Department of Engineering

A Pulse Induction Metal Detector

ENGN3227
Analogue Electronics

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Abstract

This project focuses on the adaptation, simulation and construction of a commonly available schematic for a Pulse Induction (PI) metal detector.

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

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

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

Project Aim

The aim of this project was to create a circuit that was capable of detecting metal. It had to be battery powered and use a commonly available and understood design. In addition to this, the circuit design had to be relatively simple and compact so as to fit on a size limited Printed Circuit Board (PCB) board (due to the use of the EAGLE PCB layout tool).

Background

A typical metal detector used for detecting buried coins, gold, or landmines consists of a circular horizontal coil assembly held just above the ground as shown in the figure to the right. Other uses of more specialized metal detectors include usage in medicine, security etc. Metal detectors have been used for diagnostic purposes since 1881. They have been utilised to localise a myriad of foreign objects including bullets, intraocular metallic fragments, swallowed coins and other foreign bodies and medical devices. Rapid detection of metallic objects may facilitate diagnosis or treatment. Metal detectors are diagnostically useful because of their low expense, lack of radiation exposure and ease of use[1]. Other uses include demining (the detection of land mines), the detection of weapons such as knives and guns, especially at airports, geophysical prospecting, archaeology and 'treasure hunting'. Metal detectors are also used to detect foreign bodies in food, and in the construction industry to detect steel reinforcing bars in concrete and pipes and wires buried in walls and floors[2].

Metal detectors are finding applications all over the place as the ability to detect certain types of materials at a distance become ever more crucial.

Figure 1 – A typical commercially available metal detector[3]

[1] Diagnostic uses of metal detectors: a review - http://www.medscape.com/viewarticle/509541
[2] http://en.wikipedia.org/wiki/Metal_detector

Theory

The kind of metal detector we have built is based on pulse induction (PI). PI systems may use a single coil as both transmitter and receiver, or they may have two or even three coils working together. This type of metal detector sends powerful, short bursts (pulses) of current through a coil of wire. Each pulse generates a brief magnetic field. When the pulse ends, the magnetic field reverses polarity and collapses very suddenly, resulting in a sharp electrical spike. This spike lasts a few microseconds (millionths of a second) and causes another current to run through the coil. This current is called the reflected pulse and is extremely short, lasting only about 30 microseconds. Another pulse is then sent and the process repeats. A typical PI-based metal detector sends about 100 pulses per second, but the number can vary greatly based on the manufacturer and model, ranging from a couple of dozen pulses per second to over a thousand.

If the metal detector is over a metal object, the pulse creates an opposite magnetic field in the object. When the pulse's magnetic field collapses, causing the reflected pulse, the magnetic field of the object makes it take longer for the reflected pulse to completely disappear. This process works something like echoes: If you yell in a room with only a few hard surfaces, you probably hear only a very brief echo, or you may not hear one at all; but if you yell in a room with a lot of hard surfaces, the echo lasts longer. In a PI metal detector, the magnetic fields from target objects add their "echo" to the reflected pulse, making it last a fraction longer than it would without them.

A sampling circuit in the metal detector is set to monitor the length of the reflected pulse. By comparing it to the expected length, the circuit can determine if another magnetic field has caused the reflected pulse to take longer to decay. If the decay of the reflected pulse takes more than a few microseconds longer than normal, there is probably a metal object interfering with it.

The sampling circuit sends the tiny, weak signals that it monitors to a device call an integrator. The integrator reads the signals from the sampling circuit, amplifying and converting them to direct current (DC). The direct current's voltage is connected to an audio circuit, where it is changed into a tone that the metal detector uses to indicate that a target object has been found.

PI-based detectors are not very good at discrimination because the reflected pulse length of various metals is not easily separated. However, they are useful in many situations in which other non PI based metal detectors would have difficulty, such as in areas that have highly conductive material in the soil or general environment. Also, PI-based systems can often detect metal much deeper in the ground than other systems[3].

[3] How Metal Detectors Work - http://home.howstuffworks.com/metal-detector3.htm

Implementation

Circuit Choice

As described earlier, the basic design of this metal detector is a pulse induction (PI) design. Although multiple coils can be used for a PI metal detector, the system chosen for this group was a single coil design, for simplicity in design and construction.

The circuit design was taken from the G.L. Chemelec[4] website which contained schematics and construction notes for both one and two coil metal detectors. The one coil design that has been used for this project is known as the Pulse 1 Metal Detector.

The circuit was chosen for its learning value and deemed complex enough to mitigate a complete design from scratch. It involved considerable study to understand the components used and how they interacted. The procurement was lengthy and difficult. The wide range of devices challenged construction including a surface mounted device. Not all parts were available due to cost and availability and minor modifications were made. This included substitution of resistors, variable resistors and capacitors. The PCB was redesigned and the version on the website was not used. A block diagram of the circuit can be seen in Figure 2.

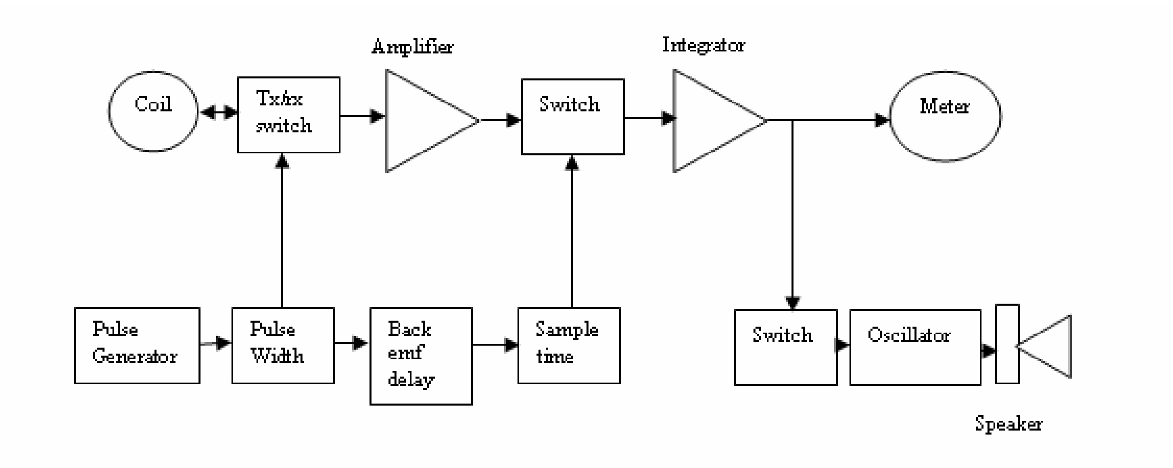


Figure 2 – Block Diagram of the Pulse 1 Metal Detector

The basic design of the metal detector consists of four parts as seen above. These are:

- The power supply (four IC's),
- The pulse generation circuit (four 555's, and coil),
- The detection system (coil, amplifier and integrator), and
- The instrumentation system (555).

