# Design and Construction of a Metal Detector


AGUNBIADE KOLAPO O.

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DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING


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SUPERVISOR: DR. Y

# DEDICATION

This project is dedicated to God Almighty for sustaining me before, during and also after the completion of this work.

# Declaration

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

AKolapo...

Agunbiade Kolapo O.

Dr. Y.A. Adediran

Supervisor

12 | NOVEMBER | 2008

Date

Date

Dr. Y.A. Adediran

H.O.D

External supervisor

Date

Date

# ACKNOLEDGEMENT

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I must sincerely appreciate colleagues, friends and associates among who includes Adebimpe, Adeola, Haruna, Ochuko, Ifraimu, Press Family and a numerous number of people whose names are unmentioned for their unending support and inspiration.

# ABSTRACT

Metal detector systems are utilized in airports and security buildings to detect transport of weapons by individuals. Increasingly, metal detector systems are used to detect presence of firearms on individuals and are also employed in other spheres of life like the military, food industry, archaeology and a household material.

This system employs a sensing coil and sensing circuit to detect the presence of a metal object in an area by comparing perturbations in the magnetic field caused by the presence of the metal object to a threshold value. An alarm is activated when the threshold value is exceeded, informing a user of the presence of the metallic object.

A test procedure and a metal detector having receiving coils and an electronic processing circuit adapted to detect variations in the signals received by the receiving coils against a reference value.

## List of Figures

# Table of Contents

**Chapter Four: Tests, Result and Discussion**



**Chapter Five: Conclusion**

# CHAPTER ONE

# INTRODUCTION

## 1.1 EXPOSITION

In our present day, the rate of crime in companies, supermarkets and even shops by robbers and petty thieves are continually on the rise. Even with the presence of security operatives, who are harmless in checking unscrupulous people when entering into such buildings, is no deterrent to the 'men of the underworld'. Metal detectors are commonly used for security in industries and for recreation. The use of metal detectors comes in handy to check for metallic objects such as hand guns, knives and metallic sheets in people when entering such places which are majorly used in perpetrating the evil acts can help reduce the crime rate reasonably. Walk-through and smaller, handheld metal detectors are used to detect hidden weapons at airports and social events. Metal detectors would go a long way in reducing the crime wave.

Metal detectors are also useful in mining, where they can guide miners along the path of a gold-ore vein in rock. It is also used in archeology in the examination of materials and artifacts usually dug up from the ground. It is also used for demining (usually in the Military to detect land mines).

In order to ensure food safety, metal detectors are often used to detect small metallic particles that may have contaminated food products. During food preparation, such as the sawing or cutting of fresh meats, small metallic pieces—for example, saw teeth—can break off and become mixed with the food. By running the food product through a metal detector, food suppliers make sure that small pieces of metal do not find their way into the food supply.

Furthermore, a child's creative mind can be expounded using the metal detector as a play tool rather than have toys with no developmental capability. With this, they can increase their level of inquisitiveness by searching out metallic objects in the house and in the walls around the house. This I believe is one way to make the future more technologically inclined and we could have children talking about gold detectors and searching out the principle behind its workings.

Moreover, the metal detector can be used as a household item to search for missing items with metallic properties within the house.

Metal Detectors work on the principle of Electromagnetic Induction. There are three types of metal detectors: Pulse-Induction metal detector, Induction-balance metal detectors and Magnetometer.

**The pulse induction detector**: It generates a rapid pulse of electricity creating a magnetic field that penetrates the area being searched. The pulse rate can be as high as 5,000 pulses per second. Each pulse is followed by an equally short non-pulse period. When the pulse comes into contact with a metallic object, the coil detects the induced magnetic field during the non-pulse interval.

**Induction-balance metal detector:** It uses a power source and two coils of tightly wound wire to detect the presence of a metal. One coil is the send coil, and the other is the receive coil. A current of electricity is sent through the send coil, creating a magnetic field around the coil. The field induces a current in the receive coil. The receive coil is adjusted to read null, or zero, on a meter. When a metallic object comes within the magnetized field of the send coil, a small electric current is induced in the metal. The induced current produces a magnetic field, which alters the null reading of the receive coil. The detector registers the change and signals the presence of metal.

**Magnetometer**: A magnetometer passively monitors the naturally occurring magnetic field of the Earth. Magnetic lines of force, called flux lines, circle Earth in parallel lines. Metallic items disturb these parallel lines of magnetic force, and the magnetometer measures this disturbance. Minerals in the ground do not affect magnetometers as much as induction-balance detectors. Nevertheless, magnetometers are less stable and less sensitive than the other types of detectors.

