DESIGN AND CONSTRUCTION OF AN UNDERGROUND METAL DETECTOR

AMUDIPE TOMILOLA OMOLADE

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Declaration

I, Amudipe .O. Tomilola, declare that this work was done by me and has never been presented elsewhere for the award of a degree. I also hereby relinquish the copyright to the Federal University of Technology, Minna.

Tomilola Amudipe
(Student)

10/12/2010
(Signature and date)

Certification

This is to certify that this project titled "Design and Construction of an Underground Metal Detector" was carried out by Amudipe Tomilola Omolade with matric. number 2005/22007EE and submitted to the department of Electrical and Computer Engineering Federal University of Technology, Minna in partial fulfillment for the award of Bachelor Degree in Engineering (B.Eng).

Engr. Dr. M.N. Nwohu
(Project Supervisor)

10/12/2010
(Signature and date)

Engr. A.G Raji
(Head of Department)

Jan 27, 2011
(Signature and date)

(External Examiner)

25/1/11
(Signature and date)

Dedication

This project work is dedicated to Almighty God for the successful completion of this work, and also to my parents for their love and support.

Acknowledgement

I wish to express my gratitude to Almighty God for keeping me all through till the completion of my project work.

My special thanks go to my Supervisor Engr. Dr. M.N. Nwohu who is a great inspiration to me, and Mallam Bagudu for his technical support and advice.

My appreciation goes to my Mum and dad, my sister, Temitope Solomon and my family as a whole for their encouragement and support in all aspects during this project work.

I also appreciate the contribution of Ademola Olajide, my colleagues (especially my group members) for their relevant advice and my friends, Aisha, Titi, Motun, Oyiwoja, Ikenna, Ojo and Alfa for helping me to achieve a positive result.

Abstract

This project focuses on the adaptation, simulation and construction of a commonly available schematic for an induction balance metal detector.

The background information of the history and uses of metal detectors is presented as well as the design criteria for this particular project. The theory behind how a basic low frequency metal detector works is examined, along with the basic details of a readily available design for a detector.

A detailed examination of the chosen schematics and the function of each component is examined and explained, as well as explanations for certain choices of component values.

The results of a computer simulation using multism are shown, and then the results of the actual construction of a breadboard prototype, along with the problems encountered are discussed.

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CHAPTER ONE

Introduction

1.1 General Background

A metal detector is a device that senses the presence of metal; metal detectors use electromagnetic fields to detect the presence of metallic objects. They exist in a variety of walk-through, hand-held and vehicle-mounted models, and are used to search personnel for hidden metallic objects at entrances to airports, public schools, courthouses, and other guarded spaces. Metal detectors are also used to hunt for landmines, archaeological artifacts, hidden or unwanted metallic objects in industry and construction sites. Metal detectors detect metallic objects, but do not image them. An x-ray baggage scanner, for example, is not classed as a metal detector because it images metallic objects rather than merely detecting their presence.

There are a number of ways to detect a metal object and alter the operation of a circuit so that an output is produced. Metal detectors detect ferrous (iron, steel, stainless steel) and non-ferrous (copper, tin, gold, lead, silver, aluminium) as well as alloys (brass, cupro-nickel, pewter etc). Depending on the complexity of the circuit, a metal detector can be able to discriminate between a lump of gold and an aluminium ring-pull from a drink-can. The simplest form of a metal detector consists of an oscillator producing an alternating current that passes through a coil having an alternating magnetic field. If a piece of electrically conductive metal is close to the coil, eddy currents will be induced in the metal, and this produces an alternating magnetic field of its own. The change in the magnetic field due to the metallic object can be detected if another coil is used to measure the magnetic field (acting as a magnetometer). The first industrial metal detectors were developed in the 1960s and were used extensively for mining and other industrial applications [7]. Uses include de-mining (the detection of land mines), the detection of weapons such as knives and guns, especially in airport security, geophysical prospecting, archaeology and treasure hunting. Metal detectors are also used to detect foreign bodies in food, and in the construction industry to detect steel reinforcing bars in concrete and pipes and wires buried in walls and floors.

Today, modern metal detectors do practically everything except dig the targets. They detect it, pinpoint it, determine its size and shape, measure its depth and tell the operator whether it is worth digging for or not. Some of this target "knowledge," however, is discerned by operators who have become very efficient with their detectors by learning to interpret and analyze detector audio and indicator information [9]. During the very early years of metal detecting the equipment was used mostly for prospecting for precious metals. As the years passed, metal detector usage has greatly expanded into many fields, which include searching for coins, relics, treasure, gold and other precious metals.

Plate I: Underground metal detector

1.2 Aims

The aim of this project is to produce a device that is capable of detecting metals buried under the ground. This is to prevent indiscriminate and random digging of the ground in case of maintenance or repair of damaged water pipes but detecting the actual location before digging. This is also to prevent damaging underground pipes and cables on construction sites. It has to be battery powered and uses a commonly available and simple design. In addition to this, the circuit design has to be relatively simple and compact so as to fit on a size limited printed circuit board (PCB)

1.3 Methodology

The circuit presented in this project is simple and works on the principle of induction balance, called amplitude modulation.

This type of metal detector is also known as the very low frequency metal detector. It has become more or less the standard general purpose detector for utility location, treasure hunting and various other uses. It has two search coils in its search head: the transmitting coil (driven coil) is fed with a signal which sets up an alternating field around it. The other coil (receiving coil) is placed so that the field around it balances having no electrical output. A metal object approaching the coils will distort the field resulting in an imbalance, so the pick up coil will produce an electrical output. This can be amplified to inform the operator of the presence of a metal.

1.4 Scope of the Project

The circuit designed for this project is powered by two 9V battery. This is to reduce the power consumption to the minimum possible value, since low power consuming electronic devices are of better use and now widely produced. The sensitivity of the device is aimed at detecting metals at a depth of about 50mm. Detection of a metal is indicated by an alarm and a LED indicator.

1.5 Motivation

In recent times, damage of underground utilities has been increased especially on construction sites. This is because of the difficulty in detecting these utilities before commencing construction. These damages cost a lot and deprive people in the location access to basic amenities. However, as a result of the cost implication in acquiring such devices, the metal detector constructed in this project is of a minimal cost. It will be easier for a lot of people to own it and can be used domestically in search of lost metal objects.

CHAPTER TWO

Literature Review

2.1 Techniques of metal detection

Scientists and engineers have contributed to the development and perfection of metal detector techniques. There are five major ways of detecting metals [11];

1. Beat frequency oscillator
2. Pulse induction
3. Off resonance
4. The magnetometer
5. Induction balance

2.1.1 Beat frequency oscillator (BFO)

This is the simplest way to detect metal. The limitation of this method is poor sensitivity. It operates just like the off resonance by detecting small charges in the search coil inductance which occur when the metal is present. When the output of the two oscillators is mixed, two total frequencies are produced. These frequencies are different because one is the sum of the frequencies of the two oscillators, and the other is the difference in the frequencies of the two oscillators. In the working state of this device, the operation of the BFO metal detector is based on superhetrodyning principle used in superheat receivers. In the absence of metal, this device produces a zero beat frequency and thus no sound from the speaker. But when there is a metal, the metal detector is brought close to the range of the search coil and the magnetic flux of this metal changes its inductance making the beat frequency not to be equal to zero and then the loud speaker is activated.