The pulse generation system provides a continuous train of pulses with a specified frequency, width, time for the back EMF to decay and time for the system to listen for any induced signals in a target. These can be changed by adjusting the capacitors and

[4] http://www3.telus.net/chemelec/Projects/Metal/Metal.htm

resistors around the integrated circuits used. A transistor acts as a switch changing the mode of the coil from generating signals to listening for signals. The detection system then amplifies any signal detected and turns it into a continuous and stable voltage that increases a slow and steady beat heard in a speaker. Another switch ensures that the signal amplifier has no output whilst the coil is generating signals. This alerts the operator to any target metals. Batteries are used for the power supply and other integrated circuits make sure that a steady voltage is supplied even as the battery is slowly drained down to a certain point.

Schematic and detailed description

We will now discuss the circuits operation in detail, so as to explain the significance and requirement for each component. The modified circuit schematic used is shown in Figure 3.

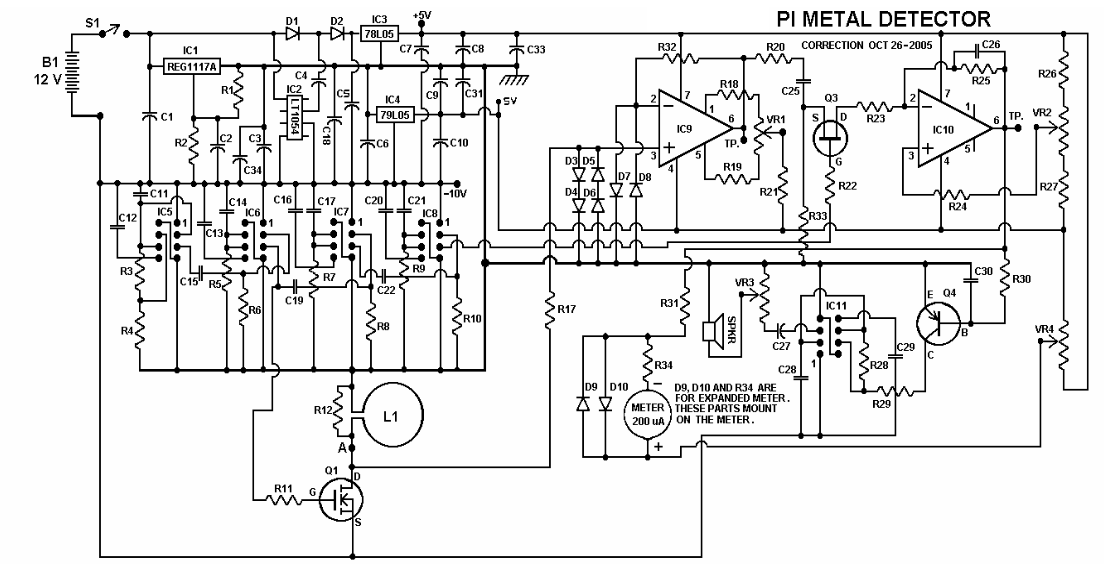


Figure 3 – Schematic of the Pulse 1 Metal Detector

Power Supply

The power for the metal detector was supplied by 12V battery or supply. The power supply circuitry then regulated this using the REG1117A voltage regulator allowing for voltage consumption of the battery down to about 3V. The LT1054 provided conversion to -10V, the 78L05 provided +5V and the 79L05 provided the -5V voltage. All the supply voltages were DC (direct current). The -10V rail was used for the 555's supply voltage and the +/-5V was used for the Op-amp supply voltage.

Pulse Generation

The pulse generation system consisted of 4 555 timer ICs. IC5 determined the frequency and duty cycle of the pulse and was configured for astable operation meaning that it was used to provide a constant clock for the rest of the pulse generation circuit. The frequency – set by C11 was approximately 100Hz whilst the duty cycle was approximately 33%. The rest of the 555's were configured as monostable, meaning that they were a 'one-shot' device. IC6 determined the pulse width and which was set to approximately 165 us. Adjusting this required making changes to the dead time which was controlled by IC7. The dead time or delay time is the time in which the system waits for the back EMF of the pulse to decay. In this case it was approximately 36us. IC8 was used to set the sample time or receive time and was approximately 50ms. Once the back EMF decays, the receive time is the length for which the system listens for a response. By changing C11 from .22uF to .01uF the frequency was changed from 47Hz to 1000Hz. Changing R3 and R4 adjusted the duty cycle. The pulse width could also be adjusted by changing the resistance associated with that particular 555. For example a value of 5.1kΩ produced a pulse width of approximately 56us and 15.1kΩ gave 166us. Likewise the dead time and receive time could be adjusted through their associated resistors. These timings correlate well with the theory of PI metal detectors as discussed above.

Coil and Instrumentation

A simple circular coil of about 8" in diameter was chosen and used for the testing of the circuit, and it should be noted that this one of the most critical aspects of the system and its sensitivity. Q1 provided the switching between generating a pulse and listening within the coil.

IC9 is the main 'detector' of any signals in the coil and provided most of the gain of the system. Q3 was used to turn on the output (in this case the speaker output) when the system is operating in the receive time so that no interference from the pulse generation was fed through to the instrumentation. This was then integrated in IC10 to produce a signal in the instrumentation part of the system. IC9 has the only calibration point of the system and the variable resistor and needs to be set for to produce an voltage of between 0.2V and 0.5V at pin 6 of IC9.

The instrumentation system consists of a 555 in astable configuration, IC11. This IC is used to provide a slow beat through the speaker. When a reflected signal is detected the beat speeds up and is easily heard. This is achieved as Q4 is turned on by the output from IC10 which increases the frequency in the output of IC11. There is the option of adding an ammeter if desired for greater sensitivity in detection. The version used in this project did not include this.

Results

The first implementation of the circuit, and the one discussed in this report is the breadboard implementation. This was the case due to the late delivery of the PCBs and an insufficient time to fully construct and test the circuit. For this relatively complex system, more time was required for construction and testing of the final circuit.

This implementation involved the construction of the timer circuit, the integrator and speaker system, but did not involve the construction of the power supply circuits. This was done to greatly simply construction, and also because at this time the required ICs for the power supply circuit had not yet been delivered following ordering. Instead, the power supplies in the lab was used to provide the required +5V, -5V and -10V.

Before proper operation of the circuit could be performed, some troubleshooting had to be carried out. The coil was substituted with inductors of varying strengths to observe the response and also to hear how the sound from the speakers changed. This mimicked the coil being passed across varies different metals in order to verify the correct operation of the circuit.

Initially, the 'beat' from the output of the speaker was inverted with a steady beat in normal operation that slowed down when the coil was in the vicinity of a metal. This was still effective for metal detection, as the difference between the speeds of the beat when the coil was moving across the metal was very noticeable. By rechecking the connections of Q4, it was found to be incorrectly connected, and reconnecting this solved the problem.

