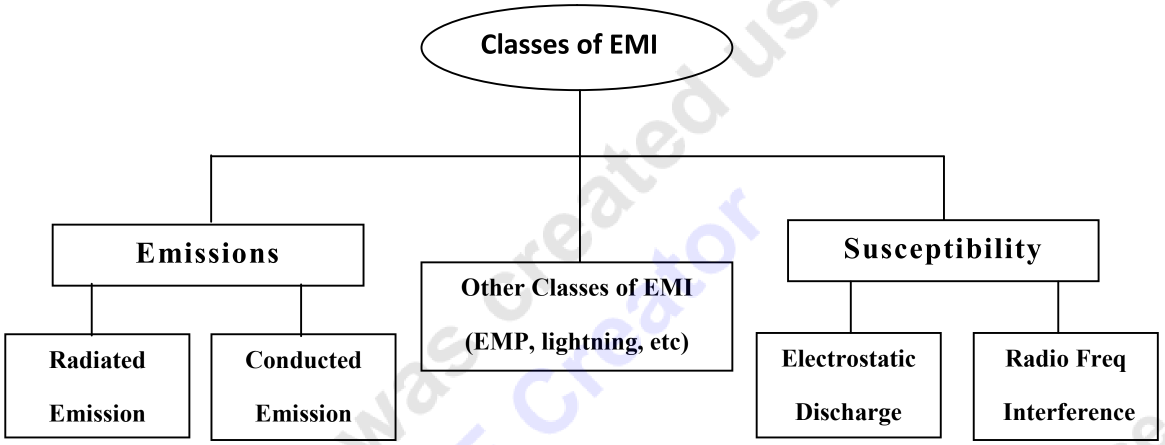


Figure 2.2 –major classes of EMI
(Source from book of EMC Analysis Methods)

2.4.1- EMI–Emissions

There are two type of Emission that affects compliance activities**:** radiated and conducted

Radiated emission: Radiated emissions are those which leave a circuit and travel through the air to interfere with a nearby receiver. The radiated emissions are considered to be an unintentional and undesired characteristic of radio system .for example radiated emission from antenna or transverse are inevitable but either intentional or desirable. Radiated emission can cause interference to receiver over wide frequency range extending from very low frequencies to frequencies in the high GHz range

Conducted emission: conducted emissions are those which leave a system through wires and cables. most discussion of conduct emission concentrate on the RF energy that appears on AC power cord of a product .conduct emission, however, can appear on any wire leaving a system and may cause trouble directly, or may be manifested ad radiated emission from the contaminated wire cable .As with radiated emission, conduct emission can extend from low frequencies to every high frequency **[19].**

2.4.2- EMI-Susceptibility

This part involves two subclasses susceptibility: Radio Frequency Interference (RFI) and Electrostatic Discharge (ESD).

*Radio frequency interference (RFI)***:** Many system products must operate in an environment where they are subjected to intense electromagnetic fields from other equipment. When these externally–generated fields intercept to cables or circuit board of system, they can upset normal operations. Whether equipment susceptibility is regulated or not, it is important to protect the equipment from RFI, as exposure to intense field is all about guaranteed. For example hand-held transceivers   are probably the most common and troublesome RFI threat to most wireless system. Since that radio frequency interference (RFI is) the main part of project, this will introduce in more detail.

Electrostsic Discharge (ESD): ESD is the unexpected and temporary electric current that flow between two things at different electrical potentials caused by direct contact or induced by an electrostatic field. The term is usually used in the electronics and other industries to describe temporary unwanted currents that may cause harm to electronic apparatus **[20].**

Also, there are another electromagnetic interference such as Lightning, and electromagnetic Pulse (EMP). This is discussed elsewhere in more detail.

EMI is usually divided into two general categories to help in analyzing conducted and radiated interference effects: narrowband **and** broadband.

Narrowband Emissions - a narrowband signal occupies a very small portion of the radio spectrum. Communication transmitters such as single-channel AM, FM and SSB fall into this category. Spurious emissions, such as harmonic outputs of narrowband communication transmitters, power-line hum, local oscillators, signal generators, test equipment.

Broadband Emissions - A broadband signal may extend its energy over hundreds of MHz or more. This type of signal is collected of narrow pulses which having reasonably a small rise and full times. They are additional divided into random and impulse sources. These may be transient, continuous or intermittent in occurrence. For example, an unintentional emission from communication, radar and communications electrical switches, computers, ignition systems, voltage regulators, pulse generators, and intermittent ground connections.

2.5-Radio Frequency Interference (RFI)

Interference probability depends on the potential energy transmit density involved due to proximity of the equipment and antenna systems, the various transfer mechanisms , and performance of equipment. The electromagnetic transfer mechanisms may various base on the modes of operation, propagation conditions, and other variables. The propagation pathway which is present to transport signal from one side of transmitter to another side of receiver surrounded by the radio frequency environment of radio communication band could be numerous. Parameters such as antenna to the antenna coupling varies depending on the antenna gain, directivity, the beam width , side lobes, polarization, separation, and the spread conditions of path loss . Properties that affect the performance of the receiver include noise, dynamic range, sensitivity and selectivity (RF, IF), desensitization, adjacent signal susceptibility, intermodulation cross modulation and spurious response susceptibility **[21]**.

The following types of interference are applicable to Radio Frequency communications equipment.

2.5.1- Receiver Co-Channel Interference

This is unwanted signals with frequency components that fall in the range of RF Pass band of receiver and are translated into intermediate frequency (IF) by Pass band by the mixer phases. Frequency interference signal is equals to the sum of the tune frequency of the receiver and one half of the narrower IF bandwidth. During the process these signal are amplified and noticed during the same procedure as the desired signals, as a result, a receiver is very sensitive to these emissions even at the lower levels.

Result: Receiver desensitization, signal masking, distortion.

2.5.2- Receiver Adjacent Signal Interference

The receiver adjacent signal interference is unwanted signal contained some frequency which fall near to the receiver of RF passband which convert to outside of the IF passband by mixer stages. These signals to great nonlinear effect in the receiver RF amplifier of mixer stages must be adequate amplitude. Since that there are some signal which involve nonlinear response signal, may convert to the IF pass band by mixer .This signal will amplified and detected by the same process as the wanted signals. At this stage it becomes like to co-channel interference signal. The predominant response for this case is desensitization.

Results: Non linear effects in the RF or mixer stages producing receiver desensitization, intermodulation and cross modulation.

2.5.3- Receiver Out of Band Interference

It is defined as unwanted signals with frequency components that are considerably separated from the receiver RF pass band. The spurious response at receiver may produced by high level signals if mixed together with local oscillator to produce signal falling within the IF pass band. The output of spurious response produces from mixing of unwanted signal with receiver local oscillator .The amplitude value of these responses is proportional to the level of the undesired signals before to mixing with local oscillator. At the receiver the spurious response usually happen at precise frequencies. Any other signals from outside the range are attenuated by IF selectivity

Results:

By mixing undesired signal with the local oscillator, undesired response produced. This unwanted signal by mixing with the local oscillator are able to translate to the IF stages are spurious response frequencies. The frequency component and interfering power level are a purpose of the receiver's susceptibility to these responses.

2.5.4- Transmitter Fundamental Emissions

It is defined as the output of signal involves feature of the power allocation over the range of frequency around the basic frequency. It is determine by the modulation characteristic and are represented by modulation envelope. The main parameter which associated with modulation envelope is transmitter's nominal bandwidth (3dB). This value can be derived from transmitter modulation characteristic measured, or from manufacture specification. The value of the power distribution in the modulation side band could be presented by the modulation function viewing the variation of the power with frequency.

2.5.5-Transmitter Harmonic Emissions

Unwanted signal outputs consider to be the main concern of harmonic emission which are the value of harmonic is related to basic of signal rather than other oscillator circuits. For particular transmitter, the power connected with harmonic may be modeled using data. But, because the harmonic output power could vary significantly from one transmitter to another transmitter at the same type and model, it ought to be represented statistically. The harmonic emission level are control the transmitter emission to predicate the frequency above the fundamental. The modulation envelope has to corresponding to for harmonics as was done for the fundamental **[21]**.

2.5.6-Transmitter Noise

It is defined as the output of spectrum that is product from thermal noise generated in driver and from final stages of amplifier; also from the synthesizer noise from lower level stages. This knows as broad band noise. But, it is generally does not cover the immediate modulation side band. The stage may be precise as the power per B.W as a function of frequency.

2.5.7-Transmitter Intermodulation

Transmitter intermodulation occurs when multiple carriers use the same amplifier, thus creating intermodulation products that may spill over into the wideband spectrum causing unwanted interference, which usually occurs in the base station transmitter. Intermodulation generated by UE will be depending on how close the UE is to an interfering base station. There are two intermodulation products that need to be considered, known as the second order and third order intermodulation product. <u>This will introduce in more detail in chapter 4.</u>

2.6-Electromagnetic Compatibility (EMC)

Electromagnetic compatibility is capability of the electronic and electric tools to work in the intended environment without suffering from the degradation as result from non-intentional electromagnetic interference. It is suggested that the performance be tested to guarantee the procedure in the clear margin of the security for necessary design level performance. "The emission level equal the value of electromagnetic interference minus the coupling of path loss, this value should be less than the value of victim's susceptibility threshold minus a predetermined safety margin". The purpose of electromagnetic compatibility is to decrease the influence of electrical noise **[18].**

2.6.1-Importance of EMC

It is significant that design electronic apparatus to ensure proper functioning in the expected electromagnetic environment, thus preserving a suitable amount of electromagnetic compatibility. Electromagnetic compatibility has become increasingly vital in recent times due to range widely in industrial and a more general society (eg medical) effect. Meeting EMC standards are the basic necessity for any electrical and electronic apparatus before introduction it on the market. EMC problems are the major anxiety of the telecommunications, electronics and automobile industries.

2.6.2-EMC Testing

The testing using for EMC involves 4 types: radiated emission, radiated immunity, conducted immunity and conducted emission. The radiated emissions testing system includes the equipment under test (EUT), antenna and signal analysis. The voltage that induced from antenna is calculated and also data used to evaluate the strength of the field by a factor of antenna. Immunity test requires EM supply to generate the environment. This is the source linked to EUT, either by radiating or conducted method. Also, it must be checked to establish whether the EUT is functioning well **[22].**

CHAPTER 3

Cosite Analysis Model (COSAM)

3.0- Introduction

COSAM is the programmed system used to analyse the electromagnetic compatibility of a single site where a large number of transmitting and receiving communications equipments are employed. It is essential for this analysis "cosite" EMC take into account the short distances between the antennas, and a high level of unwanted signals present at receiver inputs and transmitter outputs **[23]**.

This chapter involve an evaluation of cosite interference problem, a description of the engineering features of the model and a discussion of possible model applications as well introduce the model limitation of COSAM system.

3.1-purpose of cosite analysis model

Cosite interference technique fabricate it probable to share site antenna more closely together, which make it probable to:

- Collocate more systems on the same tower;
- Reduce the increase of towers by collocating more often; and
- Save build-out capital for wireless licensees by making more collocation possible.

3.2. Evaluation of the cosite problem

The problem of interference evaluation implies, firstly, close proximity between transmitting and receiving antenna and, secondly, relatively large signals impinging on receiver inputs. Example of cosite problems are, radio system sites, ship, aircraft, communication or air traffic control centres. Close proximity implies that the antenna may be in each other‘s Fresnel region or, perhaps, in the induction field. An evaluation of coupling loss measurements between operational antennas has led to the development of an empirical coupling loss model which includes the effects of antenna and transmission loss. Additional allowance is made for antenna filters, multiple-couplers and mismatch losses **[24]**.

Five Types of interference Mechanisms (interaction predicated by COSAM)

Radio Frequency Interference at a shared location is usually caused by one of the pursuing mechanisms, which have their origin in some form of equipment or other non-linearity

-Adjacent signal
-transmitter spurious radiation
-receiver spurious radiation
-transmitter intermodulation (TIM)
-receiver intermodulation (RIM)

As the most common shared site interference mechanisms is TIM & RIM, this will explain in chapter 4&5 with more detail

Adjacent signal (involving non co-channel signals close in frequency to the desired signal, but outside the nominal bandpass of the receiver). The adjacent signal problem is complicated, involving non-linear interaction between an undesired signal and desired signal. Also, many other mechanisms are possible: cross-modulation, desensitization, saturation and effects of transmitters' noise. *Spurious emission* involves emission of narrow bandwidth, from the transmitter outside the necessary bandwidth excluding transmitter noise and transmitter intermodulation effects. *Receiver spurious responses* involve one undesired signal whose frequency coincides with one of family of response associated with each receiver type. *Intermodulation (IM) interactions*: are caused by the mixing of two or more signals. If the intermodulation product closely coincides with receiver tuned frequency, it can cause interference between systems **[25]**.

Even though all the pervious interactions were considered by cosite, there are another interaction was not considered such as front-end burn-out, and case penetration. Another cosite interaction which is not considered is the effect of oxidized surfaces and joints, which are capable to generating new frequencies resulting from the interaction of two or more incident waves at different frequencies. Finally, it is necessary to consider desired signal and ambient noise levels to determine probable system performance, with or without interference.

3.3- $\boldsymbol{the}$ $[(S/(I+N)]_{ino}$ concept

The parameter $[(S/(I+N)]_{ino}$ is calculated by the **COSAM** program for each receiver specified in the analysis. This parameter is defined as the effective input on-frequency signal to interference plus noise ratio resulting from any of, or the combined effects of, the five types of interactions predicted by COSAM.

Three variables are involved. **S** is the desired signal power **(P_d); N** is the ambient noise power level (P_n); and **I** is the sum of effective input on-frequency interference power levels ($\sum P_{ino}$). P_{ino} is the effective input on-frequency interference power level due to a single interaction. The summation involves a conversion from dBm to watts; when the addition is made, the result is reconverted to dBm. We have:

Equation 3.1

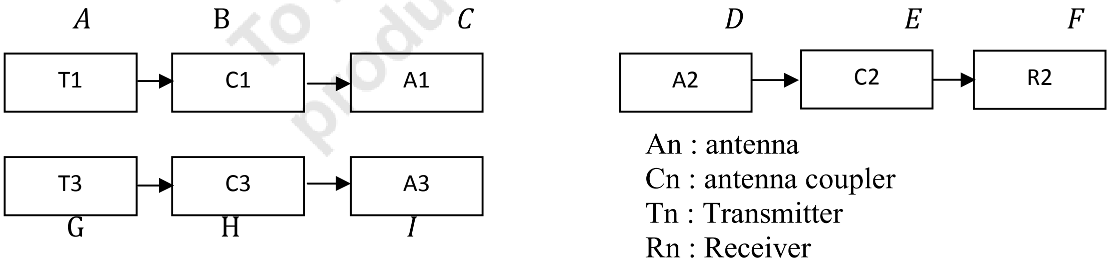
$$[(S/(I+N)]_{ino} = 10\log_{10}\left[\frac{P_d}{(P_d+\sum P_{ino})}\right]$$

In cosite situations, frequencies of interfering signals will not be equal to the desired signal (receiver) frequency. However, equations are supplied for each of the five interactions which convert input values of P_d (at fo) and P_i (at fi) to P_{ino} permitting conversion **to** $[(S/(I+N)]_{ino}$. This can then be easily converted to (S +I+N)/ (I+N), commonly called SINAD, for the model output. P_d, P_n, and P_{ino} are expressed in watts the ratio is in dB**[24].**

3.4-Outline of the model

This section will describe the engineering formulation involved in the model. In order to use and calculate the five types of interference interactions, the power present at a victim receiver due to each interfering transmitter must be calculated first (**Calculation of mean power levels)**. This will include coupling loss, antenna couplers, and power loss**[26]**..

Figure (3.1) below show the simplified cosite configuration, consisting of two transmitters and one receiver, each one operating at different frequencies.



An : antenna
Cn : antenna coupler
Tn : Transmitter
Rn : Receiver

Figure3.1- Transmitter/Receiver/antenna/coupler configuration

3.4.1-coupling loss

COSAM calculates coupling loss by one of two methods depending upon the cosite installation. If a ground or ship installation is being analyzed first method is used. If, on the other hand, the installation is an aircraft, a second method must be used so that coupling around the aircraft fuselage may be considered. Coupling loss, as defined below, includes the gains of the antenna (G_t, G_R) as well as the space loss between antennas (L)**[27].**

- Ship and Land Coupling Loss.

The statistical expression for ship and land coupling loss as used by COSAM is:

Equation 3.2 $L = -G_t - G_r - 27 + 20\log f + 20\log d + \sin^2\theta(-40 + 20\log f + 20\log d)$

L: Mean coupling loss between antennas 1 and 2. **f** ⍰frequancy of the Tx MH.

θ ⍰vertical angle, relative to antenna position.

d ⍰distance between antenna (m) And

$\mathbf{G_t}$, $\mathbf{G_r}$: average antenna gains in dB

If $\boldsymbol{\theta}$ and $\boldsymbol{G_t = G_R = 0}$ **, Equation (1)** of couple loss reduced to **free space equation** for isotropic antenna. The statistical distribution is assumed to be normal and a value of standard deviation is supplied.

-Aircraft Coupling Loss

The expression for coupling loss on an aircraft assumes that antennas are on or above a perfectly conducting cylindrically or conically shaped airframe. The expression for mean coupling loss is:

Equation 3.3 $L = -G_t - G_r + 37.9 + 20\log(d ⍰ f) + CF$

d= shortest distance in feet along the surface of the cylinder between the antennas

$=[\boldsymbol{Z}^2 + \left(\frac{\boldsymbol{A\theta}}{57.3}\right)^2]^{0.5}$

The angle **θ** is the angle in degrees separating two planes that contain the longitudinal axis and the transmitting and receiving antennas, respectively. **A** is the radius of the cylindrical airframe in feet. **Z** is the distance in feet separating the projections of the transmitting and receiving antennas. **CF** is curvature factor which is a function of the variable (curve around cylinder-ex airplane).

3.4.2-Antenna Couplers

Experimental data on standard mult-couplers indicates that classical circuit theory may be used to compute losses relatively close to the tuned frequancy. The loss for a signal at an off-tune frequancy is:

Equation 3.4 $$\beta_c = 20\,log\,\frac{E_o}{E} = 10\,N\,\log_{10}[1 + Q^2\left(\frac{fo+\Delta f}{fo} - \frac{fo}{fo+\Delta f}\right)^2]$$

N = the number of tuned stages

Δf = operating frequency minus fo (MHz).

Q = the quality factor (ratio of reactance to resistance of the circuit)

fo = tuned frequency of the circuit (MHz)

In this part the nominal value of 1 dB inseration loss is assumed. The comput values of antenna coupler (β_c) are taken to be the mean values.

3.4.3-power loss computions

To compute the mean received power at the input to the receiver ($\mathbf{R_2}$) due to a single interfering transmitter (T_1) as shown in figure (3.1) the following is used:

Equation 3.5 $$P_r = P_t - \beta_{ct} - L - \beta_{cr} - l$$

P_t = mean transmitter power output, in dBm

P_r = mean receiver power, in dBm

β_{ct} =rejection , at transmitter frequancy due to the transmitter coupler (dB)

β_{cr} = rejection , at receiver frequancy due to the receiver coupler (dB)

There are two different situations:

First situation: If the signal interest at transmitter frequency then this equation is used to work out the power loss, such as Spurious emission and transmitter intermodulation.

Equation 3.6 $$P_r = P_t - L - \boldsymbol{\beta_{ct}} - 1$$

Second situation: If the signal interest at receiver frequency then this equation is used to work out the power loss, such as adjacent signal and spurious response.

Equation 3.7 $P_r = P_t - L - \boldsymbol{\beta}_{\mathbf{cr}} - 1$

3.4.4-interaction table construction

The interaction table lists, for each receiver, each transmitter that may cause a significant interaction. These interactions include adjacent signal, spurious emission .spurious response and intermodulation .all these were discussed in chapter 2.

3.5- Analysis module method used

COSAM is a statistical model used to account for uncertainties in equipment characteristics and coupling losses in the calculation of signal power levels. The statistical distributions of the background noise power levels and the desired power levels are calculated at each receiver input. Samples from these distributions are selected randomly during a computer simulation to generate receiver performance distributions of the AS (Articulation Score) for analogy voice or of the BER (Bit Error Rate) for digital receivers**[20]**.

This section will involve two parts: F**irst part** will deal with **Computation of** $\mathbf{P_{ino}}$ Values at adjacent Signal Interference, spurious response, spurious emission, Transmitter intermodulation and Receiver intermodulation. **Second part** will deal with statistical methods which involve Application of Monte Carlo techniques, Computation of $[(S/(I + N)]_{ino}$ using performance degradation

3.5.1- Computation of $\mathbf{P_{ino}}$ Values

3.5.1.1-Adjacent Signal Interference

Figure 3.3 illustrate the adjacent signal interaction. The equation for the mean value of the effected signal input on frequency interference power level from an adjacent signal is:

Equation 3.8 $P_{ino} = P_i - \beta_{eff} + (1 - M)(P_d - R_{s)}\ dBm$

Where

P_i : input undesired power (dBm) β_{eff} : effective off − frequancy rejection(due toΔf)

β_d : input desired power(dBm) R_s : receiver sensitivy (dBm)

From equation above β_{eff} is a function of Δf, while the last term, which represent the various non-linearities that may be anticipated (e.g., cross-modulation and desensitization), is a function of the desired signal and receiver sensitivity. Also that non-linear term only applies if $P_i \geq P_{ib}$ (specified interfering power break point. below this point, the term is set to(0 or 1)

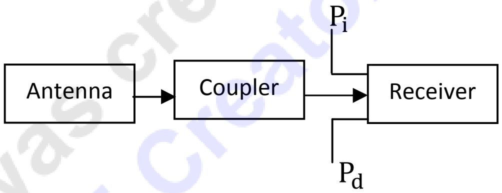


Figure3.2-Adjacent signal model: input parameter

3.5.1.2- spurious response

Equation below is used to describe the spurious response interaction:

Equation 3.9 $P_{ino} = (1 - n)R_s + n(P_i - \beta_{sr})\ dBm$

β_{sr} : effective rejection(dB) R_s: receiver sensitivy (dBm)

n: is postive integer represent the oredr or of sperious . If the n= 1, then $P_{ino} = P_i - \beta_{sr}$. If n= 2, then increase of 10 dB in P_i will result of 20 dB in P_{ino}.

