METAL DETECTOR

A Real-Time Project Report

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In partial fulfillment of the requirements for the

award of the degree of

BACHELOR OF TECHNOLOGY

in

ELECTRONICS & COMMUNICATION ENGINEERING

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Certificate

This is to certify that the Real-Time Project Report on ***"Metal Detector"*** submitted by **Rahul Nama, Chandu Beepangi, Chandu Kandikonda** bearing Hall Ticket No's. **22VE1A0439, 22VE1A0408, 22VE1A0423** in partial fulfillment of the requirements for the award of the degree of **Bachelor of Technology** in **Electronics & Communication Engineering** from Jawaharlal Nehru Technological University, Kukatpally, Hyderabad for the academic year 2023-24 is a record of bonafide work carried out by them under our guidance and Supervision.

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DECLARATION

We, **Rahul Nama, Chandu Beepangi, Chandu Kandikonda**, bearing **Roll No's 22VE1A0439, 22VE1A0408, 22VE1A0423** hereby declare that the Real-Time Project titled **"Metal Detector"** done by us under the guidance of **Mrs. M. Pavani**, which is submitted in the partial fulfillment of the requirement for the award of the B.Tech degree in **Electronics & Communication Engineering** at **Sreyas Institute of Engineering & Technology** for Jawaharlal Nehru Technological University, Hyderabad is our original work.

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Abstract

The Metal Detector involves the design and implementation of a practical metal detector using electromagnetic induction principles. The detector features a copper coil that generates a magnetic field when powered by an oscillator circuit. When a metal object is brought near the coil, it disrupts the magnetic field, causing a change in the coil's resonance frequency. This frequency alteration is detected by transistors, which amplify the signal before directing it to a buzzer. The buzzer then emits an audible alert, indicating the presence of metal.

The detector can identify both ferrous metals like iron and steel, as well as non-ferrous metals such as aluminum, copper, and brass. A potentiometer allows for sensitivity adjustment, enabling precise tuning to detect metals of various sizes and distances. This feature makes the detector versatile for applications ranging from locating hidden metal objects to educational demonstrations of electromagnetic principles.

Constructed from basic electronic components, this project exemplifies fundamental concepts such as oscillation, signal amplification, and electromagnetic field interaction with conductive materials like metals. It serves as an invaluable educational tool, offering hands-on experience in electronics and enhancing understanding of real-world applications of electromagnetic theory. Overall, this metal detector project provides practical insights into electronics and showcases its potential in diverse educational and practical settings.

Keywords: Buzzer alert, Electromagnetic induction, Oscillator circuit, Potentiometer, Sensitivity adjustment, Signal amplification, Transistors

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Chapter 1

Introduction

1.1. Objective of the Project

The objective is to design and implement a functional metal detector based on the principle of electromagnetic induction. The project aims to:

- Demonstrate the working mechanism of a basic metal detector using easily available electronic components.
- Detect both ferrous and non-ferrous metals by observing changes in the resonance frequency of a copper coil when influenced by nearby metallic objects.
- Utilize a buzzer alert system to provide real-time feedback upon detection of metal.
- Incorporate a potentiometer to adjust the sensitivity, allowing for flexible detection range and accuracy.
- Provide an educational platform for understanding fundamental electronic concepts such as oscillation, amplification, and electromagnetic field interactions.

This project is intended not only as a practical tool but also as a hands-on educational experience in electronics and physics.

1.2. Importance and Applications

1.2.1. Importance of the Project

The metal detector project is important for several reasons:

- **Educational Value**: It provides a practical demonstration of electromagnetic induction, oscillation, and signal amplification—key concepts in physics and electronics.
- **Skill Development**: Building the detector enhances hands-on skills in circuit design, soldering, and component testing, which are essential for students and hobbyists in electronics.

- **Low-Cost and Accessible**: The project uses inexpensive and commonly available components, making it an ideal educational tool for schools, colleges, and DIY learners.

