BUTTON CELL SCANNER

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STATEMENT OF CANDIDATE

I, Weihua Chen, declare that this report, submitted as part of the requirement for the award of Bachelor of Engineering in the Department of Electronic Engineering, Macquarie University, is entirely my own work unless otherwise referenced or acknowledged. This document has not been submitted for qualification or assessment on any other academic institution.

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Date: 25 October 2016

ABSTRACT

According to a statistic, In Australia, there are four children who go to an emergency department of hospital per week averagely due to an injury with swallowing button cell. Children under five years old face greater risk and the majority of them could not describe the issue or the object clearly when they swallowed an object. Therefore in this thesis, I aim to design a button cell scanner for doctors and families so that the button cell is identified as quick as possible and run an operation for the child if a button cell was swallowed. In this project, I did substantial research on the difference between button cells and coins which are similar in sharp and material, as well as find out a feasible method to solve the issue. Finally, prototypes are manufactured according to feasible design and improvements. This document reports works that I have done in this semester as well as problems I met during experiments.

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Chapter 1

Introduction

Button cell is a kind of battery that is shaped as a small cylinder and as thin as a coin. It is used for diversely small electronic devices, such as toy cars, electronic dolls and other gadgets. These devices have been more and more miniaturized nowadays, young children swallowing button cells occurs from time to time and they could not describe the issue clearly due to the age issue. In generally, symptoms of swallowing a button cell are not different to other children illnesses but coughing, drooling and discomfort. Parents usually cannot realise their children are under a deadly threaten in time, missing the prime time of rescue.

If a child swallows a button cell, it usually gets stuck in the throat, a higher risk of death, it must be taken out immediately and prepare an operation as soon as possible if required. The reason is that the internal chemical substances inside button cells could cause chemical reactions that severely cause a localised caustic injury or even cause death only within couples of hours. Worse, once the burning begins, chemical reactions and damage could be unstoppable even if the button cell has been removed.

Therefore, the button cell must be taken out as soon as possible whenever a child swallows one. However, doctors have to spend much time on confirming the object, especially between button cells and coins due to shapes and materials, even if use X-ray to scan the patient. This process usually takes longer time and it could miss the prime time of rescue

In this project, I am going to design a portable button cell scanner for hospitals, doctors and families so that they are able to finding out button cells quickly, and thereby sufferers are able to save more time for treatment that could minimise or avoid the crisis within prime time.

1.1 Project Goal

This project aims to design a portable button cell scanner for doctors which is different to the normal metal detector. The main challenge of this project is discriminating between button cells and coins. Button cells and coins are extremely close in shapes and material. However, according to literature reviews, the best method that discriminates coins and button cells is from their manufacturing materials. Although coins in different countries are made of different metals, such as copper (US and UK coins), full alloy (Australia) and alloy plated steel (New Zealand), the most common button cells in use are all made of stainless steel. Stainless steels have unique physical properties and that could be the key to the project. Therefore, this project will also focus on discriminating between button cells and coins. Finally, the scanner is expected to be designed within following specifications:

Table 1.1: the specifications of the button cell scanner

Frequency	Current (mA)	Voltage (V)	Dimension (mm)	Detection distance (mm)	Detection Diameter (mm)
30kHz	50	9	200x30x10	10-30	20mm

1.2 Baseline Review

The project is scheduled from 1st August to 28th October (last date of next semester) and the project must be finished within 13 weeks as required. However, I started from first day of last holiday to ensure finishing the project on time.

1.2.1 Time Budget Review

the works are scheduled as 13 weeks and there are divided into three following sections:

Section 1: Pulse induction system search and software practices in week 1 to week 5(approximately 5 weeks)

1.1 doing research on the project

1.2 Basic tests and equipment practices

1.3 Project circuit design

Section 2: prototype making and development in week 6 to week 10(approximately 5 weeks)

2.1 prototype designing and manufacture

2.2 prototype modeling and testing

2.3 solving met problem

2.4 optimising the prototype

Section 3: project summary in week 11 to 13(approximately 3 weeks)

3.1 presentation

3.2 finishing final project report

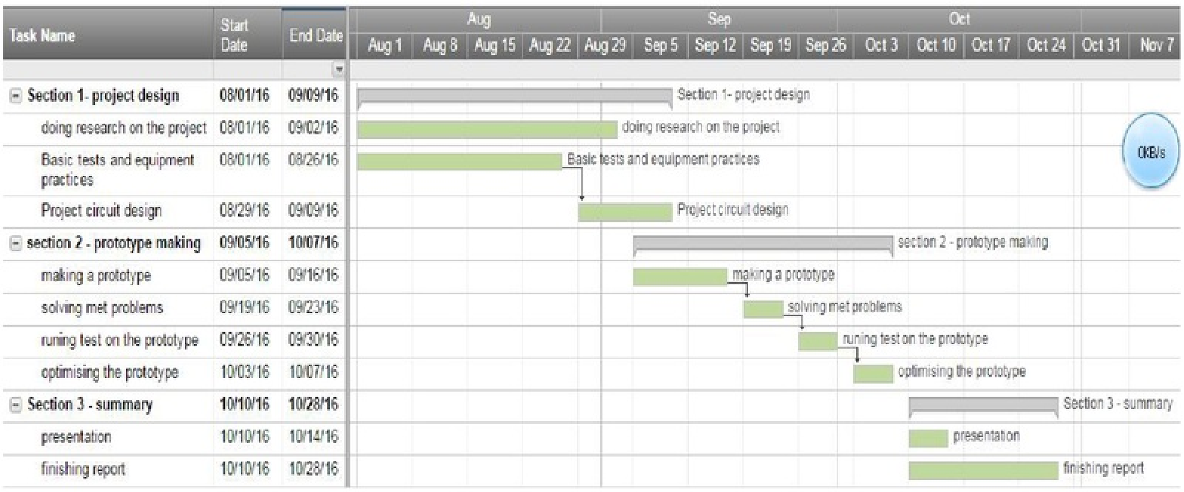

Figure 1.1 : Gantt Chart of 411 project plan

1.2.2 Financial Budget Review

In this project, the total cost should be controlled under $400. However, in my design, only several capacitors, resistors, inductors, Op-amplifiers (Op-amp), BJT and coils are used in the project as the core, and most of them are able to be acquired in the lab. Hence, $400 should cover all cost of the project. If the cost excess $400 unfortunately, I would like to afford the excess cost.

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Chapter 2

Background and related work

2.1. History and Developments

By the end of the 19th century, a number of European engineers and scientists who were specialised in the knowledge of electronic engineering attempted to invent a machine that was able to detect metals, allowing miners to locate metallic rock which gave an enormous benefit for all mining companies. However, the early-stage machine was crude, inefficient and limited. This machined had not been improved until 1874. In 1874, there is a Parisian inventor called Gustave Trouvé who invented a hand-held equipment for locating and extracting a bullet from human's body. After that, the scanner was improving in different filed for a variety of proposes.

2.1.1 Modern Developments

The modern development of detectors started from the 1920s as a consequence of a German inventor, Gerhard Fischer, who developed a radio direction-finding system which was used for accurate navigation. He noticed that his navigation system was interrupted in the region where existed a metallic rock. Therefore, he developed an equipment which was used a searching coil with his system's frequency to detect a metal object and thereby he obtained a patent for it.

During the early years of World War II, a Polish officer redesigned the detector into a practical Polish mine detector. This advanced design was widely used in World War II for clearing German minefield. As the detector was an innovative creation for military purposes, this intellectual property was kept secret for over 50 years.

2.1.2 Further improvements

with the invention and development of transistors has been spread in the 1950s, all metal-detector designers and manufacturers attempted to make the equipment lighter and smaller as well as run in an improved circuit with small battery package to satisfy a variety of increasing demands.

Modern peak detectors used an 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. In addition, modern detectors are lighter, deeper, more efficient and more accurate in the term of discriminating an object, such as underground artifacts, bullets, coins and jewelry. However, the main challenge for discriminating an object is that some of them have similar responses such as gold and tinfoil and alloy, this means the current detector probably has not a capacity to discriminate them.

2.2 Concept

However ,The basic structure and working principle of this project entirely rely on electromagnetic induction. in addition, there are two branches are involved in this report which are magnetism generating electricity and electricity generating magnetism.

The law of electricity generating magnetism is discovered by Hans Christian Ørsted who is a Danish physicist and chemist. In this law, a temporary magnetic field is able to be generated by an electric current and this magnetic field shortly disappears when the current is cut off. The generated magnetic field is dominated by the electric current, which means the current is larger the generated magnetic field is strong as well as magnetic direction depends on current's direction.

Another law is used in this project is Faraday's law of induction which is using magnetism to produce electricity. This law says that the changing magnetic field is able to generate an electric current in a wire by spinning the wire or moving the ferromagnetic source such as magnets.

In this project, a couple of coils are used at both receiver and transmitter terminals in the electromagnetic induction system to send short and powerful current pulses, a brief magnetic field is generated from each pulse. If a metal object, such as coins, button cells, enters the range of magnetic fields, an electric current is generated on the surface of the object due to the changing emitted magnetic field. This new current produces another reflected magnetic fields and this reflected magnetic fields generate another current on coils which is able to be detected by the equipment. Therefore, electromagnetic induction is the most important and basic concept throughout the project.

Figure 2.1: Pulse Induction on Object Metal[1]

2.3 Types of Current Major Detectors

In general, the button cell scanner is very similar to the metal detector but more complicated, it also requires to discriminate between coins and button cells which are very similar in shape. The best way to design the button cell scanner is that base on a metal detector design so that it is able to identify the object. However, there are three ways are used in detecting a metal object which are shown below:

Beat Frequency Oscillation

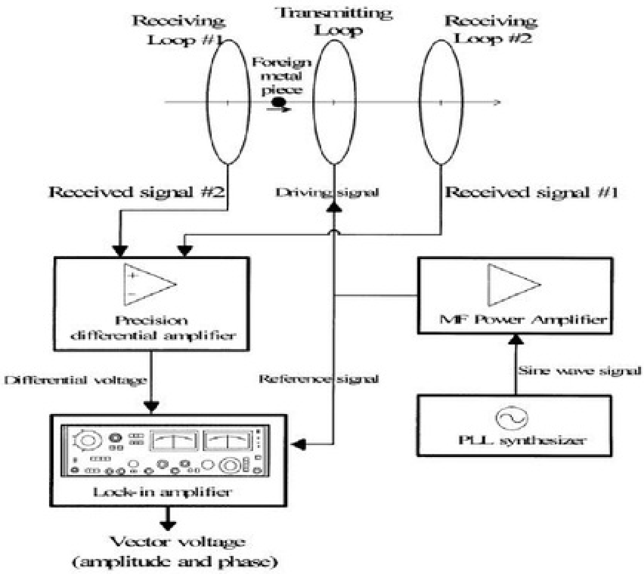


Figure 2.2: Block diagram of the beat frequency oscillation metal detector[1]

There is one transmitting coil and two receiving coils are used in Beat Frequency Oscillation(BFO). In this approach, these coils are coaxial and the transmitting coil is placed in the middle between two receiving coils which is shown in figure 2.2. The receiving coils are connected to a precision differential amplifier and all coils are connected to oscillators to generate frequencies. However, receiving coils and transmitting coils work in different frequencies. If a detector is moved over a metal object, the object generates an interference in frequency transmission and the magnetic field of the transmitter is disturbed. At the mean time, the phase and amplitude of the output voltage are affected as well. This is the evidence of the existence of a metal object. In this type of detectors, some properties of the metal object are also able to be determined, such as conductivity, size, by measuring and analysing the difference of impedance between two receiving coils[1].

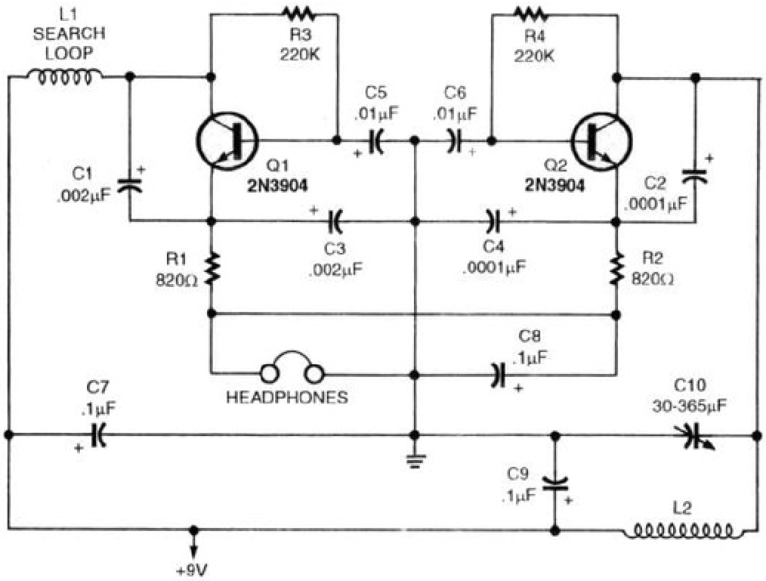


Figure 2.3 : A two-transistor sample of beat frequency oscillator[2]

Figure 2.3 is a simple example of two-transistor Beat Frequency Oscillator metal detector. The circuit base on two oscillators, one provide a signal for receivers and the other send the reference signal to transmitters. In this example, transistor Q1, inductor L1, capacitor C1 and C2 form a Colpitts oscillator circuit for receivers. On the other hand, transistor Q2, inductor L2, capacitor C2 and C4 make another oscillator for transmitters. These two transistors are coupled through resistor R1, R2 and a headphone which has very small impedance. The detector audio frequencies are sent to the headphone but the high RF frequencies(noise) are bypassed to the ground by the capacitor C8 in this design.