3.5.1.3- spurious emission

Figure 3.4 illustrate spurious emission model parameter

Equation 3.10 $P_{ino} = P_t - \beta_{se} - \beta_{ct} - L_{tr} - 1\ dBm$

β_{eff}: effective off − frequancy rejection(due toΔf) (dB)

β_{ct} : off – frequancy rejection due to the transmitter coupler (dB)

L_{tr} : coupling loss between transmitter and receiver due to antenna gain and space loss

The value of 1 dB represents the insertion loss of the receiver coupler

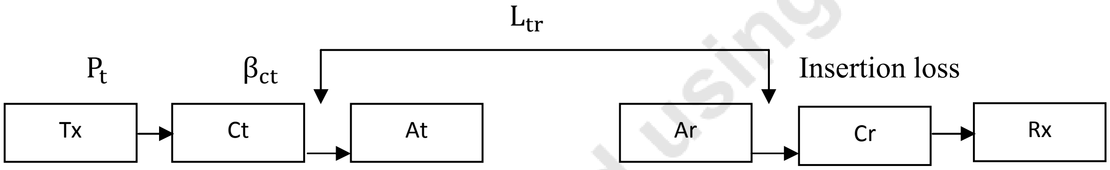


Figure 3.3-otlines the spurious emission interaction

3.5.1.4- Transmitter intermodulation

Figure 5a and 5b outline the transmitter intermodulation interaction. Here, in this part there is relationship between frequency of receiver, victim and interference f_r, f_v and f_i .

$$f_r = mf_v - nf_i \ MHz$$

Equation 3.11 $P_{iv} = P_{ti} - 1 - L_{tt} - \beta_{cv}$ *dBm*

Equation 3.12 $P_r = m P_{iv} + n(P_{iv} - \beta_{vi}) - K_{m,n}$ *dBm*

Equation 3.13 $P_{ino} = P_r - \beta_{cv} - L_{tr} - 1$ *dBm*

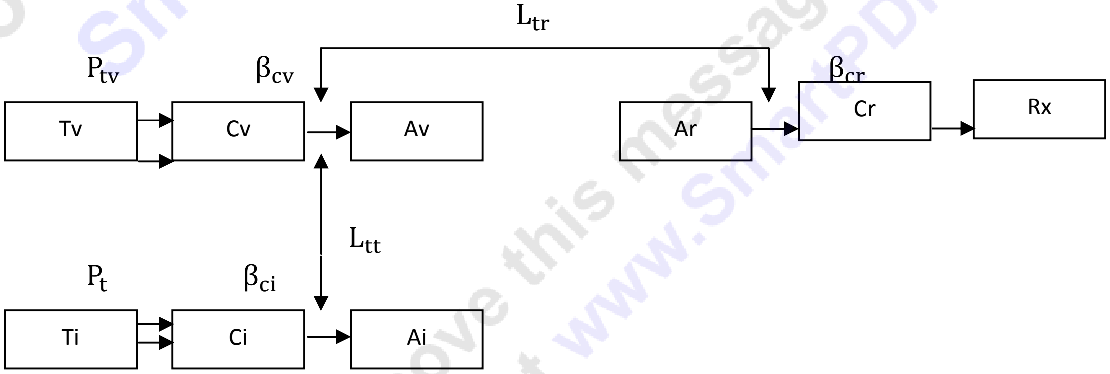


Figure 3.4-a- Transmitter intermodulation coupling parameter

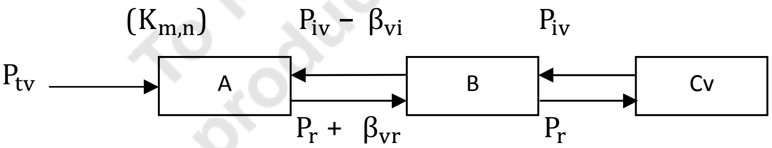


Figure 3.4-b- Transmitter intermodulation internal parameter

In above equation 1 dB represent the insertion loss due to interfering transmitter coupler and receiver coupler. Values of β_{vi} and β_{vr} are computed by using equation of antenna co couple.

3.5.1.5- Receiver intermodulation

Figure 6a and 6b illustrate the receiver intermodulation interaction. The concept of the “victim” and “interfering” transmitters do not apply since both transmitters are “interfering”. The f_v frequency will always be located between f_i and f_r , and will be multiplied by m= n+1, while the f_i frequency will be multiplied by n. The same multipliers apply to the power values.

Equation 3.14 $P_{ino} = m(P_{iv} - \beta_{vr}) + n(P_{ii} - \beta_{ir})\ K_{m,n}$ **or** $\overline{K}_{m,n}$

Non-linear coefficient due to transmitter output circuit non-linearity ($K_{m,n}$) has two select:

$\mathbf{K_{m,n}}$ is used if P_{iv} and P_{ii} are greater than P_{ibk} (interfering power break point), the loss is occur in the **frequency convertor (mixer)** , so Q is supplied ,and the effective number N of tuned stages of amplifier is used .$\mathbf{\overline{K}_{m,n}}$ is used if P_{iv} and P_{ii} is not greater than P_{ibk} (interfering power break point),the loss is occur i**n radio-frequency amplifier** and N is generally equal to unity .

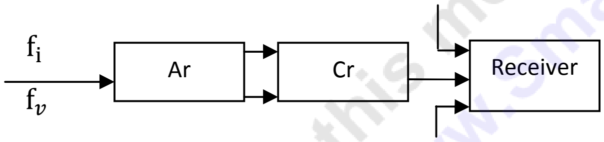
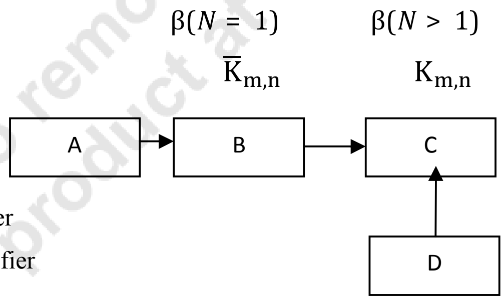


Figure 3.5-a Receiver intermodulation model: input parameter



A: first radio –frequancy amplifer
B: second radio frequency amplifier
C: frequency convertor
D: local oscillator

Figure 3.5-b Receiver intermodulation model: internal parameter

3.5.2-Statistical Methods

3.5.2.1-Application of Monte Carlo Techniques

Each of the five interactions results in intermediate predicted distributions of P_d, P_i **and** $\mathbf{P_n}$ at the input to the receiver. In order to account for certain non-linearities in the receiver, specific power break-points have been specified in the adjacent signal and receiver intermodulation model. For each equation, if the interfering power level exceeds the break-point, one constant $K_{m,n}$ is used; if it does not, another constant $\overline{K}_{m,n}$ is used.

It is anticipated that the $\mathbf{P_i}$ distributions will frequently include values above and below the break-point(s). Consequently, **a Monte Carlo** procedure is used to select a single $\mathbf{P_i}$ value from the computed distribution by employing a random number generator and, depending on the value, the appropriate equation is selected. The process is then repeated many times to compute P_{ino} and $[(S/(I+N)]_{ino}$.

In brief, one receiver is selected; an interaction table is examined to determine which transmitters are potentially significant. Then, for each interaction, the appropriate $\mathbf{P_i}$, $\mathbf{P_d}$ and other parameter distributions are selected and a single value chosen from each by means of a random number generator.

A single value of P_{ino} is computed from these values, the next interaction is considered, using the same points, as applicable, and so on. This process is termed a "run". Then, for the same receiver, approximately 1,000 runs are performed, eventually resulting in a predicted [(S+I+N)/(I+N)], output distribution. Each receiver is considered in the same **[23]**.

3.5.2.2-Computation of $[(S/(I+N)]_{ino}$

Each run contains a list of computed P_{ino} values. The last column contains the mean value of P_{ino} due to each interaction. The program considers each run separately and computes the sum of P_{ino} . Also included are values of $\mathbf{P_d}$ and $\mathbf{P_n}$. These distributions are not computed by COSAM. They are assumed for each problem and may be changed for different situations. $[(S/(I+N)]_{ino}$ is then computed using **Equation (3.1).**

3.5.2.3-performance degradation considerations

In this part, we will look to determine if the interference level and output ration will cause performance degradation and the degree of degradation. Consequently, COSAM uses transfer function to convert $[(S/(I+N)]_{ino}$ to $[(S/(I+N)]_{o}$ (the ratio of the signal to interference-plus-noise at the output). Since the distribution of $[(S/(I+N)]_{o}$ ratio is predicted, the measure can be used to select an arbitrary threshold which can be used to compute the probability of exceeding any particular level.

COSAM system will check either the system work satisfactory or degraded seriously, or marginal performance expected. To achieve numerical scale is desirable. So, it is feasible to select a value of $[(S/(I+N)]_{o}$ above which good operation is expected and a second value below which poor performance is anticipated. And the middle range would be marginal and for A3E-A3E modulation (amplitude modulation telephony, double sideband) or (A3E noise), is approximately 10 to 12 dB in width **[24]**.

COSAM provides three numerical scores, **figures 7-a and 7-b** illustrated that, the upper performance score (**UPS**) is the probability of providing "adequate" or "good" performance if no interference is present. The system performance score **(SPS)** is the probability of adequate for good performance in the presence of interference. The relative performance score (**RPS = SPS/UPS**) provides the user with another measure which, in conjunction with the other scores, gives additional understanding of receiver performance. For example, if the SPS were 0.4, one would predict poor performance, However, if the UPS also 0.4, RPS 1.0, and it can be seen that the inadequate desired signal would be the major problem **.**

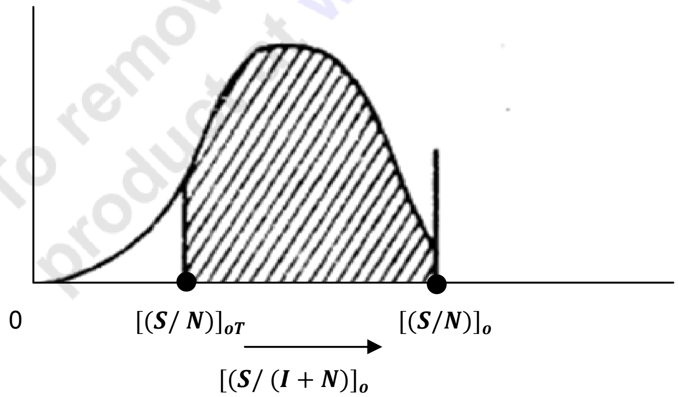


Figure 3.6-a- Representative Distribution $[(S/(I+N)]_{o}$ for a Given Receiver (Upper Performance Score Calculation)

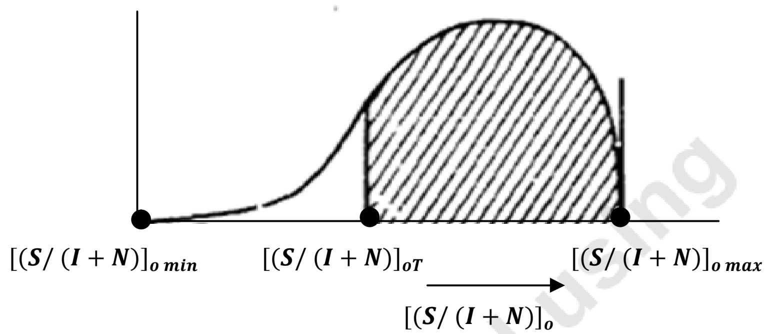


Figure3.6-b- Representative Distribution $[(S/(I+N)]_o$ for a Given Receiver (system Performance Score Calculation)

Note $[(S/N)]_{oT}$ and $[(S/(I+N)]_{oT}$ are threshold values of the ratios, signal to noise, and signal to interference –plus-noise; maximum and minimum indication are self –explanatory.

3.5.2.4-degradation computations

For the equipment under consideration in this project, there are two transfer functions are supplied, A3E versus co-channel A3E and A3E versus noise. If one or two interfering signals exceed the noise by 6 to 19 dB, A3E/A3E function is said to be applicable. On the other hand, if a large number of undesired signal exceed the noise and have approximately equal amplitudes, the said to be equivalent to the noise.

A3E- A3E (which mean AM/FM to AM/FM), where I > N

Equation 3.15 $[(S/(I+N)]_o = [(S/(I+N)]_{ino} - 8$ dB

A3E- Noise (which mean AM/FM to noise), where N > I

Equation 3.16 $[(S/(I+N)]_o = [(S/(I+N)]_{ino} + 10 \log(\text{bandwidth (MHz)}) + 11$ dB

3.6-Executive Summary

Firstly, to convert off-tune interfering powers to on-tune mean P_{ino} values for all the types of interference interactions considered. In order to do that, the power present at a victim receiver due to each interfering transmitter must be calculated. Next , different equations were analysis for each of all the interactions(adjacent signal , intermodulation ,and spurious) ,which convert input values of P_d (at f_o) and P_i (at f_i) to P_{ino} permitting conversion to$[(S/(I+N)]_{ino}$.

Secondly, To avoid the non-linearties in the receiver system, After we finish the calculate of all the interaction at the input of the receiver, the" Monte Carlo "technique are used by select a signal number from compute distribution, by process and repeated many times to compute $\boldsymbol{P_{ino}}$ and $[(\boldsymbol{S}/\,(\boldsymbol{I}+\,\boldsymbol{N})]_{ino}$ and after run the program many times the resulting of $[(\boldsymbol{S}/\,(\boldsymbol{I}+\,\boldsymbol{N})]_{o}$ outputted can be predicated .After that this process repeated to ever single receiver. Even though the value of $[(\boldsymbol{S}/\,(\boldsymbol{I}+\,\boldsymbol{N})]$ was interest, we still have performance degradation. The operation degradation is somewhat loosely defined in term which implies relating such parameters as$[(\boldsymbol{S}/\,(\boldsymbol{I}+\,\boldsymbol{N})]_{o}$ to measure will be meaningful to users, designer and analysis. The COSAM using ratio predicted and the measure used arbitrary threshold used to compute the probability of any exceeding any particular level.

Thirdly, another step will be involved after we calculate the value of ([S/(I+N)]o, the value of degradation and evaluating corrective measures require careful consideration of a number of co-site interference mechanisms. So, two transfer functions are supplied to compute the degradation.

Then, the COSAM was used to determine the receiver performance, using the appropriate degradation curve. If the AS was less than the specified receiver performance threshold, the frequency separation and/or antenna separation was increased until the required receiver output response was achieved Finally , to interest the reality and practicability , the cosite analysis using impose upper and lower limits on the distribution:

To summaries, The COSAM model computes the statistical distribution of the desired signal, the noise, and each Pin. In addition, statistical, an articulation score (AS) measure is used to select a SINAD threshold, then computes the probability of exceeding this threshold. This gives numerical values which the user may base his decision as to the significance of degradation to a system. For example, some systems use a threshold value of 10 dB, which corresponds to an articulation score of approximately 70%.

In general, the results of the exercise indicate that COSAM is a useful engineering tool that can be employed to predict co-site interactions in a large number of cases involving commonly used equipment.

3.7-Model application

Given a specific site description, with antenna locations, allocations of couplers, transmitters, receivers, frequencies and transmitter power, COSAM can compute the various scores. Also, much more than can be collect from programme **[23]**. For example:

- Improve frequency assignment
- Alternate deployment , using the same or other standard component can given by;
- Simple rule for minimizing harmful interference can be generated, permitting change in assignment in event that operation needs vary.
- Fixes of a technical or operation type can be suggested. For example, if all couplers have Q and N values (equation of antenna coupler) exceeding some threshold, all or most serious interference cases can be avoided.
- Inherent of equipment deficiencies can be isolated and quantified .for example, an examination of ($K_{m,n}$) a value clearly indicates that some equipment is more likely to cause or experience intermodulation than other. These values can be used as a basis for equipment specifications.

3.8- Limitation

A limited the number interomdulation products are considered.

- Fifty transmitters and fifty receiver are maximum number the model can be accommodate
- Twenty is maximum number of spurious response and spurious emission that can be listed per equipment.
- A capability to express of antenna gain , spurious response , spurious emission ,or adjacent signal as a function of tuned frequency has not been incorporated.
- Local oscillator radiation, case penetration and burn-out effect are not incorporated, although these items could be included with relatively little difficulty.

Chapter 4

Intermodulation and Antenna Isolation

4.0-Introduction

Many people ask the question: "Where are the additional frequencies that are created in intermodulation (IM) come from? And how much spacing need between antennas to satisfy antenna isolation?**"** This chapter attempts to address this issue, and many others in relative of passive intermodulation distortion. Intermodulation products (undesired frequencies) are generated when two or more frequencies mix up in a non-linear element. Since transistors, transmission lines and most of the components have characteristics of non-linear, intermodulation (IM) occurs to some extent in **all transmission systems [29]**.

Outline of this chapter: In this chapter I am going to break it into 4 parts. This part (**Part 1)** deals with the general principles underlying all types of intermodulation. **Part 2** deals with things specific to antenna intermodulation. **Part 3** deals with how transmitter and receiver intermodulation occur. **Part 4** deals with antenna isolation and also presents some examples of how antenna isolation evaluated using mathematical and measurement method.

4.1-Intermodulation (IM)

4.1.1- Where does intermodulation (IM) generally occurring

Intermodulation product occurs in three specifically different places within a radio system:

a) In the Antenna intermodulation,

b) Transmitter Intermodulation,

c) Receiver Intermodulation.

Antenna IM is generated in the antenna when two or more transmitters are combined into it. **Transmitter and Receiver IM** is usually happen due to interaction between systems which are attached to different antennas.

4.1.2--Numerical Form of Intermodulation (IM) Products

The form that an IM product normally takes is: -

A + n (A - B)   and   B - n (A - B)

This gives rise to the following IM products for two frequencies: -

2A – B	2B – A
3A - 2B	3B - 2A
4A - 3B	4B - 3A

By another word, if the two frequency A and B was separated by “s” kilohertz, so the IM products will fall at regular intervals of “s” kHz above the frequency of A and "s" kHz below the frequency of B.

For example, if we substitute **B = A+s** to the on top of procedures, we can see that the IM products that are generated. An example would be **3A -2B = 3A- 2(A + s) = A- 2s,** which means that the 5th order intermodulation **3A - 2B** will fall on the frequency and that is **2s** less than the frequency **A** . Therefore, we can now see how the allocation of channels with uniform spacing could have significant behaviour on the spread of IM interference in radio mobile process **[30]**.

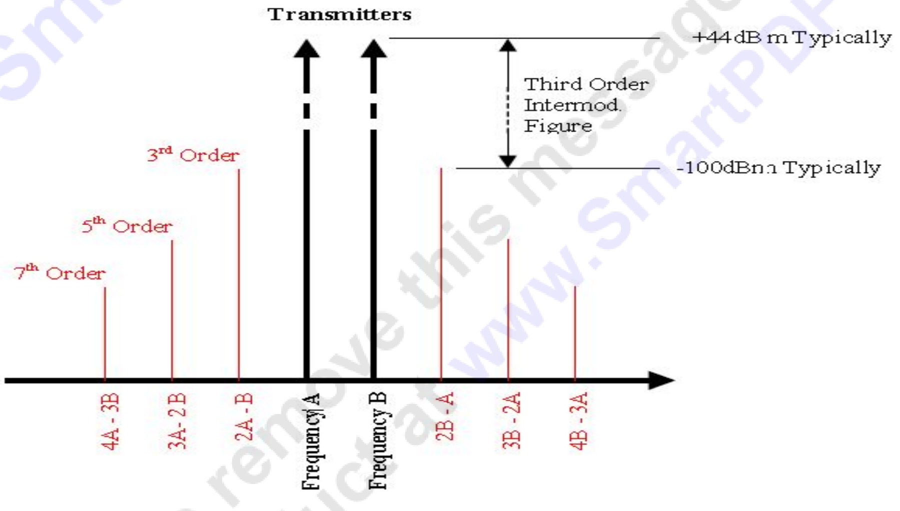


Figure 4.1 - Graphical Illustration of Intermodulation Products
(Source www.radio-electronics.com/info/receivers)

In addition , the 3rd products can also happen from the combination of three signals and get the form A + B - C, A + C - B, C + B - A, 2A - B, 2B - A, 2A - C, 2C - A, 2B - C, and 2C - B. The types of intermodulation, which involve the three basic frequencies, are frequently introduced on the site, where different frequency bands are used. And can sometimes be difficult to detect, because it is easy to forget this kind of intermodulation. However, it should be completely no kind of intermodulation can be ignored, and all kinds of valid and can always contribute to a specific problem. The best thing to do is to order them in probability each time new information becomes obtainable.

4.1.3-Minimum order which arise in given system configuration

To assist in frequency planning, a simple relationship between factors involved in making an intermodulation exists. This relationship is between:

-Transmit to receive spacing (**DS**)
-Order of system intermodulation
-The bandwidth (BW) the difference between the highest and lowest transmit or receive frequency. This relationship is: -

Equation 4.1

$$\boldsymbol{B}W < \frac{(2\boxed{?}DS)}{(0rder+1)}$$

This relation it is only interest in circumstances where multiple number of transmitter are collected into same antenna, hence can be used to examine whether IM product is can happen in a particular system configuration. By choosing the correct maximum B.W allowed <u>on any site</u>, a system designer is capable to guarantee that the minimum order selected will never happen on any site in the system. Typically, planners should attempt to maintain the frequencies as close to each other as is useful to decline the likelihood of intermodulation happening at site[31].

4.1.4 Likelihood of a particular intermodulation happening.

Depending on the precise frequency separation, some IM products happen together with each other, and some may fall on one of the transmitter frequencies itself. For the special case of the frequency separation between A and B is the same as that between B and C, only 4 major IM products result. Higher order products of 3 signals, such as fifth-order products 2A +B-2C or 3A-B-C are also possible. Third order products alone may represent a situation which appears quite complex where a large number of transmitters are concerned.

For example if we have six channel installations at same mast, this will consist of 30 IM products of the 2A- B and 60 of the A + B – C $\mathbf{3^{rd}}$ order variety. **Fortunately** many IM products coincide, making the number of significant IM products far less.

4.1.5- Bandwidth of Resulting Intermodulation

When trying to locate intermodulation product, it is often necessary to know the bandwidth of resultant intermodulation factor. This is useful to know if the product is located on the channel adjacent to one of the receivers, because some of the energy from the intermodulation product could "spill over “into the receiver and cause problems, although the “normal” accounts do not show any problem. Initial choose the largest harmonic number used in creating the Intermodulation product under consideration. And then multiply the bandwidth of the constituent frequency by this factor, which given the bandwidth of the intermodulation product[32].