2.1.2 Pulse induction

The pulse induction metal detector uses a single coil as both transmitter and receiver, or may have two or even three coils working together. The device operates by exposing the ground to powerful short burst of current through its coil. Each coil generates brief magnetic field. It also listens between pulses for signal due to eddy current set up in any metal present in the field. These types of metal detectors are very sensitive but the most expensive type of metal detectors available. Despite their sensitivity, they have a couple of draw backs: their battery consumption is heavy due to the power required by the pulse transmitter and they are extremely sensitive to even tiny metals. Their use is primarily restricted to beach searching where objects are likely to be buried at considerable depths and where large holes can be easily and rapidly dug.

2.1.3 Off –resonance

This type operates by detecting the small changes in the search coil inductance which occurs when a metal object is present. It suffers from a basically poor sensitivity.

2.1.4 The magnetometer

This type of metal detector works by detecting small anomalies in the earth's magnetic field strength. This type of metal detector is fascinating but useless for treasure hunting since it can only detect famous objects.

2.1.5 Induction balance

This type of metal detector is also known as the very low frequency or audio frequency metal detector for both serious treasure hunters and detecting hobbyist. It has two distinct coils in its search head, the driven coil (transmitting coil) is fed with a signal which sets up an alternating field around it. The other coil (receiving coil) is placed so that the field around it balances when it has no electrical output. A metal object approaching the coil will distort the field resulting in an imbalance so the receiving coil will produce an electrical output. This can be amplified and used to indicate a detection of metal. Frequently in simple detectors, an audio modulated transmitted signal is used. The output from the receiving coil is then amplified and modulated like an AM (amplitude modulated) radio signal. There are many coil arrangements but most detectors available today use one of the two coil arrangement listed below:

i. Wide scan coil arrangement: Its most sensitive area extends right across the coils
ii. Pinpoint coil arrangement: It is also known as 4B. This is far better than most coil arrangements. As wide scan has poor pinpointing ability and tends to give false signals for objects, this project work uses the pinpoint coil arrangement.

2.2 Historical Background

Toward the end of the 19th century, many scientists and engineers used their growing knowledge of electrical theory in an attempt to devise a machine which would pinpoint metal. The use of such a device to find ore-bearing rocks would give a huge advantage to any miner who employed it. The German physicist Heinrich Wilhelm Dove invented the induction balance system, which was incorporated into metal detectors a hundred years later.

Early machines were crude, used a lot of battery power, and worked only to a very limited degree. Alexander Graham Bell used such a device to attempt to locate a bullet lodged in the chest of American President James Garfield in 1881; the attempt was unsuccessful because the metal coil spring bed Garfield was lying on confused the detector [2].

Application of metal detectors to law enforcement and security situations has a surprisingly lengthy history. A number of instances have been recorded in which metal detection equipment was used by law enforcement personnel as a crime scene management and investigative tool. Metal detectors of both the walk-through and hand-held type are being used to an ever greater extent today in facilities of all types where threats of terrorism and violence are increasing at an alarming rate. Metal Detector applications are constantly being expanded and now extend into many fields. It is now being used to detect pipes and cables buried underground [6].

Ancient Chinese documents indicate that a metal detector was in use more then 200 years before the birth of Christ. A Chinese emperor had a doorway metal detector constructed to protect him against assassination. His craftsman built the doorway of a magnetic mineral called magnetite with the frame possibly built something like a horseshoe magnet. Through a combination of heating and striking the magnetite with hammers, an iron metal "attractor" was created. The heating and jarring caused the molecules to align themselves in the direction of the earth's magnetic field. If a person attempted to carry iron objects such as armor, swords or other weapons through the doorway, these objects would be drawn against the doorway [6].

In 1890 tests were made to locate sulfides through the medium of conductivity, using a telegraphic receiver connected in series with a battery and a wire brush. Electrical contacts were made in the earth, and a brush was then moved over the surface. Whenever it touched sulfides, the brush would complete the circuit, indicated by a click in the receiver. Since it could be used only on exposed mineralized surfaces, the method was of limited value. Further attempts at metal detection were made, using the Wheatstone bridge circuit for measuring resistance. Here again, conductivity was the determining factor, but the conductivity between two points on the earth's surface had to be calculated indirectly by first measuring resistance. This method also proved impractical. Still another earth conductivity method was given considerable attention. Since electrical currents flowing through the ground cause electrical potential lines to be created, equal potential points across the ground could be measured by galvanometers and plotted. The presence of an ore body caused these lines to warp or distort. Although the method was somewhat successful, many variables were involved. In addition, water layers, areas of uneven moisture and other substances in the soil gave indications which could be misconstrued as indicating the presence of an ore body, too. Failure to indicate ore would not necessarily mean barren ground. The oxidized condition existing around sulfide ore bodies forms an almost perfect insulator that prevents accurate measurement [4].

In 1925 an electrical gate checker was designed to help factories cut down on rampant theft of tools and products. Its operation was based on the use of electromagnetic waves. Two German physicists, Dr. Geffeken and Dr. Richter of Leipzig, designed the original gate checker. Their work was continued by Gebr. Wetzel of Leipzigplaqwitz. An electromagnetic field was caused to flow across the passageway. Metal carried by persons passing through the door caused alteration of the electromagnetic field and a signal was given. The apparatus, forerunner of the modern "walk-through" detector, was adjustable to allow small objects such as watches and keys to be taken through the gate undetected while larger objects were detected. A small searching coil was used to inspect those persons who produced a signal as they passed through the doorway. This coil could be adjusted to various sensitivities, allowing small objects, such as coins in pockets, to pass undetected [7].

About the same time, Shirl Herr was recognized, according to reports, as the inventor of the magnetic balance, a device used for locating underground minerals and metals. In 1927 the spark gap metal detector was invented. A report in Popular Science Monthly, September 1930, shows a man using a small two-coil metal detector. The man using the device was called an "amateur treasure finder." The caption said that it would find a silver dollar buried several inches underground and that it made a bussing noise when metal was near. The metal detector, called a "radio prospector," was widely sold in kits. From the early'30s until World War II, various companies began producing metal detector inventions based upon several of these electrical theories. During the war there was naturally a great interest in metal detectors, with resultant rapid advances in their technology [6].

At war's end, thousands of Army mine detectors were available as war surplus. They were eagerly bought by ex-military personnel whose training with the Army mine detectors enabled them to recognize the value of such equipment in locating buried treasure. Several companies began producing vacuum tube and transistorized detectors for the consumer during the 50's. Since the development of transistors permitted construction of smaller and lighter weight detectors, vacuum tube detector production ended in the early 60's. But, it was not until the late 60's and early 70's that a substantial interest in metal detectors arose; in the

70's great strides in metal detector development began taking place. Ultra-stable and very sensitive metal detectors that featured "Good/Bad" target identification and ground mineral rejection came into existence during this period [3]. The 80's ushered in target analyzer designs, and each year saw these analyzers become more accurate. The use of computerized, microprocessor-controlled circuitry represented a quantum leap in the analysis of data. Garrett's Patent #4,709,213 was the first microprocessor metal detector technology patent granted by the United States Patent Office. The company conducted ten years of design and field testing before utilizing this patent in the manufacture of a detector, an effort whose success is told in Part III's discussion of computerized detectors [7].

2.2.1 Modern developments

The modern development of the metal detector began in the 1930's. Gerhard Fisher had developed a system of radio direction-finding, which was to be used for accurate navigation. The system worked extremely well, but Fisher noticed that there were anomalies in areas where the terrain contained ore-bearing rocks. He reasoned that if a radio beam could be distorted by metal, then it should be possible to design a machine which would detect metal using a search coil resonating at a radio frequency. In 1937 he applied for, and was granted, the first patent for a metal detector. However, it was one Lieutenant Jozef Stanislaw Kosacki, a Polish officer attached to a unit stationed in St Andrews, Fife, Scotland during the early years of World War II, that refined the design into a practical Polish mine detector [3].They were heavy, ran on vacuum tubes, and needed separate battery packs.