1.2.2. Applications of the Metal Detector

- **Educational Demonstrations**: Useful in classrooms and laboratories to explain the principle of electromagnetic induction and related concepts.
- **Security Scanning**: Can be adapted for basic screening tasks such as detecting metal objects in bags or packages.
- **Hidden Object Detection**: Helps in locating metal pipes, nails, or other metal objects buried in walls or underground.
- **DIY and Hobby Projects**: Serves as a foundation for more advanced metal detection systems and encourages innovation in electronics.
- **Science Fairs and Competitions**: A compelling and functional project suitable for presentation in academic events and exhibitions.

1.3. Overview of Electromagnetic Induction in Metal Detection

Electromagnetic induction is the fundamental principle behind the operation of most metal detectors. It refers to the process by which a changing magnetic field induces an electric current in a nearby conductor. In the context of metal detection, this phenomenon is used to detect the presence of metallic objects by observing how they interact with magnetic fields.

In a basic metal detector:

- A **copper coil** is energized by an **oscillator circuit**, generating an alternating magnetic field around it.
- When a metal object comes close to this field, **eddy currents** are induced in the object. These currents create their own magnetic field that opposes the original one.

- This interaction **disrupts the coil's magnetic field**, causing a measurable change in its **resonance frequency**.
- The shift in frequency is detected by the circuit, which then triggers a **signal amplification** process using transistors.
- A **buzzer** provides an audible alert, indicating the presence of metal.

The strength and nature of the induced signal vary depending on the type of metal (ferrous or non-ferrous), its size, shape, and distance from the coil. This allows the detector to differentiate and respond to various kinds of metals.

Chapter 2

Working Principle

The metal detector operates by utilizing changes in the magnetic field when it approaches a metal object. This alteration disrupts the normal resonance frequency of the oscillator circuit within the detector. The oscillator, reacting to these changes, produces a fluctuating electrical signal. This signal is then processed and amplified by the transistors in the circuit.

Once amplified, the signal is directed to a buzzer, which converts it into an audible sound. The intensity and frequency of this sound indicate the proximity and size of the metal object detected. To fine-tune the detector's sensitivity according to specific needs, a potentiometer is integrated into the circuit. Adjusting the potentiometer allows users to regulate how easily the detector responds to variations in the magnetic field, ensuring accurate detection tailored to different environments or metal types.

2.1. Electromagnetic Induction Theory

Electromagnetic induction is the process of generating an electric current or voltage in a conductor due to a changing magnetic field. This principle was discovered by **Michael Faraday** in 1831 and forms the foundation for many electrical devices, including transformers, inductors, and metal detectors.

According to **Faraday's Law of Electromagnetic Induction**:

The induced electromotive force (EMF) in any closed circuit is equal to the negative of the rate of change of magnetic flux through the circuit.

Mathematically:

$\mathrm{EMF}=-\mathrm{dtd}\Phi\mathrm{B}$

Where:

- ΦB is the magnetic flux
- $dtd\Phi B$ is the rate of change of magnetic flux

In the context of a metal detector:

- A **copper coil** is powered by an oscillator, producing an **alternating magnetic field**.
- When a metal object enters this field, **eddy currents** are induced in the object.
- These eddy currents generate their own **opposing magnetic field**, as described by **Lenz's Law**.
- This interaction alters the original magnetic field around the coil, leading to a change in the **resonance frequency** of the circuit.

The system detects this change and processes it through **signal amplification** stages. The final output is an audible sound from a **buzzer**, indicating the presence of a nearby metal object.

This use of electromagnetic induction enables the detection of both **ferrous** (magnetic) and **non-ferrous** (non-magnetic) metals, making it an effective technique for a variety of applications.

2.2. Resonance Frequency Shift

In a metal detector circuit, **resonance frequency** refers to the natural frequency at which the LC (inductor-capacitor) circuit oscillates. This frequency is determined by the values of the **inductance (L)** of the coil and the **capacitance (C)** in the circuit, and it can be calculated using the formula:

$f=2\pi LC\ 1$

Where:

- f is the resonance frequency
- L is the inductance of the coil
- C is the capacitance in the circuit

2.2.1. How Metal Affects Resonance Frequency

When a metal object comes close to the oscillating coil:

1. **Eddy currents** are induced in the metal due to the changing magnetic field.
2. These currents create an **opposing magnetic field**, which interacts with the field of the coil.
3. This interaction **alters the inductance** of the coil, because the metal object introduces additional magnetic resistance (reluctance) or changes the magnetic permeability of the space around the coil.
4. As a result, the overall **resonance frequency of the LC circuit shifts**—either increasing or decreasing depending on the type and proximity of the metal.

