ADDIS ABABA INSTITUTE OF TECHNOLOGY, AAIT

SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

DEPARTMENT OF ELETRICAL ENGINEERING FOR RAILWAY SYSTEMS

M.Sc. Thesis on the Title

Design and Analysis of MMW Radar Technique for Railway Level Crossing Accident Prevention

For Addis Ababa LRT

By: ALENE RITIBEY (GSR/3854/05)

Advisor: 1. Mr.ABI ABATE

Advisor: 2. Dr.YALEMZEWD NEGASH

Submitted to: Addis Ababa Institute of Technology (AAIT)

March 24, 2015

Declaration

I, Alene Ritibey, declare that this thesis is my original work, has not been presented for a degree in this or other universities. All sources of materials used for this thesis work have been fully acknowledged.

Name: Alene Ritibey Signature: ______________

Place: Addis Ababa Institute of Technology, Addis Ababa University, Addis Ababa

Date of Submission: ____

This thesis has been submitted for examination with our approval as university advisors.

1. Mr.Abi Abate Signature: _____________

   Advisor's Name

2. Dr.Yalemzewd Negash Signature: _____________

   Advisor's Name

Abstract

In railways, level crossings are safety-critical points because of the risk of collisions between motorcars and trains. Since electrified railway transportation system is a new technology to our country Ethiopia, it is mandatory to use intelligent means of accident prevention by detecting obstacles rather than active way of protection which is train-oriented and which it do not show the condition of level crossing.

Therefore, in order to prevent accidents in level crossings a means of detecting obstacles and controlling the related wayside signals, traffic lights and passing information to railway operator and train driver to stop the approaching train is required.

One of the many level crossing accident prevention technologies is radar system which is one of the promising from the viewpoints of preventing accidents by sensing moving or stationary obstacles, reducing operational disturbance and decreasing installation and maintenance costs due to its high Mean Time Between Failures (MTBF) by implementing it properly and integrating it with the related wayside signals, traffic lights.

To this end, this thesis presents the investigation and design of an intelligent railway level crossing system to prevent accident for AALRT. In this scenario, the performance, reliability, cost effectiveness of radar system surveillance to level cross signaling are investigated and results obtained from simulations are presented.

After reviewing different types of accident prevention techniques, the Inductive loop which is widely used in most railway systems and the MMW Radar have been investigated as much as possible. And it was found that the Inductive loop has its own drawbacks like, it is unable to detect pedestrians and bicycles and also its installation and maintenance cost is very high. While the MMW Radar has been found to be effective and efficient with an excellent performance in all weather condition, day and night with a probability of detection (PD) 99.99%, Reliable with more than 10 years MTBF and 25% less expensive than the inductive loop to install and easy for maintenance.

Key Terms: Level Crossing, Accident Prevention, Obstacle/Target, MMW radar, FMCW

Acknowledgements

Above all I would like to thank my almighty God and the blessed Mother of Jesus Christ St.Mary for giving me hope, courage, in all the bad and good moments and without whom I would have never been able to arrive at this point.

Next, I would like to express my deepest gratitude to a number of people, who supported and helped me in the realization of this thesis work.

First of all, I would like to thank my daily supervisor, Mr.Abi Abate, Dr.Yalemzewd Negash, for their guidance, support and encouragement. They were always available to listen to my doubts and to give me advice, both on the technical and organizational points of view, and thanks to the enormous patience they had during these months, they helped me get through the difficulties encountered during this thesis work.

Last but not least, I'd like to thank my family and friends, who always supported me in the completion of my thesis.

Table of Contents

Declaration……………………………………………………………………………...…i

Abstract………………………………………………………………………………...…ii

Acknowledgments……………………………………………………………………….. iii

List of Figurs……………………………………………………………………………...vi

List of Tables……………………………………………………………………………..vii

List of Abbreviations and Symbols……………………………………………………....ix

Chapter One 1

1.1. Background 1

1.2. Statement of the Problem 3

1.3. Literature Review.. 4

1.4. Objectives.. 5

  1.4.1. General Objective 5

  1.4.2. Specific Objective.. 5

1.5. Research method 6

1.6. Thesis Limitation 7

1.7. Contributions... 8

1.8. Thesis organization 9

Chapter Two... 10

2. Technologies for preventing accidents on level crossing...10

  2.1. Level Crossing (LC)...10

  2.2. LC Accident Prevention...13

  2.3. Current technologies used for obstacle detection..14

  2.4. Over View of LRT Ethiopian Railway (thesis area)...21

Chapter Three...23

3. System Modeling..23

  3.1. Intelligent accident prevention system...23

  3.2. Modeling of System structure and working principle...24

  3.3. Design of the Hardware Component of the System..25

  3.4. Design of the Software Procedures of the system.. 27

Chapter Four……36

4. Designing of the MMW radar……36

  4.1. Introduction to Radar……36

  4.2. Radar Classification……37

  4.3. Millimeter-Wave (MMW) Obstacle Detection Radar…… 39

    4.3.1. Millimeter Wave……40

    4.3.2. Configuration of MMW Radar……40

    4.3.3. Mathematical Modeling……45

    4.3.4. The Frequency Modulation Continuous Wave (FMCW) Method…… 59

Chapter Five…… 67

5. Simulation Results and discussion……67

  5.1. Simulation Model……67

  5.2. Results and Discussion……68

Chapter Six……75

6. Conclusions and Recommendations……75

  6.1. Conclusions……75

  6.2. Recommendations……76

Reference…… .77

Appendix: *MATLAB codes for the designed radars*……79

List of Figures

Fig.2.1. Level crossing (LC) types classified by ERA……………………………………………11
Fig.2.2: Example, obstacle detection system without barrier……………………………..…….14
Fig.2.3. Inductive Loop Locations…………………………………………………………………16
Fig. 3.1 System Architecture………………………………………………………………………24
Fig.3.2 Architectural Context Diagram for the System……………………………………………25
Fig. 3.3 (a) Level Crossing track side equipments...……………………………….……….……..26
Fig. 3.3 (b) Approaching train's Onboard devices.....……………………………….………….....27
Fig. 3.4 Software Procedure of the System……………………………………………………….27
Fig. 3.4.1 Flow chart for Start-up procedure……………………………………………………....28
Fig.3.4.2 Flow chart for Obstacle detection………………………………………………………29
Fig.3.4.3 Flow chart for Approaching train detection……………………………………………..30
Fig.3.4.4 Flow chart for the traffic light…………………………………………………………...31
Fig.3.4.5 Flow Chart for Sending SMS to approaching train……………………………………...32
Fig. 3.4.6 Flow chart for Receiving SMS data…………………………………………………..…33
Fig.3.4.7 Flow chart for main……………………………………………………………………...34
Fig.3.4.8 On board Alarm Flow chart…………………………………………………….……..35
Fig. 4.1 Block diagram of improved radar………………………………………………………36
Fig.4.2 a. Obstacle Detection Radar, concept for application to railroad grade crossings ……….39
Fig.4.2 b. Approaching Train Detection Radar, concept for application
to railroad grade crossings…………………………………………………………...….40
Fig.4.3 Millimeter Wave Obstacle detection Radar Block Diagram………………………………41
Fig.4.4 Sensor Block Diagram…………………………………………………………………......42
Fig.4.5. Illustration of threshold detection…………………………………………………………47
Fig.4.6. Scheme of a pencil beam sensing level crossing at grazing angle α and

depression angle is α'. ……………………………………………………………….....51
Fig.4.7 Side view of the radar on level Crossing. …………………………………………….....52
Fig.4.8 The horizontal beam………………………………………………………………………52
Fig.4.9 Radiation diagram……………………………………………………………………......55
Fig.4.10 Atmospheric absorption of millimeter wave, Principal windows exist at

35, 94,140 and 220 GHz with extremely large available bandwidths around each…………59

Fig.4.11 Principle of FMCW radar…………………………………………………………...60
Fig.4.12: FMCW radar front-end with common transmit and receive antenna……………………61

Fig.4.13: Linear chirp signal in time-domain (left) and frequency-domain (right)………….......62

Fig.4.14 Receiver FFT Sampling Intervals………………………………………………………...64
Fig.5.1 Simulation model………………………………………………………………………….67
Fig.5.2 SNR Vs R Simulation Result with different Pt……………………………………………68
Fig.5.3 SNR Vs R Simulation Result with different RCS…………………………………………69
Fig.5.4 The Threshold for obstacle detection in heavy rain……………………………………….69
Fig.5.5 SNR Vs R Simulation Result with different Pt in clear air………………………………..70
Fig.5.6 SNR Vs R Simulation Result with different RCS in clear air……………………………70

Fig.5.7 The Threshold for obstacle detection in clear air…………………………………………71

Fig.5.8 Approaching train SNR Vs R Simulation Result with different Pt……………………….72
Fig.5.9 Approaching train SNR Vs R Simulation Result with different RCS…………………….72
Fig.5.10 The Threshold for Approaching train detection……………………………………......73
Fig.5.11 P_D Vs SNR Simulation Result with different PFA…………….…………………...…….73

List of Tables

Table 1 Embedded Inductive Loop-Based Vehicle Detection System Cost……………………….16
Table 2 Radar-Based Vehicle Detection System Cost ....…...19
Table 3 Comparison table for obstacle detection technologies………………………………....20
Table 4 Radar frequency bands…………………………………………………………………….38
Table 5 Typical used RCS…………………………………………………………………………56
Table 6 Obstacle detection Radar Parameters……………………………………………………..66
Table 7 Approaching train detection Radar Parameters………………………………………...66

List of Abbreviations and Symbols

AALRT	Addis Ababa Light Railway Transit
A_e	Effective Area
ADC	Analog to Digital Convertor
A_r	Amplitude of the received waveform
A_t	Amplitude of the transmitted waveform
B	Radar Bandweadth
B_n	Bandwidth of the radar receiver
BPF	Band Pass Filter
BS	Base Station
C	Speed of light
CPU	Central Processing Unit
DSP	Digital Signal Processing
ECTRI	European Conference of Transport Research Institutes
EMC	Electromagnetic Compatibility
ERA	European Railway Agency
ERC	Ethiopia Railway Corporation
f	Frequency
FAR	False Alarm Rate
F_{beat}	Beat Frequency
f_0	Starting frequency
FFT	Fast Fourier Transform
F_n	Noise Figure
FMCW	Frequency Modulation Continuous Wave
G	Antenna gain
G_s	Gain of the system
GSM	Global System for Mobile telecommunications
GSM-R	Global System for Mobile telecommunications of Railway
IF	Intermediate Frequency

IR	Infrared
ITS	Intelligent Transport Systems
k	Boltzmann’s constant
k’	Modulation rate
L_{ATM}	Atmospheric loss
LC	Level Crossing
LNA	Low Noise Amplifier
LO	Local Oscillator
LPF	Low Pass Filter
Ls	System loss
L_t	Total attenuation loss
MDS	Minimum Detectable Signal
MMW	Milli-Meter Wave
MTBF	Mean Time Between Failures
MTI	Moving Target Indication
N_0	Rceiver noise power density
OCC	Operation Control Center
P_D	Probability of detection
P_r	Received power
P_t	Transmitted power
PRF	Pulse Repetition Frequency
Q	Stands for Marcumsq
R	Range to target
ΔR	Range resolution
RCS	Radar Cross Section
RF	Radio Frequency
S_A	Angular resolution as a distance between the two targets
S_{beat}	Beat Signal
SELCAT	Safer European Level Crossing Appraisal and Technology
SNR	Signal to Noise Ratio
S_r	Received Signal
T	Temperature in Kelvin

t_d	Delayed time of transmitted signal
T_{sweep}	Sweep time
V_C	Efficient airborne clutter volume
VCO	Voltage Controlled Oscillator
V_t	Target velocity
λ	wavelength
σ_t	Target cross-section
σ_0	Normalized radar cross section of the target
σ_{S0}	Reflectivity of surface clutter
α	Grazing angle
α'	Depression angle
τ	Transmitted pulse length
η	Volume clutter reflectivity
μ	Attenuation coefficient
γ	Angle between the target heading

Chapter One

1. Motivation and Background

1.1. Background

The long and phenomenal story of development in science and technology manifests itself in railways in its present form, beginning from steam engines in early 19th century, through diesel engines, electrified railways and high speed trains, benefitting and significantly influencing the life of everyone. Since the world's first railway journey, the railway systems have evolved hugely. Speed, comfort, costs, quality of service led engineers to continuously invent new machines and devices to develop the rail transport. Going with this development, more and more requirements appeared. Nowadays, one wants the train to go faster, more frequently, more safely, while being cheaper and environmentally friendly.

But level crossings have been identified as a particular weak point in road and railway infrastructure, seriously affecting their safety. In road and railway infrastructure level crossing systems requires for high level of safety. Modern level crossings (or railroad crossings in American terminology) have come a long way from the early days of human railway employees waving red flags and shining lanterns to clear railroad tracks or vehicles and pedestrian traffic for oncoming trains. Road users must follow road rules and signs and pay attention to the road environment when approaching rail crossings. International police statistics show that up to 95 percent of crashes at railway crossings are caused by driver error and out of this 44 percent happened at crossings without an electronic warning system such as flashing lights and/or boom gates. This is largely attributable to inattention, driver distraction, risk taking, and disobeying and lack of knowledge of the road rules and sometimes suicide. In almost every case that the motorist failed to stop and give way to the train at the level crossing and that there was little the train driver could do to prevent the collision or minimize its effects [1].

Nowadays level crossings are protected either passively or by active/automated systems. Passive protection systems provide only a stationary sign warning of the possibility of trains crossing. Their message remains constant with time. Active protection systems activate automatic warning devices (i.e., flashing lights, bells, barrier, etc.) as they detect an approaching train. Comparison among the railway level crossings in terms of ‘driver compliance’ clearly indicates that drivers react differently to different protection systems, particularly the passive protection systems which are commonly used in rural areas. Based on the field results it is concluded that on average there is less driver compliance to passive crossings than to active ones[8].

Due to this reasons active system of protection supporting safe driving and an information collection infrastructure for sensing level crossing conditions and supplying key information to the railway operator and train driver is mandatory to prevent accident.

Active warning systems for level crossings have traditionally been train-oriented and geared more towards protecting railway assets than helping vehicles and pedestrians make better split-second decisions. Although protecting and monitoring the condition of railway assets remain crucial objectives in ensuring journey reliability and preventing derailments, smart level crossings go even further by providing more accurate, real-time information to pedestrians, vehicles, train drivers, and even a faraway OCC (operation control center). Development efforts are currently underway to come up with a practical infrastructure of this type. The information collection infrastructure is expected to detect instantaneously the positions and velocities of obstacles on roads, such as things that have been dropped, or that have fallen on the road, standing or running vehicles [2]. This technology is essential for constructing Smart way of accident prevention in our country Ethiopia. Since our country is constructing a new electrified railway infrastructure, accidents must be prevented or minimized especially in level crossings, because the higher rate of accident is in these areas.

Although other forms of obstacle detection such as video, infrared, acoustic, magnetometers and inductive loop have been selectively utilized, these technologies have not shown themselves to be sufficiently reliable in all conditions, cost effective as the radar technology [11][3].

In the signaling preliminary design for the Addis Ababa LRT there is no system of detecting an obstacle to prevent an accident, the responsibility is fallen to the train operator who is driving on sight. But what if an obstacle is there on the level crossing, what if he couldn’t see farther because it is fogy, night….etc. To solve this problem the radar system is going to be designed and analyzed for its detection performance, reliability, longevity and cost effectiveness.

1.2. Statement of the Problem

From the data obtained in the Signaling Preliminary Design of Addis Ababa LRT undergoing project, manual driving mode by viewing is adopted to control the running speed of the train and the crossing signaling system will not be set with barriers [4]. This shows that the only way of protecting motorcars from interring to the level crossing is the coordinated traffic lights and there is no way of informing to the train operator if there is an obstacle in the level crossing. The problem which has been visualized will lead to a fatal accident and also to a low performance of train speed operation due to the different aspects of errors of motorcar drivers.

To overcome these limits, this paper proposes intelligent level crossing system to balance the above disadvantages of existing system and make persons (train or vehicle drivers, pedestrians, and etc.) more secure. The proposed level crossing system informs vehicle drivers and pedestrian that train is approaching. The other important feature of this system is that it also inform train driver about the status of level crossing.

As it has been explained in the introduction part, to prevent the fatal accident occurrence a system which can detect obstacle on level crossing and inform the railway operator and train driver whether there is an obstacle or not has got to be developed. Then on this paper the proposed solution for this problem is the Radar system of obstacle detection. The system of accident prevention using radar technology is going to be designed and analyzed for its performance, reliability and cost effectiveness.

1.3. Literature Review

In the investigation for literature, different papers have been read to design and analyze the system. Since it was difficult to get resources which are related with accident prevention here some of the papers which are specially related with obstacle detection and radar working principle will be summarized.

✓ Considering reference [5]

In this paper, the radar-based and inductive loops means of detecting vehicle in a four-quadrant gate crossing are covered and the comparison between the two methods is conducted based on practical demonstration. Based on the results found it shows the potential improvement in the areas of performance, reliability, safety, and life-cycle cost over the embedded inductive loop vehicle detectors at selected locations.

✓ In reference [6]

This paper analyzes the feasibility of using a millimeter wave (MMW) radar system for detection of highway vehicles within grade crossings. The sensor system is designed to provide a warning signal whenever a vehicle appears within the danger area of the grade crossing using wave Band's spinning grating antenna. This was supported by a demonstration on a field test.

✓ In reference [7]

The concept developed under this paper is the application of a low-cost 76.5 GHz radar sensor, incorporating the Spinning Grating^{TM} Antenna, to highway-rail grade crossings for the detection of obstacles in the path of trains. The Spinning rating TM Antenna is the key enabling technology (provided by Waveband Corporation) on this paper. The antenna utilizes a principle of evanescent coupler and it was conducted with a field test.

✓ In reference [9]

This book explain the basic operation of a pulse radar system; define range, bearing, and altitude as they relate to a radar system; discuss how pulse width, peak power, and beam width affect radar performance; describe the factors that contribute to or deteriorate from radar resolution; know the advantages of a frequency diversity radar.

1.4. Objectives

1.4.1. General Objective

In general, the objective of this work is to design and investigate an intelligent railway level crossing system to prevent accident in AALRT.

1.4.2. Specific Objective

Specifically, the aim of this work is to:

- Review the conventional level crossing accident prevention techniques and analyze their role in railway transport.
- Investigate how to reduce effects of accidents before and/or after its occurrence.
- Analyze the performance, reliability, cost effectiveness of radar system surveillance to level crossing.
- Design and investigate level crossing accident prevention and development of an alarming system to predict and alarm before the occurrence of accidents.
- Propose how radar system can be used in railway level crossing accident prevention.

1.5. Research method

The method to be employed to achieve the objectives of the research includes:

- **Literature Reviewing**: It is the study of different research works; this includes reading books, articles, publications and journals on railway level crossing accident prevention and related topics. Having brief understanding of the problem, collection of necessary information which is essential to achieve the objective of this thesis is done. Even though information collection is not completed due to unavailability of the required documents; assumptions and information from different thesis, papers and books are used.
- **System Designing**: it involves designing the level crossing accident prevention system and study for internal component relationship.
- **Simulation**: involves simulating the modeled obstacle detection system for different obstacles in different conditions (e.g. distance) using MATLAB
- **Performance comparison, and Analysis and Interpretation of the results**: This involves comparing the performance of the different accident prevention methods, and analyzing and interpreting the result.

1.6. Thesis Limitation

This thesis developed, means of accident prevention for railway level crossing using the radar technology. While designing the system the radar’s performance in different weather condition, in different distance and with different types of target is covered using mathematical modeling. Since there was a shortage of references some assumptions are considered. And also since there is a limitation of time, cost & technological equipments it was not tested and analyzed on field test.

1.7. Contributions

This thesis will contribute to the AALRT in:

- ✓ Improving safety at level crossings for all users (road and rail) by:
  - Giving warning before the happening of accident on the level crossing due to the existence of obstacle.
  - Preventing accidents in level crossing
- ✓ Causing no or minimal delays for both train and road users
- ✓ Improving the speed of the train
- ✓ Minimizing the work burden of train operator
- ✓ Introducing an affordable accident prevention system in terms of costs to install, operate and maintain

1.8. Thesis organization

This thesis is organized in five chapters. The first chapter includes introduction which provides clear information about the background of the thesis work, statement of the problem, research method and limitation of the thesis.

Chapter two is about current technologies of obstacle detection. This section provides clear understanding of level crossing accident prevention system using different obstacle detection systems and some information about railway development in Ethiopia. Finally, other researchers work on the area of level crossing accident prevention is presented.

Chapter three is about Design of the Level crossing accident prevention system, System Architecture, System structure, Required Hardware components and Design of the software procedures of the system.

Chapter four is about Radar and Radar classification, Obstacle detection MMW radar, Configuration of MMW radar, designing (mathematical modeling) of the MMW radar, FMCW for the MMW radar , how to solve the mathematical model and solving algorithm.

Chapter five is about MATLAB simulation. After the development of MATLAB code depending on the solving algorithms developed in chapter four, Different graphs are generated (e.g. Range verses SNR). After having the simulation result, we discussed what the simulation result is to mean.

The final chapter is conclusions and recommendations. On this chapter the work has been concluded based on the result obtained and discussed in chapter five. Further recommendations were suggested for the development of new model or improvement of the results this thesis.

Chapter Two

2. Technologies for preventing accidents on level crossing

In the previous chapter, introduction, objective of the thesis, its organization, limitations, contribution and literature review of works related to level crossing accident prevention were briefly discussed. In this chapter the different types of accident prevention technologies are going to be discussed.

The chapter is organized as follows. In Section 2.1 The meaning of level crossing and types of level crossing are covered, In Section 2.2 Accident prevention using obstacle/target detection is discussed; In Section 2.3 The existing technologies of accident prevention on the level crossing are discussed; at last in Section 2.4 The overview of the AALRT on the thesis area is also included.

2.1. Level Crossing (LC)

Level crossing (LC) can be defined as "an intersection of a road and a railway on the same level, where roads and rail include different operator and responsibilities" [23]. Based on the definition, level crossing protection is the common task of all those involved in the operation and oversight of roads and railways. Level crossings come under the purview of laws, regulations, administrative provisions and directives.

ERA (European Railway Agency) classified LCs into two groups: active LCs (group A) and passive LCs (group B) (Fig.2.1) [23].

The simplest description for passive type LCs may be all LCs equipped with any warning signs, plates, devices, or any other protection equipment, which is permanent and independent of any traffic situation. The first analysis of operational LC risk was carried out on the basis of the active and passive LC types as defined per the European Railway Agency for the purpose of defining Common Safety Indicators. It defines an active LC as a LC where the crossing users are protected from, or warned of, the approaching train by the activation of devices when it is unsafe for the user to cross the LC. In the case of an automatic active LC (A.1 in Fig.2.1), these devices are activated by the approaching train. Manual active LCs (A.2) are activated by humans when there is no railway signal interlocked with control train movements. In the case of passive LC (B in Fig.2.1) there is no warning system and/ or protection system showing when it is unsafe for the user to cross the LC. SELCAT project carried out an analysis of accident statistics by comparing operational risk according to the different LC types. As a basis for comparison, seven basic LC types as defined per ERA were taken into account. The individual risk for road LC user was compared as per the different LC types. As basis for operational risk comparison, the seven level crossing types defined by ERA have been taken. However, only five of these types could be identified (the A1.1 and A2.2 were not clearly identified) when analyzing the 66 collected national level crossing types of countries involved in SELCAT project. Risk considering the accidents (Acc), fatalities (Fat) or injuries (In) at LC of a particular type are covered deeply [23].