The coil used in the first tests was not overly sensitive, a more elaborate coil of larger diameter and more turns was constructed however this could not be tested with the breadboard implementation and should yield better results for the PCB. Further sensitivity was lost by using capacitors that were not fully to the specification of the original instructions. Cheaper, more easily available capacitors were used, and whilst this most probably reduced the sensitivity of the circuit, it still performed satisfactorily.

Interference was noted in the waveforms on the oscilloscope and the detector was thought to be probably too sensitive to be used within the laboratory environment as it appeared to be picking up many stray EM signals from around the lab. Whilst the frequency and pulse width generation was as expected, spurious signals in the receive time were seen. This did not appear to adversely affect performance though, as the receive time was always sufficient to allow an expected response from the speaker in the presence of a metal objects.

Conclusion

A pulse induction metal detector is a device with use in many different fields such as recreation, security or medicine. PSPICE was used to simulate the circuit and the coil used for metal detection was successfully modeled by using different values for inductors. The different waveforms obtained from the simulations can be observed in Appendix B.

A breadboard prototype was then created and of such a metal detector and several iterations of construction had to occur before the completed circuit would operate as expected. This involved breaking the circuit down into components, similar to that of the block diagram as shown on page 6.

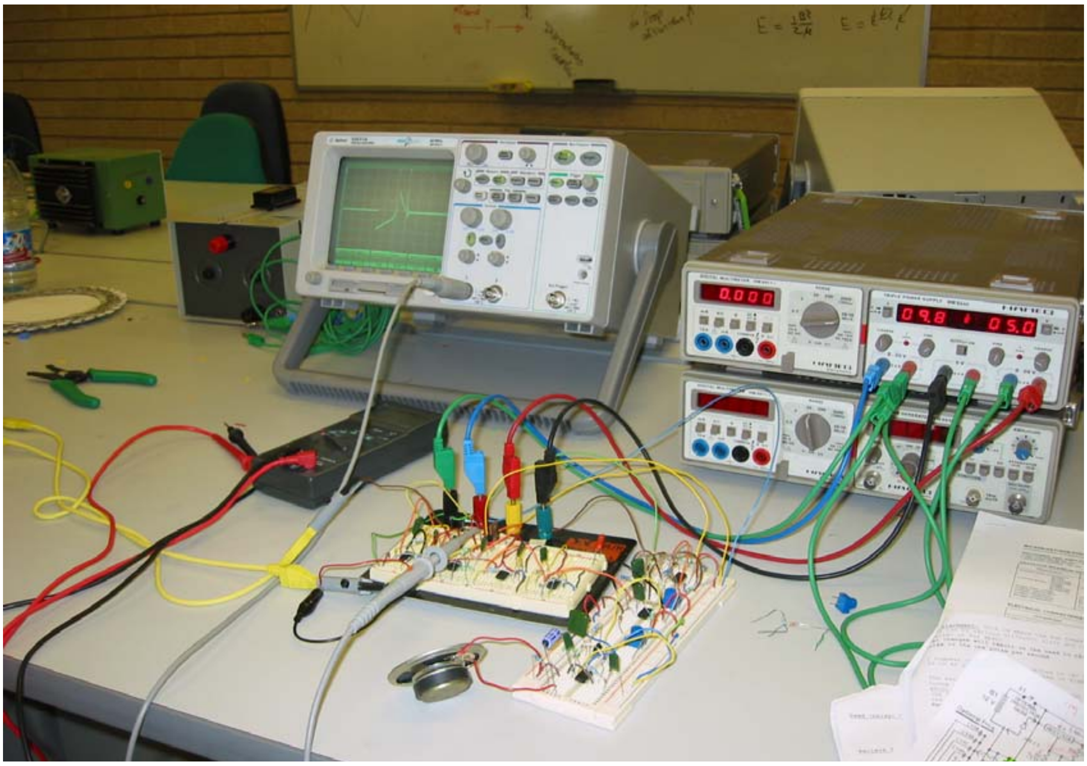
Once each stage was verified to operate correctly, the circuit was able to demonstrate detection of metal when the coil was in close proximity to a metal object, which was the aim of the circuit. Verification of the correct operation of each stage of construction was used by comparing this against waveforms obtained in the PSPICE simulations. The waveforms from the correctly functioning circuit can be seen in Appendix A.

A printed circuit board was designed, but time constraints meant that the full circuit with all power supply circuitry was unable to be constructed and tested in time.

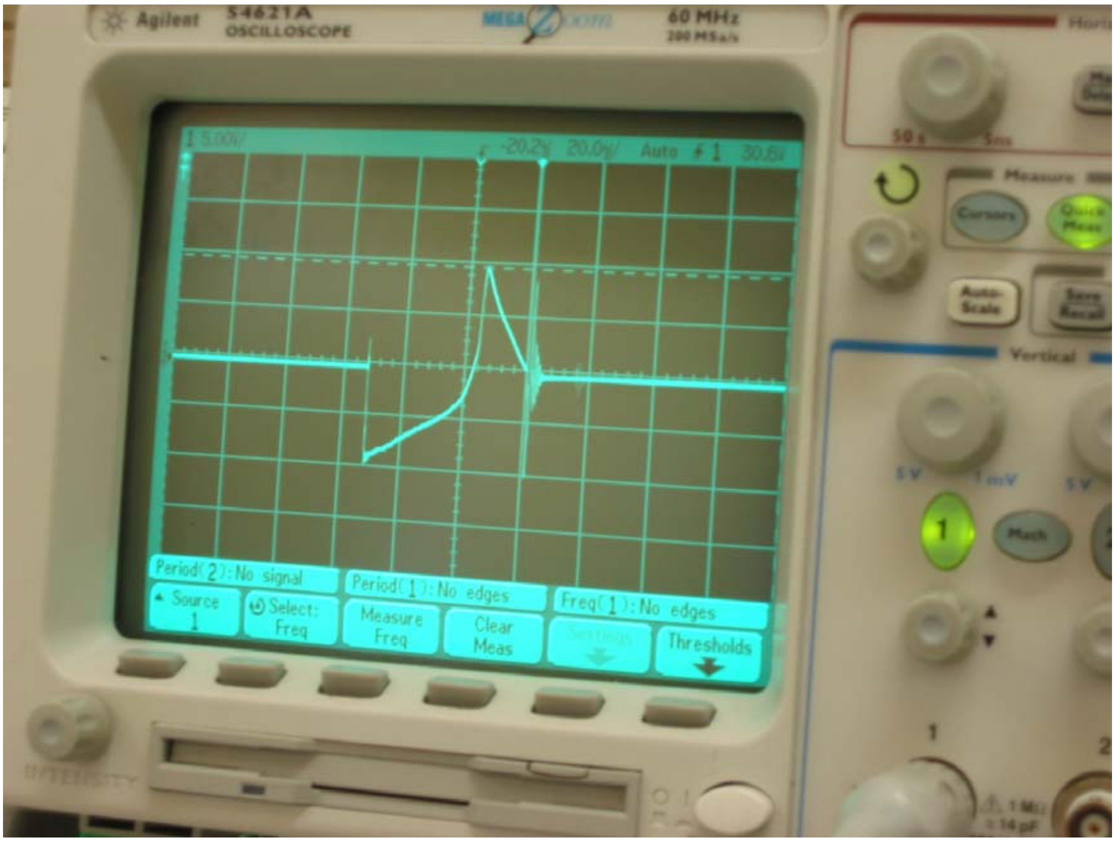
This project showed that by taking an easily available schematic of a pulse induction metal detector from the internet and redesigning sections of it to our specifications, we are able to construct a functioning example, along with in depth analysis of the behaviour of different components.

