BURIED CABLE PERIMETER INTRUSION DETECTION SYSTEM

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CERTIFICATE OF CORRECTNESS AND APPROVAL

Certified that work contained in this thesis “Buried Cable Perimeter Intrusion Detection System”,was carried out by Sundas Nayab Khalil, Saman Irfan, Waleed bin Saad and Mohsin Iftekhar under the supervision of Brig (r) Ashraf Masood for partialfulfillment of Degree of Bachelor of Telecommunication Engineering, is correct andapproved.

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ABSTRACT

BURIED CABLE PERIMETER INTRUSION DETECTION SYSTEM

Perimeter intrusion detection system is an important and integral part of most physical security systems. Target detection sensors have attracted attention as rising terrorism incidents. In recent years, various target detection systems have been studied as a security system for important facilities to prevent terrorist attacks. For this purpose, many security systems with camera system have been mainly developed and used in the past. The security systems with leaky coaxial cable have been also proposed and developed in recent years. The project pertains detection, localization and identification of different objects using a pair of leaky coaxial cables along a prescribed route. In this system, two cables are installed parallel to each other with separation sufficient enough (1m to 3m) so as to cause the two cables to be loosely coupled. A RF transmitter is connected to one of the cables to supply RF signal at 800MHz for propagation there along. A matched RF receiver is attached to one end of second cable. A chirp frequency modulation provides a continuous target response having a baseband frequency that is proportional to the distance along the length of the cable. After location determination, the amplitude of the response is compared to a location specific threshold to determine if an intruder is present. The presence of a target (anybody which reflects or absorbs radio frequency energy) alters the magnitude and phase of the signal received at the other cable and, hence, provides a change in the return signal to the receiver connected to the receiving cable. This change in signal is processed digitally to discriminate between legitimate targets and changes due to undesirable targets such as animals. Point of intrusion is also located along a prescribed route.

DEDICATED TO OUR BELOVED FAMILIES

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LIST OF ABBREVIATIONS

ADC Analog to Digital Convertor

CMC Coupled Mode Cable

DAC Digital to Analog Convertor

DDC Digital Down Convertor

DSP Digital Up Convertor

FFT Fast Fourier Transform

FPGA Field Programmable Gateway Array

GRC Gnu Radio Companion

HFSS High Frequency Simulation Software

IF Intermediate Frequency

LFM Linear Frequency Modulation

LCX Leaky Coaxial Cable

RX Receiver

SDR Software Defined Radio

SWIG Simplified Wrapper and Interface Grabber

TX Transmitter

USRP Universal Serial Radio Peripheral

VHDL Very High Speed Integrated Circuit Hardware Descriptive Language

VNA Vector Network Analyzer

CHAPTER 1

INTRODUCTION

1.1 Overview

For the past 30 years the use of buried cable structures as a perimeter detection tool has been used extensively in military, industrial facilities and nuclear installations. The covert deployment and terrain following property made this class of sensors the preferred choice for many situations. There are many different designs of buried cables available, ranging from strain-gauged cables that respond to intruder-induced ground motion, to ported coaxial cable, that generate an invisible volumetric electromagnetic field which monitors any disturbance induced by intruder.

Leaky Coaxial Cable systems have been used for several years by military organizations, government agencies and private industries to detect unauthorized entrees along the perimeters of high-value resources. Leaky Coaxial Cable systems typically consist of two cables which encircle a perimeter of site and are attached to a processor. Deploying the cables comprises of either burying the cables 5 to 6 inches deep in soil or placing the cables in slots cut in a paved surface. In both soil and pavement, the two cables are placed 1 to 3 m [1] apart. Leaky Coaxial cables are coaxial cables with periodic slots in the outer conductor. These slots allow radio frequency energy to "leak" from one cable (the transmit cable) and couple into the other (the receive cable). Detection and localization of a target occurs when the electromagnetic field between the two cables is disturbed beyond a predefined alarm threshold value.

1.2 Why We Need Buried Cable Perimeter Intrusion Detection System?

From the physical strength of barrier structure such as Great Wall of China to modern detection and surveillance systems, border security and perimeter protection has always been a vital element in the protection of not only nation state but also of corporate and private property as well as the individuals at threat.

Today we face international terrorism on global basis, the requirement to protect international borders and provide perimeter protection against sophisticated and determined intrusion is a matter of uppermost order.

The risk of intrusion, illegal immigration, smuggling, espionage, military invasion or terrorists activities etc. can be substantially mitigated, if not eliminated by applying proper perimeter protection measures. The persistent threat of terrorist attacks and new global security directives are all contributing to increase spending on perimeter security systems throughout the world, as recently reported by Frost and Sullivan. This report reviews industry considerations for perimeter security, video scrutiny, admission control, technology integration, screening, command and control and security personnel. Due to ongoing threats of international terrorism focus on perimeter security requirements has been increased, while the high value of corporate assets and the increasing need for improved safety measures are driving the adoption of enhanced perimeter security standards. It is generally known that both commercial and military fields and areas represent red zones for security requiring reliable and versatile security solutions. As a result, security industry manufacturers are supporting these trends with efficient and competent integrated solutions. The numerous types of devices currently employed in these applications all have serious shortcomings; especially for long perimeters (in access of 1 mile) during adversarial environmental conditions. Heavy rain or snowy weather can incapacitate most optical systems based upon photo electric sensors. Pressure sensitive devices can be ineffective in cold climate due to frost penetration. Both acoustic and seismic sensors are susceptible to false alarms may be due to gust of wind or the vicinity of vehicular traffic. [2]

A number of perimeter security systems are based upon the disturbance of electromagnetic fields. Some systems depend on capacitance changes between two sensing wires. Others rely upon the change of impendence of two wire transmission line. Most of these systems have comparatively poor sensitivity because they try to detect very small changes in a large quantity which typically is a function of the physical deployment of the sensors. This can cause false alarms due to rain, vibration, snow or variations in temperature and humidity. One solution that addresses the unique challenges and requirements of the security is “Buried Cable Perimeter Intrusion Detection System”. It can be used to detect unauthorized movement or access into high security areas such as prisoners, air ports, freight yards, ware houses and defense installation.

1.3 Project Description

Buried cable intrusion detection system consists of two sensing cables. Referring to figure 1-1, cable 1 is acting as transmitter while cable 2 is receiver cable. These cables are separated by 1m to 3 m distance and buried approximately 5-6 inches down the earth. A FMCW transmitter is connected to one end of the cable1 and a matched receiver to cable 2. The distance between cables is adjusted to have loose coupling between them. Cables are said to be loosely coupled if coupling coefficient between them is between .01 and .001[2]

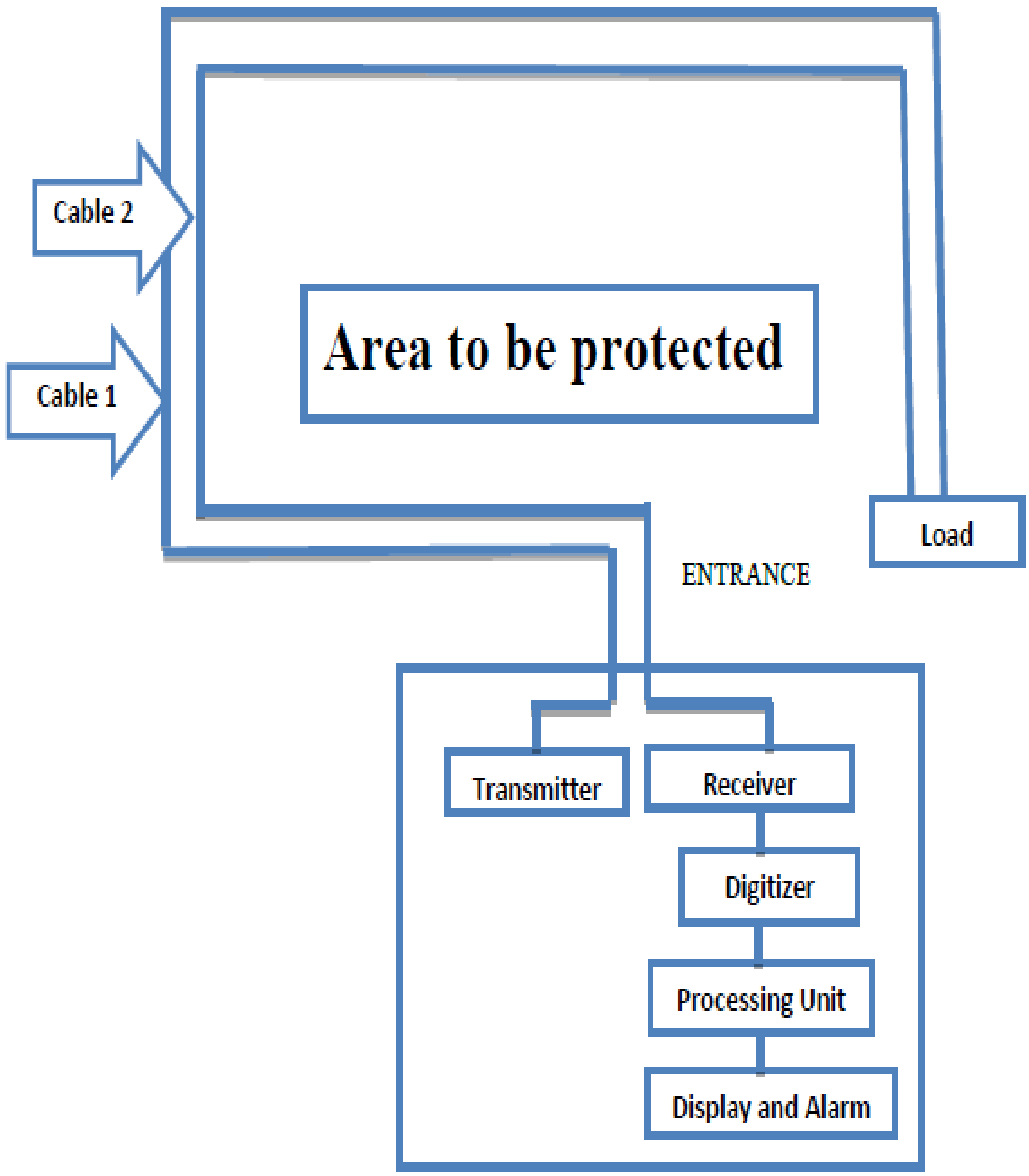

Figure 1-1 Project Description

Transmitter sends a continuous wave which is linearly modulated into the cable 1, energy leaks out from the holes milled in the outer conductor of coaxial cable.

A portion of this travelling wave is coupled into cable 2 and returned to the receiver. So electromagnetic field curtain is created between the two cables. The received signal is digitized and fed to preprocessor unit. Preprocessor is followed by processor which will process the signal and feed it to threshold unit. The phase and magnitude of received signal changes when an intruder crosses the cables. The processor will sense this change and translate this change into the distance of the intruder from cable length. If the change in signal exceeds the threshold level, it will trigger alarm unit and will make the alarm sound to indicate and locate intrusion.

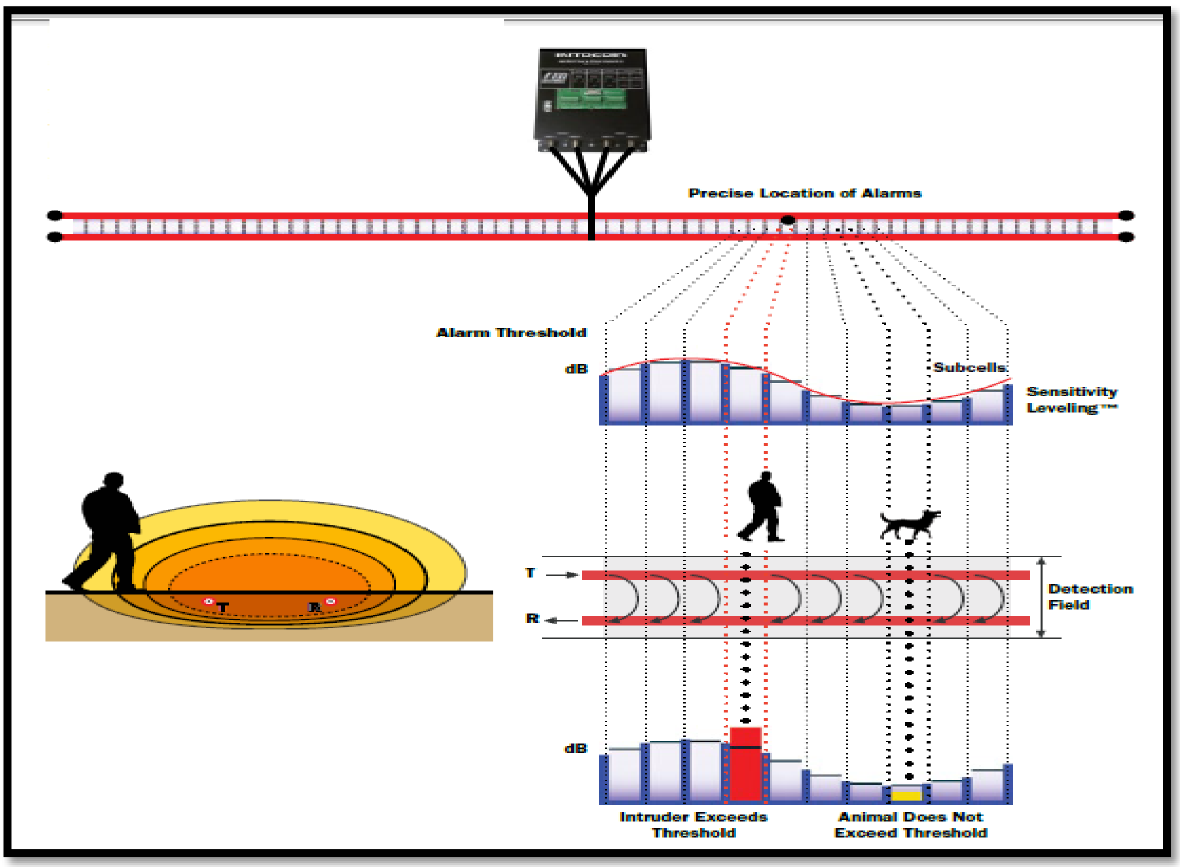

Figure 1-2 Operational Overview [3]

Referring figure 1-2, transmitter sends FMCW modulated signal into the transmitter cable. As the signal travels down the cable, electromagnetic energy continually leaks out and is coupled onto the receive cable through the surrounding environment. A portion of the electromagnetic energy which is coupled onto the receive cable travels back to the receiver. After bandpass filtering, the received signal is demodulated using the transmitter RF generator as a reference signal. Figure 1-2 shows the cable profile. An intruder crossing the cables perturbs the electromagnetic field between transmit and receive cables. This disturbance will cause a rapid change in amplitude of the signal profile which can be detected with additional signal processing. Received signal is divided into separate range zones and each zone is quantized into discrete levels. This range division and digitization process is represented in Figure 1-2. The magnitude of each range zone is compared against a predetermined threshold. If this value exceeds the threshold, an intrusion is declared.

