CONCEALED WEAPON DETECTION

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Concealed Weapon Detection

Concealed weapon detection is one of the greatest challenges faced by law enforcement community. Some kind of screening system is the need of hour to provide controlled access to the general public places. There is always a need of reliable and cost effective weapon detection system for terrorist groups and hijackers hiding different weapons.

Current weapon detection systems mostly work on the principle of metal detection as harmful weapons are metallic in general. These metal detector gates work on the principle of induced magnetic field and Eddy currents and detect metallic objects observing the change in these magnetic parameters when metallic objects are placed in some magnetic field.

Cost effective weapon detection system based on inductive magnetic field technology has been developed. The technique is further classified into three categories depending upon the frequency of operation and the input source. Beat frequency method has been used in this project. A certain frequency is generated by a colpitt's oscillator which is balanced by another oscillator. The search coil is the inductor used in the colpitt's oscillator. When a metal is brought near to the search coil its inductance varies and the frequency of colpitt's oscillator is changed. The difference of the frequencies is amplified and is used to trigger the buzzer. The gate has been divided into six zones to identify the exact location of the metallic object. Depending upon where the metallic object is detected and what is the strength of the signal at the output of the detector metal is classified to be of small, medium or large size using micro-controller.

DECLARATION

No portion of the material presented in this thesis has been submitted in support of another degree or qualification either at this institution or elsewhere.

DEDICATION

To Almighty Allah, for Whose greatness, we are short of words,

To our family and friends, without whose encouraging support and cooperation, we would not have been able to achieve our target.

ACKNOWLEDGEMENTS

Success is not possible without Allah's help. We totally owe everything with which we are acquainted to Him. We could not do a work of such magnitude without Almighty's help.

We give thanks to our parents and friends for their continuous support. We are grateful to our supervisor Dr. Abdul Ghafoor, who led us very well and supported us through the course of the project. This task would not have been possible without his guidance and help. It was him because of whom we were able to showcase our technical skills.

We are most grateful to the University Administration and our Lab staff for supporting us through the duration of the purpose and bearing with us till the end of this work.

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CHAPTER 1

INTRODUCTION

1.1 Overview

Concealed weapon detection is one of the biggest challenges faced by law enforcement community. There is always a requirement of reliable and cost effective weapon detection system for terrorist groups and hijackers hiding different weapons. A screening system is needed that can be used to check people passing through it without needing special man power. Our project, Concealed Weapon Detection is an example of such a system.

The Concealed Weapons Detector (CWD) observes the change in magnetic field produced by the metallic weapon passing through the gate. The CWD uses six coils arranged on both sides of the gate structure. Data is collected from both the panels and depending upon the strength of the signal weapon size is estimated. CWD oscillators are processed as a group to know the location and size of the metallic objects.

1.2 Problem

Our country has been dealing with the terrorism crisis for quite some time now. It has a major impact on the country's economy and prosperity. All the public places like schools, offices, parks, colleges, universities, bus and railway stations and even our mosques are not safe. There is always a threat of some kind of terrorist activity. Different people hiding weapons are a constant source of threat to the public.

1.3 Objective

The main purpose or objective of our project is to design and develop a cost effective and efficient screening system for detecting weapons. The system is quite efficient and does not give any false alarms like the traditional metal detector gates. One of the major objectives of the projects of the project is to prove that we can manufacture metal detector gates locally in Pakistan.

1.4 Deliverables

At the end of the project we want to develop a weapon detection system based on metal detection technology. The system will be in the form of a walk through gate. We want to interface it with the computer to make it so intelligent that it can avoid false alarms, and can differentiate between the different sizes of metals.

1.5 Approach

The basic approach used in CWD is of metal detection. An AC current of the frequency range 5 kHz-5MHz produces a varying magnetic field across the coil. This field results in induced magnetic field and current in nearby metallic objects. Magnetic field of these objects is also produced. These fields induce a voltage in a coil placed nearby. Beat frequency method that we have used in our project is a sub-category of this method of metal detection.

We have used the concept of beat frequency in our project. Two oscillators operate on virtually the same frequency. One of the oscillators changes its frequency in presence of any metal. The difference of frequencies is amplified and used to ring the buzzer. Size classification is done on the basis of how many zones have detected the metals. The greater the number of zones in which a metal is detected, the larger would be the metal in size. Locating the metal on the body is also part of the project. For locating the metal bar display circuits have been used. Each of the glowing column represents a zone onto either side of human body and metal can be located easily. A waveform display matrix provides with another sensitivity level. Waveform is displayed even for very small changes in frequency.

CHAPTER 2

TECHNIQUES USED FOR METAL DETECTION

2.1 Introduction

This chapter discusses recent developments in the area of CWD. These methods mostly use electromagnetic techniques including metal detection, magnetic field distortion, and resonance of electromagnetic waves. Some of these techniques are discussed in this chapter.

Current CWD technologies include the Electromagnetic spectrum based detection at one end and X-ray imaging at the other end. X-ray imaging has been used for detailed inspection like border control and luggage inspections at airports.

2.1.1 Metal Detection Using Earth Magnetic Field Distortion

This method is based on sampling of the distortion in the Earth's magnetic field. Local changes in the Earth's magnetic field caused by metal objects such as guns and knives can be detected only by sensitive magnetometers. These detection systems exist in the form of walk trough portable devices of type [2, 3].

2.1.2 Inductive Magnetic Field Method

The basic principle behind Electromagnetic inductive method for CWD is shown in Figure 2.1. An AC current of the frequency range 5 kHz-5MHz produces a varying magnetic field across the coil. This field results in induced magnetic field and current in nearby metallic objects. Magnetic field of these objects is also produced. These fields induce a voltage in a coil placed nearby [1, 4, 5].

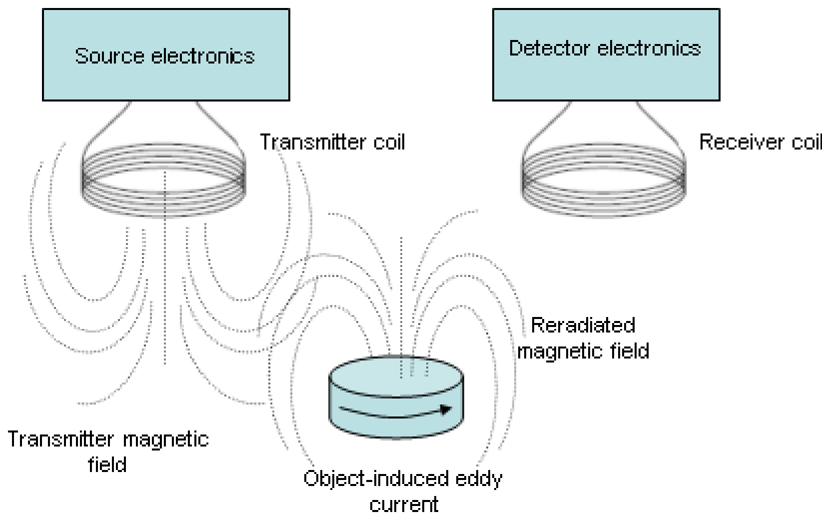


Figure 2.1: The Principle of EMI technique for CWD

2.1.3 Acoustic and Ultrasonic Detection

The detection of weapons using acoustic and ultrasonic detectors is dependent on the acoustic/ultrasonic reflectivity of materials that make up an object and the shape and orientation of the object. Hard objects provide a high acoustic/ultrasonic reflectivity and soft objects a small reflectivity. The antenna size and wavelength affect the size of the smaller object that can be detected. Acoustic/ultrasonic power will not travel in a vacuum; it is attenuated less as its travels in dense medium (solids and liquids) and is attenuated more as it propagates in the air. Also humidity in the air reduces the attenuation. The attenuation is frequency dependent; it is greater for higher frequencies. Therefore, there is a trade-off between the required spatial resolution and attenuation. Ultrasonic detectors operate from 40 kHz until frequencies well below 1 MHz because of increasing attenuation at higher frequencies. Acoustic detectors operate at audio frequencies [1, 6]. Conventional acoustic and ultrasonic based detectors are sensitive to hard objects in general and cannot differentiate between weapons and innocuous hard objects. Consequently devices based on these technologies produce many false-positive detections.

Figure 2.2 shows the principle. This technology uses ultrasonic beams of frequencies f1 and f2 to project sound onto a small spot area on a person at a distance and convert that energy probe from ultrasound to audio frequencies. The non linear interaction in the mix zone produces the following frequencies: f1, f2, f1-f2, f1+f2. The difference frequency (f1-f2), tuned in the audio range, is used to interrogate the subject with a beam able to penetrate clothing. In general this technique is harmless because does not involve ionizing radiation, is sensitive to metals and non-metals, and is able to penetrate clothing. However, fast scanning is required for ultrasonic beams to focus on and find a target [6].

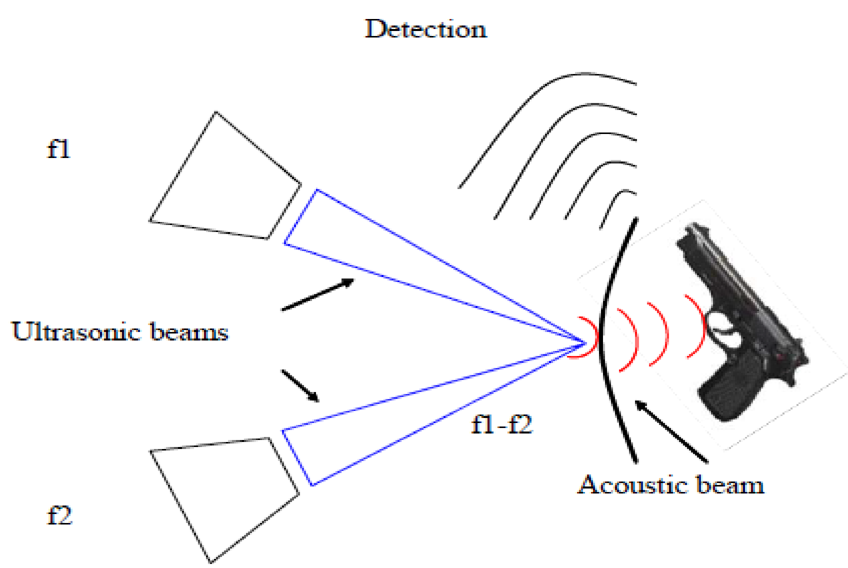


Figure 2.21: Non-Linear Acoustic CWD

2.1.4 Infrared Imaging

Infrared imaging is also used in detector system. All the bodies above 0K radiate some energy around themselves. The frequency of the radiation is dependent on the temperature and composition of the body. Most of the infrared sensors are designed such that their peak sensitivity is quite close the peak emission frequency of human body. This technology is mostly used for night vision [7]. Infrared rays radiated by people are absorbed by the clothes. Clothing gets heated by this radiation. The metallic weapon is relatively colder. Still it absorbs some heat and consequently, the image is blurred [7].

2.1.5 Millimeter Waves (MMW)

MMW based detection systems are of 2 types: passive and active. Passive sensors simply observe and report whatever is detected in the environment. In the RF frequency range, natural sources will emit different strengths of radiation depending on parameters such as temperature and composition. Metals are very much reflective to RF, which reduces its surface emissivity and allows it to produce reflections of other sources [1, 5, 8].

Active sensors basically trigger the environment by producing and emitting known signals. These signals radiate out to the objects or targets to be detected, interact with them, and reflect or refract energy back to the sensor. This is a very efficient technique in detecting the concealed weapons but, being very expensive, cannot not be adopted on a very large scale.

Figure 2.32: MMW Images

2.1.6 Hybrid Millimeter-Wave and Infrared Imager

Hybrid millimeter-wave and infrared imagers are the systems that make use of both mm-wave and infrared imaging method. The images from these two separate subsystems are merged together by an algorithm called fusion process. The resulted image is termed as fused image. Figure 2.4 shows the fusion process.