Appendices

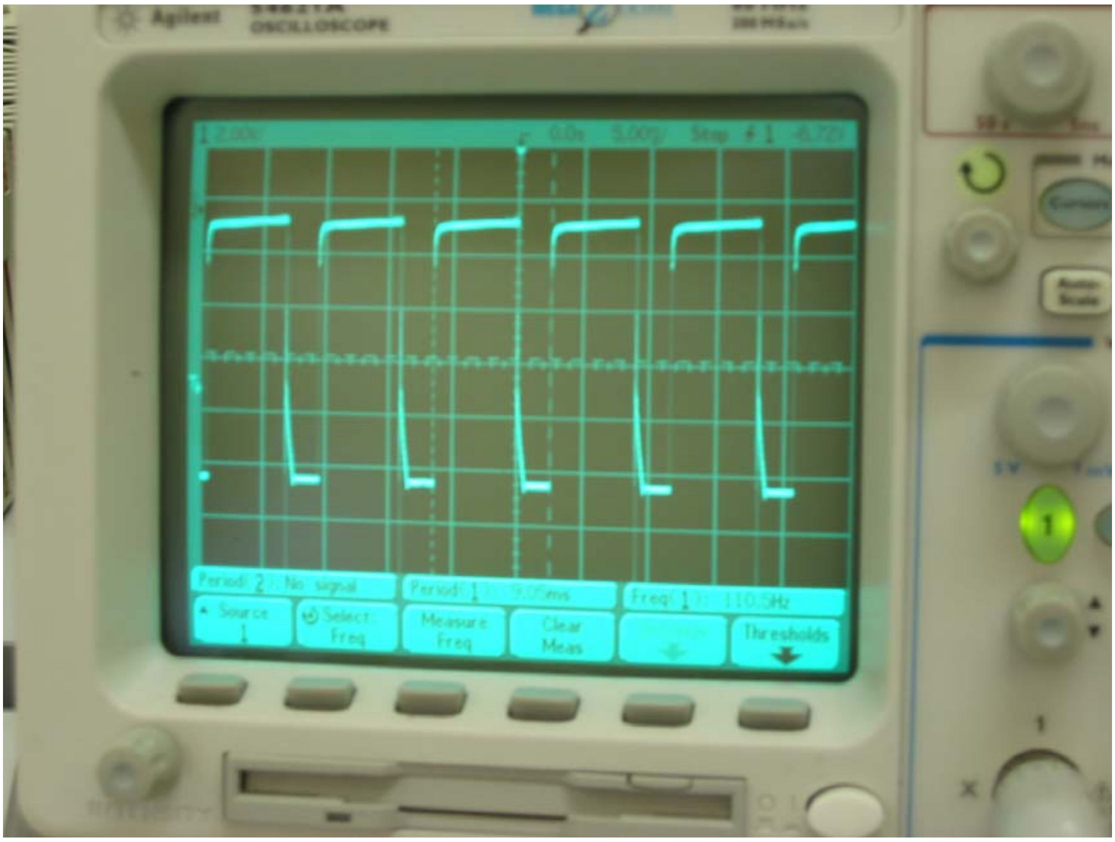
APPENDIX A



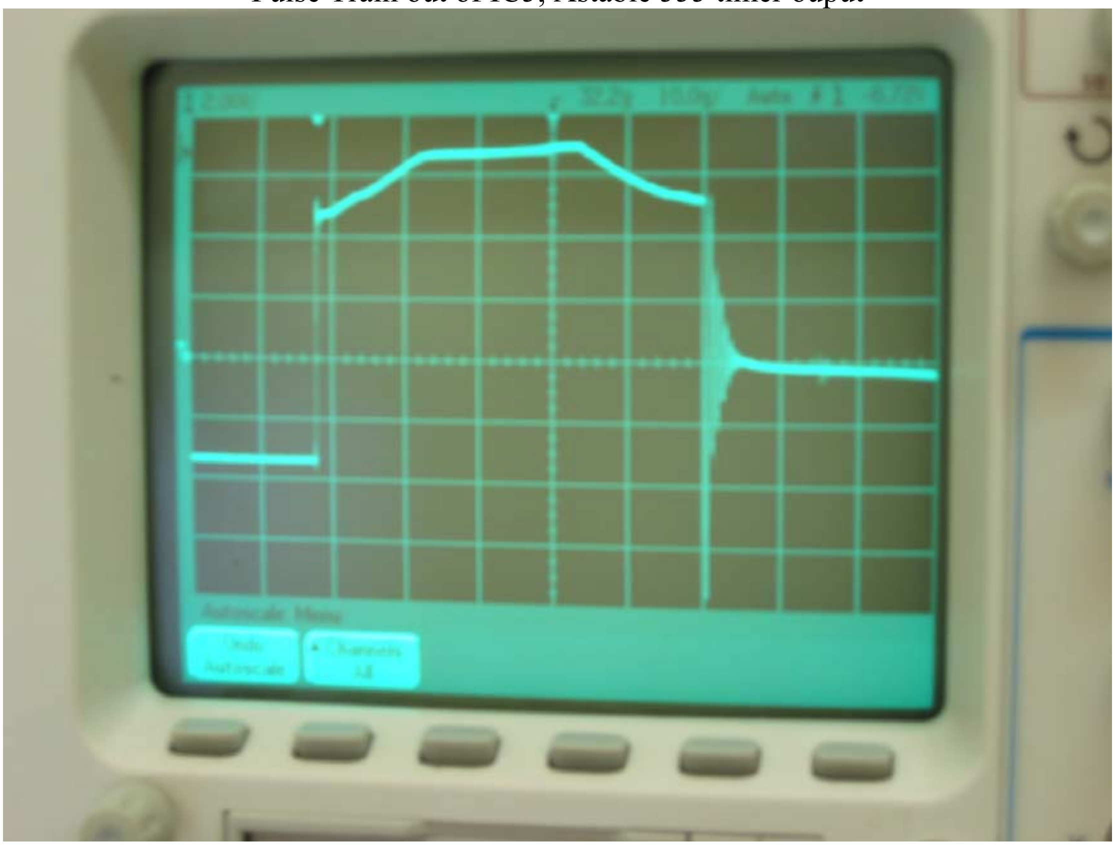
Metal Detector Circuit – Breadboard Implementation.