1.4 Scope, Specifications and Deliverables

Project is aimed at designing and producing a prototype for an intrusion detection system based on leaky coaxial cables. The intrusion detection system shall locate intruders into specific zones. Project will include design and manufacturing of leaky coaxial cable antenna according to system requirements. Length of cable antenna used is 8 m for the present system. The detection field shall be formed by radio-frequency (RF) signals carried by sensor cables that are placed along the perimeter. The RF signals shall form an invisible electromagnetic detection field around the sensor cables that can locate and detect an intruder passing through the field.

Specifications and features of prototype are given below:

- Input power used is 200mW
- Continuous wave signal used to excite the transmitter cable
- Operating Temperature: -40°C to +70°C (-40°F to +159°F) [4]

- Operating frequency: 800 MHz
- Intrusion Location Detection with 98 % accuracy
- Leaky Coaxial Cable Length 8 m
- USRP 1 as RF frontend
- Terrain Following Capability
- Uniform Detection along Coverage area
- Software-controlled zoning(optional)

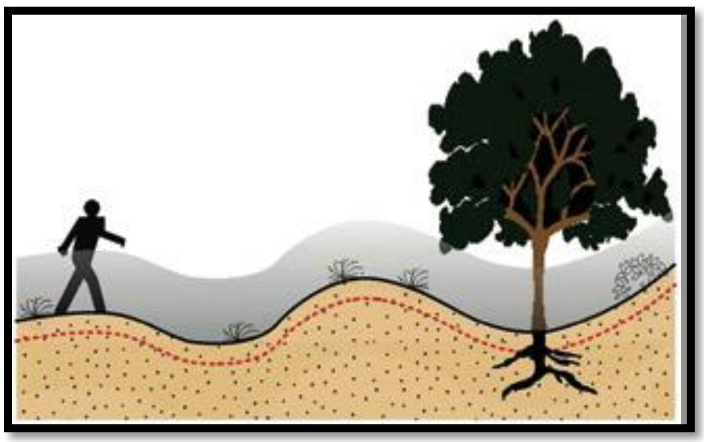

Figure 1-3 Terrain Following Capability of Leaky Coaxial Cables

1.5 Objectives

1.5.1 Project Objective

The objective of this project is to design an intelligent and innovative intrusion detection system to detect intruders by means of Leaky Coaxial cables (LCX) for wide area surveillance systems. The systems also pertains to localize intrusion, identify intrusion and determine the direction of intrusion i-e determine whether it is an intrusion or extrusion.

1.5.2 Academic Objective

The academic objectives include:

- Design of leaky coaxial feeders
- Understanding electromagnetic field between leaky cables and effects of various intrusions(bodies) on this field
- Learning of USRP processing and GNU Radio
- Learning technique to detect location of intrusion along a prescribed route

1.6 Project Approach

Project is divided into two sections. The first section comprised of design and development of leaky coaxial cable. This is referred as RF section. Second section focused on software defined radio for design of transmitter and receiver. All the signal processing required for detection and localization is being done in GNU Radio.

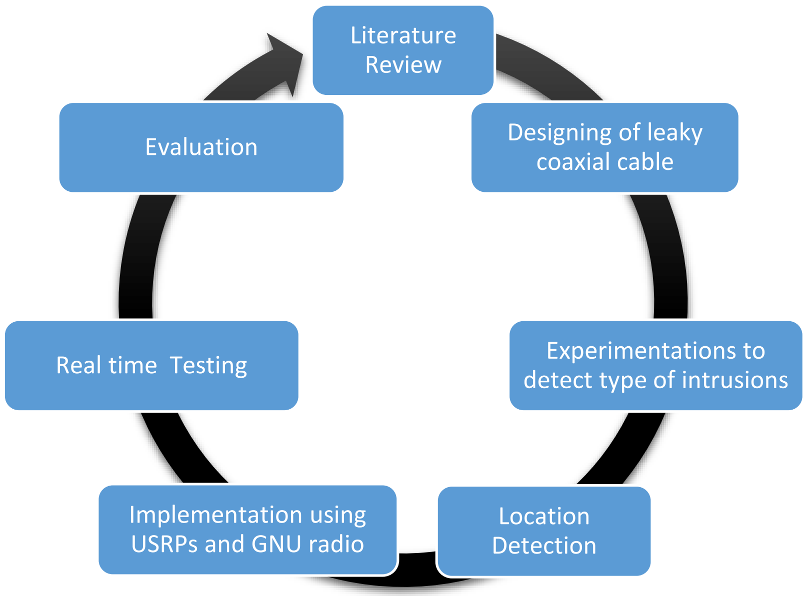

Figure 1-4 Project Approach

1.7 Organization of Thesis

Thesis is organized into seven chapters. First chapter introduces the project and its scope. Project objectives, project approach and literature review is discussed in this chapter. Second chapter focus on leaky coaxial cable. It highlights theoretical concepts of leaky coaxial cable. Different types of leaky coaxial cable and their specifications are discussed in this chapter. Various aspects of leaky cables are discussed. Field equations and analysis is being done. Advantages and limitations of leaky coaxial cables are also discussed. Applications of these cables in different fields of life are discussed.

Third chapter is based upon design and development of leaky coaxial cable. It discusses various physical parameters required for proper designing of cable in HFSS.

Fourth chapter is based upon detection algorithm to detect human intruders. It highlights basic techniques to differentiate human intruders from other type of objects. In fifth chapter, frequency modulated continuous wave transmission is discussed in detail. The project is based on FMCW transmission. In this chapter, FMCW radar principle is discussed and operation principle of project is defined. It highlights advantages and disadvantages of FMCW systems.

In sixth chapter, software defined radio is discussed in detail. It highlights the operation of USRPs in detail and their utilization in the project. GNU Radio processing and its various modules are discussed in detail.

In seventh chapter, future recommendations for the current work are discussed.

CHAPTER 2

LEAKY COAXIAL CABLE

2.1 Introduction

A leaky coaxial cable has an outer conductor having an array of slots in the direction of the cable axis such that each slot is arranged periodically at a fixed interval and a fixed shape, but with the dimensions thereof or other radiation factors of the slot being changed sinusoidal in another periodicity different from the periodicity of the slots. A leaky coaxial cable including an inner conductor, a coaxial tube-like outer conductor and a longitudinal leaky slot array in outer conductor with a fixed slot center-to-center spacing, characterized in that the slots in said array at least in part extend in length other than transverse to the axis of said cable and the radiation intensity factors of said slots are successively varied in a sinusoidal fashion such that a group of slots are present in each sinusoidal half cycle with the slot configuration and direction of slot length extension for one half cycle alternately reverse from one half cycle to the next.

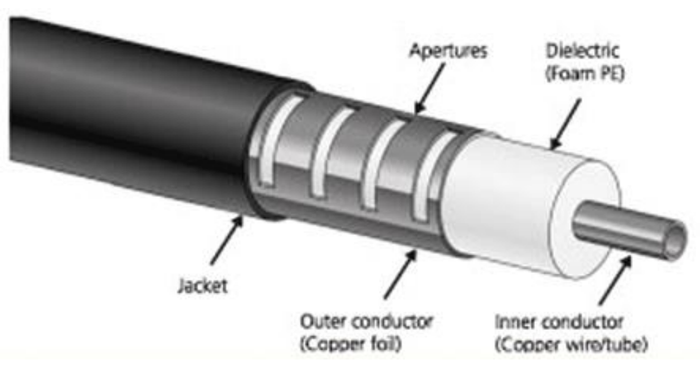

Figure 2-1 Leaky Coaxial Cable

Leaky cables are commonly used to solve the problem of radio propagation in subway lines, road tunnels and mines or in zones where the on-board receivers are momentarily in a radio electric shadow area, like in some urban environments. There use in intrusion detection systems is also very popular. Leaky coaxial cables are similar in structure to normal coaxial cables, have specific space slots milled into the outer conductor sheath to purposely leak and radiate the transmitted signal. The signal energy is guided by the length of the LCX, its generated field is confined both inside and outside the cable in its immediate neighborhood, thus enabling the signal to be coupled into mobile communication units.

2.2 Types of Leaky Coaxial Cables

Depending on the signal frequency and the design of the cable, it can work in different modes. The two main and most commonly used types of mode are the *coupling mode* and the *radiating mode*.

2.2.1 Radiating Mode LCX

The radiating mode LCX is designed with non-regular non-periodic slots. The apertures are normally configured in periodic fashion with spacing comparable to the operational frequency and hence less bandwidth, but greater radiating distance. These cables are more costly to manufacture due to the special arrangements of the slots. The arrangement also results in less longitude attenuation and higher-ordered spatial harmonics, increasing the effective radial distance.

2.2.1.1 Explanation

In the RMC (Radiating Mode Cable), cable radiates energy radially (Fig.) and the set of slots with spacing d≈ λ behave just like an array antenna of length L radiating as an alignment of magnetic dipoles m_z parallel to the cable axis.

$$m_z = (\alpha_{mz'} - \alpha_{my'}) cos\psi \; sin\psi \; \frac{V}{\pi D Z_{c0}} \text{ [4]}$$

Where $\alpha_{mz'}$ and $\alpha_{my'}$ are the components of the magnetic polarisabilities of each slot relative to axis z' and y' respectively, D is the shield diameter, Z_{c0} is the cable characteristic impedance, and V is the voltage associated with the TEM wave travelling in the cable.

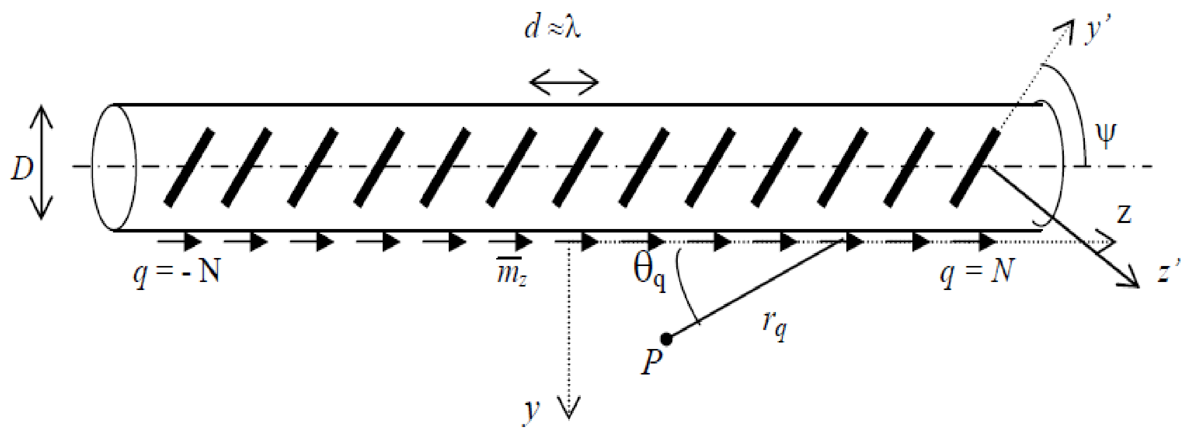

Figure 2-2 Structure of a leaky cable designed as radiating mode cable and its magnetic dipoles equivalent model

The azimuthal electric field in free space is given by

$$E_\varphi = Z_0 \frac{\pi}{\lambda^2} |m_z| \sum_{q=-N}^{q=N} \sin\theta_q \frac{e^{-j[k_0\sqrt{\epsilon_r}(N+q)d + k_0 r_q]}}{r_q} \text{ [4]}$$

Where the first term of the bracketed part in the imaginary exponent stands for the phase shift inside the coaxial cable and the second one stands for the phase shift between the q_{th} slot and the observer. Z_o is the wave impedance in free space and ϵ_r is the permittivity of the cable dielectric.

At large distance from the cable ($r_q \gg L$), angles θ_q and distances r_q are nearly the same for every slot ($\theta_q = \theta \; and \; r_q = r_0$), so that

$$E_\varphi = Z_0 \frac{\pi}{\lambda^2} |m_z| \frac{\sin\theta}{r_o} \sum_{q=-N}^{q=N} e^{-jq(k_o d \cos\theta + \frac{2\pi\sqrt{\epsilon_r} d}{\lambda})} \quad [4]$$

Every time the bracketed exponent is equal to a multiple *n* of 2p, the field strength is maximal and corresponds to a certain radiated mode. Indeed, from equation (3) the phase condition leads to the inequality

$$(\sqrt{\varepsilon_r} - 1)\frac{d}{n} \leq \lambda \leq (\sqrt{\varepsilon_r} + 1)\frac{d}{n} \quad [4]$$

The first radiated mode is for n=1 with a cut-off at $\lambda_{c1} = (1 + \sqrt{\varepsilon_r})d$. The second one is for n=2, with a cut-off at $\lambda_{c2} = (1 + \sqrt{\varepsilon_r})d/2$. Because interference between modes causes field fluctuation along the cable, it is judicious to use the RMC in a single mode.

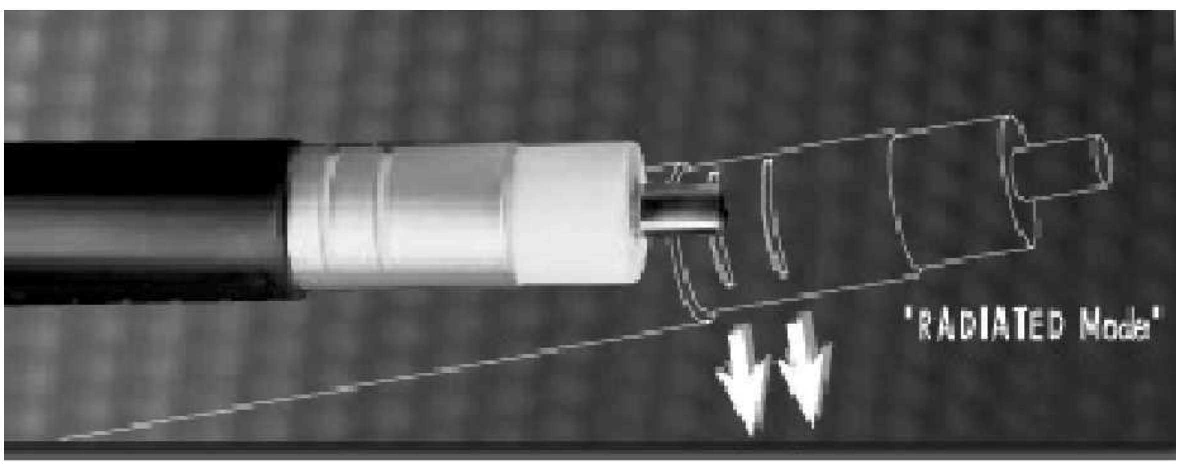

Figure 2-3 Around a RMC active power flows radially

2.2.2 Coupling Mode LCX

The second type called coupling mode, is less costly and consists of smaller spaced and regular structured slots that are smaller than the operating wavelength. The increase in slot frequency means that higher-ordered spatial harmonics become important, guiding the signal further down the longitudinal direction. However, the result of further distance means less energy to dissipate in the radial direction, and therefore less effective allocating distance and coverage volume away from the cable. The lack of signal frequency means that it can give a much larger and wider frequency bandwidth. Like regular coaxial cable, the propagation of signal depends on difference in voltage between the inner core and outer conductor sheath.