This frequency shift is often small, but it is **detectable** by sensitive circuits. In your project, this change is:

- **Amplified by transistors** to make it more noticeable.
- **Converted into a signal** that activates a **buzzer**, producing an audible alert.

2.2.2. Why This Matters

The resonance frequency shift is the core detection mechanism in many metal detectors. It allows the circuit to respond dynamically to nearby metallic objects without requiring physical contact. The inclusion of a **potentiometer** in the circuit allows users to fine-tune sensitivity, making the detector responsive to small shifts—ideal for adjusting detection range and avoiding false positives.

2.3. Metal Detection Mechanism

The **metal detection mechanism** is the process by which the circuit senses the presence of a nearby metal object and converts this interaction into a usable output signal—typically an audible alert. This mechanism combines principles of electromagnetic induction, frequency shift detection, signal amplification, and user-controlled sensitivity.

2.3.1. Step-by-Step Detection Process

1. **Oscillating Magnetic Field Generation:**

   A **copper coil**, powered by an **oscillator circuit**, generates an **alternating magnetic field**. This field continuously radiates from the coil into the surrounding space.

2. **Interaction with Metal Objects:**

   When a metal object enters the magnetic field:

   a. **Eddy currents** are induced in the metal.
   b. These eddy currents produce an **opposing magnetic field**, as per **Lenz's Law**.
   c. This opposition causes a disturbance in the coil's magnetic field, **altering the coil's inductance**.

3. **Change in Resonance Frequency:**

   The altered inductance results in a **shift in the LC circuit's resonance frequency**. This frequency change is typically small but detectable by the circuit.

4. **Signal Detection and Amplification:**

   The shifted frequency affects the voltage and current across parts of the circuit.

   a. This variation is picked up by **transistors**, which act as amplifiers.
   b. The weak signal is **amplified** to a level that can drive an output device.

5. **Audible Alert via Buzzer:**

   Once the frequency shift exceeds a defined threshold:

   a. A **buzzer** is activated.
   b. This provides an immediate, **audible alert** indicating the presence of metal.

6. **Sensitivity Control:**

A **potentiometer** is included in the circuit to:

a. Adjust the circuit’s threshold for detection.
b. Allow the user to set how sensitive the detector is to small or distant metal objects.
c. Reduce false alarms or improve precision depending on the environment.

2.3.2. Types of Metals Detected

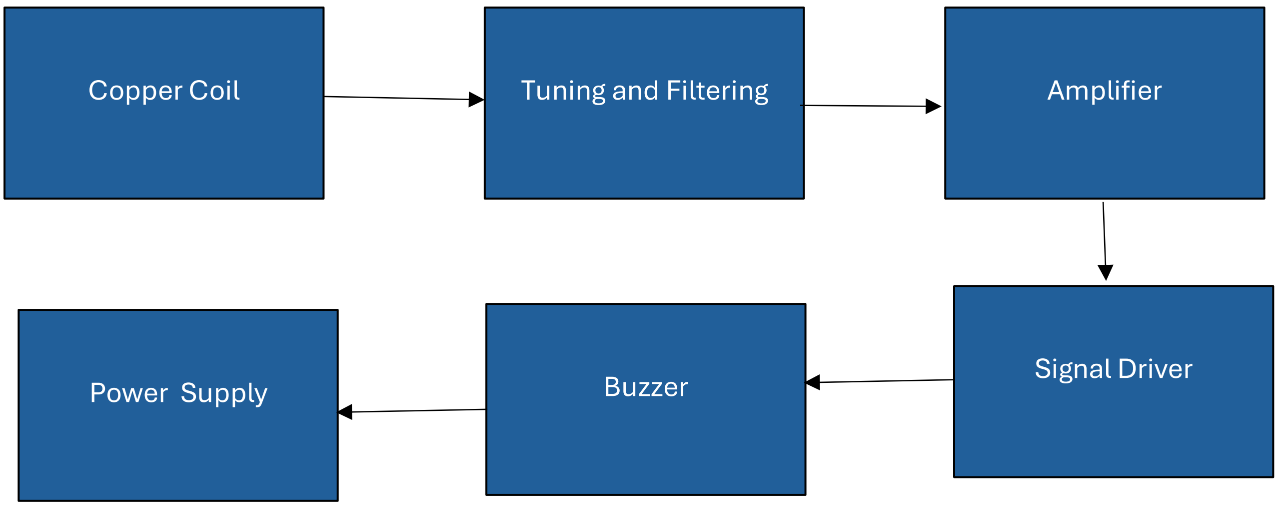
This mechanism allows for the detection of:

- **Ferrous metals** (e.g., iron, steel), which are magnetic.
- **Non-ferrous metals** (e.g., aluminum, copper, brass), which are conductive but not magnetic.

Chapter 3

System Design

3.1. Block Diagram



Each block performs the following:

- **Copper Coil**: Detects changes in electromagnetic field when metal is nearby.
- **Tuning & Filtering**: Adjusts the sensitivity and filters out noise.
- **Amplifier**: Increases the signal strength.
- **Signal Driver**: Drives the buzzer when a metal is detected.
- **Buzzer**: Produces sound as an alert.
- **Power Supply**: Provides necessary voltage to the circuit.

3.2. Circuit Description

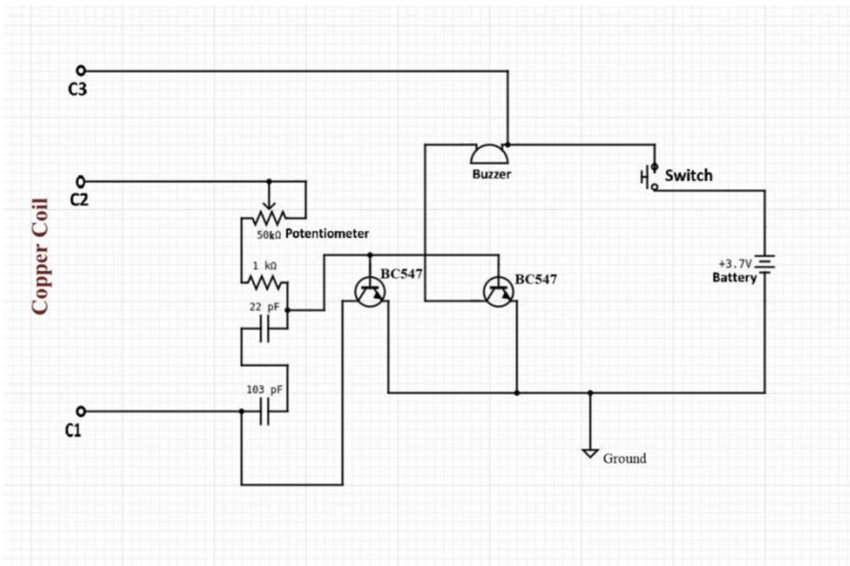


Figure 3.1: Circuit Diagram

3.3. Role of Major Components

This section outlines the functions of the primary components involved in the metal detector circuit. Each component contributes to the proper sensing, amplification, and indication of metallic objects near the detection area.

3.3.1 Copper Coil

The copper coil serves as the primary sensing element in the metal detector. When electrical current flows through the coil, it generates an electromagnetic field. The presence of a metallic object near the coil alters this field by changing the coil's inductance. This change disrupts the circuit's oscillations, which is later processed to generate an output signal. The coil's ability to detect metallic interference is fundamental to the circuit's function.

3.3.2 Oscillator Circuit

The oscillator circuit comprises a combination of capacitors, resistors, and the copper coil. It generates a high-frequency alternating current (AC) signal. This signal is sensitive to changes in the inductive properties of the coil, which occur when a metal object comes close. The disturbance in oscillation acts as the initial detection trigger, making the oscillator an essential part of the signal generation process in the metal detector.

3.3.3 Transistors and Signal Amplification

The circuit employs two BC547 NPN transistors for signal amplification and switching. The first transistor amplifies the weak variations caused by the disrupted oscillations in the coil circuit. The second transistor acts as a switch, using the amplified signal to activate the buzzer system. These transistors ensure that the small changes in the coil are effectively converted into a noticeable output.