CRO Output of a Single Pulse to the Coil and Collapse.

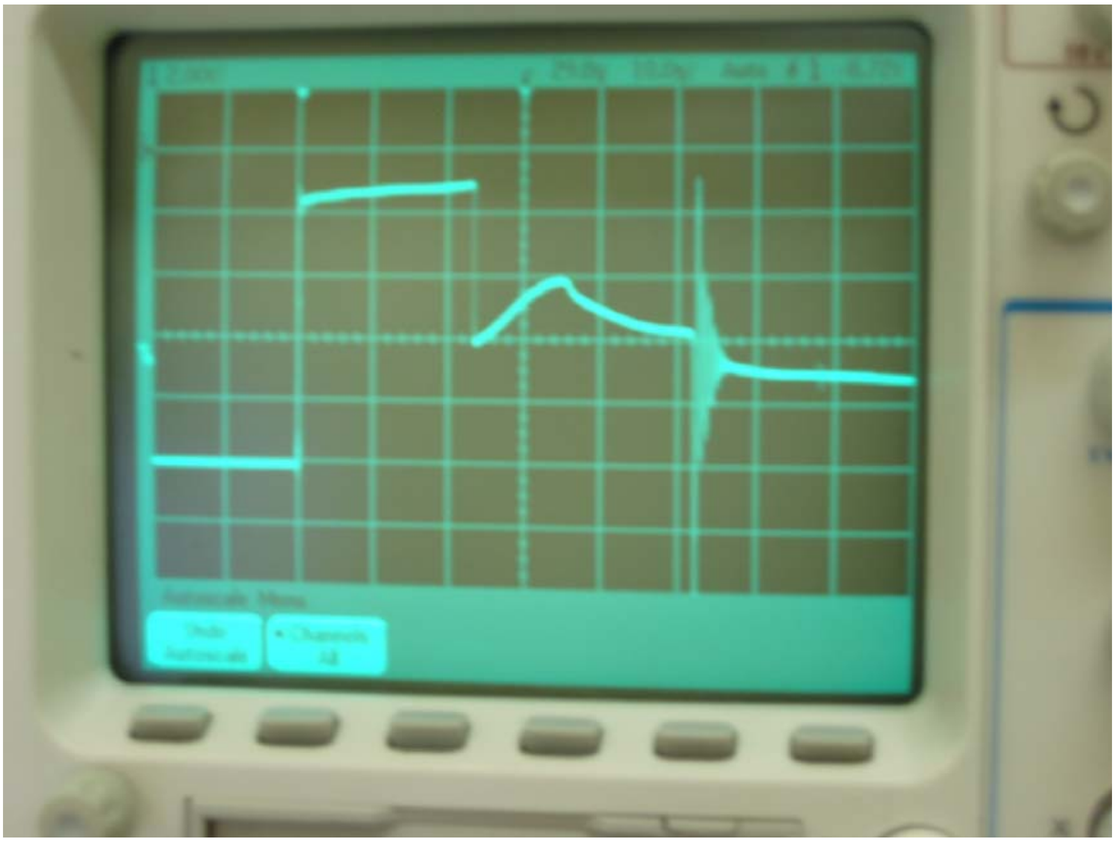


Pulse Train out of IC5, Astable 555 timer ouput

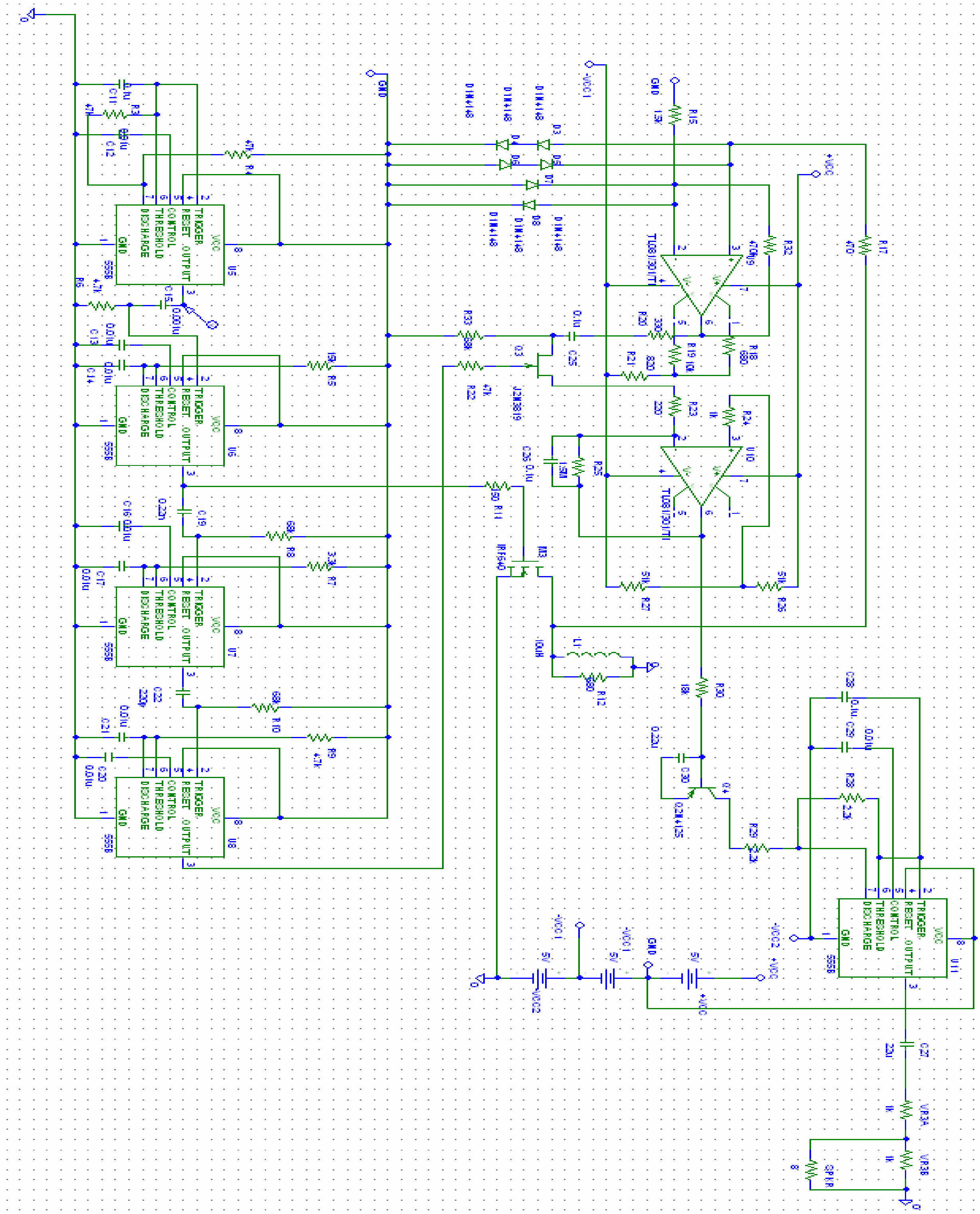


Output from IC6, Second 555 Monostable output.