Very-Low-Frequency Detectors

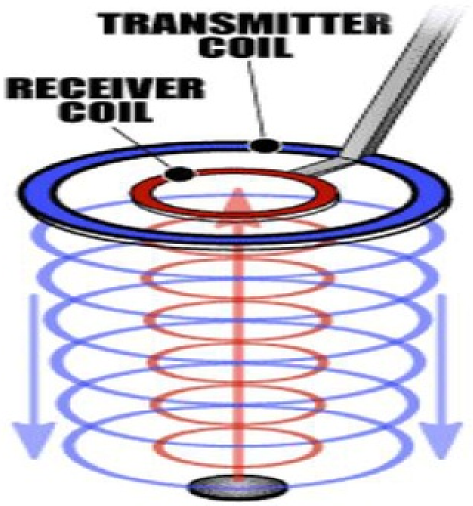


Figure 2.4: Very-Low-Frequency metal Detectors[3]

Figure 2.4 shows a very-low-frequency(VLF) metal detector which operates between 1kHz and 200kHz range. The advantage of this design is that it is able to be highly accurate and sensitive. This kind of detector has a couple of coils for transmitters and receivers. In this case, there are two orthogonal coils are used in figure 2.4 design, the large coil is the transmitter, which sends a strong electric current, and the small coil is the receiver, which acquires the signal from the main coil and amplifies this weak signal. If a detector is moved over a metal object, the object generates a magnetic current which disturbs the magnetic field. The small receiving coil is able to acquire the interference, filters and sends to a microcontroller with a built-in 10-bit A/D converter. The microcontroller is able to measure the magnetic flux density and frequency across the wide VLF bandwidth (BW)[4]. After that, the data is sent into an audio system attached to the metal detector and user is able to tell if there is a metal object exist. In addition, different metal generates different frequencies and some strong magnetic metals, such as iron, steel, generate a very powerful magnetic field as well. These fields are very distinct and it is able to be discriminated by the microcontroller.

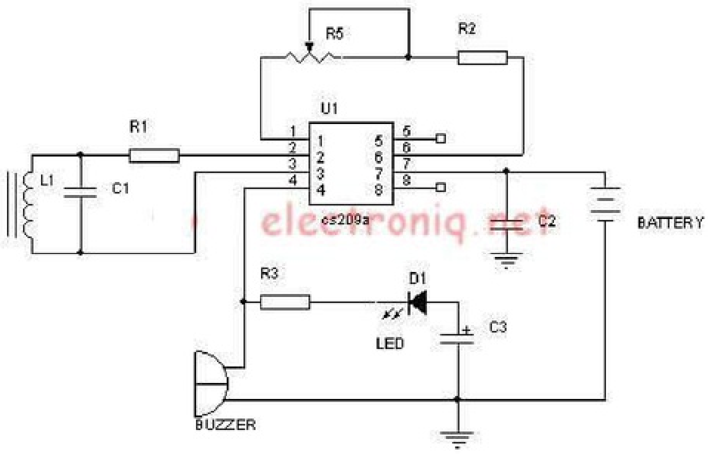


Figure 2.5 : a example of VLF metal detector[5]

Figure 2.5 is an example of VLF metal detector. In this design, a CS209A integrated circuit, which is manufactured by Cherry Semiconductor, is used for metal detecting. (The datasheet of CS209A is attached at appendix A) This chip has two regulators, one oscillator, one low-level feedback circuit. In this design, inductor L1, capacitor C1 and resistor R1 form a detecting circuit. The CS209A microcontroller controls oscillations of the LC circuit. In this case, L1 is a single 100uH coil. It a metal object enters the zone of the detecting circuit, the inductance of inductor L1 is change due to the metal object's interference. The change in oscillation is collected and amplified by the microcontroller, the preset voltage output therefore varies and switches are turned on that LED D1 lights up and the buzzer rings.

Pulse Induction

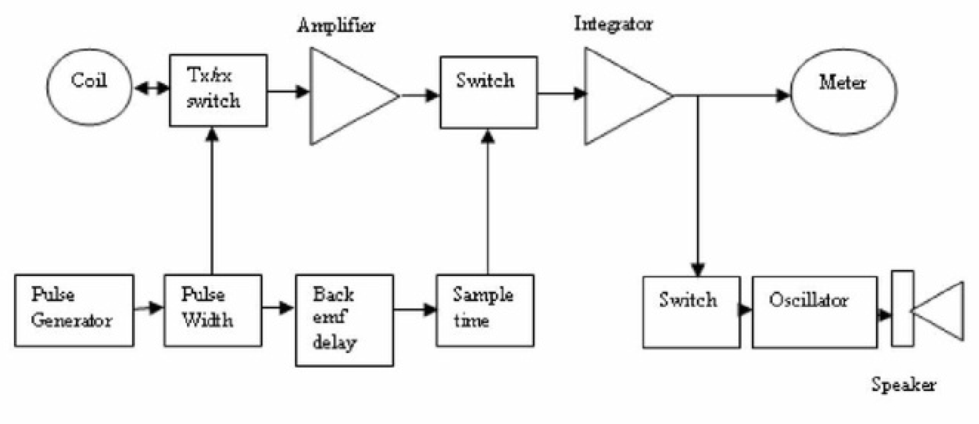


Figure 2.6: Block diagram of the pulse induction metal detector[6]

This method relies on pulse induction(PI). The basically structural concept of this design is shown in figure 2.6 which consists of four parts, a power supply, a pulse generation circuit, a coil system(coils, amplifiers and integrators) and an indicator(meter). The main difference between pulse induction metal detector and other two detectors is that this detector only depends on a single coil which is unlike other detector relied on two or more complementary coils working together. This coil sends short and powerful current pulses and a brief magnetic field is generated by each pulse. When the current is switched off, the magnetic field suddenly reverses its polarity and generate another electrical spike, which only last a few microseconds(us), at the end of each pulse. The generated electrical spike cause a new extremely brief reflected current pulse through back to the coil and this interference is able to be detected by the coil. However, although the technology is very efficient in finding metal objects and it has been widely used in the current market such as security check, it is still very difficult in differentiating the types of metal due to its theorem.

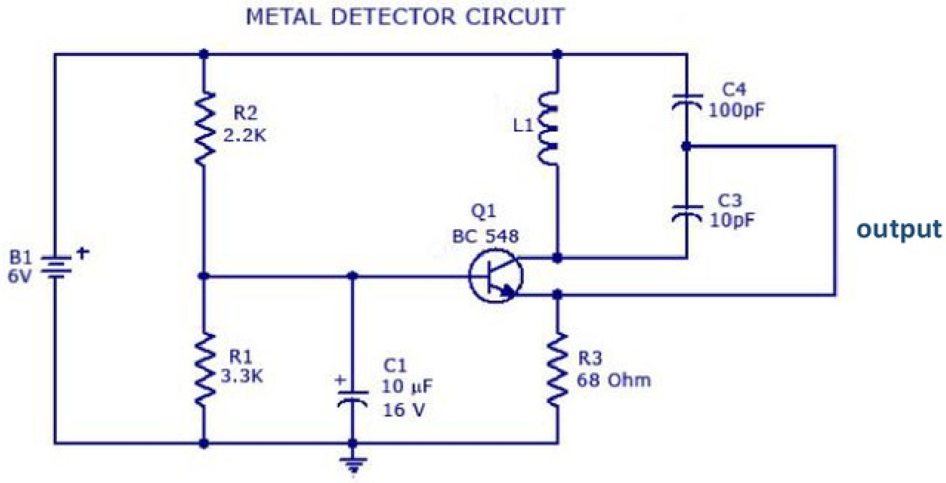


Figure 2.7 : a example of PI metal detector[9]

Figure 2.7 is an example of PI metal detector which is the simplest method of metal detectors. In the design, B1 is a DC source which is 6V; R1 and R2 are biasing resistors for controlling the gain of the BJT, C1 is a bypassing capacitor that filters high-frequency noise. The oscillator consists of transistor Q1, inductor L1, capacitor C3, C4 and resistor R3. By varying R1 and R2 to keep the transistor Q1 on the edge of saturation. If there is a metal object enters the detecting range, it interferes the inductance of L1 so that the peak to peak voltage at the output is reduced even goes to zero if the metal is close enough. By adding a rectifier and control system at the output, users will be aware of the metal existing in the way they like.

2.4.1 Oscillators

An oscillator is an electronic circuit which generates a repetitive and periodic alternating current(AC) from direct current(DC). the output Signal is usually in the form of sine or square wave. This generated wave usually has a constant amplitude and the application of oscillators is often used as the converter to convert a direct current (DC) signal to an AC signal. However, the frequency of the AC output could be either fix or variable which rely on the design of the oscillator. Oscillators are widely used in modern electronic equipment and circuits included radio transmitters, signals of computer and sounds from beepers or video games.

2.4.2 Types of Oscillators

Oscillators are usually classified by types of the output signal, such as sine wave, sawtooth wave, square wave and rectangular pulse. However, they have also been classified by the frequency ranges of output sometimes. In this report, I will introduce Oscillators by types of the output signal.

LC Oscillators

An LC oscillator is a type of sine wave oscillator which combines inductors and capacitors in a resonating circuit to generate an AC output. the output of LC oscillators is a very stable sine wave, in other words, the amplitude and frequency of LC oscillators will not vary much when DC power supply and temperature change. In addition, the frequency could be simply varied by using variable inductors or capacitors. LC oscillators are one of the most widely used oscillators which are extensively used in the field of transmitting and receiving RF signal.

RC Oscillators

For some low-frequency proposes, LC oscillators are not a good choice as it required a very large value of inductors and capacitors. In that case, adding an RC filter could make the oscillator achieve low-frequency proposes. However, the disadvantage of RC oscillators is that the output cannot represent as a perfect wine wave and it is different to design a fixed frequency.

Crystal Oscillators

In some case of requiring fixed high frequency, such as radio frequency or even higher, quartz crystal is the most common way to achieve this goal as it will change the Vpp voltage very precisely when it receives a variable input signal. The frequency of quartz crystal is fixed as long as it has been manufactured from factories and the physical dimensions of the quartz crystal can tell the frequency of itself. The crystal oscillators are so much precise that it is widely used in watches, computer systems or other accurate purposes either in sine wave or square wave.

Relaxation Oscillators

a relaxation also generates sine wave output but in a completely different principle, and it usually comes with two amplifiers. This oscillator generates pulses by fully turning on and off the power supply in a relatively low frequency although is could work in either high range or low range of frequencies. The disadvantage of relaxation oscillators is that it has not stable stage, which means its output is always fluctuating. Hence, it is majorly used in low-frequency flashing lights.

Sweep Oscillators

As it illustrated by its name, sweep oscillators generate sweep waveform output which is presented as a saw-tooth wave. A period of sweep waveform shows the linear change of voltage from a ramp generator, and it is majorly used in a voltage-controlled oscillator.

Chapter 3

Experimental Plan and Produces

3.1 Methodology and Decision

3.1.1 The Type of Button Cell scanner

According to the introduction of these three detectors in the last section, BFO detectors has the ability to discriminate metal types with high accuracy due to its design. In this detector, the equipment usually has three coaxial coils, two receiving coils on the either side and one transmitting coil in the middle, which is shown in figure 2.2. Receiving coils and transmitting coil are connect to an oscillator but in different frequencies. If there is a metal object enter this detector range, magnetic fields are interfered by the object. By vectorially measuring the difference in the impedance of two receiving coils, it is able to estimate the size, electrical, and magnetic properties of the metal object[1]. The metal object thus is identified.

Besides, VLF detectors also have the capacity of discriminating metal types. In that design, The transmitting coil sends strong electric currents at a very low frequency. If there is a metal object enter its detector range, the object will generate a magnetic current, which disturbs the magnetic field, the receiving coil is able to acquire the interference as well as send to a microcontroller[5]. The microcontroller is able to measure the magnetic flux density and frequency of the interference so that precisely identify the type of the object.

But although BFO detectors and VLF detectors have the capacity of discriminating metal types, these two detectors still are not the first choice for this project due to higher cost. The first choice of the project is PI detectors. PI is not only much cheaper than other two detectors but also more simply compared to the others. Although PI is not able to discriminate metal types, it is still a feasible method in this project.

The major challenge of this project is discriminating between coins and button cells. However, according to the literature review, the main difference between coins and button cells is the material. Australian coins are all made of alloy (copper, nickel and aluminum) which are non-magnetic[6]. On the other hand, all button cell in used are made of stainless steel which has strong magnetic performance and the interference of strong magnetic metals to the coil is much stronger than non-magnetic metals. By design a PI circuit with high frequency and weak sensitivity, PI detector is also able to discriminate between coins and button cells within the specific distance.

Table 3.1: the summary of three types of metal detectors

Type	**Advantage**	**Disadvantage**	**Cost**	**Difficulty**	**Preference**
BFO detector	High accuracy Discriminating metal	difficult Very expansive	Start from $800	high	3
VLF detector	High accuracy Discriminating metal simple	Very expansive	Start from $2000	low	2
PI detector	Simple cheap	differential to Discriminate metal type	$50 (approximately)	low	**1**

In conclusion, table 3.1 shows advantages, disadvantages, costs and difficulty of these three major types of detectors, and the result shows the most suitable approach for this project is pulse induction(PI) especially when the cost and difficulty are considered as the major factor.

As long as the microscopical approach is finalised, more detail design is also required to be solved as well, included the exact type of oscillators and the electronic circuit that oscillator.

3.1.2 The Type of the Oscillator

In the last chapter, there are five oscillators that are introduced in the report, and they have been classified by the type of output signal included sine waves, sawtooth waves, square waves and rectangular pulses. All have advantages and disadvantages and each is specialised in different purposes. However, they will be analysed in this section and conclude into a table:

Table 3.2: the summary of five types of Oscillators

Type	**waveform**	**Advantage**	**Disadvantage**	**Preference**
LC Oscillator	Sine wave	Stable Variable Simple Large range	Only for general application	**1**
RC Oscillator	Sine wave	Low frequency Variable Simple Stable	Only for general application	2
Crystal Oscillator	Sine wave or square wave	Very Accurate Simple	Example Fixed frequency Expansive	3
Relaxation Oscillator	Square wave	simple	unstable	Not suitable
Sweep Oscillator	Saw-tooth wave	Special purposes	Only for Special purposes	Not suitable

As it shown in table 3.2, the LC oscillator is the best choice for this project because of its variable frequency, low cost, stability and difficulty. All these advantages could make the tests and experiments simpler to find the proper frequency for the project.