3.3.4 Buzzer System

The buzzer serves as the audio output device for the metal detector. When the transistors detect and amplify the signal disturbance caused by a metallic object, the second transistor allows current to flow through the buzzer. This results in an audible sound that alerts the user to the presence of a nearby metal object. The buzzer provides a simple and effective interface for feedback.

3.3.5 Potentiometer and Sensitivity Control

The potentiometer is used to adjust the circuit's sensitivity. It varies the base bias voltage of the transistor, thereby affecting the frequency and amplitude of the oscillator circuit. By fine-tuning the potentiometer, the user can control how easily the circuit detects metal objects. This is particularly useful for adapting the detector to various environmental conditions or target sizes.

Chapter 4

Component List and Specifications

The electronic components and tools used in the construction of the metal detector circuit. Each component has a specific function contributing to the overall operation of the system.

4.1. Electronic Components Used

The table below summarizes the key electronic components utilized in the circuit, along with their specifications:

Component	Specification / Description
BC547 Transistors	NPN general-purpose transistors used for amplification and switching.
102 pF Capacitor	Ceramic capacitor used in the oscillator circuit for frequency tuning.
22 pF Capacitor	Ceramic capacitor contributing to the oscillation stability.
1K Resistor	Fixed resistor for limiting current and voltage control.
5V Buzzer	Audio output device that alerts on metal detection.
50K Potentiometer	Variable resistor used for adjusting circuit sensitivity.
Insulated Copper Wire	Used to form the inductive coil for metal sensing.
Push ON/OFF Switch	Controls power supply to the circuit.
2 Pin Screw Terminal	Connects the coil or external components securely to the PCB.

Table 4.1 Electric Components

4.2. Tools and Equipment

The following tools and equipment were used for assembling and testing the circuit:

Tool / Equipment	Purpose
Soldering Iron	For soldering electronic components onto a circuit board.
Multimeter	For measuring voltage, current, and resistance during testing.
Wire Stripper	For removing insulation from copper wires used in the coil.
PCB Board / Breadboard	For prototyping and assembling the circuit.
Screwdriver	For tightening the 2-pin screw terminals.
Hot Glue Gun (optional)	For insulating and securing loose components or wires.

Table 4.2: Tools and Equipment

Chapter 5

Circuit Diagram and Construction

The design and construction process of the metal detector circuit. It includes the circuit schematic, layout details, and step-by-step assembly instructions.

5.1. Circuit Schematic

The circuit schematic consists of a simple metal detector based on an LC oscillator and a transistor-driven buzzer alert system. A copper coil, along with capacitors and resistors, forms the oscillator. The change in inductance due to nearby metallic objects is amplified using two BC547 NPN transistors, which in turn activate a 5V buzzer to indicate detection.

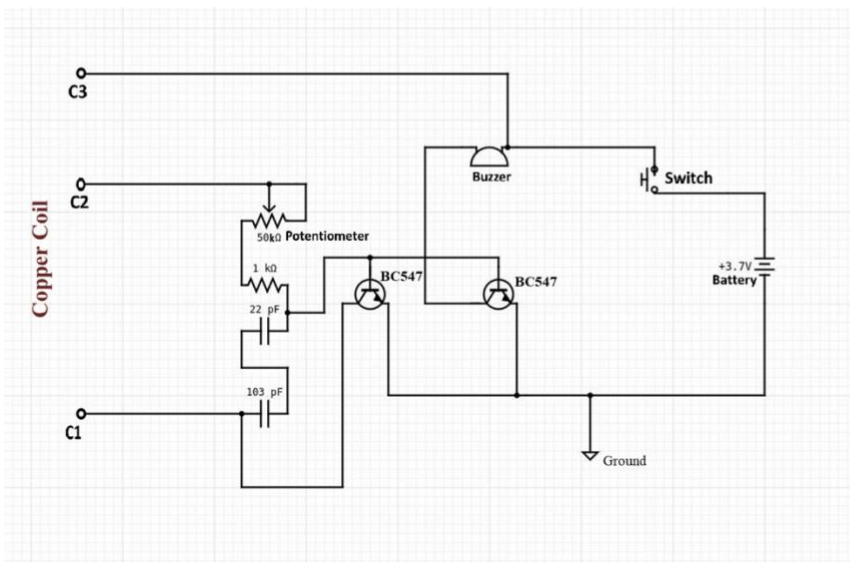


Figure 5.1: Circuit Schematic

5.2. Breadboard/PCB Layout

The layout of the circuit can be implemented in two forms:

- **Breadboard Layout (for testing)**:

- Place components logically, keeping the copper coil and oscillator section separate from the amplification and output section.
- Use jumper wires for clean connections.
- Ensure the power rails are used for positive supply and ground.

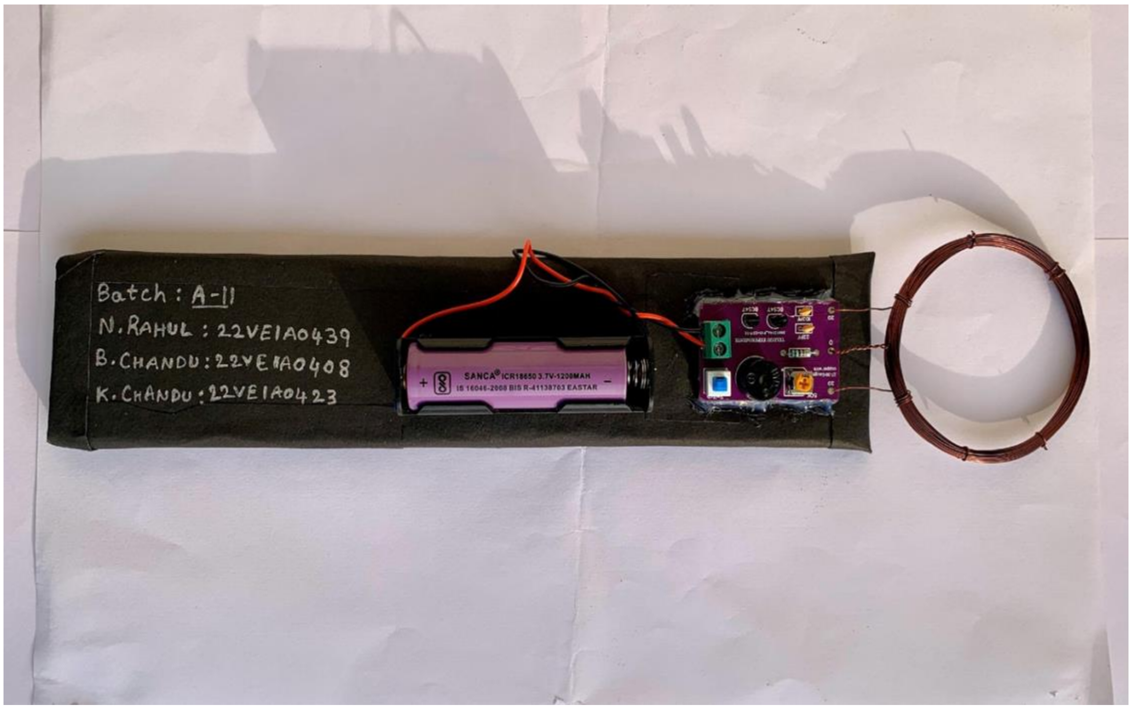


Figure 5.2: Simulated Hardware

PCB Layout (for final assembly):

- Components should be placed with minimal lead length to reduce noise.
- Keep the copper coil connection points secure using the 2-pin screw terminal.
- Buzzer and switch should be mounted externally for user accessibility.

5.3. Assembly Instructions

Follow the steps below to assemble the metal detector circuit:

1. **Prepare the Coil:**
    a. Wind insulated copper wire into a circular coil (~20-30 turns depending on desired sensitivity).

   b. Connect the ends to the 2-pin screw terminal.