The design invented by Kosacki was used extensively during the clearance of the German mine fields during the Second Battle of El Alamein when 500 units were shipped to Field Marshal Montgomery to clear the minefields of the retreating Germans, and later used during the Allied invasion of Sicily, the Allied invasion of Italy and the Invasion of Normandy. As it was a wartime research operation to create and refine the design of the detector, the knowledge that Stanislaw created the first practical metal detector was kept secret for over 50 years [4]. After the war, there were plenty of surplus mine detectors on the market; they were bought up by relic hunters who used them for fun and profit. This helped to form metal detecting into a hobby.

2.2.2 Further refinements

Many manufacturers of these new devices brought their own ideas to the market. Whites Electronics of Oregon began in the 50's by building a machine called the Oremaster Geiger Counter. Another leader in detector technology was Charles Garrett, who pioneered the BFO (Beat Frequency Oscillator) machine. With the invention and development of the transistor in the 50's and 60's, metal detector manufacturers and designers made smaller lighter machines with improved circuitry, running on small battery packs. Companies sprang up all over the USA and Britain to supply the growing demand [8].

Modern top models are fully computerized, using integrated circuit technology to allow the user to set sensitivity, discrimination, track speed, threshold volume, notch filters, etc., and hold these parameters in memory for future use. Compared to just a decade ago, detectors are lighter, deeper-seeking, use less battery power, and discriminate better. Larger portable metal detectors are used by archaeologists and treasure hunters to locate metallic items, such as jewelry, coins, bullets, and other various artifacts buried shallowly underground.

At the same time, developers were looking at using a different technique in metal detection called Pulse Induction. Unlike the Beat Frequency Oscillator or the Induction

Balance machines which both used a uniform alternating current at a low frequency, the pulse induction machine simply fired a high-voltage pulse of signal into the ground. In the absence of metal, the 'spike' decayed at a uniform rate, and the time it took to fall to zero volts could be accurately measured. However, if metal was present when the machine fired, a small current would flow in the metal, and the time for the voltage to drop to zero would be increased. These time differences were minute, but the improvement in electronics made it possible to measure them accurately and identify the presence of metal at a reasonable distance. These new machines had one major advantage: they were completely impervious to the effects of mineralization, and rings and other jewelry could now be located even under highly-mineralized black sand [1].

2.2.3 New coil designs

Coil designers also tried out innovative designs. The original Induction Balance coil system consisted of two identical coils placed on top of one another. Compass Electronics produced a new design; the two coils were made in a D shape, and were mounted back-to-back to form a circle. This system was widely used in the 1970s, and both concentric and D type (and Wide scan as they became known) had their fans. Another development was the invention of detectors which could cancel out the effect of mineralization in the ground. This gave greater depth, but was a non-discriminate mode. It worked best at lower frequencies than those used before, and frequencies of 3 to 20 kHz were found to produce the best results. Many detectors in the 1970s had a switch which enabled the user to switch between the discriminate mode and the non-discriminate mode. Later developments switched electronically between both modes. The development of the Induction Balance detector would ultimately result in the Motion detector, which constantly checked and balanced the background mineralization [5].

2.2.4 Discriminators

The biggest technical change in detectors was the development of the induction-balance system. This system involved two coils that were electrically balanced. When metal was introduced to their vicinity, they would become unbalanced. What allowed detectors to discriminate between metals was the fact that every metal has a different phase response when exposed to alternating current. Scientists had long known of this fact by the time detectors were developed that could selectively detect desirable metals, while ignoring undesirable ones.

Even with discriminators, it was still a challenge to avoid undesirable metals; because some of them have similar phase responses e.g. tinfoil and gold, particularly in alloy form. Thus, improperly tuning out certain metals increased the risk of passing over a valuable find. Another disadvantage of discriminators is that they reduce the sensitivity of the machines [5].

2.2.5 Uses of metal detectors

- Utility locator

This is the major area of concentration of this project. The detector in this case is used to locate pipes or cables buried under the ground or in walls. It is one of the newest discoveries of the use of metal detectors. It prevents indiscriminate and random digging of the ground in case of maintenance or repair of damaged pipes. Also to prevent damaging underground pipes and cables on building construction sites.

- Archaeology

- Security screening

A series of aircraft hijackings led the Finnish company Outokumpu to adapt mining metal detectors, still housed in a large cylindrical pipe, to the purpose of screening airline passengers as they walked through. The development of these systems continued in a spin off company and systems branded as Metor Metal Detectors evolved in the form of the rectangular gantry now standard in airports.

- Industrial metal detectors

Industrial metal detectors are used in the pharmaceutical, food, beverage, textile, plastics, chemicals, lumber, and packaging industries. Contamination of food by metal shards from broken processing machinery during manufacture is a major safety issue in the food industry. Metal detectors for this purpose are widely used and integrated in the production line [8].

- Civil engineering

In civil engineering special metal detectors (cover meters) are used to locate rebars. Rebar detectors are less sophisticated devices that can only locate metallic objects below the surface.

2.3 Theoretical Background

2.3.1 Diodes

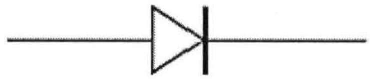

Fig. 1: Symbol of a diode

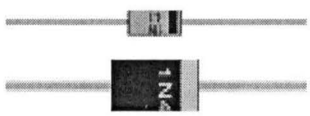

Plate II: A diode

Diodes allow electricity to flow in only one direction. The arrow of the circuit symbol shows the direction in which the current can flow. Diodes are the electrical version of a valve and early diodes were actually called valves.

Electricity uses up a little energy pushing its way through the diode, rather like a person pushing through a door with a spring. This means that there is a small voltage across a conducting diode, it is called the forward voltage drop and is about 0.7V for all normal diodes which are made from silicon. The forward voltage drop of a diode is almost constant whatever the current passing through the diode so they have a very steep characteristic (current-voltage graph). When a reverse voltage is applied a perfect diode does not conduct, but all real diodes leak a very tiny current of a few μA or less. This can be ignored in most circuits because it will be very much smaller than the current flowing in the forward direction. However, all diodes have a maximum reverse voltage (usually 50V or more) and if this is exceeded the diode will fail and pass a large current in the reverse direction, this is called breakdown.

2.3.2 Capacitors

The capacitor's function is to store electricity, or electrical energy. The capacitor also functions as a filter, passing alternating current (AC), and blocking direct current (DC).The capacitor is constructed with two electrode plates facing each other, but separated by an insulator.

When DC voltage is applied to the capacitor, an electric charge is stored on each electrode. While the capacitor is charging up, current flows. The current will stop flowing when the capacitor has fully charged.

The value of a capacitor (the capacitance), is designated in units called the Farad (F). The capacitance of a capacitor is generally very small, so units such as the microfarad (10^{-6}F), nanofarad (10^{-9}F), and picofarad (10^{-12}F) are used.

Aluminum is used for the electrodes by using a thin oxidization membrane. Large values of capacitance can be obtained in comparison with the size of the capacitor, because the dielectric used is very thin. The most important characteristic of electrolytic capacitors is that they have polarity. They have a positive and a negative electrode. Electrolytic capacitors range in value from about 1μF to thousands of μF. mainly this type of capacitor is used as a ripple filter in a power supply circuit, or as a filter to bypass low frequency signals, etc. Because this type of capacitor is comparatively similar to the nature of a coil in construction, it isn't possible to use for high-frequency circuits. (It is said that the frequency characteristic is bad.)