2.2.2.1 Explanation

For the CMC (Coupling Mode Cable), the small holes on the outer conductor are characterized by a slot spacing d much smaller than λ.

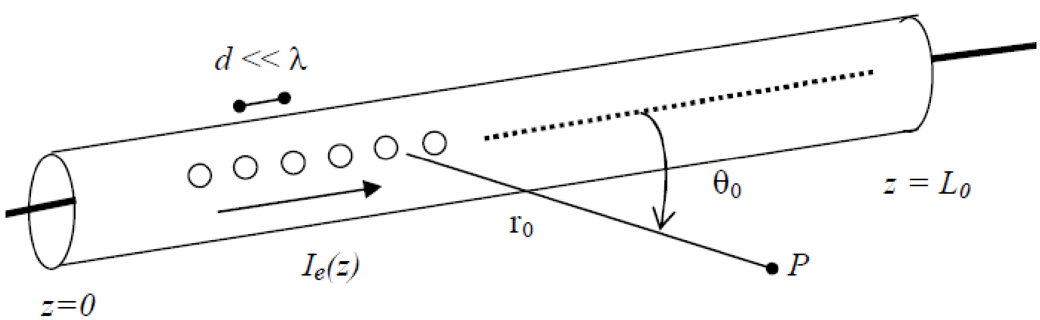

Figure 2-4 Structure of a leaky cable designed as a coupling mode cable (CMC)

The radiation of these cables is due to a conversion from the coaxial TEM mode travelling inside the cable into a surface wave flowing outside the conductor, as a result of the diffraction throughout the small openings. A current I_e flows on the outer part of the protection, so that the CMC can be seen as a long electrical antenna. The active power from a CMC flows parallel to the cable and the radial component of the electric field is given by:

$$E_\rho = \frac{-(\omega\mu_O)^2\sqrt{P_e}v\alpha_m}{4\pi^3 D^2\sqrt{Z_{co}}Z_{ce}(\beta_y-k_o)}\int_0^L \frac{sin\theta_0 cos\theta_0}{r_o} e^{-j(k_o r_o+\sqrt{\varepsilon_r}k_o z)}dz \;\ldots\ldots\ldots\ldots[4]$$

Where n is the number of apertures per unit length, α_m is the aperture polarizability, L is the cable length and Z_{ce} is the characteristic impedance of the surface wave given by an expression which depends on the distance from the wall. The presence of the wall is therefore required. P_e denotes the power inserted in the cable.

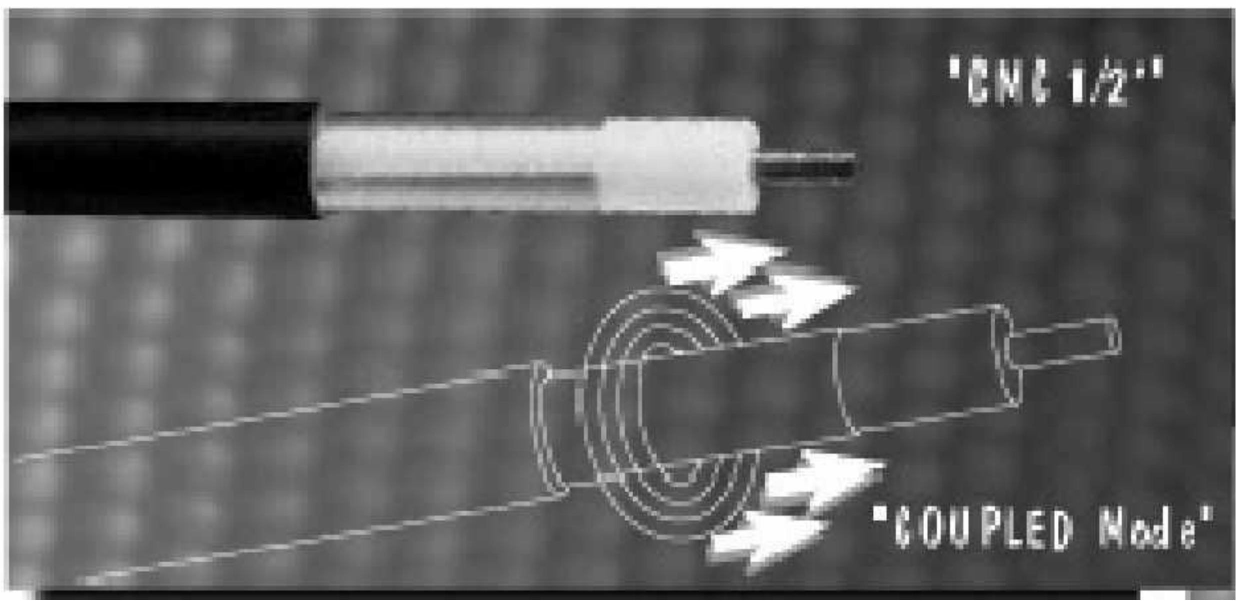

Figure 2-5 Around a CMC, active power flows longitudinally

An important application of slotted waveguide is to construct a "slotted line" for measurements. This is usually done for the TE10 mode pattern, which is the only mode propagating at sufficiently low frequencies. The slot is cut parallel to the axis of guide, in the middle of the wide face. It is a non-radiating slot, and the field pattern inside the guide is but little disturbed by it.

2.3 Modes

The condition required for radiation in the *m*th harmonic can be written from as

$$-mc / P (\sqrt{\varepsilon r} + 1) < f < -mc / P (\sqrt{\varepsilon r} - 1)$$ **[4]**

Where $m < 0$, and c is the wave velocity of free space. In the region defined by equation, the leaky cables work in a radiation mode in the m_{th} harmonic.

2.3.1 Single Radiation Mode

In the region indicated by following formula leaky cables work in a single radiation mode.

$$-c / P (\sqrt{\varepsilon r} + 1) < f < -2c / P (\sqrt{\varepsilon r} + 1)$$ [4]

2.3.2 High Order Radiation Mode

In the region given by following formula**,** leaky coaxial cables operate in a high order radiation mode radiating the beams to multiple directions. In general usage, however high order mode can be removed by adding sub slots.

$$2c / P (\sqrt{\varepsilon r} + 1) < f$$ [4]

2.3.3 Surface mode

In the region given by following formula, no radiation occurs in the entire *m*th harmonic. In this region, the leaky cables operate in a surface mode. Thus we can change the propagation mode of the leaky coaxial cables by changing the frequency band.

$$0 < f < c / P (\sqrt{\varepsilon r} + 1) \text{ [4]}$$

2.4 Field Regions

The volume surrounding an antenna can be classified into three types of regions, each with its own EM field characterization. The far field is furthest of the three, and in this region only the radiated fields exist. This is mostly associated with communication systems where distanced delivery of signals occurs. However, in this LCX system, both transmitting and receiving devices are within a few meters of each other. In this case, depending on the frequency of the signal, they can either be in the reactive near field, or radiating near field, the latter being further than the formal. The IEEE definition of the reactive near field is 'that portion of the near-field region immediately surrounding the antenna, wherein the reactive field dominates. The boundary of this field can be calculated by

$$R < 0.62\sqrt{\frac{D^3}{\lambda}} \text{ [5]}$$

Where D is the largest dimension for the antenna

2.5 Electromagnetic Field

When an electromagnetic signal propagates in medium other than air or vacuum, its propagation velocity is determined by the dielectric constant of that material, in particular, reduced by the square root of the dielectric constant ε. The velocity of propagation (v) with foam polyethylene insulator with dielectric constant ε = 1.25

$$v = \frac{c}{\sqrt{\epsilon}} \text{ [5]}$$

This is important when techniques of detection depend on the propagation speed of the signal through the transmitter cable. It is assumed that the coupling time is essentially zero as the signal is traveling in air.

Surprising, only until very recently did mathematical formulation appear to characterize the leaked EM field. The equation to describe the field of a periodic structure, relating the geometry of the slots, is given by:

$$E(r, \emptyset, z) = E_p(r, \emptyset, z)e^{-jkz} \text{ [5]}$$

Where kz= β-jα, β and α being the propagation and attenuation constants of the basic mode of the perturbed cable respectively in the z direction. These can be related mathematically with β_0 and α_0 of the unperturbed cable linearly, such as $\alpha = \alpha_0\, \kappa'$ and $\beta = \beta_0\, \kappa'$. $\beta = k_0\sqrt{\varepsilon_r}$, where k_0 is the wave number of free space, κ′ and κ the function of many factors of the cable, such as slot size, placement, arrangement and operating frequency, and ϵ_r the relative permittivity of the dielectric material of the cable. For basic TE10 slot configurations of the LCX that is being studied here, κ and κ′ can be approximated to equal 1 [4]. Since $E(r, \emptyset, z)$ in above equation are the periodic field functions of the slots in the z direction, it can be expanded into Fourier series:

$$E(r,\emptyset,z) = \sum_{m=-\infty}^{m=\infty} E_{pm}(r,\emptyset)e^{-\frac{j2m\pi z}{p}}$$ [1]

Therefore,

$$E(r,\emptyset,z) = \sum_{m=-\infty}^{m=\infty} E_{pm}(r,\emptyset)e^{-j\beta mz}$$ [1]

Where

$$\beta_m = \beta + \frac{2m\pi}{p}$$ [1]

P is the period of slots. In particular, the propagation of the mth harmonic in the radial direction is

$$\eta^2 = k_0^2 - \left(k_0\sqrt{\varepsilon_r} + \frac{2m\pi}{p}\right)^2$$ [1]

In order to suppress higher ordered harmonics of the LCX field, the operating frequency should be [2]

$$-mf_1 < f < -mf_2, m < 0$$ [1]

Suppression of higher ordered harmonics are important for systems which employ the zoning technique since multiple frequency signals are passed into the transmitter LCX and distributed in different zones. The location of the movement depends on the coupled signal's frequency.

2.6 Applications

A leaky coaxial cable comprises a radio-frequency coaxial cable, similar to television cable, on which outer braid is designed to be incomplete (about 50% coverage instead of 100%) in order to leak their radio frequency (RF) signal outside the cable. When RF signal is interrupted by the presence of human body with its mass of water, this detunes the system to provide for detection. Leaky coax system can be buried or placed on fences. Unlike Capacitance Systems, the leaky coaxial cable requires only single cable.

Leaky feeder coax radiating cables provide cost effective radio frequency coverage in enclosed or underground areas, where single point source antennas are not practical. Applications include tunnels, metro stations, ships, mines and in-building wireless systems. Leaky Coaxial Cables may also be deployed as a single backbone, supplying multiple services across a broad frequency range from AM radio rebroadcast through the higher frequency 802.11 WLAN applications.

Leaky Coaxial cable successfully provides broadband coverage in building applications for VHF, UHF, cellular, PCS and 802.11b WLAN frequencies. Typically this cable is run through building where point source antennas are not practical.

Leaky feeder cables are used to provide underground communication for a wide range of mining applications. The cable is deployed throughout the mining tunnels and allows a controlled amount of signal to leak into the surrounding environment. This cable enables the cable to receive and transmit, where radio frequency coverage is required.

Leaky Coaxial cable can be used for direct burial detection system applications. This cable provides coverage around highly sensitive areas that need high value security, such as prisons, military installations and nuclear facilities. The leaky coaxial cable radiates a signal creating an EM field, which when disturbed detects intrusions and alerts security personnel.

2.7 Advantages

Work well on fences and as equally well in underground applications. When cables are deployed underground, like the Capacitance System, they are invisible to the offender.

Leaky Coaxial cable is flexible. The cable is designed in such a way that it can bend easily. This means it can travel along paths that take it around corners and up and down walls. It has good terrain following capability.

2.8 Disadvantages

Do not work well near standing water or in rainfall. Leaky coaxial cable is very costly

CHAPTER 3

DESIGN AND DEVOLPMENT OF LEAKY COAXIAL CABLE

3.1 Leaky Coaxial Cable Design

Leaky Coaxial Cables are similar in structure to normal coaxial cables, but have specific spaced holes milled into the outer conductor sheath to purposely leak and radiate the transmitted signal. The signal energy is travels along the length of the LCX, its generated field is confined both inside and outside the cable in its immediate locality, thus enabling the signal to be coupled into mobile communication units. Based on the coupling and radiating mechanisms are two different categories of LCX, each with their own performance characteristics. [1]

1. Radiating Mode LCX

2. Coupled Mode LCX

The first, radiating mode LCX is designed with non-regular non-periodic slots. The openings are typically configured in periodic fashion with spacing comparable to the operational frequency and hence less bandwidth, but greater radiating distance. These cables are more costly to manufacture due to the special arrangements of the slots. The arrangement also results in less longitude attenuation and higher-ordered spatial harmonics, increasing the effective radial distance. The second type called coupling mode used in project, is less costly and consists of smaller spaced and regular structured slots that are smaller than the operating wavelength. The increase in slot frequency means that higher-ordered spatial harmonics comes into play, guiding the signal further down the longitudinal direction. However, the result of further distance means less energy to dissipate in the radial direction, and therefore less effective distributing distance and coverage volume away from the cable.

Figure 3-1 Leaky Corrugated Coaxial Cable

3.2 HFSS

ANSYS HFSS software is the industry-standard simulation tool for 3-D full-wave electromagnetic field simulation and is important for the design of high-frequency and high-speed components. HFSS offers multiple state-of the-art solver technologies based on either the proven finite element method or the well-established integral equation method. A suitable solver for the type of simulation can be chosen.

HFSS can be used to design high-speed modules including on-chip embedded passives, PCB interconnects, IC packages, and high-frequency components such as biomedical devices, antennas and RF/microwave components. With HFSS, engineers can mine scattering matrix parameters (S, Y, Z parameters), visualize 3-D electromagnetic fields (near- and far-field) and generate ANSYS Full-Wave SPICE models that relate to circuit simulations. HFSS can be used within conventional EDA design flows to evaluate signal quality, including reflection loss due to impedance mismatches, transmission path losses, parasitic coupling and radiation.

Each HFSS solver is based on a powerful, automated solution process where only geometry specification is required, along with material properties and the desired output. From there HFSS will automatically generate an efficient, appropriate and accurate mesh for solving the problem using the selected solution technology. With HFSS the physics defines the mesh; the mesh does not define the physics. ANSYS HFSS software has the solvers, technology and capabilities required to model RF and microwave as well as signal- and power-integrity issues.

3.3 Design Specifications of Leaky Coaxial Cable

- Pitch= 250mm
- Length of cable in Simulation: 750mm, 1250mm, 1750mm and 3m
- Length of cable in experimentation: 1.5 m and 8m
- Actual length to be used: 8 m

Operating the leaky coaxial cable in single radiation mode the frequency range comes out to be 566 MHz to 1133MHz. From this range 800MHz is selected as operating frequency for 250mm slot pitch. (Referring to the equation of single radiation mode). Interslot spacing specifies zone length used for localization of target which was selected according to prototype length.