2. **Place Components on Breadboard/PCB:**
   a. Insert the BC547 transistors, capacitors (22 pF and 102 pF), and the 1K resistor as per the schematic.
   b. Connect the 50K potentiometer to adjust the base biasing.
   c. Wire the coil and oscillator section accordingly.
3. **Connect the Power System:**
   a. Attach a 3.7V battery or suitable power supply.
   b. Connect the push ON/OFF switch in series with the power input to control the circuit.
4. **Install the Buzzer:**
   a. Connect the output of the second transistor to a 5V buzzer.
   b. Ensure proper polarity and connection to ground.
5. **Test the Circuit:**
   a. Switch on the power and bring a metal object near the coil.
   b. Adjust the potentiometer until the buzzer responds to the presence of metal.
6. **Final Fixation (if using PCB):**
   a. Solder the components onto the PCB.
   b. Use hot glue or insulation where needed to avoid short circuits.
   c. Secure the coil and buzzer externally using casing or mounting supports.

Chapter 6

Testing and Calibration

The procedures used to test the functionality of the metal detector circuit and outlines how the sensitivity is calibrated using the potentiometer. It also explores the circuit's response to different types of metals.

6.1. Testing Procedure

To ensure the circuit performs reliably, the following steps are carried out during the testing phase:

1. **Initial Power Test:**
   a. Switch ON the circuit using the push button.
   b. Ensure the buzzer remains OFF in the absence of any nearby metal object.
2. **Coil Check:**
   a. Bring a small metal object (e.g., a coin or nail) close to the coil.
   b. Observe the buzzer; it should sound when the object approaches and stop when it is removed.
3. **Component Verification:**
   a. Use a multimeter to confirm that all components (transistors, capacitors, resistors) are functioning correctly.
   b. Check voltage levels at different nodes to ensure signal flow is consistent.
4. **Noise Test:**
   a. Move the circuit into different environmental conditions (indoors/outdoors, near electrical appliances) to test for false triggering.

6.2. Calibration Using Potentiometer

The 50K potentiometer plays a key role in adjusting the **sensitivity** of the metal detector. Calibration involves tuning this potentiometer to achieve optimal detection while avoiding false alarms.

Steps to Calibrate:

1. Begin with the Potentiometer at Mid-Range.
2. Slowly rotate the potentiometer while moving a small metal object toward and away from the coil.
3. Find the position where the buzzer activates at the desired detection distance (typically 3–10 cm).
4. Avoid over-sensitivity, which may cause the buzzer to stay ON even in the absence of metal.

This process may be repeated based on the surrounding environment and the size/type of metal intended for detection.

6.3. Detecting Different Types of Metals

The circuit can detect various types of metals based on how they interact with the coil's electromagnetic field:

Metal Type	Detection Response
Ferrous Metals (e.g., iron, steel)	Strong response due to high magnetic permeability.
Non-Ferrous Metals (e.g., aluminum, copper)	Detectable but may require higher sensitivity settings.
Precious Metals (e.g., gold, silver)	Low conductivity may result in weaker detection signals.
Small Metal Objects (e.g., nails, pins)	Detected at closer ranges depending on sensitivity.

Table 6.1: Metals Types and their detection Response

Chapter 7

Results

This chapter presents the observed performance of the metal detector circuit, discusses its limitations, and proposes possible improvements to enhance reliability and detection accuracy.

7.1. Performance Analysis

The metal detector circuit was tested in a controlled environment using various metal objects. The following performance characteristics were observed:

- **Detection Range**: Small metallic objects such as coins and nails were detected within a range of 5–8 cm when the coil was properly calibrated.
- **Sensitivity**: The 50K potentiometer effectively controlled the sensitivity, allowing the circuit to detect metals of varying sizes and materials.
- **Response Time**: The circuit responded almost instantly (<1 second) when a metal object was brought near the coil.
- **Power Efficiency**: The circuit operated reliably on a 3.7V–5V DC power source, consuming minimal current due to low-power components like BC547 transistors and passive elements.

Figure 7.1: Detection of a Metal

Overall, the circuit demonstrated reliable performance for basic metal detection applications.