For example if we look at the FM transmitter deviation in the average by ± 3.3 kHz, and the maximum ± 5 kHz peak, the resultant bandwidth of signal is 25 kHz. If we look at third order products (of type 2A+ b) the resultant intermodulation product a total B.W of 50 kHz (2 × 25 kHz). And the fifth order type 3A - 2B will have bandwidth of the total 75 kHz (3 × 25 kHz). However, a seventh order three-transmitter intermodulation product of the type 3A +1B - 3C will also have a total B.W of 75 kHz (3 × 25 kHz). If an intermodulation product on an FM system is listened to off-air, then the main modulation that will be heard from the interfered-with receiver will be that of the highest harmonic involved in generating the product.

For digital radio systems the modulation is such that the transmitter occupies the full bandwidth at all times, rather than when modulation is applied in the case of FM systems. Therefore the spectrum of the transmitter will appear on a spectrum analyser as full bandwidth noise like signal. The resulting intermodulation will thus occupy a bandwidth which is the signal bandwidth multiplied by the largest multiplier involved in the resultant intermodulation product. So, consider the situation where there is a combination of modulation schemes included, each frequency must be considered separately to calculate the resultant bandwidth.

4.1.6-Relative Levels of Intermodulation Orders

According to work made on different types of apparatus of wireless system from different company has found that the relative level of each subsequent order is -5dB. In other words, if the level of the third order IM product is taken to be 0 dB (reference), then the five order IM product will be at least 5 dB below that of the third order. It is more likely to be between 5 and 10dB below it, but the relationship will vary from one to another, with the worst being only 5dB down. These relationships have been empirically derived and are demonstrating in Table below. The 'Worst' column shows the minimum difference observed over many measurements and the 'Most Likely' column shows the relative levels observed most frequently[33].

Order	Relative Level		Order	Relative Level	
	Worst	Most Likely		Worst	Most Likely
3rd	**0dB**	**0dB**	11th	-20dB	-32dB
5th	-5dB	-8dB	13th	-25dB	-40dB
7th	-10dB	-16dB	15th	-30dB	-48dB
9th	-15dB	-24dB	17th	-35dB	-56dB

Table 4.1 relative level of intermodulation products

(Source from book - Wireless network performance handbook)

4.1.7-Levels of intermodulation Products in Relation to Transmit Power

There is also another correlation between changes in the TX power and the level of IM product. if the both of TX power are cutting off by 1 dB , in that case the resulting IM product will reduced by 3 dB .(there some case where the reduction of IM product just 2dB , but this is unusual). This is the reason why IM level must be specified at specified TX power level. If the power of TX is reduced by one dB, the power of resulting IM will be reduced by 1 or 2 dB, depending on the IM product under consideration.

4. 2-Antenna Intermodulation

When multiple TX are join together in one radio mast or may into one antenna involved duplexer , as shown in **Figure 4.2** below, the IM product of transmit signal can probably create unwanted signals on receive frequencies. (This can be a receiver matching to one of the stations included in the IM product, or it may possibly be another transmitter attached to the same antenna). So, these undesired IM signals will be supplied back into RXs as an on-channel signal, and will cause many the troubles and be supposed by system as on-channel interference [29].

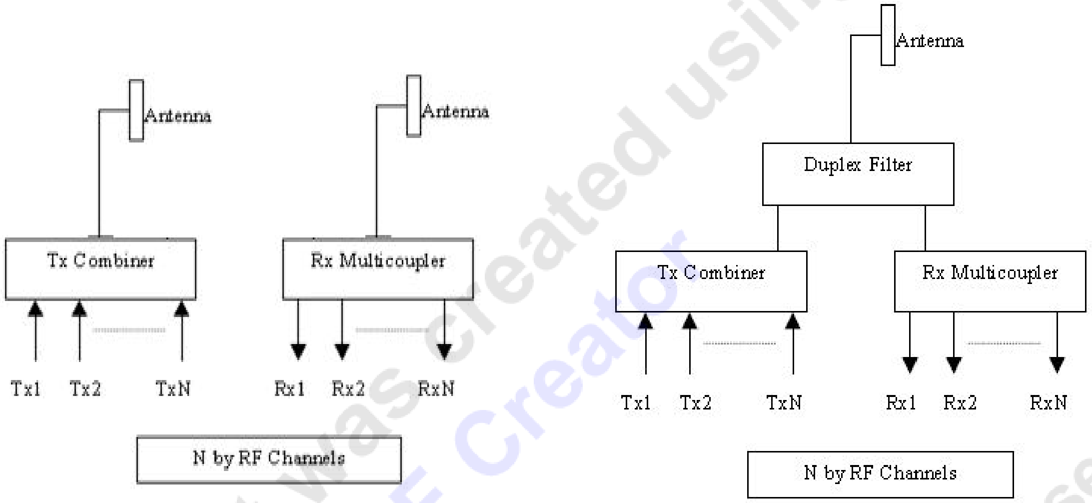


Figure 4.2 - Multi - Frequency System Configurations

(Source from www.freepatentsonline.com/6826402.html)

4.2.1-Antenna Intermodulation Levels

This section gives an example on how to calculate the required specifications of the IM for the antenna. However, it is important to realize that it is relatively easy to compute -130 dBc; it is almost not possible to measure the -150dBc. (It is essential to keep in mind that at this circumstance the power of the IM product is 10^{-15} of the power of transmitter).

The difference between -130dBc and -150dBc is two orders of magnitude or factor of 100. At these stages, the measurement systems become very hard to maintain (this involves the cables connecting the antenna to test equipment). If the Rx have a sensitivity of -106dBm and the Tx have a power of 25 Watts (+44dBm) into the antenna, then any third order IM created in the antenna would require to be 150dB under the carrier (-106-44=-150dBc).This parameter is more typically set at - 140dBc, measured at a Tx level of 7 w (+38.5dBm). It is also very difficult to measure, as the measurement performance can establish as many IM as the antenna under test [34]..

The IM Order to be tested and the Transmit Power at which the test is performed are required to specify the antenna IM parameter. The Transmit power is required because there is not a linear relationship between absolute Transmit Power and the level of the resulting Intermodulation Product.

4.2.2 Frequency Planning and Antenna intermodulation avoidance

The frequency planning considers being a very complex procedure. The system designer have to symmetry differing requests, taking into account the limited offered frequencies, channel loading and attempting to maximise frequency re-use. In addition, possible **IM product** in the antenna must be taken into account.

To make the process of selecting channels for use on a particular site easier (in relation to antenna IM), the system designer can make use of equation (4.1). A maximum spacing between any two channels allowed on any one site is decided upon. This figure is used throughout the planning process to ensure that antenna intermodulation is avoided on any order up to and including the chosen order.

This is illustrated graphically in Figure 4.3 below. It shows how the intermodulation orders are distributed along the frequency line using the transmit separation '**s**'. It is clearly visible that not 7th order intermodulation will occur no matter which site-specific frequencies are used, provided that they are within the specified Tx bandwidth **[35].**

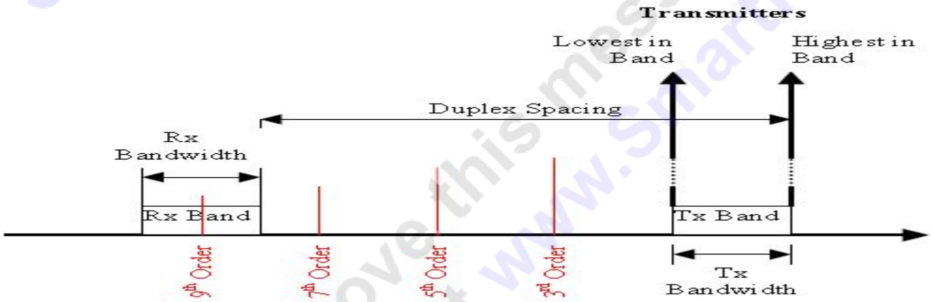


Figure 4.3-Show intermodulation orders are distributed along the frequency line
(Source from www.sigmawirelesscomms.ie/pdf_specs/Intermodulation_V3.pdf)

4.3- Transmitter and Receiver intermodulation

Both intermodulation (Transmitter and Receiver) are totally separate Incidents and always have to be healed at source. This means that if there is IM between two transmitters no quantity of filtering can affect a cure. Also vice versa is true.

This effect is illustrated in Figure 4 and Figure 5.

4. 3.1- Transmitter Intermodulation

Transmitter intermodulation is shown in Figure (4.4). Any receivers on either 140.0 MHz or on 140.3MHz will receive a signal on frequency, and demodulate them as signal. If mixing occurs in transmitter A, the received frequency will be 2B-A. To calculate the level of interference generated in this manner, the coupling between antennas should first be assessed (by measurement is best). When this is known it is possible to calculate what the equivalent transmit-power of the interference source is. If the Transmit power of Transmitter A is Tx dBw, and the inter-antenna isolation is Iso dB, then the Interfering source power will be:

Equation 4.2 Interference Source (dBw) = (Tx - Iso – 5) dBw

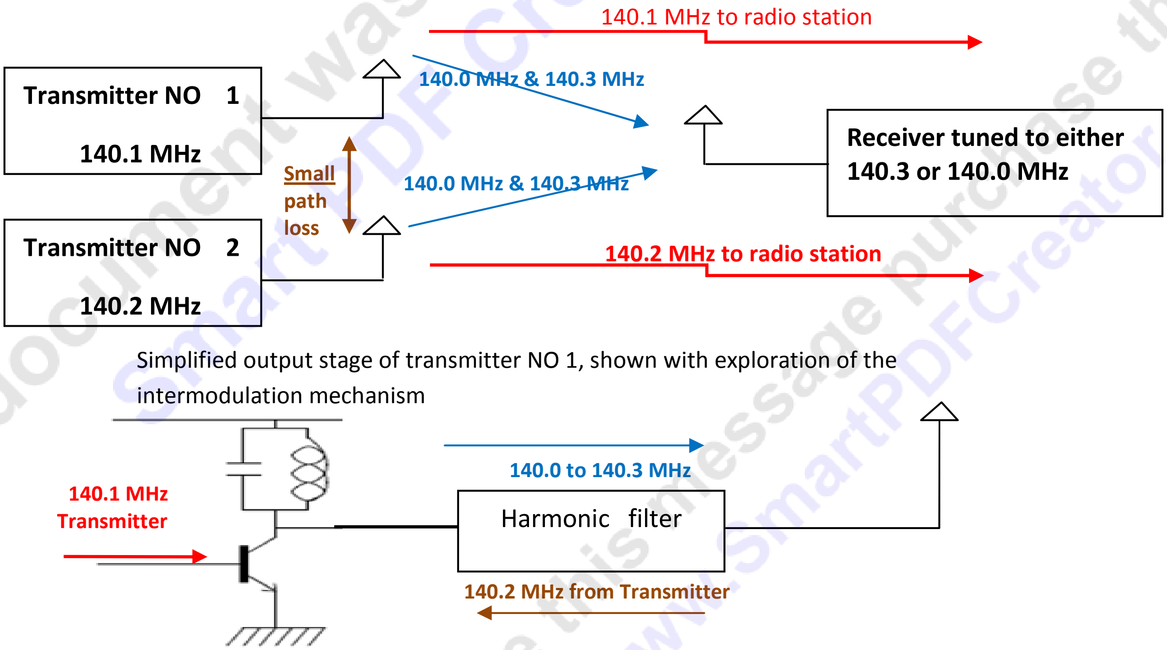


Figure 4.4 – Transmitter Intermodulation

Two frequencies mix at the collector of the transistor. The 140.2MHz coming into the output from the antenna will intermodulate with the 140.1MHz frequency of the drive to the transistor, and be fed back out to the antenna at 2*140.2 – 140.1 = 140.3 MHz.

This source of interference is an equivalent transmitter with this power at the end of the cable leading to the antenna number1. The equivalent conversion loss in a transmitter is about typically about 5dB (antenna isolation expression used to assist in estimating isolation if measurements are not available).

It will also mean that any receiver on this frequency will receive the modulation of transmitter A at its normal deviation, or of transmitter B at twice its normal deviation. The capture effect means that the receiver will demodulate the signal with the higher deviation, so it will demodulate the B transmitter's modulation. One cure for this type of intermodulation is to add an isolator (circulator) in series with each transmitter output. However, since an isolator is by definition non-linear, it will in itself produce intermodulation products.

4.3.2 Receiver Intermodulation

In Figure 4.5 receiver intermodulation is illustrated. In this example when the signals impinging on the receiver are within 20dB and both signals are above the intermodulation specification of the receiver, mixing will occur in the front end and/or the mixer.

In Figure 4.5 intermodulation of receiver is illustrated. In this example, when signals that impinge on the receiver within 20dB and both signal which above the intermodulation pattern of the receiver, mixing will occur in the front-end and / or in a mixer This intermodulation product will appear to the rest of the receiver as an on-frequency signal and be received as such. The best solution to such problems is to install a band-pass filter in front of the receiver. If the system uses a duplexer, it is best to use a bandpass duplexer to prevent issues such as this from arising.

RF amplifier and mixer are both non linear at high amplitudes, causing mixing of 140.1 and 140.2MHz,giving 140.3 MHz, which in turn mixes with local oscillator, giving 10.7MHz**.**

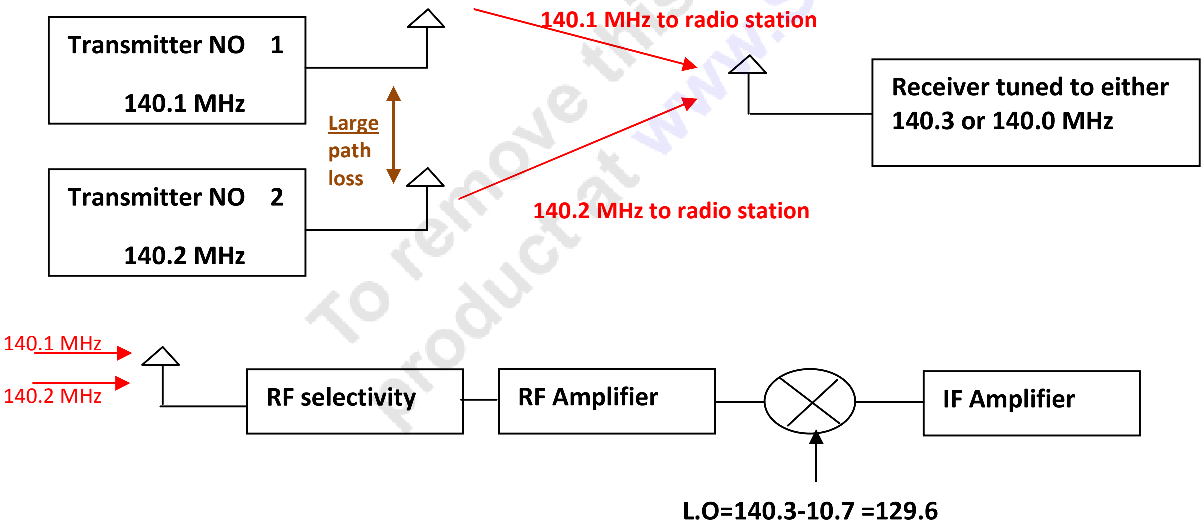


Figure 4.5 – Receiver Intermodulation

4.4-Antenna Isolation

The electromagnetic compatibility (EMC) trouble of electrically big targets is mathematically very demanding. The mutual coupling effects between antennas and platforms play a very significant role in the areas of EMC. They will vary the input impedance of each antenna, cause power to be reflected to the feed structures, and affect the antenna radiation patterns and polarization, which may degrade the antenna performance and cause electromagnetic interference problems in communication systems. Therefore, computing the isolation between antennas is a crucial issue and should be taken into account before mounting antennas. This part will introduce two methods to calculate the isolation spaced antenna: **First method** is Isolation between spaced antennas (using calculation). **Second method** is Isolation between spaced antennas (using measurement).

4.4.1- Isolation between spaced antennas (using calculation)

There are various numerical analysis techniques have been used for the electromagnetic compatibility problems of electrically great targets (to calculate the isolation between antennas). MOM (method of moment), a universal and dependable low-frequency method, has substandard efficiency when electrically large complex targets are analyzed. The high-frequency methods, such as PO (physical optics), GTD (The geometrical theory of diffraction) and UTD (The uniform geometrical theory of diffraction), is accurate relatively for the wave band above 1 GHz. In addition, all the algorithms above are frequency-domain analysis so that too multiple calculation is needed when sweeping frequency is essential. FDTD (Finite-Difference Time-Domain) is a powerful numerical technique, which is currently used for the analysis of a wide variety of EM field problems such as radiation and scattering of electromagnetic field, antenna isolation where it has achieved greatly successful applications **[36]**.

All the techniques mentioned above for mutual coupling between antennas was used to predicate the antenna coupler between antennas on ship and aircraft. Since this work need many complicated processes written in different program format such as FORTRAN and C++ language, in this project I will use another method to calculate the isolation between antenna according to (TAIT Company and Sigma Wireless Company).

Method used in this project

To operate a VHF repeater system at maximum gain, the antennas in a repeater system must be adequately isolated from each other to prevent system oscillation. The most common, and least expensive, method of isolation is to install the antennas some distance from each other using simple equation. Since most installations are on a common tower, the antennas are usually mounted so that they are vertically separated from one another. This Calculation provides with an estimate of the isolation between antennas isolated vertically. At best, it is only an estimate and the radiation pattern will affect the final result. These calculations only apply to antennas in the same frequency range. The isolation increases significantly as soon as the two antennas go 'out of band'.

Care must be taken when evaluating a strong isolation between antennas on the towers. Experiment shown that the maximum value of the isolation which can realistic is about 70dB.Different combinations of values entered on the form could result in isolation values much larger. In the example below, an Omni and a panel are shown on a mast (figure 4.6). In this project assumed that both patterns have deep nulls along the vertical axis and this will minimizes the coupling between the two antennas. As the antennas are not significantly 'out of line', so the horizontal isolation has not account. The gain of the antennas will also affect the isolation by a small amount, but this is never taken into account in the formulas **[29]**.

Isolation between vertical Spaced Antennas

To determine how much isolation a particular distance will provide, the following formula is used:

Equation 4.2 $$\text{Isolation} = 28 + 40 * \text{Log}(D_v / \lambda)$$

Where

D_v - Vertical Distance between Antennas

λ – Wavelength

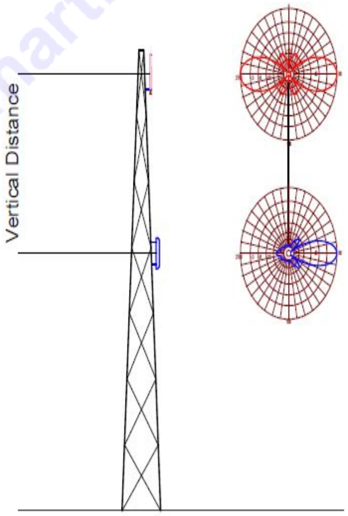


Figure (4.6) –show Omni and a panel antennas mount on a mast

(Source from wirelessapplications.com/pdf/lf/Ant_Iso.pdf)

The figure (4.7) below demonstrates the vertical technique used to fix the antenna on the mast or tower, as well horizontal and Echelon technique.

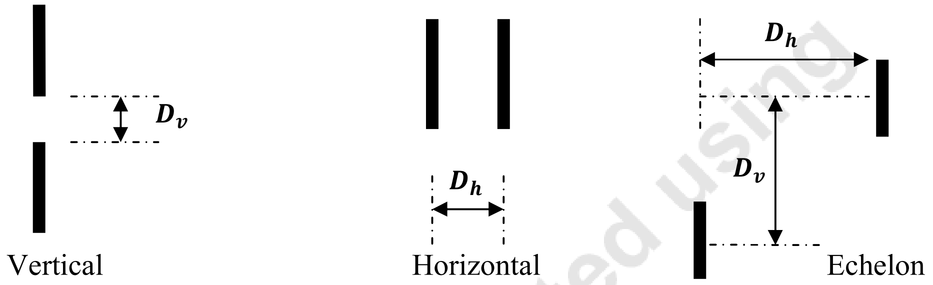


Figure (4.7)-show three different technique of antenna install

<u>Isolation between Horizontally Spaced Antennas</u>

-To determine how much horizontal isolation, the following formula is used:

Equation 4.3 $$horizontal\ isolation(L_H) = 22 + 40 \square log \frac{D_H}{\lambda} - (G_t + G_r) \text{ in dB}$$

Where $\lambda = C/F$ & D_H =Horizontal distance between antenna

<u>Echelon isolation (linear interpolation between L_H and L_v as a function of angle) in dB,</u>

-To determine how much echelon isolation, the following formula is used:

Equation 4.4 $$\text{Echelon isolation} = L_H + (L_v - L_H) \square \left(\frac{2\tan^{-1}\frac{D_v}{D_H}}{\pi}\right) \text{ in dB}$$

4.4.2- Isolation between spaced antennas (using experiment)

The Electronic Research Institute (ERI) has carried out a series of tests for radio interference from warships and from airplanes. During the test, ERI measured transmitter-to-receiver isolation level on the aircraft and warship according to the distance between antenna and evaluated the impact in the laboratory. This part gives brief discussion about the test method used and the results investigated. Also, this value was compared to isolation between spaced antennas (using calculation).

<u>Isolation between spaced antennas on the "Aircraft"</u>

During this test, 4 antennas are mounted on aircraft and the antenna isolation is measured between airborne transceiver test equipment on the aircraft. The aircraft has two antennas at top-front and bottom-after, and another two VHF antennas. The isolation level was measured with a network analyzer, Advantest connector, connected with each antenna port when the aircraft was on the ground. Measured frequencies were 113 up to 162 MHz. Most of them are those assigned for voice communications. Next, that the measurement result of the antenna isolation was recorded. The isolation levels are 28 dB minimum and 36 dB maximum for same side antennas (distance was between 3-6 m) , 39 dB minimum and 56 dB maximum for opposite side antennas(distance was between 6-10 m) **[37].**

Isolation between spaced antennas on the "Warships"

During this test, two monopoles are mounted on the warship and the position on the top. The radiation patterns are calculated. The isolation is measured from 112 MHz to 154 MHz. The isolation curve shown that the isolation between antennas is:

Isolation was between 20- 30 dB from 112 MHz to 154 MHz at near distance (2m-5 m)
Isolation was between 40- 50dB from 112 MHz to 154 MHz at far distance (6m-12m)

To conclude, antenna-to-antenna mutual coupling on warship and aircraft can be predicted by numerical analysis techniques with reasonable accuracy. Confidence in the analysis technique was obtained by comparing predictions to measurements. Overall, mutual coupling between antennas on warship and aircraft were used as reference guide in this project **[38].**

CHAPTER 5

Method of Performing Antenna Cosite Analysis using Intermodulation Technique

5.0--Introduction

Antennas for wireless communication system are often positioned on towers to improve the operating distance of the system VHF and UHF radio , and mobile telephone are just a few examples of wireless systems that utilize tower-mounted antennas .