Parameters	Size (mm)	Material
Inner conductor radius	4.75	copper
Outer conductor thickness	1.35	copper
Dielectric thickness	6.6	polyethylene
Interslot distance	2λ/3	--
Slot Radius	7	--

Table 3-1 Cable Parameters

3.4 Simulations

RF SUCO-feed 7/8 coupling coaxial cable is being used. It is coupled mode cable capable of handling frequencies up to 5 GHz. It was selected for its low attenuation at distance approximately 0.03db/meter at 800 MHz, its low coupling loss and its low cost. Being a coupling mode cable means that signals can travel further and less higher-ordered spatial harmonics generated. Also the signal is less radiating, confining more to immediate vicinity which is advantageous to couple signals in distances 1-2m away. HFSS is used for simulation and design of leaky coaxial cable which is used as transmitting and receiving feeder cable.

3.4.1 Electrical Parameters

Medium dry ground has been chosen for analysis. [4] The electrical values are as follows:

Relative Permittivity: 1.25

Relative Permeability: 1

Conductivity: 0.02 (S/m)

3.4.2 SCREEN SHOTS

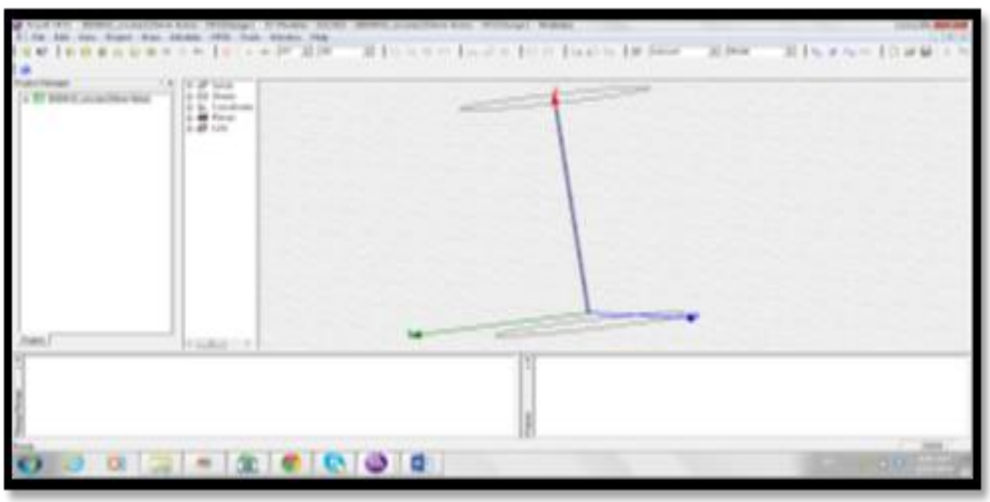

Figure 3-2 HFSS Model for Single Cable

Leaky coaxial cable design is simulated in HFSS. The HFSS model is shown in the above screen-shot. Far field pattern of cable is analyzed.

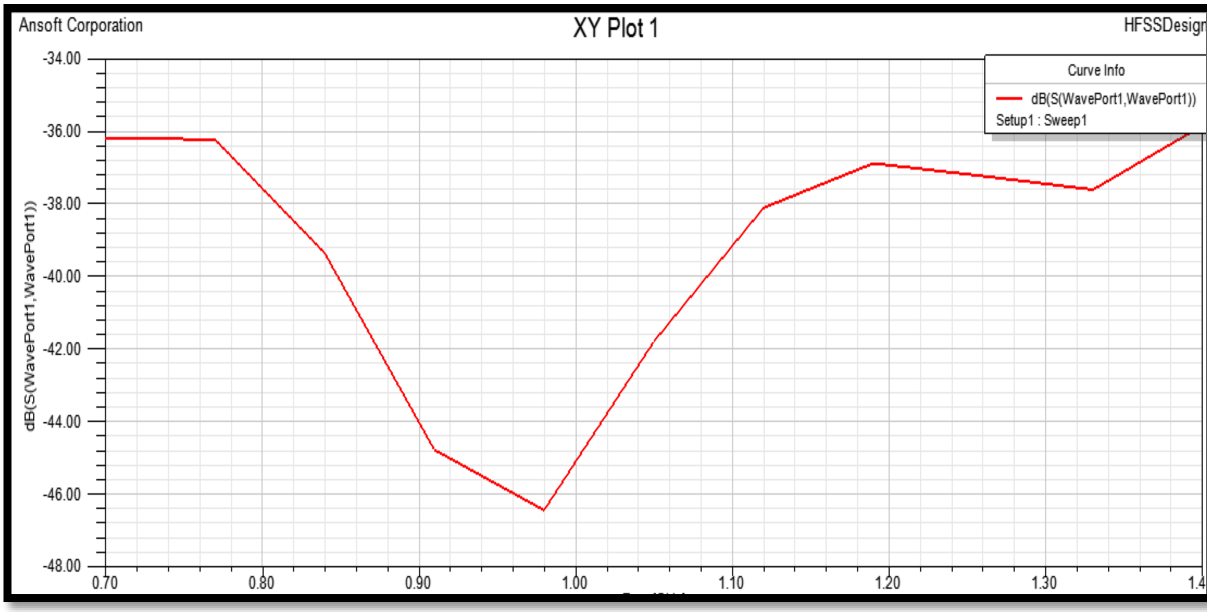

Figure 3-3 S11 Parameter Graph in HFSS

S11 parameter for our designed frequency comes out to be -46dB. Cable is designed to leak out only single mode radiation. Multimode radiation is avoided because it leads to false alarms.

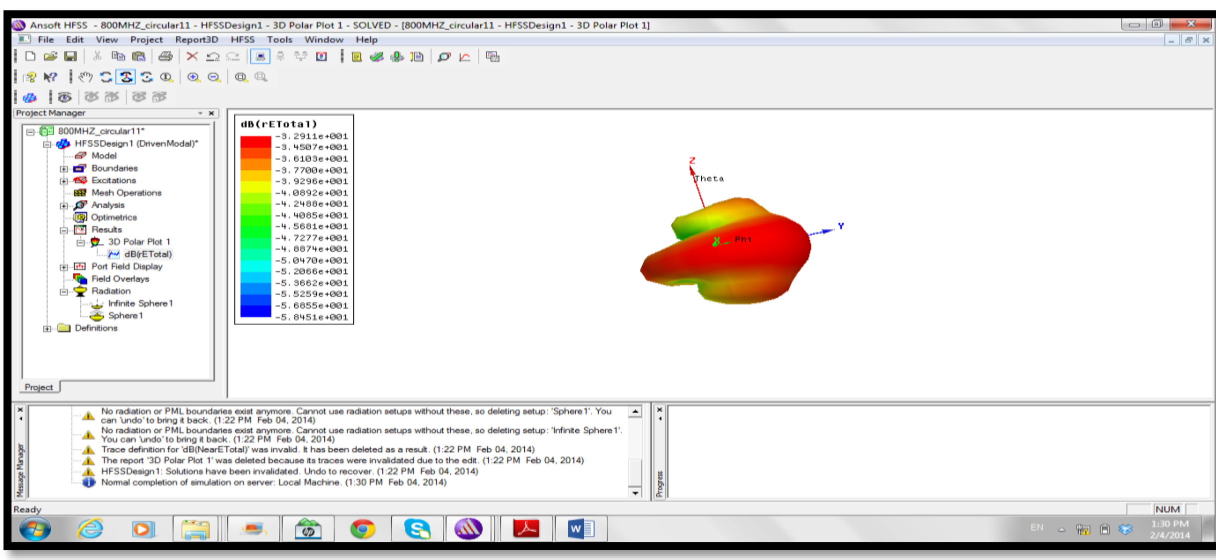

Figure 3-4 Radiation Pattern for two slots

3-d gain plot for two slots is shown. Inter slot distance is 250mm. The total length of cable is 750mm. Maximum gain is in y-direction as slots are arranged in y direction

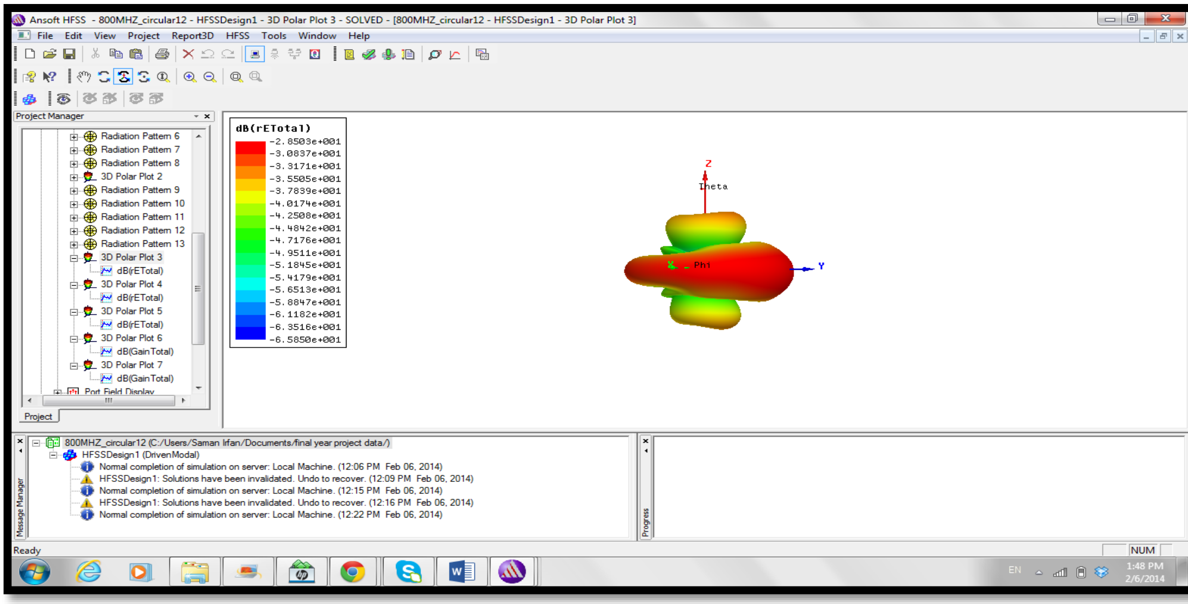

Figure 3-5 Radiation Pattern for four slots

3-d gain plot for two slots is shown. Inter slot distance is 250mm. The total length of cable is 1250mm. Maximum gain is in y-direction as slots are arranged in y direction.

3.5 Development

3.5.1 Experiment 1

SUCO FEED 7/8” cable is converted to leaky transmission line by milling holes of diameter 7mm in outer conductor at inter slot distance of 2λ/3 (250mm). Tests were conducted on cable to check its operation. S11 checked with VNA which came out to be -16 dB. Initially leaky coaxial cable was connected to signal generator through BNC wire. At the receiving end **telescopic antenna** was used and connected to spectrum analyzer.

Figure 3-6 Setup for Experiment

Distance	Power received in dBm
λ/4	-36
λ/2	-44
Λ	-48
2λ	-52

Table 3-2 Power Received at Various Inter Cable Distances

3.5.2 Experiment 2

After analyzing the power received at different distances, tests were made to analyze the effect to various bodies on the electromagnetic field developed between two leaky coaxial cables.

Figure 3-7 Setup for analyzing effect of various bodies on Electromagnetic Field

Type	Dimensions	Power Received (dBm)
1xMetallic Box	7*3 (inches)	-58
2xMetallic Box	7*3 (inches)	-62
Human Body	60 kg	-60

Table 3-3 Body Dimensions and Types

3.6 Summary

Leaky coaxial cable is designed to radiate only single mode radiation as explained in chapter 2. When cable is operated in single mode, the detection achieved is 99 % without any false alarms. In single mode, the localization is also more the 90 %. Multimode radiation leads to false alarms in perimeter intrusion detection system. Effect of various bodies on electromagnetic field is also analyzed so that differences can be recorded. These results are then used to differentiate between legitimate intruders on the basis of their profiles and the received signal strength.

CHAPTER 4

HUMAN INTRUDER DETECTION ALGORITHM

4.1 Introduction

In this chapter, emphasis is given to detection of various objects, *i.e.* human intruders, vehicles, wind/raining and animals. Each classification other than that of human intruders could cause false alarm and detection, and is partially overlapping with the category of human intruders. Therefore it is required to study how each category could distribute in the feature space to significantly reduce a large amount of false detections.

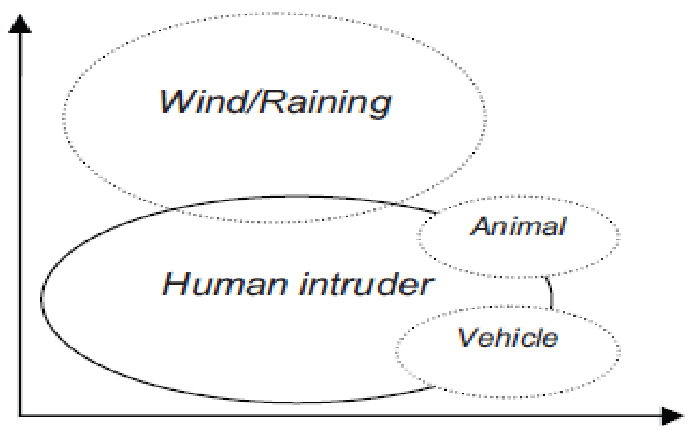

Figure 4-1 Distribution of target categories in the feature space. [5]

4.2 Explanation

The characteristics of each category are described as follows:

4.2.1 Human intruders

The in phase and quadrature (I/Q) patterns have large amplitudes with rotational trajectories around a stable position. [5]

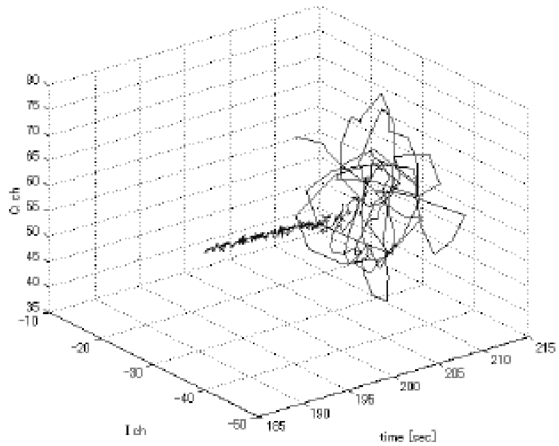

Figure 4-2 Human intruder I/Q Pattern [5]

4.2.2 Wind/Raining

The in phase and quadrature (I/Q) patterns have comparatively large amplitudes with random trajectories.