## 1.2 OBJECTIVE OF THE PROJECT

The objective of this project is to construct a laboratory model of a metal detector that can be used to locate metals and metallic substances in the ground and the walls.

## 1.3 METHODOLOGY

The methodology used in this project entailed paper design initially, after which a simulation was done using Electronic Workbench software. The designed circuit was then put on a bread board to allow for placement adjustments, and then on the actual soldering unto a Vero board.

## 1.4 SCOPE OF WORK

This project uses digitized frequency technique such that the output frequency from the oscillator is compared to the reference oscillator. Both frequencies are fed through a comparator circuit and the output is used to trigger the buzzer with the aid of a digitized mixer. This denotes the presence of a metal.

## 1.5 BLOCK DIAGRAM REPRESENTATION

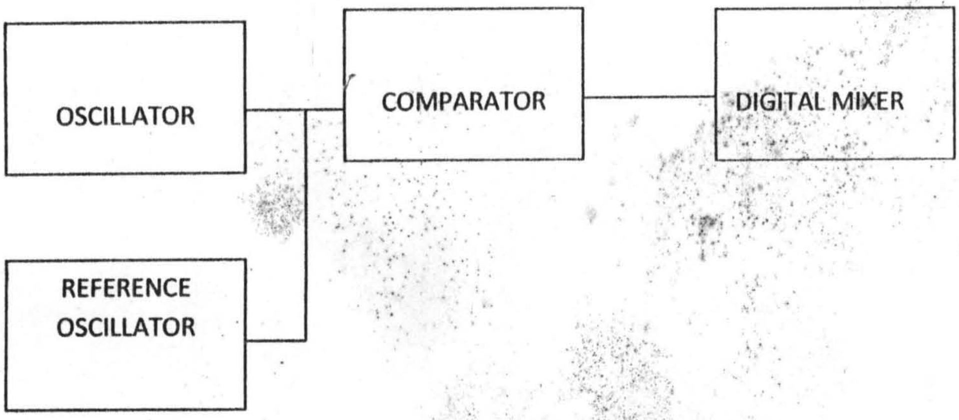


**Fig 1.1 Generalized Block Diagram**

## 1.6 DEFINITION OF TERMS

**OSCILLATOR:** It is an electronic circuit that produces a repetitive electronic signal, often a sine wave.

**COMPARATOR:** It is a device which compares two frequencies and switches its output.

**DIGITAL MIXER:** It uses the output from the comparator to trigger the buzzer.

# CHAPTER TWO

## LITERATURE REVIEW

### 2.1 THEORETICAL BACKGROUND

Metal detectors operate via the principle of induction. Induction is the coupling together of two circuits through an alternating magnetic field. The earliest technology that can be applied to detect metal is the beat frequency oscillator (BFO). In a BFO system, there are two coils of wire, the large coil often referred to as the search coil/head, and a smaller coil located inside the control box. Each coil is connected to an oscillator that generates thousands of pulses per second. The frequency of these pulses is slightly an offset between the two coils. The coils generate radio waves as the pulses travel. An audible series of tones (beats) based on the frequencies is picked up by a tiny receiver within the control box.

If the search passes over a metallic object, the magnetic field caused by the current flowing through the coil creates a magnetic field around the object; this causes an interference with the frequency of the radio waves generated by the search head. As the frequency deviates from the frequency of the coil in the control box, the audible beat changes in tone and direction.

### 2.2 HISTORY AND DEVELOPMENT

Metal detectors have been around for a very long time. English geologist and mining Engineer R. W. Fox first discovered that electricity will flow through metallic ores as well as solid metal objects. Thus, in about 1830, he devised a simple metal locator which consisted of nothing more than a battery, several metal rods and a suitable length of wire. His first method of detection was as follows: one metal rod would be driven into the earth where the suspected vein of ore was located; it was connected to one terminal of the battery. The other battery terminal was connected to a floating wire. Other metal rods were driven into the ground at several different points and successively touched with the floating wire. Where a spark occurred, it was an indication that metal was present. This device in 1870 was modified by Circa to two rods insulated from each other in a common probe and connected via battery to a bell and plunged into the earth. When contact was made by metallic ore, nugget or metal pipe, the bell rang, thus indicating the presence of a conductive object. [5]

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 bed Garfield was lying on confused the detector. [17]

### 2.2.1 MODERN DEVELOPMENTS

The modern development of the metal detector began in the 1930s. Gerhard Fisher had developed a system of radio direction-finding, 1266-X model, 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. His designs were soon put to the test in a practical way, as they were used as mine detectors during World War II. They were heavy, ran on vacuum tubes, and needed separate battery packs, but they worked. 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. [17] Although it is a good detector, it does not function clearly on saltwater surfaces.