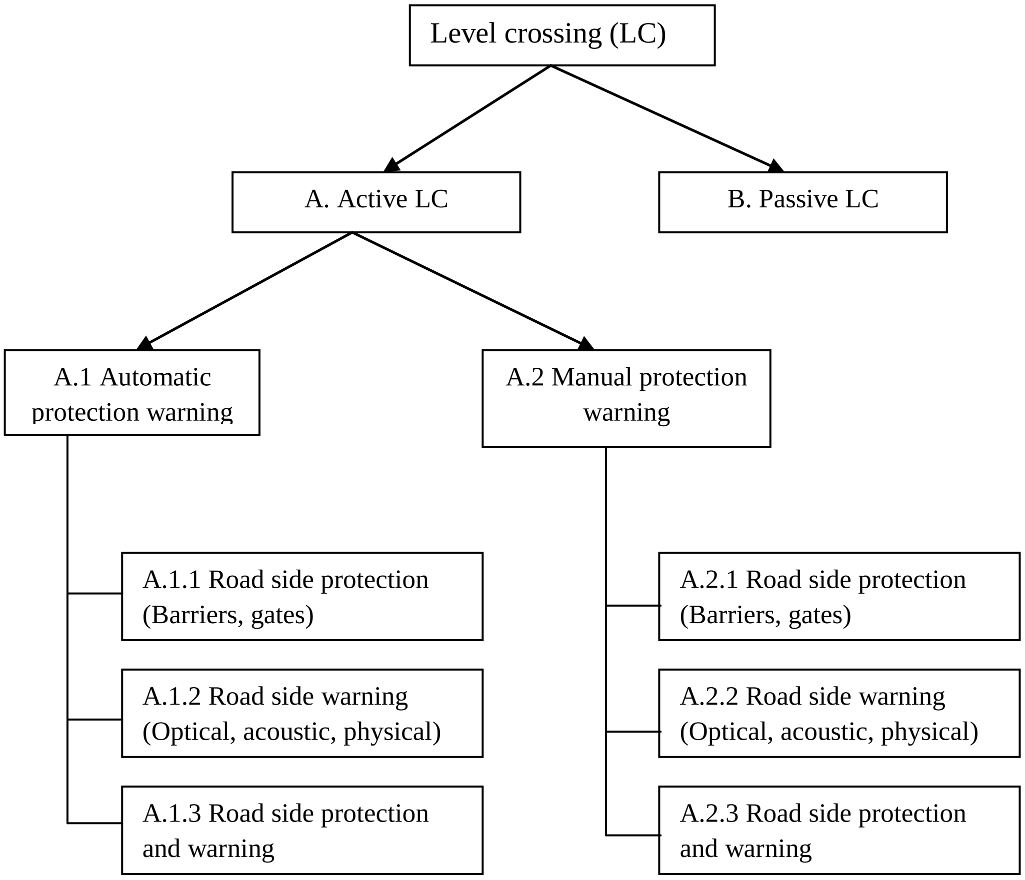


Fig.2.1. Level crossing (LC) types classified by ERA

For the European countries involved in Safer European Level Crossing Appraisal and Technology (SELCAT), the highest risk applies to LCs with warning lights (A 1.2), followed by the automatic LC with warning lights and barriers (A 1.3). Therefore, the main conclusions drawn from the statistics analysis by the European Conference of Transport Research Institutes (ECTRI) in 2008 are as follows:

– Safety at LCs is a definite problem for rail companies as they have no control over actions of road vehicle drivers and pedestrians at LCs and as it represents 29% of total accidents in a rail system compared to the road sector which represents 0.9% of total accidents. Clearly, while LCs represents a significant risk area for the safe operation of a rail network, this is in fact only a small element of the overall road safety issue.

– The highest operational risk in Europe is attributed to automatic LCs fitted with warning lights but without barriers. The second highest risk is attributed to automatic LCs with warning lights and with barriers.

– The results of investigations into causes of LC accidents have identified inappropriate or inadequate human behavior as the main source of the problem. Human factors play an important role for both the road and the rail. Violations of traffic regulations, disregard of warning signals, and trespassing by road vehicle drivers and pedestrians contribute to most of the fatalities. In terms of rail, staff with safety related responsibilities (i.e. manually operated LCs, warnings given by train drivers, supervision, and fallback operations) are particularly vulnerable to human errors [23]. Therefore, design of new technological solutions which will help increase people’s awareness of risk at LCs, the operational speed of the train and it will minimize the impact of intentional and unintentional hazardous human behavior. The solution suggested for these problems on the LC is to use the active and automatic warning system in addition to the automatic train braking system which is called in this thesis the “Intelligent level crossing accident prevention system”.

2.2. LC Accident Prevention

Since LC is a risky part of rail transportation system, it has got to be protected using reliable, fast and cost-effective means of technology to prevent accident before happening or to minimize the risk. In this thesis the proposed means of accident prevention on the LC of Addis Ababa LRT is Active LC with Automatic warning system and automatic train braking system using the radar technology to detect obstacle and the train. This system connects both the train control system and the highway traffic signal system. It would control the traffic signals and provide information to motorists on roadside variable message signs. Then Obstacle detection systems appear as a breakthrough solution to improve LC safety and lower the number of fatalities.

What is obstacle/target detection?

It is important to understand what is meant here by 'obstacle/target detection': in this context it is a means of identifying the presence of an object on a level crossing as the train approaches and/or the presence of train which is approaching to the LC. So that by providing information to guide a suitable response collision can be avoided or the consequences minimized. Obstacle/target detection is not just about the type or technology of the detector; what is done with the output is also critical for an effective system. At present there are no obstacle detection systems in operation at level crossings in Ethiopia. However, there is growing use of these systems in other countries.

Ideally, an obstacle detection system would:

- ✓ Improve safety at level crossings for all users (road and rail)
- ✓ Cause no or minimal delays for both train and road users
- ✓ Be affordable in terms of costs to install, operate and maintain
- ✓ Be practical to use and maintain

These requirements are often in conflict. For example it might be possible for a particular system to offer good safety benefits, but only at the expense of causing significant operational disruption (which itself can introduce safety risks). Another issue is the requirement for any candidate obstacle detection system(s) to interface effectively with the existing railway infrastructure, rolling stock and operations standards.

Given the definition used at the start of this section for obstacle detection, there are three main components (see Fig.2.2) that can be used to describe the configuration of such a system at level crossings:

- ✓ Detection: determining whether or not the crossing is clear
- ✓ Communication: a means of informing a person or system the need to take action
- ✓ Response: the action taken to mitigate collision [21]

Even though the obstacle detection on the level crossing is discussed widely, the detection of the train using the radar technology is included in this thesis using the same principle of detecting the obstacle on the level crossing.

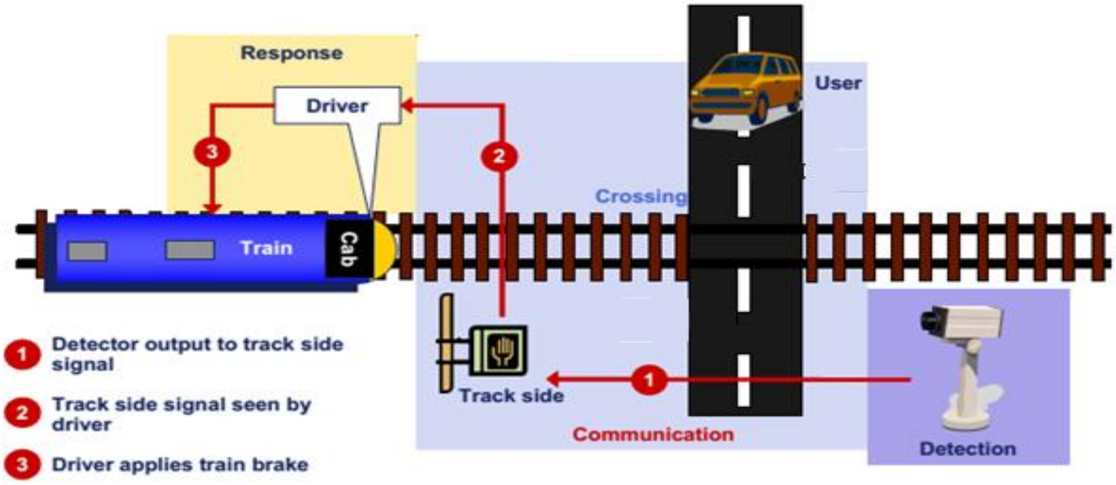


Fig.2.2: (Example) Obstacle detection system without barrier

2.3. Current technologies used for obstacle detection

The detection of vehicles, pedestrians or other obstacles approaching a LC requires the setting up of detectors. Numerous object presence detection technologies have been developed and implemented, with varying degrees of success and satisfaction. These have included technologies that utilize infrared light, video analytics, microwave, and buried (embedded) technologies such as magnetometers and inductive loops.

The choice of the appropriate detector depends strongly on external factors, e.g. environmental conditions or the size of the object to detect.

Obstacle detectors can be divided into two major categories: conventional and advanced. Conventional obstacle detection has been used to prevent crashes between trains and vehicles (optical beam, sonic detection, inductive loop). Obstacle detection systems using advanced methods are constituted by Radar Method and video imaging [23].

Some of the obstacle detections for prevention of accident on LC are discussed below:

A. Infrared and Video Analytics

Visible and non-visible light emission and detection (e.g. infrared) operate at wavelengths that can be obscured easily by rain and snow, and occasionally overwhelmed by background sunlight. Despite the sophistication of video systems and the ability of analytic processing to recognize and classify vehicles, these systems are unreliable without sufficient light levels. As with infrared detection systems, the performance of video analytic systems may be impaired by the presence of rain, fog, snow, or the glare of bright background sunlight [3][24].

B. Buried or Embedded Detection Technologies

Magnetometers and buried inductive loops operate on simple physical principals: they detect changes in a magnetic field or inductance resulting from a proximate highway vehicle with sufficient metallic content. But these sensors are embedded in the roadway itself, a requirement that carries a number of disadvantages. With a magnetometer, 'hockey-puck' sized detectors/transponders are set into core-drilled receptacles in the roadway. These devices detect the overhead passage of vehicles and wirelessly communicate the information to a local concentrator. This system introduces the complexity associated with a local wireless network which could impact reliability—and adds a battery maintenance responsibility to the life cycle cost of the detectors [3][24].

❖ Buried Inductive Loops

Of the aforementioned vehicle detection technologies, buried inductive loop systems are most typically utilized in crossing applications. This system is easy to install and is not subjected to environmental conditions. The main drawbacks are that it cannot detect pedestrians or bicycles, and the high cost of installation and maintenance, because it needs a large number of loops to be efficient [24].

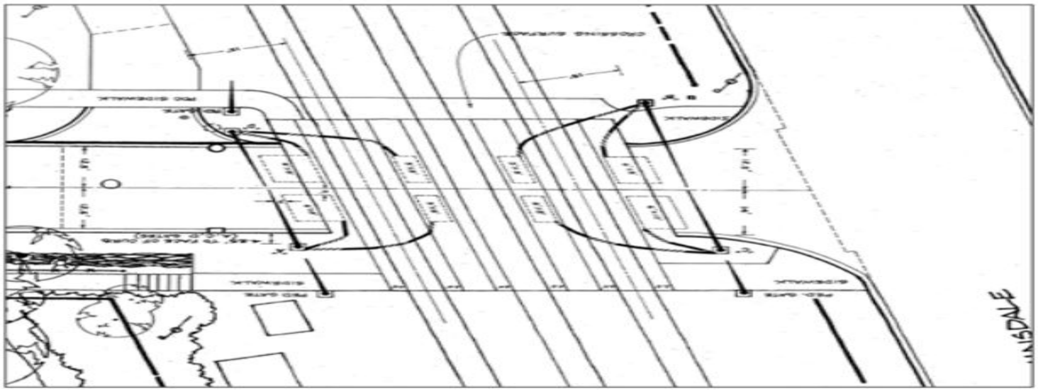


Fig.2.3. Inductive Loop Locations

Inductive Loop Detection System Cost

New Inductive Loop Systems

The cost estimate for a standard dual track, 6-loop inductive vehicle detection system was obtained from Railroad Controls Limited (RCL). Labor costs and the number of hours or days typically required for installation were provided as low-high ranges. The following system cost breakdown conservatively used the lower amounts from the ranges provided.

New Loop Installation Costs, Double-Track System with Six Embedded Loops				
Loop Materials	**Quantity**	**Cost**	**Total**	**Notes**
Preformed Loops	6	$400	$2,400	With integrated check loops
Junction Boxes	2	$300	$600	Mast base junction boxes
Loop Detector Electronics	2	$4500	$9000	Railroad type U1400, 4-Loop Detector
Cabling	600 ft	$5/ft	$3000	Home run cable
Total Materials			$15,000	
Loop Installation Labor	**Quantity**	**Cost**	**Total**	**Notes**
Construction	3 days(d)	$3,000	$9,000	Four-man crew, 3,000-4,000 per day, 2-5d
Boring	200 ft	$20/ft	$4,000	20-75 per foot, allow one day for boring
Flagger	4 d	$1,000/d	$4,000	100/h, not including crew mobilization time
Total Installation Labor			$17,000	
Roadway Surface				**Notes**
Asphalt Milling, Overlay			$4,680	3.5 in mill and overlay, 144 yd^2
Total Loop Installation			$36,680	

Table 1 Embedded Inductive Loop-Based Vehicle Detection System Cost [3]

Loop Replacement Cost

Whether due to the initial installation yield, limited lifetime, or corridor upgrades, the reinstallation process for a single loop and lead in cable can cost up to $25,000 for a saw-cut installation and $34,000 for an installation involving asphalt milling and resurfacing (costs are based on 2012 quotes to the City of Olathe, KS). Even more important to the railroad is the time required to engage a contractor to perform this repair and replacement work, during which time train speed restrictions are generally in place [3].

D. Microwave Radar

Microwave and ultra wideband radar systems have the advantage of operating at gigahertz (GHz) wavelengths that pass through rain, snow, and fog. They do not rely on visibility, ambient light levels, and are not affected by background sunlight. But to cover the large detection area at a crossing island, multiple radars and reflectors, or radars that feature mechanical or optical scanning, are required. Additionally, the cost and complexity involved in the use of these earlier radar solutions have generally rendered them unsatisfactory, maintenance intensive, and cost prohibitive for railroad application. In fact, until recently, microwave radars operated on a Doppler process, detecting frequency shifts in emissions that were then reflected back to the radar detector. In essence, these Continuous Wave (CW) Doppler radar devices did not explicitly detect stopped vehicles, but instead utilized a counter technique that added vehicles coming into a detection zone and subtracted vehicles moving out of the detection zone. According to these systems, a non-zero counter value indicated that more vehicles had entered the detection zone than had left it, implying the continued presence of a stopped vehicle. Newer Frequency Modulated Continuous Wave (FMCW) radars and more advanced classification algorithms are better able to detect stationary vehicles, based on their reflection of returned radar energy and adaptive 'learning' of the detection environment. In a process called 'washout,' the radars maintain detection of stationary vehicles for a considerable period of time (e.g. 15–60 minutes) before beginning to treat those objects as part of the permanent 'background'[3][24].

The main Characteristics of the radar system are:

Ability to Detect Moving and Stopped Vehicles

Because the MMW radar sensors are based on Frequency Modulated Continuous Wave (FMCW) rather than just Continuous Wave (CW) emissions, they do not rely on Doppler-shift detection and are therefore capable of detecting stopped vehicles, fulfilling another important objective of a radar-based solution. Differentiation from objects that are always stationary (poles, buildings, etc.) is accomplished by sophisticated algorithms that continuously 'learn' the sensors' environment and begin to ignore objects that have remained stationary for longer than 15-60 minutes (min).

Long Life, High Mean Time between Failures

Calculated Mean Time Between Failures (MTBF) for the MMW radar sensor is greater than 10 yr, a not unexpected longevity given that the solid-state device is safely mounted above and just outside of the crossing island and therefore not subject to the trauma of in-road installation and post-installation lift layers of hot asphalt. It should be noted that this MTBF is a calculated value based on a prediction model, and is not intended as a guarantee of field failure rates; nor is it supported by actual field experience [3][24].

Radar-Based Detection System Cost

Because of the non-embedded nature of the radar vehicle detection system, installation time and labor is considerably less than for an inductive loop system. Table 2 below shows the new Radar Detection System Cost Estimate [3].

New Radar Detection System Installation Costs				
Radar Materials	**Quantity**	**Cost**	**Total**	**Notes**
Radar Sensor	2	$6,400	$12,400	WX-ss-300 SmartSensor-Rail
Radar Mast Extension	2	$300	$600	
Junction Boxes	2	$200	$400	Mast Base Junction Boxes
Radar Electronics	1	$4,500	$4,500	VDR24, Two Radar, Four Zone
Mast Cable	2	$200	$400	With weatherproof connector
Cabling	600 ft	$2/ft	$1,200	Home run Cable
Total Materials			$19,500	
Loop Installation Labor	**Quantity**	**Cost**	**Total**	**Notes**
Construction	1 day(d)	$3,000	$3,000	Four-man crew, 3,000-4,000 per day, 2-5d
Boring	200 ft	$20/ft	$4,000	20-75 per foot, allow one day for boring
Flagger	1 d	$1,000/d	$1,000	100/h, not including crew mobilization time
Total Installation Labor			$8,000	
Total Radar Installation			**$27,500**	

Table 2 Radar-Based Vehicle Detection System Cost [3]

The cost of a new inductive loop detection system for a dual-track, six-loop system is estimated to be $36, 680. In contrast, as shown in Table 2, installation of a dual radar system to detect vehicles within the same type of crossing is estimated to be $27,500, or 25 percent less than the cost for a loop based system.

As discussed in this thesis, emerging radar-based detection technology holds potential for successful adaptation to highway-rail grade crossing applications, and offers distinct improvements over existing embedded vehicle detection solutions [3].

The main advantages of the MMW range are:

Short wavelength: the component sizes are reduced compared to those in the microwave band. This makes them suitable for mobile platforms such as aircrafts, helicopters, cars or even small robotic platforms. It is also possible to achieve lower beamwidth which results in better resolution.

Wide bandwidth: Investigating atmospheric absorption for horizontal propagation over 300

GHz of bandwidth including the MMW band represents that the principal windows exist at 35, 94, 140 and 220 GHz with extremely large available bandwidths around each.

This has a number of advantages:

- ✓ High data rate for communication systems,
- ✓ High resistance to jamming since wide bandwidth is available,
- ✓ Very high range resolution for tracking and target detection,
- ✓ Increased recognition capability of slowly moving target due to the high Doppler frequency Low sensitivity to environmental characteristics Atmospheric absorption and attenuation due to inclement weather condition such as fog, dust or smoke are much lower compared to optical and IR frequencies [22].

There for Recently developed radar-based systems for traffic intersection and other ITS applications suggest that improvements in performance and life cycle cost factors over those of embedded detection technologies are possible.

MMW Radar	**Embedded type (Inductive loop)**	**Infrared (IR)**	**Video**
Able Detect Moving and Stopped motor bicycle, Vehicles and human beings	cannot detect pedestrians or bicycles		Can detect all
Physically small equipment	Physically large equipment	Physically small equipment	
Large area of coverage	Limited area of coverage	Limited area of coverage	
Small beamwidths • high accuracy • reduced interference • low multipath/clutter • high antenna gain	introduces the complexity associated with a local wireless network (interference is there)		
Large bandwidth • high range resolution • Doppler processing	Low resolution		
Atmosphere penetration • fog, smoke, and dust • much better than for IR/EO	not subjected to environmental conditions	Can be obscured easily by rain and snow and sometimes by background sunlight.	Is affected by night, fog, rain and dust which is unreliable without sufficient light levels
Low cost	High cost of installation and maintenance		
High longevity	Low longevity		

Table 3 Comparison table for obstacle detection technologies

Table 3.above shows the summarized comparison between different technologies of obstacle/target detection. From the data that we have been discussing on the above sections of this chapter, the Inductive loop is the widely used type of technology to detect obstacles (vehicles) on level crossing to prevent accident. But the MMW radar has high reliability and performance in all weather condition, also it is cost effective than the widely used buried Inductive loop technology.

2.4. Over View of LRT Ethiopian Railway (thesis area)

Referring to reference number 4 the Preliminary Design of Addis Ababa E-W & N-S (Phase I) Light Rail Transit Project, on page 10-12 we can see the design of the signaling system on the level crossing, which is written below on some of the parts word by word:

- ✓ With respect to the operation requirements and safety at level crossings, the crossing signaling control system should provide the following functions:
    1) Allow the train at the level crossing to be given the priority to pass through the level crossing;
    2) Detect trains approaching and leaving the level crossings.
    3) Control the signal at crossings;
    4) Monitor the crossing signal state and transmit relevant information to the operation assistant dispatching system.
- ✓ The passing priority of LRT at level crossings is mostly realized through the interface between the LRT signaling system and the traffic light control system of the roads. The LRT signaling system transmits the information of the train approaching the level crossing to the traffic light control system of the roads. After receiving such information, the traffic light control system of the roads will control the traffic signal light so as to allow the train can have the priority to pass through the level crossing.

  In Addis Ababa, no traffic light control system is available at the level crossing between the line of the Project and the public roads. However, the aforesaid solution has some reference significance for the design of the signaling system at the level crossing for the Project in urban environment.

Therefore, the design of the signaling system at the level crossing for the Project shall adhere to the following principle:

(1) Since manual driving mode by viewing is adopted for the Project, the running speed of the train shall be controlled manually by the driver.

(2) The signaling system at level crossing shall be designed to avoid any serious impact on the urban road car flow caused by fault of the signaling equipment at the crossing.

(3) The signaling system at level crossing shall be designed in full combination with the urban roads environment where the line runs through.

- ✓ According to the content of Article 46 “Physical level crossing barriers should not normally be used for on-street tramways” in Part 2 “INTEGRATING THE TRAMWAY” of the GUIDANCE ON TRAMWAYS (0RR-Nov.2006), the crossing barrier doesn’t apply to the level crossing for this project.
- ✓ The crossing barriers will not be able to protect the level crossing and may harm the rolling stocks located below the crossing barriers. Through the analysis of above reasons, the crossing signaling system will not be set with barriers in this project (AALRT project).

Then from the above overview information of the AALRT project we can see that there is no way of detecting an obstacle on the level crossing to prevent accident. Then based on this information the work of this thesis will be on preventing accident on the level crossing using a radar technology to detect the target/obstacle.

Chapter Three

3. System Modeling

After discussing the thesis plan on chapter one, in chapter two, the meaning of LC, Technologies of accident prevention on LC by obstacle detection and the overview on Ethiopian Railway for AALRT have been covered. In addition on the previous chapter after comparing the characteristics of different LC accident prevention technologies the radar technology has been proposed. Here on this chapter the modeling of the proposed accident prevention system using the radar technology is done.

The chapter is organized as follows. In Section 3.1 The system architecture for Intelligent accident prevention is discussed, In Section 3.2 Modeling system structure and working principle of the system is discussed; In Section 3.3 Designing the hardware components of the system is conducted and at last in Section 3.4 The Software procedure for the system is designed.

3.1. Intelligent accident prevention system

The number of vehicles on the road continues to rise dramatically. This has led to heavy traffic congestion which is blamed for a growing number of car accidents. Particularly serious accidents can occur because of violations of level crossing regulations. Many researchers have proposed schemes to prevent level crossing accidents. However, more intelligent technology is required to prevent accidents at level crossings. Fig. 3.1 shows architecture that employs an intelligent system at level crossings. Hereafter, the architecture is referred as the intelligent level crossing system. The intelligent level crossing accident prevention system provides warning information to train and roadside traffic adjacent to a level crossing, using a wireless one-way communication link, for the purpose of preventing accidents and reducing damage. Level crossing events (like warning messages) and radar information about obstacles on the crossing (vehicles and pedestrians, etc.) are transmitted to a train from the level crossing, and information related to the train (direction, velocity, distance, etc.) is processed and the traffic lights to the vehicles and pedestrians is controlled according to the information found from the radar.

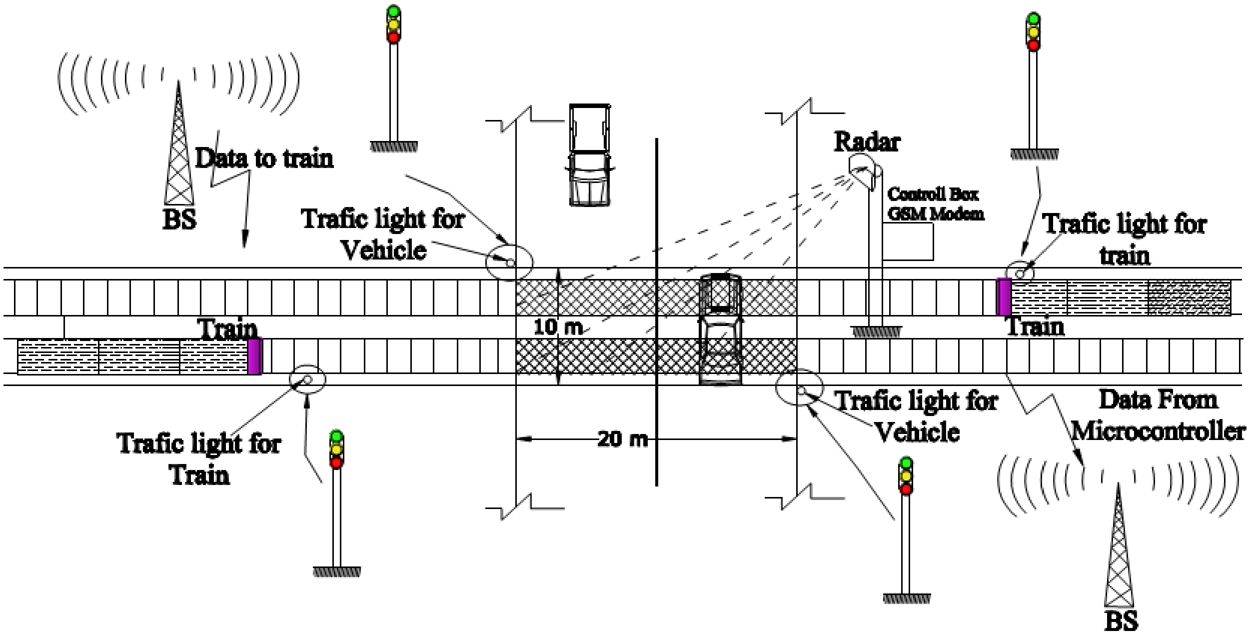


Fig. 3.1 System Architecture

3.2. Modeling of System structure and working principle

The main components and functions of the intelligent level crossing system are explained in Fig. 3.2 below.