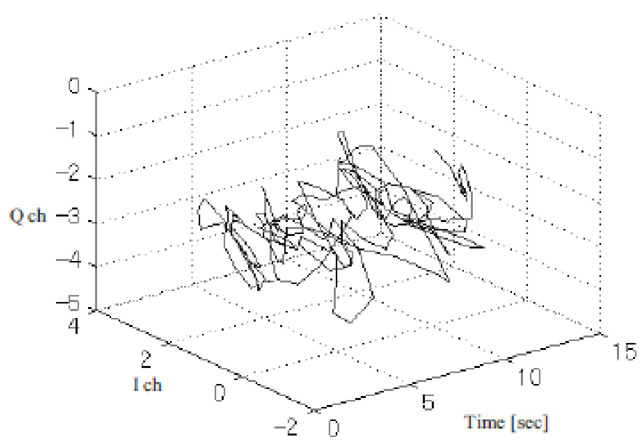

Figure 4-3 Wind/Raining Effects [5]

4.2.3 Vehicles

The in phase and quadrature (I/Q) patterns have similar characteristics to human intrusions but have small variations of amplitudes compared to that of human intruders.

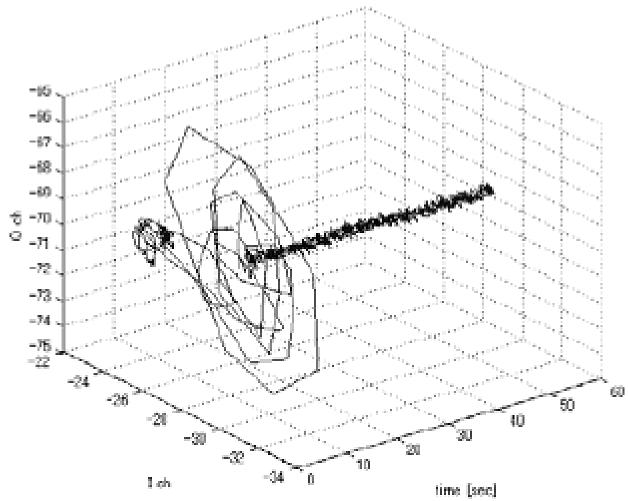

Figure 4-4 Vehicle Effects [5]

4.2.4 Small animals

The amplitudes of the trajectories change as a function of phase.

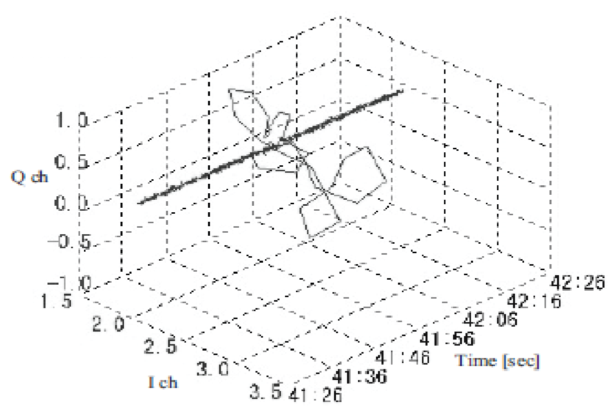

Figure 4-5 Animal Effects [5]

4.3 Feature Extraction

All the features are expressed based on characteristics described previously. Consider in phase and quadrature (I/Q) time sequence of period T. We assume that in phase and quadrature (I/Q) signal point has the angle θ from the ground position **c** and radius r, shown as in figure

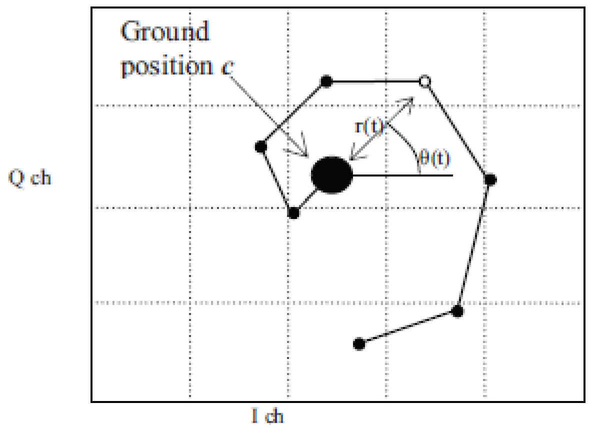

Figure 4-6 IQ signal pattern [5]

4.3.1 Human intruders

The feature criterion for human intruders is defined by computing the roughness of rotation speed. f_1 calculates the amount of the change of the rotation speed during the period T. In the human intrusion pattern, IQ signal indicates rotational pattern. The degree of change of the speed is low in the human intrusion generally. When any human intrudes, this value become small as compared to other intrusions. [5]

$$f_1 = \int_T \left(\frac{d^2\, \theta(t)}{dt^2} \right)^2 dt$$

4.3.2 Wind/Raining

$$f_2 = \int_T \left(\frac{d\,\theta(t)}{dt}\right)^2 dt$$

$$if\ \left(\frac{d\,\theta(t)}{dt}\right)^2 > \sigma$$

f_2 calculates the degree of change in the θ position during the period. In the wind/raining pattern, IQ signal shows random movement. When robust wind/raining occurs in the area to be protected, f_2 rise. However, the human intrusion pattern also has the same features as f_2 . Therefore, we present threshold σ to evade the bad effect. The threshold σ is defined based on the level f_2 of the human intrusions.

4.3.3 Vehicles

This computes the unsmoothness of the change in radius. In the vehicle intrusion pattern, IQ signal shows rotating pattern similar to human intrusion and the radius of the rotation is steady compared to the human intrusion. f_3 calculate the degree of the change of the rotation radius during the period. When a vehicle intrudes, the value of this pointer reaches zero. [5]

$$f_3 = \int_T \left(\frac{dr(t)}{dt}\right)^2 dt$$

4.3.4 Small animals

$$f_4 = \frac{max_\theta R(\theta)}{min_\theta R(\theta)}$$

$where$

$$R(\theta) = \int_T r(t,\theta)\, dt$$

f_4 is calculated by the ratio of the integration of the radius. When a small animal intrudes, this value rises compared to other interruptions. [5]

4.4 Conclusion

For intruder detection system, it is desirable to detect targets in 100 % correctness. On the other hands, wrong detection is tolerable to some extent. However, false detection causes the human operator to check the actions. Therefore, regular false detection increase human costs and make the system trustworthiness down.

CHAPTER 5

CONTINOUS WAVE FREQUENCY MODULATED RANGING SYSTEM

5.1 Introduction

Localization of different things crossing the cables is done on basis of Frequency Modulated Continuous Wave Radar. FMCW radar differs from pulsed radar in that an electromagnetic signal is unceasingly transmitted. The frequency of this signal changes over time, generally in a sweep across a set bandwidth. The change in frequency between the transmitted and received (reflected) signal is determined by mixing the two signals, producing a new signal which can be measured to regulate distance or velocity.

The linear frequency modulated signal (LFM) was chosen for transmission, also known as a chirp. This signal starts at a particular frequency and increases or decreases linearly to another definite frequency over a given amount of time. Chirp covers all frequencies in its bandwidth and therefore is a good representation of the various signals that can be present in that range.

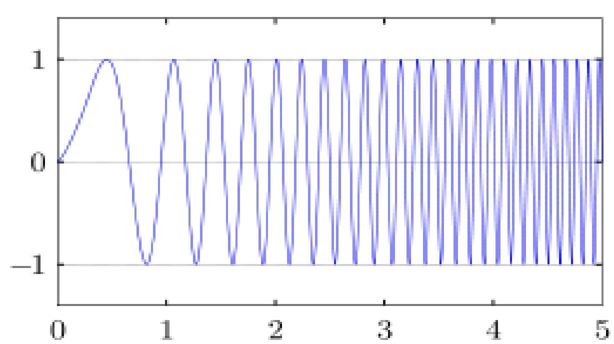

Figure 5-1 Linear Modulation/Sawtooth Modulation

5.2 Principle of Operation

Radar senses and localizes any object on the basis of energy returned to it. It transmit a signal which strikes an object and reflect back to radar. It processes the reflected signal and defines the target and its location. Whereas scheme under discussion works on same principle with only change that it detects the change in signal. Transmitter is transmitting FMCW signal which is unceasingly being received by receiving cable. Receiver will detect the change in the signal. It will further process the change to determine the intrusion, its position and direction of intrusion. A chirp frequency modulation provides a continuous target response having a baseband frequency that is proportional to the distance along the length of the cable. After location determination, the amplitude of the response is compared to a position specific threshold to conclude if an intruder is present. The presence of a target (anybody which reflects or absorbs radio frequency energy) changes the magnitude and phase of the signal received at the other cable and, hence, delivers a change in the return signal to the receiver linked to the receiver cable. This change in signal is processed digitally to distinguish between legitimate targets and changes due to undesirable targets such as animals. Point of intrusion is also located along a agreed route.

5.3 Background

Cable guided radar has been used to detect intruders since the early 1970's. One of the earliest leaky coaxial cable intrusion sensors is the subject of US. Pat. No. 4,091,367. In this system, parallel leaky coaxial cables are buried around the perimeter of the site being protected. A pulse of RF energy is transmitted along one cable to setup an external electromagnetic field that transmits along the length of the cable. The second leaky coaxial cable receives energy reflected from the intruder thereby returning a portion of the transmitted signal back to the receiver. The time delay between the onset of the transmit pulse and the reception of the reflected pulse is used to regulate the location of the intruder along the length of the cable pair. In order to reimburse for attenuation, “graded cables” in which the hole size increases with distance, are used. While many different means of grading cables have been established, all such methods increase the cost of the cable.

In the system disclosed in US. Pat. No. 4,091,367, a 400-nanosecond pulse with a carrier frequency of 60 MHZ is used. An analog to digital converter is used to find 84 in-phase and 84 quadrature samples of the received signal from a 5280-foot long cable. This provides a digital sample for 62-foot cells or segments along the length of the cable pair. Based on a calibration walk, a separate threshold is applied to each cell. One factor limiting the performance of the system described in US. Pat. No. 4,091,367 is the relatively low duty cycle. The 400 nanoseconds pulse width and a 30 kHz repetition rate limits the duty cycle to about 1.2%. The FMCW approach utilized in the present system allows for up to a 100% duty cycle and hence a significant improvement in Signal to Noise Ratio. The FMCW approach utilized in the present system allows for up to a 100% duty cycle and hence a significant improvement in SNR. Furthermore, the ability of the system to locate the intruder before applying the threshold has proven to be very effective in overcoming variations in sensitivity along the length of the cable. This “Sensitivity Leveling” benefit is provided in the FMCW cable guided radar.

5.4 Description

The scheme under discussion uses a chirp FMCW transmission on one leaky coaxial transmission line to generate an external electromagnetic field, which is checked, by a second leaky coaxial transmission line in a parallel cable structure to detect and locate intruders. The ultra-wide bandwidth chirp transmission minimizes the variation in sensitivity along the length of the cable by averaging over the sweep.

FMCW radar differs from traditional pulsed radar systems in that an RF signal is unceasingly output. Thus, time of flight to a reflecting object cannot be calculated directly. In its place, the FMCW radar radiates an RF signal that is usually swept linearly in frequency. The received signal is then mixed with the radiated signal and due to the delay caused by the time of flight for the returned signal, there will be a frequency dissimilarity that can be discovered as a signal in the low frequency range.

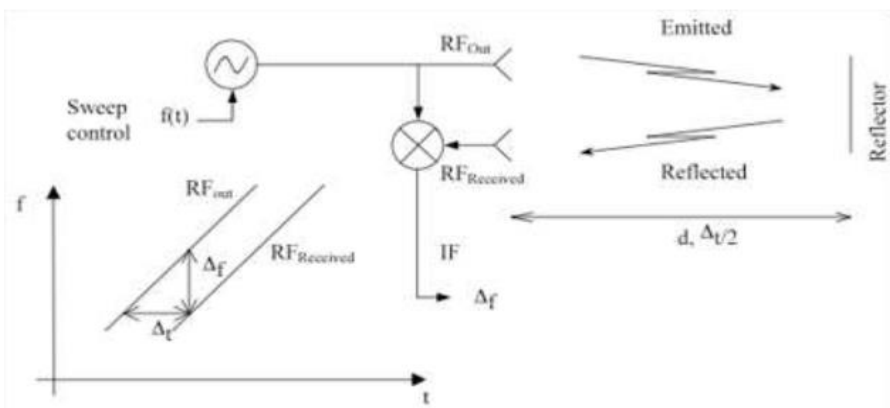

Figure 5-2 Basic FMCW Radar Principle [6]

Schematic performance is showing how a low frequency signal is generated by mixing the received RF signal with the output RF signal. Due to the delay Δt caused by emitted signal traveling the distance to the reflector and back to the receiver, there will be a small difference in signal frequency between the two RF signals. This is output as an IF-signal with frequency Δf.

A basic derivation of the intermediate frequency (IF) signal with the frequency Δf can be made in the following way. Assume that the RF signal generator will produce a frequency that is varying linearly over time as: [6]

$$f_{rfout} = f_{rfo} + k_f \times t, 0 \leq t < T$$

Where f_{rfout} is the starting frequency, T is the frequency sweep time and k_f is the slope of the frequency change, i.e. the sweep rate: [6]

$$k_f = \frac{BW}{T}$$

Where BW is the frequency sweep bandwidth. The delay caused by the round-trip of the emitted signal to the reflector is calculated as: [6]

$$\Delta t = \frac{2d}{c}$$

Where d is the distance between the radar antenna and the reflector and c is the speed of light. Due to the postponement, the frequency of the received signal associated with the emitted signal will be: [6]

$$f_{rfreceievd} = f_{rfo} + k_f \times (t - \Delta t), \Delta t \leq t < T + \Delta t$$

The difference in frequency Δf between $f_{rfreceived}$ and f_{rfo} is thus:

$$\Delta f = k_f * (-\Delta t)$$

This is the signal that is output from the detector. The minus sign can be eliminated since the actual signal frequency output from the detector is wrapped to a positive frequency.

Thus the expression can be written as: [6]

$$\Delta f = \frac{2 * d * BW}{T * c}$$

Where d is distance from cable, BW is bandwidth and c is speed of light. The essential range measurement resolution of the system can be projected as follows. The Fourier transform of a time limited signal can only detect an IF signal frequency with a resolution of 1/T, keeping in mind that $\Delta t << 1/T$; thus the sampling time can be approximated by T. Using equation , this gives the minimum change in d, Δd, as: [6]

$$\frac{1}{T} = \frac{BW}{T} . 2 \times \frac{\Delta d}{c}$$

Which can be transformed into: [6]

$$\Delta d = \frac{c}{2BW}$$

It shows that the range measurement resolution is only limited by the sweep bandwidth. This is significant comment since it is says that resolution is not reliant on the frequency of the RF signal itself, but rather only on the sweep bandwidth.

5.5 Advantages of FMCW System

5.5.1 Better Electrical and Radiation Safety

As compared to pulsed ranging systems, the peak radiated electromagnetic radiation is far lower in a FMCW radar system. This is vital in applications where people are close to the antenna, as the highest emitted energy is far lower. The lower peak power requirements also permit for lower power consumption in the supporting electronics, resulting in lower costs and technology wants. Infrared and video based systems are passive systems, and therefore do not produce a signal for measurement determinations. Most laser based ranging systems use low power emitters, and are measured eye-safe.