Fig. 2: Symbol of a capacitor

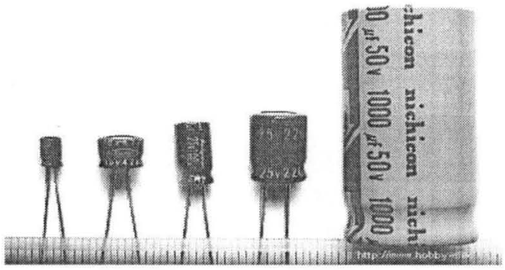

Plate III: A capacitor

2.3.3 Resistor

Resistors are elements of electrical networks and electronic circuits and are commonly found in most electronic equipment. Practical resistors can be made of various compounds and films, as well as resistance wire (wire made of a high-resistivity alloy, such as nickel/chrome).

A resistor is a two-terminal electronic component that produces a voltage across its terminals that is proportional to the electric current passing through it in accordance with Ohm's law. The primary characteristics of a resistor are the resistance, the tolerance, maximum working voltage and the power rating. Other characteristics include temperature coefficient, noise and inductance.

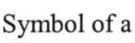

Fig. 3: Symbol of a resistor

Plate IV: A resistor

2.3.4. Transistor

A transistor is a semiconductor device used to amplify and switch electronic signals. It is made of a solid piece of semiconductor material with at least three terminals for connection to an external circuit. A voltage or current applied to one pair of transistor's terminal changes the current flowing through another pair of terminals. Because the output (controlled) power can be much more than the input (controlling power) the transistors provides amplification of a signal. Transistors are packaged individually but many are found embedded in integrated circuits.

The transistor is the fundamental building block of modern electronic devices and is ubiquitous in modern electronic systems. Following its release in early 1950s the transistor revolutionized the field of electronics and paved way for smaller and cheaper radios, calculators and computers, amongst other things.

Transistor is the key active component in practically all modern electronics and is considered by many to be one of the greatest inventions of the twentieth century. Its importance in today's society rests on its ability to be mass produced using a highly automated process (semi conductor device fabrication) that achieves astonishingly low per-transistor cost. The essential usefulness of a transistor comes from its ability to use a small signal applied between one pair of its terminals. This property is called gain. A transistor can control its output in proportion to its input; that is, it can act as an amplifier. Alternatively, the transistor can be used to turn current on or off in a circuit as an electrically controlled switch where the amount of current is determined by other circuit elements.

Transistors are categorized by

i. Semiconductor material: germanium, silicon, gallium arsenide, silicon carbide, EST.
ii. Structure: NPN, PNP, IGFET, MOSFET, IGBT, EST.
iii. Polarity

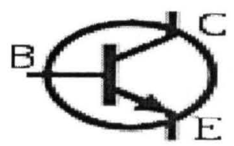

Fig. 4: Symbol of a transistor

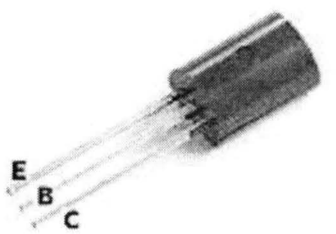

Plate V: A transistor

CHAPTER THREE

Design and Construction

3.1 Circuit design analysis

3.1.1 Feedback oscillator design

To calculate the inductance of the air core inductor [10]

$$L = \frac{r^2N^2}{9r+10l} \quad \text{.. (1)}$$

r = radius of the coil = 1.57inches

N = number of turns = 50turns

l = length of conductor = 1181.12inches

$$L = \frac{1.57^2 \times 50^2}{9(1.57) + 10(1181.12)}$$

$$L = \frac{2.4649 \times 2500}{14.13 + 11811.2}$$

$$L = \frac{6162.25}{11825.33}$$

$L = 0.5211H$ or 521.1mH

The formula stated in equation (2) is used to calculate the frequency of the inductor

$$f = \frac{1}{2\pi\sqrt{LC}} \ldots\ldots (2)$$

L = 521.1mH   C = 47nF

$$f = \frac{1}{2\pi\sqrt{(521.1 \times 10^{-3})(47 \times 10^{-9})}}$$

$$f = \frac{1}{2\pi\sqrt{(2.44917 \times 10^{-8})}}$$

$$f = \frac{1}{2\pi(1.565 \times 10^{-4})}$$

$$f = \frac{1}{9.833 \times 10^{-4}}$$

f = 10169.8 or 10.17 KHz

3.1.2 Design of the output driver

The output driver was designed by the use of a BC338 NPN transistor that effectively powers the buzzer. The buzzer used operates within a voltage range of 3V – 28V depending on the desired loudness. The internal resistance of the buzzer is 500Ω with a frequency of 10 KHz. The output driver was connected as shown in Fig. 5:

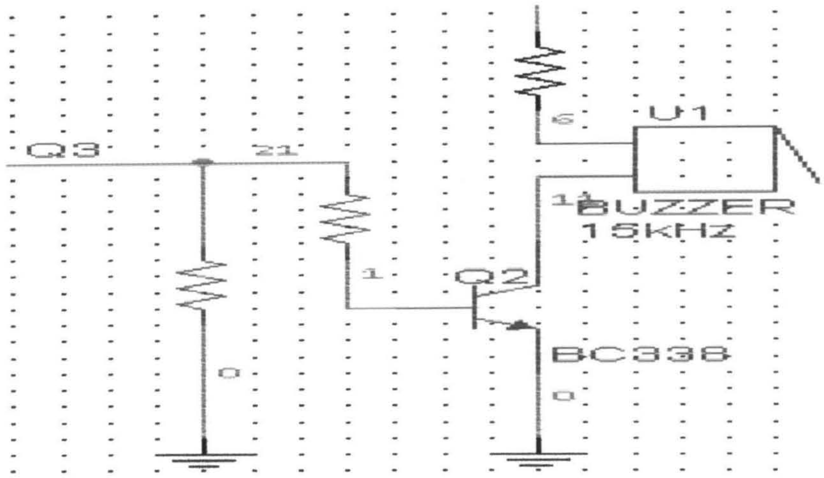

Fig 5: Output driver

For an NPN transistor, the collector – emitter terminals allow conduction if sufficient base current is driven through the base to saturate it. However, a value of 9V was used in this circuit. At this voltage, the current through the buzzer is determined as illustrated below:

$$I = \frac{9V}{500\Omega}$$

$I = 0.018$A or 18mA

Thus, required collector current is 18mA

$$R_c = \frac{v_{cc} - 0.7}{I_c}$$

$$R_c = \frac{18 - 0.7}{18}$$

$R_c = 961\Omega \approx 1000\Omega$

A 1KΩ resistor was used as R_c

The current gain of a transistor can be calculated using the formula shown in equation (3)

$$h_{fe} = \frac{I_c}{I_b} \qquad \text{.. (3)}$$

Where I_c is the collector current of the transistor.