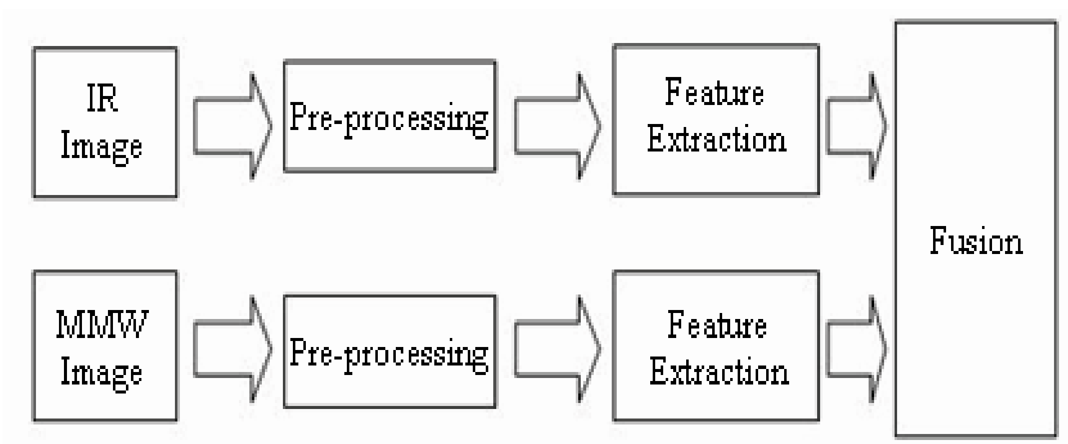


Figure 2.43: Image Fusion

2.2 Conclusions

A general concealed weapon detection system collects data and transmits to the operator. Different sensor technologies are being developed to capture different types of radiations that contain information about the detected objects. Some methods provide an image and other indicate the presence with the help of some tone or alarm.

All technologies have advantages and disadvantages in issues such as operating range, material composition of the detected objects, penetrability and attenuation factors. Each method has some advantages and some disadvantages. It is clear that no single method can meet all requirements for an efficient CWD system. Most of the methods described here are used in combination.

CHAPTER 3

PRINCIPLES OF MAGNETIC INDUCTION

3.1 Inductors

A two-terminal electrical component that is passive and can store energy in its magnetic field is called an inductor. All conductors have inductance. Loops of conductor are wound in order to reinforce the magnetic field. Whenever there is a time-varying magnetic field inside inductor, voltage is induced, in accordance with Faraday's law of electromagnetic induction. The induced voltage opposes it's caused according to Lenz's law. Inductors have ability to delay and reshape alternating currents and are one of the basic components used in electronics.

3.2 Inductor Construction

A coil of conducting material, mostly copper wire, is termed as an inductor. It is wrapped around a core material that is either of air or some ferromagnetic material. Greater the permeability of the core material stronger will be the magnetic field. Stronger magnetic field is confined close to the inductor and increase the inductance. Cores of electrical steel are used in low frequency inductors used in transformers. Soft ferrite cores are used above audio frequencies, since they do not dissipate energy at high frequencies like ordinary iron alloys. Inductors are of many shapes. Some inductors have an adjustable core, and allow variable inductance.

3.3 Types of Inductor

There are many types of inductors depending upon the material they are made from, their shape and the material used to form their core. These inductor types have been discussed in detail in this chapter.

3.3.1 Air Core Inductor

Air core coil is an inductor that uses air instead of a magnetic material as core. These are wound on plastic, ceramic, or other nonmagnetic materials. Some of these have only air inside the windings. Air core coils have smaller value of inductance than magnetic core coils. These are free from energy losses termed as core losses that occur in magnetic cores. That is why these are often used in high frequency applications. A disadvantage in air core coils is that if the windings are not rigid, mechanical movement of the windings can cause changes in the inductance.

3.3.2 Ferromagnetic Core Inductor

Ferromagnetic core inductors use a magnetic material as core. The core is made of some ferromagnetic material e.g. iron or ferrite. A magnetic core increases the inductance of an inductor several thousand times. These cores have high magnetic permeability and produce strong magnetic field. However due to magnetic properties of the core material there are several losses and construction of these inductors requires special care.

3.3.3 Laminated Core Inductor

These inductors are used in low frequency operations and are laminated to prevent eddy currents. The core is constructed of thin steel sheets placed parallel to the field, with an insulated lamination on the surface. The insulation is there to prevent eddy currents between the sheets. Any currents remain within the cross sectional area of single lamination and reduce the area of the loop. Hence the energy loss is reduced greatly.

3.3.4 Ferrite-Core Inductor

Inductors with cores of ferrite are used or higher frequencies. Ferrite is a nonconductive ferromagnetic material, so eddy currents cannot flow within it. The chemical formula of ferrite is xxFe2O4 where xx stands for various metals. Soft ferrites are used in inductors, which have low hysteresis losses.

3.4 Factors Affecting Inductance of a Coil

There are four major factors of inductor construction that affect the value of inductance. These factors change inductance by affecting the strength of magnetic flux developed for a given amount of current.

3.4.1 Number of Wire Wraps, Or "Turns" In the Coil

A greater number of turns of wire in inductor produce greater inductance. Less turns of wire will result in less inductance. Explanation: Larger turns of wire mean that the inductor generates more amount of magnetic field force, for a particular amount of current through the coil.

Figure 3.14: Coil Turns vs Inductance

3.4.2 Coil Area

Greater coil cross sectional area results in greater inductance and vice versa. Explanation: Greater coil area puts less resistance to the building magnetic flux, for a given amount current.

Figure 3.25: Coil Area vs Inductance

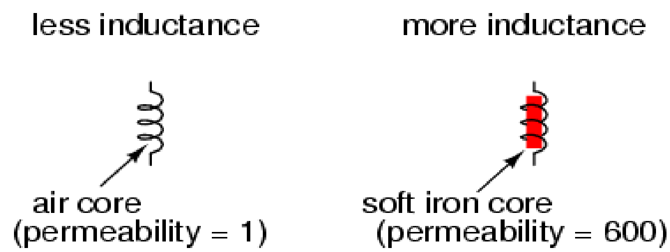
3.4.3 Coil Length

The longer the coil, the lesser will be the inductance and vice versa. Explanation: A longer wire will have more resistance to current as compared to a shorter wire.

Figure 3.36: Coil Length vs Inductance

3.4.4 Core Material

The greater the permeability of the material of the core, the greater will be the inductance. Explanation: A core material with greater permeability produces a stronger flux.



Following formula can be used to find out the inductance of any coil:

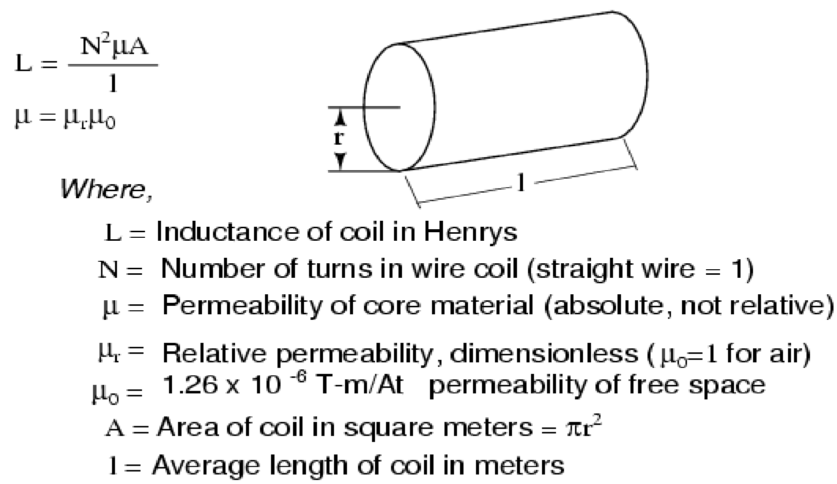


Figure 3.47: Calculating Inductance of a Coil

It must be taken into account that this formula gives approximate values only. A reason for this may be that permeability changes as the field strength varies. Obviously, if permeability (μ) in the above relation is unstable, then the value of inductance (L) will also be variable to some extent as the current magnitude changes.

3.5 Concepts Used in Detection (CWD)

3.5.1 Self Induction

Self induction is defined as phenomenon of a coil producing induced emf in itself as the current through the coil is varied. Self induced voltage in an inductor varies directly with the current in the coil.

$$Emf \alpha - DI/Dt$$

$$Or\ emf = -L\ DI/Dt$$

Self inductance of a coil is the ratio of induced emf to the rate at which current changes in the coil.

$$Self\ inductance = emf/\ DI/Dt$$

It is denoted by 'L' and depends upon the physical properties of the coil. Henry is the unit of self inductance. The self inductance of a coil is one Henry if an emf of 1 V is produced by the current changing at a rate of one ampere per second.

1 Henry = 1volt/1amp/sec

3.5.2 Mutual Induction

If a change of current in one coil produces an emf in a nearby placed coil, the phenomenon is termed as mutual induction. The first coil is called primary coil and the coil in which emf is produced is the secondary coil.

3.5.3 Coils in CWD

We have used air core coils in our project as the search coils. The basic concepts behind using the air core coils are that air being core of the coils helps in detection of the metallic objects. Whenever some metallic object is brought in vicinity of the coil it acts as the core for the coil and according to the concept of self induction inductance of the coil is varied. This varies the frequency of the colpitt's oscillator and metal is detected.

CHAPTER 4

RADIO FREQUENCY

4.1 Introduction

Radio frequency is a term that represents the oscillations of radio waves, and the AC currents that are carried by the radio waves. RF is used for electrical oscillations rather than mechanical vibrations. Range of radio frequencies is 3 kHz to 300 GHz. These frequencies are generally used in radio communications. This frequency range has been divided into two further ranges or bands.

4.2 Radio Frequency Spectrum

Every electronic device radiates some kind of radio signals and it's quite difficult to avoid these. In the Pakistan the FAB (Frequency Allocation Board) is the regulatory authority for radio signals, and dictates what is allowed and what it forbidden.

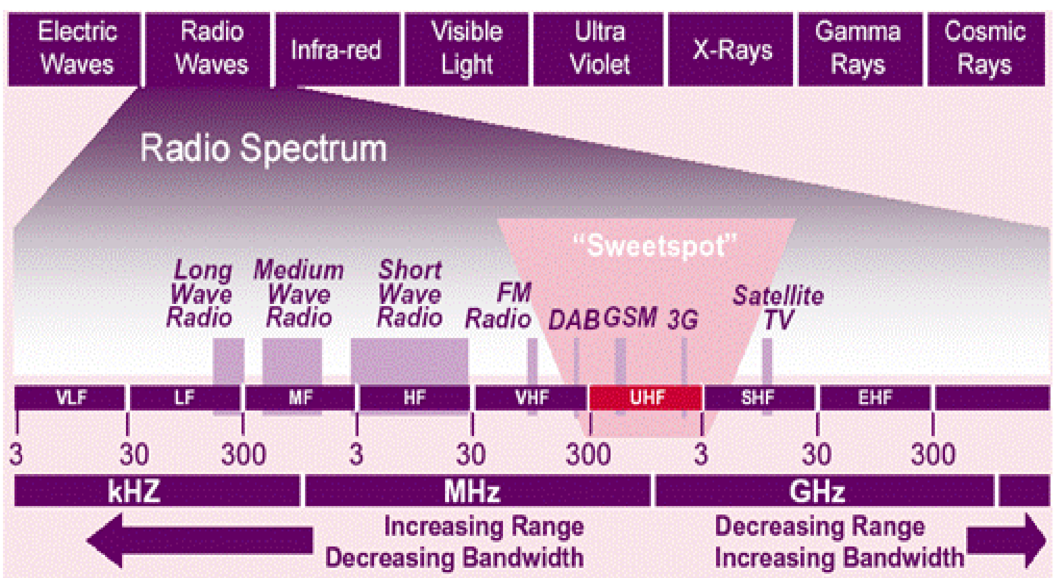


Figure 4.1: RF spectrum

Table 4.1 RF bands with frequency and wavelength

Band	Frequency range	Wavelength range
Extremely low frequency (ELF)	< 3 kHz	>100 km
Very low frequency (VLF)	3 - 30 Hz	10 - 100 krn
Low frequency(LF)	30 - 300 kHz	1 - 10 km
Medium frequency (MF)	300 kHz - 3 MHz	100m - 1km
High frequency (HF)	3 - 30 MHz	10 - 100m
Very high frequency (VHF)	30 - 300 MHz	1 - 10m
Ultra high frequency (UHF)	300 MHz - 3 GHz	10cm - 1m
Super high frequency (SHF)	3 - 30 GHz	1 - 10cm
Extremely high frequency (EHF)	30 - 300 GHz	1mm - 1cm

4.3.1 Extremely Low Frequency

Extremely low frequency (ELF) is a term used for the frequencies ranging from 3 to 300 Hz. Frequencies below 3 Hz are considered to lie in the ultra low frequency range range. Its applications include military radio communications, metal detection and pipe line inspection.