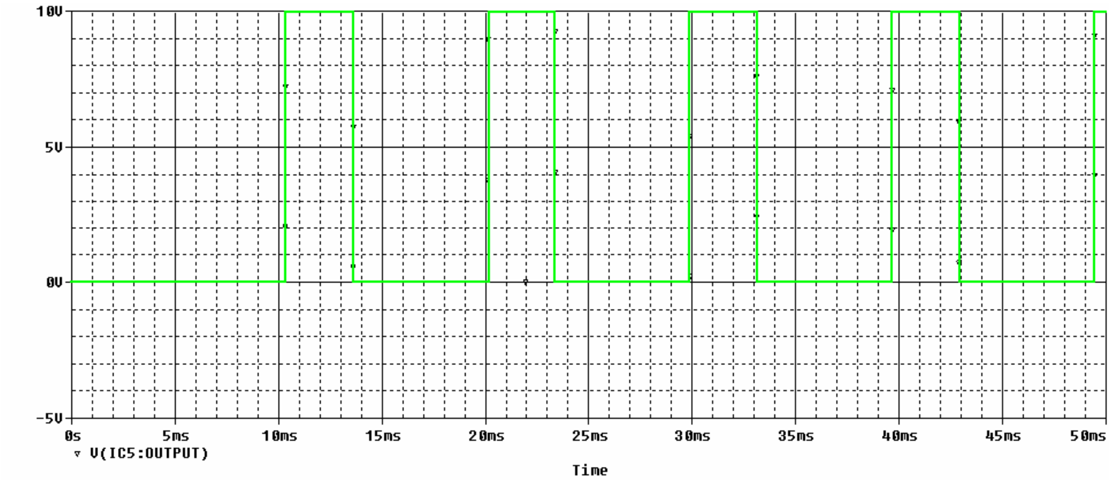
This is a very short pulse about 62us and is hence heavily zoomed, this is why non-linearity is shown in the output.


Output from 555 Timer 3

APPENDIX B



Screenshot of the PSPICE schematic, the coil has been simulated by an inductor of 10mH, the speaker has been simulated by an 8Ω resistor. By using a friends full version of PSPICE we were able to get all of the proper components, and able to actually simulate a schematic of this size.



Simulated output of first 555timer; Astable configuration.

Theoretically

$T_H = 0.693\ C\ (R_1 + R_2)$

$T_H = 0.693 \times 0.1 \times 10^{-6} \times (47 \times 10^3 + 47 \times 10^3)$

$T_H = 6.51ms$

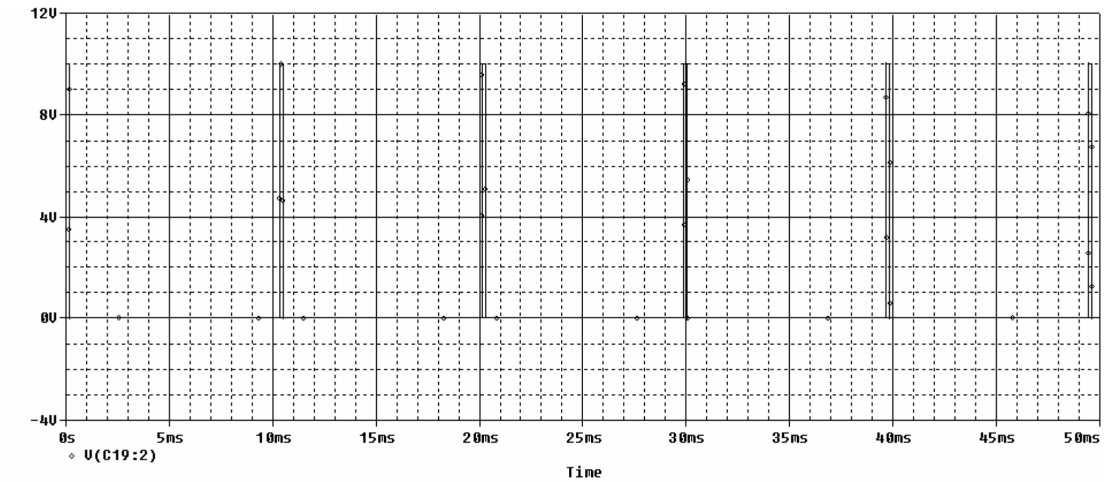
From the simulation $T_H = 6.50ms$

$T_L = 0.693\ C\ R_2$

$T_L = 0.693 \times 0.1 \times 10^{-6} \times 47 \times 10^3$

$T_L = 3.26ms$

From the simulation, $T_L = 3.278ms$



Simulated output from second 555 timer, monostable configuration

This monostable configuration is being trigger by the first pulse train. Hence the train of pulses shown.

Theoretically pulse length is equal to

$T = 1.1 \times RC$

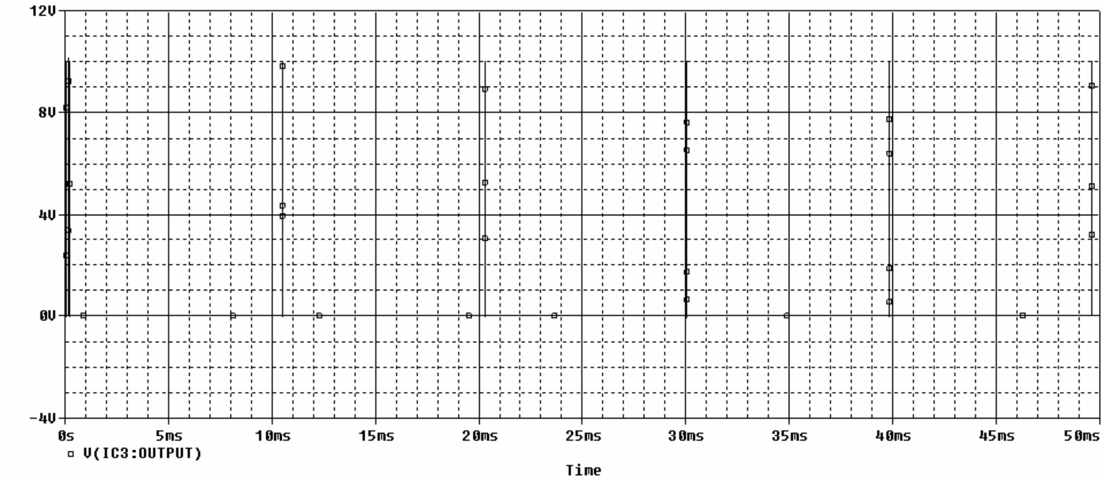
$T = 1.1 \times 15 \times 10^3 \times 0.01 \times 10^{-6}$