Minimum base current (I_b) for saturation is: $\frac{I_c}{h_{fe}} = \frac{18mA}{195}$

$I_b = 0.092\text{mA}$

Maximum base resistance $= \frac{18\text{V}}{0.092\text{mA}} = 195.75\text{K}$

3.2 Circuit Description

The circuit involves five (5) units which are illustrated by the block diagram below:

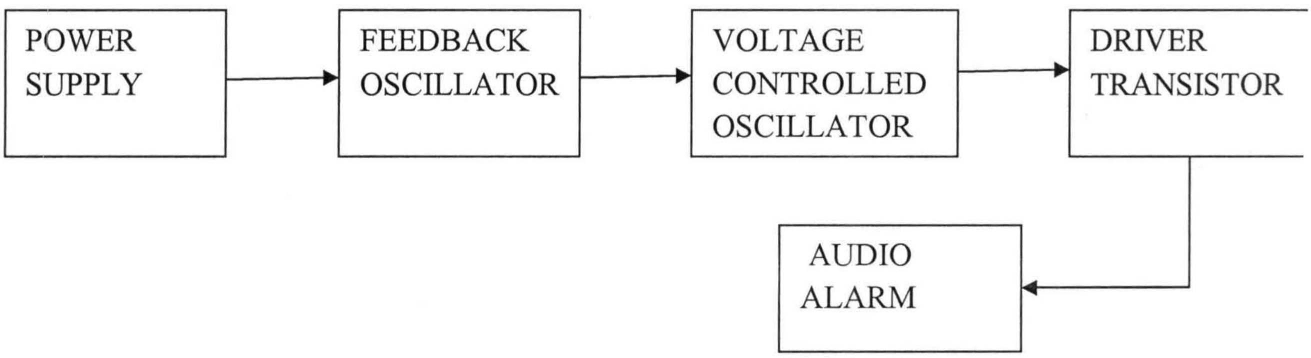

Fig. 6: Block diagram of the system

3.2.1 Power supply unit

The system is powered by two 9V batteries connected in series. The series connection is to obtain a high voltage (18V) in order to achieve a high sensitivity. The higher the voltage, the greater the electromagnetic field created by the transmitting coil. The LED in the circuit serves as a power indicator

3.2.2 Feedback oscillator

The second block is a feedback oscillator that gets its feedback via inductors (the two coils act like a transformer). This uses the first two transistors (Q_1 and Q_5). The first transistor (Q_5) is turned on via the diode connected to the emitter of Q_1. This diode is forward biased and is turned on by R_9. The resistance of the Rx (receiving coil) is very small and the base of the first transistor sees a "turn-on" voltage from the voltage across the diode (D_1). The variable resistor connected to the emitter starts at a low value for the circuit to function properly.

The first transistor (Q_5) has a high gain at this point in time, the transmitting coil (T_1) and C_2 (47nF) form a tuned circuit with a frequency of approximately 10 KHz. The power rail is stabilized by the 6V zener diode and a small amount of noise is always present in any circuit and causes a small waveform to be produced by the inductor and capacitor. This waveform is passed to the receiving coil of the inductor T_2 (through the air) that consequently produce a small voltage. Since the end of the receiving coil connected to the diode is fixed and rigid, the signal produced by the coil is passed to the base of both transistors (Q_1 and Q_5). The coil is orientated so that the voltage it produces turns the first transistor (Q_5) on harder and thus the waveform produced by the tuned circuit is increased. Since the resistance of the pot is at minimum, the amplitude of the waveform will be at maximum and this will have the effect of turning on the second transistor so that the voltage on the collector will be very low. The signal on the collector will be a waveform but this will be smoothed by the 100nF capacitor. As the resistance of the pot is increased, a voltage will appear at the emitter. Thus the base-to-emitter voltage will be less and the transistor will not be turned on. The waveform produced by the tuned circuit will reduce. This will be reflected in the receiving coil and the second transistor (Q_1) will also get turned off slightly. The voltage on the collector will rise and this will be passed to the third building block (the voltage controlled oscillator).

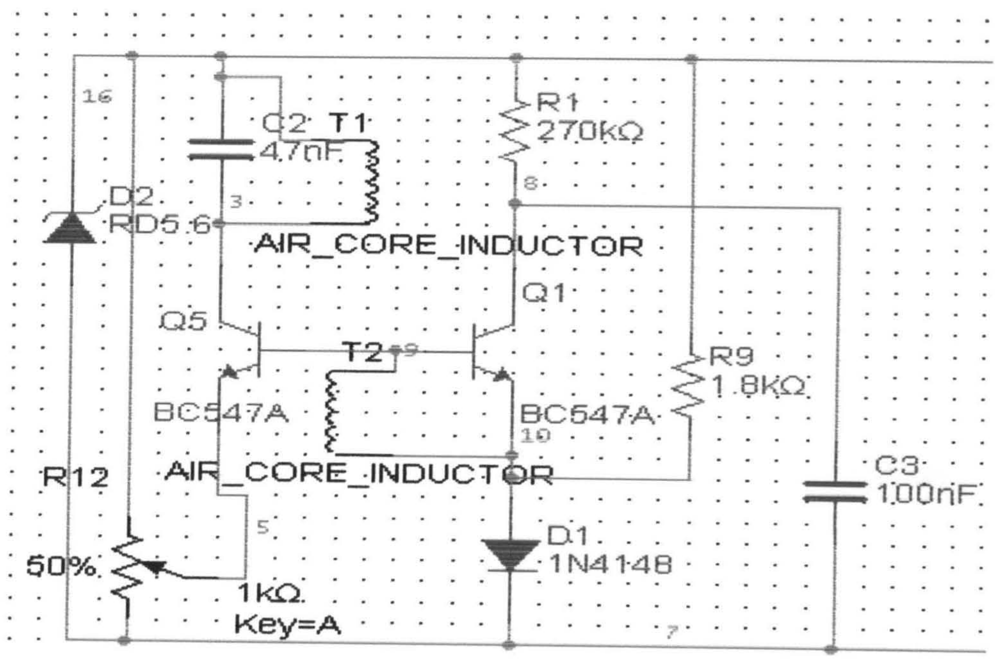

Fig. 7: Feedback oscillator of the circuit

3.2.3 The voltage controlled oscillator

The voltage controlled oscillator is simply a direct-coupled high-gain amplifier with a 10nF feedback capacitor (C_4) to provide oscillation. When a voltage appears on the base of the third transistor (Q_4), it turns on and this triggers the PNP transistor. The voltage on the collector of the PNP transistor rises and this pulls one end of the 10nF capacitor (via the 1k resistor) towards the positive rail. The other end of the capacitor is connected to the base of the third transistor. This turns on the third transistor (Q_4). They keep turning on until both are fully saturated (turned on). This happens very quickly and during this time the 10nF capacitor starts to charge. The charging current flows through the base-emitter junction of Q_4 and as the capacitor charges, it develops a voltage across it. This causes the charging current to reduce. The third transistor gradually turns off and this turns the fourth transistor off slightly. The voltage on the collector of the fourth transistor (Q_3) drops and the voltage across the 10nF capacitor cause the third transistor to turn off completely. This turns off Q_3 and now both are fully turned off. The 10nF discharges through the 56KΩ resistor and the cycle repeats. The capacitor takes a very short time to charge and a longer time to discharge. This is why the output consists of very short spikes. Now we come to the reason why the frequency alters. As the voltage from the previous building block rises, the charge-time for the first 10nF capacitor is less and thus the Q_3 is turned on in a shorter period of time. This capacitor is discharged when the two transistors are turned off and the second 10nF is taken near the 0V rail by the 1k resistor. This is how the two-transistor direct-coupled amplifier turns into a variable-frequency oscillator.