Another recent type of metal detector is the pulse induction detector, which uses a different electronic principle. Instead of relying on a balanced electromagnetic field, the pulse induction detector generates a rapid pulse of electricity, creating a magnetic field that penetrates the area being searched. The pulse rate can be as high as 5,000 pulses per second. Each pulse is followed by an equally short non pulse period. When the pulse comes into contact with a metallic object, the coil detects the induced magnetic field during the non pulse interval. Pulse induction detectors are popular for deep-sea exploration, because they ignore the limiting effects of salt water, which contains minerals and carries a charge that can thwart induction-balance detectors. The Pulse Induction metal detectors have several disadvantages. In order for such devices to be able to detect a metal object at some distance from the search coil, they must have a very high gain receiver. A pulse sampling network is coupled to the search coil for sampling signals on the search coil at predetermined times to provide sampled pulse induction signals. An integrator network is responsive to the sampled pulse induction signal which has a predetermined but relatively fast response characteristic or time constant. The output of the integrator circuit is coupled to an RC coupling circuit which has substantially the same time constant as the integrator circuit. The output of the RC coupling circuit is connected to an audio circuit which generates an audio tone, the intensity of which indicates the proximity and size of metal objects. [12] A high gain receiver, however, which increases sensitivity, also results in an increase in the amount of random noise and false signals. Also, they are less sensitive to smaller targets, more difficult to use on heavily mineralized or iron contaminated ground and less accurate pinpointing.

### 2.2.2 TECHNOLOGY TOMORROW

Modern top models are fully computerized, using microchip 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. The operation of this device using this technology can present a challenge to a new user because of the settings that needs to be adjusted like the White's metal detectors. [10]

New genres of metal detector have made their appearance. BB (Beat Balance) and CCO (Coil Coupled Operation) were unveiled by the electronics press in 2004. Both were invented by electronics writer and designer Thomas Scarborough and combine unprecedented simplicity with good sensitivity. [17]

Another development is the induction-balance system. Here, a central excitation coil is arranged coaxially with a pair of receiver coils. The three coils are typically coaxial and of similar diameter. The receiver coils are spaced equidistantly on either side of the excitation coil, typically with a spacing of 30 40 mm between the excitation coil and each receiver coil. A highly stable, pure sine wave having a typical frequency between 30 kHz and 1 MHz is applied to the excitation coil and the magnetic field thus generated results in a flux which links each receiver coil equally. The two receiver coils are connected to one another in series opposition so that the induced voltages (strictly, the induced e.m.f.'s) in each cancel out and a net zero output signal is in principle obtained. Any ferromagnetic or electrically conductive material adjacent to this arrangement causes an imbalance in the flux linking one or other of the receiver coils, so that a voltage of non-zero amplitude is generated in them.[16] This enables the detector to discriminate metals. This results in reducing the sensitivity of the detector, so it may be unable to find deep object. They are known as discriminators. [17]

A U.S. Patent in June 2007 described a passive metal detector termed expendable metal detector (EMD). The expendable metal detector system of the invention can include active metal detection via pulsed electromagnetic induction (EMI) technology comprising: means for generating a current pulse or a series of current pulses and a transmitter antenna connected to the current pulse generating

means for creating a magnetic field. The antenna being a coil of wire for transmitting the current pulse or series of current pulses, a receiver
antenna for receiving a signal indicative of nearby metal. The receiver antenna being the same or different coil of wire used for the transmitting current means; means for amplifying and processing received signals; means for transmitting the received signals to the means for receiving signals; means for providing power to the means fro generating; and means for analyzing and displaying the received signals to the operator indicating the presence of metal. One of the advantages the EMD possesses is that the electronics and the power providing means are symmetrically placed between the at least two magnetic field sensors thereby minimizing any potential adverse magnetic field distortions caused by ferrous material in the electronics and power providing means. This is due to the combination of the magnetic anomaly detection (MAD) and electromagnetic induction (EMI) technology. [15]

Australian scientists are developing a handheld land mine detector. It combines a ground-probing radar and a conventional metal detector that could detect both metal and plastic mines.