5.5.2 Good Range

Compared to systems operating in the visible or infrared light spectrum, or those using ultrasonic waves, FMCW radar sensors have excellent measurement range due to superior signal propagation.

5.5.3 Quick Updating of Measurements

Because FMCW methods are continuously transmitting a signal, there is little postponement in measurement informs, as can be the case with pulsed systems.

5.6 Disadvantages of FMCW System

5.6.1 More Expensive Than Competing Technologies

Similar economies of scale have not been attained in FMCW systems associated to pulsed and Doppler ranging systems, due to the maturity of the existing technologies in the marketplace. Compared to infrared and ultrasonic systems, FMCW systems will generally be far more expensive.

5.6.2 Susceptible to Interference from Other Radio Devices

Because they are always transmitting across a frequency band, FMCW systems may be more susceptible to interference from other electronic systems. This is due to the larger range of frequencies encountered and due to the lower “peak” power, resulting in the returned signal being overwhelmed by other emissions. Pulsed systems can normally overcome interference by increasing transmitted power or by switching frequencies. Distance measurement or detection systems using infrared, video, or lasers are generally immune to interference, given their operating principles.

5.6.3 Can Be Jammed

When use in defense usage, FMCW radars can be at a disadvantage associated to pulsed systems. Due to the lower power and continuous transmissions of FMCW systems, they may be more easily jammed by electronic warfare systems. Pulsed systems have an advantage in this regard in that their transmissions are intermittent in nature, their transmission frequency can be varied, and their power output is generally higher.

5.6.4 Not Passive

FMCW radar systems continuously transmit, meaning that they are easily detected by electronic warfare systems. Pulsed systems may be more difficult to detect as they are not continuously transmitting. This would make the position of an FMCW easier using detection and triangulation techniques. Furthermore, pulsed systems may also more easily be modified to work as passive detectors of other transmitters. Their non-passive nature and use of microwaves also means that they are be subject to rules regarding radio interference and licensing.

5.7 Summary

The FM CW cable guided radar provides a cost effective perimeter field disturbance sensor with a high duty cycle along with all of the benefits linked with the ability to locate an intruder along the length of the cable and decreases the likelihood of indicating a false alarm condition by using location specific thresholds.

CHAPTER 6

SOFTWARE DEFIND RADIO

6.1 Introduction

As compared with hardware-based communication systems, software-defined radio is a communication system whose constituent functionalities are applied in software running on an embedded device. Due to its flexibility and re-configurability, the SDR technology has become communication of the future, envisioning seamless communication among various units. Momentum has been built up in academic world and industry to accept the SDR for applying next generation communication systems. Universal Software Radio Peripheral (USRP) is one of the most popular SDR platforms established so far to support the open-source GNU radio software package. In this project, USRP 1 boards are being used as RF frontends at both transmitting and receiving sides. This chapter covers design of transmitter and receiver as well as detection algorithms implemented in GNURADIO.

6.2 Basic Design of SDR

A usual software radio consists of RF front and Analogue to Digital Converter (ADC) and Digital to Analogue Converter (DAC) interfaced with Central Processing Unit (CPU) and software. The systems on either side possess an RF frontend, each consisting a daughterboard and antenna, along with digital to analog and analog to digital converters and an FPGA that is loaded with software from GNU Radio. It should be noted that either panel is capable of being the transmitter or receiver. Receive and transmit path of usual software radio is shown in figure below:

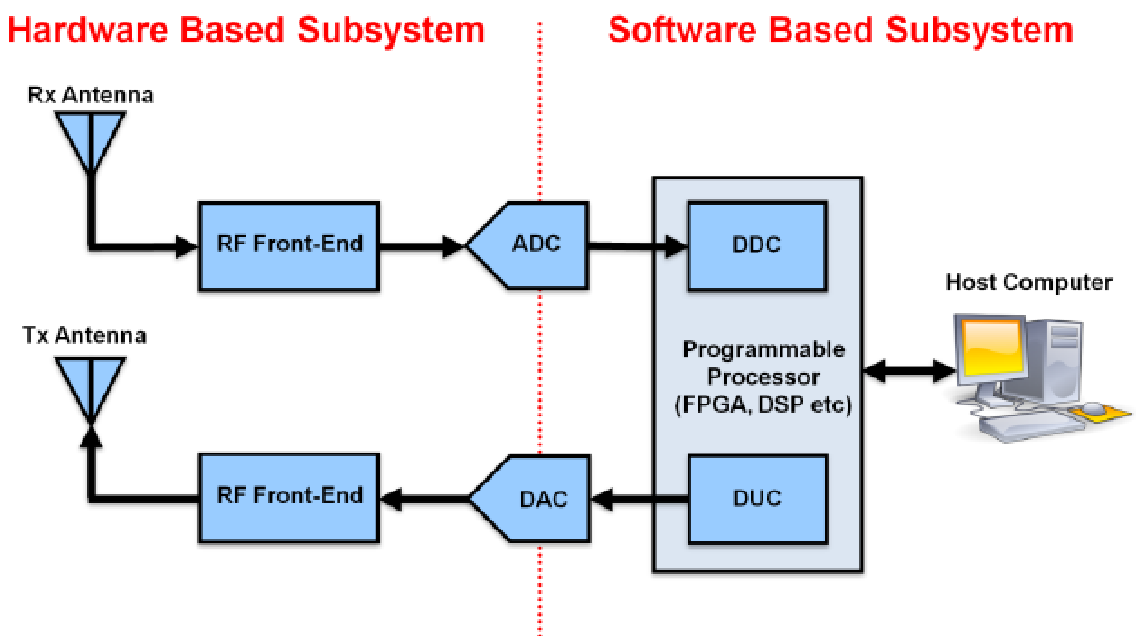

Figure 6-1 SDR Overview

This project includes a device called RF frontend which mixes signal between carrier RF and lower frequencies suitable for sampling rates of ADC/DAC. These lower frequencies may be intermediate frequencies (IF) or baseband frequencies. As a result the ADC/DAC components are only vital to achieve sampling rates adequate to handle modulation bandwidth rather than carrier frequency bandwidth. A programmable processor is used to perform modulation, demodulation or other computationally expensive digital signal processing tasks that would present a significant burden on host computer. The processor may consists of Field Programmable Gateway Array (FPGA), Digital Signal Processor (DSP) or other form of programmable processor.

This subsystem also numerically up converts or down converts the signal between IF and BB (unless direct conversion to baseband is performed by RF-frontend). The digital up-conversion/down-conversion can be achieved by processor itself or by separate Digital Up Converters (DUC) or Digital Down Converters (DDC).

6.3 Universal Serial Radio Peripheral

USRPs are a line of hardware platforms for hosting software defined radios. Designed originally to support GNU Radio, the USRP can now be used with other GUI control software such as MATLAB and Lab View or can be run from a computer command line. The USRP products are sold by Ettus Research and their parent company is National Instruments. The two products required to provide functionalities of software defined radio are a USRP (with internal motherboard), and a RF daughterboard that supports the motherboard. The USRP then attaches to host computer (with GNU Radio or other software) via USB 2.0 or Gigabit Ethernet cable.

Figure 6-2 USRP

In the context of general SDR discussed in section 5.2, USRP contains of FPGA with components to provide the ADC, DAC, DUC and DDC functionality, whereas the RF daughter board provides the RF frontend functionality. A block diagram illustrating this is shown in the figure 6-3. A range of RF daughter boards exits to address different frequency ranges and can be easily interchanged.

Similarly different series of USRP models occur with additional features to meet different requirements.

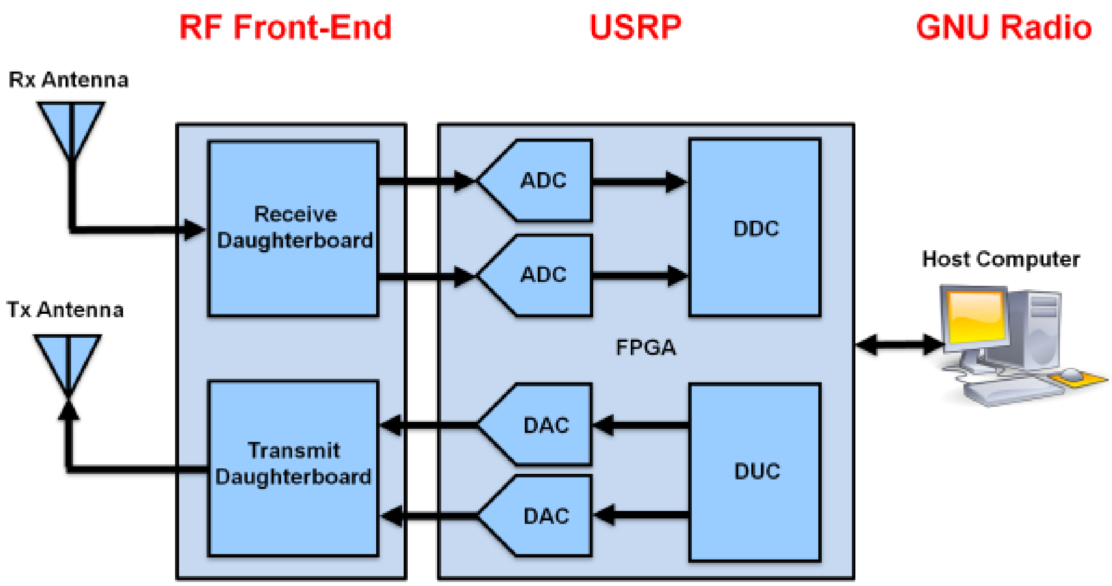

Figure 6-3 USRP Operational Overview

6.3.1 Daughterboard

The RFX900 is a high-performance transceiver planned specifically for operation in the 900 MHz band. With a classic power output of 200 mW, and noise figure of 8 dB. Jumper settings can bypass an on-board SAW filter to permit operation in a wider frequency range. Example application areas include cellular, paging, two-way radio and 902-928 MHz ISM band.

6.3.2 Transmit Signal Path

The host computer running GNU Radio is used to improve the signal processing software, which is transmitted and loaded to FPGAs volatile memory through Gigabit Ethernet/ USB 2.0 interface earlier to operation. Samples for transmission are created at baseband frequency in a complex valued format (in-phase and quadrature components). This is termed as complex baseband. The user selects to use either 16-bit or 8-bit complex samples.

These are collected in first in first out buffers (FIFO), then interleave into data packets which are transferred from host computer into FPGA. The FPGA collects host packets in a FIFO buffer which are then de-interleaved and transmitted into AD9777 module.

AD9777 module obtains 16-bit complex samples across dual channels. It includes DUC process that achieves filtering and interpolation of input to user specified factor, then complex mixing the input with complex modulator. RF daughterboard up converts to the RF frequency specified by user.

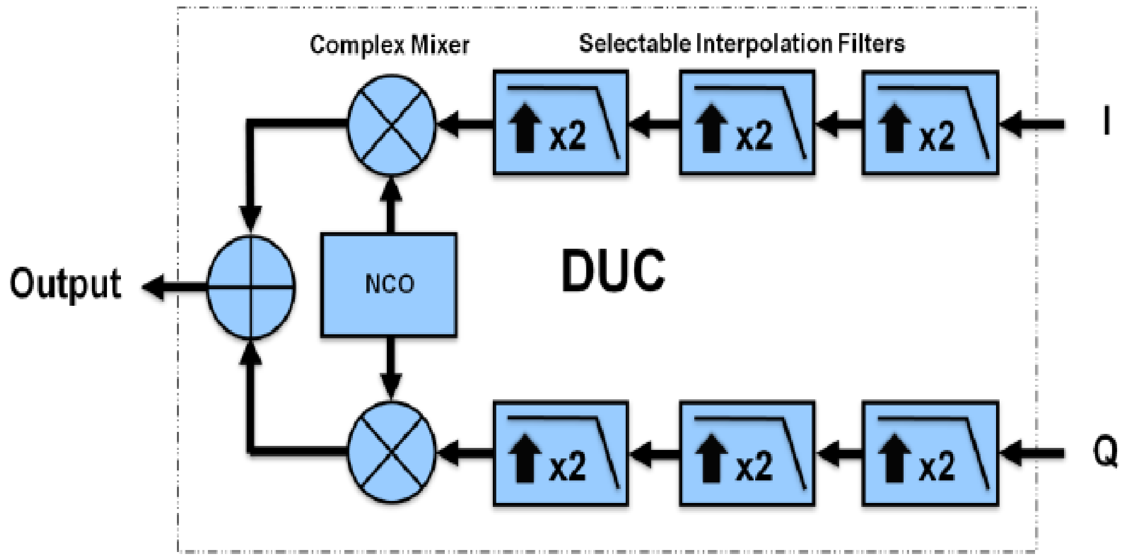

Figure 6-4 Transmit Signal Path in USRP

6.3.3 Receive Signal Path

The receive signal path, with few exceptions, is reverse of transmit signal path. The input received from RF port passes through a diplexer then branches off into low band path and high band path. The signal progressing along low band path undergoes band pass filtering whereas signal on high band path does not.

The signal on either path enters the MAX289 IC where it experiences power amplification. It is then mixed down to a baseband frequency and passed through a low pass filter and passed to ADS62P4X module.

ADS62P4X module digitizes the analog input at 100 M samples/sec using 14 bit samples across dual channels. A DDC process is the applied that involves mixing the signal with complex modulator down to baseband frequency if not done so already, then decimating the signal with user specified value. The complex value signal is then handed into FPGA.

The FPGA assembles the received samples in a FIFO buffer then incorporates them in data blocks that are transmitted to host computer via USB 2.0/ Gigabit Ethernet interface. These are collected in host computer, de-interleaved and processed as required.