3.1.3 Types of LC Oscillators

An LC oscillator is just a general type of sine-wave oscillators which combines inductors and capacitors in a resonating circuit to generate an AC output. However, the more particular circuit is required to be finalised in this section.

There are five particular oscillators under the LC oscillators, included tuned collector oscillators, Tuned Base Oscillators, Hartley Oscillators, Colpitts Oscillators and Clapp oscillators, and all will be introduced and analysed in this section.

Tuned Collector Oscillators

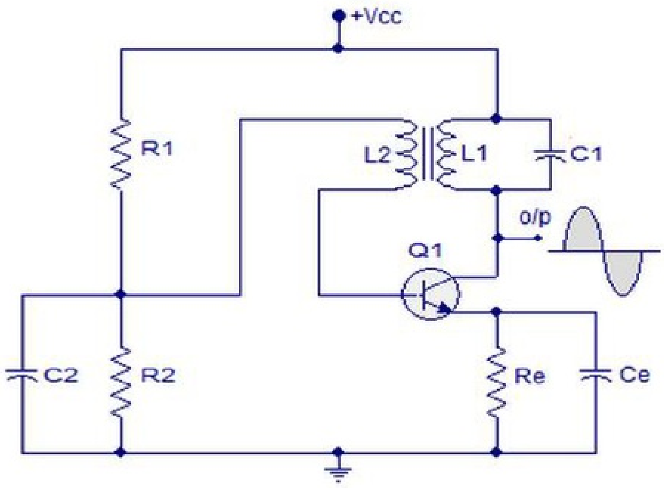


Figure 3.1 : a circuit of tuned collector oscillators

Tuned collector oscillator is a fundamental type of LC oscillators which is shown in figure 3.1. A transformer and a capacitor connected in parallel at the transistor's terminal of the collector which form a tank circuit. This tank serves as a resistive load in oscillation and it affects the frequency of the oscillator. This is also the simplest LC oscillator and its application includes frequency demodulators, mixers, etc.

Tuned Base Oscillators

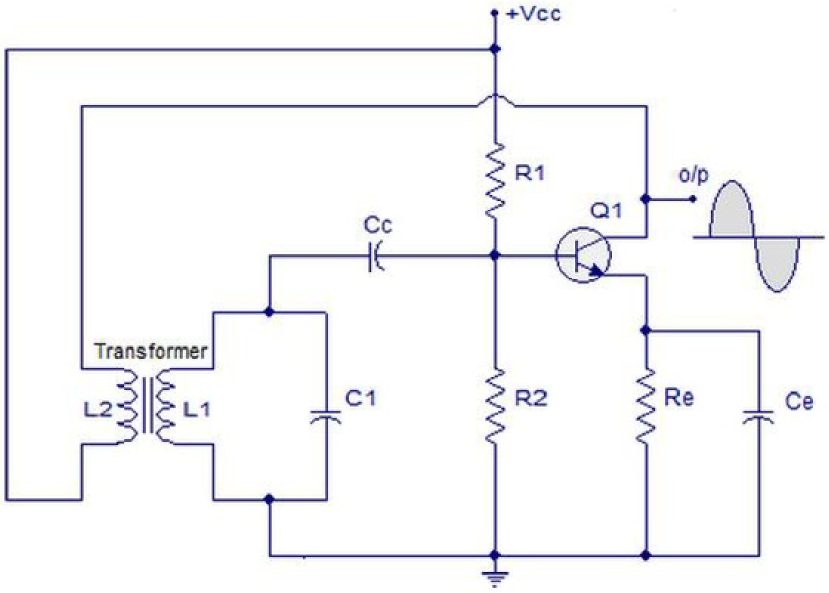


Figure 3.2 : a circuit of tuned base oscillators

Tune base oscillator is another type of LC oscillators which is also known as Armstrong oscillator named after its inventor. In figure 3.2, a transformer and a capacitor connected in parallel between base and ground to form a tank circuit. The tank circuit controls the frequency of the oscillator as same as the Tuned Collector Oscillator.

Hartley Oscillators

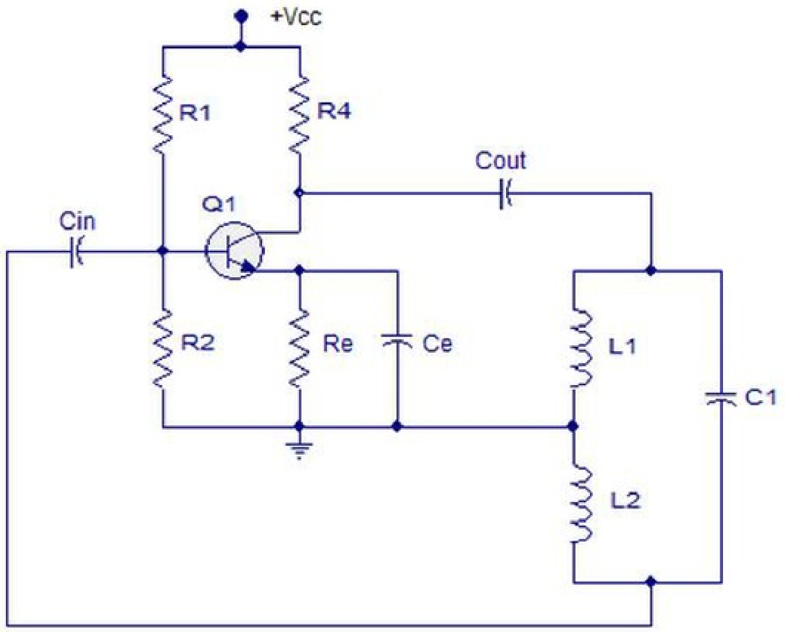


Figure 3.3 : a circuit of Hartley Oscillators

The Hartley oscillator is a type of LC oscillators which is shown in figure 3.3. It also named after Ralph Hartley who is the inventor of itself. The uniqueness of The Hartley oscillator is that the tank circuit consists of two inductors and one capacitor that the capacitor parallel to two inductors in series. The frequency of typical Hartley oscillator is from 20KHz up to 20MHz, the output signal is also able to be amplified by connecting a BJT or op-amp right behind output terminal.

Colpitts Oscillators

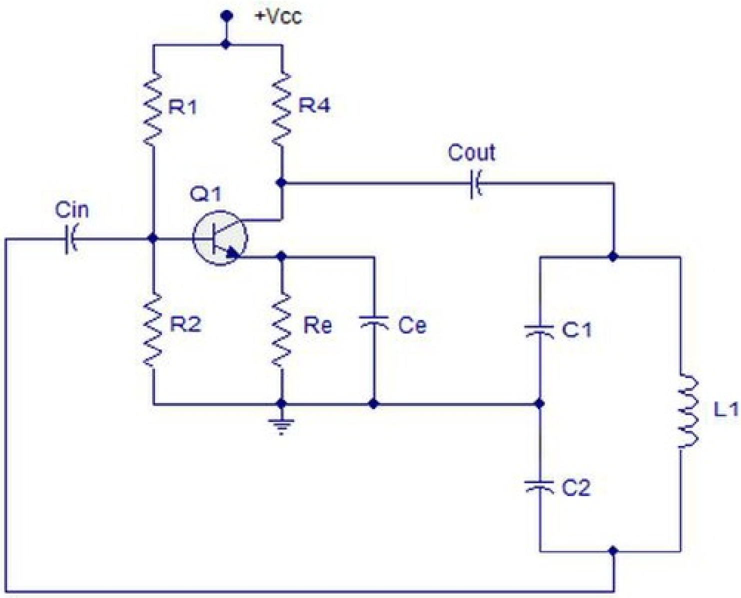


Figure 3.4 : a circuit of Colpitts Oscillators

The Colpitts Oscillator is very similar to Hartley oscillators which is shown in figure 3.4. The frequency range of the Colpitts Oscillator is from 20KHz to 20MHz which is as same as Hartley oscillators. Actually, the Colpitts Oscillator is an alternative design of Hartley oscillators and this is the reason why their circuits are so similar. The only difference between Colpitts Oscillators and Hartley oscillators is the tank circuit that consists of two series inductors and one parallel capacitor.

Compared to Hartley oscillators, Colpitts Oscillators only have a single inductor, which is able to represent as coil circuit, and it has better frequency stability. In addition, it is easier to control the frequency of the oscillator by just varying the value of the inductor.

Clapp oscillators

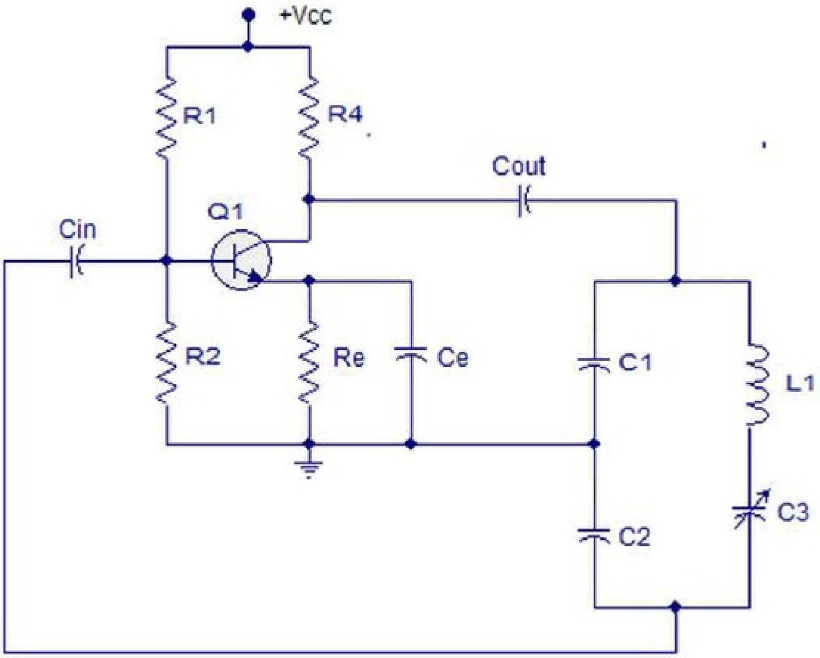


Figure 3.5 : a circuit of Clapp Oscillators

The Clapp Oscillator,which is shown in figure 3.5, is almost exact same to Colpitts Oscillators as it just a modification of the Colpitts oscillator instead of an innovative design. Actually, It just adds an addition variable capacitor following the inductor in the tank circuit. This new capacitor isolates other two capacitors from the effects of transistor parameters to further improve its frequency stability.

3.1.4 Decision in LC Oscillators

In conclusion, there are five particular oscillators under the LC oscillators, include Tuned Collector Oscillators, Tuned Base Oscillators, Hartley Oscillators, Colpitts Oscillators and Clapp oscillators, and all have advantages and disadvantages. In order to make the comparison clear, all information are concluded into a table shown below:

Table 3.3: the summary of five types of LC Oscillators

Type	**Advantage**	**Disadvantage**	**Preference**
Tuned Collector Oscillators	Easy setup Easy design	Need a extra transform Old design	5
Tuned Base Oscillators	Easy setup Easy design	Need a extra transform Old design	4
Hartley Oscillators	Innovative design Very low cost Easy setup	Two inductors	3
Colpitts Oscillators	Improvement of Hartley Oscillators Very low cost Singe indcutor	Existing a modification	2
Clapp oscillators	Improvement of Colpitts Oscillators Very low cost Singe indcutor Latest design More stable	Not easy to setup	**1**

As it shown in the table and related material in this section, the design of Clapp oscillators and Colpitts Oscillators are the best choices which are preference 1 and 2 as these two oscillators are exactly the same circuit design unless an additional variable capacitor. These two are also the latest and best design of LC oscillator with several very simple and common electronic components such as resistors, capacitors and inductors.

3.2 Circuit Design

In general, PI detector circuit has fives sections in the design draft: an oscillator,an amplifier, a rectifiers, a control system and a power supply. Before building the circuit, I designed an electronic circuit in AWR for simulation. Simulation is a very important in the design stage, it could show errors of the design and find out required component value for the system by using the tuner tool.

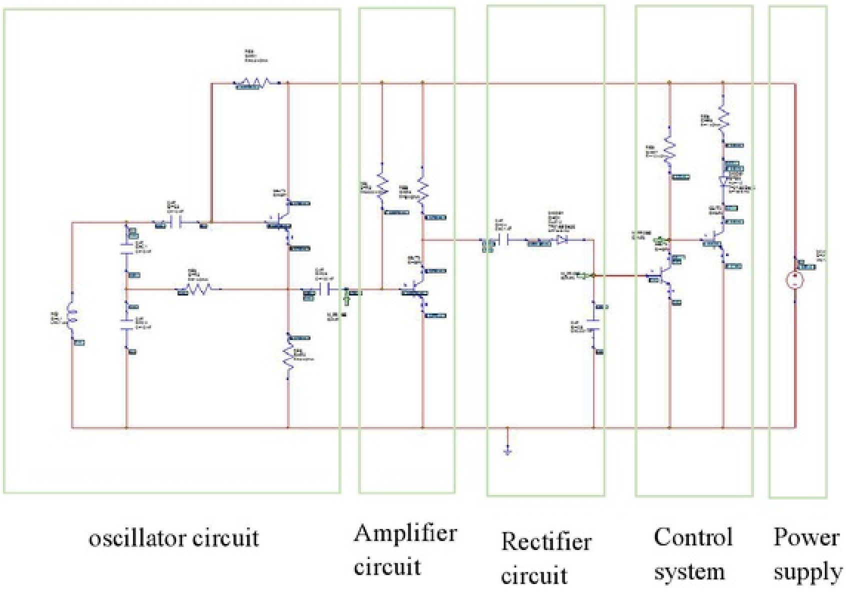


Figure 3.6: Initial PI circuit design

Figure 3.6 is the initial PI circuit design of the project(the bigger image is attached in appendix B). The button cell scanner is expected to be a small portable equipment, so I assume 3V as the power supply at this stage. The detail of other four sections is shown below individually.