When multiple transmitters, receivers, and antennas located on tower several type of interference may occur. **Intermodulation** occur when the RF signal from one transmitter at the site leaks into other transmitter or receiver at site causing intermodulation products to be generated. If the intermodulation products occur in transmitter, they may escape from transmitter and cause interference in the receiver at the site. Another type of interference occurs when noise from transmitter at the site interferes directly with the receivers at the site.

Analysis technique has been used that predict the extent of interference between transmitters and receivers at shared radio site. Such analysis technique is described, for example, in the chapter 3 “Cosite Analysis Model”.

In this part, the computation of intermodulation interference will describe with respect to typical antenna site containing ⍰ number of transmitters and β number of receivers (figure 5.1). Also, Example to calculate the intermodulation interference between 3 transmitters and 2 receivers will examine by two methods**:** Mathematical Method and Program Method(matlab).

5.1-Technique used for performing antenna cosite analysis using intermodulation

The technique relates to a process for determining intermodulation interferences between transmitters and one or more receivers. The process comprises the following steps of **[39]**:

First step

At each transmitter, determining a minimum susceptibility to interference of the receivers, to do that, we need to involve these points: 1-To determine the minimum susceptibility to interference of the one or more receiver at each transmitter the system determines the susceptibility of each receiver at victim transmitter and then determines the minimum of susceptibility of one or more receivers.

$\boldsymbol{S_{minT1}}$ = **min** $(\boldsymbol{S_{R1,,T1}} \ldots .\boldsymbol{s_{R\beta,T1}})$, S_{minT1} is most susceptible receiver to interference at TX1

2-To determine the susceptibility of each receiver at the victim transmitter the system subtracts the coupling loss between the receiver and victim transmitter from susceptibility to interference of the receiver at receiver. $\boldsymbol{S_{R\beta,T1} = S_{R\beta} - C_{R\beta,T1}}$

Where $S_{R\beta}$ is the susceptibility to interference of receiver RX_{β} and $S_{R\beta,T1}$ is the coupling loss between the victim transmitter TX_1 and receiverRX_{β}, and coupling loss is $C_{R\beta,T1}$.

3-The coupling loss $C_{R\beta,T1}$ between victim transmitters TX_1 and receiver RX_{β} is determined as shown in **figure (5.1)** by summing the coupling loss, at frequency of RX_{β}, between RX_{β} and it's antenna $A_{R\beta}$, between $A_{R\beta}$ and the antenna of the transmitter A_{T1}.

4- Determining the susceptibility of the receiver involves determining the noise level at receiver by subtracting the carrier-to-noise ratio (C/N) of receiver from usable sensitivity of the receiver, and then subtracting 6 dB from noise level at receiver. Value of 6 dB is sufficient to cause a 1dB change in the noise floor, from the noise level to get susceptibility.

Noise level at Rx = Usable Sensitivity – C/N ratio

Susceptibility = Noise level at receiver – 6 dB

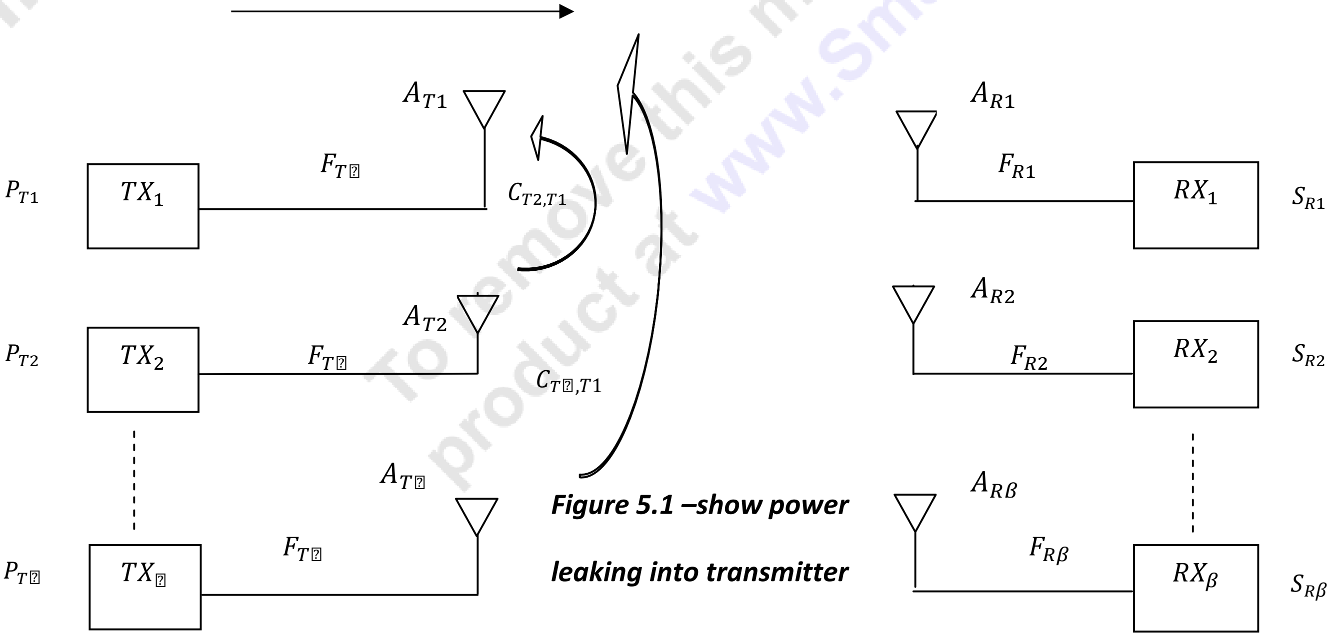


Figure 5.1 –show power leaking into transmitter

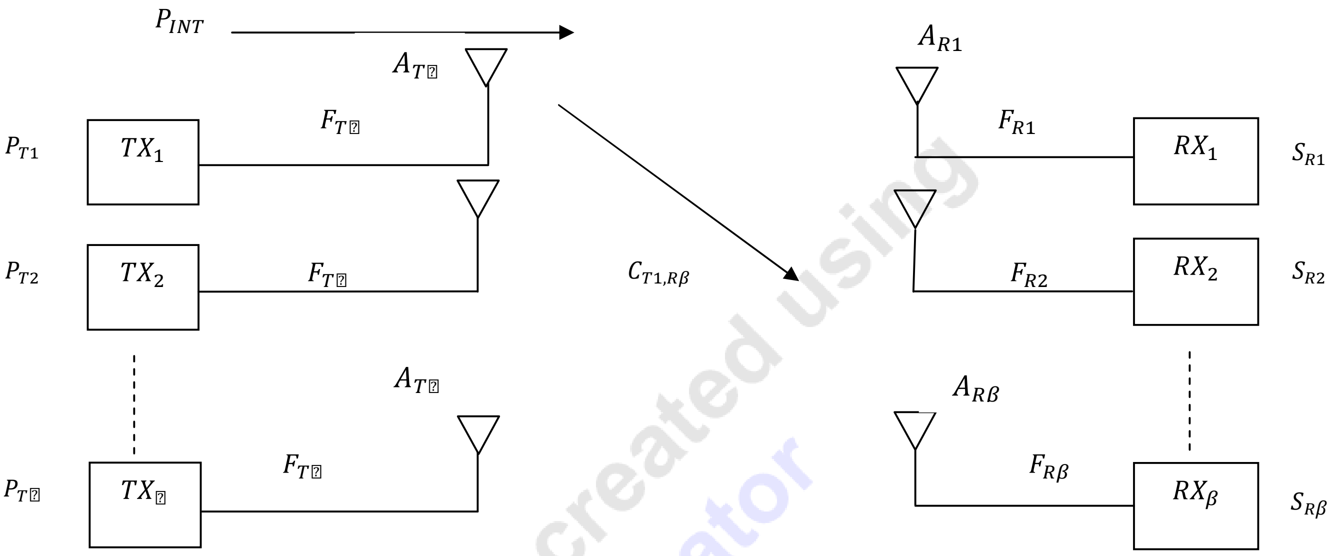


Figure 5.2 –show power of intermodulation at Victim Transmitter

Second step

individually considering each transmitter as victim transmitter paired with each other transmitter , and for each such other transmitter–victim transmitter pair , determining from lowest order up to highest order intermodulation product (the highest order here assumed to give the minimum leakage transmitter and lowest order assumed to give maximum leakage of transmitter) generated as result of interference between the victim transmitter and other transmitter with power level sufficient to exceed the minimum susceptibility of one or more receivers at victim transmitter ,and then each the order intermodulation product for each other transmitter victim pair put in specific matrix **[40]** .

-The process mentioned above started with lowest order intermodulation products, i.e 2nd order, and then order is increased. For a transmitter TX2 interferening with a victim transmitter TX1, the interference power $P_{\mathrm{INT\ at\ TX1}}$ at TX1 is calculated as follows

$$P_{\mathrm{INT\ at\ TX1}} = L_{\mathrm{T2,T1}} + \text{conversion loss (order)}$$

Where $L_{\mathrm{T2,T1}}$ is the leakage power between transmitter TX2 and Victim transmitter TX1, conversion loss is take from table of values used to calculate losses for different intermodulation order, and order is the order of intermodulation product. $L_{\mathrm{T2,T1}}$ is determined using the following equation which has been previously described

$$L_{T2,T1} = P_{T2} - C_{T2,T1}$$

Where P_{T2} is the power of TX2 and $C_{\mathrm{T2,T1}}$ is the coupling loss from TX2 to TX1 at frequency TX2

- After we got the power level of intermodulation product from equation above, the power level of each intermodulation product for each transmitter-victim transmitter pair is compared, in increasing order, to susceptibility of most susceptible receiver at the victim transmitter to susceptible receiver at victim transmitter.

-If the value of S_{minT1} (most susceptible receiver) <$P_{INT\ at\ TX1}$ (Order), the highest order that passes the comparison for each transmiiter-victium transmitter pair is the highest order that need to be calculated between transmitter pair .This process is repeated for each transmitter-victim transmitter pair, and the result is put in the matrix .A sample matrix for a sit with transmitter TX1, TX2 and TX3 is shown below:

Interfering transmitter	Victim transmitter		
TX IM	TX A	TX B	TX C
TX A	-	**?**	?
TX B	?	-	?
TX C	?	?	-

Third step

Determines an intermodulation product frequency F_{INT} and an intermodulation product bandwidth BW_{INT} as follows:

F_{INT}=$M_1 x F_{T1} \pm M_1 x F_{T2} \ldots\ldots\ldots\ldots \pm M_{\square} x F_{T\square}$

BW_{INT}=$M_1 x BW_{T1} \pm M_1 x BW_{T2} \ldots\ldots\ldots\ldots \pm M_{\square} x BW_{T\square}$

Where [M_1, $M_{2,}M_{3,}M_{4,}$, $M_{1,}$...] are positive integers

Fourth step

After determining the intermodulation product frequencyF_{INT} and intermodulation product bandwidth BW_{INT} , then compares each intermodulation product frequency to frequency band of each receiver to determine if intermodulation product falls within the frequency band of any receiver. Next, identify interfering intermodulation product, which are intermodulation product with frequency falling within the band of one of receivers and determines the power of the each interfering intermodulation product at victim transmitter $P_{INT\ at\ TX}$ as follows:

$$P_{INT\ at\ TX} = L_{min} + \text{conversion loss (order)}$$

Where L_{min} is minimum leakage power of interfereing transmitter at victim transmitter.

$$L_{min} = min\ (L_{T2,T1}, \ldots\ldots L_{T\square,T1})$$

For each interfering intermodulation product, determines the intermodulation product power level $P_{\mathrm{INT\ at\ RX}}$ at victim receiver Rx by summing the losses in coupling $C_{T1,R\beta}$ between the victim transmitter and victim receiver Rx:

$$P_{INT\ at\ RX} = P_{INT\ at\ TX} + C_{T1,R\beta}$$

Finally step

Comparing intermodulation IM Product with susceptibility of victim receiver, if the intermodulation product power level $P_{\mathrm{INT\ at\ RX}}$ at receiver R_{β} is greater than susceptibility of victim receiver $S_{R\beta}$,then interference is caused at receiver. If not, no interference will occur.

5.2- Flowchart Technique

To understand how the method calculates intermodulation interference between the Receiver and Transmitter, for both systems, the program flow chart is illustrated through the next page in Figure 2.1. A more rigorous matlab program flow, with more details, is given in Appendix A.

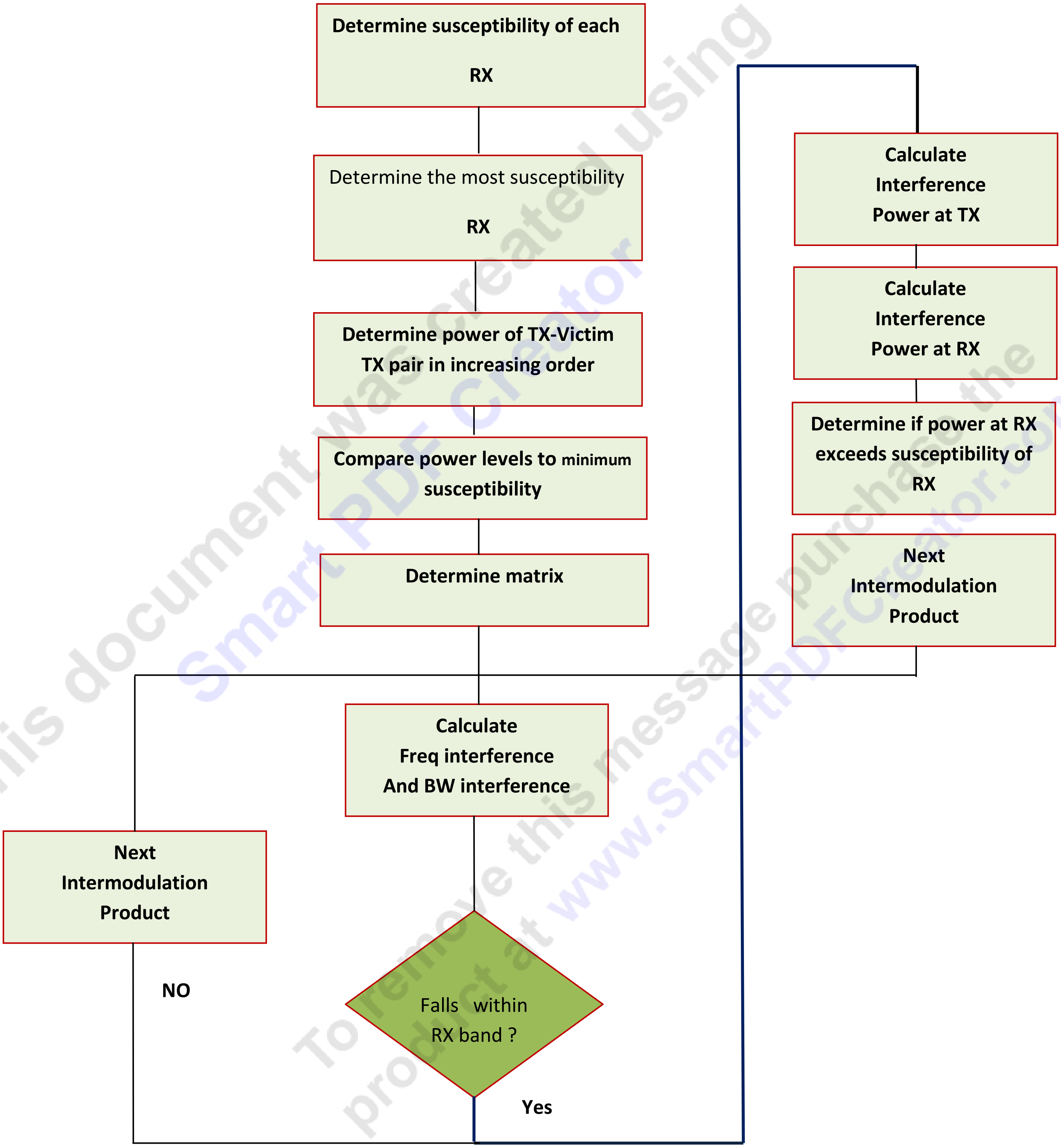
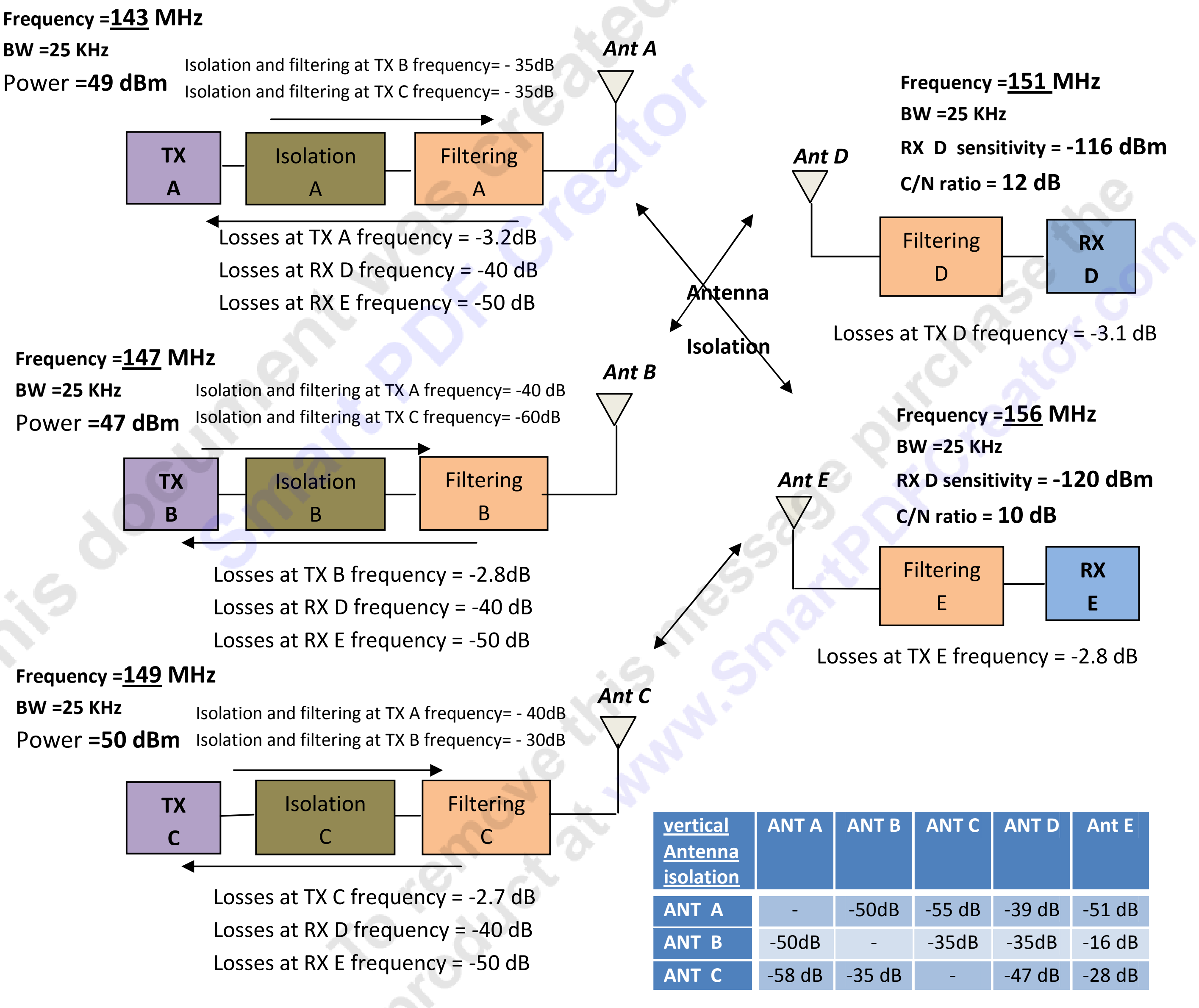


Figure 5.3 Flowchart illustrates the process used to determine either the intermodulation cause interference or No.