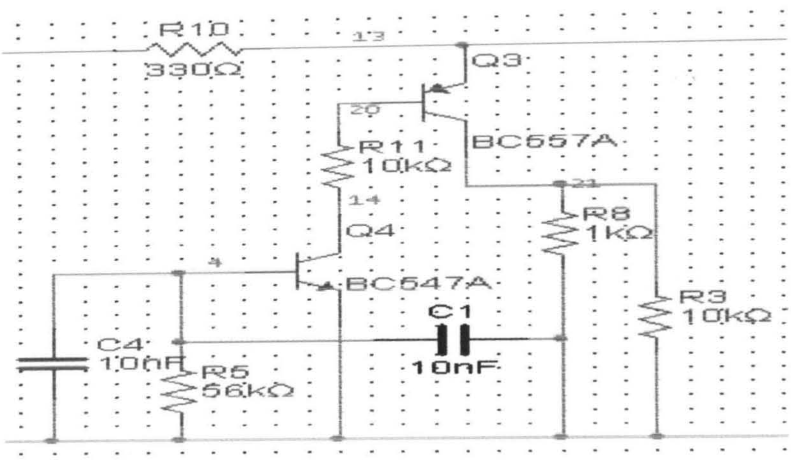

Fig. 8: voltage controlled oscillator of the circuit

3.2.4 The driver transistor

The output of the oscillator is connected to a driver transistor via a 1k resistor (R_4). This resistor prevents high currents flowing when both transistors are turned on. The driver transistor is directly connected to an 8Ω speaker. The 18Ω resistor reduces the volume and prevents large spikes appearing on the power rails. The result is a clicking sound. For this type of circuit to perform successfully, the supply voltage must be maintained. This is very difficult to do as the efficiency of the battery reduces with time, and an increase in temperature affects the efficiency of the semiconductor devices. The supply voltage must be as stable as possible as the circuit is detecting a very small change in amplitude and the supply voltage has an effect on the size of the signal. The circuit uses a zener diode to create a fixed supply but as the temperature of the diode heats-up with current-flow, the circuit-settings change and a tone is gradually produced by the speaker. This has to be stopped by adjusting the pot on the emitter of the first transistor (Q_5).

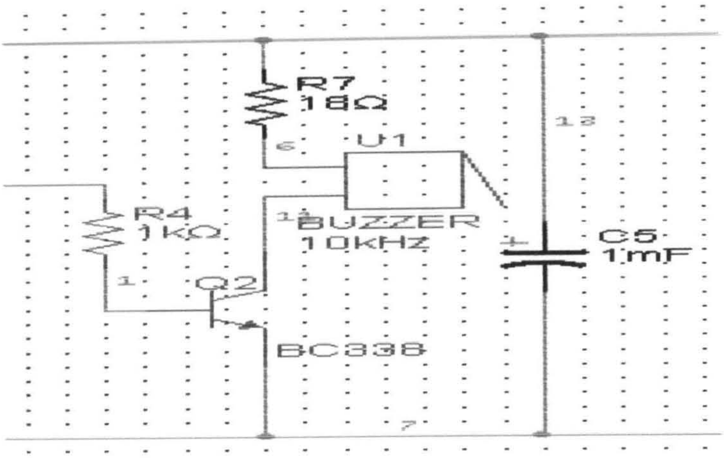

Fig. 9: The driver transistor in the circuit

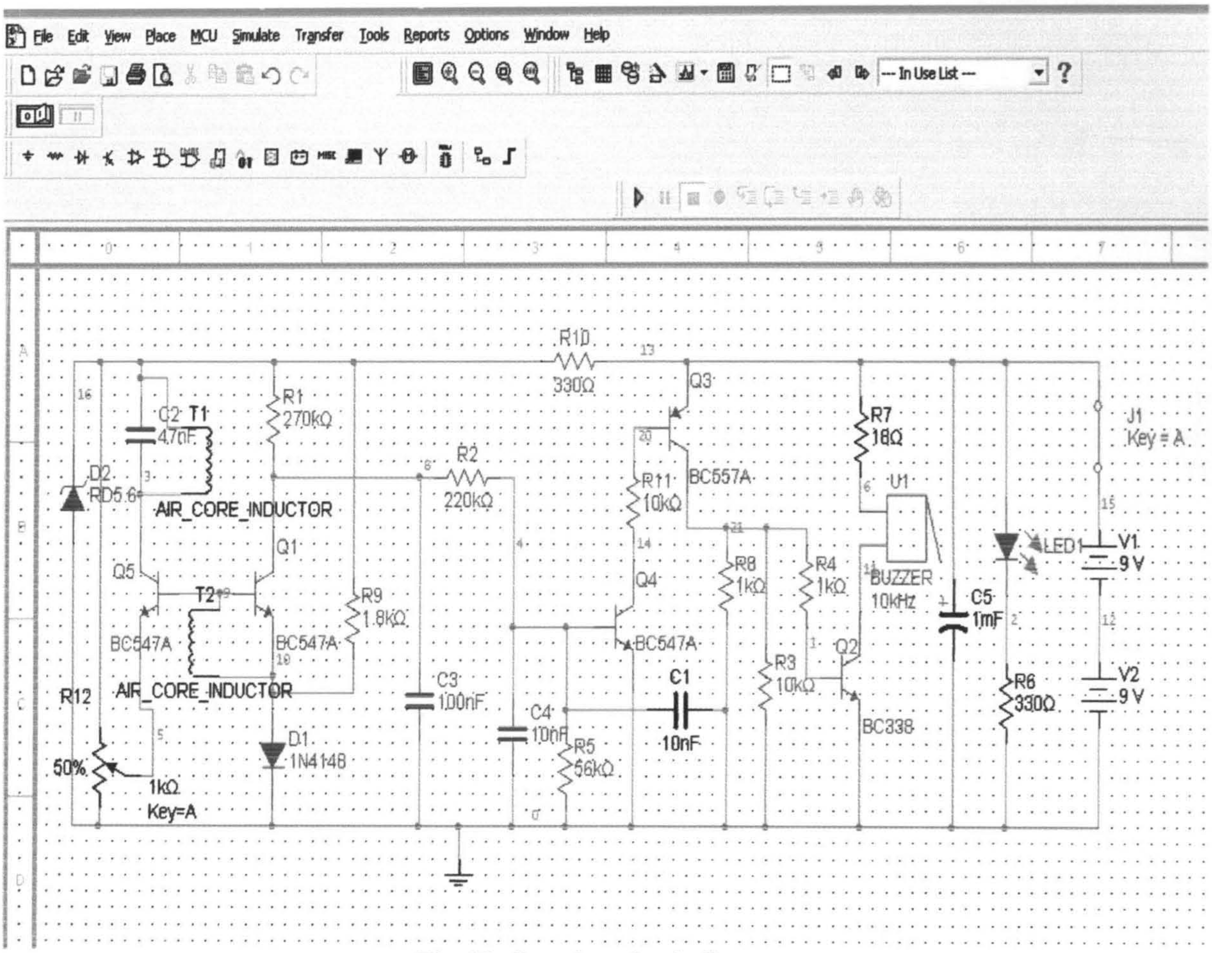

Fig. 10: Complete circuit diagram

3.3 Construction

The coil used was 0.5mm enameled wire wound on an 80mm diameter former. The two coils were placed beside each other and changing the number of turns of the receiving coil does not alter the sensitivity of the circuit. The transmitting coil is 50 turns and the detecting coil is 70 turns. The two coils must be placed together but insulated with tape to keep them together. The connection of the second can be reversed if the circuit does not work. The circuit will detect a metal about 5cm above the coil.