3.2.1 Oscillator Circuit

As it mentioned in the introduction chapter, the target frequency of the Button cell scanner is assumed as 30Hz and the coil(the inductor) is the key to controlling the frequency. In the simulation stage, I built a Colpitts oscillator circuit as my oscillator. As it explained in the last section, the Clapp oscillator and the Colpitts oscillator are exactly same but an extra variable capacitor as a result of further reducing noise. However, variable capacitors are not available in MQ laboratory, and thereby I use the Colpitts oscillator circuit as my oscillator in this stage

.

In the next simulation stage, I also have to find out the specific range of the inductor. Therefore, I used the tuner to vary the inductance until finding the required value and the data are shown below.

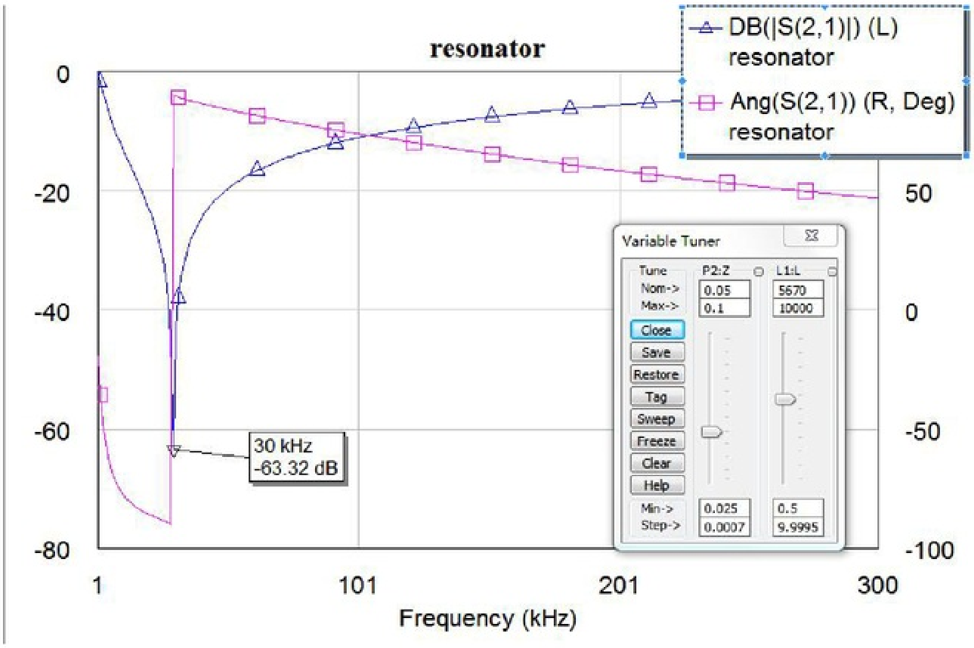


Figure 3.7: the maximum power of 5670uH

The blue line in figure 3.7 shows the power dissipation of the oscillator at 5670uH point in the unit of dB. As we can see from the figure, when the inductance increased to 5670uH, the 30kHz point reach the lowest point, -63.32dB, which means that the power dissipation at this value is very close to zero. In addition, the pink line shows the degree of the gain, which also indicates that 5670uH could make the frequency of the oscillator to 30kHz. However, this is only an estimated value because this value is test out under an ideal environment and the BJT used in the circuit is not the one I want. There are several limitations of the simulation and I am not able to obtain the specified BJT from the internet as well as the library of AWR.

Table 3.4: Inductance VS Frequency in Simuation

Inductance (uH)	8830	7420	6450	5670	5080	4420	3920	3550
Frequency (kHz)	24	26	28	30	32	34	36	38

Table 3.2 show the relationship of Inductance and frequencies. It is shown that the frequency is increased as inductance is reduced. If the circuit requires 30 kHz, the inductance value is approximately 5670uH. However, this is only a reference value because I will build a prototype in real condition with a different transistor.but at least, I confirm that this is a feasible circuit, the relationship between Inductance and frequencies also give me a lot of help for later experiments.

3.2.2 Amplifies

The output voltage of oscillator is not high enough to convert to DC for controlling system. In this case, an amplifier is very necessary for achieving this goal. There are several methods to achieve such as BJT amplifiers and operational amplifiers(Op-amp). In the initial design, I used the Class A amplifier circuit which is a kind of BJT amplifier, and I will explain the reason below:

Even in the BJT amplifier circuit, there are still a lot of class amplifier circuits could be used such as class A, class B and class C. In the design, I used class C as the amplifier which is the simplest common-emitter amplifier. This common-emitter amplifier needs the fixed bias and this class is able to achieve the maximum voltage amplification.

In this design, it is very important to be aware of DC current gain and AC current gain to design a correct amplifier circuit. This is not an easy stage, two same model transistor could have different gain even if they come from the same manufacturer. Hence, in the later stage, it is necessary to measure the value by hand.

However, the op-amp is also a feasible method to achieve the amplifying purpose. An op-amp is a high-gain electronic voltage amplifier chip with eight or sixteen pins. op-amps have been widely used in the electronic field for different purposes such as amplifiers and rectifiers.

3.2.3 Rectifier Circuit

A rectifier is an electronic circuit which converts AC signal to DC signal to flow in one direction for DC equipment. The reason why a rectifier is required is that the Control System, as a DC circuit, is only able to receive the DC signal as the input.

This is a very important stage before building a Control System. The output voltage of oscillator is AC which amplitudes could be effected by varying the inductance of the coil. In order to send a message to the Control System, the signal must be converted back to DC.

There are a lot of methods for converting AC to DC, such as precision rectifiers, full-wave rectifiers and half-wave rectifiers. In this initial design, I used a half-wave rectifier for the system. This button cell scanner is not a very precision equipment, all forms of rectifier will work at this stage. Half-wave rectifier is one of the simplest and cheapest rectifier, the only difference between the full-wave rectifier and the half-wave rectifier is that the frequency of full-wave rectifier is double than half-wave rectifier. Therefore, the half-wave rectifier is selected as my first choice at this stage, but other possible methods are also considered in the later experiment stage.

Table 3.5 data of rectifier circuit

Input Vpp	0.87V	1.6V	3.2V	4.0V	4.8V	5.0V
Output Vpp	17mV	90.7mV	462mV	683mV	901mV	1020mV

The output of rectifier should be as close to 700mV as possible because it is the minimum switch-on voltage for a BJT. According to the table, the target of amplified voltage should be slightly higher than 4V(683mv at 4Vpp). This point will be the edge of oscillation which means this point of voltage will maximise the sensitivity.

3.2.4 Control System

In the control system, I design that use a LED light and a Buzzer to send the message to users. Therefore, I use a couple of BJT as switches to control the LED and the buzzer. The base voltage of the first BJT which is connected following the rectifier circuit is set to 0.7V. When a metal object moves close to the coil vertically, the inductance of the coil is receded and the voltage of BJT's base is reduced as well. When the voltage less than 0.7V, the switcher cut off the circuit directly and start another circuit that includes a LED and a buzzer. Users will be aware of a button cell existing form the lighting LED and the ring buzzer. Once the button cell removed, the LED and the buzzer will stop as base voltage of the BJT recover 0.7V.

Chapter 4

Result and improvement

4.1 Oscillator Circuit

IIn the experiment and test stage, I realised that the simulation data is much different to the real value as the exact model transistor unit cannot be found from the internet. In this experiment stage, I choose the model S9014(datasheet is attached at appendix c) as the transistor for the entire system. S9014 is one of the most popular NPN transistors in used and it is also one of the cheapest BJT in the market that 50 pieces for $2.

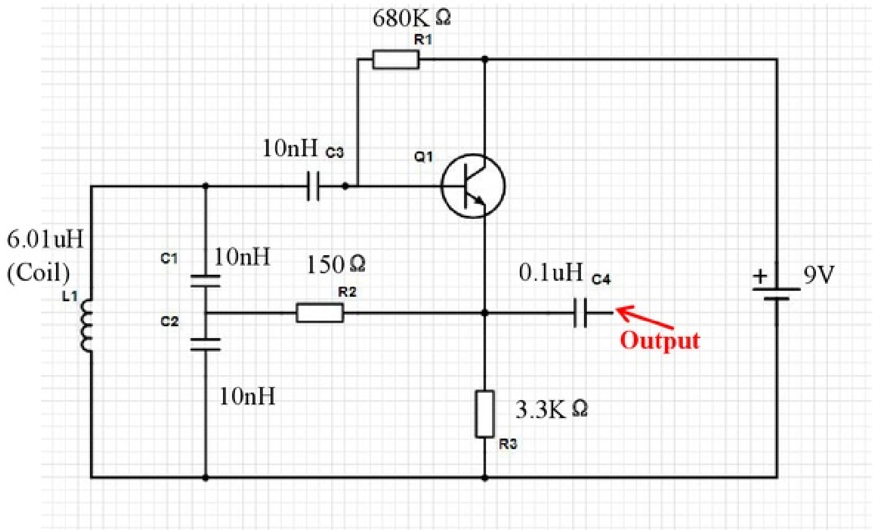


Figure 4.1 : the initial oscillator circuit of prototype

As I explained in the last Chapter, I built the Colpitts Oscillators circuit as the oscillator which is shown in Figure 4.1. As long as it had been built in the lab, several problems came with it that there is no output at all. I check the circuit again and again to make every component in a correct value and in a correct place but unfortunately this was not the problem came from. By doing more research on it, I overcame the problem eventually. The reason of no output it that the power supply(3V) is not so high enough that the feedback of the oscillator circuit is too weak to oscillate. Then I increased the power supply to 6V, and output showed up which is shown below:

Table 4.1: power supply vs output value (6.01uH inductance coil)

Power supply (V)	3	4	5	6	7	8	9	10
Vpp (V)	20	25	0.653	0.889	1.10	1.32	1.50	1.62
Frequency (kHZ)	None	None	778	791	790	781	781	788

The table shows the relationship between the power supply and the oscillator output. In the simulation, I assumed 3V as the power supply for the system. In fact, 3V is not enough for this type of BJT, the system does not oscillate at all until power supply was increased. As we can see from the table, the oscillator start oscillate from 5V with 937Hz. In the final design, I will probably choose 9V battery as the power supply because it is one of the most popular batteries in used and it is an available model from the market.

In addition, as it shown on the table, the frequency not changes with increasing power supply, and the power supply dominates the start point of oscillation and the voltage of output.

Besides, another finding of the oscillation circuit is that the power supply is not the only factor to dominates the start point of oscillation, the coil' inductance is also able to dominate the oscillation point. I did a set of experiments and the data is shown below:

Table 4.2: the relationship between coil' indutance and oscillation start point

Turns (d=20mm)	7	8	9	10	11	12	13
Frequency	1522kHz	1373kHz	1239kHz	1154kHz	960kHz	931kHz	910kHz
Inductance	2.06uH	3.09uH	3.69uH	4.15uH	4.85uH	6.01uH	6.85uH
Oscillation start point (in unit of V)	14V	13V	11.2V	9.2V	8.4V	5.8V	5.4V

Table 4.3 shows the start point value in different inductance. In this table, when the inductance of the coil increase, the output frequency and the oscillation start point decrease as well. In order to make the relationship more clear, all data of the table had been converted into a chart which is shown below:

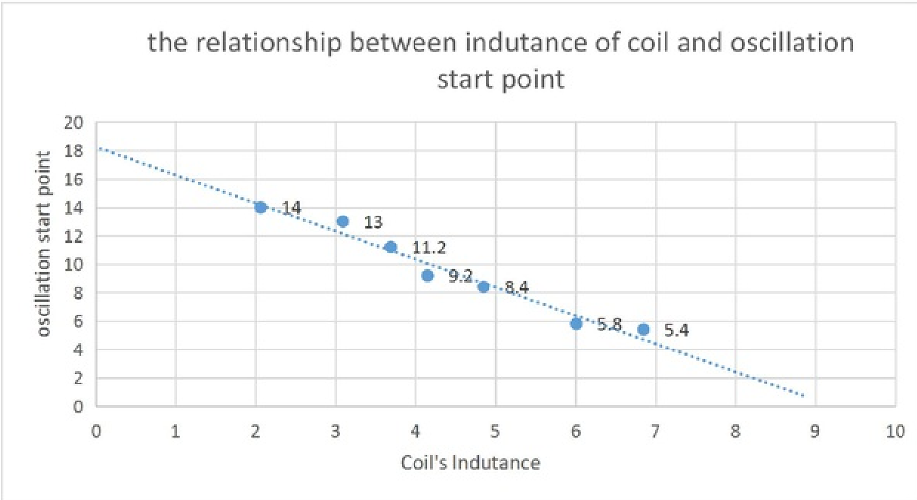


Figure 4.2: the relationship between indutance and oscillation start point in chart

In figure 4.2, all value had been represented in a chart to make the relationship clear. As we can see from the chart, the relationship between coil and oscillation point is clearly in a linear. When the inductance increased, the frequency of the output reduced and the oscillation started decreasing as well. This relationship is very important for the later stage to build a proper control system and choose a proper amplifier circuit.