5.3- Example and method used

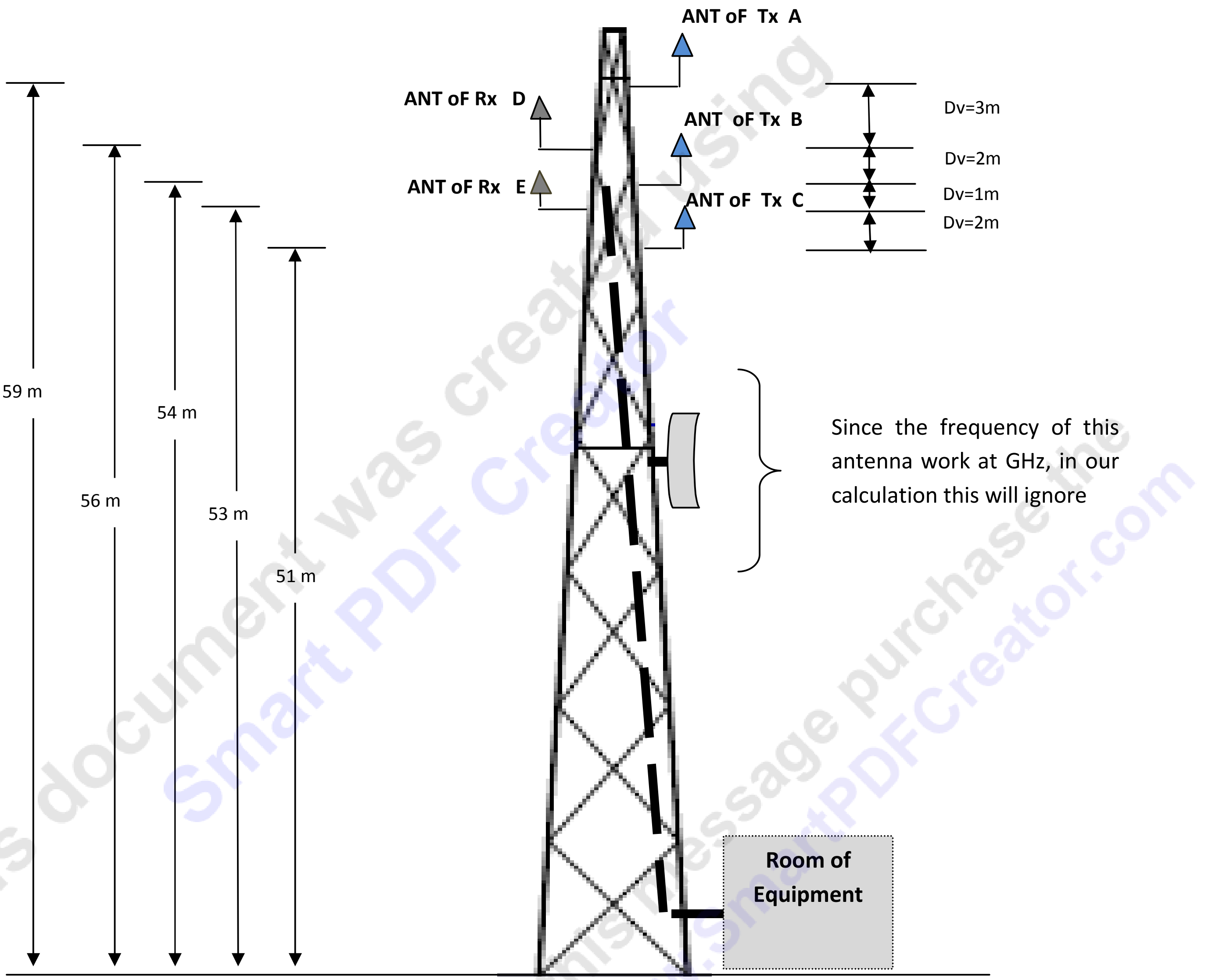
Technique used for performing antenna cosite analysis using intermodulation described above will now be applied with respect to the example of figure (5.4)which involve the specification of transmitters(TX A, TXB and TXC,) receivers (RX D , RX E), and antennas (ANT A, ANT B, ANT C, ANT D and ANT E) used in example.



vertical Antenna isolation	ANT A	ANT B	ANT C	ANT D	Ant E
ANT A	-	-50dB	-55 dB	-39 dB	-51 dB
ANT B	-50dB	-	-35dB	-35dB	-16 dB
ANT C	-58 dB	-35 dB	-	-47 dB	-28 dB

Figures (5.4) - Show block diagram and table of the process for determining intermodulation interference in transmitter.

Figure (5.5) -Show the design structure of tower and antennas as it is.



<u>Specification of base stations, analysis and measurement system</u>

There are two main points are necessary to know before starting evaluates our example:

- Specification of the base stations (See appendix A)
- Analysis and measurement :(See appendix B) - This will involve evaluate cable loss, evaluate the isolation between antenna, Conversion loss and isolation and filtering loss.

Victim Transmitter A

Step1- calculates the most susceptible receiver at transmitter TX A. [Figure (5.6)]

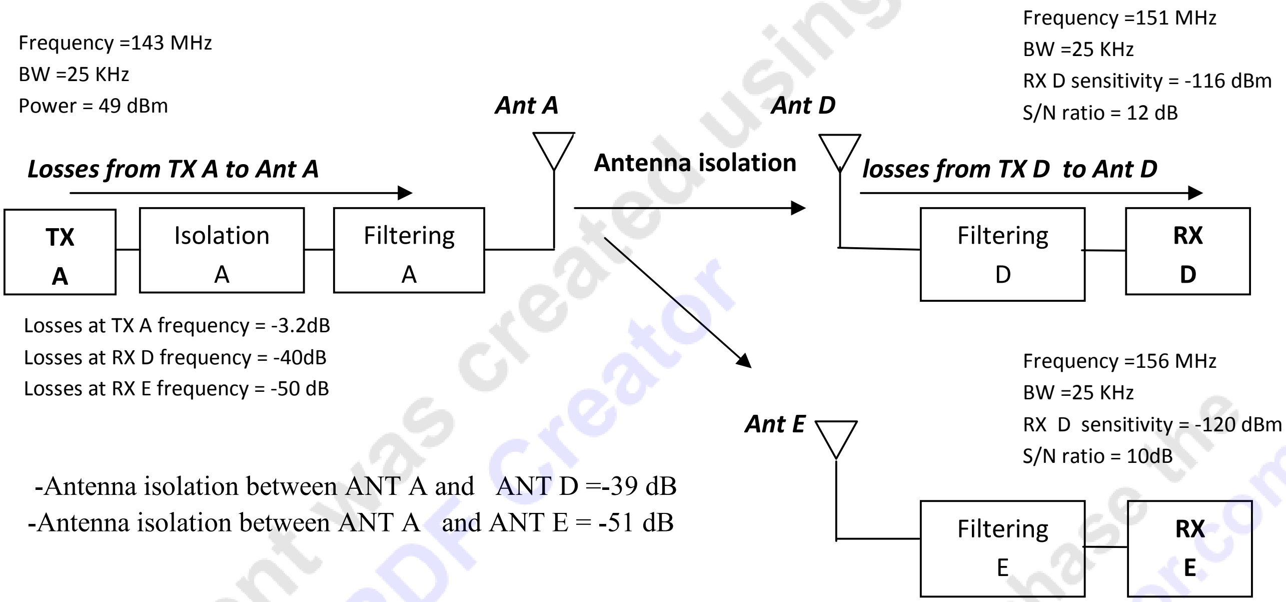


Figure- 5.6-power of intermodultion at victim Transmitter A

a) Susceptible of RX D = Sensitivity of RX D- S/N ratio – 6 dB
= -116 dBm- 12- 6 = -134 dBm

b) Susceptibility of RX D at TX A = Susceptible of RX D – losses from ANT D to RX D at frequency of RX D – Antenna isolation between ANT A and ANT D at frequency of RX D – losses from TX A to ANT A at frequency of RX D
= -134 dBm-(-3.1dB)-(-39dB)-(-40dB) = -51.9≈ -52dBm

c) Susceptible of RX E = Sensitivity of RX E- S/N ratio – 6 dB
= -120 dBm- 10- 6 = -136 dBm

E) Susceptibility of RX E at TX A = Susceptible of RX E – losses from ANT E to RX E at frequency of RX E – Antenna isolation between ANT A and ANT E at frequency of RX E – losses from TX a to ANT A at frequency of RX E
= -136dBm-(-2.8dB)-(-51dB)-(-50dB) = -32.2≈ -32dBm

F) Most Susceptible of RX at TX A = min (of all susceptibilities)

= min (-52 dBm, -32dBm) = ***<u>-52dBm</u>***

Step 2 – for the first other transmitter at site (TX B) the leakage power was calculated and compared to the most susceptible receiver (-52dBm). [Figure (5.7)]

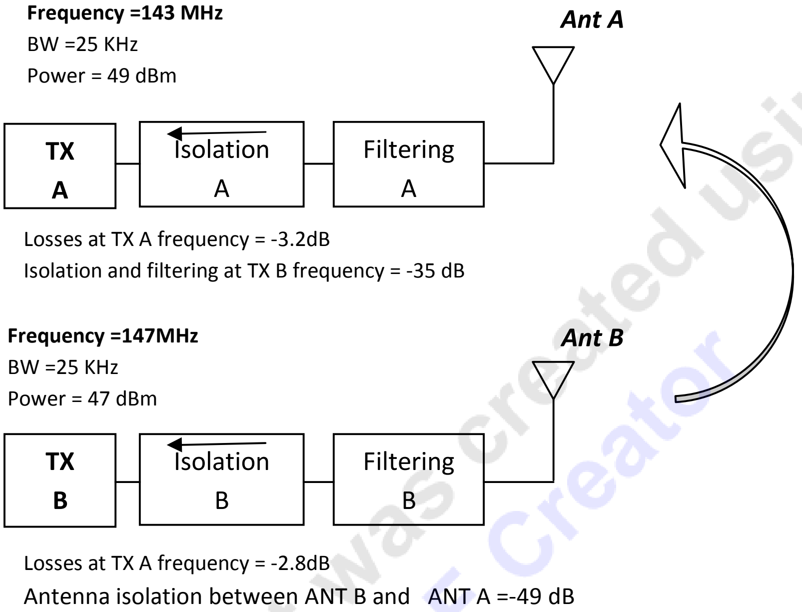


Figure -5.7

Power leaking from TX B to TX A

a) Leakage power of TX B at TX A= power of TX B– losses from TX B at ANT B at frequency of TX B – Antenna isolation from ANT B to ANT A at frequency of TX B – losses from filtering and isolation from ANT A to TX A at frequency of TX B
= 47 dBm – 2.8 dB -49dB-35 dB = -39.8dBm ≈ **-**40 dBm

b) Find from lowest order up to highest order that could cause interference

-calculate Intermodulation level = leakage power + Conversion loss (order)
-This process will repeat until (Intermodulation level < most susceptible RX).

Next, possible of TX IM could determine by (possible TX IM = order -1).

Intermodulation level
= leakage power + Conversion loss(2nd order)=-40 dBm+(-7) dBm= -47dBm>-52dBm
= leakage power + Conversion loss(3nd order)=-40 dBm+(-10)dBm= -50dBm>-52dBm
= leakage power + Conversion loss(4nd order)=-40 dBm+(-20)dBm= -60dBm<-52dBm

Since last process satisfied that interrmodulation level less than susceptible receiver at Conversion loss (4nd order), this value subtract from one to determine number of TXIM. Also TXIM can evaluate directly by account number of repeated process.

So as result the possible TXIM = 4-1= ***<u>3order</u>***

TX IM matrix			
TX IM	TX A	TX B	TX C
TX A	-	**3**	?
TX B	?	-	?
TX C	?	?	-

Step 3 – for the second other transmitter at site (TX C) the leakage power was calculated and compared to the most susceptible receiver (-52 dBm). [Figure (5.8)]

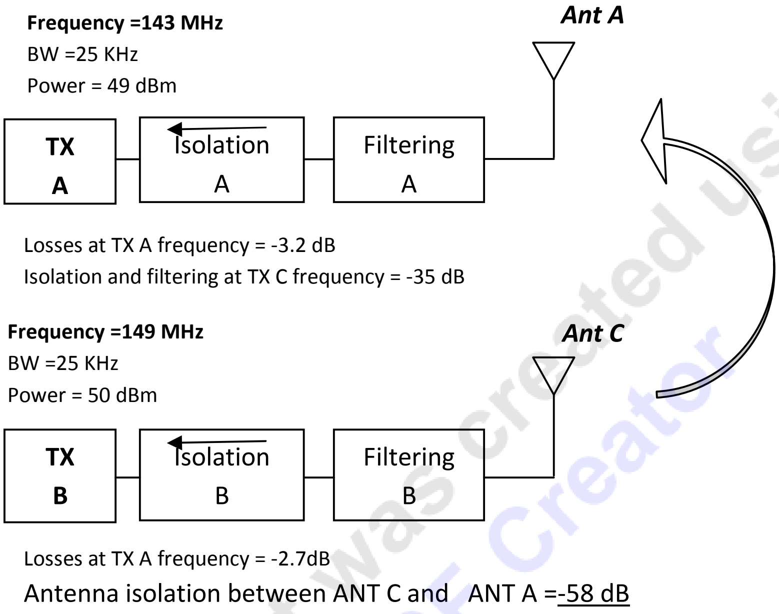


Figure -5.8

Power leaking from TX C to TX A

a) Leakage power of TX C at TX A =power of TX B –losses from TX C at ANTC at frequency of TX C – Antenna isolation from ANT C to ANT A at frequency of TX C – losses from filtering and isolation from ANT A to TX A at frequency of TX C
= 50 dBm – 2.7 dB -58 dB-35dB = -45.7≈ − 46dBm

b) Find from lowest order up to highest order that could cause interference
-calculate Intermodulation level = leakage power + Conversion loss (order)

-This process will repeat until (Intermodulation level < most susceptible RX).Next,

Intermodulation level
= leakage power + Conversion loss(2nd order)=-46 dBm+(-7) dBm= -53dBm<-52dBm

Since that intermodulation level will not affect on TX, as result the possible TX IM = 0

(Because the value of susceptible receiver greater than intermodulation level).

TX IM matrix			
TX IM	TX A	TX B	TX C
TX A	-	**3**	**0**
TX B	?	-	?
TX C	?	?	-

Victim Transmitter B

Step4- calculates the most susceptible receiver at transmitter TX B. [Figure (5.9)]

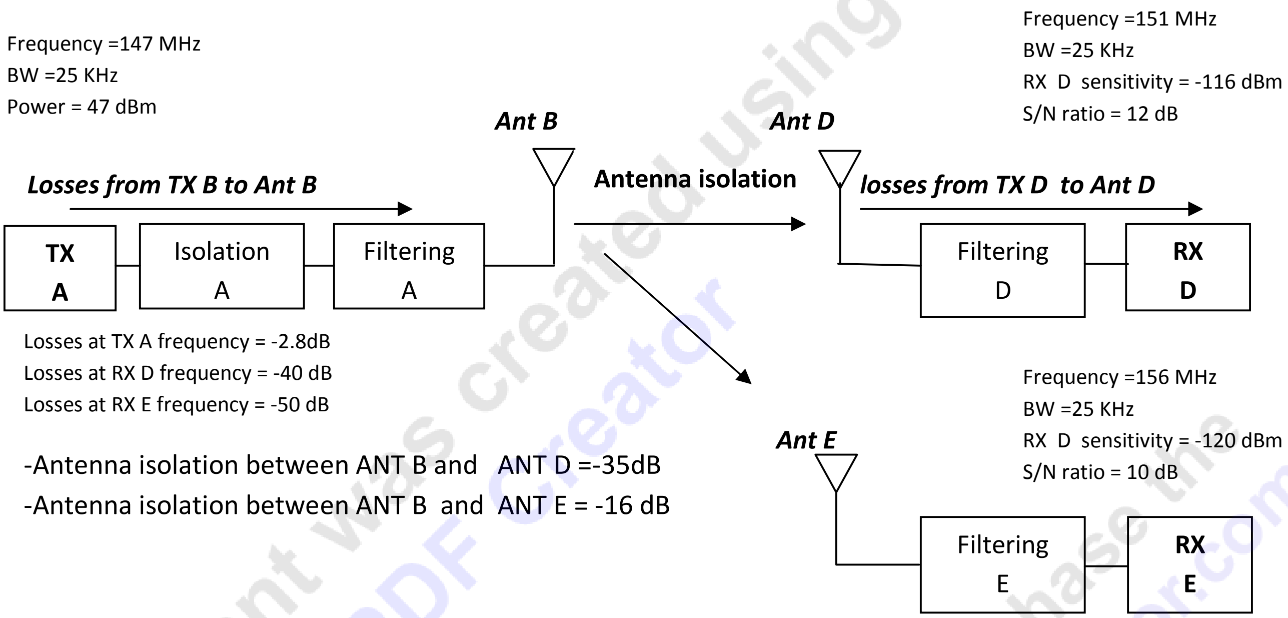


Figure -5.9- power of intermodultion at victim Transmitter B

a) Susceptible of RX D = Sensitivity of RX D- S/N ratio – 6 dB
= -116 dBm- 12- 6 = -134 dBm

b) Susceptibility of RX D at TX B= Susceptible of RX D – losses from ANT D to RX D at frequency of RX D – Antenna isolation between ANT B and ANT D at frequency of RX D – losses from TXB to ANT B at frequency of RX D
= -134 dBm-(-3.1dB)-(-35dB)-(-40dB) = -56.1dBm ≈ -56 dBm

c) Susceptible of RX E = Sensitivity of RX E- S/N ratio – 6 dB
= -120 dBm- 10- 6 = -136 dBm

d) Susceptibility of RX E at TX B = Susceptible of RX E – losses from ANT E to RX E at frequency of RX E – Antenna isolation between ANT B and ANT E at frequency of RX E – losses from TX B to ANT B at frequency of RX E
= -136dBm-(-2.8dB)-(-16dB)-(-50dB) = -67.2≈ -67 dBm

e) Most Susceptible of RX at TX B = min (of all susceptibilities)
= min (-56 dBm, -67dBm) = ***-67dBm***

Step5 **–** for the first other transmitter at site (TX A) the leakage power was calculated and compared to the most susceptible receiver (-67dBm). [Figure (5.10)]

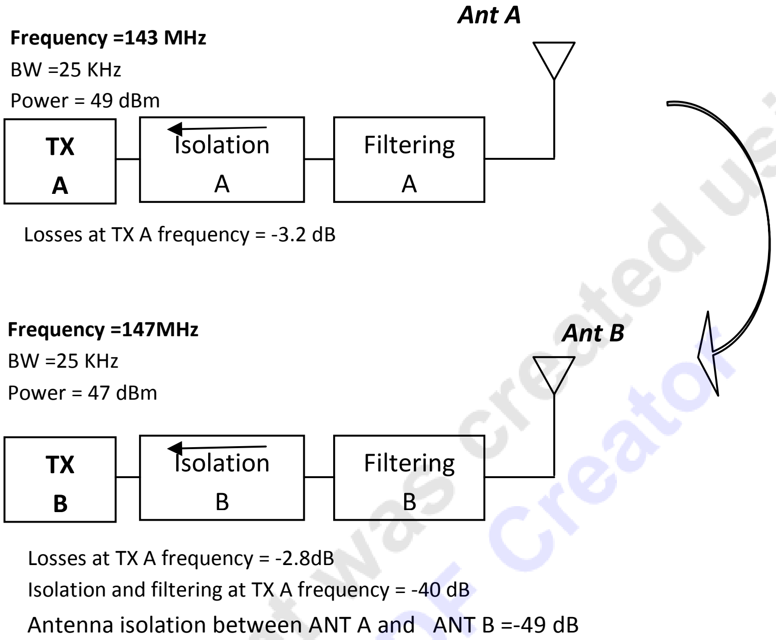


Figure -5.10

Power leaking from TX A to TX B

a) Leakage power of TX A at TX B =power of TX A –losses from TX A at ANT A at frequency of TX A – Antenna isolation from ANT A to ANT B at frequency of TX A – losses from filtering and isolation from ANT B to TX B at frequency of TX A

= 49 dBm – 3.2 dB -49 dB-40 dB = **-**43.2 ≈ -43dBm

b) Find from lowest order up to highest order that could cause interference

-calculate Intermodulation level = leakage power + Conversion loss (order)
- Possible TX IM = order -1

Intermodulation level
= leakage power + Conversion loss(2nd order)=-43 dBm+(-7) dBm= -50dBm>-67dBm
= leakage power + Conversion loss(3nd order)=-43 dBm+(-10)dBm= -53dBm>-67dBm
= leakage power + Conversion loss(4nd order)=-43 dBm+(-20)dBm=-57dBm>-67dBm
= leakage power + Conversion loss(5nd order)=-43 dBm+(-30)dBm=-73dBm<-67dBm

Since last process satisfied that intermodulation level less than susceptible receiver at Conversion loss (5nd order), this value subtract from one to determine number of TXIM. Also TXIM can evaluate directly by account number of repeated process.

.

TX IM matrix			
TX IM	TX A	TX B	TX C
TX A	-	**3**	?
TX B	?	-	?
TX C	?	?	-

So as result the possible TX IM = 5-1= ***4 order***

Step 6 – for the second other transmitter at site (TX C) the leakage power was calculated and compared to the most susceptible receiver (-67dBm). [Figure (5.11)]

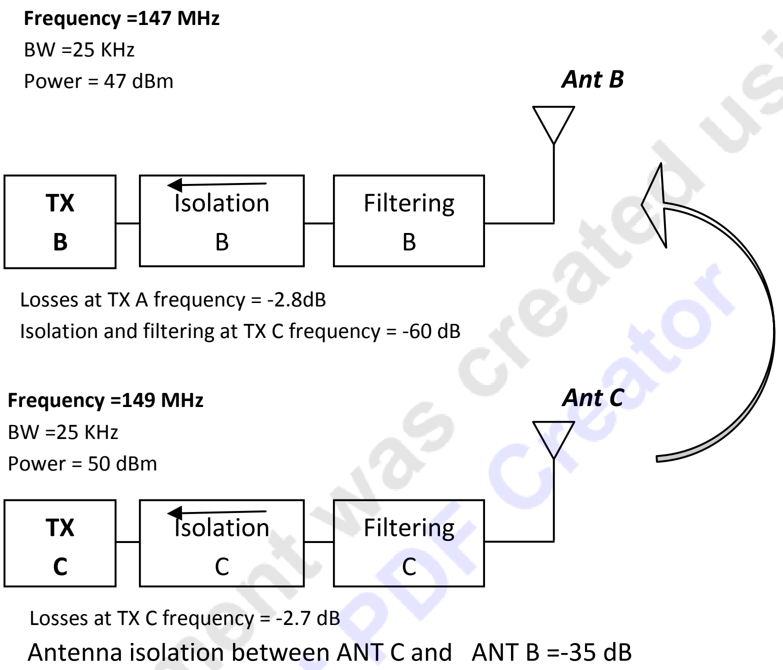


Figure -5.11

Power leaking from TX C to TX B

a) Leakage power of TX C at TX = power of TX C –losses from TX C at ANTC at frequency of TX C – Antenna isolation from ANT C to ANT B at frequency of TX C – losses from filtering and isolation from ANT C to TX C at frequency of TX B
= 50 dBm – 2.7 dB -35 dB-60 dB = -47.7≈ -48dBm

b) Find from lowest order up to highest order that could cause interference

-calculate Intermodulation level = leakage power + Conversion loss (order)
- Possible TX IM = order -1

= leakage power + Conversion loss(4nd order)=-48 dBm+(-7)dBm= -55dBm>-67dBm
= leakage power + Conversion loss(4nd order)=-48 dBm+(-10)dBm= -58dBm>-67dBm
= leakage power + Conversion loss(4nd order)=-48 dBm+(-20)dBm= -68dBm<-67dBm

So as result the possible TX IM = 4-1= 3 order

TX IM matrix			
TX IM	TX A	TX B	TX C
TX A	-	**3**	**-**
TX B	4	-	3
TX C	?	?	-

Victim Transmitter C

Step7- calculates the most susceptible receiver at transmitter TX C. [Figure (5.12)]