The Architectural Context Diagram for the System will inter-relate the train and the level crossing wayside warning device, radar sensors, transceivers, GSM /GSM-R module and microcontrollers.

In general, from the system context modeling on fig.3.2 below, the working principle of this system is to detect an obstacle on the level crossing using the radar technology and to let know the train operator about the current status of the level crossing so that he/she can take a measure, and to detect an approaching train using the same technology and to control the level crossing traffic signals. This operations are controlled using the microcontroller, which helps to interface each devices needed and to process and get the needed information.

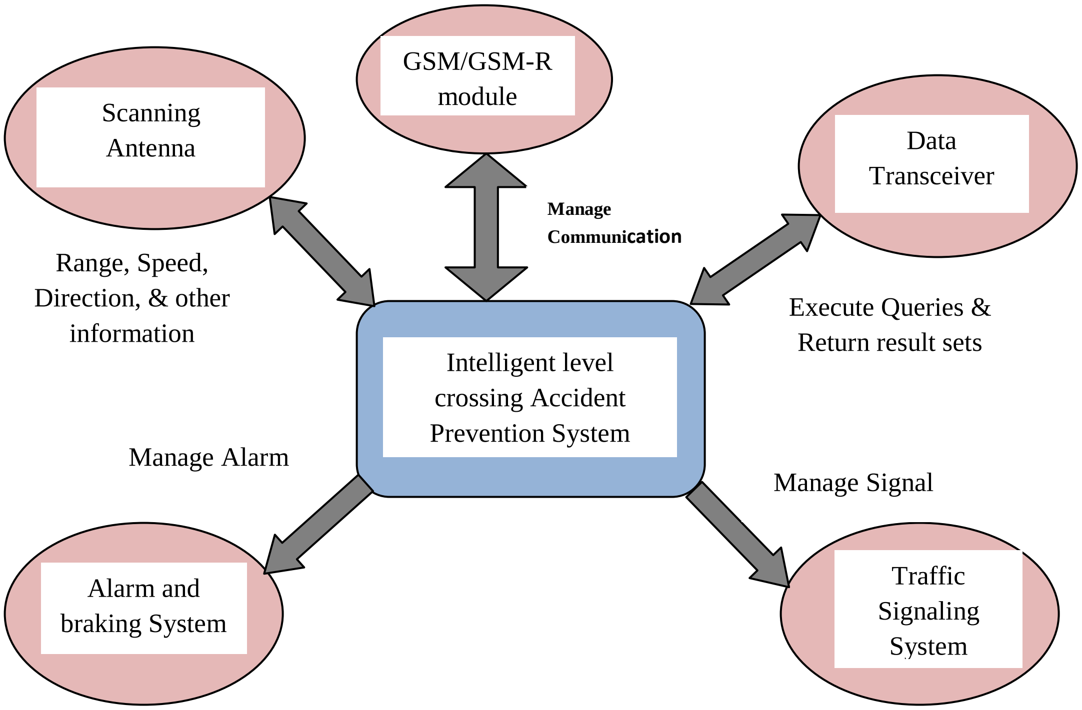


Fig.3.2 Architectural Context Diagram for the System

3.3. Design of the Hardware Component of the System

To accomplish this task certain components are required. Fig. 3.3 shows us the overall system block diagram of the system. The following are the basic Components of the system.

- **Radar**

The radar is the hardware which is used for the detection of the targets (the obstacle on the level crossing and the approaching train) so that the raw data found from it is going to be used by the microcontroller.

- **GSM/GSM-R modem**

The GSM/GSM-R modem is selected for permanent data exchange between the approaching train and the level crossing wayside Microcontroller. The GSM information transmitted from the level crossing Microcontroller is received by the on board GSM module and processed by the onboard microcontroller and then the appropriate signal is shown to the train driver so that the train driver can take a measure to reduce the speed of the train or stop the train before approaching the level crossing to prevent accident.

- **Microcontroller**

This serves as the CPU for the system. It captures a raw data provided by the radar receiver and processed to extract the required location, speed and direction information. It holds all the required information that is to be sent to the train or to flash the appropriate wayside traffic signal to clear the level crossing quickly. It also controls data transmission module (GSM module) to send information to the approaching train. Which means it is responsible for monitoring any danger of accident between trains and obstacles on the level crossing. It actually acts as a bridge between radar receiver, traffic lights and system.

- **Traffic Light**

Is the hardware component which helps to show the Red, Yellow or Green signals for the vehicles and pedestrians interring or leaving the level crossing. This signals works according to the data sent by the microcontroller.

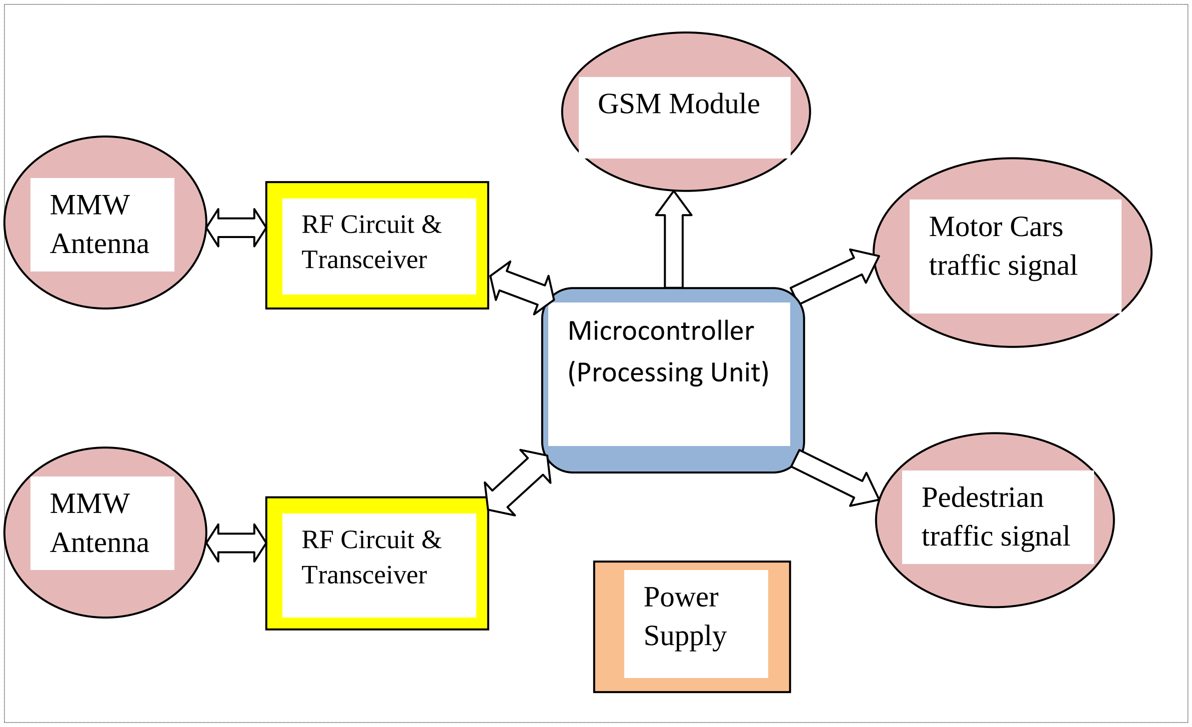


Fig. 3.3 (a) Level crossing track side equipments

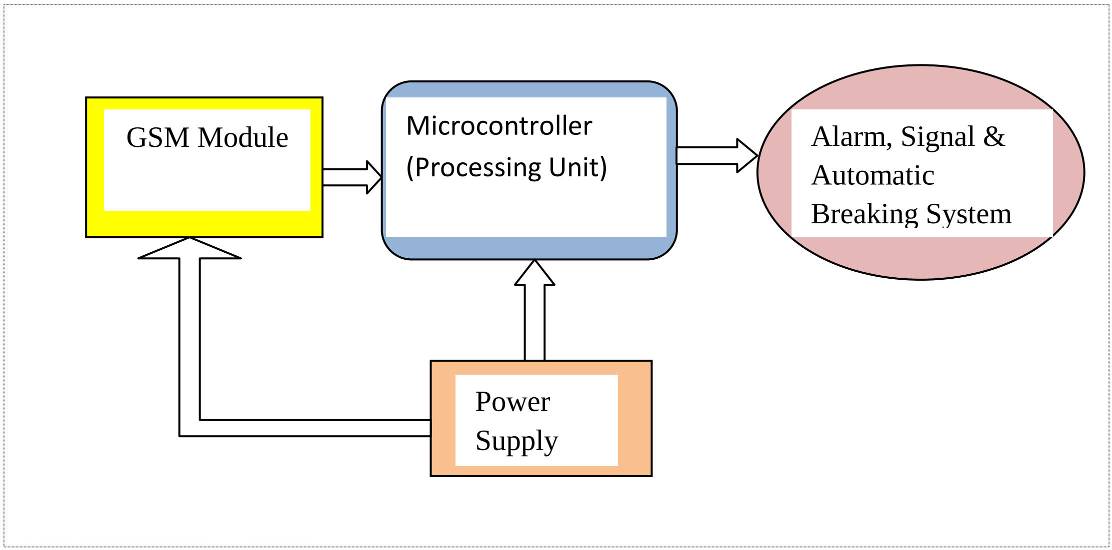


Fig. 3.3 (b) Approaching trains On board devices

3.4. Design of the Software Procedures of the system

Microcontroller is acting as Central Processing Unit for the System. All operations of the system are to be controlled by the microcontroller. Microcontroller needs instructions to operate the whole system. These instructions are provided to microcontroller by writing the software into microcontroller‘s flash memory. It reads the software instruction by instruction and performs the action as required by instruction. Complete software is broken down into small subroutines as shown by the Figure 3.4.

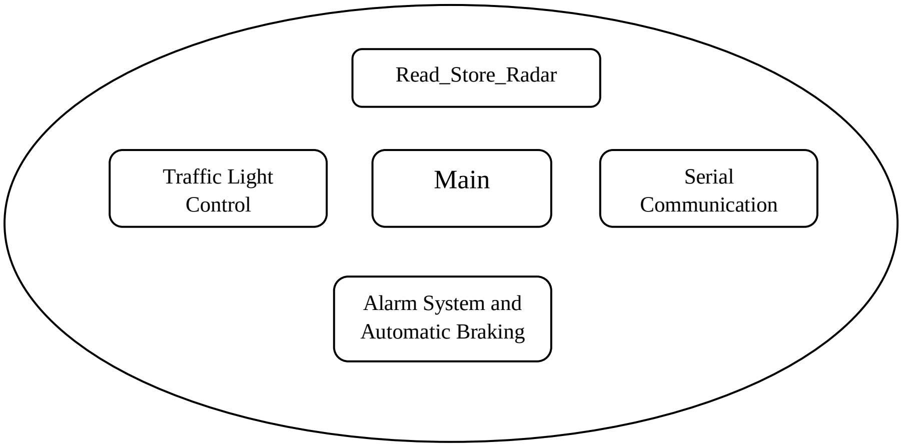


Fig. 3.4 Software Procedure of the System

Initialization and checking status of devices procedure

This is the flow chart which helps to initialize the microcontroller and helps us to check the status of the obstacle detection radar, approaching train detection radar, Modem presence and SIM readiness.

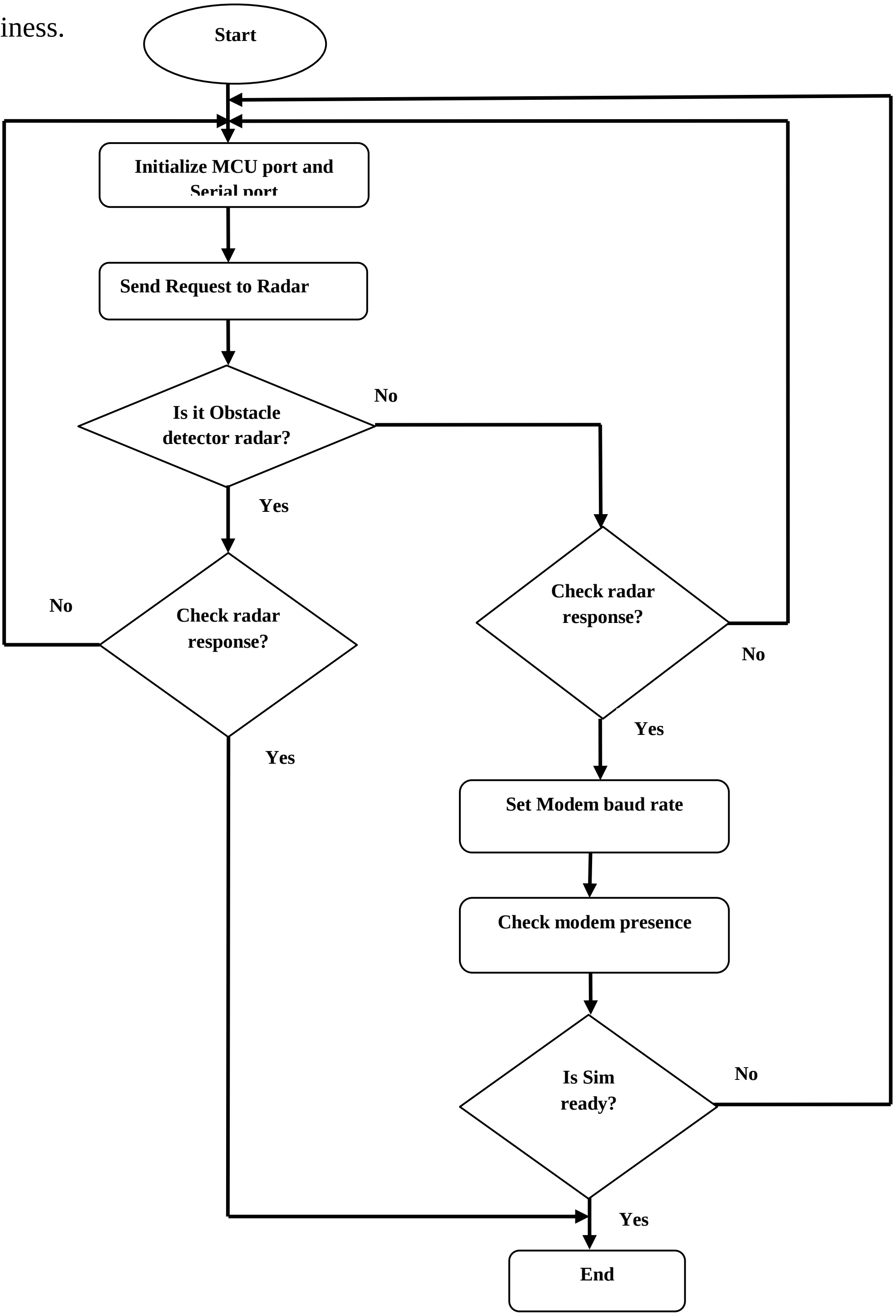


Fig. 3.4.1 Flow chart for Start-up procedure

Obstacle Detection Read Radar Data Procedure

This subroutine helps to get the real time location and speed information of the obstacle from the Radar, process Radar data and extract useful information and store information in a formatted string. This stored information is used by the microcontroller and it sends information to the train operator or to OCC.

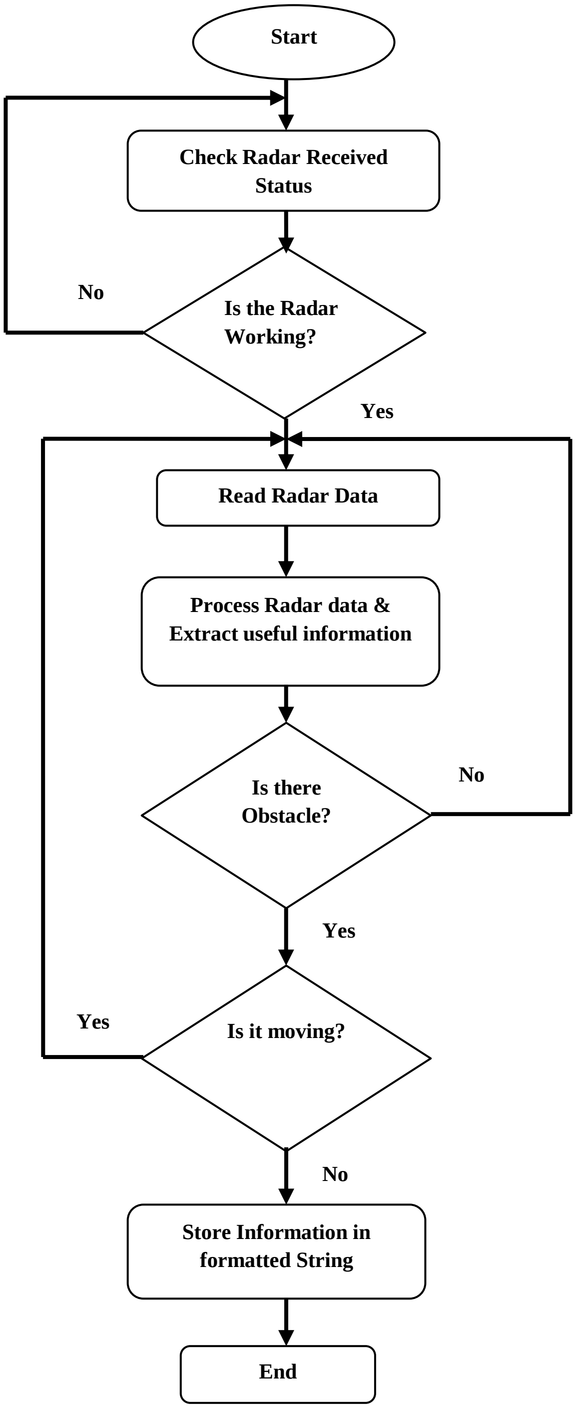


Fig.3.4.2 Flow chart for Obstacle detection

Approaching Train detection procedure

This procedure helps to process the radar data and get the useful information to detect the approaching train. If the reflected back frequency increases (wavelength decreases), the deference between the center frequency and the reflected back will result a negative signed Doppler frequency shift, which shows us that the train is approaching otherwise the train is leaving or going away from the level crossing.

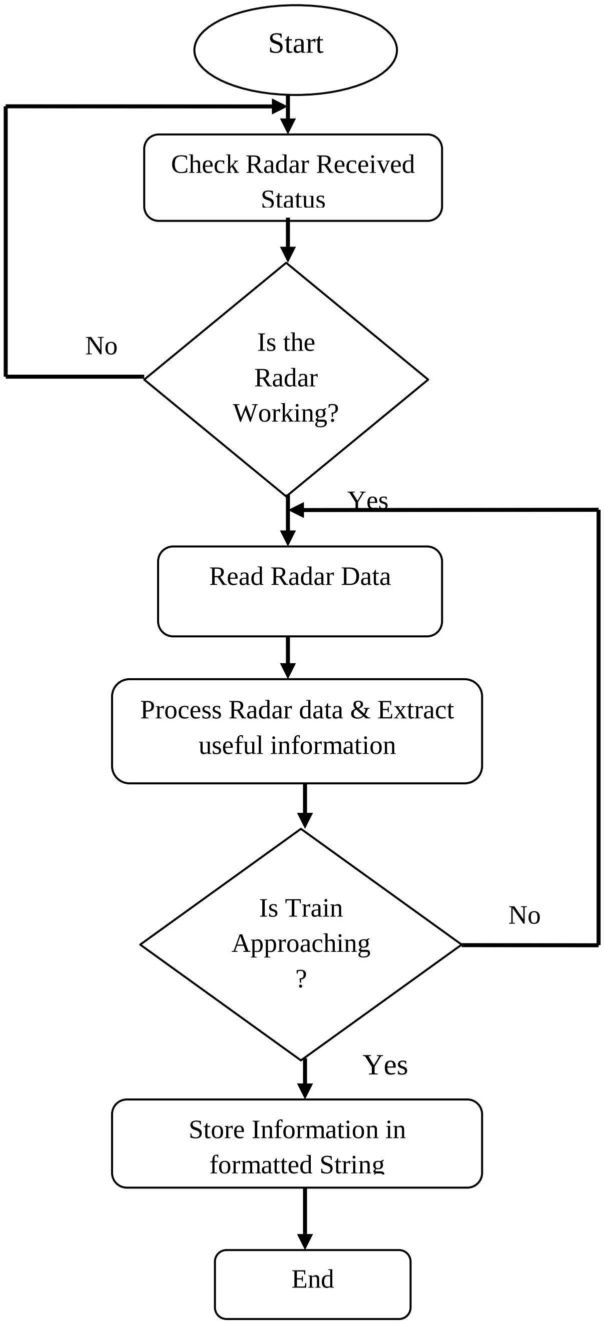


Fig.3.4.3 Flow chart for Approaching train detection

Traffic Light Control procedure

The Traffic Light Control subroutine controls the traffic light for vehicles, motorbikes, bicycles and pedestrians whenever an approaching train is detected. The flow chart on Fig.3.4.4 is based on an assumption of approaching train with a speed of 70km/hr, and the fixed block is 1km. for a train within a distance of 1km it will need 51sec to clear out from the fixed block of the level crossing. With a contingency of 4 sec the red light will flash for 55seconds. Then, after the yellow light flashes for 5sec the Vehicles and pedestrians will be allowed to cross the level crossing. If the distance of the train from the radar is greater than 2km green light will flash, if distance is between 1km and 2km the yellow light will flash for the vehicles and pedestrians to clear out from the level crossing.

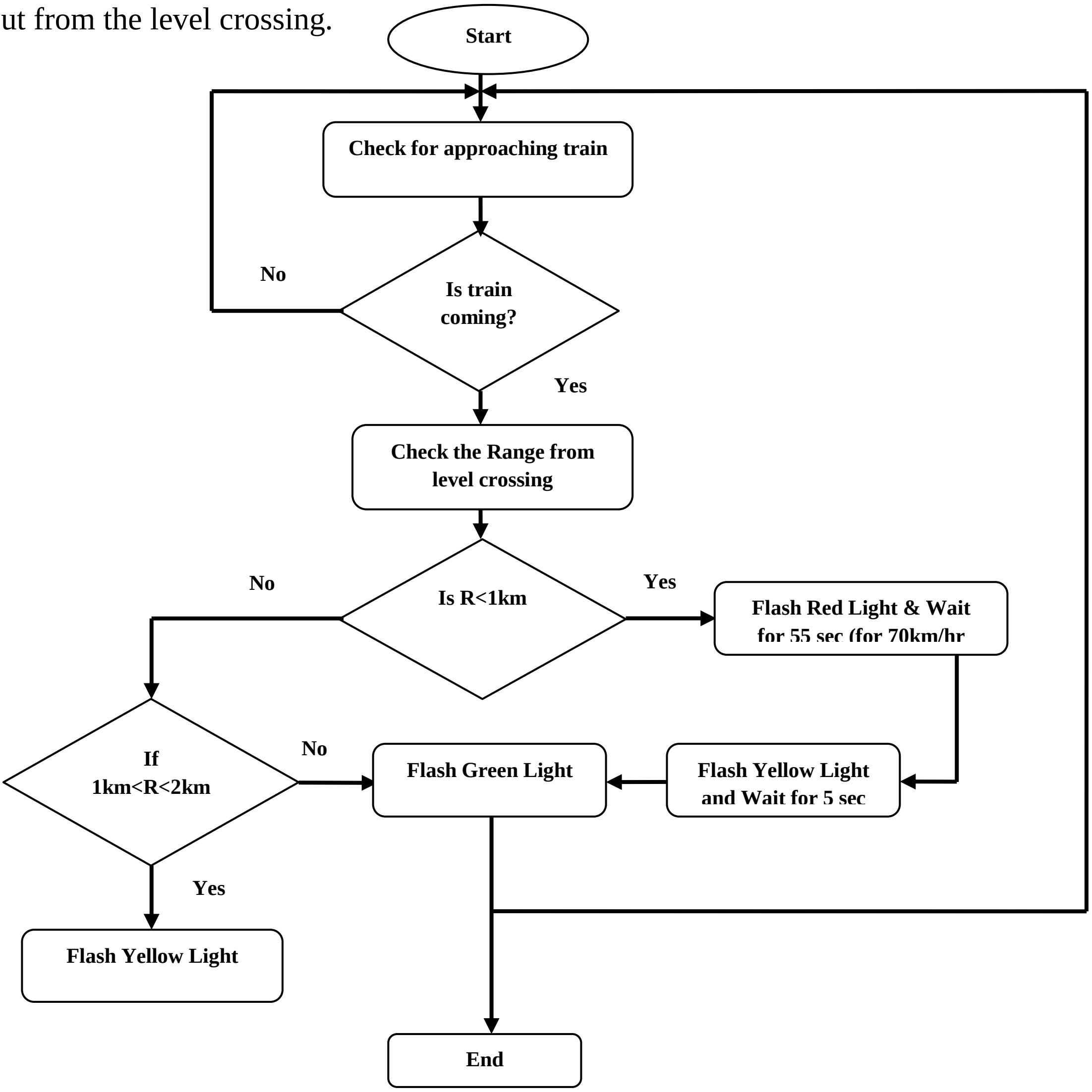


Fig.3.4.4 Flow chart for the traffic light

Serial Communication Procedure

The Serial communication subroutine handles the communication system between the approaching train or OCC and the level crossing wayside microcontroller. Here the GSM Communication system (if available the GSM-R Communication system) can be used to send data to the approaching train.