4.1.1 Inductance Selecting

In the initial design plan, I assumed 30Hz as the frequency of the oscillator which needs approximately 5670uHz. According to the experiment data in the last section, this value is too large to achieve and specification of detecting distance of system should be in the range between 100mm and 300mm. Therefore, I also did substantial experiments on the relationship between the distance and inductance to find a proper value. I tested a range of inductance in 9V power supply to determine the inductance of coil and I made a table of these data which is shown below:

Table 4.3 the relationship between detecting distance and the coil (9V power supply)

Turns (d=20mm)	7	8	9	10	11	12	13
Frequency	1522kHz	1373kHz	1239kHz	1154kHz	960kHz	931kHz	910kHz
Inductance	2.06uH	3.09uH	3.69uH	4.15uH	4.85uH	6.01uH	6.85uH
Detecting distance of **button cell**	138mm	161mm	210mm	231mm	282mm	322mm	362mm
Detecting distance of **coin** ($1)	25mm	40mm	89mm	109mm	122mm	153mm	171mm

In this experiment, I connect the output node to the oscilloscope to measure the distance where start affecting the output voltage.

As we can see from the table 4.3, the shaded area is the target range which is supposed to be between 7 to 10 turns if the power supply is 9V. Another information was told from the table was that when the inductance increased, detecting distance increased as well. in other words, the frequency is lower, the distance is larger.

However, this is not the only method to control the detecting distance. Another method to control the detecting distance is varying the converted DC voltage flowing into Control System. More detail will be introduced in following Control System Section.

4.2 Amplifier Circuit

The output of the oscillator is not high enough to satisfy the requirement of the control system(0.7V Vpp) when it was converted back to DC, and thereby an amplifier circuit is required to achieve it. However, there are a few methods are able to amplify the output signal, such as BJT amplifying circuit or op-amp. In this stage, I will compare both methods in the laboratory to determine the best decision.

4.2.1 BJT Amplifier Circuit

As it introduced in project plan, common emitter amplifier is one of the feasible method for the project. The output's impedance of the common-emitter amplifier relies on the impedance which connected behind the Cout(shown in Figure 4.3) and the value of output's impedance also depends on the RC resistor shown in figure 4.3. Hence determining the RC value is a very important stage of the circuit design.

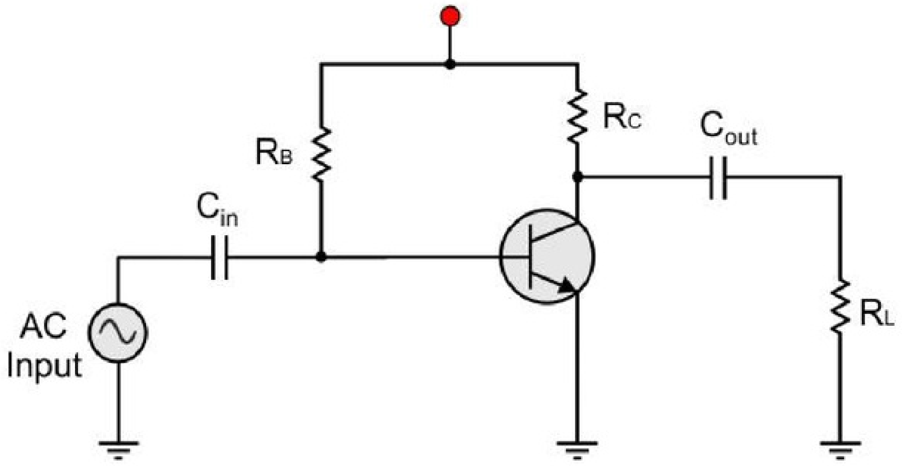


Figure 4.3 common emitter amplifier circuit

As we know that, if the load is high enough we could assume that $Vce = \frac{Vcc}{2}$ and we also know $Vcc = Vrc + Vce$ and $Ic = \frac{Vrc}{Rc}$, the $R_B = \frac{Vcc}{I_B}$ and the internal emitter resistance $r'_e = \frac{25mV}{Ic}$. The base impedance $Zin(base) = h_{FE} \times r'_e$.

Due to R_B is parallel to the Zin(base), the total input impedance $Zin = \frac{R_B \times Zin(base)}{R_B + Zin(base)}$. now the base AC voltage U_B , AC base current I_B , AC collector current I_c and AC voltage across R_C , U_{RC} is also able to determine by equation. The overall gain $Av = \frac{U_{Rc}}{AcVpp}$.

However, the design is not as simple as I though, and the gain of BJT amplifying circuit is hard to be accurate. At the end of the experiment, I planned to use another precise amplifier,op-amp,even if the cost will be much more than BJT.

4.2.2 Op-amp

The op-amp is an alternative design for the amplifier circuit. In this case, I used the LM748CN Op-amp, which is available in Macquarie laboratory, for the experiment. LM748CN is a single-Op-amp chip with 8 pins(datasheet is attached at appendix D). The operational power supply of the OP-amp is from $\pm 5V$ to $\pm 20V$ and it requires an operational capacitor for the system which in the range of 3pF and 30pF. The amplifying application circuit is shown below:

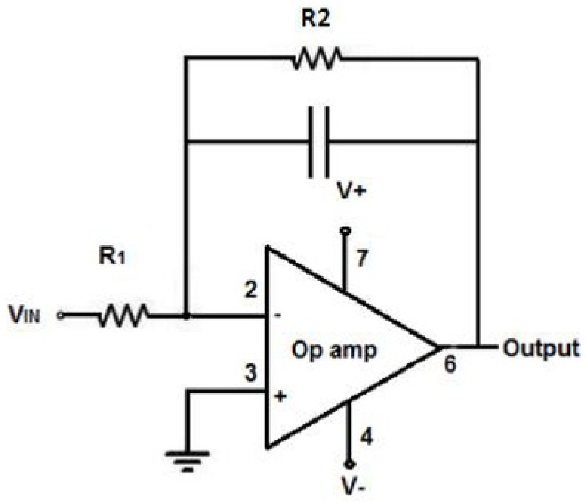


Figure 4.4: Op-amp circuit

According to the voltage gain rule, the output voltage is equal to the ratio of $\frac{R2}{R1}$. In this case, I set $R1 = 18k\Omega$ and $R2 = 180k\Omega$, the ratio of $\frac{R2}{R1} = 10$ which means the output of the amplifier is 10 times of input. The input signal I set it as 900mVpp with 960kHz and thereby the output should be 9Vpp in 960kHz as well.

However, the output voltage is not perfectly in a sine wave and the output gain is less than 1. I checked circuit and the datasheet again and again. Eventually, I realised the problem is that this Op-amp is not used for the high-frequency purpose. If the input signal frequency exceeds the specific range, the voltage gain will drop. '

Table 4.4: the relationship between voltage gain and input frequency

Frequency (kHz)	1	10	20	50	100	300	500	1000
Input voltage(V)	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
Output voltage(V)	9.2	9.1	8.6	5.4	3	0.88	0.51	0.37

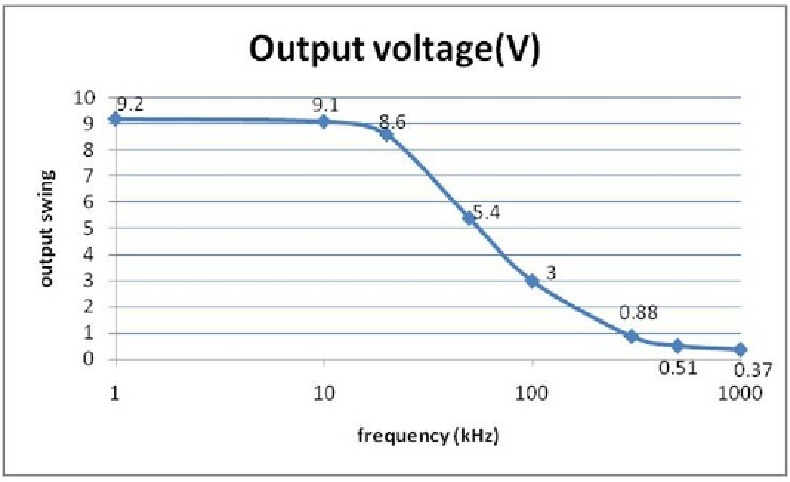


Figure 4.5:Large Signal Frequency Response

According to the table 4.4 and figure 4.5, the operational frequency of LM748CN in between 1kHz and 10kHz. If the input frequency exceeds 10kHz, the voltage gain start decreasing.

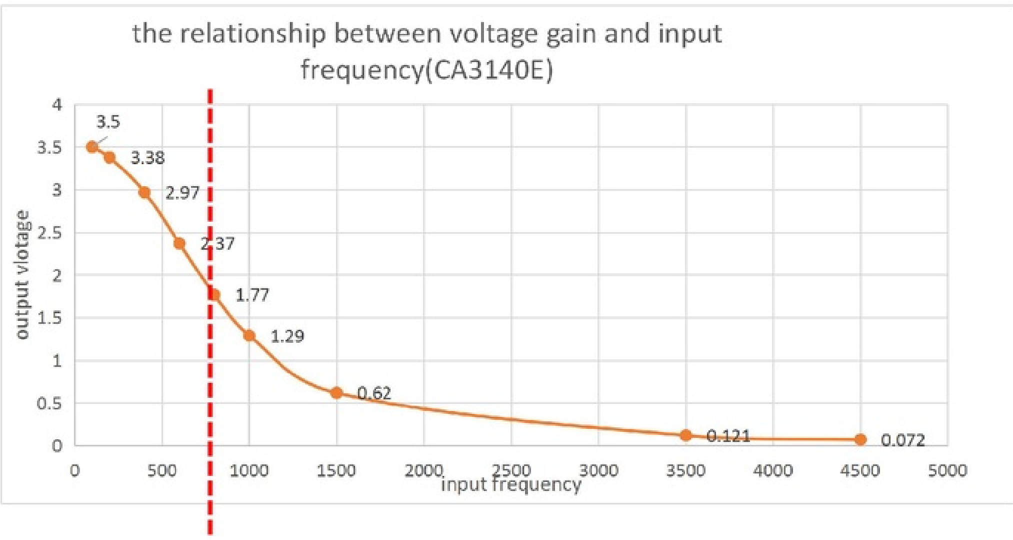
In order to amplify the input signal in the project, there are two alternative methods could be considered, using high-speed Op-amp or reduce the output frequency.

In order to solve this problem, I book a new model op-amp from Internet which is CA3140E(datasheet is attached at appendix E) with 4.5MHz bandwidth. At the beginning of the experiment, I used a 350mv Vpp with different frequencies as the input signal to test how output gain change of CA3140E. In the experiment, we default that the ratio of $\frac{R2}{R1} = 10$ which means the output of the amplifier is 10 times of input.

Table 4.5: the relationship between voltage gain and input frequency(CA3140E)

Frequency (kHz)	100	200	400	600	800	1000	1500	3500	4500
Input voltage (mv)	350	350	350	350	350	350	350	350	350
Output voltage(V)	3.5	3.38	2.97	2.37	1.77	1.29	0.62	0.121	0.072

Table 4.4 show the relationship between voltage gain and the input frequency. In order to make the comparison more clear, the data had been converted into a chart which is shown below:



As we predicted, the output gain drops when the input signal's frequency increases even if this model has 4.5MHz. However, it is much better than the model LM748CN. At the point of 800KHz ,which is labeled by a red line, the overall gain still has approximate 5(350mv compared to 1.77V). This is a very good news for the project, if we used 9V as the scanner's power supply, the output of the amplifier will be much larger than 350mv and it will be enough for the Control System. In addition, if a higher gain is required in the project when the power supply is less than 9V, another method to obtain the higher gain is that increase the inductance of the coil.

4.3 Rectifier circuit

There are a lot of methods to convert AC to DC, such as half-wave rectifiers, full-wave rectifiers and precision rectifiers. In this section, I will test all of these three methods and make the best decision for the project.

4.3.1 Half-wave Rectifier

Half-wave rectifier is the simplest rectifier which only needs one diode to cut off the negative direction voltage and remains positive part which can be used for Control System.

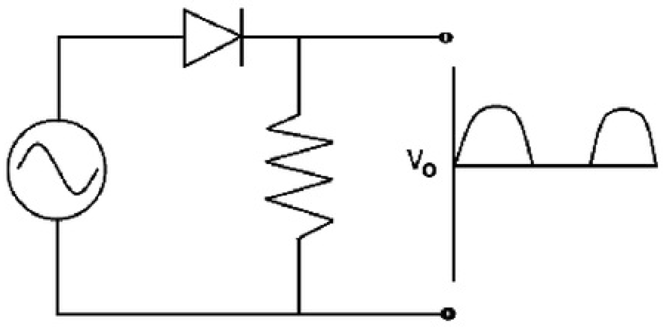


Figure 4.6 Half-wave rectifier circuit

Table 4.6 data of Half-wave rectifier circuit

Input Vpp	0.87V	1.6V	3.2V	4.0V	4.8V	5.0V
Output Vpp	17mV	90.7mV	462mV	683mV	901mV	1020mV

The table shows different output voltage in different inputs with a 900kHz frequency. The control system consists of several BJT, which means the output voltage has to be approximate 0.7V to turn the loop on. In the table, if we want to get a 0.7V output, the input voltage has to be amplified up to 4V Vpp. This input voltage is higher than I though and I have to compare other two rectifiers to make the best decision.

4.3.2 Full-wave Rectifier (Bridge Rectifier)

The full-wave rectifier is another method to convert AC to DC. The difference between the half-wave rectifier and the full-wave rectifier is that the output waveform of the full-wave rectifier is much stable. There are two ways to build a full-wave rectifier included a center tapped transformer and two diodes combination and a four diodes Bridge rectifier which is shown below.