4.3.2 Very Low Frequency

Very low frequency or VLF ranges from 3 kHz to 30 kHz. The bandwidth of this band is small therefore only simple signals are used. It is mostly used for radio navigation. Its applications include sea depth measurements, submarine communications and geophysical surveys.

4.3.3 Low Frequency

Low frequency or LF ranges from 30 kHz–300 kHz. Some part of the LF band is used for AM broadcasting as the long wave band. It’s also used for aircraft beacons and weather systems. The wavelengths ranges from one to ten km there it's also known as the kilo meter band. Its applications include military communications, amateur communications, information broadcasts over AM and radio navigation.

4.3.4 Medium Frequency

Medium frequency or MF ranges from 300 kHz to 3 MHz. A Part of this portion of spectrum is used for medium wave broadcast. The wavelengths range from ten down to one hectometer therefore it's also known as the hectometer band. Its applications include maritime and aircraft navigation, medium wave broadcast and portable telephones.

4.3.5 High Frequency

High frequency or HF ranges from 3 to 30 MHz. It is also known as the decameter band. Its applications include amateur radio operations and RFID tagging.

4.3.6 Very High Frequency

Very high frequency or VHF ranges from 30 MHz to 300 MHz as the range allocated by ITU by ITU. It is commonly used for FM radio broadcast, television broadcast, land mobile stations and long range data communication with radio modems.

4.3.7 Ultra High Frequency

Ultra High Frequency or UHF ranges from 300 MHz to 3 GHz. It is also known as the decimeter band. Physically short wave is produced by the high frequency. This reduces the size of antennas used for the transmission and reception. Less conspicuous antennas can be used while dealing with UHF range.

A major disadvantage of this range of frequencies is that the equipment used for this range is very costly and complicated to manufacture. Line of sight is also required for communicating in this range of frequencies.

4.3.8 Super High Frequency

Super high frequency or SHF ranges from 3 GHz to 30 GHz. This band of frequencies is also known as the centimeter band.

4.3.9 Extremely High Frequency

Extremely high frequency or EHF ranges from 30 to 300 gigahertz. The radiations above this frequency are considered to be infrared light or terahertz radiation. This band is also known as millimeter wave's band. Its applications include scientific research, telecommunications, weapons systems, security screening and medicine.

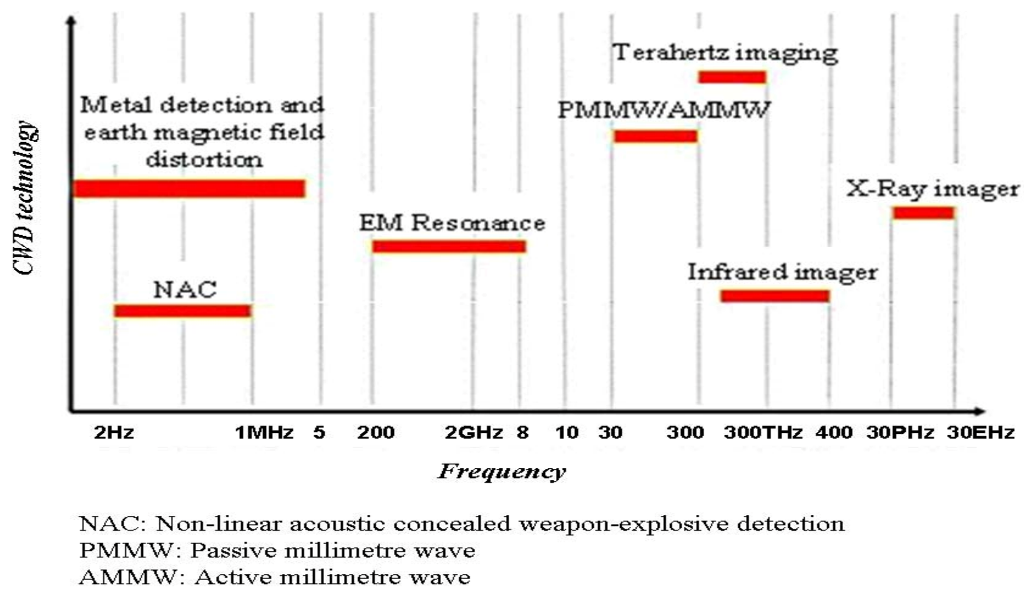


Figure 4.2: Frequencies used in CWD Technology [1]

CHAPTER 5

NOISE GATES AND FILTERS

5.1 Introduction

Noise is termed as random fluctuation in a signal. It is omnipresent and a characteristic of all electronic components. Noise produced by electronic circuits varies a lot, as it can be caused by different effects. Thermal noise is always there at non-zero temperature, while other types of noise depend on component type and quality and semiconductor defects, such as changes in conductance etc.

In communication systems, the noise is an undesired frequency within given range of frequencies. It is introduced before or after the detector and decoder. The noise is a collective sum of undesired energy from natural and often man-made sources. Noise, however, can be distinguished from interference.

5.2 Noise Reduction Techniques

Noise is never wanted. A person wants a noise free operation from his circuit. There are many methods for reducing the noise that can change a noisy signal to a more theoretical signal.

5.2.1 Faraday Cage

A Faraday cage is a good technique to reduce the noise in a complete working circuit. It can be thought of an enclosure that separates the mechanics from outside power lines interference and any other disturbing signal. A Faraday cage blocks out most electromagnetic noise.

5.2.2 Capacitive Coupling

A current flowing through two conductors placed close to each other can create undesired capacitive coupling. If this happens, an AC signal from one part of the circuit will be undesirably picked up in another part. The two conductors behave like a capacitor and transfer AC signals.

5.2.3 Ground Loops

It is important to avoid ground loops in any circuit. Ground loops occur if there occurs a voltage drop between the two zero potential points. In this case, a true ground is not present in the circuit. A good method to solve this problem is to put all your ground wires in a ground bus to same potential.

5.2.4 Shielding Cables

Using shielded cables is a good way to protect your wires from undesired noise in a sensitive circuit. A shielded wire acts as a small Faraday cage for a specific wire as the shield encloses the actual wire. The conductive covering of the shield is grounded to straight away ground the unwanted signals. Shield must be grounded at only one point to avoid ground loop.

5.2.5 Twisted Pair Wiring

Twisting wires very tightly together reduces electromagnetic noise to a large extent. Twisting the wires reduces the loop size in which a magnetic field can pass through to produce unwanted signal between the wires. Even if the wires are twisted very tightly, there exist small loops between them. Since they are twisted the magnetic field present in the smaller loops induces a current that opposes its cause according to Lenz's law and cancels out the noise.

5.2.6 Notch Filters

Notch filters are important when eliminating a particular noise frequency. For example, in many cases the power cables within a building run at 60 Hz. Sometimes your sensitive circuit may pick up 60 Hz noise through some unwanted antenna. Running the desired output through a notch filter set at 60 Hz will amplify the true signal without giving any gain to noise.

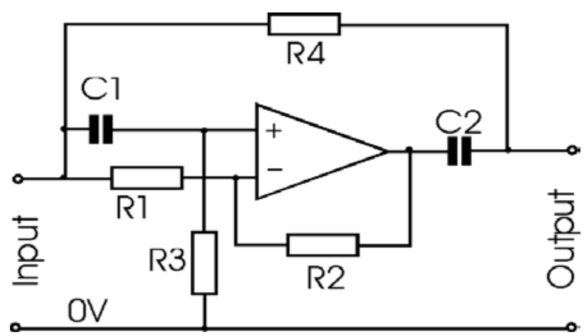


Figure 5.1: Opamp as Notch Filter

5.2.7 RC Filters

An RC filter is an electric circuit consisting of resistors and capacitors energized by a source. A first order RC circuit includes one resistor and one capacitor and is the simplest type of RC circuit. RC circuits can block certain frequencies and allow certain frequencies to eliminate noise.

A low-pass filter is an RC circuit that allows low-frequency signals but attenuates signals with frequencies higher than a particular frequency called the cutoff frequency. Since the noise lies aver entire frequency range it will be blocked while our desired signal will be allowed.

One simple low pass filter consists of a resistor in series with a capacitor and load is placed in parallel with the capacitor. The cutoff frequency is calculated by the time constant as:

$$f_c = \frac{1}{2\pi\tau} = \frac{1}{2\pi RC}$$

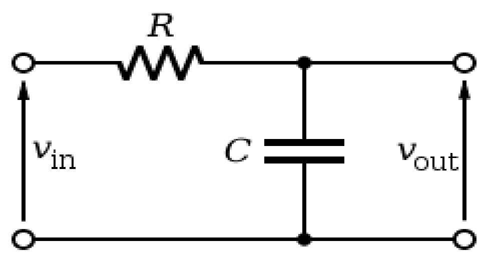


Figure 5.2: A Simple Low-Pass RC Filter

Active low pass filter includes an amplifier for gain provision as signal will be attenuated generally by a simple capacitor and resistor.

$$f_c = \frac{1}{2\pi R_2 C}$$

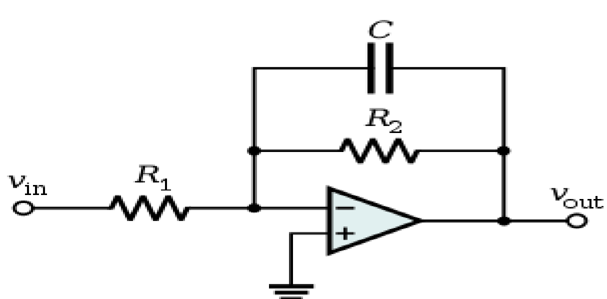


Figure 5.3: An Active Low-Pass Filter

CHAPTER 6

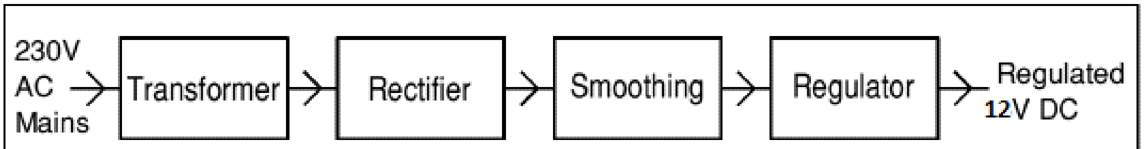
POWER SUPPLY

A power supply is an electronic device that powers up electric loads. The term is most commonly used for collection of components that convert particular type of electrical energy to another. It may also represent devices that convert another form of energy to electrical form. Every power supply requires the energy at its input that it supplies to the load. It also needs energy for its operation from an energy source. Depending on its type, a power supply may take any of the forms from electrical transmission energy systems, batteries and fuel cells, generators and alternators or solar power system.

A power supply may be manufactured as a stand-alone device or as an integrated device. Examples of the integrated systems are the low voltage DC power supplies that are used for desktop computer. Important features of power supply include voltage and current ratings and stability of the output

6.1 Power Supply Used in CWD

The power supply used in CWD broken into a block diagram representation is shown in Figure 6.1.