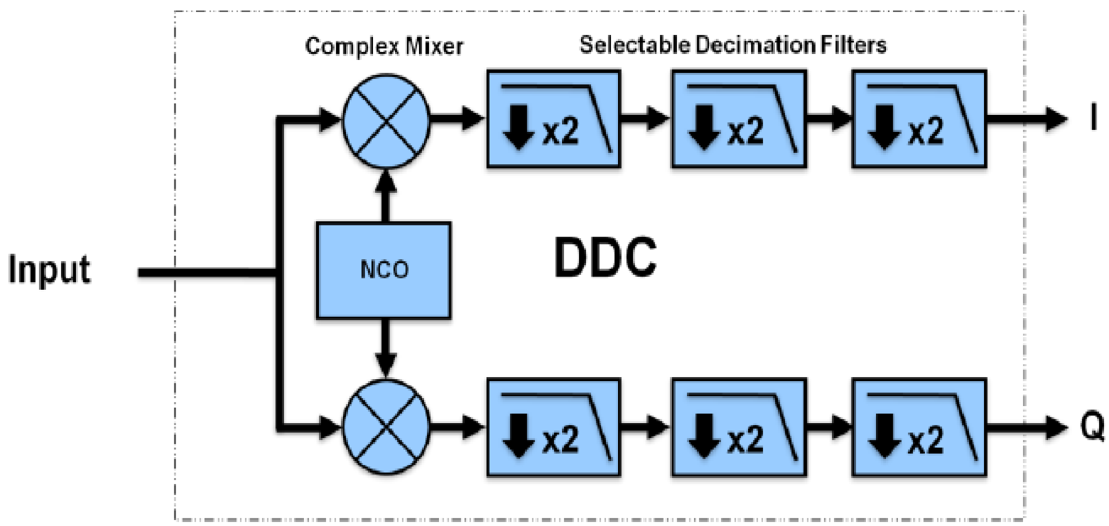

Figure 6-5 Receive Signal Path in USRP

6.4 GNU Radio

GNU Radio is an open source development platform for signal processing and communication applications focusing on implementation of SDRs with low cost external RF hardware. It contains tons of libraries with signal processing routines written in C/C++ programming language. It is broadly used in the wireless communication research and real time implementation of software radio systems. GNU Radio applications are typically written and developed by using Python programming language. Python offers a user friendly frontend environment to the designer to write routines in a speedy way. The performance critical signal processing routines are written in C++. Python is a high level language; it acts as a glue to integrate the routines written in C++ and fulfils through python. Python uses simplified wrapper and interface grabber (SWIG) for the purpose of interfacing C++ routines with python frontend application as shown in Figure 6-5. Very high speed integrated circuits hardware description language (VHDL) is a hardware descriptive language. This part of the code is executed in the Field Programmable Gate Array (FPGA) of front end hardware which is USRP1 in this project.

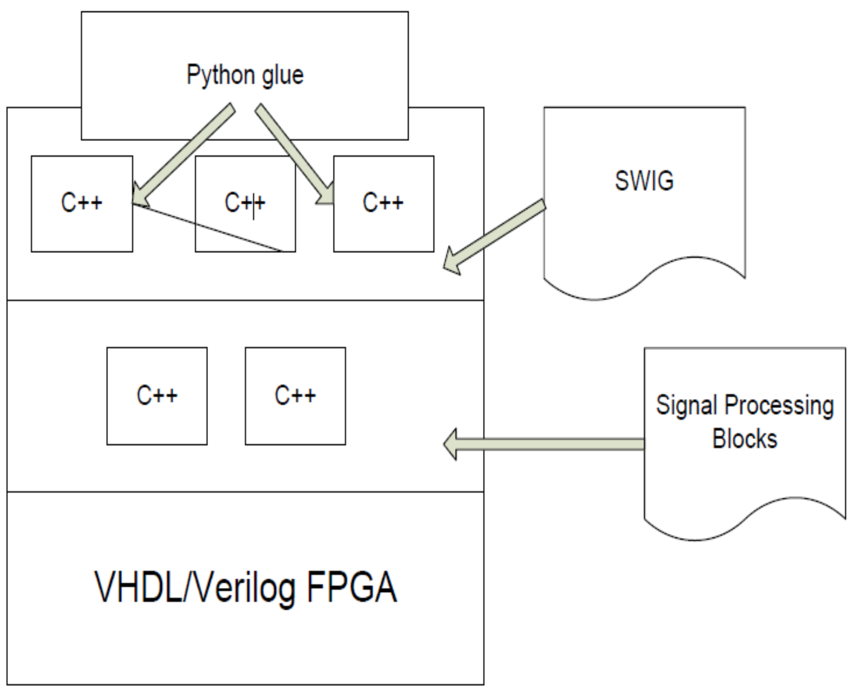

Figure 6-6 Layers of GRC [7]

GNU radio applications can be developed using both Object Oriented Method and Procedural Method depending upon the complexity of the problem under consideration. Some of the modules available in the current release of GNU Radio are shown in Figure 6-7

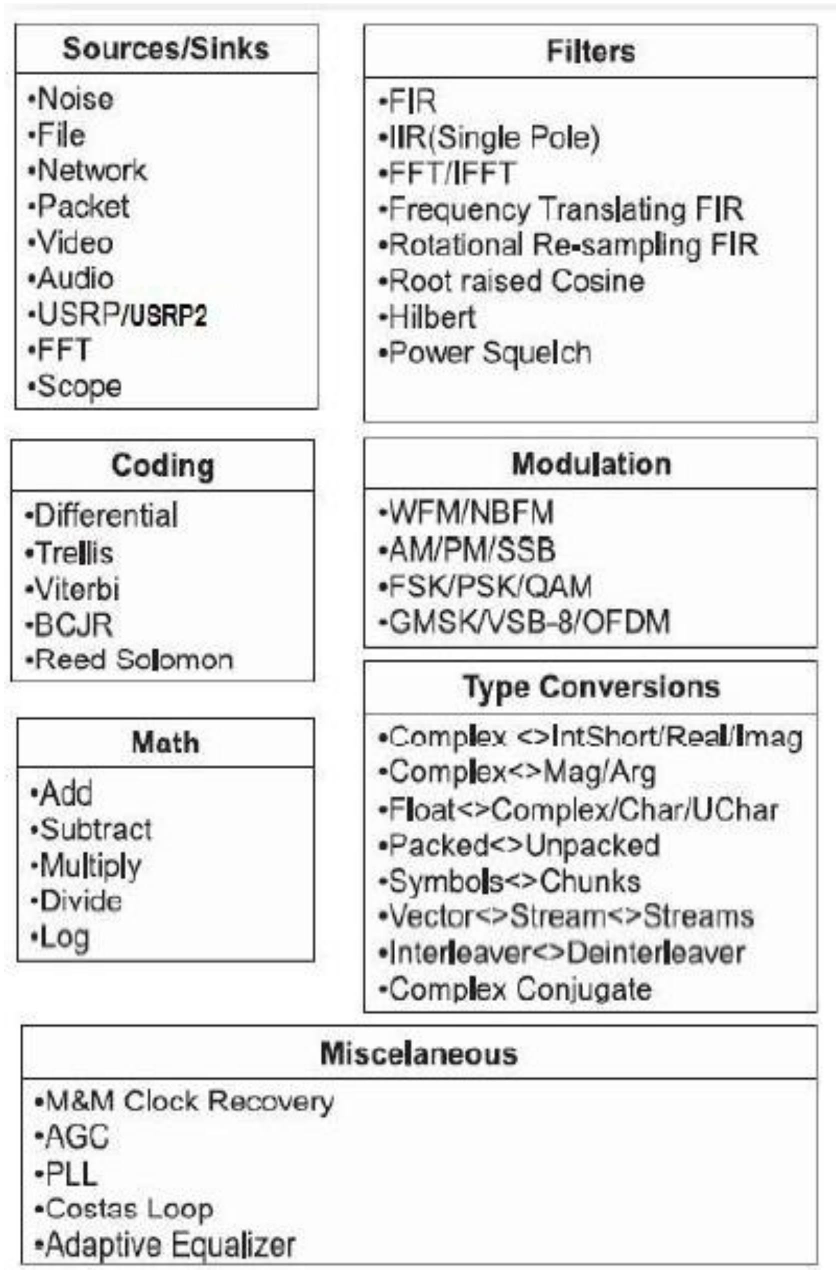

Figure 6-7 Signal Processing Blocks [7]

6.4.1 GNU Radio Flow graphs

Any GNU Radio application can be offered as a collection of flow graphs as in graph theory. The nodes of such flow graphs are called processing blocks. Processing blocks are the code routines written in C++. These processing blocks are tied together through flow graphs or lines connecting blocks. Data flows from one block to another through these flow graphs. All data types which are available in C++ can be used in GNU Radio applications e.g. real or complex integers, floats, etc. Each block connecting one end of flow graph performs one signal processing operation for example encoding, decoding, hardware access etc. Every flow graph in GNU Radio requires at least one source or sink.

6.4.2 GNU Radio Companion

GNU Radio Companion (GRC) is a graphical user interface that permits you to form GNU Radio flow graphs. It is an outstanding way to study the basics of GNU Radio. It comprises of different signal processing blocks that can be combined together in form of flow graphs to offer dissimilar signal processing functions. Flow graphs are executed to accomplish the operations. Since it is easier to handle information flow graphically, GNU Radio deals with its application

GNU Radio Companion the possibility to form a flow chart with graphical block elements.

This application provides numerous predefined blocks, organized in different groups like signal sources, signal sinks as well as modulation and demodulation functions.

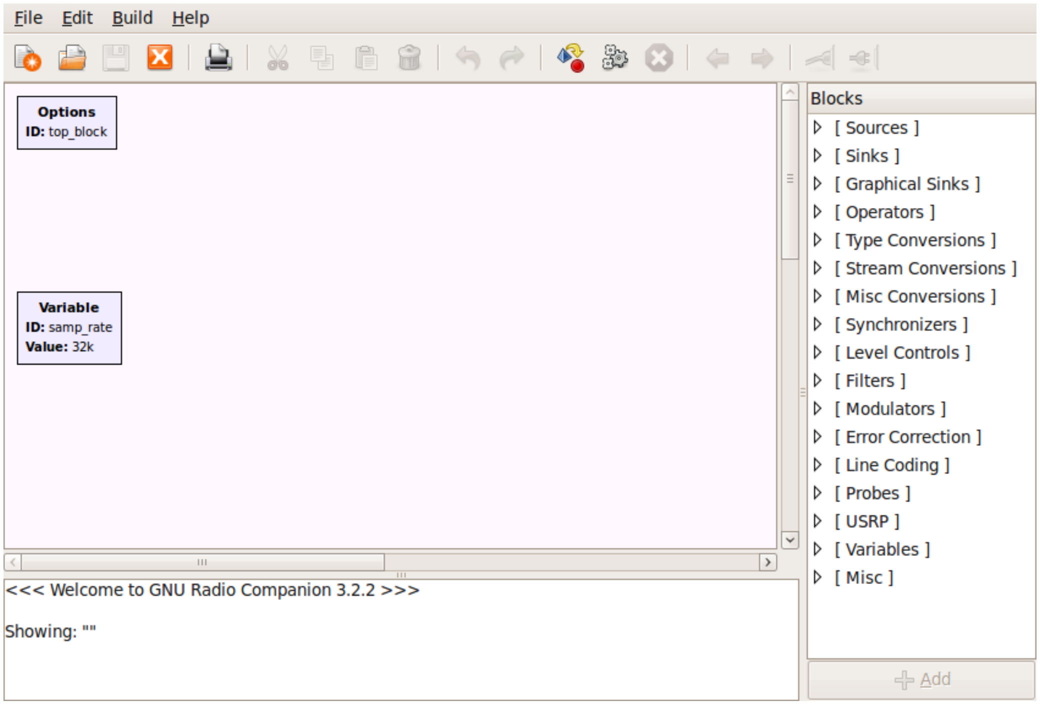

Figure 6-8 GRC Window

6.5 Transmitter Design in GNU Radio

The current system uses a chirp FM CW transmission on one leaky coaxial transmission line to generate an external electromagnetic field, which is observed by a second leaky coaxial transmission line. A chirp frequency modulation delivers a continuous target response having a baseband frequency that is proportionate to the distance along the length of the cable. After location determination, the amplitude of the response is compared to a location specific threshold to control if an intruder is present. Operation principle is alike FMCW radar with difference that in radar energy is only reflected when it strikes with the target whereas in this system, change in energy will be observed to detect and locate intrusions. Increasing the duration of a transmitted pulse increases its energy and improves target detection capability.

FMCW Modulation Parameters	
Local Oscillator Frequency	800 MHz
Sweep Frequency	100 KHz
Sample Rate	1 M samples/sec
Gain	20 dB
Transmit Power	200 mW

Table 6-1 FMCW Modulation Parameters

FMCW transmitter design is shown below. It is developed using GRC in GNURADIO. USRP 1 is used as frontend for the transmitter. Frequency modulation sweep of 5 MHz was investigated over 10 us time period. To implement this in GNURADIO, output from saw-tooth signal source was used to regulate the frequency shift required from frequency modulation block. The frequency modulation block in GNURADIO GRC uses a parameter frequency sensitivity which defines the rate at which signal experiences frequency modulation.

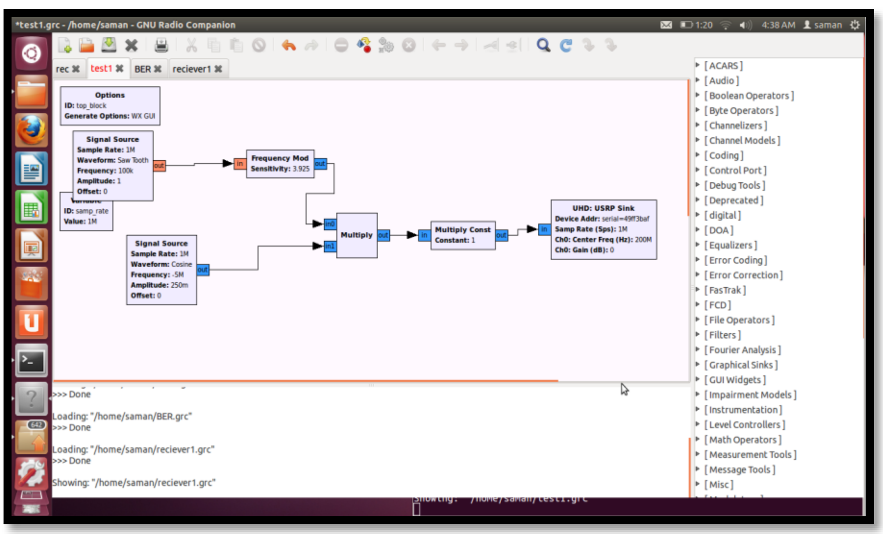

Figure 6-9 Transmitter Flow Graph

Detailed description of blocks is given below:

6.5.1 Signal Source

Signal source block produces sawtooth signal at frequency 100K. This signal will be used for linear frequency modulation or chirp modulation in which a signal starts at a selected frequency and rises or falls linearly to another specified frequency over a given amount of time. The frequency of the signal changes over time, generally in a sweep across a set bandwidth. Frequency of the sawtooth will define time sweep for linear frequency modulation, which in present case comes out to be 10 microsecond. A sawtooth function is the simplest, and most often used, change in frequency pattern for the emitted signal.

6.5.2 Frequency Mod Block

This block works by modelling the frequency modulation of a sine wave after an input signal. For example, a saw tooth signal will result in an LFM that rises in frequency, while a triangle wave would result in one that increases and then decreases linearly. Sending a saw tooth signal with the aforementioned repetition frequency will generate the desired LFM. Frequency sensitivity is calculated by above mentioned formula which defines the rate at which modulation happens. [8]

$$f_{sens} = \Delta f \times \frac{2\pi}{f_s}$$

Where fsens is frequency sensitivity, delta F is frequency difference between highest and lowest frequency. It defines frequency shift and fs is sampling rate.