# CHAPTER THREE

## DESIGN AND IMPLEMENTATION

### 3.1 PRINCIPLE OF OPERATION

The principle of operation of this device involves the comparison of two frequencies using NAND gates. The first frequency is generated by a Colpitts oscillator as shown in figure 3.1 and the second determined by a function generator (fixed or reference oscillator) in figure 2. The output of the NAND gate is fed into a D-flip flop which is wired in such a way that the result will only be noticed via an earpiece.

### 3.2 OSCILLATORS

### 3.2.1 COLPITTS OSCILLATORS

The Colpitts oscillator comprises two NOT gates, a coil, a coupling capacitor and other supporting capacitors all grounded. The Colpitts oscillator can act as an amplifier but it uses a 'tank circuit' to generate its frequencies. A tank circuit consists of an inductor and a capacitor whose frequency is determined by its resonant frequency given by the formula;

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

where $f$ = frequency

L = Inductance

C = Capacitance

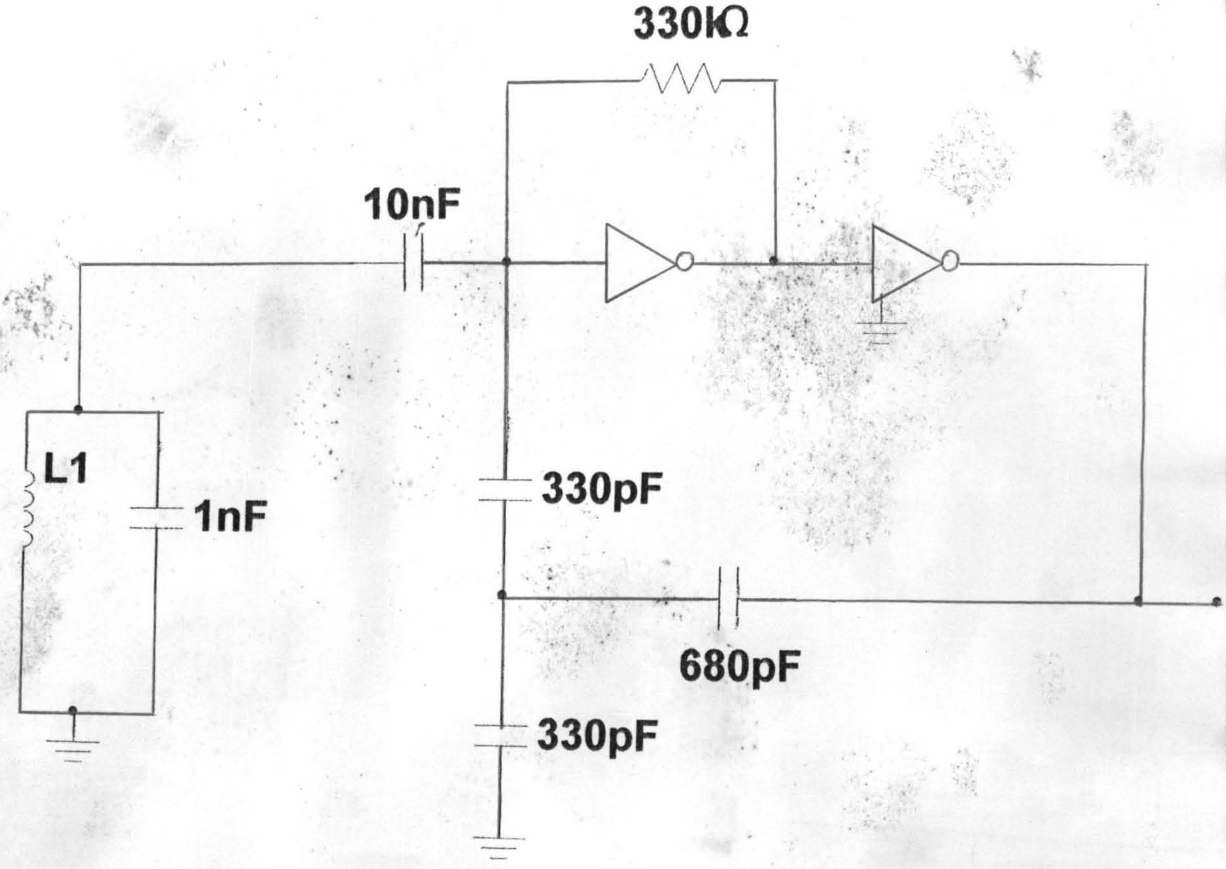


**Fig. 3.1 Circuit diagram of a Colpitts oscillator**

But inductance of a coil L is given as, $\mathbf{L} = \frac{\mu o A N}{l}$

where $\mu_o$ is the permeability of free space whose value is 1.2566 x $10^{-6}$ $Hm^{-1}$