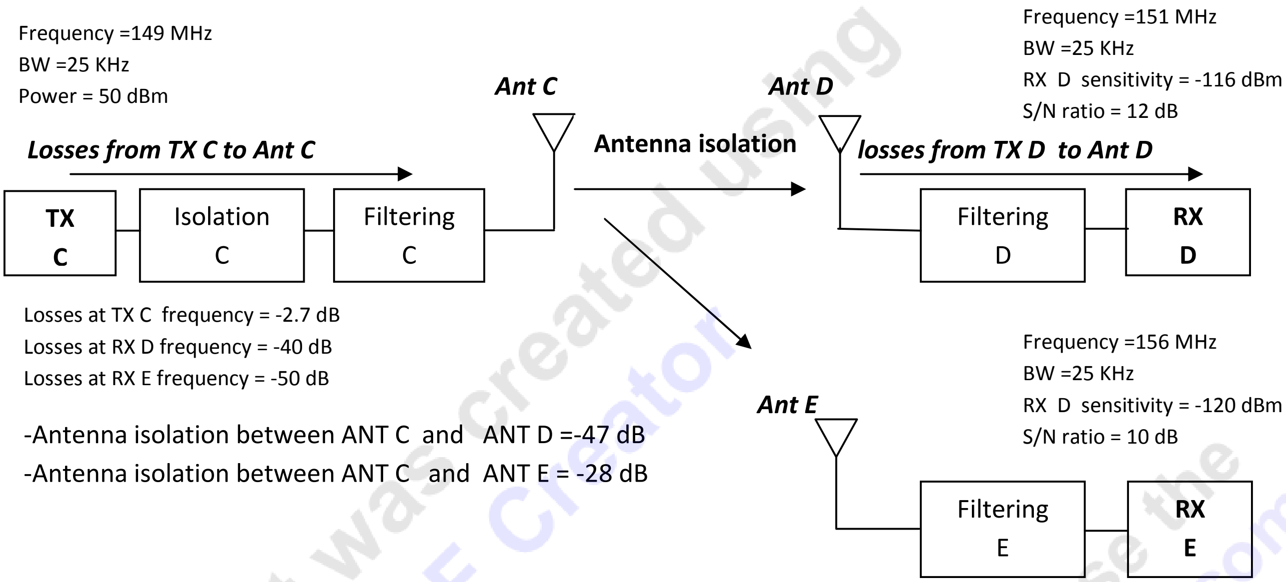


Figure -5.12- power of intermodultion at victim Transmitter C

a) Susceptible of RX D = Sensitivity of RX D- S/N ratio – 6 dB
= -116 dBm- 12- 6 = -134 dBm

b) Susceptibility of RX D at TX C= Susceptible of RX D – losses from ANT D to RX D at frequency of RX D – Antenna isolation between ANT C and ANT D at frequency of RX D – losses from TX C to ANT C at frequency of RX D
= -134 dBm-(-2.7dB)-(-47dB)-(-40dB) = -44.3dBm ≈ -44 dBm

c) Susceptible of RX E = Sensitivity of RX E- S/N ratio – 6 dB
= -120 dBm- 10- 6 = -136 dBm

d) Susceptibility of RX E at TX B = Susceptible of RX E – losses from ANT E to RX E at frequency of RX E – Antenna isolation between ANT C and ANT E at frequency of RX E – losses from TX C to ANT C at frequency of RX E
= -136 dBm-(-2.8dB)-(-28dB)-(-50dB) = -55.2dBm ≈ -55dBm

e) Most Susceptible of RX at TX B = min (of all susceptibilities)
= min (-44 dBm, -55dBm) = ***<u>-55 dBm</u>***

Step8 – for the first other transmitter at site (TX A) the leakage power was calculated and compared to the most susceptible receiver (-55dBm). [Figure (5.13)]

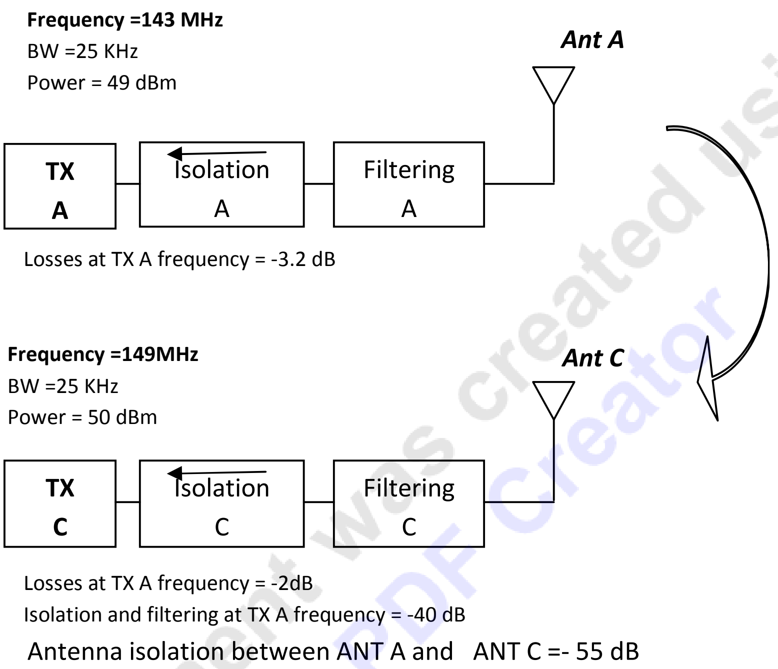


Figure -5.13

Power leaking from TX A to TX C

a) Leakage power of TX A at TX C = power of TX A –losses from TX A at ANT A at frequency of TX A – Antenna isolation from ANT A to ANT C at frequency of TX A – losses from filtering and isolation from ANT C to TX C at frequency of TX A

= 49 dBm – 3.2 dB -55 dB-40 dB = **-**49.2dBm≈ -49dBm

b) Find from lowest order up to highest order that could cause interference

Intermodulation level
= leakage power + Conversion loss (2^{nd} order)=-49 dBm+(-7)dBm= -56dBm<-55dBm

Since that intermodulation level will not affect on TX, as result the possible TX IM = 0

(Because the value of susceptible receiver greater than intermodulation level).

TX IM matrix			
TX IM	TX A	TX B	TX C
TX A	-	**3**	0
TX B	4	-	3
TX C	0	?	-

Step 9 – for the second other transmitter at site (TX B) the leakage power was calculated and compared to the most susceptible receiver (-55dBm). [Figure (5.14)]

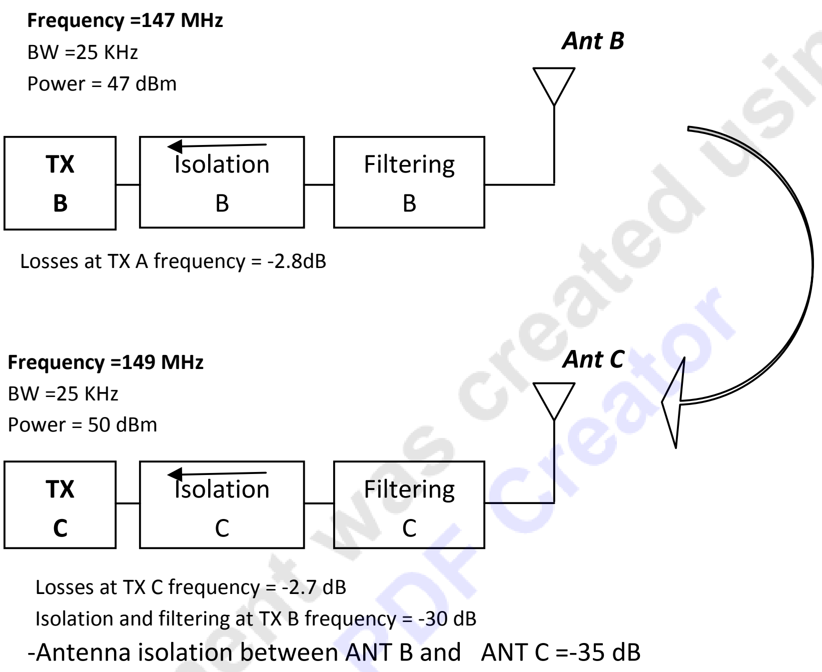


Figure -5.14

Power leaking from TX B to TX C

a) Leakage power of TX B at TX C = power of TX B –losses from TX B at ANT B at frequency of TX B – Antenna isolation from ANT B to ANT C at frequency of TX C – losses from filtering and isolation from ANT C to TX C at frequency of TX B

= 40 dBm – 2.8 dB - 35 dB-30 dB = -27.8dBm ≈ -21 dBm

b) Find from lowest order up to highest order that could cause interference

= leakage power + Conversion loss(2^{nd} order)=-21 dBm+(-7)dBm= -28dBm>-55dBm
= leakage power + Conversion loss(3^{nd} order)=-21 dBm+(-10)dBm= -31dBm>-55dBm
= leakage power + Conversion loss(4^{nd} order)=-21 dBm+(-20)dBm= -41dBm>-55dBm
= leakage power + Conversion loss(5^{nd} order)=-21 dBm+(-30)dBm= -51dBm>-55dBm
= leakage power + Conversion loss(6^{nd} order)=-21 dBm+(-40)dBm= -61dBm<-55dBm

So as result the possible TX IM = 6-1= 5 ***order***

TX IM matrix			
TX IM	TX A	TX B	TX C
TX A	-	**3**	**0**
TX B	4	-	3
TX C	0	5	-

Step10- Calculate two TX intermodulation products

After we determine the values of the most susceptible receiver RX as well as we got all the possible transmitter intermodulation (TX IM) between A, B and C, frequency generation will calculate as shown below by using the technique of TX IM matrix:

a) Starting at TX A calculates the Frequency and bandwidth of all intermodulation products between Frequency A and frequency B up to **orders 3**.

Mix Type

1+1 centre Frequency		= 143 MHz +147 MHz=290 MHz	B.W= 25kHz+25kHZ =50kHz
1 -1	//	=143 MHz - 147 MHz= 4MHz	B.W= 25kHz+25kHZ =50kHz
1+2	//	=143 MHz +2*(147) MHz = 437 MHz	B.W= 25kHz+2*25kHZ=75kHz
1 -2	//	**=143 MHz -2*(147) MHz= 151MHz**	B.W= 25kHz+2*25kHZ=75kHz
2- 1	//	= 2*(143) MHz -147 MHz=139 MHz	B.W=2* 25kHz+25kHZ=75kHz
2+1	//	=2*(143) MHz+147 MHz=433 MHz	B.W= 2*25kHz+25kHZ=75kHz

b) Calculate the frequency and bandwidth of all intermodulation products between Frequency B and frequency A up to order 3.

Mix Type

1+1 centre Frequency		= 147 MHz +143 MHz=290 MHz	B.W= 25kHz+25kHZ =50kHz
1 -1	//	=147 MHz - 143 MHz= 4MHz	B.W= 25kHz+25kHZ =50kHz
1+2	//	=147MHz +2*(143) MHz = 433 MHz	B.W= 25kHz+2*25kHZ=75kHz
1 -2	//	=147 MHz -2*(143) MHz= 139MHz	B.W= 25kHz + 2*25kHZ =75kHz
2- 1	//	**= 2*(147) MHz -143 MHz=151 MHz**	B.W= 2* 25kHz+25kHZ =75kHz
2+1	//	=2*(147) MHz+143 MHz= 437 MHz	B.W= 2*25kHz+25kHZ=75kHz

c) Calculate the frequency and bandwidth of all intermodulation products between Frequency B and frequency C up to order 4.

Mix Type

1+1 centre Frequency		= 147 MHz +149 MHz=296 MHz	B.W= 25kHz+25kHZ = 50kHz
1 -1	//	=147 MHz - 149 MHz= 2MHz	B.W= 25kHz+25kHZ = 50kHz
1+2	//	=147MHz +2*(149) MHz = 455 MHz	B.W= 25kHz+2*25kHZ = 75kHz
1 -2	//	**=147 MHz -2*(149) MHz= 151MHz**	B.W= 25kHz+2*25kHZ = 75kHz
2- 1	//	= 2*(147) MHz -149 MHz=145 MHz	B.W= 2*25kHz+25kHZ = 75kHz

2+1	//	=2*(147) MHz+149 MHz= 433 MHz	B.W= 2*25kHz+25kHZ = 75kHz
2+2	//	=2*(147)MHz +2*(149) MHz= 492MHz	B.W= 25kHz+2*25kHZ =100kHz
2- 2	//	=2*(147)MHz -2*(149) MHz = 4MHz	B.W= 2*25kHz+25kHZ =100kHz
3 -1	//	=3*(147)MHz -149MHz= 292MHz	B.W=3* 25kHz+25kHZ =100kHz
3+1	//	= 3*(147) MHz +149 MHz=588 MHz	B.W= 3*25kHz+25kHZ =100kHz
1- 3	//	=147 MHz-3*(149) MHz=300 MHz	B.W= 25kHz+3*25kHZ =100kHz
1+3	//	=147 MHz+3*(149) MHz= 594 MHz	B.W= 25kHz+3*25kHZ =100kHz
0+ 3	//	= 0+3*(149) MHz=300 MHz	B.W= 0+3*25kHZ =75kHz
3+0	//	=3*(147) MHz+0= 594 MHz	B.W= 3*25kHz+0 =75kHz

Calculate the frequency and bandwidth of all intermodulation products between Frequency C and frequency B up to order 5.

Mix Type

1+1 centre Frequency		= 149 MHz +147 MHz=296 MHz	B.W= 25kHz+25kHZ =50kHz
1 -1	//	=149 MHz - 147 MHz= 2MHz	B.W= 25kHz+25kHZ =50kHz
1+2	//	=149MHz +2*(147) MHz = 455 MHz	B.W= 25kHz+2*25kHZ =75kHz
1 -2	//	**=149 MHz -2*(147) MHz= 151MHz**	B.W= 25kHz+2*25kHZ =75kHz
2- 1	//	= 2*(149) MHz -147 MHz=145 MHz	B.W=2* 25kHz+25kHZ =75kHz
2+1	//	=2*(149) MHz+147 MHz= 433 MHz	B.W=2* 25kHz+25kHZ =75kHz
2+2	//	=2*(149)MHz +2*(147) MHz= 492MHz	B.W= 2*25kHz+25kHZ =100kHz
2- 2	//	=2*(149)MHz -2*(147) MHz = 4MHz	B.W= 2*25kHz+25kHZ =100kHz
3 -1	//	=3*(149)MHz -147MHz= 292MHz	B.W= 3*25kHz+25kHZ =100kHz
3+1	//	= 3*(149) MHz +147 MHz=588 MHz	B.W= 3*25kHz+25kHZ =100kHz
1- 3	//	=149 MHz-3*(147) MHz=300 MHz	B.W= 25kHz+3*25kHZ =100kHz
1+3	//	=149 MHz+3*(147) MHz= 594 MHz	B.W= 25kHz+4*25kHZ =100kHz
1+4	//	= 149 MHz +4*(147) MHz=737 MHz	B.W= 25kHz+4*25kHZ=125kHz
1 -4	//	= 149 MHz -4*(147) MHz=439 MHz	B.W= 25kHz+4*25kHZ=125kHz
4- 1	//	=4*(149) MHz-147 MHz= 449 MHz	B.W=4* 25kHz+25kHZ=125kHz
4+1	//	=4*(149)MHz +147 MHz= 743MHz	B.W= 4*25kHz+25kHZ=125kHz
3+2	//	=3*(149)MHz +2*(147) MHz =741MHz	B.W= 3*25kHz+25kHZ=125kHz
2+3	//	=2*(149)MHz+3*(147)MHz= 739MHz	B.W= 2*25kHz+25kHZ=125kHz
2- 3	//	= 2*(149) MHz -3*(147) MHz=143 MHz	B.W=2* 25kHz+25kHZ=125kHz
3- 2	//	=3*(149) MHz- 2*(147) MHz=153 MHz	B.W=3* 25kHz+25kHZ=125kHz

Step11- Calculate three TX intermodulation products

a) For TX A , calculate the Frequency and bandwidth of all intermodulation products between frequency A, frequency B and Frequency C up to the min (3,0) = 0

b) For TX B , calculate the Frequency and bandwidth of all intermodulation products between frequency B, frequency A and Frequency C up to the min (3,4) = 3

Mix Type

1+ 1 -1	//	=143 MHz + 147MHz-149MHz= 141MHz	B.W= 25kHz +25kHz+25kHZ =75kHz
1-1 +1	//	=143MHz -147MHz+149MHz = 145 MHz	B.W= 25kHz +25kHz+25kHZ =75kHz
1 -1-1	//	=143 MHz -147 MHz-149MHz=153MHz	B.W= 25kHz +25kHz+25kHZ =75kHz
1 +1-1	//	=149 MHz -+49 MHz-147MHz=151MHz	B.W= 25kHz +25kHz+25kHZ =75kHz

c) For TX C, calculate the Frequency and bandwidth of all intermodulation products between frequency C, frequency A and Frequency B up to the min (0,5) = 0

Finally step – Determine interfering intermodulation products

a) Of the intermodulation products generated at TXA, one fall into bands of the receivers. Calculate intermodulation power level and compare to susceptibility.

1+2 centre Frequency =143 MHz -2*(147) MHz= 151MHz B.W= 25kHz+2*25kHZ=75kHz

Leakage power +conversion level (order) > receiver susceptibility

-40 dBm + (-10) dBm =-50 dBm < -52 dBm, ***will cause interference***

b) Of the intermodulation products generated at TX B, two fall into bands of the receivers. Calculate intermodulation power level and compare to susceptibility.

2+1 centre Frequency = 2*(147) MHz -143 MHz=151 MHz B.W= 2* 25kHz+25kHZ =75kHz

Leakage power +conversion level (order) > receiver susceptibility

-43 dBm + (-10) dBm =-53 dBm <-52dBm, ***will not cause interference***

2+1 centre Frequency = (147) MHz -2(149)MHz=151 MHz B.W= 2* 25kHz+25kHZ =75kHz

Leakage power +conversion level (order) > receiver susceptibility

-48 dBm + (-10)dBm =-58 dBm <-56 dBm , ***will not cause interference***

c) Of the intermodulation products generated at TX C, one fall into bands of the receivers. Calculate intermodulation power level and compare to susceptibility.

1+2 centre Frequency = 149 MHz -2*147 MHz=151 MHz B.W= 25kHz+2*25kHZ =75kHz

Leakage power +conversion level (order) > receiver susceptibility

-21dBm + (-10) dBm =-31 dBm <-44 dBm, ***will cause interference***

Since intermodulation product generated at TXB will not cause interference when interaction between TXB and TXA as well TXB and TXC, all analysis above re-evaluate intermodulation interference using the formula of the Echelon isolation (interpolation between L_H and L_v as a function of angle) in dB, where the vertical distance of antenna is unchanging, but the horizontal distance of antenna B was changing from 0.3meter up to 1.4 meter. Echelon isolation was mentioned with diagram in chapter (4).

Isolation between Echelon Spaced Antennas

-To determine how much echelon isolation, the following formula is used:

$$\textbf{Echelon isolation} = L_H + (L_v - L_H) \square \left(\frac{2\, ta \tan^{-1} \frac{D_v}{D_H}}{\pi} \right) \text{ in dB}$$

Where D_v - Vertical Distance between Antennas D_H =Horizontal distance between antenna

By using the formula above at different frequency and different distance for each transmitter, echelon isolation at antenna A, B, C, D was calculated as shown below:

ANTB change by 0.3 meter (horizontal axis)					
Antenna isolation	ANT A	ANT B	ANT C	ANT D	Ant E
ANT A	-	-48dB	-55 dB	-39 dB	-51 dB
ANT B	-48dB	-	-32dB	-32dB	-16 dB
ANT C	-56 dB	-32 dB	-	-48 dB	-28 dB
ANTB change by 0.5 meter (horizontal axis)					
Antenna isolation	ANT A	ANT B	ANT C	ANT D	Ant E
ANT A	-	-47dB	-55 dB	-39 dB	-51 dB
ANT B	-47dB	-	-30dB	-30dB	-16 dB
ANT C	-56 dB	-30 dB	-	-47 dB	-28 dB
ANTB change by 0.7 meter (horizontal axis)					
Antenna isolation	ANT A	ANT B	ANT C	ANT D	Ant E
ANT A	-	-46.2dB	-55 dB	-39 dB	-51 dB
ANT B	-46.2dB	-	-29.5dB	-29.5dB	-16 dB
ANT C	-56 dB	-29 dB	-	-46.2 dB	-28 dB
ANTB change by 0.9 meter (horizontal axis)					
Antenna isolation	ANT A	ANT B	ANT C	ANT D	Ant E
ANT A	-	-45dB	-55 dB	-39 dB	-51 dB
ANT B	-45dB	-	-28dB	-28dB	-16 dB
ANT C	-56 dB	-28 dB	-	-45 dB	-28 dB
ANTB change by 1.2 meter (horizontal axis)					
Antenna isolation	ANT A	ANT B	ANT C	ANT D	Ant E
ANT A	-	-44dB	-55 dB	-39 dB	-51 dB
ANT B	-44dB	-	-27dB	-27dB	-16 dB

ANT C	-56 dB	-27 dB	-	-44 dB	-28 dB
ANTB change by 1.4 meter (horizontal axis)					
Antenna isolation	ANT A	ANT B	ANT C	ANT D	Ant E
ANT A	-	-43dB	-55 dB	-39 dB	-51 dB
ANT B	-43dB	-	-26dB	-26dB	-16 dB
ANT C	-56 dB	-26 dB	-	-43dB	-28 dB

Table (5.5) show the echelon antenna isolation where all the antenna in vertical axis unchanged , but antenna ANTB changing from 0.3meter up to 1.4 meter.

After echelon antenna isolation was calculated, all the steps involved in the example above were repeated by implementing matlab program to evaluate intermoulation power level, then compared to susceptibly receiver to check either cause interference or NO.

As distance of ANT B changed through horizontal axis, the intermodulation power level generated at TXB from TXA and from TXC was changed.