Send SMS procedure

All the information got from the Radar is sent to the approaching train using this subroutine. In this subroutine the SIM presence and readiness checked and if it is ―"OK" it waits Radar data and sent it immediately.

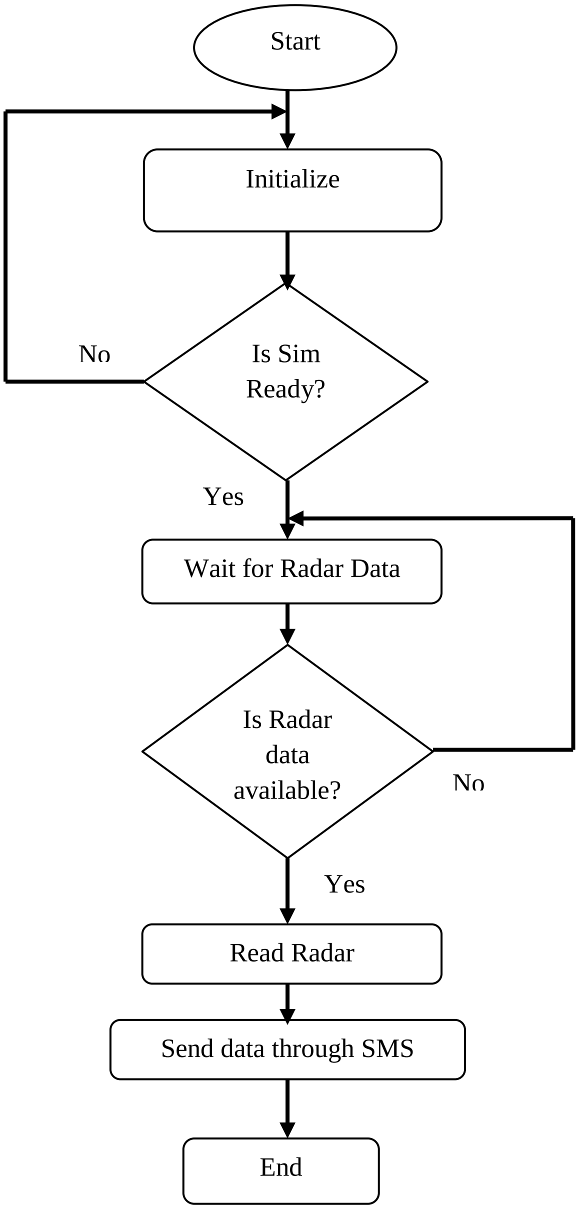


Fig.3.4.5 Flow Chart for Sending SMS to approaching train

Receive SMS Procedure

All the information from the level crossing wayside microcontroller is received by the approaching train using this procedure.

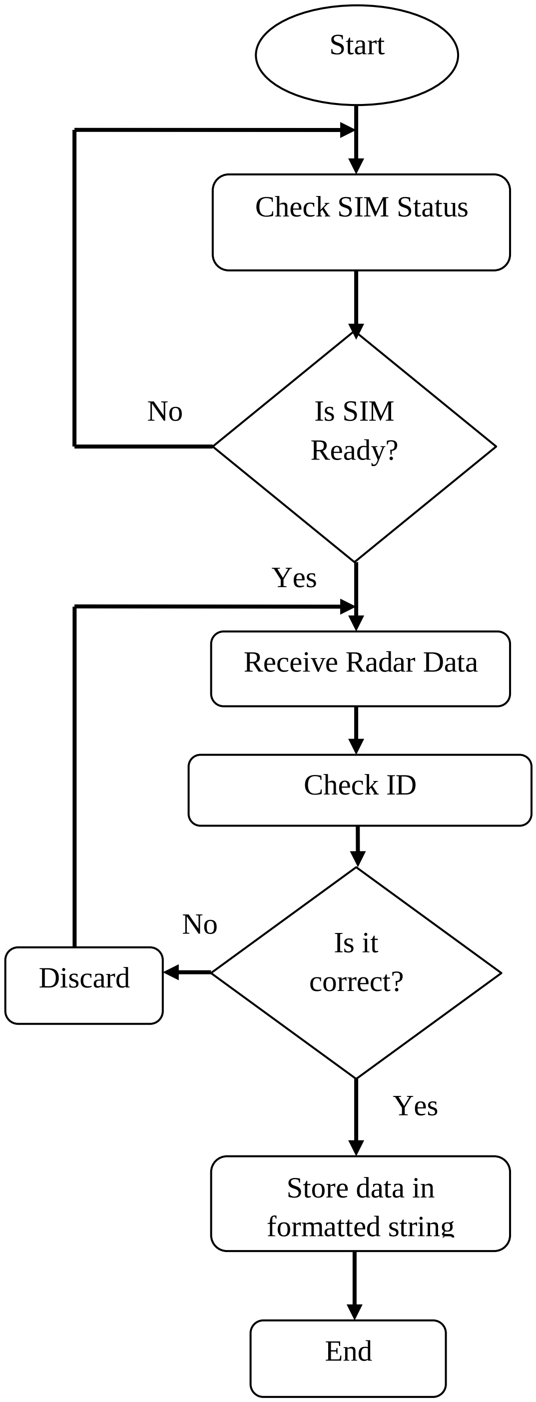


Fig. 3.4.6 Flow chart for Receiving SMS data

Main procedure

The main procedure which interrelate all the system procedures and to send message to the approaching train using the GSM communication system or if it exists using the GSM-R communication system.

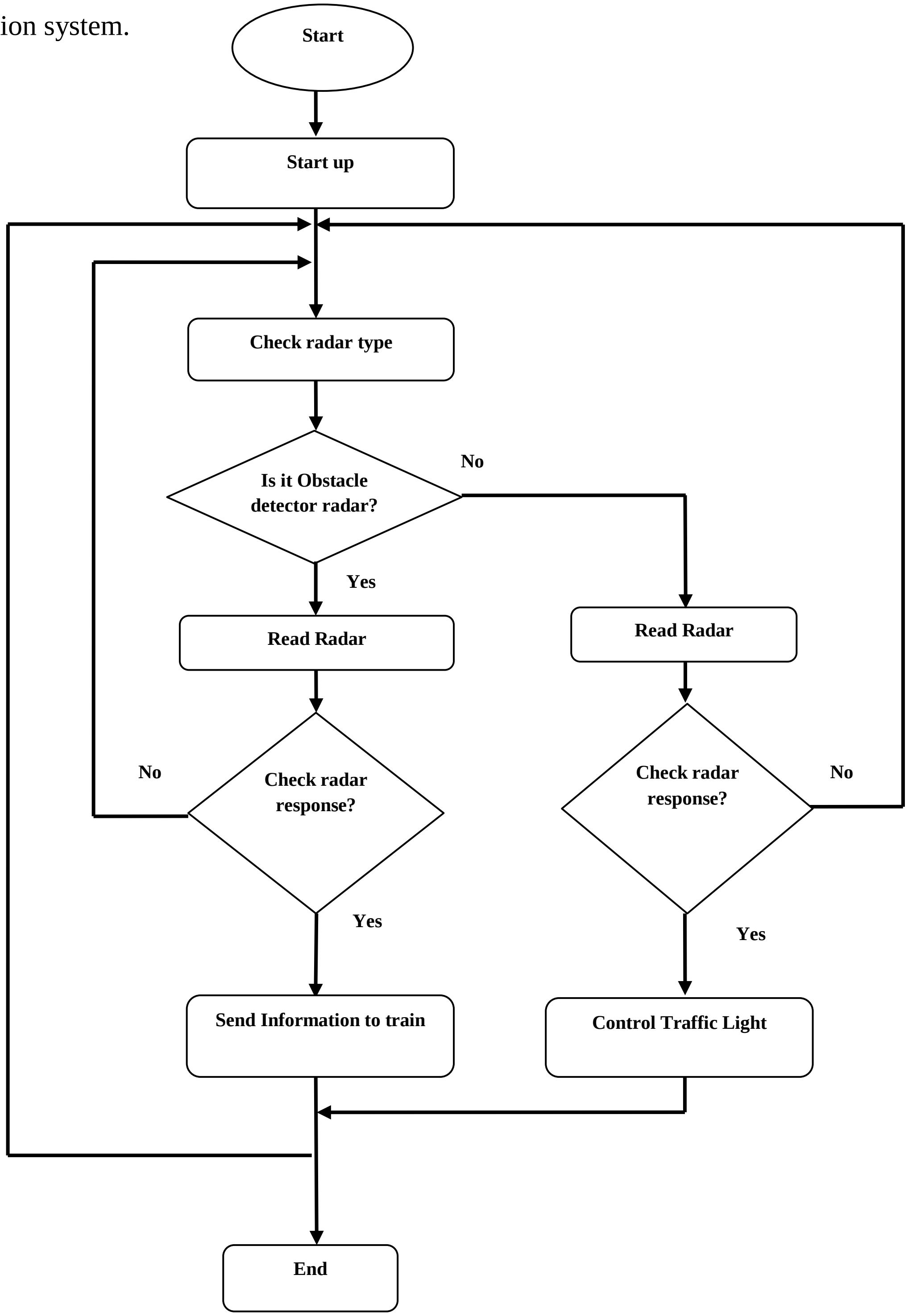


Fig.3.4.7 Flow chart for main

Alarm system subroutine (On board monitoring)

This subsystem is installed in the cab of the train. Warning messages and real-time information of any obstacles are provided to help the train driver notice obstacles and stop the train before reaching the level crossing. If the train driver fails to react appropriately, this system is designed to immediately deploy the emergency brake. The alarm system subroutine includes flashing light, buzzing sound to attract the attention of the train controller and motor control to deploy automatic braking.

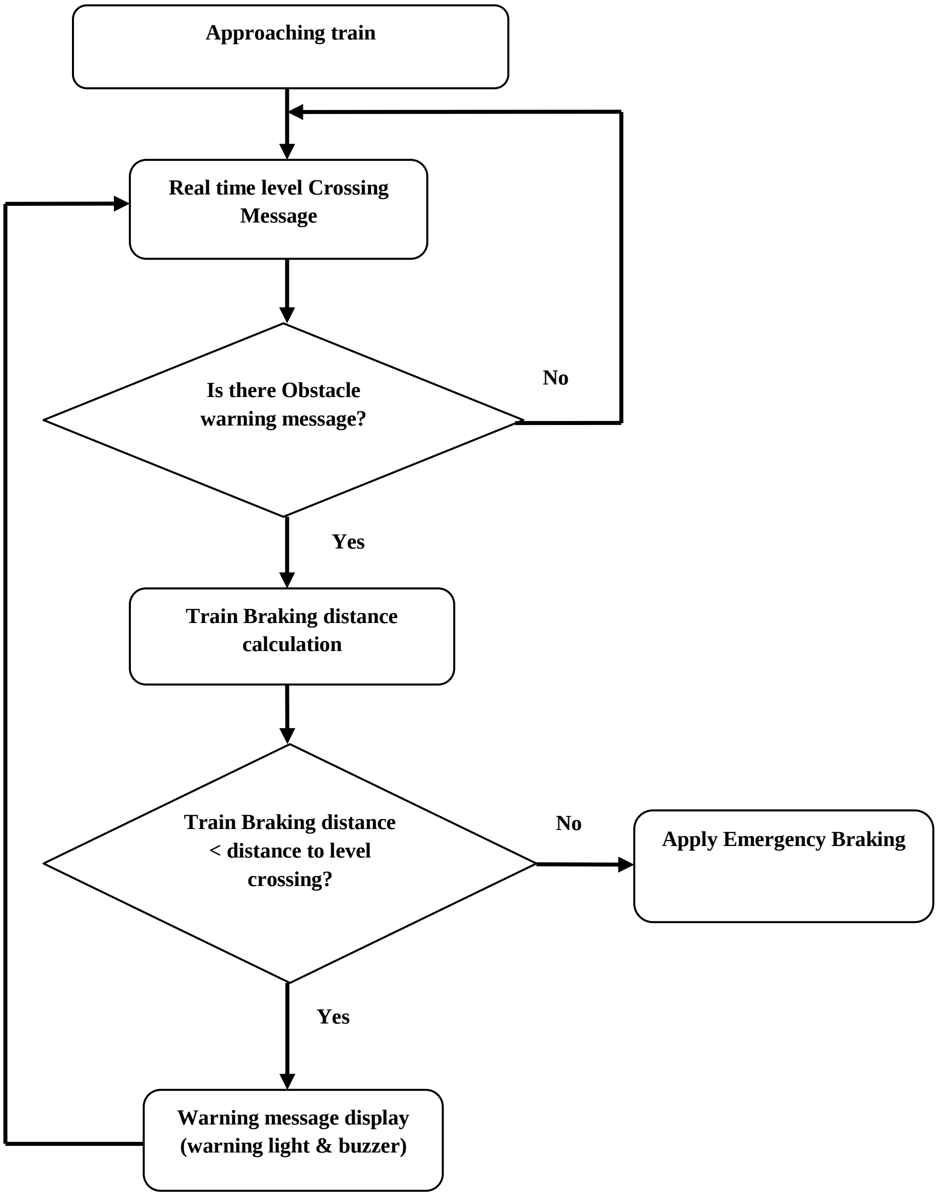


Fig.3.4.8 On board Alarm Flow chart

Chapter Four

4. Designing of the MMW radar

On the above chapter which is chapter three the overall system architecture, system structure and working principle, and its hardware and software modeling of the proposed accident prevention system on the level crossing using the radar technology have been discussed. This chapter will cover the designing part for the radar technology.

Here are the different sections of this chapter. In Section 4.1 Introduction to radar technology is discussed, In Section 4.2 Radar Classification is discussed; In Section 4.3 The MMW obstacle detection radar including its meaning, configuration, Mathematical modeling and the method of modulation FMCW which is used for the obstacle/target detection is designed. And at last the parameters of the designed radar for the prevention of accident are summarized in a tabular form.

4.1. Introduction to Radar

The word radar is an abbreviation for RAdio Detection And Ranging. In general, radar systems use modulated waveforms and directive antennas to transmit electromagnetic energy into a specific volume in space or an area on the ground to search for targets (Obstacle). Objects (targets) within a search volume will reflect portions of this energy (radar returns or echoes) back to the radar as it is shown on Fig.4.1 below. In this process the frequency of the reflected energy is changed (shifted). This shift in frequency is known as the DOPPLER EFFECT. These echoes are then processed by the radar receiver to extract target information such as range, velocity, direction of movement, and other target identifying characteristics.

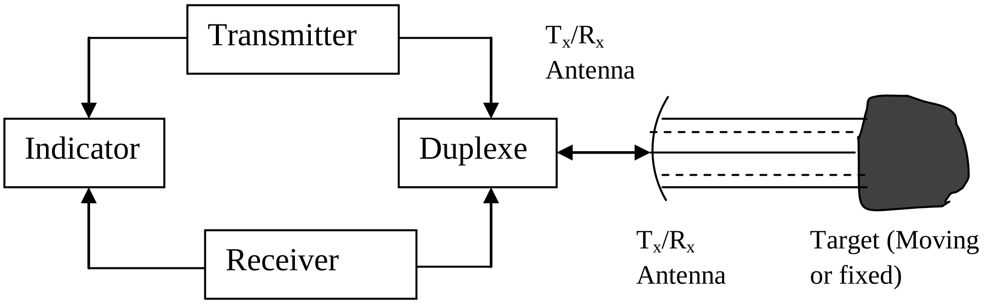


Fig. 4.1 Block diagram of improved radar

4.2. Radar Classification

Radars can be classified as ground based, airborne, space borne, or ship based radar systems. They can also be classified into numerous categories based on the specific radar characteristics, such as the frequency band, antenna type, and waveforms utilized. Another classification is concerned with the mission and/or the functionality of the radar. This includes: weather, acquisition and search, tracking, track-while-scan, fire control, early warning, over the horizon, terrain following, and terrain avoidance radars. Phased array radars utilize phased array antennas, and are often called multifunction (multimode) radars. A phased array is a composite antenna formed from two or more basic radiators. Array antennas synthesize narrow directive beams that may be steered mechanically or electronically. Electronic steering is achieved by controlling the phase of the electric current feeding the array elements, and thus the name phased array is adopted.

Radars are most often classified by the types of waveforms they use, or by their operating frequency. Considering the waveforms first, radars can be Continuous Wave (CW) or Pulsed Radars (PR). CW radars are those that continuously emit electromagnetic energy, and use separate transmit and receive antennas. Unmodulated CW radars can accurately measure target radial velocity (Doppler shift) and angular position. Target range information cannot be extracted without utilizing some form of modulation. The primary use of unmodulated CW radars is in target velocity search and track, and in missile guidance. Pulsed radars use a train of pulsed waveforms (mainly with modulation). In this category, radar systems can be classified on the basis of the Pulse Repetition Frequency (PRF) as low PRF, medium PRF, and high PRF radars. Low PRF radars are primarily used for ranging where target velocity (Doppler shift) is not of interest. High PRF radars are mainly used to measure target velocity. Continuous wave as well as pulsed radars can measure both target range and radial velocity by utilizing different modulation schemes. Table 4 below has the radar classifications based on the operating frequency.

Letter Designation	**Frequency(GHz)**	**New band designation**
HF	0.003 - 0.03	A
VHF	0.03 - 0.3	A<0.25; B>0.25
UHF	0.3 - 1.0	B<0.5; C>0.5
L-band	1.0 - 2.0	D
S-band	2.0 - 4.0	E<3.0; F>3.0
C-band	4.0 - 8.0	G<6.0; H>6.0
X-band	8.0 - 12.5	I<10.0; J>10.0
Ku-band	12.5 - 18.0	J
K-band	18.0 - 26.5	J<20.0; K>20.0
Ka-band	26.5 - 40.0	K
V-band	46-56	-
W-band	56-110	-
MMW	Normally >34.0	L<60.0; M>60.0

Table 4 Radar frequency bands

High Frequency (HF) radars utilize the electromagnetic waves reflection off the ionosphere to detect targets beyond the horizon. Very High Frequency (VHF) and Ultra High Frequency (UHF) bands are used for very long range Early Warning Radars (EWR). Because of the very large wavelength and the sensitivity requirements for very long range measurements, large apertures are needed in such radar systems.

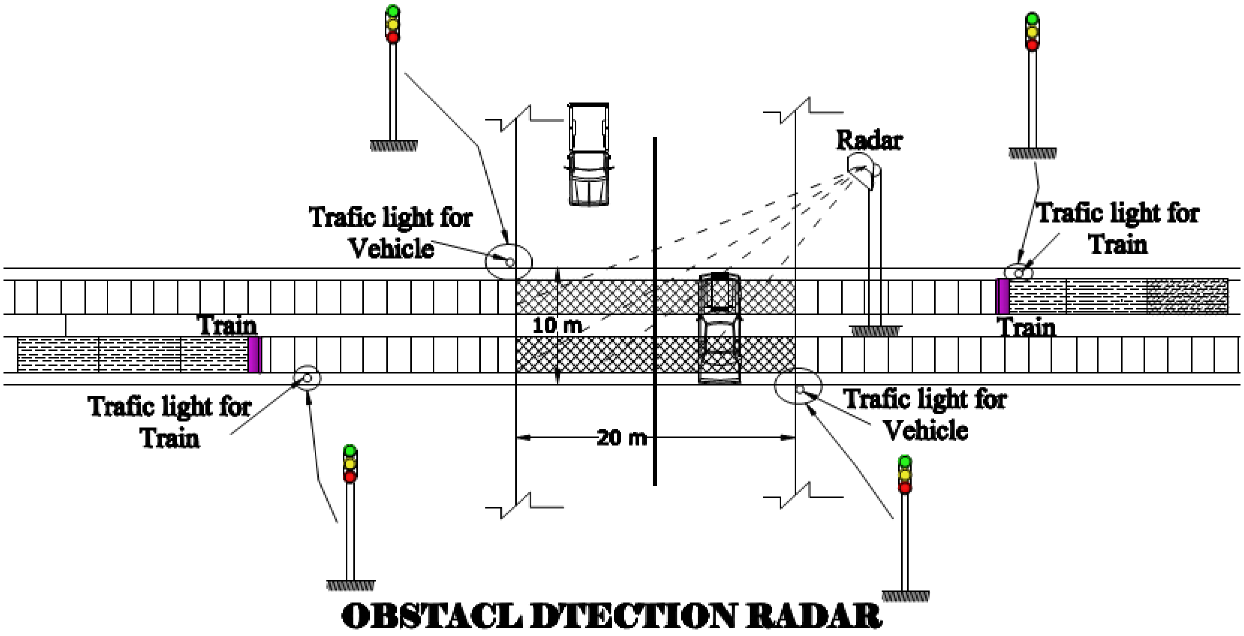
Radars in the L-band are primarily ground based and ship based systems that are used in long range military and air traffic control search operations. Most ground and ship based medium range radars operate in the S-band. Most weather detection radar systems are C-band radars. Medium range search and fire control military radars and metric instrumentation radars are also C-band. The X-band is used for radar systems where the size of the antenna constitutes a physical limitation; this includes most military multimode airborne radars. Radar systems that require fine target detection capabilities and yet cannot tolerate the atmospheric attenuation of higher frequency bands may also be X-band. The higher frequency bands (Ku, K, and Ka) suffer severe weather and atmospheric attenuation. Therefore, radars utilizing these frequency bands are limited to short range applications, such as police traffic radar, short range terrain avoidance, and terrain follows radar. Milli-Meter Wave (MMW) radars are mainly limited to very short range Radio Frequency (RF) seekers and experimental radar systems [12][16][25].

4.3. Millimeter-Wave (MMW) Obstacle Detection Radar

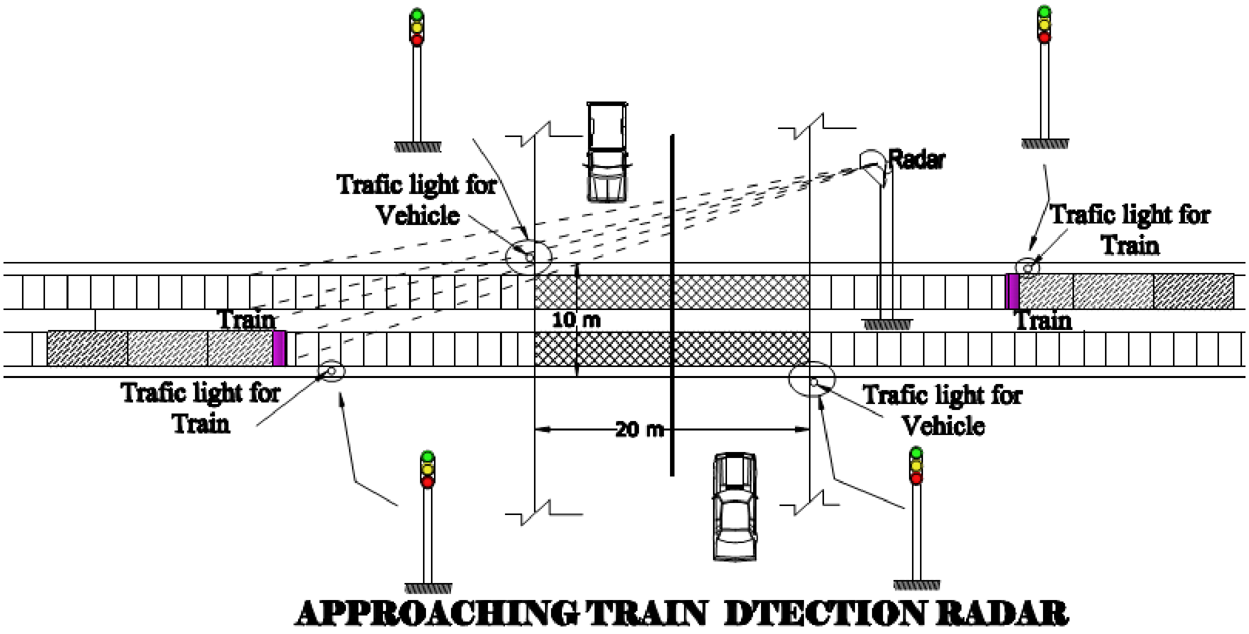
In this thesis the continuous wave (CW) MMW radar is used. Fig.4.2 a. shows the obstacle detection radar on the level crossing. The obstacle detection radar should be able to promptly detect the positions and velocities of things that were dropped, or that have fallen on level crossing, and vehicles either standing or running on level crossing, irrespective of the time zone or weather conditions to prevent fatal accidents on the level crossing. Whenever an obstacle is detected the information from the microcontroller is sent to the train or OCC to take measure so that the accident will be prevented from happening.

Fig.4.2 b. Shows how the approaching train is detected using radar. Whenever an approaching train is detected the microcontroller will pass information to the traffic light control box so that the vehicles, pedestrians will be prohibited or permitted to cross the level crossing.