6.5.3 URSP Source

It signifies the USRP hardware portion. Local Oscillator frequency has been set to 200MHz. Sample rate is set between computer and USRP hardware by interpolation factor. Supported data rate came out to be 64Msamples/sec / interpolation for grc gnu radio 3.7.2. [8]

6.5.4 FFT Sink

It is used to visualize the FFT of incoming signal. Hamming window is selected for FFT with FFT size equal to 4.

6.6 Receiver Design in GNU Radio

Basic Operation and Theory of resembles FMCW (Frequency Modulated Continuous Wave Radar) as described earlier. The frequency of the signal alterations over time, generally in a sweep across a set bandwidth. The alteration in frequency between the transmitted and received (reflected) signal is determined by mixing the two signals, creating a new signal which can be measured to decide distance or velocity. A sawtooth function is the simplest, and most often used, change in frequency pattern for the produced signal.

USRP Source is used to specify USRP hardware. The sample rate used is 1M samples/sec. The time delay associated with propagation of the transmitted signal to the target and back to the receiver generates an IF frequency that is proportional to the distance to the target. FM demodulation block demodulate the received signal from IF to baseband. The channel rate defines the input samples to the FM demod block whereas audio decimation rate defines the decimation of the input samples to the required samples used for processing. After demodulation we have taken FFT of our received signal. The purpose of FFT is to convert the target response information to target location information. The number of FFT points corresponds to the range bins we want to form. Let suppose we want to divide our length of cable to 4 range bins then we will take 4 point

FFT of received signal, where each point corresponds to particular range bins along length of cable. The 4 point complex FFT outputs contain both the amplitude and phase information pertaining to targets along the length of cable. The square root of the sum of the squares of the real and imaginary parts of each bin output is a measure of the amplitude of the response. [6] The response of the present invention to multiple simultaneous targets is that if the targets are sufficiently far apart along the length of the cable, the FFT Will in fact locate each of the multiple targets. If there are two simultaneous targets that are relatively close to each other, it is difficult to determine that there are two separate targets. Resolution is largely dependent upon the bandwidth of the sensor. In the FM CW cable guided radar described herein, the bandwidth is the difference between frequency f1 and f2. The Wider the bandwidth, the better the resolution. All of four point FFT are extracted in parallel. Then we took magnitude of all four FFT points which corresponds to the signal from each range bin. For each range bin a threshold is defined. These thresholds are measured by connecting the cable to the signal generator, and measuring the received signal with telescopic antenna at each range bin. When the intruder intruders the variations of signal are recorded for each range bin. These variations of received signals are then shown on number plot. In this way location can be determined by having threshold activated for that range bin.

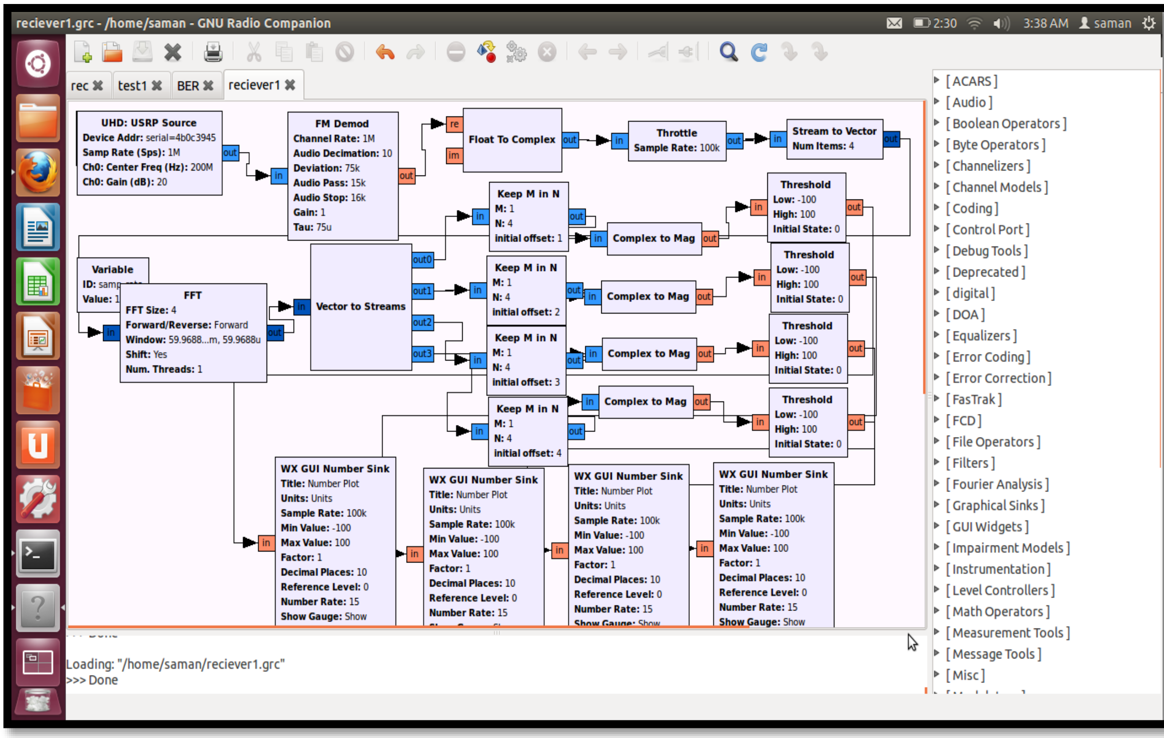

Figure 6-10 Receiver Flow Graph

Detailed description of blocks is given below:

6.6.1 USRP Source

USRP (Universal serial Radio Peripheral) is used to indicate the actual USRP device. In this block we set the sample rate, RF frequency to be set by USRP Board, and gain. The sample rate defines the samples that USRP board can input to our computing device. The sample rate used in new version of GNURADIO should be in multiple of 4M samples/sec. RF frequency used in our design in 800MHz.Gain used is 20dB which is optimum in our scenario.

6.6.2 FM Demodulator

The channel rate defines the input samples in this block, whereas the audio decimation rate defines the decimation of input signal and signal with decimated samples are output from this block and used in further processing. All other parameters are used as default.

6.6.3 Float to Complex

Float to complex block convert float input to complex output. This block is used to convert the type of signal so that FFT can be taken.

6.6.4 Throttle

Throttle is used to stop the memory congestion of CPU, and do efficient processing.

6.6.5 Stream to vector

This block is used to convert the stream input to vector. FFT is done vectorially. So convert the stream into 4 vectors, because we want to compute FFT of size 4. The size of FFT determines the range bins and the resolution we want in out intrusion detection

6.6.6 FFT

This block is the main block. FFT is used in forward direction with blackmanharris window. The FFT of size 4 is taken. FFT resolution can be determined by

6.6.7 Vector to stream

The vector to stream convert the input from FFT to stream output for further processing.

6.6.8 Keep M in N

Keep M in N block is used the extract the particular FFT bin.

6.6.9 Complex to Magnitude

Magnitude of signal is taken in this block.

6.6.10 Threshold

On each range bin the predetermined threshold is already set. This threshold is set during testing of our cable and by check the received signal in each range bin. The threshold is also verified against intrusion phenomena. The default value used is 0 for each range bin. If an intruder intrudes in any of the range bin the threshold will trigger and the number sink will show output 1 for the particular range bin.

6.7 Limitations

The limitations of USRP based systems vary depending upon application requirements. However, the primary issues effecting the performance are the computer processor speed and host connection bandwidth. The low transmit power of Ettus research products is also worth addressing.

6.7.1 Processor Speed

A USRP based system must have sufficient processor resources to keep the desired throughput rate from host computer to USRP. A failure to retain this is referred to as transmit under-run. The demand on processor will vary depending upon the applications. Due to small transmit buffer size, the average transmit rate over a very small window needs to be reliable. If CPU is focusing processor resources on other tasks, transmit under-run will happen.

6.7.2 Host Connection Bandwidth

The host connection bandwidth refers to the throughput between host computer and USRP. Although the new model USRPs offer Gigabit Ethernet connection to host computer surpassing the USB 2.0 interface of earlier models, the host connection bandwidth is still bottleneck controlling USRP performance. The host connection bandwidth not only bounds the maximum sampling rate that is achievable but also MBW of the system and samples per period for a given intermediate frequency.

6.7.3 Transmit Power

The transmit power is the main factor effecting signal to noise ratio at receiver. This may be up to 250 mW depending upon the daughterboard model and type. Depending upon the performance requirements this may require careful selection of waveform parameters to ensure adequate SNR is maintained at receiver. FMCW waveforms can offer better performance at low transmit powers.

6.8 Typical Errors

Symbols	**Meaning**
UoUoUoUo	**USRP overrun**
UuUuUuUu	**USRP underrun**
aOaOaOaO	**Audio overrun**
aUaUaUaU	**Audio underrun**

Table 6-2 Typical Errors in Gnu Radio

6.9 Summary

A large amount of time was spent to overcome the steep learning curve that complemented this project. GNU Radio alone took a while to become familiar since any of the little documentation that exists was scattered throughout the GNU Radio website and forums. Moreover, it was critical to know the USRP boards, Ubuntu, and digital communication theory rapidly for undertaking of the project. USRP along with GNU Radio provided RF frontend that can be controlled through software. It provided flexibility in testing different designs for both transmitter and receiver with leaky coaxial cables. It was a good learning platform. Efficient transmitter and receiver design is implemented in GNU Radio.

CHAPTER 7

CONCLUSION

7.1 Introduction

Buried cable perimeter intrusion detection system is an important perimeter detection tool. It works by radiating EM field and disturbance in that field is processed digitally to detect and locate intrusion. It also works on characterizing the difference between legitimate intruders.

7.2 Applications

The use of buried cable structure as a perimeter detection tool has been used widely in military, industrial facilities and nuclear installation. The covert deployed and terrain following capability made this class of sensor the ready choice for many scenarios.

The scheme can be used to detect unauthorized access into high security areas for example to safe aircraft parking sites, military air fields, storage facilities and public place.

This scheme can also be installed on critical areas of border of Pakistan to detect and prevent an unlawful access into our country.

Leaky coaxial systems are classified as active detection system because energy is constantly inputted into the volume to be protected. Disturbances in this energy are monitored and would trigger an alarm accordingly.

7.3 Advantages

One of the strongest advantages of these buried sensors for perimeter protection is the fact that they are completely hidden to potential intruders, making the possibility of attempts to damage or overpower them is very low.

The buried security sensors can be provided in various forms to suit precise requirements. Pressure and radio frequencies can be set to suit the environment and constitution of the perimeter. Further benefits of the buried sensors include minimal maintenance requirements and the ability to detect intrusion threats and information to precise detail all whilst hidden.

In certain cases, two buried sensor systems can be used collectively to provide even higher levels of sensitive perimeter detection for high-security applications.

Figure 7-1 System Deployment

7.4 Limitations

7.4.1 Tracking Only one Person

Our current design can track only one person at any point in time. This does not mean that only one person will be existing in the environment. Other people can be around, but they have to be behind the directional antennas. We believe that this limitation is not important to the design of our project and this is addressed in the research.

7.4.2 Motion Required for Localization

A second limitation stems from the fact that our designed project needs the user to move in order to locate him. This is because the leaky coaxial cables receive reflections from all static objects in the environment; hence, it cannot differentiate the static user from a piece of furniture. To remove these static reflectors, we need to subtract consecutive FMCW sweeps. Unfortunately, that removes the reflections of the stationary user as well. Future research may address this issue by having training period where the device is first presented with the space without any user so that it may learn the presence of the static objects. Obviously, this would require retraining every time the static objects are moved in the environment.

7.5 Future Recommendations

7.5.1 Locate Multiple Intrusions

Future work in this area should stress the ability to locate multiple intrusions. This can be done by using advance processing of Fast Fourier Transform. Wide bandwidth of FMCW transmitter can localize multiple intrusions positively.

The ability to detect multiple disturbances can be attained by working on phase of received signal. This would provide a better understanding of the applied application of the sensor to perimeter security as the ability to detect simultaneous disturbances along varying points of the perimeter is essential.

7.5.2 Stabilization of System

Initial results show the capability to detect and locate intrusions, but further work must go into the stabilization of the system and refining the detection and localization range. Refining Localization range require wide bandwidth of transmitting system. Moreover, work on signal processing is required. This leads to the expectation that, with suitable signal analysis, the system may be able to discriminate between people, vehicles, animals, and environmental disturbances. This step is key to the practical implementation of this system, as false alarm rates will depend on the ability to differentiate human intruders from animals or environmental disturbances.

7.5.3 Adaptive Learning Techniques

Significant reduction in false and nuisance alarms can be found by applying an adaptive learning technique. With the adaptive learning technique, the signal processing algorithms are repeatedly adapted to the changing soil conditions and nuisance alarm rates. The adaptive learning technique states an alarm when the processed signal parameters are within the range of human target and it announces an alert when a cell threshold is exceeded but the processed signal parameters are not within the range of human target. The adaptive learning process both time and frequency domain features of sensor signal and then applies target recognition technique to distinguish true target from false alarms. The frequency domain features are processed using Fast Fourier transform algorithm.

7.5.4 Instrumenting Geological Faults

This type of sensor might be used in areas other than perimeter security as well. For example, it could be used for instrumenting geological fault lines to monitor seismic disturbances as well as for the early discovery of earthquakes. Work in this area would not only monitor the location of interference but also seek to determine the magnitude of the disturbance. Once authenticated in the field, this system could see countless beneficial uses throughout our world.

APPENDIX

APPENDIX A

GNU RADIO INSTALLATION

Install Ubuntu 10.04 Lucid

2. Open terminal

#Install the dependencies for GNU Radio on Ubuntu 10.04:

sudo apt-get -y install libfontconfig1-dev libxrender-dev libpulse-dev swig

g++ automake autoconf libtool python-dev libfftw3-dev \

libcppunit-dev libboost-all-dev libusb-dev fort77 sdcc sdcc-libraries \

libsdl1.2-dev python-wxgtk2.8 git-core guile-1.8-dev \

libqt4-dev python-numpy ccache python-opengl libgsl0-dev \

python-cheetah python-lxml doxygen qt4-dev-tools \

libqwt5-qt4-dev libqwtplot3d-qt4-dev pyqt4-dev-tools python-qwt5-qt4

3. #Install git and cmake:

sudo apt-get install git-core cmake

4. #Download and install UHD from git:

git clone git://code.ettus.com/ettus/uhd.git

cd uhd/host

mkdir build

cd build

cmake ../

make

make test

sudo make install

#Check where your path is with "find |grep libuhd"

export LD_LIBRARY_PATH=$LD_LIBRARY_PATH:/usr/local/lib

5. #Download and install GNU Radio from git:

git clone http://gnuradio.org/git/gnuradio.git

cd gnuradio

git branch --track next origin/next

git checkout next

git branch #Checks if you have correct path

export PKG_CONFIG_PATH=/usr/local/lib/pkgconfig:${PKG_CONFIG_PATH}

./bootstrap

./configure --enable-gr-uhd

make

make check

sudo make install

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