Block Diagram of a Regulated Power Supply System

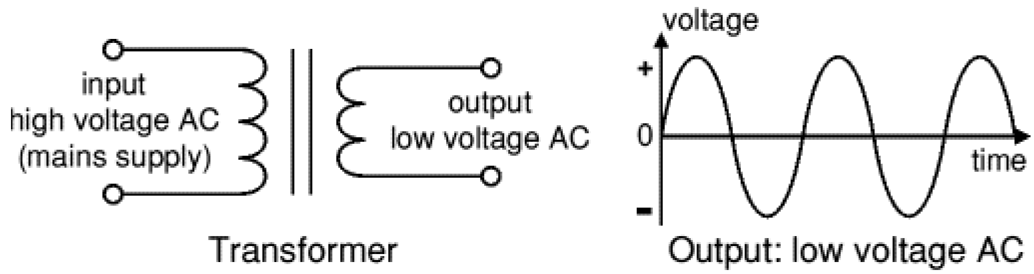


Figure 6.1: Transformer (Power Supply Block Diagram)

The low voltage AC output is not suitable for our circuit. Our circuit operates on DC supply. So output of the transformer must be rectified. Step-up transformers increase voltage whereas step-down transformers reduce voltage down to some lower value. Most of the power supplies utilize a step-down transformer to reduce the 220-240 to the voltage required for the operation.

The input coil in transformer is called as the primary and the output coil is the secondary. The two coils have no electrical connection but these are linked magnetically. The ratio of the number of turns is equal to the ratio of the voltages in transformer. Primary coil has larger number of turns than the secondary in case of a step down transformer and vice versa.

if

Vp = primary (input) voltage

Vs = secondary (output) voltage

Np = number of turns on primary coil

Ns = number of turns on secondary coil

Ip = primary (input) current

Is = secondary (output) current

then

Vp/Vs=Np/Ns and Vp.Ip=Vs.Is

6.1.1 Transformer + Rectifier

Rectifier is a combination of diodes to convert an AC signal to DC signal. There are many types of rectifiers depending upon the number of diodes used for the purpose.

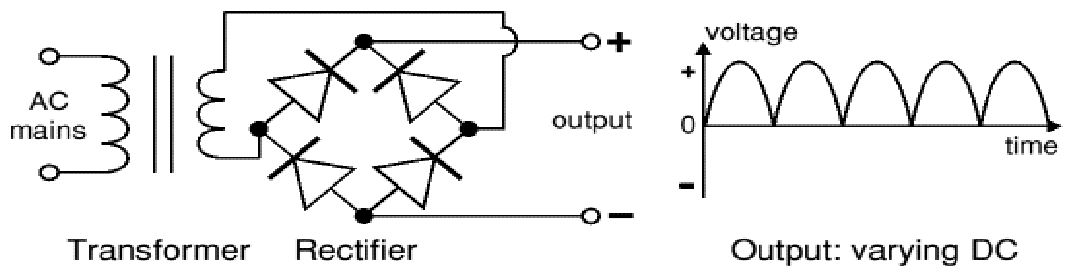
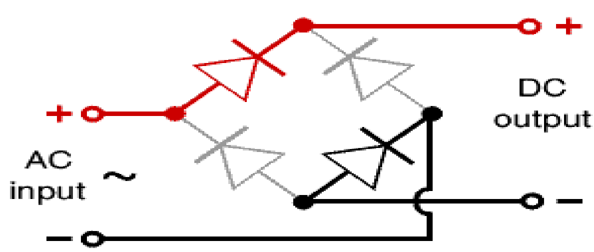


Figure 6.2: Transformer + Mixer

Bridge rectifier is made of four individual diodes, but it is also available in a single unit packaged item. It is a full-wave rectifier as it rectifies the entire AC wave. 1.4 V is used up in the bridge rectifier as each diode uses 0.7 V as its reverse voltage drop. Bridge rectifiers are rated by the amount of current they can pass and the maximum reverse voltage they can tolerate.



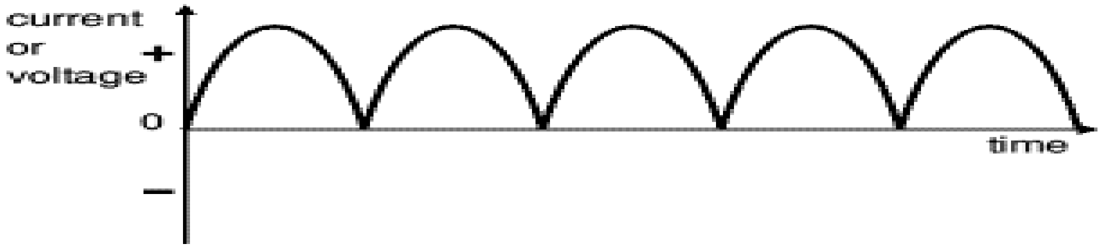


Figure 6.3: Bridge Rectifier

A single diode rectifier is a half wave rectifier as it rectifies only the positive cycle of the AC signal and blocks the negative cycle. Smoothing this signal is very difficult therefore it's not mostly used.

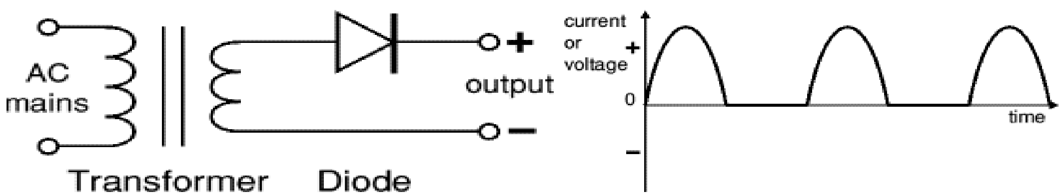


Figure 6.4: Single Diode Rectifier

6.1.2 Transformer + Rectifier + Smoothing

The bridge rectifier output has a small ripple that includes noise. The ripple is not desirable for many electronic circuits and must be removed.

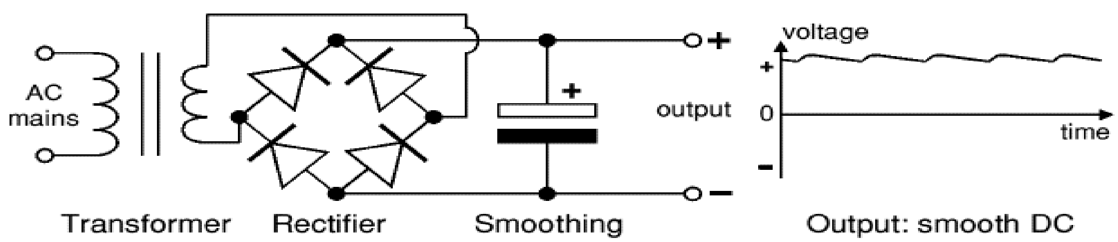


Figure 6.5: Smoothing Capacitor Output

Large valued electrolytic capacitors are used for smoothing the ripple from the output of the bridge rectifier. Capacitor has a large time constant and keeps the voltage constant across its output when the ripple comes. The diagram below shows the unsmoothed output against the smoothed output of the capacitor.

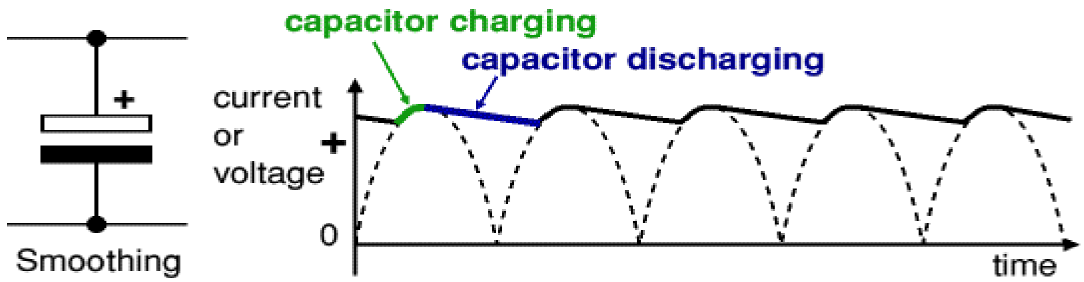


Figure 6.6: Working of smoothing capacitor

It must be taken into account that smoothing increases the average DC voltage to almost the peak value (1.4 × RMS value). For example 6V RMS AC will be rectified to full wave DC of about 4.6 V RMS as 1.4 volts are lost at the bridge. When applied smoothing, this increases to almost the peak value giving 1.4 × 4.6 = 6.4V smooth DC.

6.1.3 Transformer + Rectifier + Smoothing + Regulator

The regulated DC output is very smooth with no ripple. It is suitable for all electronic circuits.

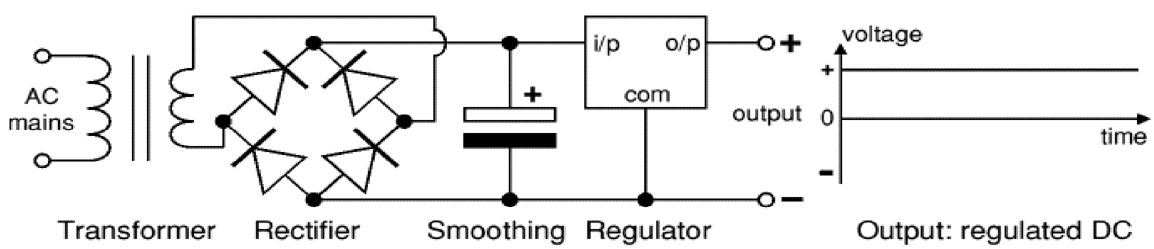


Figure 6.7: Voltage Regulator Included

Voltage regulator ICs are available in market with fixed or variable output voltages. They are rated by maximum amount of output current. Negative voltage regulators are also available. Most of the regulators have some protection mechanism to avoid extra current or over-current.

CHAPTER 7

COIL DESIGN

7.1 Choice of wire

A general rule while selecting the diameter of the search coil is that the larger the coil the farther it will detect, but the trade-off is less sensitivity to smaller targets and less accurate detection. Larger coils are also heavier and increase the overall physical footprint of the detector body. In addition to size variation there are two different types of coil constructions: Concentric and Wide Scan construction. Concentric coils have an inverted cone like magnetic field pattern. This gives maximum range only at the centre of the coil.

Wide scan construction coils have pudding basin shaped detection pattern and while they do not achieve as great range as the same sized concentric coil they do take in larger volume of target proximity. So if the gate is small and objects like small packages have to pass through then it's a good choice, otherwise for more range concentric coil is better.

Wire gauge refers to the diameter of the wire. The higher the gauge thinner will be the wire. Thinner wires are used for lower amp-city applications, but for more demanding jobs thicker wire must be used. Thicker wire has lower electrical resistance and can result in less fluctuation and steadier power with minimal heat loss over longer distances.

American Wire Gauge (AWG) is an American standard used for non-ferrous wire conductor sizes. Typical house wiring is AWG number 12 or 14. Telephone wire is 22, 24 or 26.

Table 7.1: Wire gauges and uses

Uses	Current	Gauge
Low voltage lighting and lamp cords	10 Amps	18
Extension cords	13 Amps	16
Light fixtures, Lamps	15 Amps	14
Receptacles, 110 volt air conditioners, Sump pump, Kitchen appliances	20 Amps	12
Electric clothes dryers, 220 volt window air conditioners, Built in Ovens, Electric water heaters	30 Amps	10
Cook tops	45 Amps	8
Electric Furnaces, Large electric heaters	60 Amps	6
Large electric water heaters, Sub panels	80 Amps	4
Service panels, Sub panels	100 Amps	2
Service entrance	150 Amps	1/0
Service entrance	200 Amps	2/0

AWG is a system of numerical wire sizes that start with the lowest numbers for the largest size. The gauge sizes are each 20.6% apart based on the cross sectional area. Some other wire measurement systems are:

SWG= Standard or Sterling Wire Gauge. It is a UK measurement system.