In addition to the on board alarming system the train traffic light can be included to give emphasis for preventing accident.



a. Obstacle detection radar concept for application to railroad grade crossings



a. Approaching train detection radar

Fig.4.2 a. Obstacle Detection Radar, b. Approaching Train Detection Radar, concept for application to railroad grade crossings

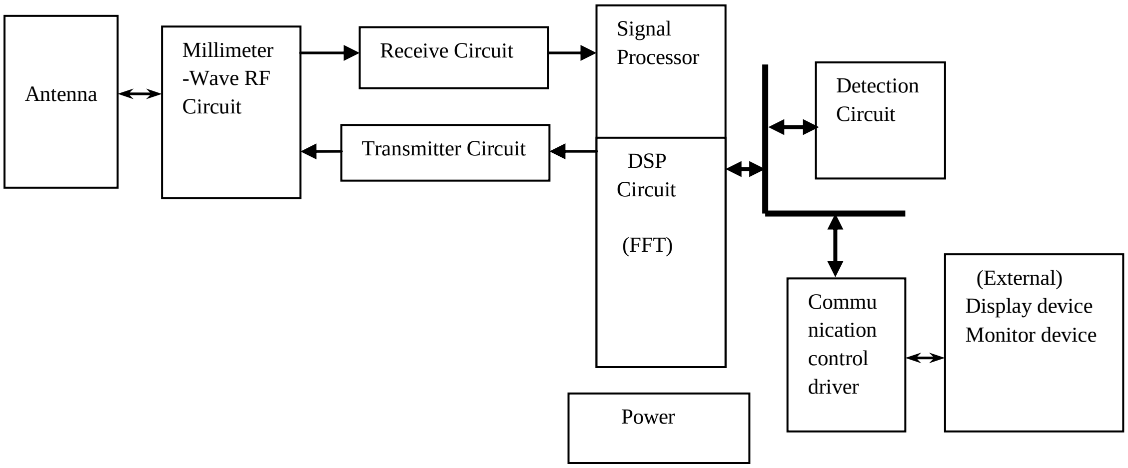
4.3.1. Millimeter Wave

A millimeter wave is an electronic wave whose wavelength is 10 to 1 mm or whose frequency is 30 to 300 GHz. This wave is not very affected by natural environments (rain, fog, air turbulence, or sunlight) or the color of the targets detected. Compared to the microwave band or lower frequencies, this wave has a significant Doppler shift and makes possible the high precision measurement of relative velocities. Because of these characteristics, the wave is very advantageous for the sensing function of obstacle detection equipment installed on roads [13].

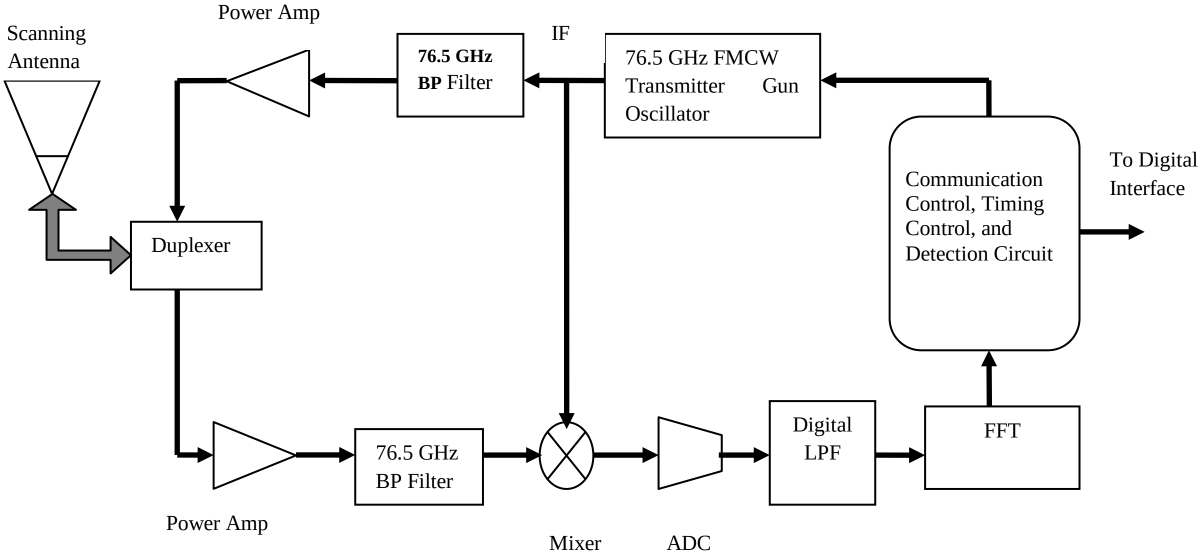
4.3.2. Configuration of MMW Radar

Fig.4.3 shows a block diagram of the radar. A parabolic Scanning antenna is connected to the millimeter-wave circuit through a waveguide and driven with the transmitting and receiving circuits by an actuator for sideway scanning. The signal processor converts the beat signals from the radar, from analog into digital. The DSP circuit then analyzes frequencies and computes relative velocities, distances, and direction information. The computed values are sent through a bus to the detection circuit. The detection circuit ascertains the degree of danger and outputs the judgments thereon to the external display device or GSM Modem through the communication control driver [13].

The figure below shows the MMW radar obstacle detection block diagram.



a. simplified block diagram



b. Detailed block diagram

Fig.4.3 Millimeter Wave Obstacle detection Radar Block Diagram

Almost all modern radars use digital signal processors to perform processing operations such as correlation, Doppler filtering, image rejection, detection processing and tracking. As we can see from fig.4.3 b. to provide signal for digital processing, A/D converters are placed at the end of the receiver signal path. Data processors are used to convert data produced by the signal processor into a form that is readily interpretable by radar operators. A low-power processor is used to extract the frequency content of the signal. ADC and FFT modules are important parts of the processor with a developed circuit design techniques to enable high circuit activity and peak energy efficiency during FFT computation.

Components of the MMW radar

In the following paragraphs, a brief description of the operation of each of the major components is given.

A. The Sensor (Antenna)

A sensor system block diagram is provided for reference in Fig.4.4 the antenna consists of a rotating drum that contains a grating designed to create a beam of the desired shape and scanning angles. Millimeter wave energy from the transmitter is coupled to a dielectric waveguide placed in proximity to the drum. Energy is coupled from the waveguide and directed toward a parabolic reflector that shapes the resulting beam in the elevation plane. The drum is rotated by a dc motor at a constant rate, which in turn causes the generated beam to scan in the horizontal plane. The antenna system includes the antenna, transmission lines and waveguide from the transmitter to the antenna, and the transmission line and waveguide from the antenna to the receiver. In some publications the duplexer is included as a component of the antenna system [7][25].

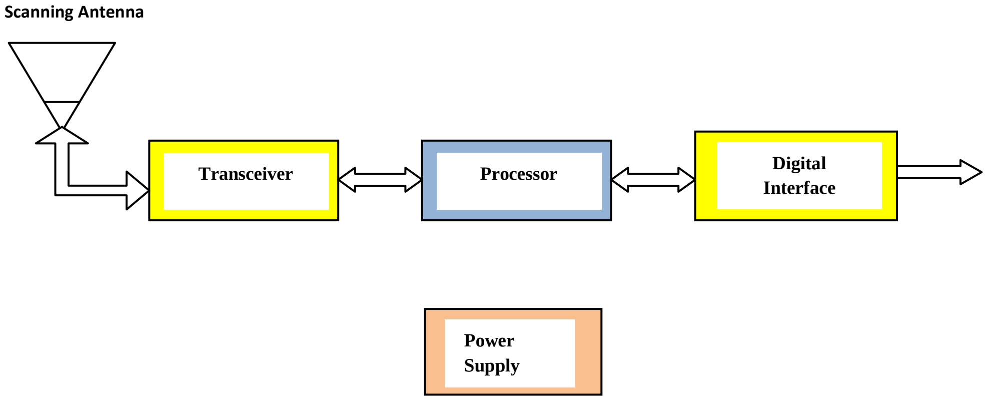


Fig.4.4 Sensor Block Diagram

Near/Far-Field Effect

Most radar applications sense targets in the antenna far-field region where the radiated power density varies inversely with the square of the distance and in which the antenna pattern remains constant for each angle. The beginning of the far-field region occurs at a distance R_{min} for which

$$R_{min} = D^2/\lambda$$

The above Equation results in R_{min} =2m for the radar of obstacle detection used in this study [15].

Methods of Beam Scanning

The two basic methods of beam scanning are MECHANICAL and ELECTRONIC. In mechanical scanning, the beam can be moved in various ways: (1) The entire antenna can be moved in the desired pattern; (2) the energy feed source can be moved relative to a fixed reflector; or (3) the reflector can be moved relative to a fixed source. In electronic scanning, the beam is effectively moved by such means as (1) switching between a set of feeder sources, (2) varying the phasing between elements in a multielement array, or (3) comparing the amplitude and phase differences between signals received by a multielement array. A combination of mechanical and electronic scanning is also used in some antenna systems [25].

B. Duplexer

A duplexer is essentially an electronic switch that permits a radar system to use a single antenna to both transmit and receive. The duplexer must connect the antenna to the transmitter and disconnect the antenna from the receiver for the duration of the transmitted pulse. The receiver must be completely isolated from the transmitted pulse to avoid damage to the extremely sensitive receiver input circuitry.

After the transmitter pulse has ended, the duplexer must rapidly disconnect the transmitter and connect the receiver to the antenna. As previously mentioned, the switching time is called receiver recovery time, and must be very fast if close-in targets are to be detected. Additionally, the duplexer should absorb very little power during either phase of operation. Low-loss characteristics are particularly important during the receive period of duplexer operation. This is because the received signals are of extremely low amplitude [25].

C. Signal Generator

Depending on the application, the radar transmit signal can be pulse or CW. CW transmissions employ low continuous power compared to the high peak power of the pulsed radars. However, CW radars using unmodulated waveforms cannot measure the target's range. The issue is addressed by frequency or phase modulation of the signal. The frequency modulated CW signal (FMCW) has many advantages over pulse radars. They spread the transmitted energy over a large modulation bandwidth providing good range resolution and their circuitry is well-matched to solid-state transmitters leading to low cost and high reliability systems. The purpose of the radar and the expected characteristics of the targets, in addition to the demands of moving target indication (MTI) and electromagnetic compatibility (EMC) are some of the factors that determine waveform design. For the W-band radar, a CMOS digital VCO is used to generate the basic or starting FMCW signal.

D. Synchronizer (Timer)

The synchronizer ensures that all circuits connected with the radar system operate in a definite timed relationship. It also times the interval between transmitted signals to ensure that the interval is of the proper length. Timing signals are used to ensure synchronous circuit operation and are related to the pulse-repetition frequency (PRF).

The pulse-repetition frequency (PRF) can be set by any stable oscillator, such as a sine-wave oscillator, multivibrator, or a blocking oscillator. That output is then applied to pulse-shaping circuits to produce timing pulses. Associated components can be timed by the output of the synchronizer or by a timing signal from the transmitter as it is turned on.

E. Transmitter

The transmitter generates powerful pulses of electromagnetic energy at precise intervals. The required power is obtained by using a high-power microwave oscillator, such as a magnetron, or a microwave amplifier, such as a klystron, that is supplied by a low-power RF source [25]. The main components in transmitters are the up-converting mixer or frequency multiplier, filters and the power amplifier. The IF signal is converted into the RF frequency signal by mixers or frequency multipliers. The undesired harmonics and images are attenuated using band pass filters. Finally the power amplifier provides amplification for the transmit signal before it excites the antenna. Couplers are commonly used to provide a sample of the transmit signal or the LO for the receiver down convertor.

F. Receiver

The receiver accepts the weak echo signals from the antenna system, amplifies them, detects the pulse envelope, amplifies the pulses, and then routes them to the indicator. One of the primary functions of the radar receiver is to convert the frequency of the received echo signal to a lower frequency that is easier to amplify. This is because radar frequencies are very high and difficult to amplify. This lower frequency is called the INTERMEDIATE FREQUENCY (IF). The type of receiver that uses this frequency conversion technique is the SUPER HETERODYNE RECEIVER. Super heterodyne receivers used in radar systems must have good stability and extreme sensitivity. Stability is ensured by careful design and the overall sensitivity is greatly increased by the use of many IF stages [25].

4.3.3. Mathematical Modeling

A. Radar Equation

The radar equation represents the physical dependences of the transmit power, that is the wave propagation up to the receiving of the echo-signals. Furthermore one can assess the performance of the radar with the radar equation given in equation 1 below. The radar equation relates the important parameters affecting the received signal of radar and the received energy is an extremely small part of the transmitted energy. Equation 2 adds the loss of the overall system [9].

$$P_r = \frac{P_t * G^2 * \lambda^2 * \sigma_t}{(4\pi)^3 * R^4} \qquad (1)$$

The above calculation of Pr corresponds to the absence of any attenuation. In the presence of a real atmosphere, we take attenuation into account.

$$P_r = \frac{P_t * G^2 * \lambda^2 * \sigma_t * G_p}{(4\pi)^3 * R^4 * L_t} \qquad (2)$$

Where:-

P_r = received power

P_t = transmitted power

G = antenna gain

G_s = Gain of the system

λ = wavelength

σ_t = target cross-section

L_t = Ls+LATM = total attenuation loss

L_s = system loss (> 1.0)

L_{ATM} = atmospheric loss (> 1.0)

R = range to target

Minimum Detectable Signal (MDS)

The minimum discernible signal is defined as the useful echo power at the reception antenna, which gives on the screen a discernible blip. The minimum discernible signal at the receiver input-jack leads to the maximum range of the radar; all other nominal variables are considered as constant. A reduction of the minimal received power of the receiver gets an increase of the maximum range. The maximum range R_{max} is the distance beyond which the target cannot be detected due to insufficient received power Pr. For every receiver there is a certain receiving power as of which the receiver can work at all. This smallest workable received power is frequently often called MDS – Minimum Discernible Signal or Minimum Detectable Signal in radar technology [9].

In most cases optimal performance of a radar system can be obtained using the technique of threshold detection. In this method, the magnitude of each complex sample of the radar echo signal, possibly after signal conditioning and interference suppression is compared to a pre-computed threshold. If the signal amplitude is below the threshold, it is assumed to be due to interference signals only. If it is above the threshold, it is assumed that the stronger signal is due to the presence of a target echo in addition to the interference, and a detection or "hit" is declared. In essence, the detector makes a decision as to whether the energy in each received signal sample is too large to likely have resulted from interference alone. If so, it is assumed a target echo contributed to that sample. Fig.4.5 illustrates the concept [7].

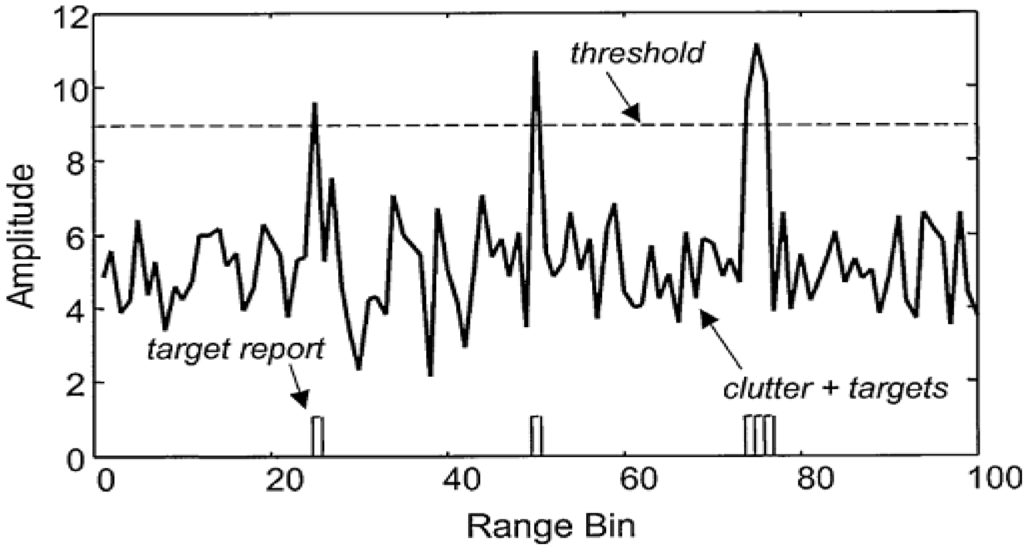


Fig.4.5. Illustration of threshold detection [7]

Signal-to-Noise Ratio

The value of the MDS echo depends on the Signal-to-Noise-Ratio, defined as the ratio of the signal energy to the noise energy. All radars, as with all electronic equipment, must operate in the presence of noise. The main source of noise is termed thermal noise and is due to agitation of electrons caused by heat.

The noise can arise from:

- ✓ Received atmospheric or cosmic noise
- ✓ Receiver noise - generated internally in the radar receiver.

The overall receiver sensitivity is directly related to the noise figure of the radar receiver. It becomes clear, that a low noise figure receiver is accomplished by a good design in the very front-end components. An aspect to a very low noise figure receiver is achieved through minimizing the noise factor of the very first block. This component usual is characterized by a low noise figure with high gain. This is the reason for the often used denomination, low noise preamplifier (LNA) [9].

The ability to detect a target in noise is determined by the signal-to-noise ratio (SNR). The radar input noise is described by the input noise power N, which is a function of the radar receiver bandwidth,

$$N_{IN} = N_0 * B_n \quad and \quad N_0 = KT$$

Where:-

N_0 is the receiver noise power density in Watt/Hz, B_n is the bandwidth of the radar receiver, T is the temperature in Kelvin, then the effective temperature $T=290K^0$ is used, and k = 1.38 x10 $^{-23}$ J/K is Boltzmann’s constant.

The radar range equation is the ration of the received target signal power to the receiver noise. If the various losses that exist in the system are lumped together in a single term, the radar range equation is given in Equation 3. We often represent the signal-to-noise ratio (S/N) in decibels. The same goes for the radar system losses. If low RCS targets are to be engaged, a combination of high power, high antenna gain and low noise seems to be dictated. For FMCW radar with receiver noise is dominant, the SNR at the input of the radar receiver is defined as the ratio between received power and noise power:

$$\frac{\mathrm{S}}{\mathrm{N}} = \frac{\mathrm{P_r}}{\mathrm{N_{IN}}} = \frac{\boldsymbol{P_r}}{\boldsymbol{KTB_n}} = \frac{\mathrm{P_t} * \mathrm{G}^2 * \lambda^2 * \sigma_\mathrm{t}}{(4\pi)^3 * \mathrm{KTB_n} * \mathrm{R}^4 * \mathrm{L_s} * \mathrm{L_{ATM}}} \tag{3}$$

The radar detection threshold, however, is set equal to the minimum SNROUT at the output of the radar receiver.

$\mathrm{F_n} = \frac{\mathrm{SNR_{In}}}{\mathrm{SNR_{OUT}}} = (\frac{\mathrm{S_{In}}}{\mathrm{N_{In}}})/(\frac{\mathrm{S_{OUT}}}{\mathrm{N_{OUT}}})$ is called the radar noise figure which is 8.5dB on this thesis. Thus, the maximum detection range is estimated by Equation 4 and the $\mathrm{SNR_{out}}$ min is found using this equation:

$$\mathrm{R_{Max}} = \sqrt[4]{\frac{\mathrm{P_t * G^2 * \lambda^2 * \sigma_t * G_p}}{\mathrm{(4\pi)^3 * (KTB_n) * F_n SNR_{OUT\,Min} * L_t}}} \tag{4}$$

Or equivalently:- $$\mathrm{SNR_{Out\,Min}} = \frac{\mathrm{P_t * G^2 * \lambda^2 * \sigma_t * G_p}}{\mathrm{(4\pi)^3 * KTB_n * F_n * R_{Max}^4 * L_t}}$$

Where:-

$$S_{Min} = (KTB_n) * F_n SNR_{OUT\;Min}$$

False Alarm Rate

A false alarm is "an erroneous radar target detection decision caused by noise or other interfering signals exceeding the detection threshold". In general, it is an indication of the presence of a radar target when there is no valid target. The False Alarm Rate (FAR) is calculated using the following formula:

$$FAR = \left(\frac{false\ targets\ per\ PRT}{number\ of\ rangecells}\right)$$

False alarms are generated when thermal noise exceeds a pre-set threshold level, by the presence of spurious signals (either internal to the radar receiver or from sources external to the radar), or by equipment malfunction. A false alarm may be manifested as a momentary blip on a cathode ray tube (CRT) display, a digital signal processor output, an audio signal, or by all of these means. If the detection threshold is set too high, there will be very few false alarms, but the signal-to-noise ratio required will inhibit detection of valid targets. If the threshold is set too low, the large number of false alarms will mask detection of valid targets. On this thesis FAR is taken to be 10e-6.

Probability of Detection

As with any radar system it is important to identify the probability of detection (Pd) for the MMW grade crossing sensor.

The received and demodulated echo signal is processed by threshold logic. This threshold shall be balanced so that as of certain amplitude wanted signals being able to pass and noise will be removed. Since high noise exists in the mixed signal tops which lie in the range of small wanted signals the optimized threshold level shall be a compromise. Wanted signals shall on the one hand reach the indication as of minimal amplitude; on the other hand the false alarm rate may not increase.

$$P_D = \left(\frac{detected\ targets}{all\ possible\ blibs}\right) * 100\%$$

The system must detect, with greater than or equal to 99.99 % probability at a defined range, for a 0.1 square meter radar cross section [9].

Parl developed an excellent algorithm to numerically compute the probability of detection of radar using the MATLAB Function "marcumsq.m". The formula is summarized by Parl as follows:

$$Q[a,b] = \left\{ \begin{array}{ll} \frac{\propto_n}{(2\beta_n)} \exp\left(\frac{(a-b)^2}{2}\right) & a < b \\ 1 - (\frac{\propto_n}{(2\beta_n)} \exp\left(\frac{(a-b)^2}{2}\right) & a \geq b \end{array} \right\} \tag{5}$$

Same as Chapman & Hall/CRC here we are going to use Parl's MATLAB Function to compute the probability of detection of the radar system and the syntax is as follows: Pd = marcumsq (alpha, beta) (see the program on appendix)[26].

Selection of the transmitting frequency

The most promising frequencies for MMW radar appear to lie in the 76-77GHz band and the 94-95GHz band (W band) [12]. Millimeter-wave radar has been used extensively for applications that require fine angular resolution with a limited antenna size [15]. This investigation used a mechanically scanned millimeter-wave radar designed for obstacle avoidance and detection, and level crossing navigation in rainy, foggy conditions and in day and night. The sensor is a monostatic 76.5-GHz FMCW millimeter-wave radar with a wavelength is λ = 3.92mm for the obstacle detection on the level crossing and 35GHz FMCW MMW radar with a wavelength is λ = 8.57mm for the approaching train detection. The selected frequencies are standard frequencies of MMW which are used for shorter distance target detection.

Grazing Angle, Footprint Shape and Beamweadth

Grazing angles stretch the pencil-beam footprint. This results in range-echo spread. Fig.4.6 and Fig.4.7 illustrates the grazing angle, footprint, height of the radar hanging pole, the length of the level crossing and Fig.4.8 shows the azimuth beamwidth for the obstacle detection radar. This scheme assumes that backscatter exists and that the footprint is within far-field conditions, which give the beam a conical shape. The footprint is the major axis of an ellipse with longitude determined by a slant range R to the surface taken to be 50m, the height h where the radar is fixed is 6m, and to cover the assumed footprint FD (level crossing) width 20m the grazing angle α and beamwidth θ can be approximated as [15].

$$sin\alpha = \frac{h}{R} = \frac{6}{50} = 0.12 => \alpha = sin^{-1}0.12 = 7°$$

$$|FD| = \frac{R*\theta}{sin\alpha} \qquad (6)$$

$$\theta = \frac{sin\alpha * |FD|}{R} = \frac{sin\alpha * (40-20)}{50} = 0.049rad \cong 3°$$

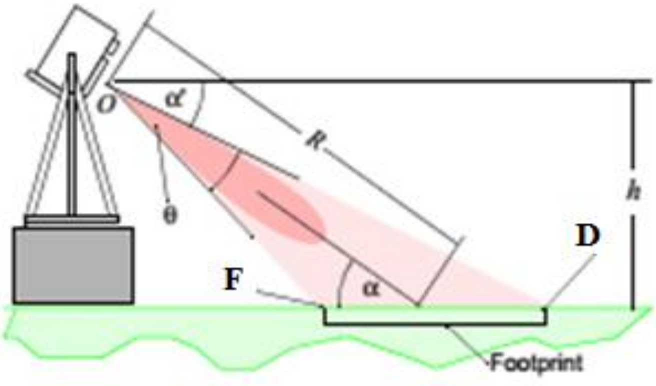


Fig.4.6. Scheme of a pencil beam sensing level crossing at grazing angle α and depression angle is α'.