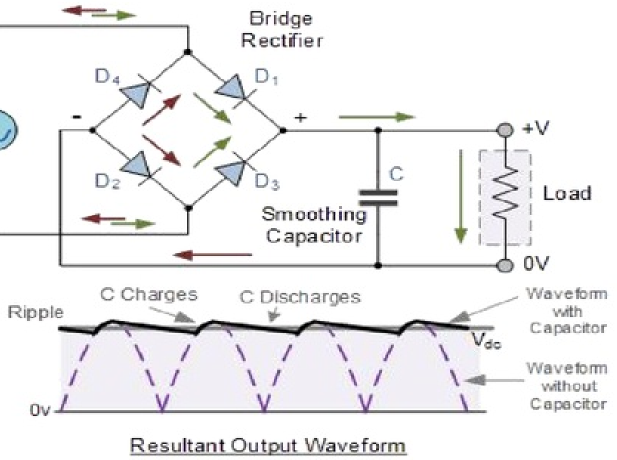


Figure 4.7 Full-wave rectifier circuit

In the experiment stage, I tested a range of different input voltage with 900kHz to see how it convert AC to DC, as well as to find the point which obtains the 0.7V output. The experiment data is shown below in table 4.6:

Table 4.7 data of Full-wave rectifier circuit

Input Vpp	1.2V	1.25V	1.3V	1.35V	1.4V	1.45V
Output Vpp	520mV	540mV	600mV	640mV	680mV	720mV

The table shows different output voltage of different inputs with a constant 900kHz frequency. As we can see from the table, when the input voltage as high as 1.4V, the output come out an about 0.7V DC. Compared to the half-wave rectifier(4V Vpp), the efficiency of full-wave rectifier is much high than half-wave rectifier, but it needs an individual ground for DC system, which means the system has to use two separated battery for the oscillator and the Control System. Instead, half-wave rectifier has the common ground for the entire system but its efficiency is too low.

4.3.3 Precision Half-wave Rectifier

The precision rectifier is an application of Op-amp which is widely used for high-precision signal processing. Precision rectifiers is a very good design as it is an alternative design based on the op-amp. Precision rectifier could achieve amplifying and rectifying within one single stage which could make the button cell scanner circuit much smaller. Precision rectifier includes two types, a half-wave rectifier and a full-wave rectifier. As the Op-amp chip is a single op-amp chip, the half-wave rectifier Op-amp design is considered as the first preference.

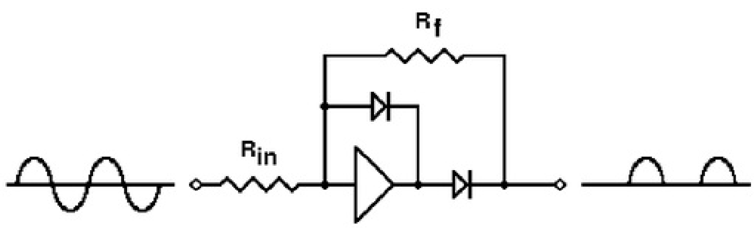


Figure 4.8 Half-wave rectifier circuit

As it shown in figure 4.7, The ratio of $\frac{R_f}{R_{in}}$ is the output gain of the precision rectifier, whose applications are as same as the amplifier. In addition, there are two diodes are used in the above circuit to cut off negative part of AC input and enhance the output voltage processed by the rectifier. I measured a set of input voltage value and the data is shown below in table 4.7

Table 4.8 data of precision Half-wave rectifier circuit

Input Vpp	1V	1.2V	1.3V	1.35V	1.4V	1.5V
Output Vpp	400mV	580mV	660mV	700mV	740mV	840mV

As we can see from the table 4.7, the 0.7V output came out when the input voltage as high as 1.35V. Compared it to the traditional full-wave rectifier(1.35V compared to 1.4V), the efficiency of Half-wave rectifier is slightly higher than traditional full-wave rectifier. More importantly, the amplifying stage and the rectifying stage could be integrated into one single stage.

But although precision rectifier seems is the best approach for the project, the model CA3140E is not good enough for the project. The model CA3140E is a dual power supply model that needs one positive power supply and one negative power supply to support work of the op-amp. I have not mentioned this issue when I bought it, and I have to book a single power supply model for the button cell scanner circuit in the future if I have time.

4.3.4 Summary of Rectifier Approaches

Table 4.9 Summary of rectifier approaches

Types	Efficiency	Cost	Advantage	Disadvantage	preference
Half-wave rectifier	Low	Very low	Common ground	Low converting rate	2
Full-wave rectifier	High	Low	Low cost High efficiency	Individual grounds	3
Precision rectifier	High	intermediate	Simple small	Individual power supply	1

The precision rectifier is the most suitable method for the project so far especially when the integration is considered as an important factor. However, the op-amp model I have is not good enough, hence the combination of a half-wave rectifier and an amplifier is also a good way to achieve it. On the other hand, the full-wave rectifier is not good for this project because it needs an extra close circuit for DC loop.

4.4 Control System

As we known that the DC output is converted from the AC output, and the value of AC depends on the oscillator's inductor which as the form of a copper coil. When a metal object enters the detecting range, the inductance of the coil reduces until zero. In the meanwhile, the AC output drop and the DC value drop as well due to the reduction of coil's inductance.

4.4.1 initial design of control system

The control system is designed to catch the change of the DC. BJT is one of the most popular ways to catch the change. We could make the DC flowing into the base terminal of BJT to 0.7V or higher, when the DC drop, the BJT will switch off and send the information to users. Hence by controlling the input voltage at the base terminal also has the capacity to vary the detecting distance.

This is the basic theory of the design of control system, but we have two kinds of design which are shown below:

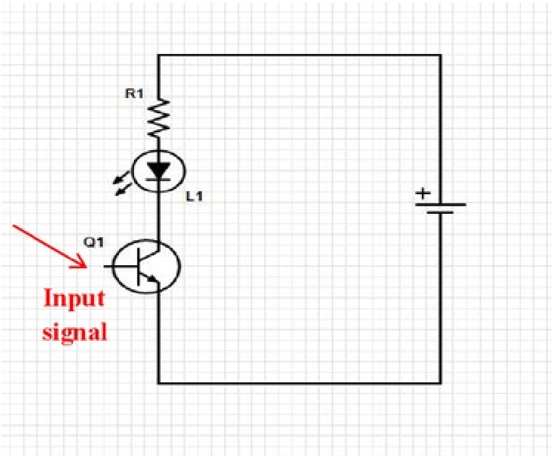


Figure 4.9 simplest control system design

In figure 4.8, L1 is a LED light, and Q1 is an NPN BJT, in this case, I still used S9014 as the switcher. According to the datasheet, the base-emitter on voltage is approximately 0.63V. Therefore, I make the input voltage to 0.7V to make it completely switch on. When a button cell enters the detecting distance of the coil, the input voltage will drop down, and when the voltage lower than 0.58V, the loop has been switched off and the LED light off as well. Users will be aware of the existing of button cell from the light.

However, it is not a good design, most of the successful design is not work in this way. It is supposed to be that the LED only light up when a button cell was found instead of lighting off. It will save more energy for the system and make more sense for user.

4.4.2 alternative design of control system

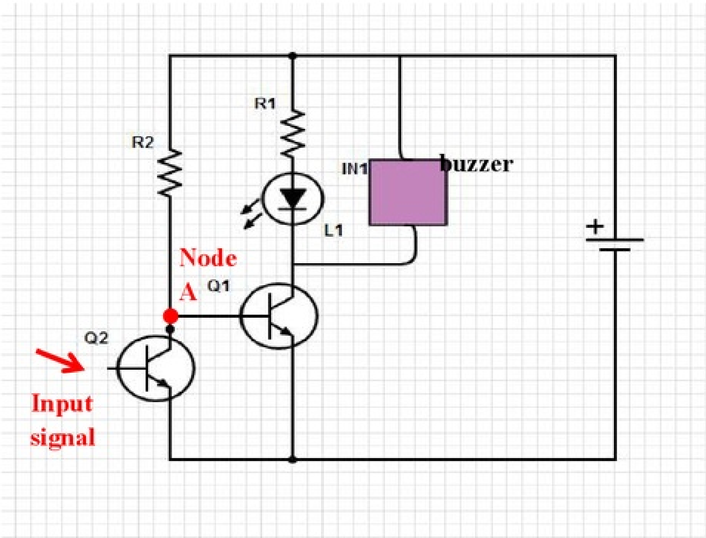


Figure 4.10 alternative control system design

This is a better design for Control System which adding an extra BJT(Q2) in front of Q1. When the input signal is higher than 0.7V, the Q2 will switch on and the node A is connected to the ground directly. This means the entire control system is in a short circuit status. As long as the input voltage drop lower than 0.7V, the Q2 is switched off and the node A voltage is as higher as the power supply due to an open circuit. The Control System is switched on at the meantime, a LED and a buzzer are turned on as well. Users will be aware of existing of button cell from the working LED and the buzzer.

4.5 Improvements

The prototype has been manufactured already at this time, but it still reminds a few problems. In this stage, I was trying to make the prototype better and simpler, so in the last few weeks, I have been working on optimising the design and redrawing the electronic circuit.

4.5.1 Oscillator improvements

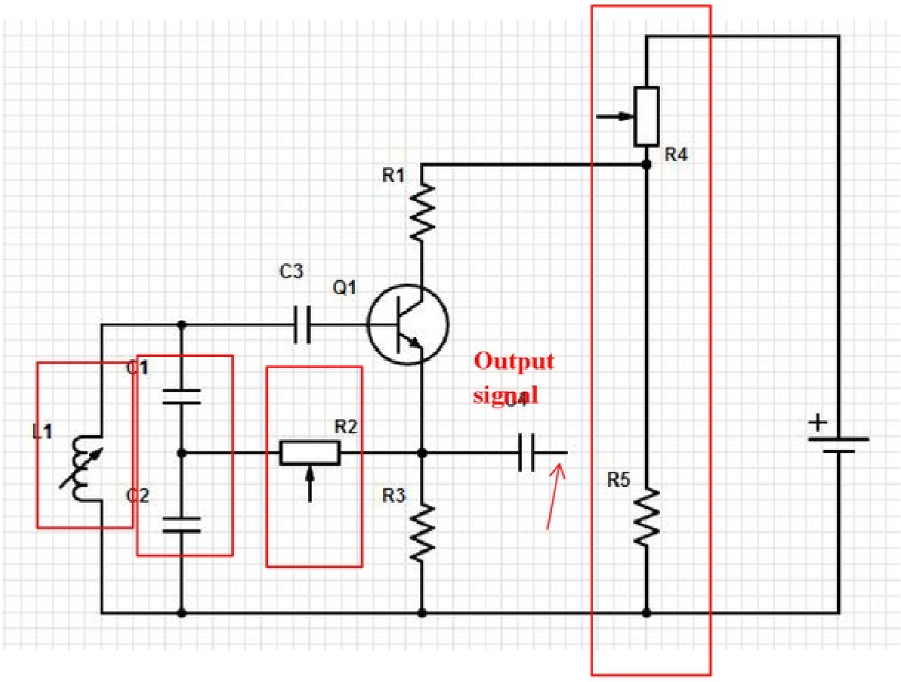


Figure 4.11 improvement of oscillator

The oscillator has been redesign again and all changes have been labeled in figure 4.10. The first change is that the impedance of coil had been increased from 6uH to 30uH. The reason for this change is to make the oscillation start point and the frequency lower(reduce from 900kHz to 300kHz). This change will reduce the power supply required for the oscillation and make the rectifier voltage more flat by reducing the output frequency.

The second change of the circuit is that increases the capacitor from 10nH to 20nH. The capacitor dominates the limit of Vpp of output, when the capacitor is double, the Vpp range limit is double and the minimum value of the Vpp had been increased as well. This will make rectified voltage easier to obtain 0.7V.

The third change of the circuit is that two variable resistors had been added into the circuit. The left-hand-side variable resistor has the capacity to vary the Vpp in small scale in the unit of 0.01V, the right-hand-side has the capacity to vary the Vpp in the unit of 0.1V by varying the power supply of oscillator. These two variable resistors are not only able to control the sensitivity of Button Cell Scanner but also able to tune input power of the rest of section which will make the circuit easier for testing.

4.5.2 Amplifier and rectifier improvements

Even a precision amplifier is a good method to integrate amplifier and rectifier into one single stage, I was still looking for another low-cost way to achieve this. There is a kind of low-cost circuit which could also amplify and rectifier the signal which is call Voltage Multipliers.

Voltage multipliers could generate an output from AC to DC with multiple voltages of the circuit's peak input voltage such as voltage doublers, voltage triplers, voltage quadruplers or even higher. But in this project, a voltage doubler is high enough to generate a 0.7V DC output and I will focus on a voltage doubler.

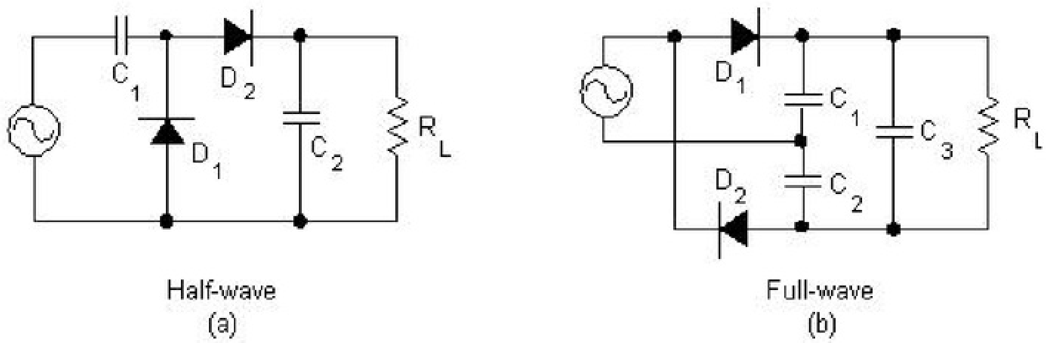


Figure 4.12 Voltage Doublers

There are two types of voltage doublers could be used for the circuit included Half-wave voltage doublers and Full-wave voltage doublers which are shown in Figure 4.11. As we can see from the Full-wave doubler, it has to use a separated DC loop for the Control System. Instead, Half-Wave Double only has one common ground, which means the entire Button Cell System could be supported by a single battery.