Antenna isolation	Intermodulation power level
-50dB (vertical)	-53.00 dBm (could not cause interference)
-48dB(0.3m)	-52.200 dBm (could not cause interference)
-47dB(0.5m)	-50.00 dBm (could cause interference)
-46.2(0.7m)	-49.200 dBm (could cause interference)
-45dB(0.9m)	-48.00 dBm (could cause interference)
-44dB(1.2m)	-47.200 dBm (could cause interference)
-43dB(1.4m)	-46.00 dBm (could cause interference)

Figure (5.6) –show relation between Intermodulation power levels generated at TXB from TXA and antenna isolation

Antenna isolation	Intermodulation power level
-35dB (vertical)	-58.00 dBm(could not cause interference)
-32dB(0.3m)	-57.00 dBm(could not cause interference)
-30dB(0.5m)	-56.20 dBm(could not cause interference)
-29.5(0.7m)	-55.200 dBm(could cause interference)
-28dB(0.9m)	-54.00 dBm(couldl cause interference)
-27dB(1.2m)	-53.200 dBm (could cause interference)
-26dB(1.4m)	-52.00 dBm(could cause interference)

Figure (5.7) –show relation between Intermodulation power levels generated at TXB from TXC and antenna isolation

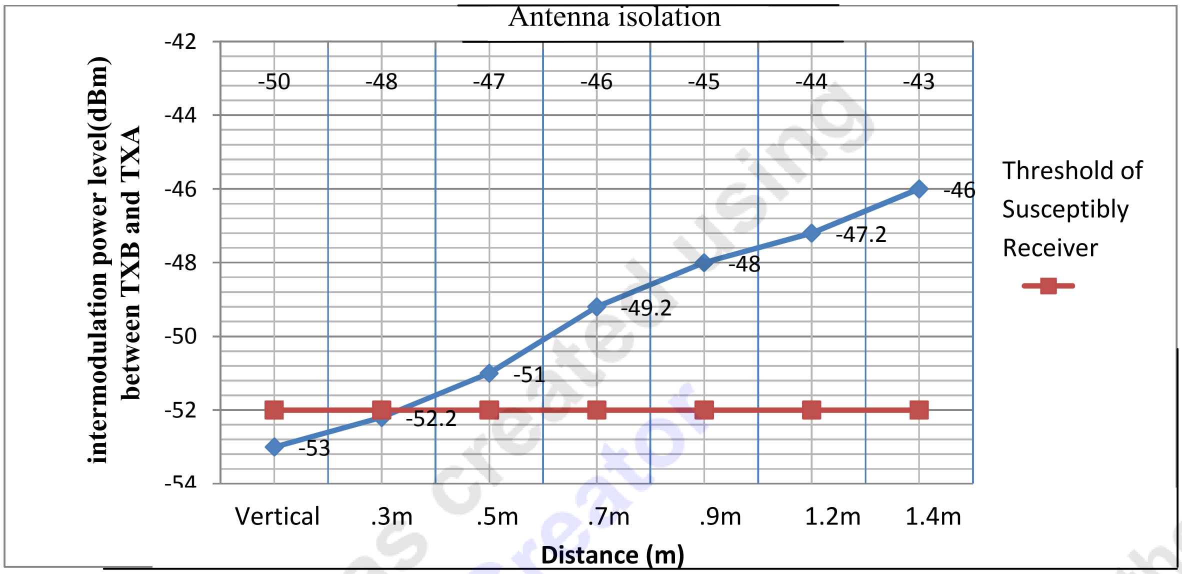


Figure (5.15) –show relation between Intermodulation power levels generated at TXB from TXA and antenna isolation

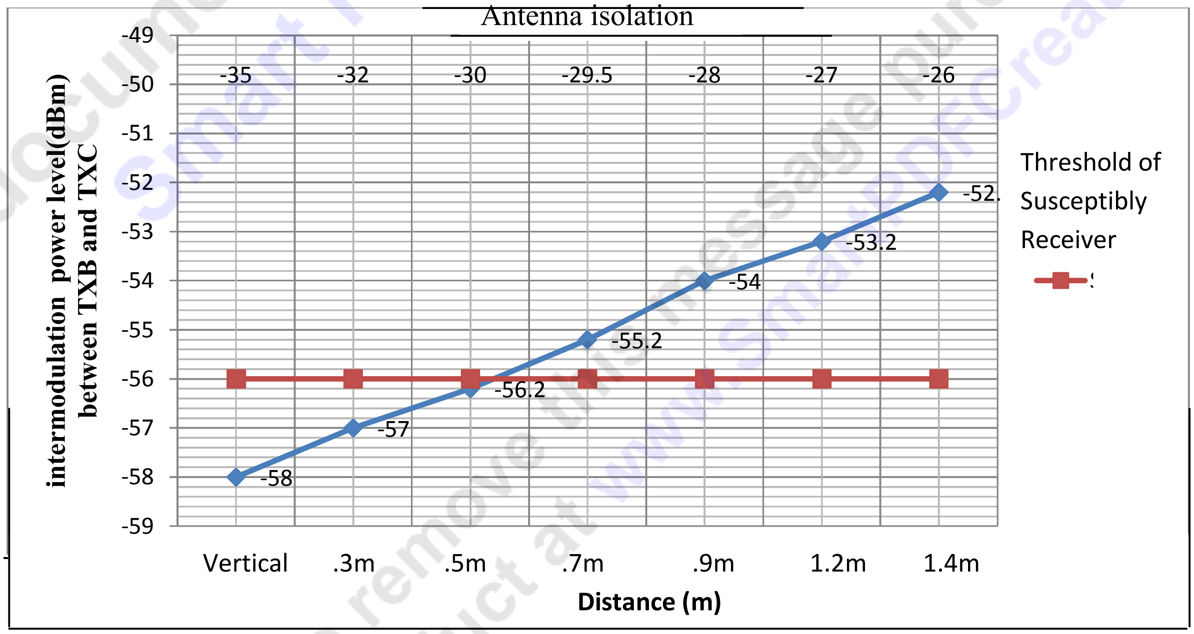


Figure (5.16) –show relation between Intermodulation power levels generated at TXB from TXC and antenna isolation

5.5-Discussion

This chapter described the analysis of Intermodulation (IM) interference technique and how it is analyzed. The method used to evaluate intermodulation interference involved two processing phases. **First phase,** analysis technique performs a pre-processing phase in which it calculates all of the possible IM hits that fall within each receiver's bandwidth. If the IM frequency does not fall within a receiver's bandwidth, it is ignored and continues to calculate other possible hits. This calculation continues until all possible hits are determined. T**he second phase** is to calculate a signal level associated with each hit to determine if the IM signal level exceeds the associated receiver's minimum sensitivity performance level. If it does, the additional isolation or change the space between antennas is required.

In our analysis 3 transmitters and 2 receivers were examined. This system examined two times. With vertical isolation the result shown that there is no intermodulation product will affect on the receiver **E** at frequency 156 MHz, but at receiver **D** at frequency 151 MHz there are 4 intermodulation. Although there are 4 intermodulation at receiver **D**, just only two cause interference. With Echelon isolation (interpolation between L_H and L_v as a function of angle, the result shown that there is no intermodulation product will affect on the receiver **E** at frequency 156 MHz, but at receiver **D** at frequency 151 MHz there are 4 intermodulation. All the 4 intermodulation generated at receiver **D** will cause interference due to changing of the distance of horizontal axis.

Intermodulation interference with vertical antenna isolation

- Intermodulation product generated at TXA from TXB produce intermodulation power level = -50 dBm which represent value greater than the value of receiver susceptibility (-52dBm). Therefore this will cause interface.
- Intermodulation product generated at TXB from TXA produce intermodulation power level = -53 dBm which represent value less than the value of receiver susceptibility (-52 dBm). Therefore this will not cause interface.
- Intermodulation product generated at TXB from TXC produce intermodulation power level = -58 dBm which represent value less than the value of receiver susceptibility (-56dBm). Therefore this will not cause interface.
- Intermodulation product generated at TXC from TXA produce intermodulation power level= - 31 dBm which represent value greater than the value of receiver susceptibility (-44dBm). Therefore this will cause interface.

Intermodulation interference with echelon antenna isolation

“Vertical distance of antenna is unchanging but the horizontal distance is change”.

Antenna isolation increases with distance. Antennas spaced at 0.3 meter horizontal spacing provide about -52.2dB and -57dB loss (isolation) between TXB and TXA as well between TXB and TXC respectively. This decrease to about -52 and 56.2 dB at 0.5 meter. As with anything RF, there are many factors which can affect system performance. A big one when dealing with antenna isolation is that coupling to tower structures can reduce effective path loss between antennas. This could change the necessary spacing for any given installation. Even though the analysis technique by using echelon antenna isolation instead of vertical isolation shown that all the intermodulation power level will cause interference, the example above give us two significant points:

- Figure (5.15) illustrated the ability of ANTB to shift up to 0.3 meter in horizontal axis without cause interference. Consequently, this value can make the ANTB closer to ANTA than before with respect to vertical direction, without any interference.

- Figure (5.16) illustrated the ability of ANTB to shift up to 0.5 meter in horizontal axis without cause interference. Consequently, this value can make the ANTB closer to ANTC than before with respect to vertical direction, without any interference.

Chapter 6

Conclusion and Future work

6.0- Conclusion

In the past several years, the issues of interference have changed significantly. Transmitter noise, spurious nose, harmonic, intermodulation and receiver desensitization are become the main reason of interference and cause more harm with the plethora of transmitters. Therefore, tools and processes technique are necessary to effectively eliminate these types of interference. This project given comprehensive case study about how to evaluate interference between antennas by a cosite analysis model (COSAM), designed to evaluate the performance of a group of collocated voice communications transmitters and receivers. COSAM was converse as one of available technique to calculate the intermodulation (IM), harmonic, and adjacent channels of interaction with co-located frequency assignment records.

The most important Conclusion, illustrated together the observations arising from interference analysis, and computation and analysis of intermodulation. It answered the following questions:

The answer to the question of ***how much spacing one actually needs between antennas*** at radio sites depends on the configuration of each individual site. Analysis technique have illustrated that the distance of 15 feet or some time more than of vertical antenna spacing which used as common guideline by wireless operators is not always necessary. In various conditions, just only the physical dimensions of antennas dictate the antenna spacing requirements. But, without use high-quality analysis software developed as well detailed information on the site, it will be difficult to know when the significant spacing is required, and all the more hard to know what are the necessities for minimum spacing, mainly at sites antenna with numerous collocated systems.

The use of sophisticated software tools such as ***method of performing antenna cosite analysis using Intermodulation technique*** makes it possible to analyze whether the interference is to be expected on share antenna sites, and also makes it probable to optimize the antenna placement to accommodate for more than systems than would be possible using normally adopted antenna spacing guidelines.

Overall, in our analysis 3 transmitters and 2 receivers were examined. This system examined two times. With vertical isolation the result shown that there is no intermodulation product will affect on the receiver **E** at frequency 156 MHz, but at receiver **D** at frequency 151 MHz there are four intermodulation will affect. Although there are 4 intermodulation at receiver **D**, just only two cause interference. With horizontal isolation, the result shown that there is no intermodulation product will affect on the receiver **E** at frequency 156 MHz, but at receiver **D** at frequency 151 MHz there are four intermodulation will cause interference.

Although four intermodulation generated at receiver **D** will cause interference due to changing the distance of horizontal axis, this result leaded to another interesting point during change the distance of ANTB from 0.3m up to 1.4 meter . This point gives us that the specification of the system install more important than the distance between antennas. For example since we found there is no intermodulation will cause interference between ANTB and ANTA as well between ANTB and ANTC, this antenna was examined by moving in horizontal axis from 0.3 meter up to 1.4 meter. Consequently, the result shows ability of ANTB antenna to move up to 0.5 meter in horizontal axis without cause interference. This space can make the ANTB closer to ANTA or ANTC than before without any interference.

Reduce the antenna spacing provides a number of benefits including: collocating more systems on the same mast tower, and limit the spread of towers by collocating more often, and also saving build capital of the wireless licensees by make the cost of effective collocation more possible

6.1-Future work

The following recommendations are suggested for the future work in this area.

. In the future investigations, analysis and experimentation on newer technologies of antenna isolation with faster and more powerful driver tool such as GTD (The geometrical theory of diffraction) and UTD (The uniform geometrical theory of diffraction) are required instead of simply calculation method (equations to evaluate vertical isolation between antenna).

. Take the account of another interaction which is not considered in cosite analysis model such as the effect of oxidized surfaces and joints, which are capable to generating new frequencies resulting from the interaction of two or more incident waves at different frequencies.

. Measure the values of filtering and isolation loss, cable loss and conversion loss of all the transceiver instead of estimated the values by comparing to another experiments.

. Since that one direction of future work is to examine more than 25 transmitters and receivers, as a result more complicated MATLAB functions is required. This will include simulation program and toolbox simulator.

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Appendix A

Involve specification of systems used in this project.

Transmitter A

Frequency	143 MHz
IF Amplifiers:	21.4MHz and 455kHz
Power input	49 dBm
Length of coaxial cable of feeder	61 m
Bandwidth	25 kHz
Type of antenna	Fibreglass Omni Antenna
Antenna gain	3.2dBi
Load SWR	1.5:1
Type of coaxial cable used	Belden9913(RG-8)
total loss of cable was	3.2dB

Transmitter B

Frequency	147MHz
IF Amplifiers:	21.4MHz and 455kHz
Power input	47 dBm
Length of coaxial cable of feeder	54 m
Bandwidth	25 kHz
Type of antenna	Fibreglass Omni Antenna
Antenna gain	3.2dBi
Load SWR	1.5:1
Type of coaxial cable used	Belden9913(RG-8)
total loss of cable	2.8dB

Transmitter C

Frequency	149 MHz
IF Amplifiers:	21.4MHz and 455kHz
Power input	50dBm
Length of coaxial cable of feeder	51 m
Bandwidth	25 kHz
Type of antenna	Fibreglass Omni Antenna
Antenna gain	3.2dBi
Load SWR	1.5:1
Type of coaxial cable used	Belden9913(RG-8)
total loss of cable	2.7dB

Receiver D

Frequency Range	151 MHz
IF Amplifiers:	21.4MHz and 455kHz
Sensitivity	-116dBm
Length of coaxial cable of feeder	57 m
Bandwidth	25 kHz
Type of antenna	Fibreglass Omni Antenna
Antenna gain	3.2dBi
Type of coaxial cable used is	Belden9913(RG-8)
By using Coax Cable and Line Loss Calculator (total loss of cable was)	3.1dB

Receiver E

Frequency Range	156 MHz
IF Amplifiers:	21.4MHz and 455kHz
Sensitivity	-120dBm
Length of coaxial cable of feeder	53 m
Bandwidth	25 kHz
Type of antenna	Fibreglass Omni Antenna
Antenna gain	3.2dBi
Type of coaxial cable used is	Belden9913(RG-8)
total loss of cable	2.8dB

Appendix B

Analysis and measurement

This will involve evaluate cable loss, evaluate the isolation between antenna and measure Conversion loss, isolation and filtering loss.

1- Evaluate Cable loss

Cable loss is the total insertion loss of transmission cable system. This will typically include insertion loss of the transmission cable, jumper cables, connectors and lightning protection. Cable loss can be measured with the same equipment used to measure antenna VSWR or return loss levels or calculate by simple program.

In our example, the transmission cable system of all transmitter and receiver involve the following parameters:

Type of Transmission cable is Belden9913 (RG-8),

Attenuation Per 100 feet at 144 MHz is 1.3 dB,

Jumper at transmitter and jumper at antenna together = 0.35 dB, also

Lightning protection = 0.1 dB

So by using the parameter given above of each transmitter and receiver and using simple software such as Excel software the total loss was calculated as shown below:

Antenna	ANT A	ANT B	ANT C	ANT D	ANT E
Total loss	3.2dB	2.8dB	2.7dB	3.1dB	2.8dB

Table (5.1) Show loss of cable

2- Evaluate the isolation between antennas

Antenna-to-antenna isolation on tower can be predicted by numerical analysis techniques with reasonable accuracy. Confidence in the analysis technique was obtained by comparing predictions to measurements of another situation which has nearly same specification. Although there are various accurate methods have been used for the EMC problems which are mentioned in chapter 2, the simple method of isolation used here is to mount the antennas some distance from each other by using simple formula.

Isolation between Vertically Spaced Antennas

-To determine how much vertical isolation, the following formula is used:

$$\boldsymbol{vertical\ isolation}(\boldsymbol{L_v}) = \mathbf{28} + \mathbf{40}\ \boldsymbol{log}\ \frac{\boldsymbol{D_v}}{\boldsymbol{\lambda}}\ \text{in dB}$$

Where λ = C/F & D_v=vertical distance between antenna

By using the formula above at different frequency and different distance for each transmitter, vertical isolation at antenna A, B, C, D and E was calculated as shown below:

Vertical Isolation between antenna A and other antenna at transmitter frequency =143 MHz

Distance between ANT A and ANT B = 5 m Isolation = 28 +40*log (Dv/λ) = 48.9 dB≈ 49 dB

Distance between ANT A and ANT C = 8 m Isolation = 28 +40*log (Dv/λ) = 55.128 dB≈ 55 dB

Distance between ANT A and ANT D = 3 m Isolation = 28 +40*log (Dv/λ) = 39.2dB≈ 39dB

Distance between ANT A and ANT E = 6 m Isolation = 28 +40*log (Dv/λ) =51.25≈ 51 dB

Vertical Isolation between antenna B and other antenna at transmitter frequency =147 MHz

Distance between ANTB and ANT A = 5 m Isolation = 28 +40*log (Dv/λ) = 48.7 dB≈ 49 dB

Distance between ANT B and ANT C =3 m Isolation = 28 +40*log (Dv/λ) = 34.7 dB≈ 35 dB

Distance between ANT B and ANT D =2 m Isolation = 28 +40*log (Dv/λ) = 34.7 dB≈ 35 dB

Distance between ANT B and ANT E =1 m Isolation = 28 +40*log (Dv/λ) = 15.6 dB≈ 16 dB

Vertical Isolation between antenna C and other antenna at transmitter frequency =149 MHz

Distance between ANT C and ANT A = 8 m Isolation = 28 +40*log (Dv/λ) = 55.8 dB≈ 56 dB

Distance between ANT C and ANT B =3 m Isolation = 28 +40*log (Dv/λ) = 34.9 dB≈ 35 dB

Distance between ANT C and ANT D =5 m Isolation = 28 +40*log (Dv/λ) = 46.9dB≈ 47 dB

Distance between ANT C and ANT E =2 m Isolation = 28 +40*log (Dv/λ) = 27.8 dB≈ 28dB

Antenna isolation	**ANT A**	**ANT B**	**ANT C**	**ANT D**	**Ant E**
ANT A	-	-50 dB	-55 dB	-39 dB	-51 dB
ANT B	-50 dB	-	-35dB	-35dB	-16 dB
ANT C	-56 dB	-35 dB	-	-47 dB	-28 dB

Table(5.2) Show the value of vertical antenna isolation (V-isolation)

Tables (5.2) show all the loss isolation between transmitters antennas to transmitter antennas as well between transmitters to receiver's antennas. These values were compared to another measurement which has same situation and nearly same frequency such as Analysis of Mutual Coupling of Antennas on Coast Guard Vessel; the results were little bit different.

3- Measure Conversion loss, isolation and filtering loss

These values were estimate by comparing to another system measurement which are have nearly same specification and used approximately same frequency.

Table (5.3)-Show the values used to calculate losses for different IM product orders.

Table (5.3)-Show the values of isolation and filtering loss.

Order of intermodulation product	Conversion loss (dBm)
2	-7
3	-10
4	-20
5	-30
6	-40
7	-50
8	-60
9	-70

Table (5.3)-conversion loss

isolation and filtering loss	ANT A	ANT B	ANT C
ANT A	-	-35 dB	-35dB
ANT B	-40 dB	-	-60dB
ANT C	-40 dB	-30 dB	-

Table (5.4) - Isolation and filtering loss

Appendix C

Abbreviation according to Cosite Analysis System

G_t, G_r : average antenna gains in dB
Θ : vertical angle,relative to antenna postion
D ⍰distance between antenna (m)
F ⍰frequancy of the Tx signal (MHz)
N : the Number of tuned stage
Fo : tuned frequency of circuit
Δf : operating frequancy minus fo ,
Q : the quality factor or ratio of reactance to resistance of the circuit
P_r : recieved power(dBm)
P : transmitter power(dBm)
L : coupling losss
β_{ct} : rejection , at transmitter frequancy due to transmitter coupler (dB)
β_{cr} : rejection , at receiver frequancy due to receiver coupler (dB)
P_i : input undesired power (dBm)
M : is value of slop $\Delta P_i/\Delta P_d$, $\leq$ 1
β_d : input desired power(dBm)
β_{eff}: : effective off – frequancy rejection(due toΔf) (dB)
β_{sr} : effectiverejection(dB)
R_s: : receiver sensitivy (dBm)
P_t ⍰P_t: transmitter power (dBm)
β_{ct} : off – frequancy rejection due to the transmitter coupler (dB)
f_{iv}: : freauqncy of the victium transmitter (MHz)
f_i : frequancy of the interfering transmitter (MHz)
P_{tv} : output power of the victim transmitter (dBm)
P_{ti} : output power of interferering transmitter (dBm)
L_{tt} : coupling loss between two transmitter including antenna gains (dB)
β_{cv} : off – frequancy rejection due to the victim transmitter coupler (dB)
β_{vi-} : frequancy rejection due to the victim transmitterout put circit $\Delta f = |\, f_v - \ f_i |$ (dB)
β_{vr}: : frequancy rejection due to the victim transmitterout put circit $\Delta f = |\, f_v - \ f_r |$ (dB)
L_{rt} : coupling loss between transmitter and receiver due to antenna gain and space loss (dB)
$K_{m,n}$: non-linear coefficient due to the transmitter circuit non-linearity
P_{iv} : input power from the the victim transmitter (dBm)
P_{ii} : input undesired power from interferering transmitter (dBm)
m, n : integers: 3rd order ; $m = 2, n = 1$: 5th order ; $m = 3, n = 2$: 7th order ; $m = 4 , n = 3$

Appendix D

This appendix presents the main computer code developed in MATLAB for the analysis of the scenarios discussed in this thesis.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%
%
                %
%Program: intermodulationinterference.m
%
%Authors: Meftah Mehdawi
%
%Date Written: 7/21/2010
%
%Description:  This m-file evalute the intermodulation interference
%
%              between two receiver and three transmitter.this
%
%              result will show if there are any interfernce come  from
%
%              transmitter will effect the receiver.
%
%
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%
                 %%% parameter involved in this example %%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%

SRXd = -116;  SNR1= 12; SRXE=-120; SNR2=10;

TXofFreq1=143;TXofFreq2=147; TXofFreq3=149;RXofFreq4=151;RXofFreq5=156;

ConversionLOSS=[ -7 -10 -20  -30 -40 -50 -60 ];

% power of transmitter)(dBm =[ Power  atTXA=49  P0wer at TXB=47 Power at
TXc=50]
PowerofTX=[49   47  50];