$T = 0.165ms$

From the simulation

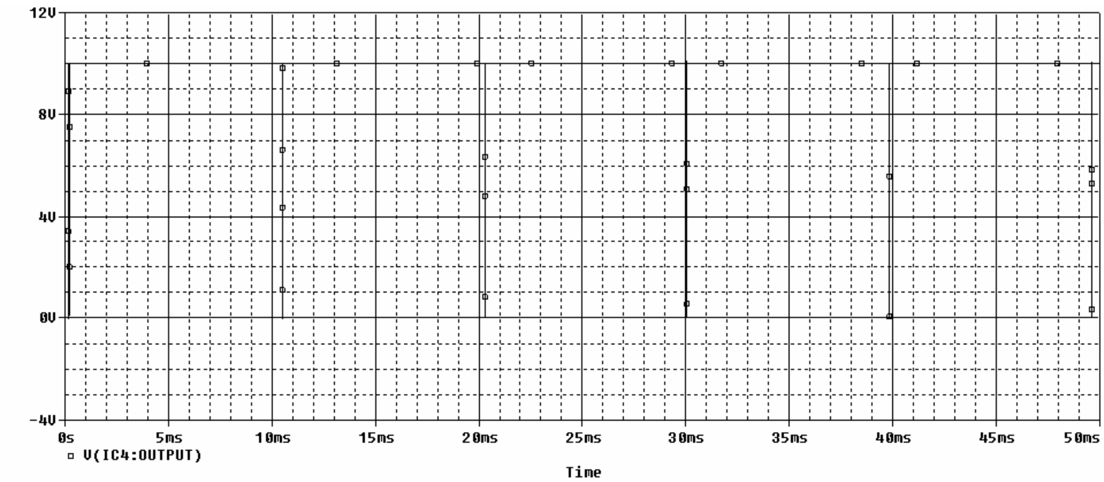
$T = 0.162ms$

This output is used to pulse the coil. A big 10V pulse of 165 μs length is sent to the coil every 10ms.



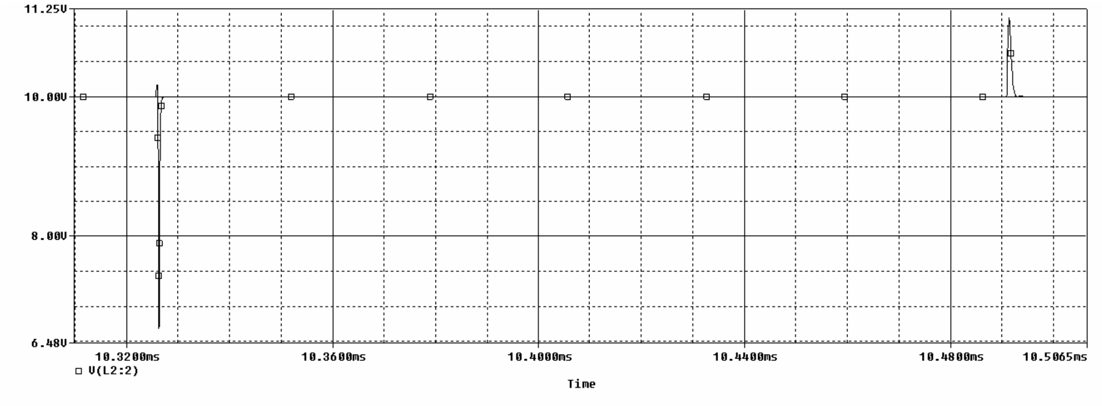
Output of 555 timer 3; Monostable configuration

Theoretically
$T = 1.1\times3.3\times10^{3}\times0.01\times10^{-6}$
T = 36.3 μs
From the simulation
T = 36.26μs



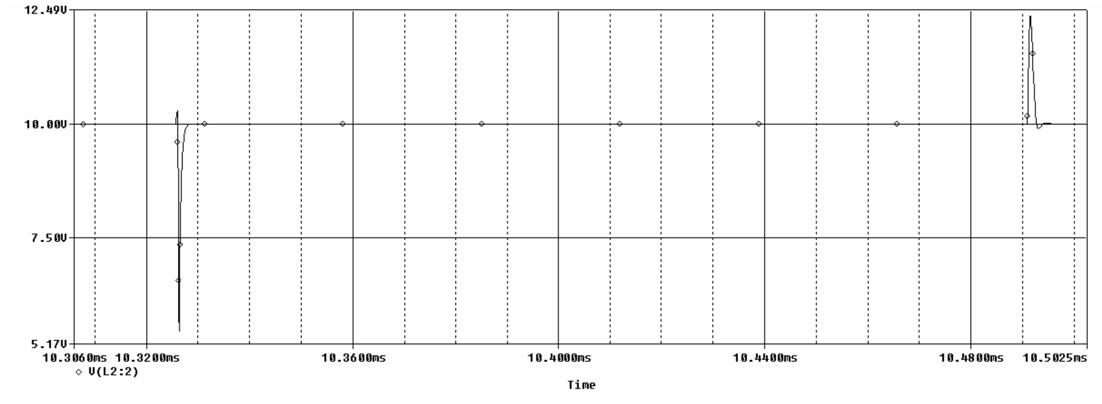
Theoretically,
$T = 1.1\times4.7\times10^{3}\times0.01\times10^{-6}$
T = 51.7 μs

From the simulation
T = 50.2 μs
This output is sent to the JFET in between the amplifier and the integrator. Most of the time the JFET is on, except for 50.2 μs when the output is 0V, this stops the circuit from reading the output from the coil when we are pulsing.



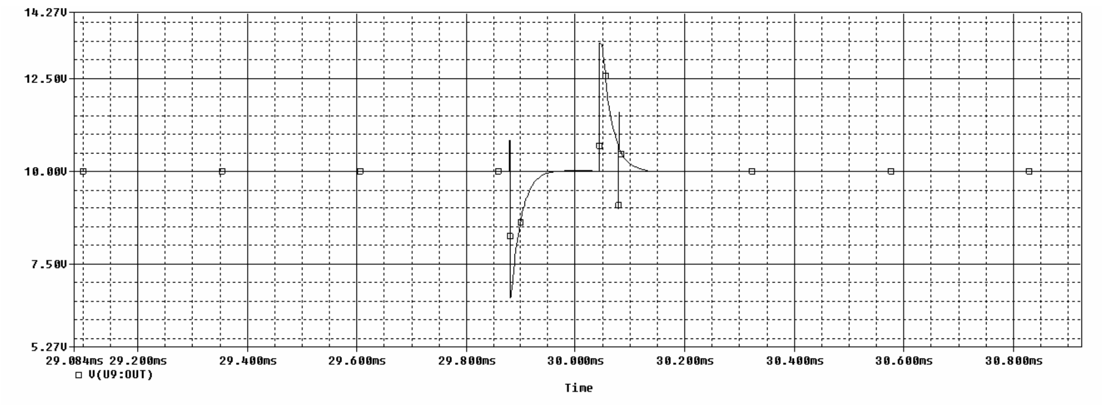
Simulation of the Coil L = 40uH

The pulse on the left is the send pulse from the second 555 timer (IC6 in Figure 3). The second pulse is the reflected back emf pulse.