The purposes of capacitor C1 and C2 is for bypassing the AC signal, so in the circuit, I used 0.1uF capacitor for the doubler and the diode is 1N4148(the datasheet is attached at appendix E) which is a general high-speed model for low and high frequencies purposes

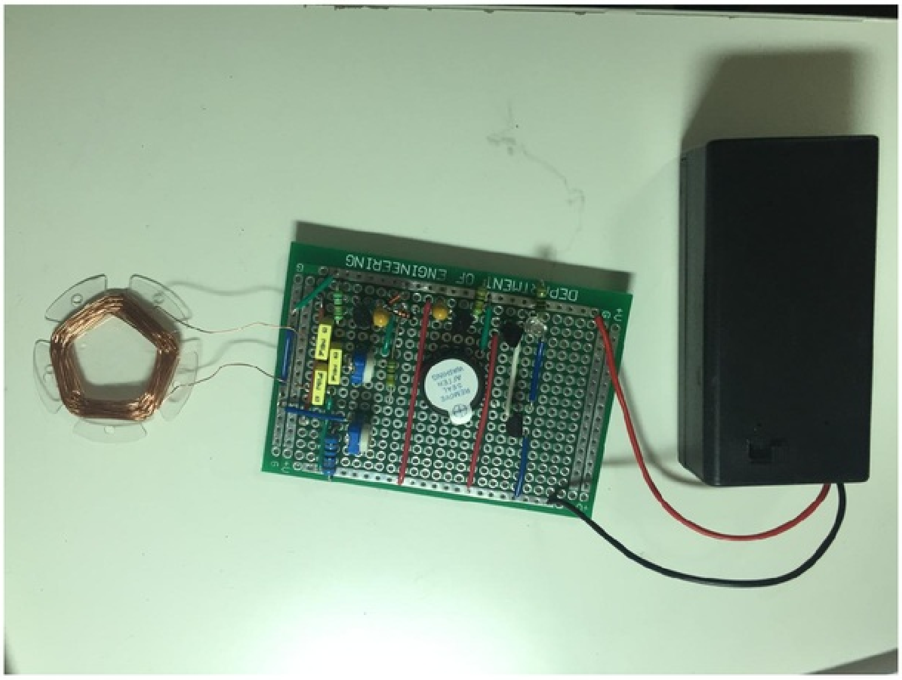


Figure 4.13 The prototype of Button cell scanner

4.6 Final testing results

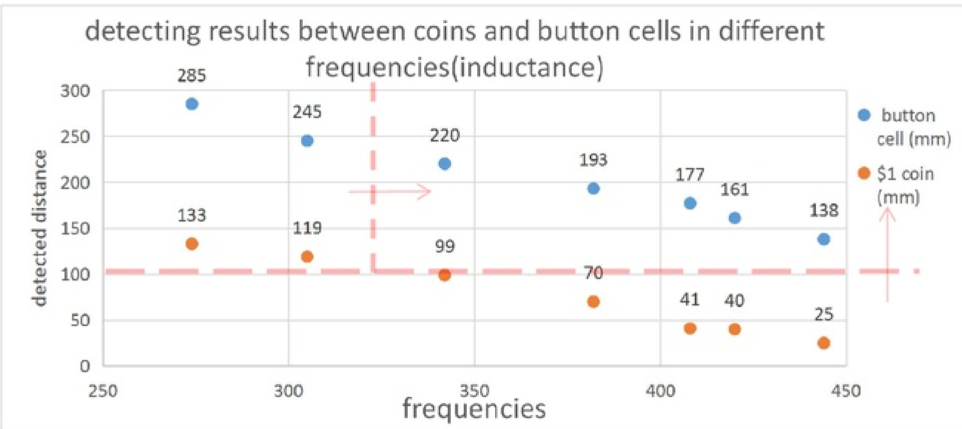
According to Figure 4.11, the final circuit of the button cell scanner which consists of four parts which are the oscillator, the voltage doubler, control system and power. Even if the sensitives is designed as adjustable, I still did a set of test to give users some suggestion for the setting.

Table 4.10 detecting results between coins and button cell in different frequencies

Frequency(kHz)	444	420	408	382	342	305	274
Inductance(uH)	26.3	28.8	30.2	31.5	35.5	38	42.3
Distance of button cell (mm)	138	161	177	193	220	245	285
Distance of $1 coin (mm)	25	40	41	70	99	119	133

As I mentioned in the introduction chapter, the specification of detecting distance is between 100mm and 300mm. Therefore, the shaded area is the best frequency area as there is no coin's data between these frequencies. In order to make the difference more clear, the table is converted into a chart which is shown below:

Figure 4.14 The detecting results of coins and button cells



As it shown in figure 4.13, it is clear to see that when the frequency is 342kHz or higher, only button cells could be found within the range of the specification. But the if the frequency of the button cell scanner is higher 500kHz approximately, the button cell could not be found either. Therefore the best frequency for the button cell scanner is between 342kHz and 500kHz approximately which depends on how sensitive the user wants.

4.6 Limitations

The prototype is completely based on pulse induction system, and it is able to detect the button cell at the moment. in addition, it is one of the simplest and cheapest ways to find the button cell but it still remains some limitations.

I design the equipment as a distance-variable Button Cell Scanner, but its maximum distance for detecting a Button cell only have 5cm. This equipment is only able to use for detecting a button cell instead of other general purposes like a metal detector.

Another limitation is that it work for detecting button cell with a strict distance such as 1-2cm or 2-4cm. If the scanner gets as close to a coin as enough, the buzz and the LED are also sent an alarm to users. According to the theory of my Button Cell Scanner, it is able detecting coins and button cells with the same frequency but at different distances. However, although there is a defect of the design, it still able to detect a button cell for saving more time for treatment. It is a very low-cost equipment(less than $5) and every family and hospital worth to keep one.

55

Chapter 5

Conclusions and Future work

5.1 Conclusions

Young children swallowing button cells occurs from time to time and they could not describe the issue clearly due to the age issue. When a child swallows a button cell, it usually gets stuck in the throat and chemical substances inside button cells could cause chemical reactions that severely cause a localised caustic injury or even cause death only within couples of hours.Hence this project aims to design a portable button cell scanner for hospitals, doctors and families so that they are able to discriminate between button cells and coins quickly,and thereby sufferers are able to save more time for treatment, minimising or avoiding the crisis within prime time.

I was working on this thesis from last semester holiday and I built out a prototype before the end of the semester eventually although there are a few limitations left. However, This is a very good topic, I learned a lot of skills and knowledge from it and I hope this button cell scanner could help families and doctors to avoid the problem because it only needs a couple of dollars. The design of the thesis had been changing during the entire semester to make it more efficient, stabler and as cheap as possible. Time elapse so quick, there are some improvements have not finished within this semester, if I still have a couple of weeks left, I can make it better.

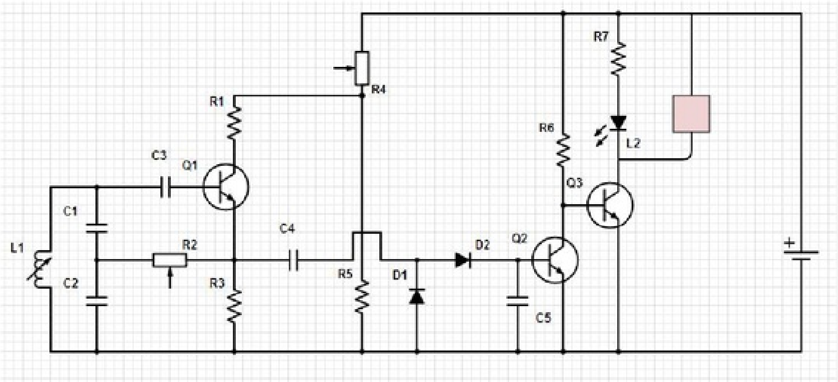


Figure 5.1 Final circuit design

5.2 Future Work

Although this prototype works very well at the moment, there are still have several improvements could be added up. The time lapse so quick that I do not have enough time to finish all improvements. If I have a few more week, it must be better. In this section, I will introduce two three major possible improvements which could make the button cell scanner much better.

5.2.1 voltage regulators

The voltage regulator is voltage stabilizer which designed to generate a constant voltage level from an unstable input voltage. It is very useful for stabilising the voltage level especially when the dropping dry battery is considered as the power supply. The size could be as same as a transistor. for example, 78L05 is a very suitable voltage regulator for the circuit with 5V fixed voltage output. 5V is enough for the oscillation of the project. another type of voltage regulator is the variable regulator, the output change with different inputs, the only thing it does is to keep the output as stable as possible. in the project, whenever the voltage of dry-battery power supply drops, the sensitive of the button cell scanner need to readjust. However, in order to avoid the issue, I use the 9V battery as the power supply to slow down the decay due to its very large capacity.

5.2.2 Print Circuit Board(PCB)

I spend much longer time on experiment stage due to poor connections of the breadboard. It is very annoy, even a simple circuit will not always work as expected due to the poor connecting breadboard. As we known that a breadboard is a very important and convenient board for building an electronic circuit and users are able to replace the components easily as well as measure voltage of nodes where they want. However, some pins of components are very thin sometime and breadboard holes become loose if they have been used for long years. this is the issues which lead me waste a lot of time and sometimes even come out an incorrect result which may mislead me to a wrong direction. In addition, wire connections will also affect the experimental result. Sometimes longer wires probably generate a loop which could interrupt the circuit severely, therefore a solution is required to be found for such an issue such as PCB.

PCB is one of the best solutions for this issue. PCB is a glass fabricated plastic which comes with copper tracks and holes required for components. A good PCB could make a circuit much smaller. In addition, PCB could avoid all wiring mistake so that save more time from further inspection. All holes and components are fixed in the correct place, and it is able to be reproductive if required.

5.2.3 Inductive Censors

Inductive Sensing is a contactless, short-range sensing technology which enables low-cost, high-resolution sensing of conductive targets in the presence of dust, dirt, oil, and moisture, making it extremely reliable in hostile environments. One of the cheapest models is LDC 1000 which could convert an inductance value to a digital value and its size is as small as a quarter coin. More importantly, the power supply of it only needs 5V which perfectly matches the 78L05 voltage regulator which I have mentioned before.

When the inductance of coil reduces, this sensor will convert the change into a digital data. As we known that, different metal has different interruptions, it is also able to discriminate possible object by amplifying the change and sending the data to a microcontroller for analysing.

Figure 5.2 a Inductive Censor of LDC1000

Chapter 6

Abbreviations

AWR	Automatic Workload Repository
Op-amp	Operational amplifier
BOF	Beat Frequency Oscillation
VLF	Very-Low-Frequency Detectors
PI	Pulse Induction
BJT	Bipolar junction transistor
PCB	Print Circuit Board
AC	Alternating Current
DC	Direct Current

Appendix A - datasheet of CS209

CS209A

AUTOMOTIVE GRADE

Proximity Detector

Description

The CS209A is a bipolar monolithic integrated circuit for use in metal detection/proximity sensing applications. The IC (see block diagram) contains two on-chip current regulators, oscillator and low-level feedback circuitry, peak detection/demodulation circuit, a comparator and two complementary output stages.

The oscillator, along with an external LC network, provides controlled oscillations where amplitude is highly dependent on the Q of the LC tank. During low Q conditions, a variable low-level feedback circuit provides drive to maintain oscillation. The peak demodulator senses the negative portion of the oscillator envelop and provides a demodulated waveform as input to the comparator. The comparator sets the states of the complementary outputs by comparing the input from the demodulator to an internal reference. External loads are required for the output pins.

A transient suppression circuit is included to absorb negative transients at the tank circuit terminal.

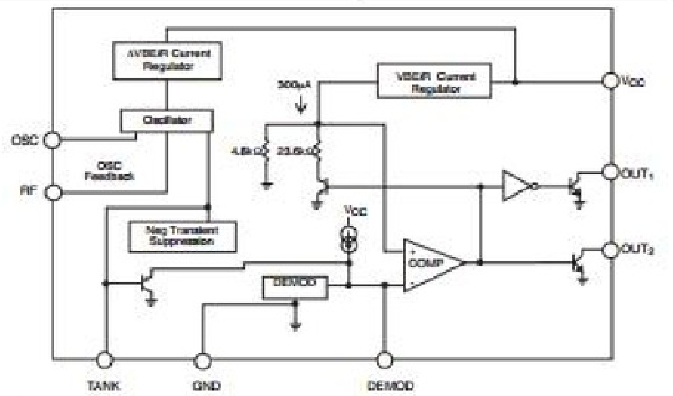
Features

- Separate Current Regulator for Oscillator
- Negative Transient Suppression
- Variable Low-Level Feedback
- Improved Performance over Temperature
- 6mA Supply Current Consumption at V_{CC} = 12V
- Output Current Sink Capability
  20mA at $4V_{CC}$
  100mA at $24V_{CC}$

Absolute Maximum Ratings

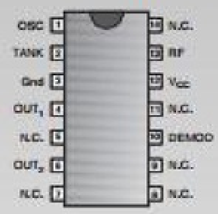
Supply Voltage 24V
Power Dissipation (T_A = 125°C) 200mW
Storage Temperature Range .... –55°C to +165°C
Junction Temperature .... –40°C to +150°C
Electrostatic Discharge (except TANK pin) 2kV
Lead Temperature Soldering
  Wave Solder(through hole styles only) .... 10 sec. max, 260°C peak
  Reflow (SMD styles only) .... 60 sec. max above 183°C, 230°C peak