N is the number of turns = 80 turns

$l$ = length of loop = 30cm = 0.3m

A is the area expressed as $\pi r^2$ (d = 100mm)

r = d/2 =100mm/2

r = 50mm = 5cm = 0.05m

Inserting the above values and evaluating the inductance, L

$$= \frac{1.2566 \cdot 10^{-6} \pi \cdot (0.05)^2 \cdot 80}{0.3}$$

$L = 2.63 \times 10^{-6}$ H ≈ 263μH

Using the derived value of the inductance, the resonant frequency and the frequency of the tank circuit becomes;

$$f = \frac{1}{2\pi\sqrt{(263\mu H \times 1nF)}}$$

$$f = \frac{1}{2\pi\sqrt{(263 \times 10^{-6} H \times 1 \times 10^{-9} F)}} = 310.2 \times 10^3 \text{ Hz} = 310.2 \text{ KHz}$$

This signal generated of the above frequency (310.2 KHz) changes whenever the tank circuit comes in an atmosphere consisting of metals and metallic particles. This change in frequency at the output of the Colpitts oscillator is as a result of the metal interaction with the electromagnetic wave generated by the coil (interference).

The signal is coupled into the NOT gate system by a coupling capacitor (10nF), which is used to filter or block a.c. signals. This signal is then re-inverted by another NOT gate so that the original signal fed into the system is still achieved but in an amplified form.

Frequency of the Colpitts oscillator is expressed as $f = \frac{1}{2\pi\sqrt{LC}}$

Where $C = C_1.C_2/ (C_1+C_2)$

$$= \frac{330pF \cdot 330pF}{330pF + 330pF}$$

C = 0.165 x $10^{-9}$ F = 0.000165μF

Therefore,

$$f = \frac{1}{2\pi\sqrt{263\,\mu H \cdot (0.000165)\,\mu F}}$$

$$f = \frac{1}{1.3089 \cdot 10^{-6}}$$

$f$= 764.12 KHz

The above frequency is the frequency generated at the output of the Colpitts oscillator.

### 3.2.2 REFERENCE OSCILLATOR

The reference oscillator is a function generator shown in figure 3.2 that generates square waves shown in figure 3.3. It consists of a variable resistor (used to vary the resistance), two inverted NAND gates (acting as inverters) with a capacitor (150pF). The frequency of the function oscillator is given as:

$$fo = \frac{1}{2.2RC}$$

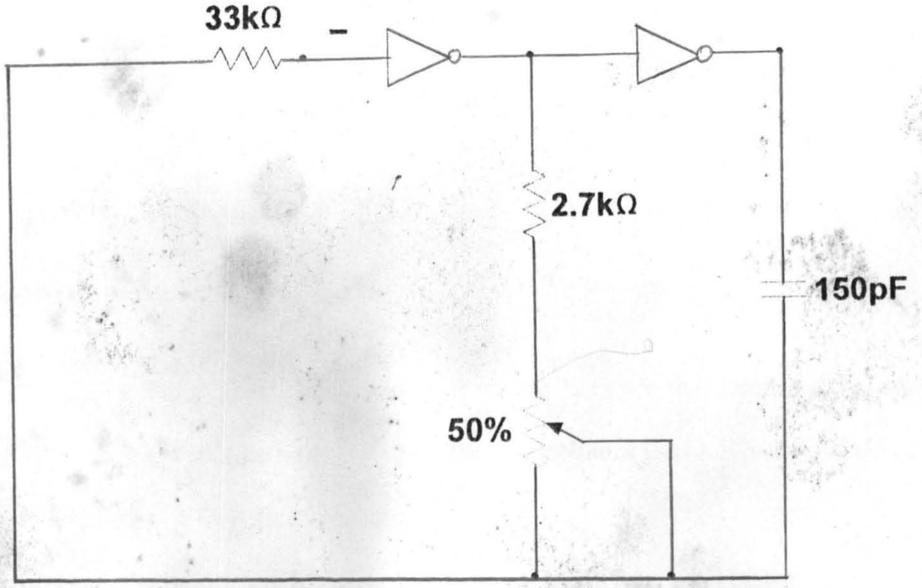


**Fig. 3.2 Circuit diagram of reference oscillator (Function generator)**

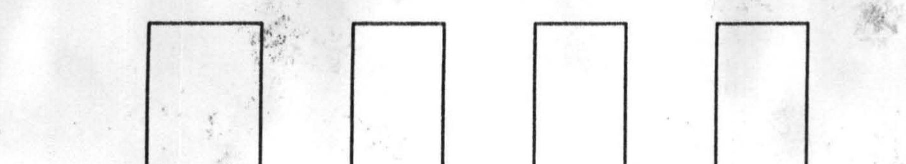

**Fig. 3.3 Waveform of a function generator**

The unloading resistor, Ru (33 KΩ) is ten time the value of the timing resistor, Rt (the series combination of the 2.7 KΩ resistor and the variable resistor). This implies that the frequency of the generator becomes;

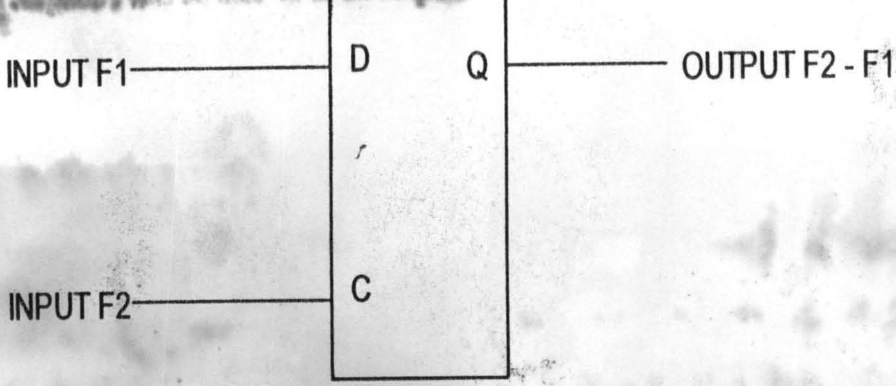


**Fig. 3.6 D flip flop implementation**

Assume initially that F1 and F2 are identical in phase and frequency. The D input will be 1 the instant clocking occurs, and the output will be a 1. Now, let the frequency of F1 vary slowly "slip cycles" with respect to F2. The output will alternate at the difference F2 - F1, and we have the equivalent of a digital mixer or down-converter.

## 3.5 POWER SUPPLY UNIT

The power supply unit consists of a series arrangement of dc cells supplying 9V of power source into the circuit. Any voltage source below the proposed voltage would render some elements useless (not being able to function) while any voltage above could lead to potential damage of the components.

## 3.6 CONSTRUCTION

This project was constructed using integrated circuits to reduce the number of components on the Vero board. A 4011 NAND gate was used to implement the workings of the circuitry. The components were placed on the line Vero board and neatly soldered where necessary. A picture of the soldered work is shown in figure 3.6. An earphone was connected as an output.

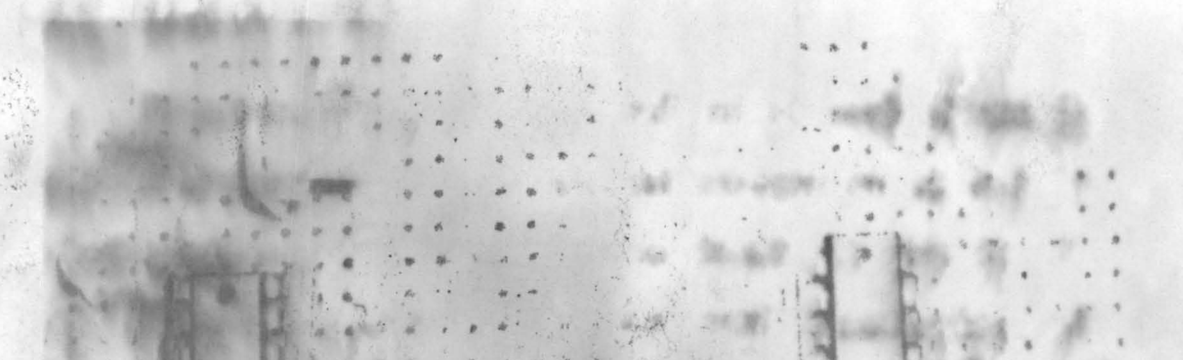

Fig. 3.7 Vero Board connection of a metal detector

### 3.6.1 CASING

For a metal detector, the casing is restricted to either plastic or wood to avoid interference from the body. A wooden case along a plastic slab was used to house the circuitry and a long wooden handle to hover. The search coil was glued to the bottom of the casing and a switch was connected as shown below in figure 3.7.