BWG= Birmingham Wire Gauge. It was an old form of SWG which was used in most of the countries.

Cir Mils or CMA= Circular Mil area which is equal to 1/1000 of an inch in diameter.

7.2 Orientation of Coil

Since the coil we have used is concentric, the limitation is that detection strength is maximum at the centre as mentioned earlier and gradually decreases as the target moves away from the centre. The flux produced can be explained by the following illustration. As can be seen, the maximum flux is when the target makes an angle of 0° (cos0=1) and flux is least when angle is 90° (cos90=0).

In Figure 7.1 the rings show the surface boundaries. The arrows show the flow of the magnetic flux. The number of arrows that pass through each ring is the flux. A coil that is parallel to the target can detect the target better than a coil that is making some angle with the target.

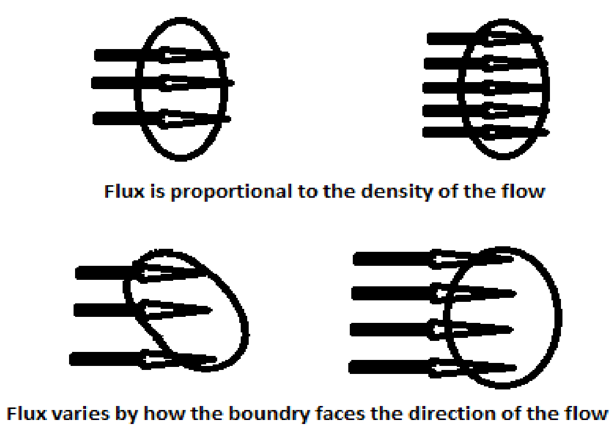


Figure 7.1: Orientation of Coils

7.3 Search Coil Design in Project

In our project we have used the concentric design for the coils. Wire rating is 22 AWG. The total six coils have been designed with different number of turns in order to avoid frequency locking between the coils. Coils with 16, 18, 20 and 22 turns have been made. A concentric coil covers up to 2 times of its diameter for the purpose of detection. The width of our gate is 30 inches. So coils of diameter 9 inches have been made as search coils.

CHAPTER 8

HARDWARE DESIGN OF OUR PROJECT

Concepts built in the previous chapters will be discussed at length in this chapter. Complete design of hardware has been illustrated in this chapter.

8.1 Our Choice of BFO Technique

Choice of BFO technique is based on the fact that it is a popular and proven technique which can be realized with relative ease, and any unnecessary complications are always avoided. It is a sensitive technology and can provide even better results if a Faraday screen is fit to reduce capacitive effects on the coils. Another advantage of working with this technique is that the hardware components required to implement this technique are locally available and are quite less expensive.

As far as Pulse Induction is concerned it generates brief high current pulses after some nominal repetition time. The pulse induction is an active device and is only sensitive to the extent of the power of the pulses, which requires a large amount of power, so high amount of power is dissipated [1, 5]. Also BFO generates the detection signal in audio frequency range, so audio amplifier is used for the first stage amplification. Thus the other signals such as noise will not be amplified as much. In Pulse Induction all signals are amplified the same, thus all noise, especially electrical noise is amplified.

8.2 Block Diagram

The block diagram of project is shown in figure 8.1. It illustrates the project as an interconnected framework of blocks which independently working and connecting together give a particular functionality to the project.

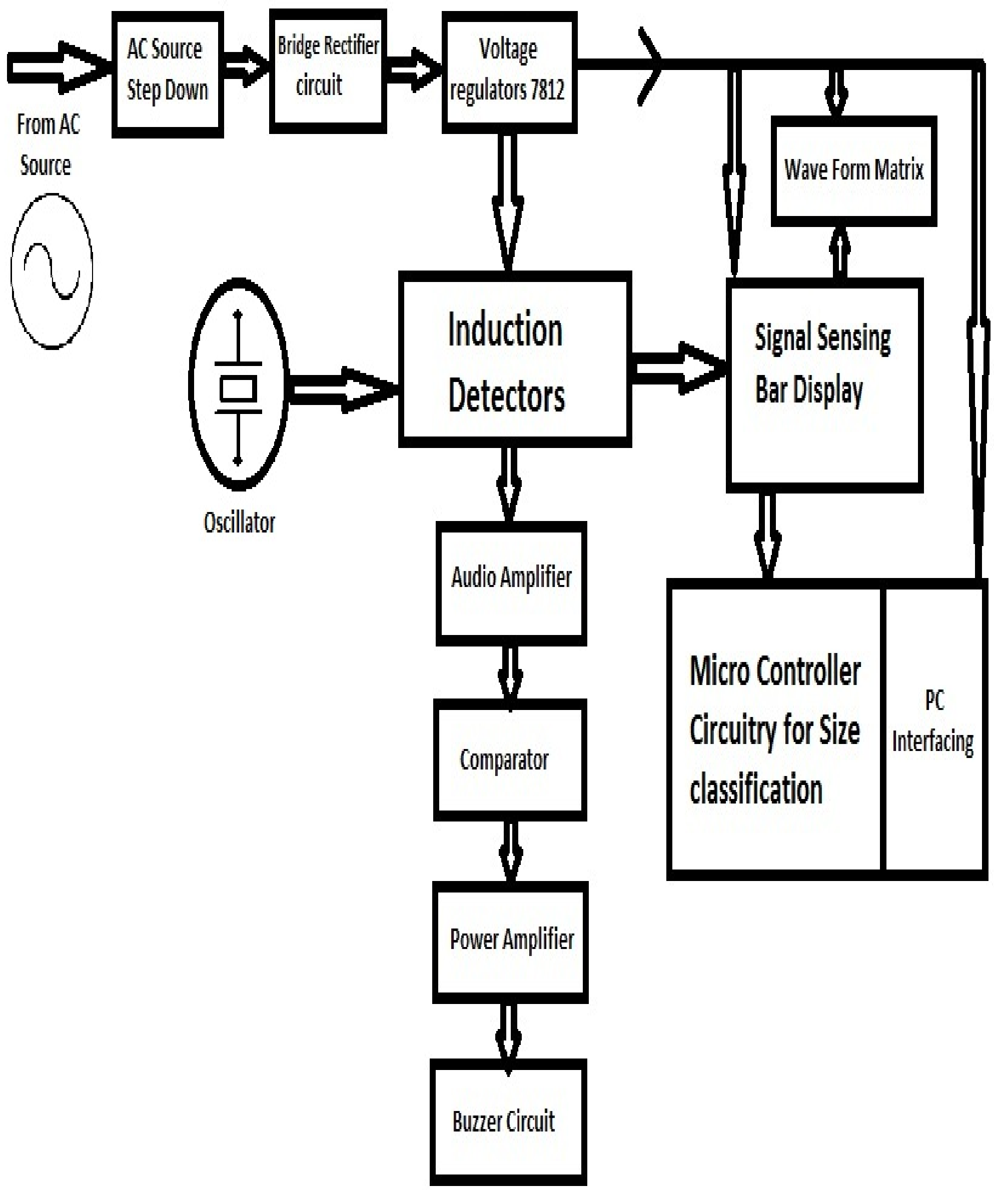


Figure 8.1: Block Diagram

The block diagram is discussed in detail.

8.3 Power Supply

We are going to discuss the power supply of our hardware in reference to the components of the power supply discussed in the 6th chapter.

8.3.1 Step Down Transformer

In our hardware we have used a total of 7 step down transformers in order to provide good power supply isolation. 6 of these transformers power up the six detector circuits and the remaining one high current transformer powers up the bar display circuit, LED oscilloscope circuit and the micro-controller circuit. The exact specifications of these transformers are as below:

High power Transformer (1 used)

Input=220-240 V   Output=15 V & 1 Amp

Low Power Transformers (6 used with dual output)

Input=220-240 V   Output=12 V, 12 V & 0.25 Amp each

The current from the two outputs of these low power transformers was combined in parallel to get 0.5 Amp current from a single transformer.

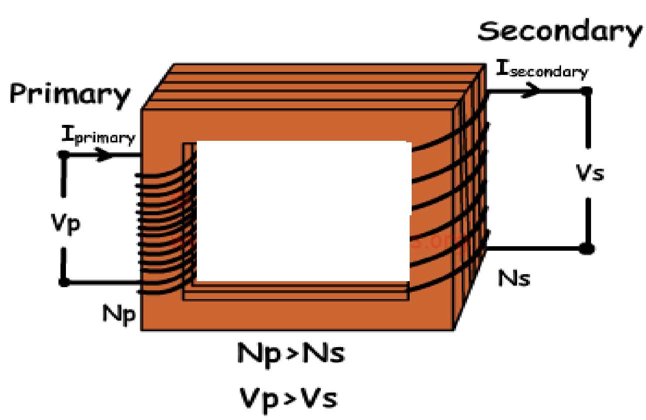


Figure 8.2: Step Down Transformer

8.3.2 Bridge Rectifier

A diode bridge consists of four diodes connected back to back. This arrangement provides the same polarity of output for either polarity of input. Mostly the bridge functions as AC to DC converter. It is also called a bridge rectifier as it acts as a bridge between input and the output. Bridge rectifier has been used at the output of each transformer as all our detector circuits operate on DC. We made the 4 diode bridge rectifiers of commonly used diode 1N4001.

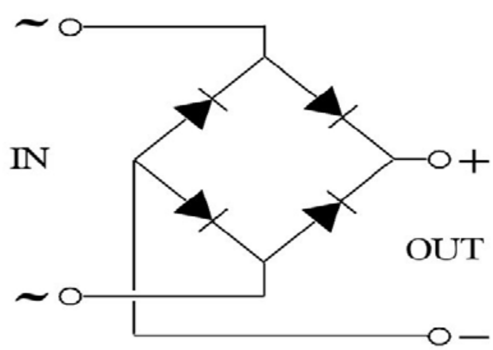


Figure 8.3: 4 Diode Bridge Rectifier

8.3.3 Smoothing Capacitors

A capacitor is a component that stores electrical charge. In the simplest meanings it can be considered as a rechargeable battery that it stores charge to be used at a later time. Charging a capacitor simply means putting voltage across its legs until it acquires the highest level of voltage across itself. Capacitors are major component in the most of electronic circuits. These are used for many purposes, however one of the most important uses is in smoothing the output of a bridge rectifier after it has converted AC electricity into DC.

Figure 8.4 shows the output of a full wave rectifier.

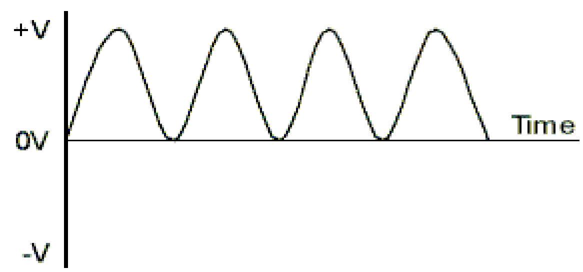


Figure 8.4: Output of Rectifier

This signal has fluctuations in it called ripples. Ripples must be removed using capacitors. Capacitors have high value of time constant and take long time to discharge and provide a smoothing effect.

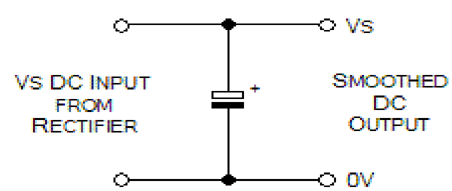


Figure 8.5: Smoothing Capacitor Connection

The smoothing capacitor circuit as shown in Figure 8.5 just one capacitor placed in parallel to the output from the rectifier. As the output voltage increases, the capacitor is charged, and as the output voltage falls back to zero, the capacitor releases its charge.

8.3.3.1 Capacitor Ratings

Capacitors are rated with respect to their voltage and storage capacity. The larger the value of a capacitor, the more energy it can store and the more time it will take to discharge. However, a very large valued capacitor will take longer to charge at first and so it will take some time before a constant voltage is obtained at the output. If circuit draws a large amount of current the capacitor will discharge quickly and amount of ripple will increase. If a capacitor is made to operate at a voltage higher than its rated voltage it may explode damaging the other circuit components as well. Therefore it must be taken care of that they are operated at their rated voltages.