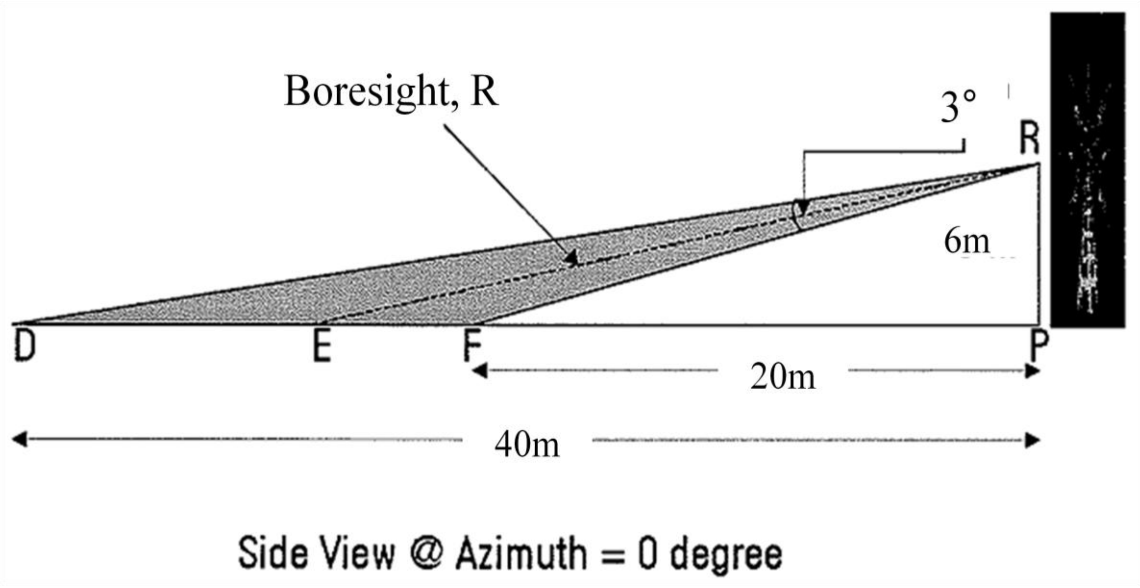


Fig.4.7. Side view of the radar on level Crossing

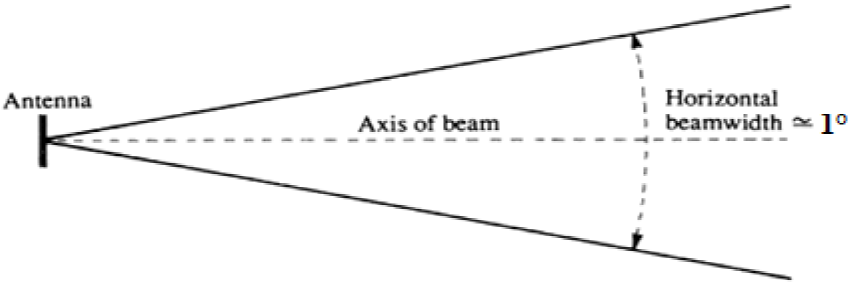


Fig.4.8. The horizontal beam

Then the beam width is 3° in elevation and 1° in azimuth. The monostatic-antenna scans horizontally across the angular range of 45°. Which means the azimuth field of view is 45°.The beamwidth of the diffraction limited antenna can also be given by Equation 7. Using this equation we can get the aperture of the antenna which in this thesis is diameter of a parabolic antenna.

$$\theta = \frac{K\lambda}{D} \text{ (radians)} \qquad (7)$$

Where θ is the half power beamwidth in the plane corresponding to dimension D, which for a circular aperture would be the diameter and λ is the wavelength in the same units. The constant k may be in the range from 0.9 to 1.4 depending on the amplitude taper across the aperture, which frequently is chosen to reduce sidelobe levels to a desired value. A typical empirical rule of thumb equation is [16]:

$$\theta = \frac{65\lambda}{D}\ (\text{degrees}) \tag{8}$$

$$D = \frac{65 * (\frac{\pi}{180}) * 3.92 * 10^{-3}}{3^0 * \frac{\pi}{180^0}} = 0.085\text{m} \cong 8.5\text{cm}$$

Antenna gain (G)

The antenna gain of the radar is a known value. This is a measure of the antenna's ability to focus outgoing energy into the directed beam.

$$G = \frac{Maximum\ Radation\ Intensity}{Average\ Radation\ Intensity}$$

Antenna gain describes the degree to which an antenna concentrates electromagnetic energy in a narrow angular beam. The two parameters associated with the gain of an antenna are the directive gain and directivity. The gain of an antenna serves as a figure of merit relative to an isotropic source with the directivity of an isotropic antenna being equal to 1. The power received from a given target is directly related to the square of the antenna gain, while the antenna is used both for transmitting and receiving.

- ✓ The antenna gain increases the transmitted power in one desired direction.

Power gain is determined by both the antenna pattern and by losses in the antenna [17].

In our case for the parabolic antenna that we have designed to direct and receive the power will have an antenna Gain:-

$$G = \frac{4\pi * A_e}{\lambda^2} \tag{9}$$

Where: - For a parabolic antenna, Using A_e=Effective Area

$A_e = (0.65*\pi D^2)/4 = (0.65*\pi*(.0.085)^2)/4 = 0.0037\text{m}2$ [18]

$$G = \frac{4\pi * A_e}{\lambda^2} = \frac{4\pi * 0.0037\text{m}^2}{(3.92 * 10^{-3})^2} = 3016.3 \cong 34.8\text{dB}$$

Radar Resolution

The target resolution of radar is its ability to distinguish between targets that are very close in either range or bearing. Weapons-control radar, which requires great precision, should be able to distinguish between targets that are only yards apart. Search radar is usually less precise and only distinguishes between targets that are hundreds of yards or even miles apart. Radar resolution is usually divided into two categories; range resolution and angular (bearing) resolution.

Range Resolution

Range resolution, denoted as ΔR, is a radar metric that describes its ability to detect targets in close proximity to each other as distinct objects. Radar systems are normally designed to operate between a minimum range R_{min}, and maximum range R_{max}. The distance between R_{min} and R_{max} is divided into M range bins (gates), each of width ΔR,

$$M = \frac{R_{max} - R_{mim}}{\Delta R}$$

Targets separated by at least ΔR will be completely resolved in range. In this thesis a range resolution of 0.5 meters is considered adequate at this time. Targets within the same range bin can be resolved in cross range (azimuth) utilizing signal processing techniques. Denote the difference between those two ranges as ΔR [12]:

The range resolution ΔR can be calculated using the formula:-

$$\Delta R = \frac{\mathbf{C}}{\mathbf{2B}} = \frac{\mathbf{C\tau}}{\mathbf{2}} = \frac{\mathbf{3*10^8}}{\mathbf{2*300MHz}} = 0.5\text{m} \qquad (10)$$

Where: - τ =3.3ns is the transmitted pulse length in case of pulse modulation and B=300MHz, is the Bandwidth.

Angular Resolution

Angular resolution is the minimum angular separation at which two equal targets at the same range can be separated. The angular resolution characteristics of a radar are determined by the antenna beam width represented by the -3 dB angle Θ which is defined by the half-power (-3 dB) points as seen on Fig.4.9. The half-power points of the antenna radiation pattern (i.e. the -3 dB beam width) are normally specified as the limits of the antenna beam width for the purpose of defining angular resolution; two identical targets at the same distance are, therefore, resolved in angle if they are separated by more than the antenna beam width. An important remark has to be made immediately: the smaller the beam width Θ, the higher the directivity of the radar antenna, the better the bearing resolution. The angular resolution as a distance between two targets depends on the slant-range and can be calculated with help of the following formula [9]:

$$S_A \leq 2R.Sin\left(\frac{\theta}{2}\right) \ \ [m]$$

$$S_A \leq 2R * Sin\left(\frac{\theta}{2}\right) = 2 * 50 * Sin\left(\frac{3}{2}\right) = 2.6m$$

Where:

Θ = antenna beam width (Theta)

S_A = angular resolution as a distance between the two targets

R = slant range aims - antenna

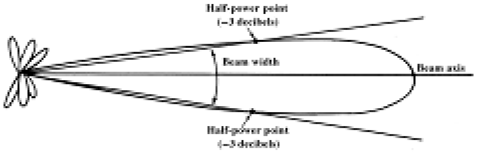


Fig.4.9 Radiation diagram

Radar Cross Section (RCS)

The amount of the radiated energy is proportional to the target size, orientation, physical shape and material which are all lumped together in one target-specific parameter called Radar Cross Section (RCS) denoted by "σ_t" [17]. The RCS is a measure of the effectiveness of the target as a radar reflector. The RCS of a target is formulated as the product of the normalized radar cross section of the target σ_0 (m^2 /m^2), also called reflectivity of the target, and the projected efficient area (Ae) of the target, and is expressed as [19]:

$$\sigma_t = \ \sigma_O Ae \ (m^2) \qquad (11)$$

These accident prevention radar systems will require detection of objects starting from 0.1m^2 radar cross-section (RCS) at approximately 2-250 meter range in bad weather for level crossing obstacle detection and 1-3Km for the train detection. Table 5 lists the radar cross-sections that are used on this thesis to get different parameters of the detection system.

Used Target RCS in m^2	RCS In dBsm
0.1	-10
1	0
10	10
100	20

Table 5 Typical used RCS

The smallest target (0.1m^2) that the system must detect reliably is that of a human for obstacle detection and 0.1m^2 RCS for the approaching train. To detect a man at 50 meter range, a transmitter power of about 10 mW should be used, the aim being to obtain a detection probability of 99.99% [16].

The Clutter RCS

One another item to consider is the clutter. Clutters are divided into surface and volume clutters. Surface clutter, often called area clutter, includes ground terrains with different vegetations, rocky surfaces, snow and water surfaces. Area clutter manifests itself a major hazard in helicopter landing in unknown areas under poor visibility conditions. It is a major concern for helicopter searching for targets at low grazing angles. The ground clutter RCS can be calculated from:

$$(\mathrm{RCS})_{\mathrm{Surface}} = \mathrm{A_e} * \sigma_{\mathrm{so}}$$

Where σ_{S0} is the reflectivity of surface clutter and A_S is the projected efficient area of the surface clutter. The surface clutter at low grazing angles is often referred to as diffuse clutter, A_e is given by:

$$\mathrm{A_e} = \frac{\mathrm{R_c} * \theta_{3\mathrm{dB}} * \mathrm{C} * \tau * \mathrm{Sec}\,\alpha}{2\beta}$$

Where c is the speed of light, τ is the pulse length, β is the beam shape factor, θ_{3dB} is the beamwidth and α is the grazing angle.

Thus, the power returned by the surface clutter is given by:

$$P_s = \frac{P_t * G^2 * \lambda^2 * \sigma_{so} * C * \tau * \mathrm{Sec}\,\alpha}{(4\pi)^3 * R^3 * L_T * 2\beta} \tag{12}$$

Volume clutter normally includes rain, snow, dust and fog. Volume clutter manifests itself by degrading or scattering and absorbing the radar transmitting energy. It is a critical concern for helicopter searching for vertical or air targets and landing in poor weather environments. The volume clutter RCS is represented as:

$$(\mathrm{RCS})_{\mathrm{Volume}} = V_c * \eta$$

Where η is the volume clutter reflectivity in m^2 /m^3 and V_C is the efficient airborne clutter volume. Assuming that the azimuth and elevation beamwidths are identical, at a given volume clutter range R_C, the radar resolution cell (volume) is measured by:

$$V_c = \frac{\pi}{4} \frac{R_c^2 * \theta_{3dB}^2 * C\tau}{2\beta^2}$$

The power returned by the volume clutter is:

$$P_V = \frac{\pi}{4} * \frac{P_t * G^2 * \lambda^2 * \eta * \theta_{3dB}^2 * C\tau}{(4\pi)^3 * R_c^2 * L_T * 2\beta^2} \tag{13}$$

In short range applications, especially, all-environment helicopter operations; the receiver noise may not be the major factor in comparison with the ground clutter power, which may be much higher than the thermal noise power. This simulation shall take account of various signal-to clutter ratios (SCRs). The SCR is defined as the ratio of the received target power to the received clutter power and is given as follows [19]:

For surface clutter:

$$\mathrm{SCR_s} = \frac{\sigma_t}{\sigma_s} = \frac{\sigma_t}{A_e \sigma_{so}}$$

For Volume clutter

$$\mathrm{SCR_V} = \frac{\sigma_t}{\sigma_V} = \frac{\sigma_t}{V_s \eta}$$

For this thesis RCS of surface and volume has been assumed to be $0.01\mathrm{m}^2$ and $0.01\mathrm{m}^3$ respectively.

External and Internal Losses

This is the sum of all loss factors of the radar. This is a value that is calculated to compensate for attenuation by precipitation, atmospheric gases, and receiver detection limitations. The attenuation by precipitation is a function of precipitation intensity and wavelength. For atmospheric gases, it is a function of elevation angle, range, and wavelength. Since all of this is taken in account for e.g. 3 Decibels loss, all signals are weakened by half the value. Some of these losses are unavoidable. Some of these can be influenced by radar technicians. In this design the losses due to internal factors, rain and atmosphere are going to be included for the design purpose.

Because of the small size of the suspended particles that make up dust and smoke, this type of obscurant will have a negligible effect on MMW radar operation [16].

As the radar signal is propagated through the atmosphere, its amplitude and intensity are reduced through the atmospheric attenuation process. For the MMW simulation, this attenuation is accounted for in the return power equation by the loss factor L_{Atm} given by [19]:

$$L_{Atm} = 2\mu R \tag{14}$$

Where: μ is the attenuation coefficient for rain, fog…etc, and it is generally given in units of dB/km as shown on the Fig.4.10 below [22].

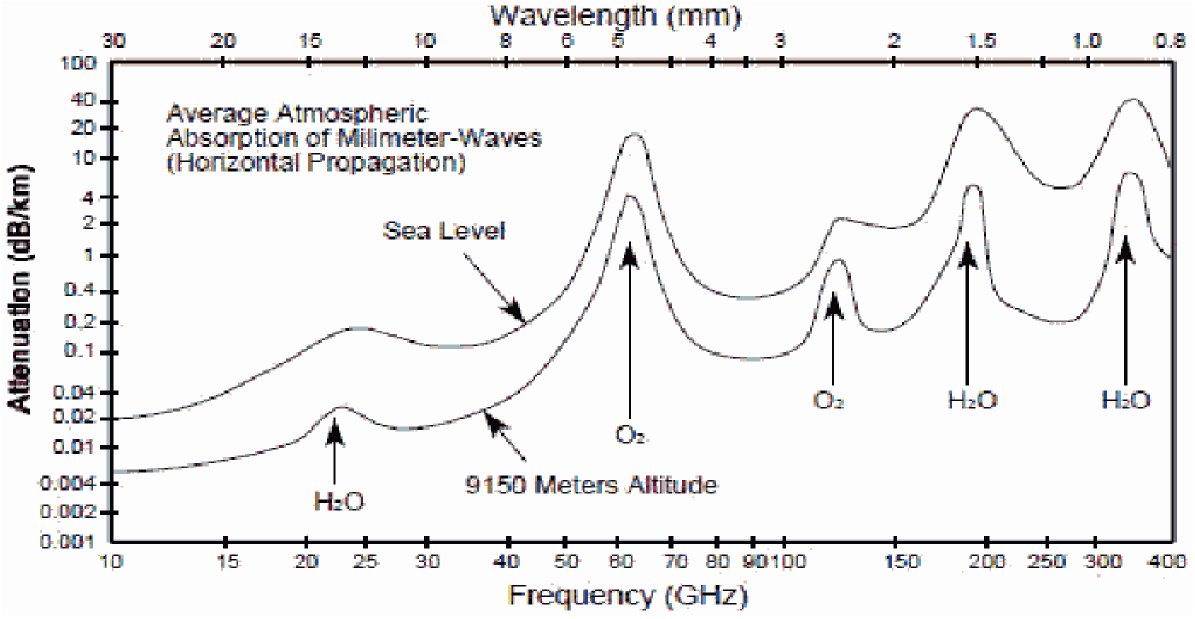


Fig.4.10 Atmospheric absorption of millimeter wave, Principal windows exist at 35, 94,140 and 220 GHz with extremely large available bandwidths around each.

4.3.4. The Frequency Modulation Continuous Wave (FMCW) Method

The measurement of range in CW radars can be accomplished by frequency modulation (FM) of the transmitted waveform. The FMCW technique operates by continuously changing the frequency of the transmitted energy in some predetermined fashion. Fig.4.11 depicts the operation of the FMCW waveform showing the transmitted signal and the received signal for a given set of targets.

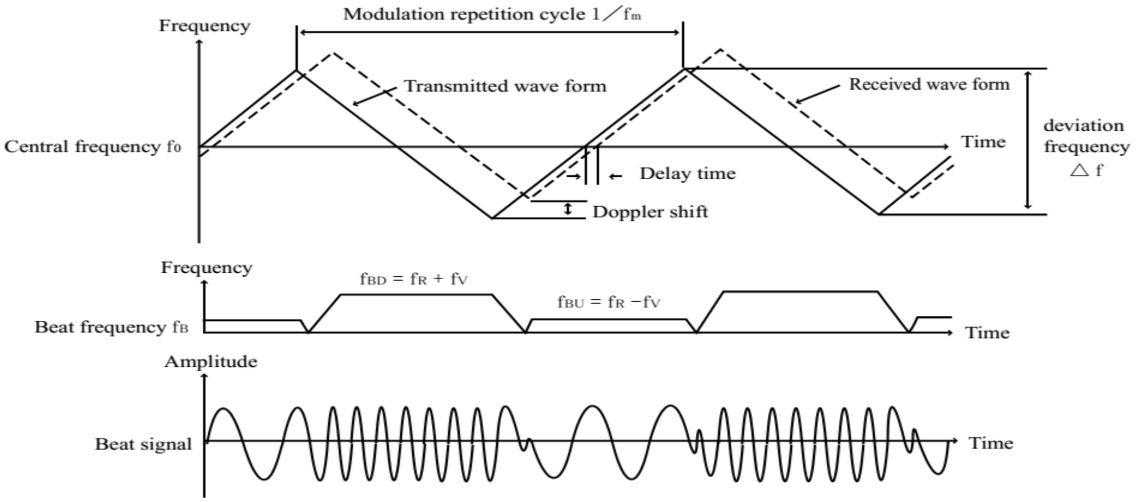


Fig.4.11 Principle of FMCW radar

General description of FMCW radar block diagram

An FMCW radar system produces a continuous wave signal which is frequency modulated over a determined bandwidth. The basic ranging principle of FMCW radar consists in measuring the frequency shift caused by the time delay of a reflected signal, when the transmitted signal is frequency modulated by a periodic waveform.

In its simplest form, FMCW radar uses a receiver which requires a reference signal directly coupled from the transmitter, to be mixed with the echo signal. As a matter of fact, the signal generated by the radar is split into two parts: a smaller part is allowed to pass into the LO port of the mixer, where it is used as a reference signal for detection of echo signal, while the other, larger portion of the generated signal passes out into the antenna and is transmitted. By mixing the reference signal directly coupled from the transmitter with the echo signal, the receiver performs a direct conversion from RF to zero-IF frequency, extracting the target information in only one conversion stage. A typical FMCW radar front-end is shown in fig.4.12.below.

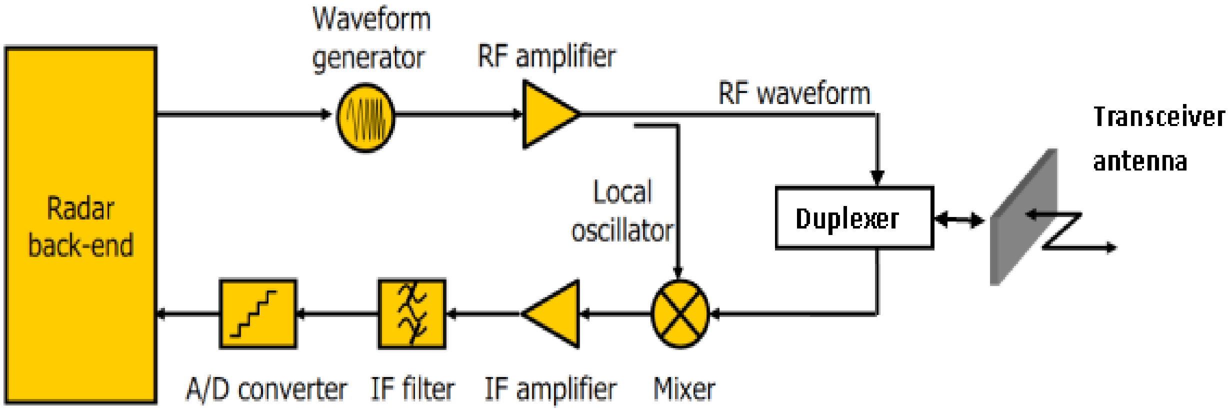


Fig.4.12: FMCW radar front-end with common transmit and receive antenna

The transmitted waveform is represented by the equation

$$S_t(t)=A_t \operatorname{Cos}(2f_0t+2\pi\varphi\ (t)) \qquad (15)$$

Where A_t is the amplitude of the transmitted waveform, f_0 is the starting frequency,

$$\varphi(t) = \frac{1}{2} * kt^2$$

is the phase variation due to the frequency sweep, and k is the modulation rate.

The instantaneous frequency f(t) of the transmitted signal is then obtained by differentiating the instantaneous phase with respect to time:

$$f(t) = \frac{1}{2\pi} * \frac{d(2\pi f_0 t+\pi kt^2)}{dt} = f_0 + kt \qquad (16)$$

Typically the modulation is linear in frequency, as shown in fig.4.13. This signal is also known as a chirp, named after the sound a bird makes when it increases the pitch of its call over a short period of time. The total time needed for the waveform to cover the entire frequency range B from f_0 to f_1 is the Sweep time T_{sweep}.

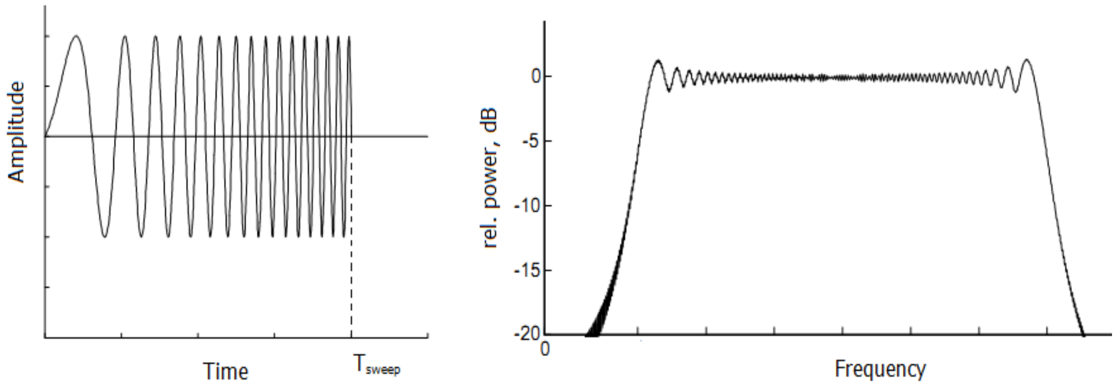


Fig.4.13: Linear chirp signal in time-domain (left) and frequency-domain (right).

For the modulation rate k’, for the T_{sweep}=0.3ms is thus found by the equation

$$k' = \frac{(f_1 - f_0)}{T_{sweep}} = \frac{B}{T_{sweep}} = \frac{300*10^6}{0.3*10^{-3}} = 1\mathrm{KHz}/\eta s \tag{17}$$

After emission from a transmit antenna, the transmitted signal propagates into the air to a target where part of it is reflected back towards the radar. The echo signal is thus an attenuated version of the transmitted signal that is delayed by the time t_d needed for the waveform to travel the two-way path between the target and the antenna, and it is found as:

$$t_d = \frac{2R}{C} = \frac{2*250}{3*10^8} = 1.67^{-06} = 1.67\mu s \tag{18}$$

For the maximum range of the radar to target which is 100m and for the minimum range 2m:

$$t_d = \frac{2R}{C} = \frac{2*2}{3*10^8} = 1.3^{-08} = 13\eta s$$

Where R represents the distance between the radar and the target, and c represents the propagation velocity of the waveform.

The received signal is then expressed as

$$S_r(t) = A_r \cos(2\pi f_0\,(t - t_0) + 2\pi\varphi\,(t - t_0)) \tag{19}$$

Where A_r the amplitude of the received signal, accounts for propagation losses, target reflectivity and a variety of radar performance parameters.

At the mixer stage the received signal is multiplied with the reference signal that came into the LO port of the mixer. This process produces sum and difference frequency terms. The sum frequencies are in the order of twice the radar carrier frequency, and can be easily filtered out with a low pass filter. The other term represents the difference frequencies between transmitted and received waveform, and is directly related to the time delay due to the two way path between radar and target, and thus their distance. This difference term, also called beat signal, is represented as:

$$S_{beat}(t)= S_t(t) \otimes S_r(t)= A_{beat} \cos(2\pi f_0 t_0+2\pi kt t_0-\pi k t_0^2)) \quad (20)$$

The beat frequency is finally obtained by taking the first derivative of the phase:

$$f_{beat} = \frac{1}{2\pi} * \frac{d(2\pi f_0\tau+2\pi ktt_0-\pi kt_0{}^2)}{dt} = K.t_0 = \frac{B.t_0}{T_{sweep}} = \frac{2R.B}{C.T_{sweep}} \quad (21)$$

$$= \frac{2 * 250 * 300 * 10^6}{3 * 10^8 * 0.3 * 10^{-3}} = 1.67\text{MHz}$$

Due to the analog mixer circuit, the receive low-pass filter only needs to pass the difference between the receive and transmit signals, and does not need to pass the 300 MHz bandwidth of the receive signal over the transmit cycle. This passing of the difference in signals is most easily illustrated by example. Let us assume receive reflections at the range extremes of the system, say at distances of 2 m and 250 m. With a frequency ramp of 300 MHz in 0.3 ms, or 1 kHz per ns, the frequency of the receive signal will be as follows,

Using the above equation 21, the frequency of the receive signal will be as follows:

During the positive frequency ramp, the return from the object at a 2 m distance will be a -13 kHz offset. During the negative frequency ramp, the return from the object at a 2 m distance will be a +13 kHz offset.