**Fig. 3.8 Prototype metal detector**

## 3.7 COMPREHENSIVE CIRCUIT DIAGRAM

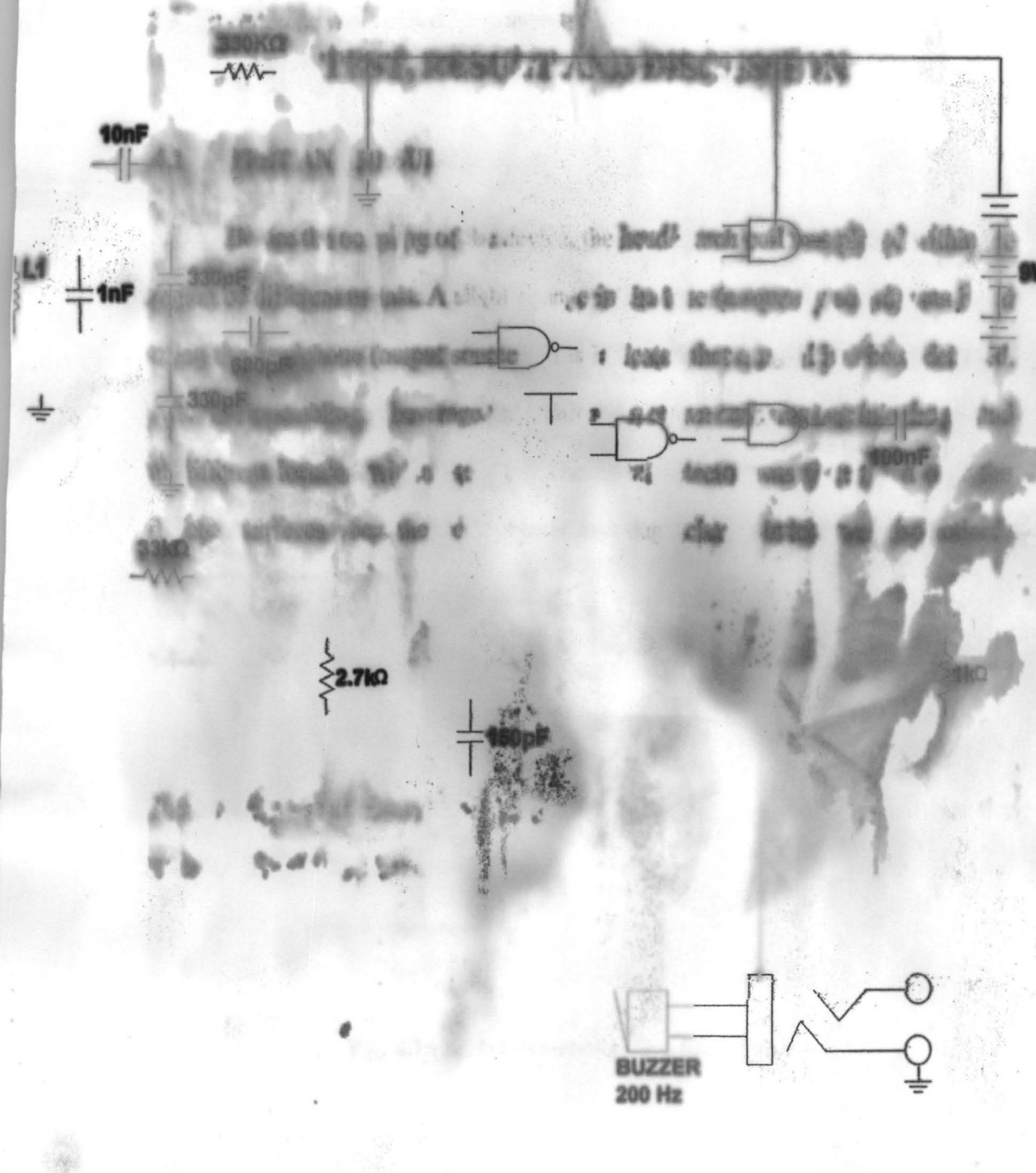


**Fig. 3.9 Comprehensive circuit diagram**

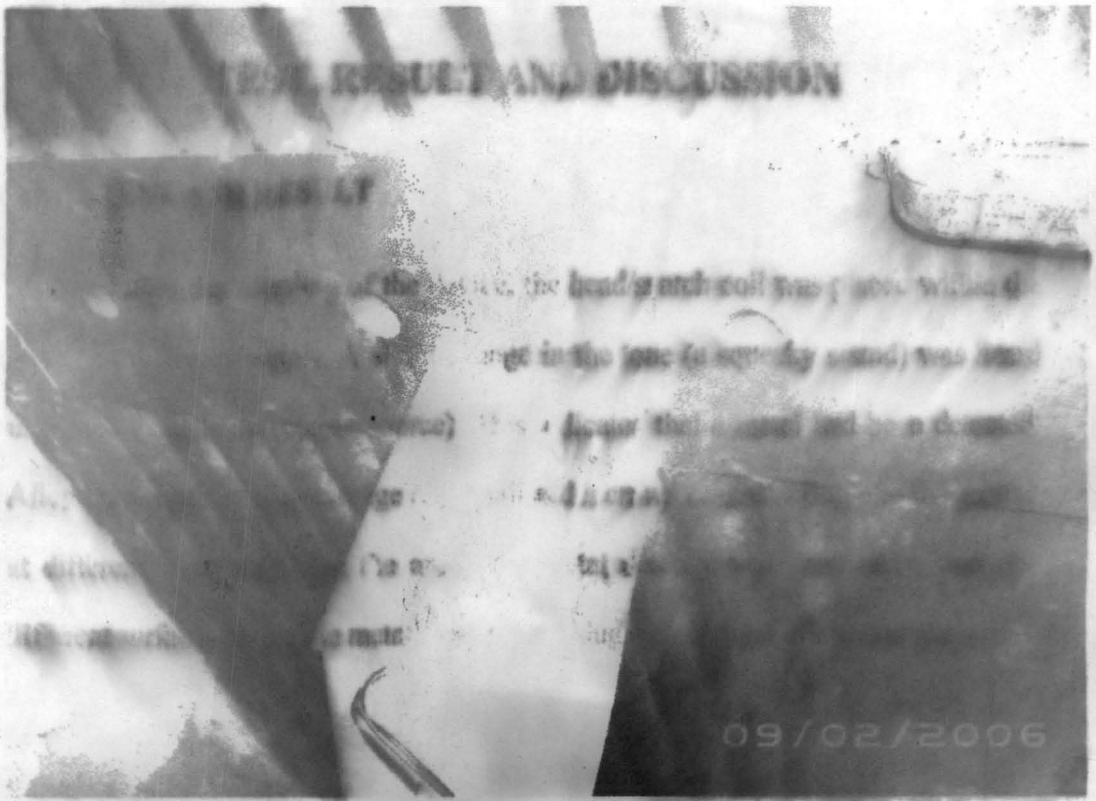


**Fig. 4.1b Metal detector with a metallic door**

The squeaky sound observed at the output is due to the voltage supplied into the circuitry. The 4011 IC has a maximum voltage capacity of 12V but 9V was used.

## 4.2 TROUBLESHOOTING

In the advent of a very slight change in the frequency (tone) when placed around a metal, the number of turns on the coils was increased for better frequency discrimination. The components were observed to be heated up during the testing of this device and this led to the removal of the voltage regulator and stepping down the voltage level to 9V both for safety of the components and efficiency as a whole.

## 4.3 LIMIATATION

The limitation of this device is in its inability to detect metals at great depths inside the ground. This is as a result of the small diameter used for the search coil. The larger the diameter of the coil, the greater the penetration depth and less sensitivity to small objects. Also, the inability of this device is to clearly differentiate the different kinds of metals it comes in contact with although the tune varies, the kind of metal cannot be stated.

# CHAPTER FIVE

## CONCLUSION

### 5.1 PROBLEMS ENCOUNTERED

The problem encountered during the execution of this project was mainly due to negligence which resulted in the 'burning' of components due to excessive voltage. Also, during the assembling on a Vero board, some pins of the components broke. The battery used (as source of power) was continually weakened when powered on without use.

### 5.2 RECOMMENDATIONS

After the completion of this project work, I would recommend that students be made to embark on at least three project designs before graduation. Also, the students should be made to understand the use of simulators in this computer age to ease workability and design.

I would also recommend that for a project of this kind and magnitude, a frequency discriminator should be incorporated to differentiate different kinds of metals.

### 5.3 CONCLUSION

After the successful testing of this device, I would categorically say in the advent of the set out objective of this project, the project was successful.

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