7.2. Limitations

Despite its functional performance, the metal detector circuit has several limitations:

- **Limited Range**: The detection range is relatively short, making it unsuitable for deep or buried object detection.
- **Non-Selective Detection**: The circuit cannot differentiate between different types of metals (e.g., ferrous vs. non-ferrous).
- **Susceptibility to Interference**: Nearby electronic devices or power sources can cause false triggering.
- **No Visual Output**: The system relies solely on a buzzer, with no visual feedback like LEDs or displays.
- **Manual Calibration Required**: The potentiometer needs to be manually adjusted for each usage environment, which may be inconvenient.

7.3. Possible Improvements

To overcome the limitations and enhance the overall functionality, the following improvements are recommended:

1. **Use of Microcontroller (e.g., Arduino):**
   a. Enables digital signal processing and discrimination between metal types.
   b. Allows inclusion of visual indicators (LEDs or LCD display).
2. **Increasing Coil Turns and Shielding:**
   a. Enhances sensitivity and range while reducing interference from surrounding electronics.
3. **Battery Management System:**
   a. Adding a rechargeable battery circuit with a voltage regulator would improve portability and power stability.
4. **Auto-Calibration Feature:**
   a. Implementation of an auto-calibration routine using sensors or microcontrollers can eliminate manual adjustments.
5. **Visual Output Integration:**
   a. Adding LEDs or a simple bar graph display can help in visualizing the proximity or strength of the metal signal.

Chapter 8

Applications and Advantages

8.1. Applications

The metal detector circuit can be applied in various real-world scenarios, especially where low-cost and simple detection solutions are required:

- **Security Screening**: Useful in handheld devices for detecting concealed metallic objects in security-sensitive areas such as schools, malls, and public events.
- **Stud and Nail Detection**: Helpful in locating nails, screws, or metal studs behind walls or in construction and carpentry work.
- **Educational Demonstrations**: Ideal for teaching basic electronics, electromagnetism, and circuit assembly to students in schools and colleges.
- **Object Recovery**: Assists hobbyists or individuals in finding lost metallic items like rings, coins, or keys.
- **Embedded Systems Projects**: Can be integrated into larger embedded systems for smart detection applications.

8.2. Advantages

The metal detector circuit offers several advantages, particularly for beginners and low-budget implementations:

- **Low Cost**: Utilizes inexpensive and readily available electronic components, making it affordable for educational and DIY use.
- **Easy to Build**: Simple circuit design with minimal components makes it suitable for learners and first-time builders.
- **Compact and Portable**: Can be assembled into a small handheld device due to its low component count.

- **Low Power Consumption**: Operates efficiently on a small DC supply, increasing its usability in portable applications.
- **Adjustable Sensitivity**: The inclusion of a potentiometer allows for user-controlled detection range, offering flexibility in different environments.

Chapter 9

Future Scope and Conclusion

9.1. Future Scope

Although the current metal detector circuit meets basic detection requirements, there is significant scope for future enhancements and applications:

- **Integration with Microcontrollers**: Future versions can incorporate microcontrollers like Arduino or Raspberry Pi to process sensor data, automate calibration, and enable metal type classification.
- **Wireless Alerts and IoT Connectivity**: Implementing wireless modules (e.g., Bluetooth or Wi-Fi) can allow alerts to be sent to smartphones or integrated systems, enabling remote detection.
- **Enhanced Detection Algorithms**: Using frequency analysis or pulse induction techniques could improve depth detection and distinguish between various metal types.
- **Graphical Interface**: Adding an LCD or mobile app interface can provide real-time feedback, including detection range, object size estimation, and metal type indicators.
- **Solar-Powered or Rechargeable Models**: Future iterations can include energy-efficient designs with solar panels or rechargeable batteries to improve sustainability.
- **Commercial and Industrial Use Cases**: With appropriate scaling and design improvements, the circuit can be adapted for use in industrial scrap sorting, mining, or automated safety checks.

9.2. Conclusion

The design and implementation of a basic metal detector circuit using transistors, a copper coil, and passive components successfully achieved its goal of detecting nearby metallic objects. The circuit's simplicity and low cost make it highly suitable for educational and prototyping purposes. Key features include adjustable sensitivity and audio feedback via a buzzer.

While the current design serves its intended purpose, there is considerable potential to enhance its functionality with advanced electronics and smart features. Overall, this project has demonstrated the fundamental principles of metal detection and laid the groundwork for further innovation and practical deployment.

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