Block Diagram

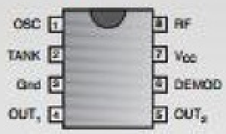


Package Options

14L SO



8L PDIP & SO



Cherry Semiconductor

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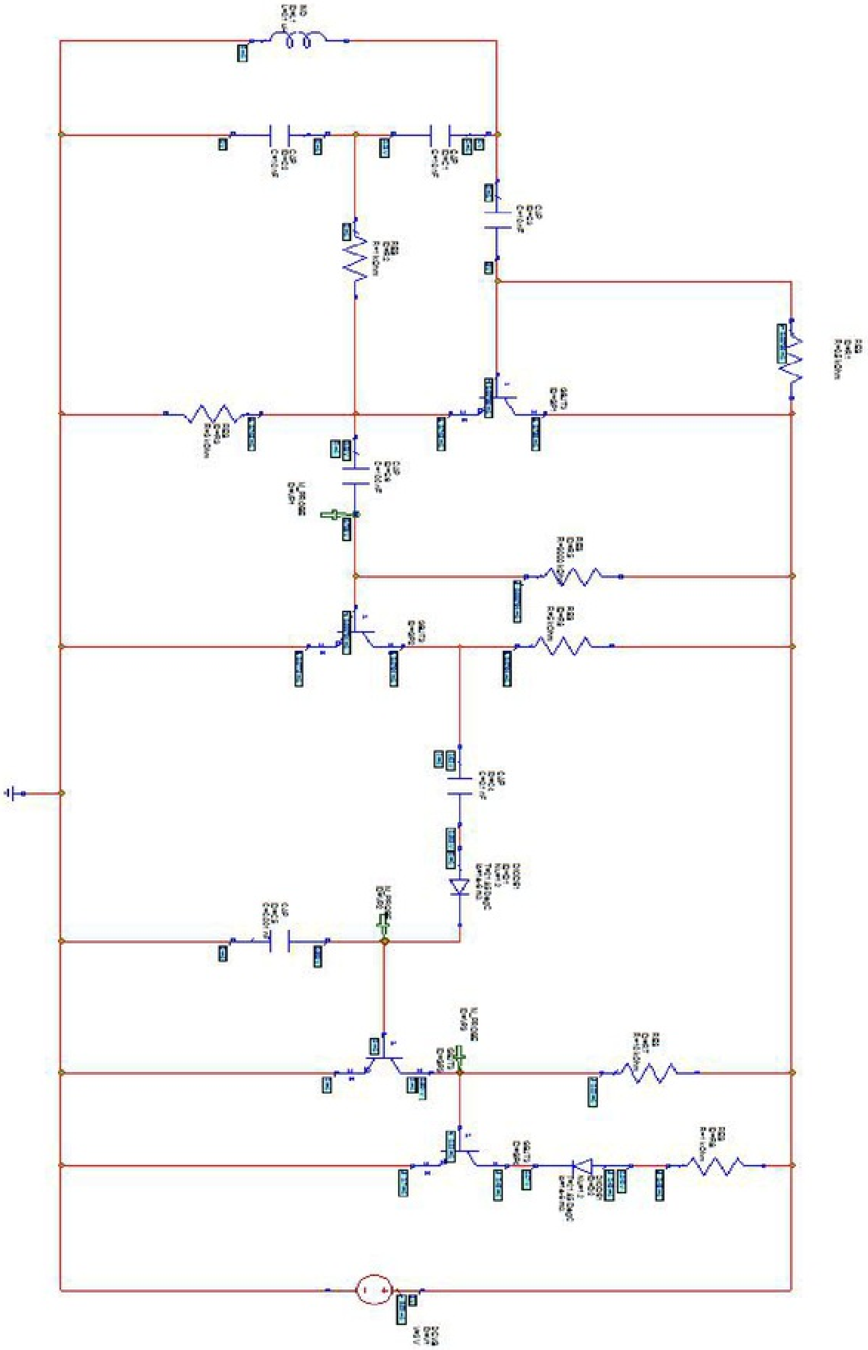
2000 South County Trail, East Greenwich, RI 02818
Tel: (401)885-3600 Fax: (401)885-5786
Email: info@cherry-semi.com
Web Site: www.cherry-semi.com

Appendix B - initial design simulation



Appendix C - datasheet of S9014

WEITRON

S9014

NPN General Purpose Transistors

Pb Lead(Pb)-Free

TO-92

1. EMITTER
2. BASE
3. COLLECTOR

ABSOLUTE MAXIMUM RATINGS (Ta=25°C)

Rating	Symbol	Value	Unit
Collector-Emitter Voltage	V_{CEO}	45	Vdc
Collector-Base Voltage	V_{CBO}	50	Vdc
Emitter-Base Voltage	V_{EBO}	5.0	Vdc
Collector Current	I_C	100	mAdc
Total Device Dissipation T_A=25°C	P_D	0.4	W
Junction Temperature	T_j	150	°C
Storage, Temperature	Tstg	-55 to +150	°C

ELECTRICAL CHARACTERISTICS

Characteristics	Symbol	Min	Max	Unit
Collector-Emitter Breakdown Voltage (I_C= 0.1 mAdc, I_B=0)	$V_{(BR)CEO}$	45	-	Vdc
Collector-Base Breakdown Voltage (I_C= 100uAdc, I_B=0)	$V_{(BR)CBO}$	50	-	Vdc
Emitter-Base Breakdown Voltage (I_E= 100 uAdc, I_C=0)	$V_{(BR)EBO}$	5.0	-	Vdc
Collector Cutoff Current (V_{CB}= 50 Vdc, I_E=0)	I_{CBO}	-	0.1	uAdc
Emitter Cutoff Current (V_{EB}= 3.0Vdc, I_C=0)	I_{EBO}	-	0.1	uAdc

WEITRON

http://www.weitron.com.tw

Appendix D- datasheet of LM748

OBSOLETE

Texas Instruments **LM748**

www.ti.com SNOS660C – NOVEMBER 1994 – REVISED APRIL 2013

LM748 Operational Amplifier

Check for Samples: LM748

FEATURES

- **Frequency Compensation with a Single 30 pF Capacitor**
- **Operation from ±5V to ±20V**
- **Continuous Short-Circuit Protection**
- **Operation as a Comparator with Differential Inputs as High as ±30V**
- **No Latch-Up When Common Range is Exceeded**
- **Same Pin Configuration as the LM101**

DESCRIPTION

The LM48 is a general purpose operational amplifier with external frequency compensation.

The unity-gain compensation specified makes the circuit stable for all feedback configurations, even with capacitive loads. It is possible to optimize compensation for best high frequency performance at any gain. As a comparator, the output can be clamped at any desired level to make it compatible with logic circuits.

The LM748C is specified for operation over the 0°C to +70°C temperature range.

Connection Diagram

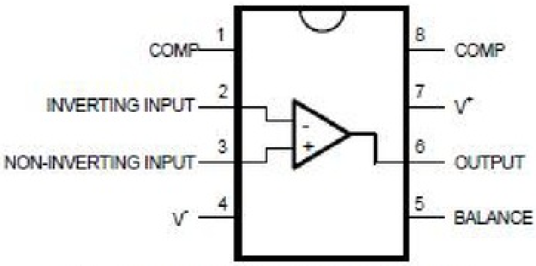


Figure 1. Dual-In-Line Package (Top View)
See Package Number P0008E

Appendix D- datasheet of CA3140E

intersil

CA3140, CA3140A

Data Sheet **September 1998** **File Number 957.4**

4.5MHz, BiMOS Operational Amplifier with MOSFET Input/Bipolar Output

The CA3140A and CA3140 are integrated circuit operational amplifiers that combine the advantages of high voltage PMOS transistors with high voltage bipolar transistors on a single monolithic chip.

The CA3140A and CA3140 BiMOS operational amplifiers feature gate protected MOSFET (PMOS) transistors in the input circuit to provide very high input impedance, very low input current, and high speed performance. The CA3140A and CA3140 operate at supply voltage from 4V to 36V (either single or dual supply). These operational amplifiers are internally phase compensated to achieve stable operation in unity gain follower operation, and additionally, have access terminal for a supplementary external capacitor if additional frequency roll-off is desired. Terminals are also provided for use in applications requiring input offset voltage nulling. The use of PMOS field effect transistors in the input stage results in common mode input voltage capability down to 0.5V below the negative supply terminal, an important attribute for single supply applications. The output stage uses bipolar transistors and includes built-in protection against damage from load terminal short circuiting to either supply rail or to ground.

The CA3140 Series has the same 8-lead pinout used for the "741" and other industry standard op amps. The CA3140A and CA3140 are intended for operation at supply voltages up to 36V (±18V).

Ordering Information

PART NUMBER (BRAND)	TEMP. RANGE (^oC)	PACKAGE	PKG. NO.
CA3140AE	-55 to 125	8 Ld PDIP	E8.3
CA3140AM (3140A)	-55 to 125	8 Ld SOIC	M8.15
CA3140AS	-55 to 125	8 Pin Metal Can	T8.C
CA3140AT	-55 to 125	8 Pin Metal Can	T8.C
CA3140E	-55 to 125	8 Ld PDIP	E8.3
CA3140M (3140)	-55 to 125	8 Ld SOIC	M8.15
CA3140M96 (3140)	-55 to 125	8 Ld SOIC Tape and Reel	
CA3140T	-55 to 125	8 Pin Metal Can	T8.C

Features

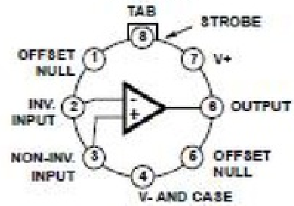
- MOSFET Input Stage
  - Very High Input Impedance (Z_{IN}) -1.5TΩ (Typ)
  - Very Low Input Current (I_I) -10pA (Typ) at ±15V
  - Wide Common Mode Input Voltage Range (V_{ICR}) - Can be Swung 0.5V Below Negative Supply Voltage Rail
  - Output Swing Complements Input Common Mode Range
- Directly Replaces Industry Type 741 in Most Applications

Applications

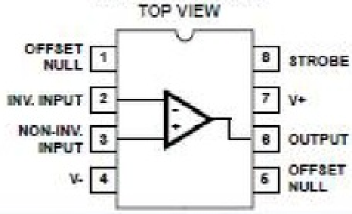
- Ground-Referenced Single Supply Amplifiers in Automobile and Portable Instrumentation
- Sample and Hold Amplifiers
- Long Duration Timers/Multivibrators (μseconds-Minutes-Hours)
- Photocurrent Instrumentation
- Peak Detectors
- Active Filters
- Comparators
- Interface in 5V TTL Systems and Other Low Supply Voltage Systems
- All Standard Operational Amplifier Applications
- Function Generators
- Tone Controls
- Power Supplies
- Portable Instruments
- Intrusion Alarm Systems

Pinouts

CA3140 (METAL CAN)
TOP VIEW



CA3140 (PDIP, SOIC)
TOP VIEW



Appendix D- datasheet of 1N4148

NXP Semiconductors | Product data sheet

High-speed diodes — 1N4148; 1N4448

LIMITING VALUES

In accordance with the Absolute Maximum Rating System (IEC 60134).

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{RRM}	repetitive peak reverse voltage		–	100	V
V_R	continuous reverse voltage		–	100	V
I_F	continuous forward current	see Fig.2; note 1	–	200	mA
I_{FRM}	repetitive peak forward current		–	450	mA
I_{FSM}	non-repetitive peak forward current	square wave; T_j = 25 °C prior to surge; see Fig.4			
		t = 1 μs	–	4	A
		t = 1 ms	–	1	A
		t = 1 s	–	0.5	A
P_{tot}	total power dissipation	T_{amb} = 25 °C; note 1	–	500	mW
T_{stg}	storage temperature		–65	+200	°C
T_j	junction temperature		–	200	°C

Note

1. Device mounted on an FR4 printed-circuit board; lead length 10 mm.

ELECTRICAL CHARACTERISTICS

T_j = 25 °C unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_F	forward voltage	see Fig.3			
	1N4148	I_F = 10 mA	–	1	V
	1N4448	I_F = 5 mA	0.62	0.72	V
		I_F = 100 mA	–	1	V
I_R	reverse current	V_R = 20 V; see Fig.5		25	nA
		V_R = 20 V; T_j = 150 °C; see Fig.5	–	50	μA
I_R	reverse current; 1N4448	V_R = 20 V; T_j = 100 °C; see Fig.5	–	3	μA
C_d	diode capacitance	f = 1 MHz; V_R = 0 V; see Fig.6	–	4	pF
t_{rr}	reverse recovery time	when switched from I_F = 10 mA to I_R = 60 mA; R_L = 100 Ω; measured at I_R = 1 mA; see Fig.7	–	4	ns
V_{fr}	forward recovery voltage	when switched from I_F = 50 mA; t_r = 20 ns; see Fig.8	–	2.5	V

THERMAL CHARACTERISTICS

SYMBOL	PARAMETER	CONDITIONS	VALUE	UNIT
$R_{th(j-tp)}$	thermal resistance from junction to tie-point	lead length 10 mm	240	K/W
$R_{th(j-a)}$	thermal resistance from junction to ambient	lead length 10 mm; note 1	350	K/W

Note

1. Device mounted on a printed-circuit board without metallization pad.

Appendix E - Consultation Meeting Form

Consultation Meetings Attendance Form

Week	Date	Comments (if applicable)	Student's Signature	Supervisor's Signature
Week1	2/8/2016	Circuit design	[signature]	Mukhopadhyay 02/08/16
Week2	11/8/2016	buying components & simulation	[signature]	Mukhopadhyay
Week3	15/8/2016	resonator design	[signature]	Mukhopadhyay
Week4	23/8/2016	resonator tests	[signature]	Mukhopadhyay
Week5	29/8/2016	finishing report	[signature]	Mukhopadhyay
Week6	5/9/2016	amplifier circuit building	[signature]	Mukhopadhyay
Week7	12/9/2016	rectifier design	[signature]	Mukhopadhyay
Week8	3/10/2016	rectifier tests	[signature]	Mukhopadhyay
Week9	10/10/2016	Control system design	[signature]	Mukhopadhyay
Week10	17/10/16	Control system optimizing	[signature]	Mukhopadhyay
Week11	24/10/16	optimizing prototype	[signature]	Mukhopadhyay
Week12	31/10/16	preparing report & presentation	[signature]	Mukhopadhyay

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