A 1000 micro Farad (1000uF) capacitor is choosed for smoothing mostly in energy applications. These are available with a range of voltage ratings including 10V, 16V, 25V, 35V, 63V. If the amount of ripple in the circuit is still there a capacitor with 10% higher value must be used. As far as CWD hardware design is concerned 1000 uF capacitors have been used at the output of the high power transformer and 1000 uF capacitors at the output of the low power transformers.

8.3.4 Voltage Regulator

A voltage regulator is an electrical regulator designed to maintain a constant voltage level at its output. These have special preventive measures such as feedback to avoid over-current in the circuit. Our hardware operates on 12 V DC. Therefore the voltage regulator to be used must maintain 12 V output voltages. The type of voltage regulator that we have used is a linear regulator that comes in the form of a 3 pin IC. The series is called 78XX where the last two characters of the name mention the output voltage of the regulator. We have used 7812 voltage regulators. After combining the above described components a single power supply unit looks like shown in Figure 8.6.

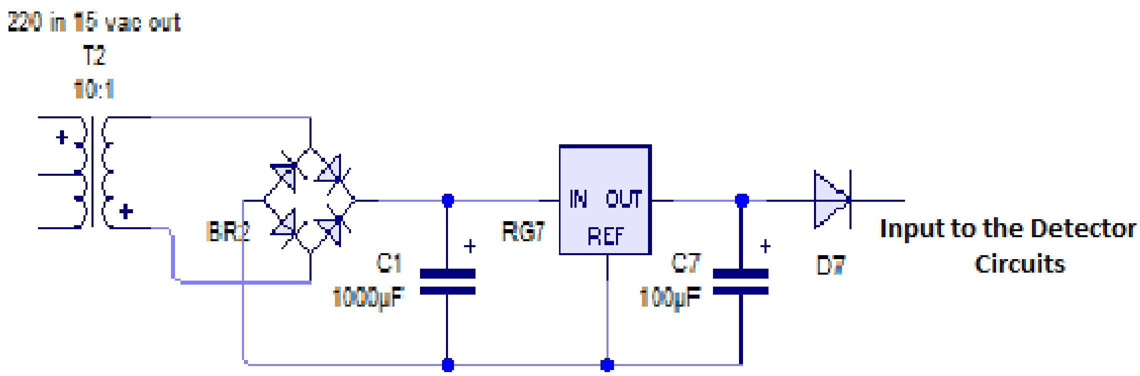


Figure 8.6: Power Supply Circuit Diagram

Seven of such power supply circuits are developed; 6 for each of the detectors and 1 for bar display, waveform display and the micro-controller circuit.

8.4 Detector Circuit

The basic working principle of our detector is Beat Frequency i.e. a category of Induced Magnetic field method. The two oscillators i.e. colpitt's oscillator and the inductive feedback oscillator (reference oscillator) operate on virtually the same frequency. Receiver is adjusted to pick up their signals and produce beat tune. Beat tune is of the frequency which is the difference in the frequency of the two oscillators.

Tunable oscillator is tuned such that its frequency matches with the colpitt's oscillator frequency. Whenever a metallic object is brought in range of the search coil its inductance is varied and the frequency of the colpitt's oscillator is changed. The difference in the frequency is read by the peak detector and then amplified by the audio amplifier. Audio amplifier triggers the comparator and buzzer rings in order to show the presence of the metal.

Detector circuit in out project consists of the following parts:

Colpitt's Oscillator

Reference Oscillator

Audio Amplifier LM 386

Power Amplifier UC 575

Opto-Coupler

Voltage Comparator

8.4.1 Colpitt's Oscillator

A Colpitt's oscillator, invented in 1920 by American engineer Edwin H. Colpitt's, is one of a number of designs for LC oscillator circuits consisting of a combination of an inductance (L) with a capacitor (C) for frequency calculation. Therefore it is also called LC oscillator. The prominent feature of the Colpitt's oscillator is that the feedback signal is taken from a voltage divider made by two capacitors in series. The colpitt's oscillator is very simple and stable in its design [1].

A Colpitt's oscillator is the electrical dual of a Hartley oscillator. Figure 8.7 shows the basic circuit of the Colpitt's oscillator, where two capacitors and one inductor specify the frequency of oscillation. The feedback required for oscillation is taken from a voltage divider made of two capacitors. On the other hand in the Hartley oscillator the feedback is taken from a voltage divider made of two inductors.

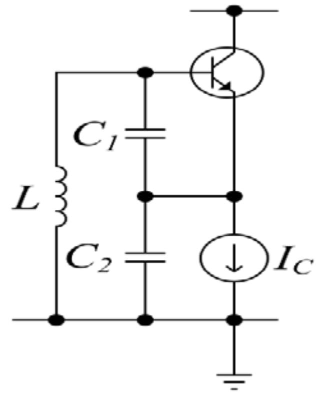


Figure 8.7: Colpitt's Oscillator

The amplification of the active device should be larger than the loss of the capacitive voltage divider, to obtain stable operation in case of any oscillator. A variable frequency oscillator can also be made of the same configuration if variable inductor and capacitor is used. Figure 8.7 shows a preferred form of Colpitt's oscillator, where the coil is also grounded that makes operations at high frequency quite stable. Feedback signal is fed into the voltage divider between the two capacitors. The ideal frequency of oscillation for the circuit is given by the equation:

$$f_0 = \frac{1}{2\pi\sqrt{L \cdot \left(\frac{C_1 \cdot C_2}{C_1 + C_2}\right)}}$$

CWD colpitt's oscillator consists of the following valued components:

Inductor: Our search coil is the inductor of Colpitt's Oscillator

C1: 6.8 nF

C2: 10 nF

Transistor: C1815 NPN BJT

Frequency of operation: We have used different frequencies for all the six detector circuit to avoid the frequency locking between the detector circuits. The detailed calculations of the frequencies are included under the topic “Coil Design and Frequency Calculations” in the same chapter.

8.4.2 Reference Oscillator

Reference Oscillator is there to balance the frequency of the Colpitt’s Oscillator. Another LC oscillator has been used as the reference oscillator. The oscillator comprises of a variable inductor and variable capacitor. Intermediate frequency oscillator has been used. IFT frequency range is 452 kHz which has been brought down by shunting its capacitor by a variable capacitor. Figure 8.8 shows circuit diagram for the reference oscillator.

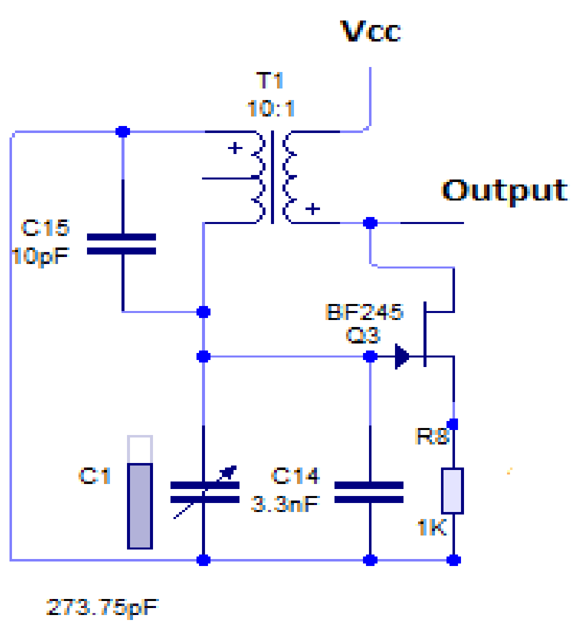


Figure 8.8: Reference Oscillator

8.4.3 Audio Amplifier LM386

As it has been discussed above that the difference of frequencies lies in the audio frequency range. Therefore an audio amplifier is used for the amplification of the disturbance signal. LM 386 has been used as power amplifier because of the following reasons:

- Operates on DC power supply
- Minimum external parts used
- Wide operating voltage range: 5V-18V
- Current drain is low: 4mA
- High voltage gain
- Ground referenced input
- Output quiescent voltage is self-centering
- Low distortion: 0.2%
- Available in 8 pin MSOP package

The circuit diagram of audio amplifier is shown in figure 8.9.

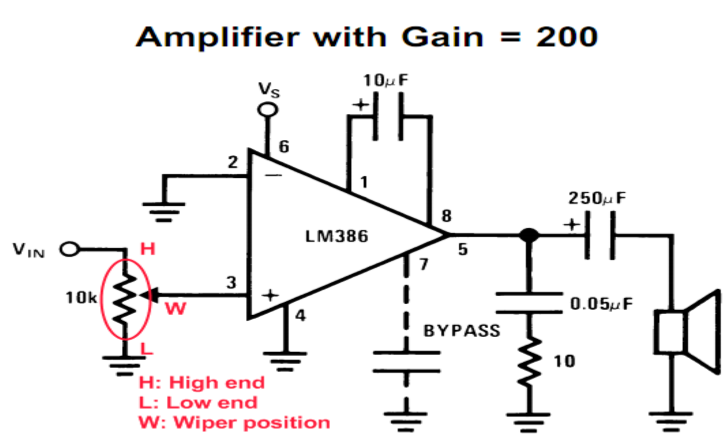


Figure 8.9: Audio Amplifier

8.4.4 Power Amplifier UPC 575

UPC 575 is an IC design for low noise and high power (2.0W at 8 ohm and 13V) audio amplifier mostly used in car stereo systems. It's encapsulated in 8 pin dual in line Package. In CWD circuit the output of audio amplifier is fed to the power amplifier UPC 575 which gives two levels of amplification. The output of UPC 575 is fed into the opto-coupler.

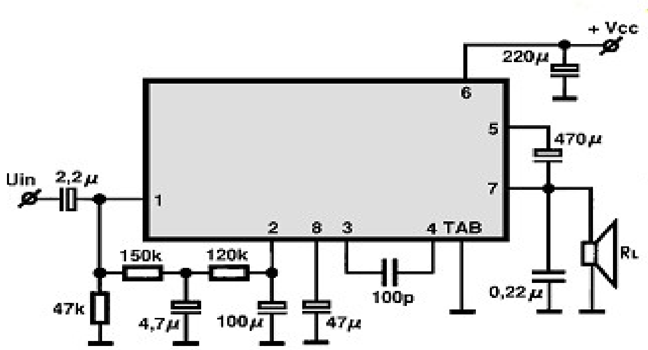


Figure 8.10: UPC 575 Power Amplifier

8.4.5 Opto-Coupler

In electronics, an opto-isolator, also known as an optocoupler, photocoupler, or optical isolator, is a device designed to transfer electrical signals between the circuits without direct electrical connection. It utilizes light waves to provide electrical isolation between its input and output and couple the signal. The main purpose of using an opto-coupler is that it prevents slight variations or impedance effects onto one side of the circuit to affect the other side of the circuit. In CWD circuit opto-coupler is used to couple the signal from the power amplifier into comparator. The opto-coupler is used so that very minute frequency variations may not ring the buzzer result into false alarms.

8.4.6 Voltage Comparator

A comparator is a compares the two voltages applied at its terminals. One of these voltages is called the reference voltage and the other one is called the input voltage. Operational amplifier based voltage comparator is used. One pin is grounded. Whenever a slight signal is received at the other pin, the output is triggered and buzzer rings.

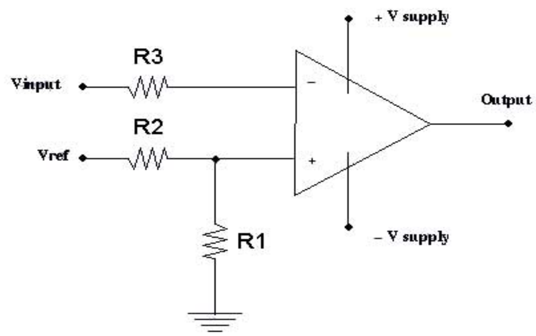


Figure 8.11: Voltage Comparator

The Complete Circuit diagram of the detector is shown in Figure 8.12.