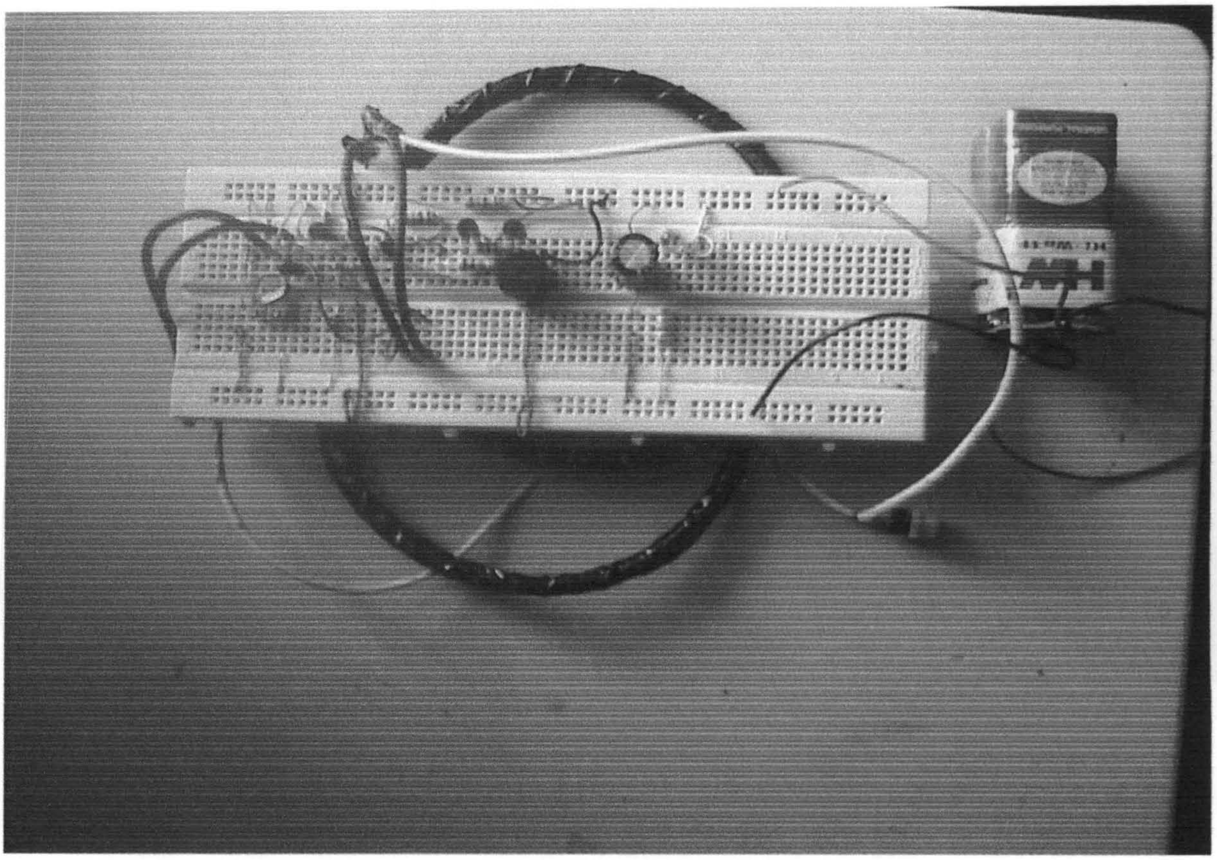

Plate VI: Temporary construction (breadboard)

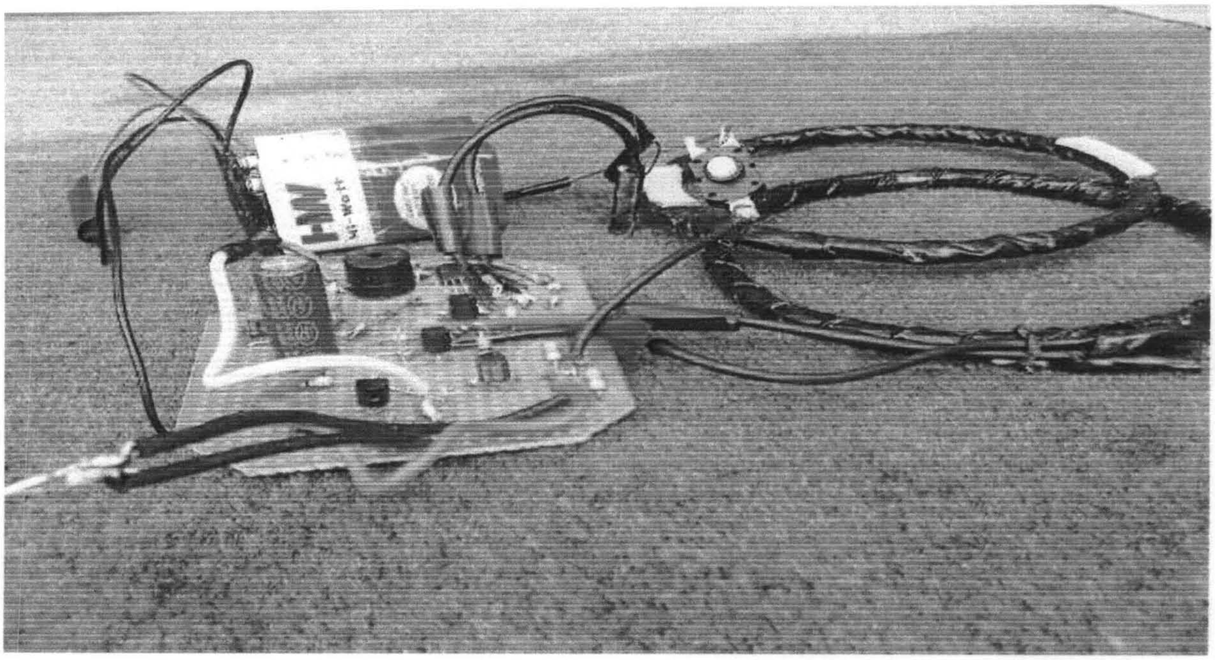

Plate VII: Permanent construction (veroboard)

CHAPTER FOUR

Tests, Results and Discussion

Simulation tests and results were obtained in the course of the design and implementation.

4.1 Results

4.1.1 Measured quantities

The measured quantities of the various units are tabulated below

Table 1: Measured currents and voltages of power module

S/N	Description of measured quantity	Voltage (V)	Current(mA)
1	Current flowing into LED	18	1.645
2	Current flowing out of LED	16.34	1.961

Table 2: Measured currents and voltages of frequency oscillator

S/N	Description of measured quantity	Voltage (V)	Current(mA)
1	Collector current of Q_5	5.739	54.55
2	Base current of Q_5	2.867	3.185
3	Emitter current of Q_5	0.627	13.399
4	Base current of Q_1	6.271	3.185
5	Collector current of Q_1	2.875	0.371
6	Emitter current of Q_1	0.063	3.1888

Table 3: Measured currents and voltages of voltage controlled oscillator

S/N	Description of measured quantity	Voltage (V)	Current(mA)
1	Collector current of Q_3	14.762	33.931
2	Base current of Q_3	17.19	17.944
3	Emitter current of Q_3	18	0
4	Base current of Q_4	0.034	0.062
5	Collector current of Q_4	16.792	1.714
6	Emitter current of Q_4	0	0

Table 4: Measured currents and voltages of driver transistor

S/N	Description of measured quantity	Voltage (V)	Current(mA)
1	Collector current of Q_2	5.739	212.088
2	Base current of Q_2	0.991	14.341
3	Emitter current of Q_2	0	0