%loss of cable  dB)=[Loss at TXA=-3.2  Loss at RXB=-2.8 Loss at TXc=-2.7
%                   Loss at RX DatA=-3.1  Loss at RXE atA=-2.8 ].
LossOFcable=[-3.2 -2.8 -2.7 -3.1 -2.8 ];


%loss from ANT to ANT(dB) =[Loss of RXD at ANTA=-40  loss of RX E at ANTA=-
50;
%                           Loss of RXD at ANTB=-40  Loss of RX E at ANTB=-
50;
%                           Loss of RXD at ANTC=-40  Loss of RX E at ANTC=-
50].
LossANTtoANT=[-40 -50 ; -40 -50 ; -40 -50 ];
```

```
%  Isolation and filter loss(dB)=[ Loss at ANTAB=-35  Loss at ANTAC=-35;
%                                  Loss at ANTBA=-40  Loss at ANTBC=-60;
%                                  Loss at ANTCA=-40  loss at ANTCB=-30]
ISLandFIlTER=[-35 -35 ; -40  -60 ; -40  -30];

%Antenaa_isilation(dB) =[isl ANT AB=-50  isl ANT AC=-55   isl ANT AD=-39
isl ANT AE=-51;
%                        isl ANt BA=-49  isl ANT BC=-35   isl ANT BD=-35
isl ANTBE=-16;
%                        isl ANT CA=-56  isl ANT CB=-35   isl ANT CD-47
isl ANTCE=-28]
% antenna isolation (vertical position )
ANTisl=[-43  -55  -39  -51 ;-43 -26 -26 -16 ; -56 -26 -43 -28];

%Antenna isolation as ANTB change in Horizontal Axis from (0.3m upto 1.4m)
%
%ANTisl 0.3m)=[-47 -55  -36  -27 ;-43 -32 -35 -13 ; -51 -32 -42 -23];
%ANTisl(0.5m)=[-47 -55  -36  -27 ;-43 -32 -35 -13 ; -51 -32 -42 -23];
%ANTisl(0.7m)=[-47 -55  -36  -27 ;-43 -32 -35 -13 ; -51 -32 -42 -23];
%ANTisl(0.9m)=[-47 -55  -36  -27 ;-43 -32 -35 -13 ; -51 -32 -42 -23];
%ANTisl(1.2m)=[-47 -55  -36  -27 ;-43 -32 -35 -13 ; -51 -32 -42 -23];
%ANTisl(1.4m)=[-47 -55  -36  -27 ;-43 -32 -35 -13 ; -51 -32 -42 -23];


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%victim transmitter A
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%

 %%%%%%%%%%%STEP1

%calculate most suceptible receiver at TXA
%susceptible RXDatA= sensitivity or RX D - S/N ratio - 6 dB;

susceptRXDatA=SRXd -SNR1-6 ;

%susceptible of RX D at TXA= susceptibly of RX D-loss from ant D to RXD at
freq RXD-%antenna isolation between ant A and ant D at freq RXD- loss from
TXA to antA at %frequency RXD

RXDatTXA=susceptRXDatA-LossOFcable(1,4)-ANTisl(1,3)-LossANTtoANT(1,1);

susceptRXEatA=SRXE -SNR2-6;

%susceptible of RX D at TXA(RXDatTXA) = susceptibly of RX D- loss from ant
D to RXD
%at freq RXD -antenna isolation between ant A and ant D at freq RXD- loss
%from TXA to antA at frequency RXD

 RXEatTXA=susceptRXEatA-LossOFcable(1,5)-ANTisl(1,4)-LossANTtoANT(1,2);

mostsusceptibleRXatTXA=min(RXDatTXA,RXEatTXA);

%%%%%%%%%%%STEP2
```

```
%calculate the laeakge power and compare to most susceptible receiver
```

% (Leakage power of TX B at TX A= power of TX B– losses from TX B at ANT B at frequency of TX B – Antenna %isolation from ANT B to ANT A at frequency of TX B – losses from filtering and isolation from ANT A to TX A %at frequency of TX B)

```
%find highest order cause interference

 [m,n]=size(ConversionLOSS);
for a=1:n;
    INT(m,a)=LegTXBatTXA+ConversionLOSS(m,a);
    if INT(m,a)<mostsusceptibleRXatTXA;
      order1=a ;
    break
    end
end
if order1==1 ;
    TXIMorder11=order1-1;
else TXIMorder11=order1;
end

%%%%%%%%%%STEP3

     %calculate the laeakge power and compare to most susceptible receiver
```

%Leakage power of TX C at TX A =power of TX B –losses from TX C at ANTC at frequency of TX C – %Antenna isolation from ANT C to ANT A at frequency of TX C – losses from filtering and isolation from %ANT A to TX A at frequency of TX C

```
LegTXcatTXA=PowerofTX(1,2)+LossOFcable(1,3)+ANTisl(3,1)+ISLandFIlTER(1,2);

%find highest order cause interference

[m,n]=size(ConversionLOSS);
for a=1:n;
    INT(m,a)=LegTXcatTXA+ConversionLOSS(m,a);
    if INT(m,a)<mostsusceptibleRXatTXA ;
      order2=a ;
    break
    end
end
if order2==1;
    TXIMorder22=order2-1;
else TXIMorder22=order2;
end


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%
        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%victim transmitter B
%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%


%%%%%%%%%%STEP4
```

```
% calculate most suceptible receiver at TXA
%susceptible RXDatB= sensitivity or RX D - S/N ratio - 6 dB;

  susceptRXDatB=SRXd -SNR1-6 ;

%susceptible of RX D at TXA= susceptibly of RX D- loss from ant D to RXD at
freq RXD-%antenna isolation between ant A and ant D at freq RXD- loss from
TXA to antA at %frequency RXD

RXDatTXB=susceptRXDatA-LossOFcable(1,4)-ANTisl(2,3)-LossANTtoANT(2,1);

susceptRXEatB=SRXE -SNR2-6;

%susceptible of RX D at TXB= susceptibly of RX D - loss from antD to RXDat
freq RXD-%antenna isolation between ant B and ant D at freq %RXD- loss from
TXB to antB at %frequency RXD

RXEatTXB=susceptRXEatB-LossOFcable(1,5)-ANTisl(2,4)-LossANTtoANT(2,2);

mostsusceptibleRXatTXB=min(RXDatTXB,RXEatTXB);


%%%%%%%%%%STEP5

%calculate the laeakge power and compare to most susceptible receiver
```

%Leakage power of TX A at TX B =power of TX A –losses from TX A at ANT A at frequency of TX A – Antenna %isolation from ANT A to ANT B at frequency of TX A – losses from filtering and isolation from ANT B to TX B %at frequency of TX A

```
LegTXcatTXA=PowerofTX(1,1)+LossOFcable(1,1)+ANTisl(2,1)+ISLandFIlTER(2,1);

 %find highest order cause interference


[m,n]=size(ConversionLOSS);
for a=1:n;
    INT(m,a)=LegTXcatTXA+ConversionLOSS(m,a);
    if INT(m,a)<mostsusceptibleRXatTXB ;
      order3=a ;
    break
    end
end
if order3==1;
    TXIMorder33=order3-1;
else TXIMorder33=order3;
end

%%%%%%%%%%STEP6

%calculate the laeakge power and compare to most susceptible receiver
```

%Leakage power of TX C % at TX = power of TX C –losses from TX C at ANTC at frequency of TX C – Antenna %isolation from ANT C to % ANT B at frequency of TX C – losses from filtering and isolation from ANT C to TX C %at frequency of TX B

```
 LegTXcatTXB=PowerofTX(1,3)+LossOFcable(1,3)+ANTisl(3,2)+ISLandFIlTER(2,2);

%find highest order cause interference

[m,n]=size(ConversionLOSS);
for a=1:n;
    INT(m,a)=LegTXcatTXB+ConversionLOSS(m,a);
    if INT(m,a)<mostsusceptibleRXatTXB ;
      order4=a ;
    break
    end
end
if order4==1;
    TXIMorder44=order4-1 ;
else TXIMorder44=order4  ;
end


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%
        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%victim transmitter C
%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%

%%%%%%%%%%STEP7

%calculate most suceptible receiver at TXA
%susceptible RXDatB= sensitivity or RX D - S/N ratio - 6 dB;

 susceptRXDatc=SRXd -SNR1-6 ;

%susceptible of RX D at TXc(RXDatTXc) = susceptibly of RX D- loss from ant
D to RXD
%at freq -antenna isolation between ant c and ant D at freq RXD- loss from
TXc to antc at %frequency RXD

RXDatTXc=susceptRXDatA-LossOFcable(1,4)-ANTisl(3,3)-LossANTtoANT(3,1);

susceptRXEatc=SRXE -SNR2-6;

%susceptible of RX E at TXB=susceptibly of RX D(susceptRXD) -loss from ant
E to RXE
%at freq RXED-antenna isolation between ant c and ant E at freq RXE-
lossfrom TXc to antc %at frequency RXE

RXEatTXc=susceptRXEatc-LossOFcable(1,4)-ANTisl(3,4)-LossANTtoANT(3,2);

mostsusceptibleRXatTXc=min(RXDatTXc,RXEatTXc);

RXSUSceptible=[mostsusceptibleRXatTXA  mostsusceptibleRXatTXB
mostsusceptibleRXatTXc];
```

```
minRXSUSceptible=max(RXSUSceptible);

%%%%%%%%%%STEP8

%calculate the laeakge power and compare to most susceptible receiver
```

% (Leakage power of TX A %at TX C = power of TX A –losses from TX A at ANT A at frequency of TX A – %Antenna isolation from ANT A to %ANT C at frequency of TX A – losses from filtering and isolation from ANT %C to TX C at frequency of TX A

```
 LegTXAatTXc=PowerofTX(1,1)+LossOFcable(1,1)+ANTisl(1,2)+ISLandFIlTER(3,1);

%find highest order cause interference

[m,n]=size(ConversionLOSS);
for a=1:n;
    INT(m,a)=LegTXAatTXc+ConversionLOSS(m,a);
    if INT(m,a)<mostsusceptibleRXatTXc;
      order5=a ;
    break
    end
end
if order5==1;
    TXIMorder55=order5-1 ;
else TXIMorder55=order5 ;
end

%%%%%%%%%%STEP9

%calculate the laeakge power and compare to most susceptible receiver
```

Leakage power of TX B %at TX C = power of TX B –losses from TX B at ANT B at frequency of TX B   – Antenna isolation from ANT B to %ANT C at frequency of TX C – losses from filtering and isolation from ANT C to TX C at frequency of TX B

```
%LegTXBatTXc=PowerofTX(1,2)+LossOFcable(1,2)+ANTisl(2,2)+ISLandFIlTER(3,2);

%find highest order cause interference

[m,n]=size(ConversionLOSS);
for a=1:n;
    INT(m,a)=LegTXBatTXc+ConversionLOSS(m,a);
    if INT(m,a)<mostsusceptibleRXatTXc ;
      order6=a ;
    break
    end
end
if order6==1;
     TXIMorder66=order6-1;
else TXIMorder66=order6;
end


% the matrix below determine all possible transmitter intermodulation order
% that could cause interference
Matrix= [TXIMorder11 TXIMorder22 ;
```

```
        TXIMorder33 TXIMorder44 ;
        TXIMorder55 TXIMorder66 ]


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%

%%%%%%%%%%STEP10

%%%% Frequency generation
%1-calculate Frequancy and bandwidth of IM between frequancy A and B up  to
TXIMorder11

   for n=1:6;
    for m=1:6;
        x(n,m)=n*TXofFreq1-m*TXofFreq2;
            end
end
a=x;
w=0;
y=0;
[t,o]=size(a);
for i=1:t;
    for j=1:o;
        h=abs(a(i,j));
        if h==RXofFreq4;
            if i+j>TXIMorder11;
            w=0  ;
            else w=w+1;
            nnw=i;
            mmw=j;
            end
        else w=w;
        end
        if h==RXofFreq5;
             if i+j>TXIMorder11
            y=0;
            else y=y+1;
            nny=i;
            mmy=j;
             end
             else y=y;
        end
           end
end

 w and y represent the number of IM hit the RXE(F4) and RXD(F5)
 nnw and mmw represnt the value n and m of TX frequency which Hit at
RXD(F4)
 nny and mmy represnt the vlaue n and m of TX frequency which HIt at
RXE(F5)

numberofF4andF5betweenAB=[w  y];
numberofnnwANDmmw=[nnw  mmw];
%numberofnnyANDmmy=[nny  mmy];

 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%1-calculate Frequancy and bandwidth of IM between frequancy A and C up  to
TXIMorder22
 for n=1:6;
```

```
    for m=1:6;
        x(n,m)=n*TXofFreq1-m*TXofFreq2;
            end
end
a=x;
w=0;
y=0;
[t,o]=size(a);
for i=1:t;
    for j=1:o;
        h=abs(a(i,j));
        if h==RXofFreq4;
            if i+j>TXIMorder22;
            w=0 ;
            else w=w+1;
            nnw1=i;
            mmw1=j;
            end
        else w=w;
        end
        if h==RXofFreq5;
             if i+j>TXIMorder22
            y=0;
            else y=y+1;
            nny1=i
            mmy1=j
             end
             else y=y;
        end
           end
end

 w and y represent the number of IM hit the RXE(F4) and RXD(F5)
 nnw1 and mmw1 represnt the value n and m of TX frequency wich Hit at
RXD(F4)
 nny1 and mmy1 represnt the vlaue n and m of TX frequency wich HIt at
RXE(F5)

numberofF4andF5betweenAC=[w  y];
numberofnnwANDmmw1=[nnw1  mmw1];
numberofnnyANDmmy1=[nny1  mmy1];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%2-calculate Frequancy and bandwidth of IM between frequancy B and A up  to
TXIMorder33

   for n=1:6;
    for m=1:6;
        x(n,m)=n*TXofFreq2-m*TXofFreq1;
            end
end
a=x;
w=0;
y=0;
[t,o]=size(a);
for i=1:t;
    for j=1:o;
        h=abs(a(i,j));
        if h==RXofFreq4;
```

```
            if i+j>TXIMorder33;
            w=0 ;
            else w=w+1;
            nnw2=i;
            mmw2=j;
            end
        else w=w;
        end
        if h==RXofFreq5;
             if i+j>TXIMorder33;
            y=0;
            else y=y+1;
            nny2=i
            mmy2=j
             end
             else y=y;
        end
           end
end

 w and y represent the number of IM hit the RXE(F4) and RXD(F5)
 nnw2 and mmw2  represnt the value n and m of TX frequency wich Hit at
RXD(F4)
 nny2 and mmy2 represnt the vlaue n and m of TX frequency wich HIt at
RXE(F5)

numberofF4andF5betweenBA=[w  y];
numberofnnwANDmmw2=[nnw2  mmw2];
numberofnnyANDmmy2=[nny2  mmy2];


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%

 %3-calculate Frequancy and bandwidth of IM between frequancy B and C up
to TXIMorder44

   for n=1:6;
    for m=1:6;
        x(n,m)=n*TXofFreq2-m*TXofFreq1;
            end
end
a=x;
w=0;
y=0;
[t,o]=size(a);
for i=1:t;
    for j=1:o;
        h=abs(a(i,j));
        if h==RXofFreq4;
            if i+j>TXIMorder44;
            w=0 ;
            else w=w+1;
            nnw3=i;
            mmw3=j;
            end
        else w=w;
        end
        if h==RXofFreq5;
             if i+j>TXIMorder44;
```

```
            y=0;
            else y=y+1;
            nny3=i
            mmy3=j
             end
             else y=y;
        end
           end
end

 w and y represent the number of IM hit the RXE(F4) and RXD(F5)
 nnw3 and mmw3 represnt the value n and m of TX frequency wich Hit at
RXD(F4)
 nny3 and mmy3 represnt the vlaue n and m of TX frequency wich HIt at
RXE(F5)

 numberofF4andF5bteweenBC=[w  y];
 numberofnnwANDmmw3=[nnw3  mmw3];
 numberofnnyANDmmy3=[nny3  mmy3];
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%

%1-calculate Frequancy and bandwidth of IM between frequancy C and A up  to
TXIMorder66

   for n=1:6;
    for m=1:6;
        x(n,m)=n*TXofFreq3-m*TXofFreq2;
        end
end
a=x;
w=0;
y=0;
[t,o]=size(a);
for i=1:t;
    for j=1:o;
        h=abs(a(i,j));
        if h==RXofFreq4;
            if i+j>TXIMorder55;
            w=0 ;
            else w=w+1;
            nnw4=i;
            mmw4=j;
            end
        else w=w;
        end
        if h==RXofFreq5;
             if i+j>TXIMorder55;
            y=0;
            else y=y+1;
            nny4=i
            mmy4=j
             end
             else y=y;
        end
           end
end

 w and y represent the number of IM hit the RXE(F4) and RXD(F5)
```

```
 nnw4 and mmw4 represnt the value n and m of TX frequency wich Hit at
RXD(F4)
 nny4 and mmy4 represnt the vlaue n and m of TX frequency wich HIt at
RXE(F5)

numberofF4andF5betweenCA=[w  y];
numberofnnwANDmmw4=[nnw4  mmw4];
numberofnnyANDmmy4=[nny4  mmy4];


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%

%1-calculate Frequancy and bandwidth of IM between frequancy C and c up  to
TXIMorder66

   for n=1:6;
    for m=1:6;
        x(n,m)=n*TXofFreq3-m*TXofFreq2;
        end
end
a=x;
w=0;
y=0;
[t,o]=size(a);
for i=1:t;
    for j=1:o;
        h=abs(a(i,j));
        if h==RXofFreq4;
            if i+j>TXIMorder66;
            w=0 ;
            else w=w+1;
            nnw5=i;
            mmw5=j;
            end
        else w=w;
        end
        if h==RXofFreq5;
             if i+j>TXIMorder66;
            y=0;
            else y=y+1;
            nny5=i
            mmy5=j
             end
             else y=y;
        end
           end
end

 w and y represent the number of IM hit the RXE(F4) and RXD(F5)
 nnw1111 and mmw1111 represnt the value n and m of TX frequency wich Hit at
RXD(F4)
 nny1111 and mmy1111 represnt the vlaue n and m of TX frequency wich HIt at
RXE(F5)

numberofF4andFbetweenCB=[w  y];
numberofnnwANDmmw5=[nnw5  mmw5];
numberofnnyANDmmy5=[nny5  mmy5];
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Finally step
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%              Determine interfering intermodultion products
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%

% 1-of the intermdulation product generated at TXA,claculate IM power level
and compared to susceptibility.

if nnw+mmw==2; conv1=ConversionLOSS(1,1);
else if nnw+mmw==3;conv1=ConversionLOSS(1,2);
else if nnw+mmw==4;conv1=ConversionLOSS(1,3);
else if nnw+mmw==5;conv1=ConversionLOSS(1,4);
end
end
end
end
RX_min_susceptibly_receiver=RXDatTXA

INTERMODPOWERLEVEL=LegTXBatTXA+conv1
if INTERMODPOWERLEVEL>RXDatTXA,'IMP generate from TXB at TXA  will case
interfernce at RXD '
else 'IMP generate from TXB at TXA  will not case interfernce at RXD '
end

%%%


if nnw1+mmw1==2; conv1=ConversionLOSS(1,1);
else if nnw1+mmw1==3;conv1=ConversionLOSS(1,2);
else if nnw1+mmw1==4;conv1=ConversionLOSS(1,3);
else if nnw+mmw1==5;conv1=ConversionLOSS(1,4);
end
end
end
end
RX_min_susceptibly_receiver=RXDatTXA

INTERMODPOWERLEVEL1=LegTXcatTXA+conv1
if INTERMODPOWERLEVEL1>RXDatTXA 'IMP generate from TXc at TXA  will case
interfernce at RXD '
else 'IMP generate from TXc at TXA  will not case interfernce at RXD '
end

% 2-of the intermdulation product generated at TXB,claculate IM power
%level and compared to susceptibility.

if nnw2+mmw2==2; conv1=ConversionLOSS(1,1);
else if nnw2+mmw2==3;conv1=ConversionLOSS(1,2);
else if nnw2+mmw2==4;conv1=ConversionLOSS(1,3);
else if nnw2+mmw2==5;conv1=ConversionLOSS(1,4);
end
end
end
end

RX_min_susceptibly_receiver=RXDatTXB
```

```
INTERMODPOWERLEVEL2=LegTXAatTXB+conv1
if INTERMODPOWERLEVEL2>RXDatTXB,'IMP generate from TXA at TXB  will case
interfernce at RXD '
else 'IMP generate from TXA at TXB  will not case interfernce at RXD '
end

%%%%

if nnw1+mmw1==2; conv1=ConversionLOSS(1,1);
else if nnw3+mmw3==3;conv1=ConversionLOSS(1,2);
else if nnw3+mmw3==4;conv1=ConversionLOSS(1,3);
else if nnw3+mmw3==5;conv1=ConversionLOSS(1,4);
end
end
end
end

RX_min_susceptibly_receiver=RXDatTXB

INTERMODPOWERLEVEL3=LegTXcatTXB+conv1
if INTERMODPOWERLEVEL3>RXDatTXB,'IMP generate from TXA at TXc  will case
interfernce at RXD '
else 'IMP generate from TXA at TXc  will not case interfernce at RXD '
end

% 3-of the intermdulation product generated at TXC,claculate IM power
%level and compared to susceptibility.


if nnw5+mmw5==2; conv1=ConversionLOSS(1,1);
else if nnw5+mmw5==3;conv1=ConversionLOSS(1,2);
else if nnw5+mmw5==4;conv1=ConversionLOSS(1,3);
else if nnw5+mmw5==5;conv1=ConversionLOSS(1,4);
end
end
end
end

RX_min_susceptibly_receiver=RXDatTXc

INTERMODPOWERLEVEL5=LegTXBatTXc+conv1
if INTERMODPOWERLEVEL5>RXDatTXc,'IMP generate from TXB at TXc  will case
interfernce at RXD '
else 'IMP generate from TXB at TXc  will not case interfernce at RXD '
end

x=[1  2  3  4   5];
y1=[RXDatTXA RXDatTXA  RXDatTXB RXDatTXB RXDatTXc  ];
y2=[INTERMODPOWERLEVEL INTERMODPOWERLEVEL1 INTERMODPOWERLEVEL2
INTERMODPOWERLEVEL2  INTERMODPOWERLEVEL5];
plot(x,y1,'*',x,y2,'*');
legend('N=thresould of min susceptibly receiver','N=intermodultion power
level');
title('Eveluation of Intermodulation Interference');
```