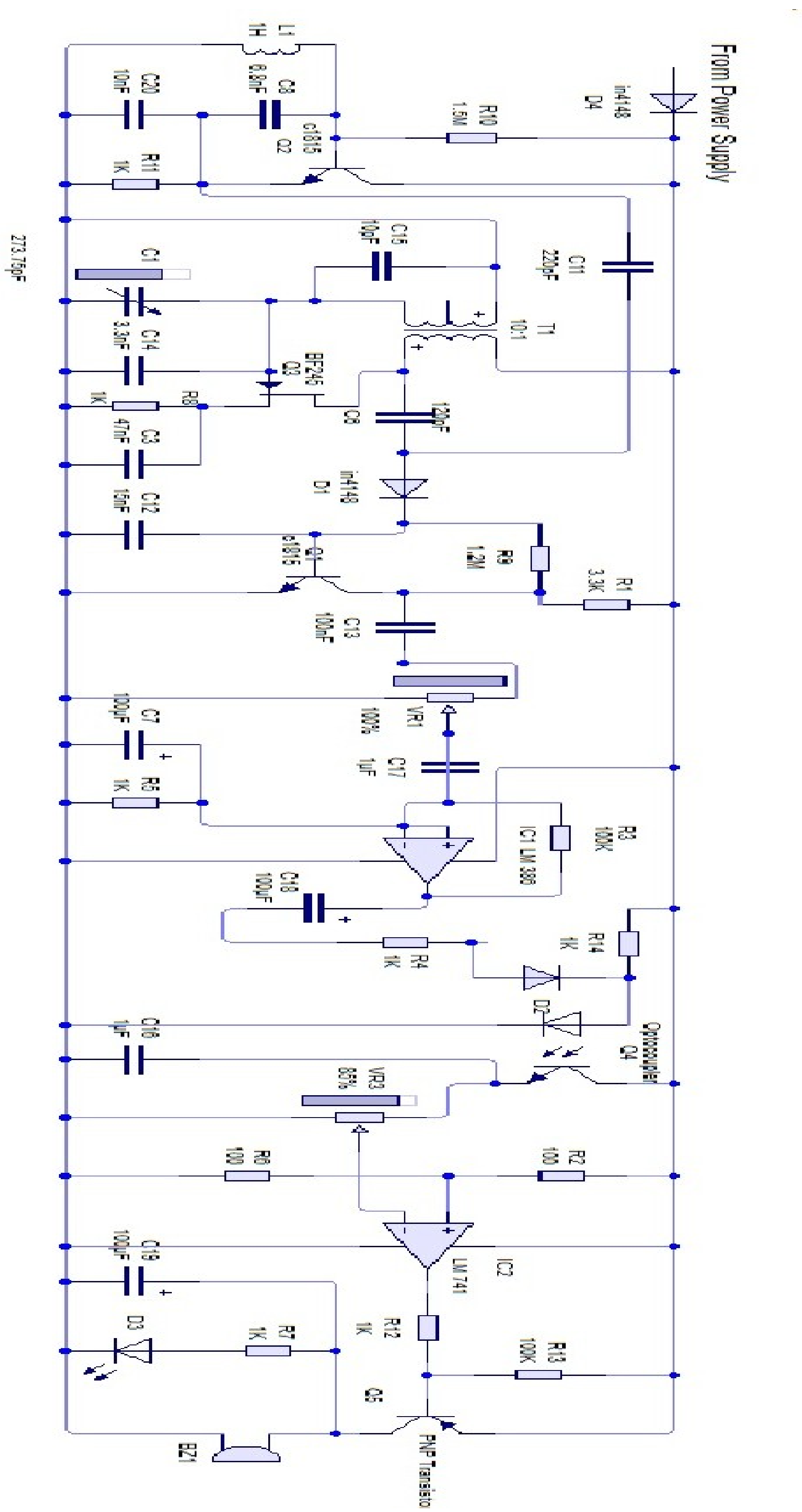


Figure 8.12: Detector Circuit

8.5 Coil Design and Frequency Calculations

As discussed in the previous chapter we have used the coils of following specs:

Wire Gauge: AWG 22

Coil Diameter: 9 inches

At first we prepared coils for all the six detectors with the same number of turns but it appeared that there was strong frequency locking between the coils. That's why coils with different number of turns were prepared for each of the detectors in order to avoid the frequency locking. The number of turns and the related frequency of the Colpitt's oscillator can be calculated by the formula.

16 turns coil

Inductance (L) = 135 uH

Frequency of Operation= 214 kHz

18 turns coil

Inductance (L) =171 uH

Frequency of operation= 190 kHz

20 turns coil

Inductance (L) = 211 uH

Frequency of Operation= 171 kHz

22 turns coil

Inductance (L) = 255 uH

Frequency of Operation= 155 kHz

24 turns coil

Inductance (L) = 302 uH

Frequency of Operation= 143 kHz

Two coils of the same turns have been used in order to save resources. However it is recommended that all the coils with different number of turns should be used. If two coils operating at the same frequency are used they must be physically separated by enough distance to not lock into each other.

8.6 Bar Display Circuit

Bar graph display circuit is there to display the level of the signal received and differentiate the zones from each other. LM 3914 based bar display circuit has been used. Six such circuits have been fabricated and given input from each of the detector circuit output. The bar display has been made with the help of a matrix of LED's where each column of LED's represents a particular zone. LM 3914 works in a fashion that each of its next output pin goes high with a 3db increase in the level of input. It has total 10 output pins.

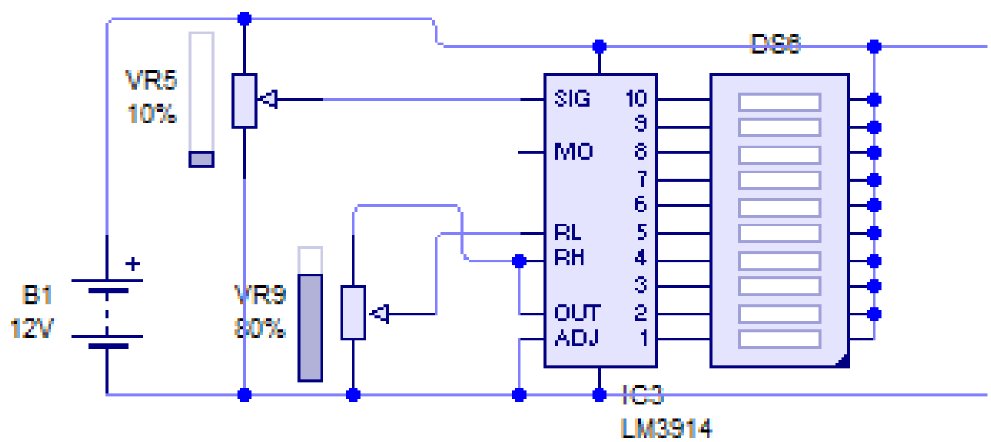


Figure 8.13: Bar Display Circuit

VR5 is taken as the variable signal from the power amplifier. Sensitivity of the bars can be adjusted with the help of VR9. Six duplicates of bar display circuits have been developed to show the six distinct zones.

8.7 Waveform Display Matrix

A waveform matrix has been developed to display the frequency difference produced by the interfering metallic object. It just gives another level of sensitivity. The waveform display is very sensitive and displays output for the signals which are weak for the bar display to indicate something. The input to this waveform display is taken from the output of the detector circuit.

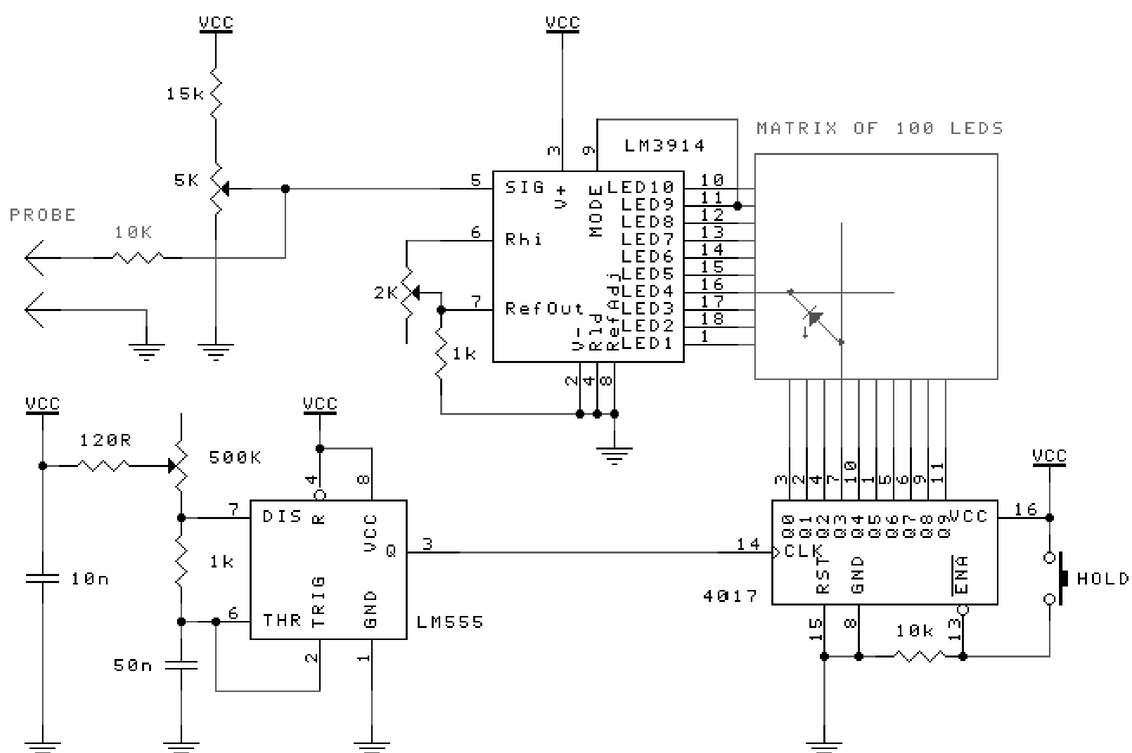


Figure 8.14: LED Oscilloscope

The working principle of the circuit is that the 555 timer IC provides timing reference hare which can be set with the help of variable resistance to set the acceptable frequency range. LM 3914 acts the same way as was acting in the bar display circuit. It just turns on the LED’s vertically according to the signal strength whereas 555 timer shifts the LED columns horizontally resulting into display of a proper waveform.

8.8 Size Classification Circuit

Micro-controller circuitry has been developed in order to distinguish the metal sizes. The main logic behind size classification is that if a metal is detected by a single zone it will be classified as small; if two zones detect a metal it will be medium and if the metal is detected by three zones simultaneously it will be classified as large sized object. In our hardware micro-controller Atmel 89C51 has been used.

8.8.1 Atmel 89C51 Micro-controller

AT89C51 is an 8-bit microcontroller and from Atmel's 8051 family. It has 4KB of Flash programmable and erasable read only memory (PEROM) and 128 bytes of RAM. It can be erased and program to a maximum of 1000 times. In 40 pin AT89C51, there are four ports designated as P1, P2, P3 and P0. All these ports are 8-bit bi-directional ports, i.e. they can be used as both input and output ports. Except P0 which needs external pull-ups, rest of the ports have internal pull-ups. When 1s are written to these port pins, they are pulled high by the internal pull-ups and can be used as inputs. These ports are also bit addressable and so their bits can also be accessed individually.

Port P0 and P2 are also used to provide low byte and high byte addresses, respectively, when connected to an external memory. Port 3 has multiplexed pins for special functions like serial communication, hardware interrupts, timer inputs and read/write operation from external memory. AT89C51 has an inbuilt UART for serial communication. It can be programmed to operate at different baud rates. Including two timers & hardware interrupts, it has a total of six interrupts.