During the positive frequency ramp, the return from the object at a 250 m distance will be a -1.67 MHz offset. During the negative frequency ramp, the return from the object at a 250 m distance will be +1.67 MHz offset.

These offsets tell us that the receiver will see frequencies in the range of ±1.67 MHz, depending upon the range of the target generating the return. This frequency can be detected by operating a fast Fourier transform (FFT) for the time intervals shown in Fig.4.14.

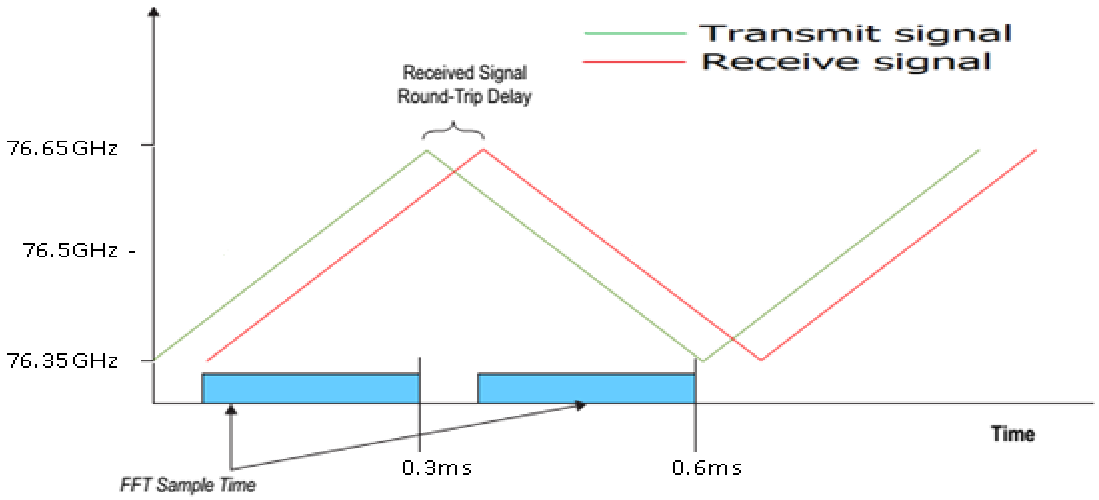


Fig.4.14 Receiver FFT Sampling Intervals

In FMCW radar applications, targets are found by performing Fourier analysis on the mixer's output signal. Using a Fourier transform with a rectangular window of integration extending over a time interval of length T_{sweep} leads to the following representation of the power in the mixer output signal:

$$S_{IF}(f) = P_r\left(\frac{\sin[\pi(f-f_{beat})T_{sweep}]}{\pi(f-f_{beat})T_{sweep}}\right)^2 \tag{22}$$

Where f is the analysis frequency, and $p_r = A_{beat}^2$ is the power of the target echo [14]:

The Doppler Frequency

Where f_0 is the carrier frequency of the incident signal, the Doppler frequency f_d for a closing target is given by:

$$f_d = f_0' - f_0 = \left(\frac{2V_t \mathrm{Cos}\,\gamma}{\lambda}\right) = \left(\frac{2V_t f \mathrm{Cos}\,\gamma}{C}\right) \tag{23}$$

and for an opening target

$$f_d = f_0' - f_0 = -\left(\frac{2V_t \mathrm{Cos}\,\gamma}{\lambda}\right) = -\left(\frac{2V_t f \mathrm{Cos}\,\gamma}{C}\right) \tag{24}$$

Where f is the operating frequency, V_t is the target velocity, γ is the angle between the target heading and the line of sight of the radar, and c is the velocity of propagation.

This indicates that the Doppler shift is proportional to the target velocity, and, thus, one can extract from range rate and vice versa.

Doppler frequency shift is a function of the carrier center frequency, which is beneficial in some MMW radar applications. The ability of a radar to measure Doppler frequencies is determined in part by the noise sidebands and the coherency of the transmitter and local oscillator. At millimeter wavelengths such sources are visually more noisy than at microwave frequencies and therefore phase-locking, injection locking, and/or frequency stabilization are often necessary [16].

The Radar Parameters

With the assumption of the system specified on the above the parameters of the obstacle detection radar and the approaching train detection radar are listed on the table 6 & 7 below.

Radar Parameter	**Values(s)**	**Units**
Type	FMCW	
Frequency	76.5	GHz
Power	10	milliWatts(mW)
Minimum detectible power with 15dB S/N	-105.2	dBm
Target RCS	0.1, 1.0, 10.0, 100.0	Meters^2(m^2)
Antenna Gain	34.8	dB
Clear Air Attenuation	0.6	dB/km
40mm/hr Rain Attenuation	15	dB/km
Transmit Losses	1	dB
Random Loss	0.5	dB
Receive Losses	1	dB
Bandwidth	300	MHz
Signal Processing Gain	10	dB
Noise Figure	8.5	dB
PFA	10^{-6}	-
Range Resolution	0.5	m

Minimum Range	2	m
Maximum Range	250	m
Antenna Elevation Beamweadth	3	degrees
Azimuth Beamweadth	1	degrees
Azimuth Field of view	45	degrees
Angle of depretion	8	degrees
Scan rate	1	KHz
Antenna Aperture (D)	8.5	cm

Table 6 Obstacle detection Radar Parameters

Radar Parameter	**Values(s)**	**Units**
Type	FMCW	
Frequency	35	GHz
Power	1	Watts(W)
Minimum detectible power with 13.1dB S/N	-146.4	dBm
Target RCS	0.1, 1.0, 10.0	Meters2(m2)
Antenna Gain	28	dB
Tau	1.3e-6	Second
Total System Losses	15	dB
Bandwidth	300	MHz
Signal Processing Gain	12	dB
Noise Figure	5	dB
PFA	10-6	-
Range Resolution	200	m
Minimum Range	57	m
Maximum Range	3000	m
Azimuth Field of Veiw	8	degrees
Azimuth Beamweadth	0.8	degrees
Antenna Aperture (D)	69.64	cm

Table 7 Approaching train detection Radar Parameters

Chapter Five

5. Simulation Results and discussion

On chapter four the MMW obstacle detection radar's Mathematical modeling has been done and the parameters of the designed radars for the prevention of accident are summarized in a tabular form. In this chapter using the mathematical modeling and assumptions the simulation results of the MATLAB programs are presented and discussion for those results is done.

5.1. Simulation Model

The simulation is based on the evaluation of the returned power from target, background, clutter and MMW radar receiver noise, and the use of the returned power to generate sensor data (image).

The Target Model

- ✓ Provides a description of the simulated targets including the position, velocity, Target RCS which takes in to consideration physical sizes, target reflectivity as a function of wavelength, emissivity of target (material types).

The Environment Model

- ✓ Simulates the effect of atmospheric attenuation and backscattering, such as rain, fog and dust (including dust storm).

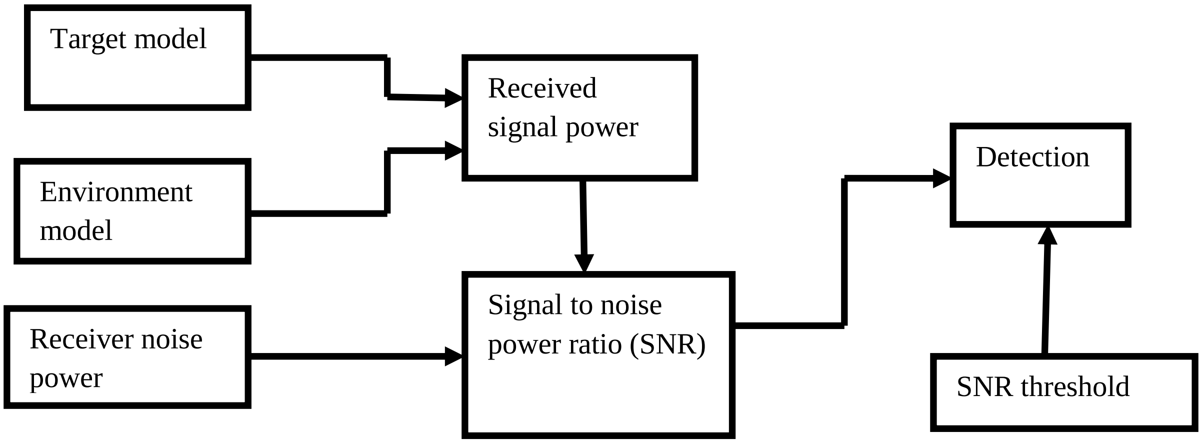


Fig.5.1 Simulation model

5.2. Results and Discussion

On Fig.5.2, 5.3 and 5.4 since the smock, dust and fog doesn't have a considerable effect on the radar system only a 40mm/hr rainfall is taken under consideration in addition to the other system losses. The simulation result for a target with RCS of 0.1m^2 Fig.5.2 shows that whenever the distance of the target increases the SNR decrease and vice versa. In addition it shows us that for different transmitted power if the power Increases the SNR also increases and vice versa. But for the obstacle detection purpose 10mW of Pt is used for the other simulation results.

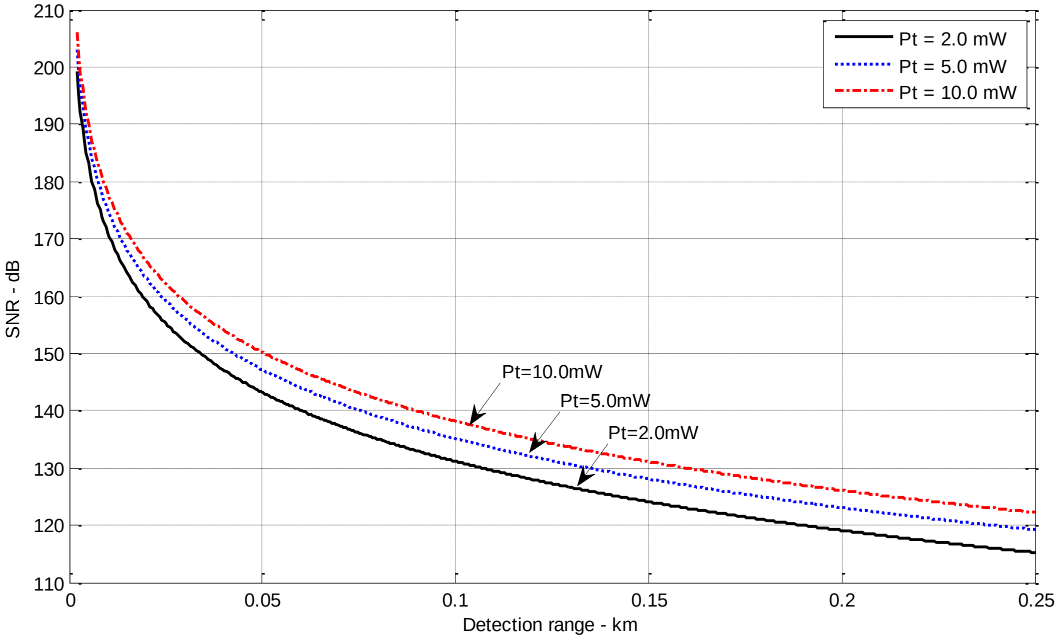


Fig.5.2 SNR Vs R Simulation Result with different Pt

The simulation result on Fig.5.3 shows us that objects with different RCS are detected by the obstacle detection radar at different range from the radar. For example for the four different RCS 0.1m^2, 1m^2, 10m^2, 100m^2 using 10mW transmitted power, 50m range from the radar, the SNR is 150dB, 160dB, 170dB and 180dB respectively. This shows that the radar can detect an object starting from a 0.1m^2 RCS and whenever the RCS increases the SNR (the reflected back signal) increases too.

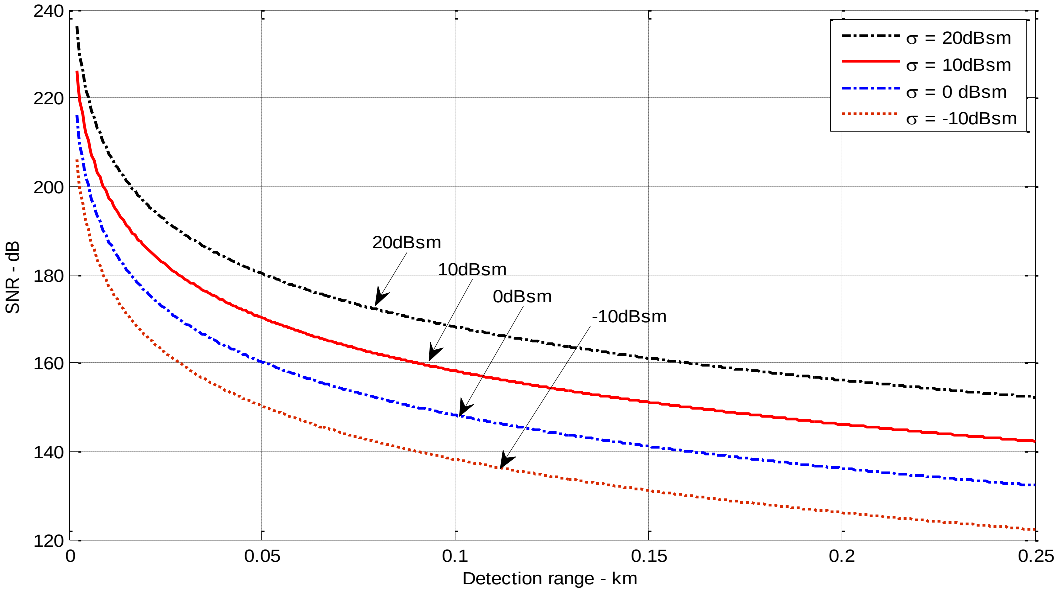


Fig.5.3 SNR Vs R Simulation Result with different RCS

Fig.5.4 is the threshold graph of the obstacle detection radar considering 0.01m2 surface clutter RCS. From this graph referring back to fig.5.2 and fig.5.3 the detection of the target with minimum RCS which is 0.1m2 is possible. For example for RCS 0.1m2 at R=50m, Pt=10mW the SNR is 150dB while the threshold is 140dB, which means that the smallest object considered is detectible because it is 10dB above the threshold of detection.

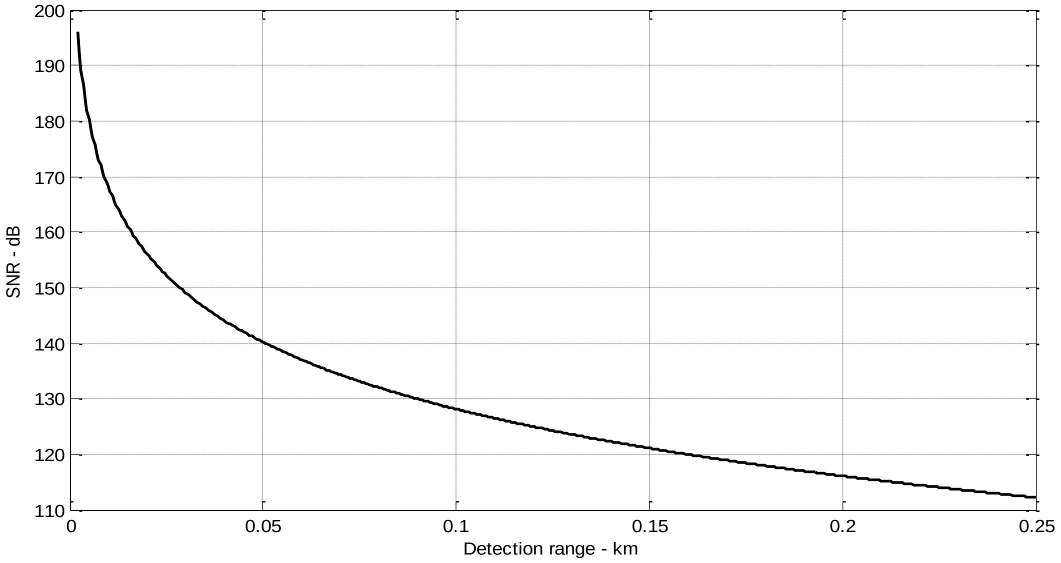


Fig.5.4 The Threshold for obstacle detection in heavy rain

The Figures below 5.5, 5.6, and 5.7 shows the same result as the above results except that the rainfall effect is excluded. If only the other losses (e.g. transmit, receive...) are considered and the rainfall is not considered the simulation result shows that on Fig.5.5 and Fig.5.6 that there is an increase on SNR in approximately 1-2dB. For the Pt of 10mW at a distance of target 50m with RCS of 0.1m^2 (-10dBsm). This result shows that whenever it is clear air a slight increase in detection range is shown.

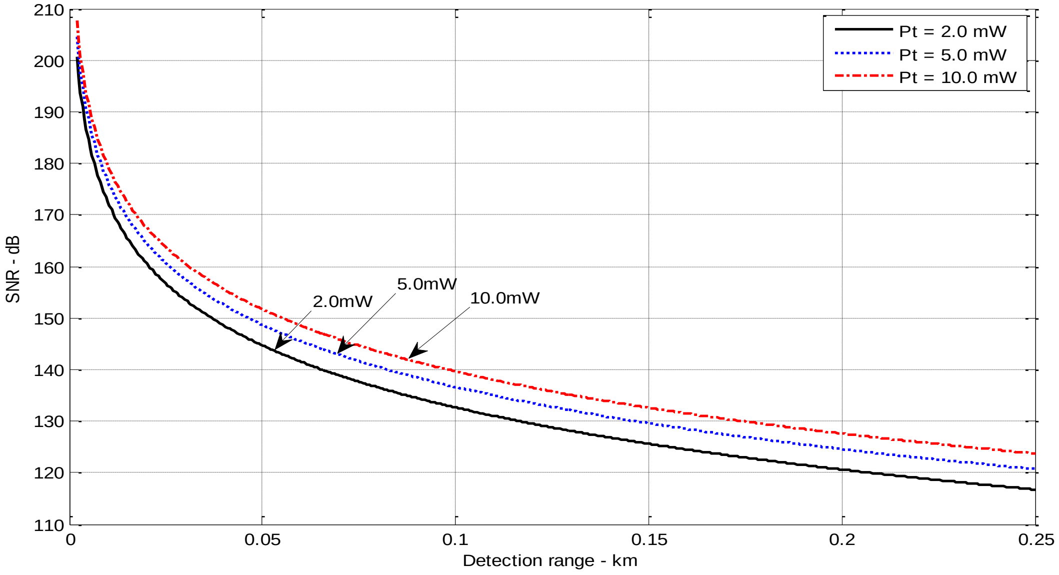


Fig.5.5 SNR Vs R Simulation Result with different P_t in clear air

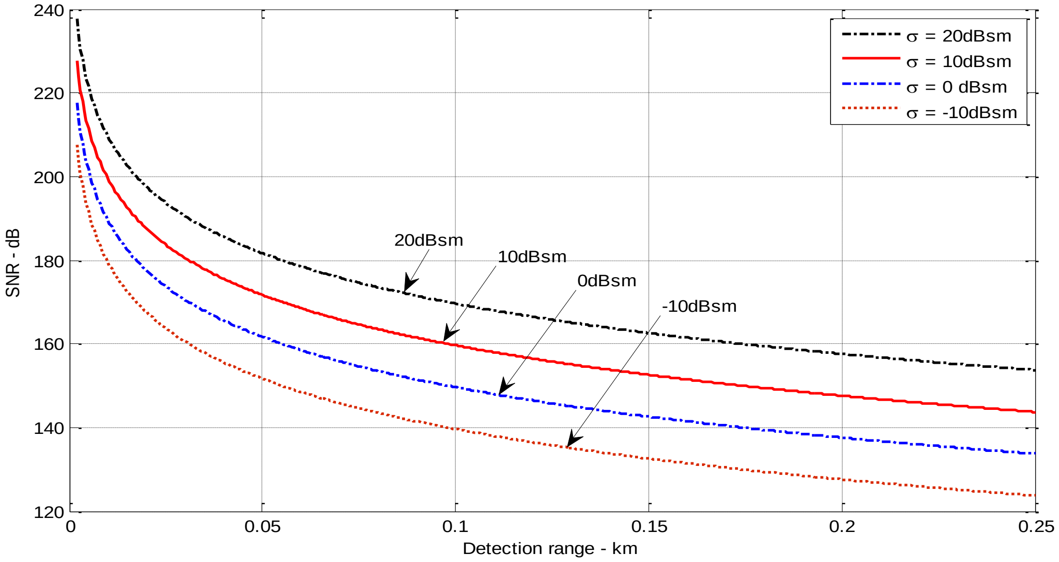


Fig.5.6 SNR Vs R Simulation Result with diff RCS in clear air

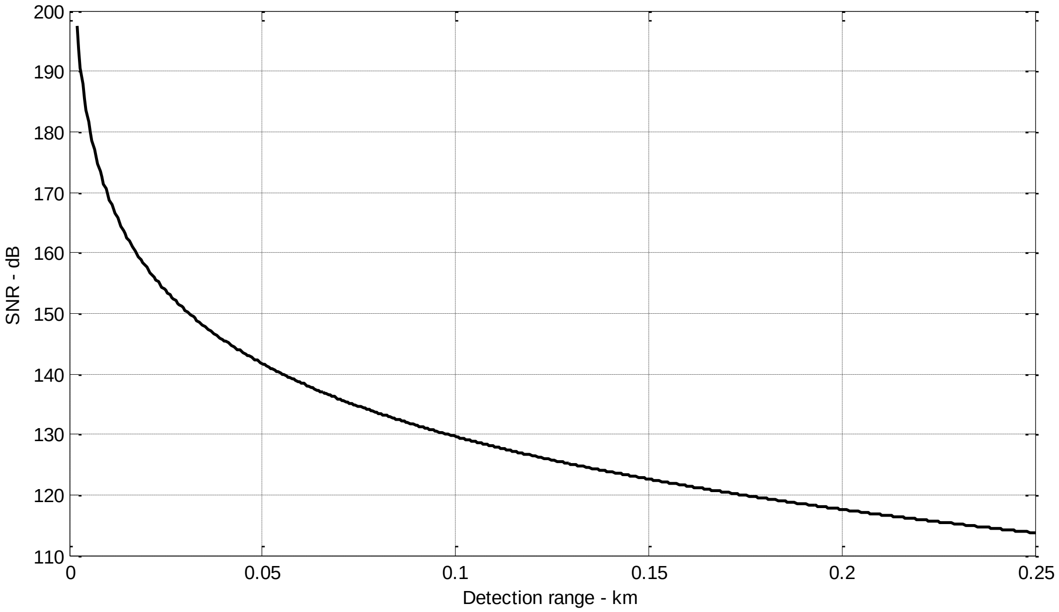


Fig.5.7 The Threshold for obstacle detection in clear air

The Figures below Fig.5.8, Fig.5.9 and Fig.5.10 shows the simulation result for different transmitted power (P_t) and for different radar cross-section (RCS) of the approaching train with 15dB loss of the system including 40mm/hr rainfall. Here on these results also we can see that there is 10dB deference between the smallest RCS of the approaching train's SNR at any distance and the threshold SNR for a 0.01m^3 volume clutter. This shows that the minimum RCS is detectible in a maximum range of 3km. The minimum threshold for the detection of the approaching train using Pt=1kw in a range of 3km is approximately 63dB. Any SNR below 63dB will be considered as a noise signal.