4.1.2 Simulation results

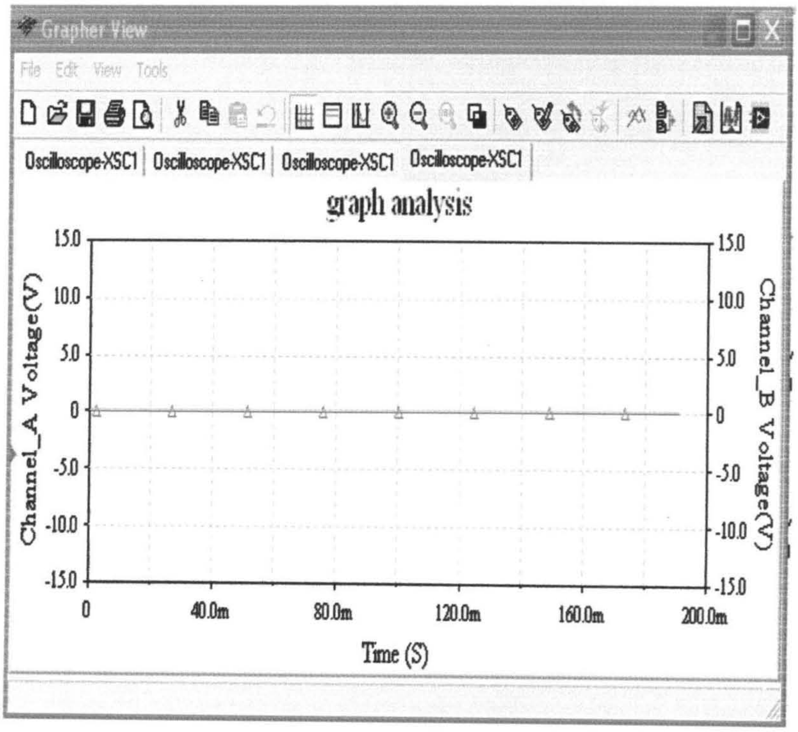

Plate VIII: Wave form when the buzzer does not produce sound

The output wave form shown in Plate VIII is produced when there is no metal close to the search coil of the metal detector. In this case, there is no magnetic field generated by the transmitting coil. Hence, the buzzer does not produce any sound.

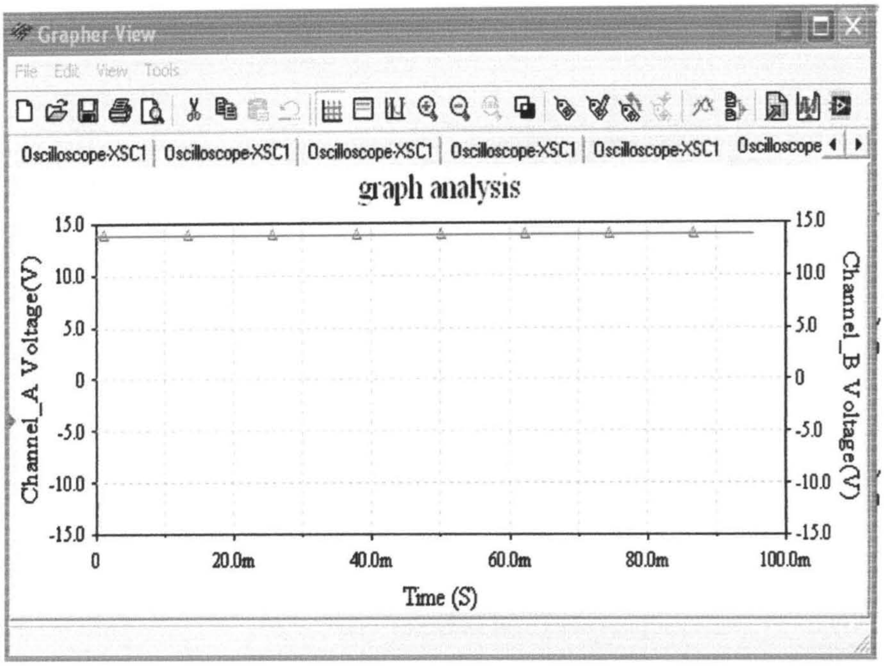

Plate IX: Wave form when the buzzer produces sound

The waveform shown in Plate IX is the output waveform when a metal is brought close to the search coil of the metal detector and the buzzer produces a sound.

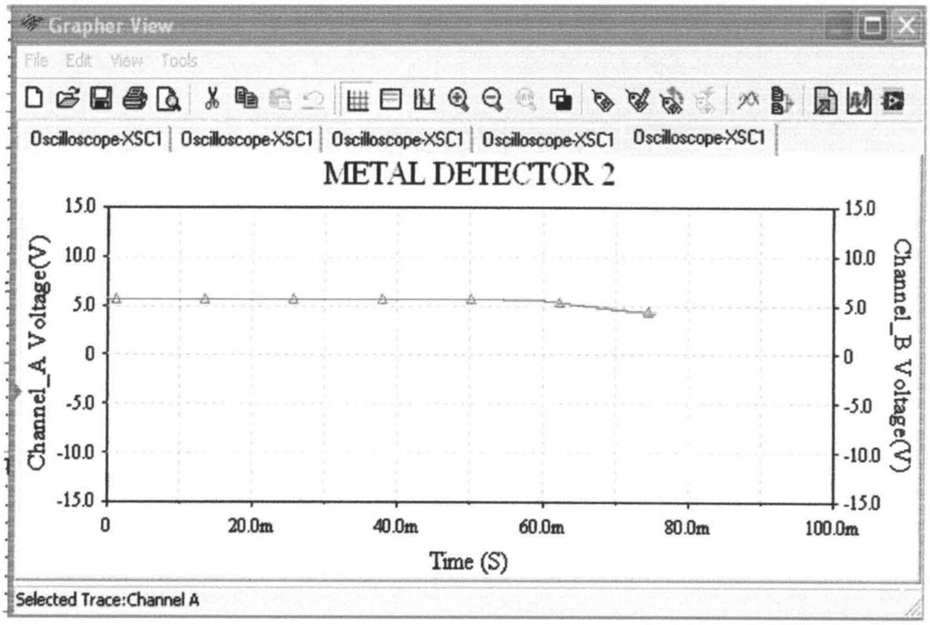

Plate X: Output waveform as a result of short capacitor charge time

The output waveform shown in Plate X is produced when the capacitor takes a very short time to charge and a longer time to discharge. This is why the output consists of very short spikes.

4.2 Discussion of result

The metal detector was able to detect the presence of metals. Because the device is powered by a battery, a sudden change in the voltage can alter the sensitivity of the detector; also as the temperature of the diode is increased the system becomes unstable. When the temperature of the diode heats up and current flows, the circuit settings change and a tone is produced by the buzzer. The constant resetting of the circuit is called "instability" and is one of the limitations of the design. However, for a simple circuit it offers very good sensitivity and an audio output

4.3 Precautions

1. All components were carefully tested to ascertain their condition (state) before mounting onto the Vero board.

2. The right component values were used to avoid overloading the circuit and avoid distortion effect.

3. A good soldering lead was used for all soldering process. Also during soldering, care was taken to avoid overheating the components and the formation of dry joints.

4. Component polarities were thoroughly considered before connection in order to prevent damage of component and ensure proper sequence of operation.

5. The coil was insulated to prevent contact between them. This was done to avoid the formation of a short-turn in the middle of the assembly.

6. A limiting resistor was placed in the circuit to limit the current if faults occur.

CHAPTER FIVE

Conclusion and Recommendation

5.1 Conclusion

A test was carried out on Multism to ascertain the certainty of the circuit's functionality before starting the physical construction. After the construction, the circuit functioned properly; it was able to detect metals underneath the earth at the depth of 5cm. Hence, the aim of the project was achieved. The metal detector constructed is affordable, portable and relatively sensitive.

5.2 Recommendation

The sensitivity of the metal detector is affected by various factors such as the principle of operation of the circuit. It is recommended that for the metal detector to be more sensitive, the circuit design should be based on the principle of pulse induction.

Also the search head of the metal detector (coil) should be insulated and placed at a fixed point to avoid distortion.

It is recommended that the battery be changed before it is totally drained to avoid instability as a result of reduced voltage level. Otherwise, an AC power source can be used.

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