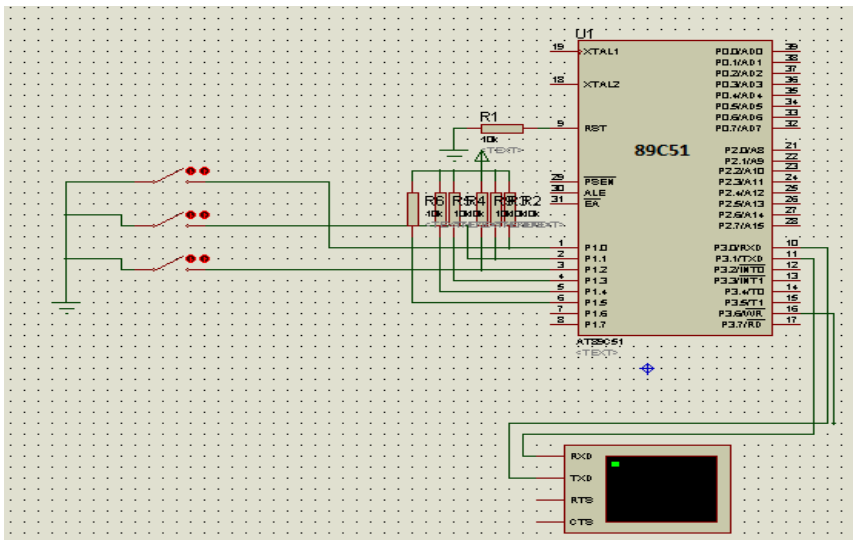


Figure 8.15: Micro-controller Circuit

The IC display the size of the metals detected on the computer screen as shown in the Figure 8.16.

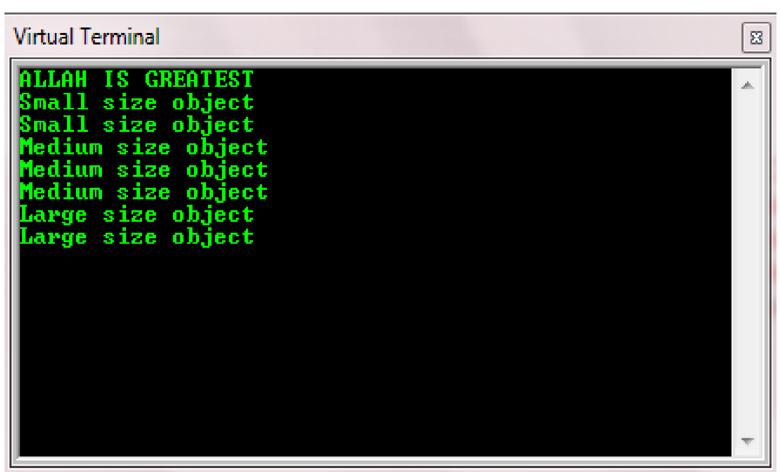


Figure 8.16: Hyper Terminal Display

8.9 Buzzer and LED

Buzzer and an LED are used as an audio and video aid to indicate the presence of metal by the response coming from the detector circuit. They are connected in parallel scheme and supply is given to each of them from the output coming from the output of the opto-coupler in the detector circuit. In CWD circuit design piezo buzzers have been used in parallel with 30 uF capacitors in order to give a stable ring.

8.10 Gate Construction

Wooden frame has been used as the gate structure. The frame is made of ply wood height = 6 feet, width = 2.5 feet and depth = 2 feet. Coils have been mounted over the gate using 2mm thick plastic sheet and glue. Respective detector circuits have been attached towards the outer side of the gate in vicinity of the search coil. The power supply, bar display circuit and the waveform display matrix have been mounted on a plastic sheet of 4 square feet and are kept on top of the wooden gate. The overall arrangement is shown in Figure 8.17.

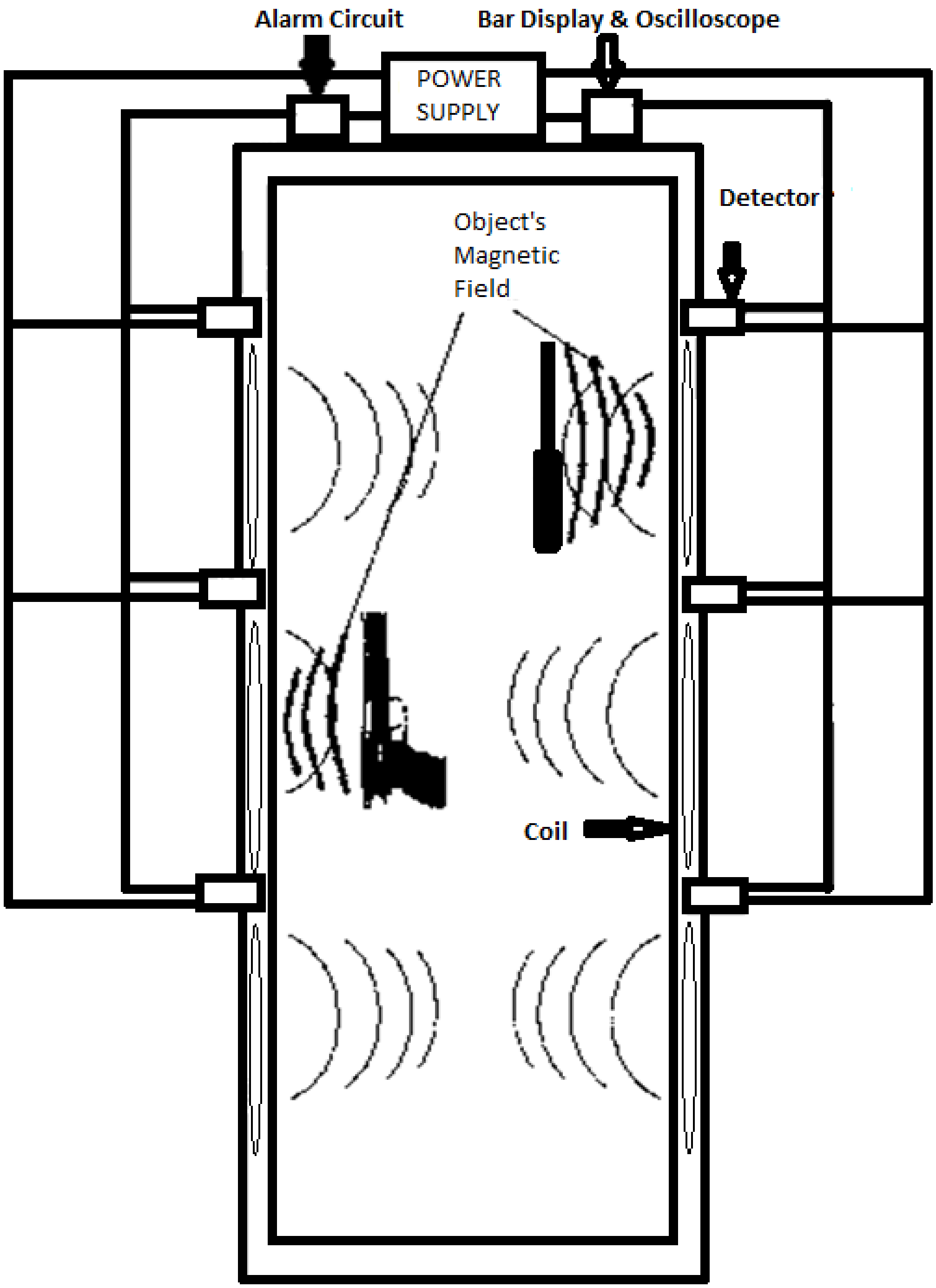


Figure 8.17: Gate Construction

Figure 8.18: Actual Gate Picture

CHAPTER 9

CONCLUSION

Considering the tools and components at disposal and the conspicuous absence of any person who might have attempted a similar project, and hence may have helped us in any way, the results of the project have seen satisfactory as far as main purpose of the project is concerned. The gate functions correctly with six working zones and provides the requisite alarm when any weapon e.g. pistol is passed through it. The project does not violate any IEEE standards/ protocols and it has been conclusively proven that a full scale project like this can be done at the Bachelor's level, at a much less cost and performance can be achieved which is near, if not equal to, a mass produced commercially available product.

What must be kept in mind however is that electromagnetic is not exact science. As mentioned in the beginning, the somewhat security/ defense related nature of the project was a brick wall in acquiring concrete resources/information regarding the construction and working of the device like this. Neither has reverse engineering been done as no access was available to any such related device since. It is hoped that junior semester students will be inspired to improve and refine the project.

9.1 Possible Problems and Improvement

The fundamental limitations arise due to the quality of the components used, for which considerable effort was done to ensure were up to scratch and the choice of frame. Still, hardware being hardware, the margin for error is always present. One of the problems that were faced while constructing the project was the frequency locking between the coils. First detectors were made to operate on the same frequency. It was observed that all the detector circuits were working quite fine individually but were giving no response when turned on simultaneously. The problem was found out to be locking between the coils. 4 different frequencies of operations were chosen for the detectors to get rid of this problem. Same frequencies were used for the detectors which were physically separated by sufficient distance to avoid frequency lock.

Secondly, the frame used is constructed of plywood. Now the presence of nails and moisture inside the wood contributes noise and that interferes somewhat with the operation of the circuit; the range suffers as well. This problem would have been mitigated if a fiberglass or plastic frame had been used. Unfortunately, a constraint of resources rendered that opinion unfeasible. More financial resources would no doubt help to mitigate these problems. And as mentioned before, the first basis of this project has been made in our institution; further refinements should be carried out by the junior semester students willing to take up this as their Final Semester Project.

One of the improvements that can be made in this project is to work on Image Processing side of the project. Different metals give different signatures when brought inside a walk-through gate. These signatures can be extracted with the help of different signal processing techniques and can be stored in database. Metal type can be identified with the help of this database later on.

BIBLIOGRAPHY

[1] G. Alan, "New Proposal for the Detection of Concealed Weapons: Electromagnetic Weapon Detection for Open Areas", Master thesis, University of Huddersfield, 2009.

[2] N.G. Paulter, "Guide to the Technologies of Concealed Weapons and Contraband Imaging and Detection", National Institute of Justice Guide 602-00, pp. 33-50, Feb 2001.

[3] L.G. Roybal, P.M. Rice, and J.M. Manhardta, "A new approach for detecting and classifying concealed weapons", *Proceedings of the SPIE, The International Society for Optical 54 Engineering, Conference on Surveillance and Assessment Technologies for Law Enforcement*, vol. 2935, pp. 95-107, Boston, MA, November 1996.

[4] P.V. Czipott, and M.D. Iwanoswki, "Magnetic sensor technology for detecting mines, UXO, and other concealed security threats", *Proceedings of the SPIE, The International Society for Optical Engineering, Conference on Terrorism and Counterterrorism Methods and Technologies*, pp. 67-76, Boston, MA, November 1996.

[5] C.V. Nelson, "Metal Detection and Classification Technologies", Johns Hopkins APL technical Digest, Vol. 24, Number 1, pp. 62-66, 2004.

[6] J.E. Duchateau, M. HIinders, "Using Ultrasound in Concealed Weapons Detection", NDE Lab, Department of Applied Science, College of William and Mary, April 2005.

[7] P.W. Kruse, and D.D. Skatrud, "Uncooled Infrared Imaging Arrays and Systems in Semiconductors and Semimetals", R.K Willardson, Eds., Academic Press, New York, 1997.

[8] R. Appleby, “Passive millimeter-wave imaging and how it differs from terahertz imaging”, The Royal Society, Vol. 362, pp. 379- 393, Number 1815, February 15 2004.

[9] N.G. Paulter, “Hand-Held Metal Detectors for Use in Weapons Detection and Contraband Detection”, National Institute of Justice Guide 602-02, February 2003.

[10] M.J. Caruso and T. Bratland, “A New Perspective on Magnetic Field Sensing”, Honeywell, Carl H. Smith and Robert Schneider, Nonvolatile Electronics, Inc.