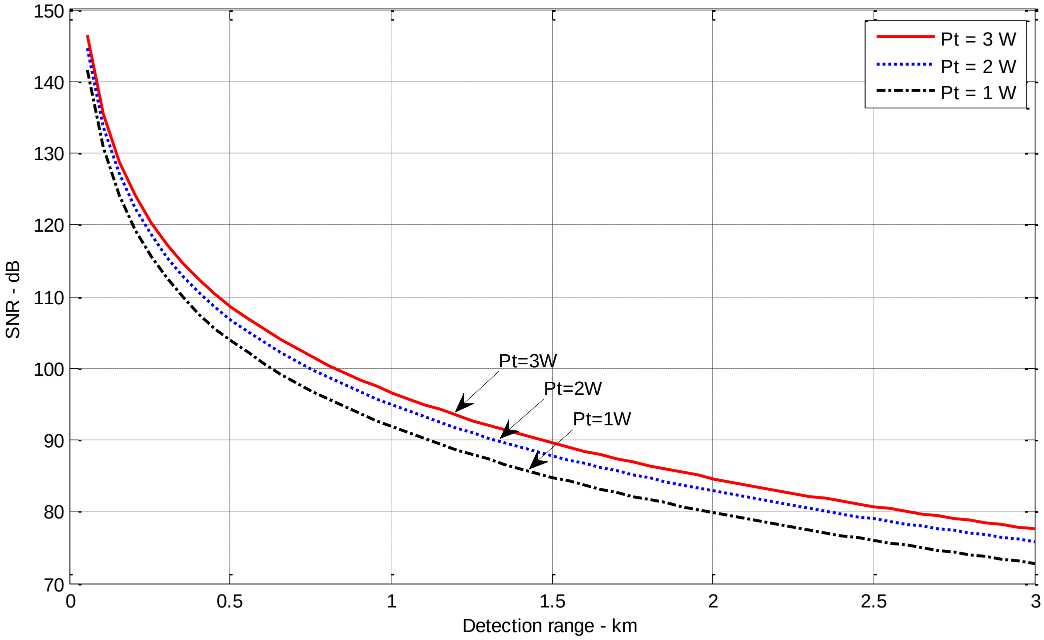


Fig.5.8 Approaching train SNR Vs R Simulation Result with different Pt

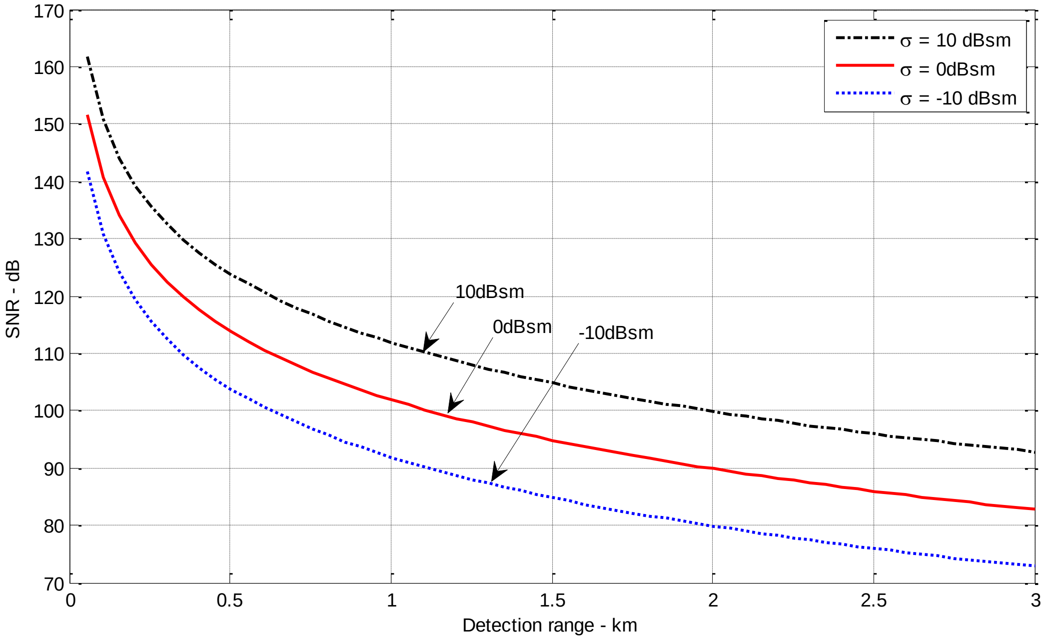


Fig.5.9 Approaching train SNR Vs R Simulation Result with different RCS

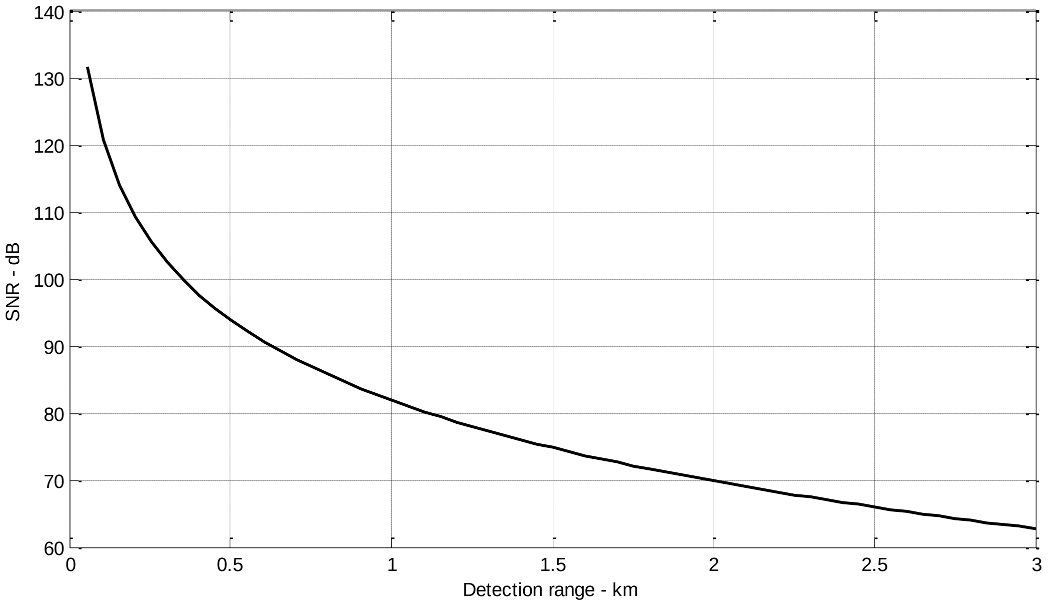


Fig.5.10 The Threshold for Approaching train detection

In the case where the receiver noise is the dominant source of interference, the required SNRs for different FAR values are shown in Fig. 5.11. On this figure for PFA of 10e-6 the probability of detection to be 99.99% the SNR of the radar has got to be greater than or equals to 15dB. Then since the SNR that we got from the above simulation results are much greater than 15dB then the P_D of the radar is 99.99% for the designed system.

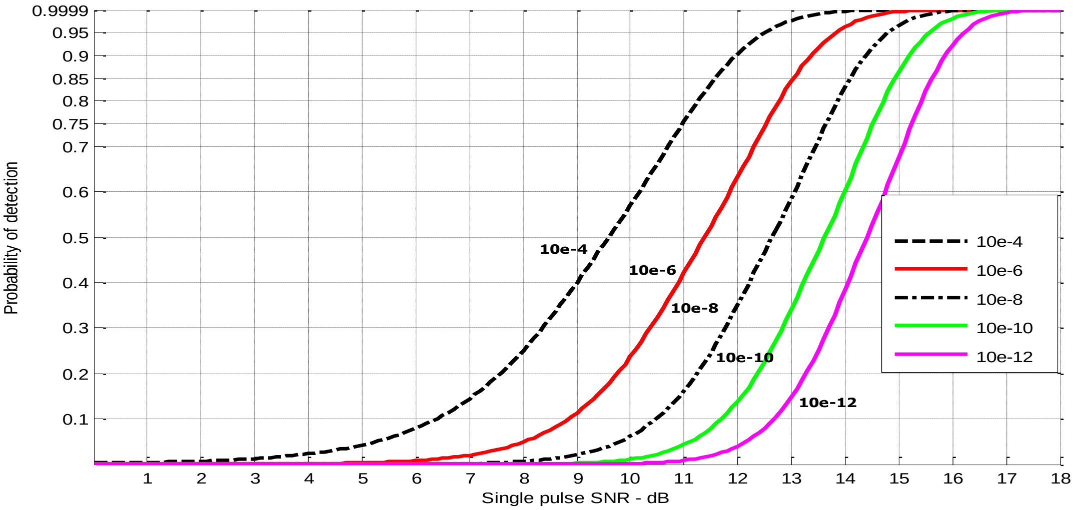


Fig.5.11 P_D Vs SNR Simulation Result with different PFA

It is also possible to get the probability of detection (safety) of the radar system for the PFA of 10e-6 for 1(one) year duration of time using the equation below.

$$P_D = e^{-\lambda_D t}$$

Where λ_D is dangerous failer rate and it is given by:

$$\lambda_D = \frac{PFA}{t} = \frac{10^{-6}}{8760} = 1.14 * 10^{-10} \quad , \qquad t = 1yr = 8760hrs$$

$$P_D = e^{-\lambda_D t} = e^{-1.14*10^{-10}*8760} = 0.999999 = 99.99\%$$

Then the radar system has good performance or it is safe, High MTBF which means reliable and cost effective means of obstacle/target detection to prevent accident.

Chapter Six

6. Conclusions and Recommendations

6.1. Conclusions

This thesis has looked at the Designing of Intelligent Accident Prevention system on the level crossing. This system designing has covered the hardware and software interrelation of the overall system. The accident prevention system is accomplished using the FMCW MMW radar. The designing basic principle of FMCW radars in different weather conditions, size of target and distance of target has been also conducted. It should be evident that FMCW MMW radar techniques are well suited to applications calling for high range resolution for which the range interval to be observed is small. Some of the practical accident prevention systems by obstacle detection have been compared with the radar system. But the radar system is the perfect technology with good performance, reliability, longevity with reasonable cost. The results which are now being obtained for the intelligent accident prevention system show that modern technology has made it possible to fulfill the long-standing dream of making practicable radar systems for railway industry. It promises to be a significant commercial application that will reduce the driver's workload so that driving can become safer and less tiring. And also accidents are prevented before happening.

6.2. Recommendations

After analyzing the results which have been found in this thesis and concluding that this system is the best technology for the prevention of accident on the level crossing, I would like to recommend:

- ✓ The Ethiopian Railway Corporation (ERC) to use this technology which is called in this thesis “Intelligent level crossing accident prevention” on the Addis Ababa Light Railway Transit (AALRT) to prevent accidents in the newly constructed railway after conducting a field test.
- ✓ Researchers to further investigate the MMW radar for its performance, reliability in preventing accident in level crossing.
- ✓ Researchers to add simulation results of the overall system using ADS (Advanced Design System), or Proteus simulation soft ware.
- ✓ Researchers on the improvement of train speed and also the improvement of overall traffic flow on the level crossing using this designed system.

Reference

1. Road Safety and Rail Crossings/ Level Crossings, www. Road safety and/Road-Safety-and-Rail-Crossings-Level-Crossings.htm
2. T.Yamawaki et al., FUJITSU TEN ,"Millimeter-Wave Obstacle detection Radar", TECH. M., NO.15 (2000)
3. "A Radar Vehicle Detection System for Four-Quadrant Gate Warning Systems and Blocked Crossing Detection", Office of Research and Development Washington, DC 20590, Final Report December 2012
4. Addis Ababa E-W & N-S (Phase I) Light Rail Transit Project, "Preliminary Design" Chapter XIV Signaling System (Volume in One), June 2013
5. U.S. Department of Transportation, Federal Railroad Administration "A Radar Vehicle Detection System for Four-Quadrant Gate Warning Systems and Blocked Crossing Detection", Final Report December 2012
6. Wave Band Corporation, Torrance, California 90501 "Railroad grade crossing obstacle detection radar"
7. Dr. Vladimir Manasson "MMW Obstacle Detection Radar for Highway Grade Crossings and Quad Gates" WaveBand Corporation Torrance, CA, April 2000
8. Li-Sian Tey and Luis Ferreira, "Driver compliance at railway level crossings", The University of Queensland, Brisbane St Lucia, QLD 4072, Australia & University Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia, 2010
9. Radartutorial ,Book 1 "Radar Basics" , www.radartutorial.eu (Revision from 20.12.2009)
10. J.C. Toomay, Paul J.Hannen, " Radar Principles for the Non-Specialist" third edition ,Wright State University, Fairborn, Ohio
11. Hiroto Takeuchi, Tetsuyoshi Shozawa, " Development of Advanced Obstacle-Detecting Methods for Level Crossings", Central Japan Railway Company, Aichi, Japan
12. Bassem R.Mahafza, Ph.D., Atef Z.Elsherbeni, Professor "MATLAB Simulations for Radar Systems Design", 2004 by Chapman & Hall/CRC CRC Press LLC
13. Toshiki Yamawaki , Shin-ichi Yamano, Yutaka Katogi Toshihito Tamura, Yasuyuki Ohira, "Millimeter-Wave Obstacle detection Radar" FUJITSU TEN TECH. M., NO.15 (2000)

14. Eugenio Pasqua "UWB FMCW Radar for Concealed Weapon Detection: RF front-end development" , February 8th, 2012
15. Alex Foessel, "Short-Range Millimeter-Wave Radar Perception in a Polar Environment" Sachin Chheda and Dimitrios Apostolopoulos Robotics Institute, Carnegie Mellon University Pittsburgh, PA 15213-3890
16. William David "FMCW MMW Radar for Automotive Longitudinal Control" California PATH Research Report, UCB-ITS-PRR-97-19, May 1997
17. Devendran.B, Dr.Sudesh Kumar Kashyap, Dr.T.V.Rama Murthy" Modeling specifications for HiVision Millimeter Wave Radar for multisensory Enhanced Vision Systems"
18. "Principles of Radar", chapter 12
19. Osichinaka C. Ubadike, Huamin Jia., and Paul C. Brook, "Multiple Sensor Simulation in Support of Helicopter Day, Night and All Weather (DNAW) Operation", Cranfield University, Cranfield, MK43 0AL, United Kingdom and Thales Avionic Limited, United Kingdom, 6-9 April 2009, Seattle, Washington
20. Osman YILDIRIM "MILLIMETER WAVE RADAR DESIGN CONSIDERATIONS" ISTANBUL UNIVERSITY –JOURNAL OF ELECTRICAL & ELECTRONICS ENGINEERING,2003
21. Jay Heavisides, John Barker & Michael Woods, "Hot topics in controlling risk at level crossings", Arthur D. Little, UK and 2Rail Safety & Standards Board, UK
22. Mehrnoosh Vahidpour, "A Millimeter-Wave Radar Microfabrication Technique and Its Application in Detection of Concealed Objects" The University of Michigan , 2012
23. Louahdi Khoudour & Mohamed Ghazel & Fouz ia Bouko ur & Marc Heddebaut & El-Miloudi El-Koursi "Towards safer level crossings: existing recommendations, new applicable technologies and a proposed simulation model", European Conference of Transport Research Institutes (ECTRI) 2008
24. N. Fakhfakh, L. Khoudour, E.M. El-Koursi, J. Jacot and A. Dufaux, "A Video-Based Object Detection System for Improving Safety at Level Crossings", The Open Transportation Journal, 2011, 5, 45-59
25. "Radar Fundamentals", chapter 1
26. Chapman & Hall/CRC, "Radar Detection", Chapter 4,2000

27. Barry Scheiner, “A MATLAB Radar Range Equation and Probability of Detection Evaluation Tool”, Army Research Laboratory, January 1999

Appendix: *MATLAB codes for the designed radars*

MATLAB Function for radar_eq.m[12]

```
function [snr] = radar_eq(pt, freq, g,gs, sigma, te, b, nf, loss, range)
% This program implements the radar equation
c = 3.0e+8; % speed of light
lambda = c / freq; % wavelength
p_peak = 10*log10(pt); % convert peak power to dB
lambda_sqdb = 10*log10(lambda^2); % compute wavelength square in dB
sigmadb = 10*log10(sigma); % convert sigma to dB
four_pi_cub = 10*log10((4.0 * pi)^3); % (4pi)^3 in dB
k_db = 10*log10(1.38e-23); % Boltzman's constant in dB
te_db = 10*log10(te); % noise temp. in dB
b_db = 10*log10(b); % bandwidth in dB
range_pwr4_db = 10*log10(range.^4); % vector of target range^4 in dB
num = p_peak + g + g + lambda_sqdb + sigmadb+gs;
den = four_pi_cub + k_db + te_db + b_db + nf + loss + range_pwr4_db;
snr = num - den;
return
```

MATLAB Program for the simulation of fig 5.2 and fig 5.3

```
% Use this program to reproduce Fig. 5.2 and Fig. 5.3 [12]
close all
clear all
pt = 10e-3; % peak power in Watts
freq = 76.5e+9; % radar operating frequency in Hz
g = 34.8; % antenna gain in dB
gs = 10.0;  % System gain in dB
sigma = 0.1; % radar cross section in m squared
te = 290.0; % effective noise temperature in Kelvins
b = 1.67e+6; % radar operating bandwidth in Hz
nf = 8.5; %noise figure in dB
loss = 3.61; % radar losses in dB, when the 40mm/hr rain is excluded it becomes 2.11dB
range = linspace(2.0e-3,0.25,496); % target range 2.0e-3 - 0.25 km, 496 points
snr1 = radar_eq(pt, freq, g,gs, sigma, te, b, nf, loss, range);
snr2 = radar_eq(pt, freq, g,gs, sigma*10, te, b, nf, loss, range);
snr3 = radar_eq(pt, freq, g,gs, sigma*100, te, b, nf, loss, range);
snr4 = radar_eq(pt, freq, g,gs, sigma*1000, te, b, nf, loss, range);
% plot SNR versus range
figure(1)
rangekm = range ./ 1.0;
plot(rangekm,snr4,'k -.',rangekm,snr3,'k',rangekm,snr2,'k -.',rangekm,snr1,'k:')
```

```
grid
legend('\sigma = -10 dBsm','\sigma = 0dBsm','\sigma = 10 dBsm','\sigma = 20dBsm')
xlabel ('Detection range - km');
ylabel ('SNR - dB');
snr1 = radar_eq(pt, freq, g,gs, sigma, te, b, nf, loss, range);
snr2 = radar_eq(pt*.5, freq, g,gs, sigma, te, b, nf, loss, range);
snr3 = radar_eq(pt*0.2, freq, g,gs, sigma, te, b, nf, loss, range);
figure (2)
plot(rangekm,snr3,'k',rangekm,snr2,'k:',rangekm,snr1,'k -.')
grid
legend('Pt = 10 mW','Pt = 5.0 mW','Pt = 2.0 mW')
xlabel ('Detection range - km');
ylabel ('SNR - dB');
```

MATLAB Program for Threshold during Heavy rain

```
% Use this program to reproduce Fig. 5.4 of text.
close all
clear all
pt = 10.0e-3; % peak power in Watts
freq = 76.5e+9; % radar operating frequency in Hz
g = 34.8; % antenna gain in dB
gs = 10.0;  % System gain in dB
sigma = 0.01; % Assumed Clutter cross section in m squared
te = 290.0; % effective noise temperature in Kelvins
b = 1.67e+6; % radar operating bandwidth in Hz or receiver bandwidth ( the dominant)
nf = 8.5; %noise figure in dB
loss = 3.61; % radar losses in dB
range = linspace(2.0e-3,0.25,496); % target range 2.0e-3 – 0.25 km, 496 points
snr1 = radar_eq(pt, freq, g,gs, sigma, te, b, nf, loss, range);
% plot SNR versus range
figure(1)
rangekm = range ./ 1.0;
plot(rangekm,snr1,'k:')
grid
%legend('\sigma = 20dBsm','\sigma = 10dBsm','\sigma = 0 dBsm','\sigma = -10dBsm')
xlabel ('Detection range - km');
ylabel ('SNR - dB');
```

MATLAB Program for Threshold during Clear Air

```
% Use this program to reproduce Fig. 5.7 of text.
close all
clear all
pt = 10.0e-3; % peak power in Watts
freq = 76.5e+9; % radar operating frequency in Hz
g = 34.8; % antenna gain in dB
gs = 10.0;  % System gain in dB
```

```
sigma = 0.01; % Assumed Clutter cross section in m squared
te = 290.0; % effective noise temperature in Kelvins
b = 1.67e+6; % radar operating bandwidth in Hz or receiver bandwidth ( the dominant)
nf = 8.5; %noise figure in dB
loss = 2.11; % radar losses in dB
range = linspace(57.0e-3,3,60); % target range 57.0e-3 - 3 km, 60 points
snr1 = radar_eq(pt, freq, g,gs, sigma, te, b, nf, loss, range);
% plot SNR versus range
figure(1)
rangekm = range ./ 1.0;
plot(rangekm,snr1,'k:')
grid
%legend('\sigma = 20dBsm','\sigma = 10dBsm','\sigma = 0 dBsm','\sigma = -10dBsm')
xlabel ('Detection range - km');
ylabel ('SNR - dB');
```

MATLAB Function “marcumsq.m”

```
function PD = marcumsq (a,b) % This function uses Parl's method to compute PD
max_test_value = 1000.; % increase to more than 1000 for better results
if (a < b)
 alphan0 = 1.0;
 dn = a / b;
else
 alphan0 = 0.;
 dn = b / a;
end
alphan_1 = 0.;
betan0 = 0.5;
betan_1 = 0.;
d1 = dn;
n = 0;
ratio = 2.0 / (a * b);
r1 = 0.0;
betan = 0.0;
alphan = 0.0;
while betan < max_test_value,
 n = n + 1;
 alphan = dn + ratio * n * alphan0 + alphan;
 betan = 1.0 + ratio * n * betan0 + betan;
 alphan_1 = alphan0;
 alphan0 = alphan;
 betan_1 = betan0;
 betan0 = betan;
 dn = dn * d1;
end
```

```
PD = (alphan0 / (2.0 * betan0)) * exp( -(a-b)^2 / 2.0);
if ( a >= b)
 PD = 1.0 - PD;
end
return
```

MATLAB Program “prob_snr1.m”

```
% This program is used to produce Fig. 5.11
clear all
for nfa = 2:2:12
 b = sqrt(-2.0 * log(10^(-nfa)));
 index = 0;
 hold on
 for snr = 0:.1:18
 index = index +1;
 a = sqrt(2.0 * 10^(.1*snr));
 pro(index) = marcumsq(a,b);
 end
 x = 0:.1:18;
 set(gca,'ytick',[.1 .2 .3 .4 .5 .6 .7 .75 .8 .85 .9 .95 .9999])
 set(gca,'xtick',[1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18])
 loglog(x, pro,'k');
end
hold off
xlabel ('Single pulse SNR - dB')
ylabel ('Probability of detection')
grid
```

MATLAB Program for approaching train detection radar

```
% Use this program to reproduce Fig. 5.8 and Fig. 5.9 of text.
close all
clear all
pt = 1; % peak power in Watts
freq = 35.0e+9; % radar operating frequency in Hz
g = 28.0; % antenna gain in dB
gs = 12.0;  % System gain in dB
sigma = 0.1; % radar cross section in m squared
te = 290.0; % effective noise temperature in Kelvins
b = 300.0e+6; % radar operating bandwidth in Hz
nf = 5; %noise figure in dB
loss = 6; % radar losses in dB
range = linspace(57.0e-3,3,60); % target range 57.0e-3 - 3 km, 60 points
snr1 = radar_eq(pt, freq, g,gs, sigma, te, b, nf, loss, range);
snr2 = radar_eq(pt, freq, g,gs, sigma*10, te, b, nf, loss, range);
snr3 = radar_eq(pt, freq, g,gs, sigma*100, te, b, nf, loss, range);
% plot SNR versus range
```

```
figure(1)
rangekm = range ./ 1.0;
plot(rangekm,snr3,'k',rangekm,snr2,'k -.',rangekm,snr1,'k:')
grid
legend('\sigma = -10 dBsm','\sigma = 0dBsm','\sigma = 10 dBsm')
xlabel ('Detection range - km');
ylabel ('SNR - dB');
snr1 = radar_eq(pt, freq, g,gs, sigma, te, b, nf, loss, range);
snr2 = radar_eq(pt*2, freq, g,gs, sigma, te, b, nf, loss, range);
snr3 = radar_eq(pt*3, freq, g,gs, sigma, te, b, nf, loss, range);
figure (2)
plot(rangekm,snr3,'k',rangekm,snr2,'k:',rangekm,snr1,'k -.')
grid
legend('Pt = 1 W','Pt = 2 W','Pt = 3 W')
xlabel ('Detection range - km');
ylabel ('SNR - dB');
```

MATLAB Program for Threshold of approaching train

```
% Use this program to reproduce Fig. 5.10 of text.
close all
clear all
pt = 1.0; % peak power in Watts
freq = 35.0e+9; % radar operating frequency in Hz
g = 28.0; % antenna gain in dB
gs = 12.0;  % System gain in dB
sigma = 0.01; % Assumed Clutter Cross section in m squared
te = 290.0; % effective noise temperature in Kelvins
b = 300.0e+6; % radar operating bandwidth in Hz or receiver bandwidth (the dominant)
nf = 5.0; %noise figure in dB
loss = 6.0; % radar losses in dB
range = linspace(57.0e-3,3,60); % target range 57.0e-3 - 3 km, 60 points
snr1 = radar_eq(pt, freq, g,gs, sigma, te, b, nf, loss, range);
% plot SNR versus range
figure(1)
rangekm = range ./ 1.0;
plot(rangekm,snr1,'k:')
grid
%legend('\sigma = 20dBsm','\sigma = 10dBsm','\sigma = 0 dBsm','\sigma = -10dBsm')
xlabel ('Detection range - km');
ylabel ('SNR - dB');
```

Submitted by:

	ALENE RITIBEY	________________	________________
	Student Name	Signature	Date

Approved by:

1.	Mr.ABI ABATE	________________	________________
	Advisor	Signature	Date
2.	Dr.YALEMZEWD NEGASH	________________	________________
	Advisor	Signature	Date
3.	________________	________________	________________
	Chairman, Dept.'s Graduate Committee	Signature	Date
4.	________________	________________	________________
	Chairman, Faculty's Graduate Committee	Signature	Date
5.	________________	________________	________________
	Dean, Graduate school	Signature	Date