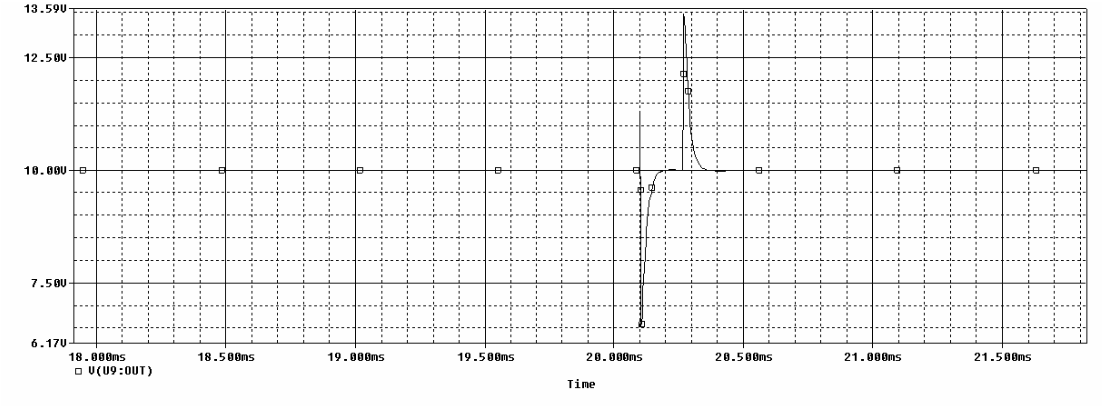
Simulation of Coil L = 100uH

The pulse on the left is the transmit pulse as before, because of the increase in inductance the pulse on the right is dramatically larger and takes longer to decay to zero. The idea is to calibrate the sampling circuit to sample a little after a pulse in the presence of no metal has already decayed, then in the presence of metals the back emf pulse should still have a noticeable voltage because of the increased inductance.



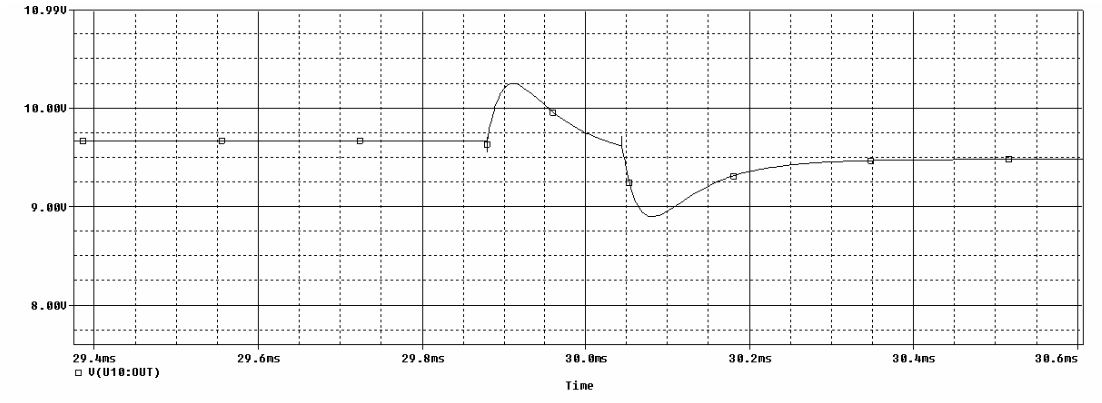
Output of Amplifier L = 40uH

The decay time for the second pulse is 29us.

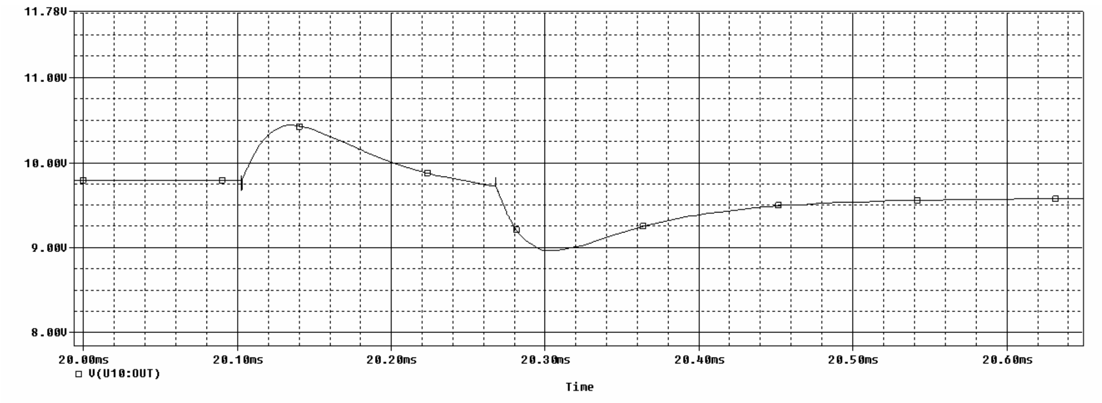


Ouput of Amplifier L = 100uH

Decay timefor the second pulse is 88us.

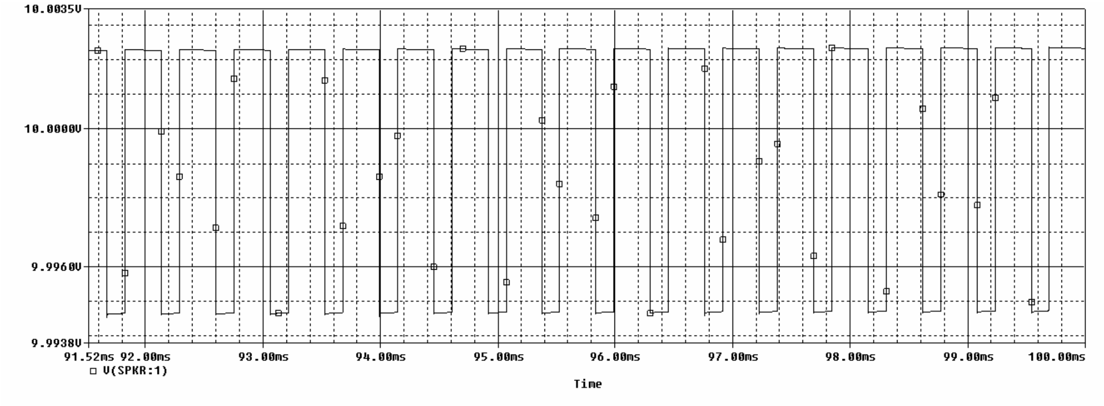


Output from IC10, L = 40us.



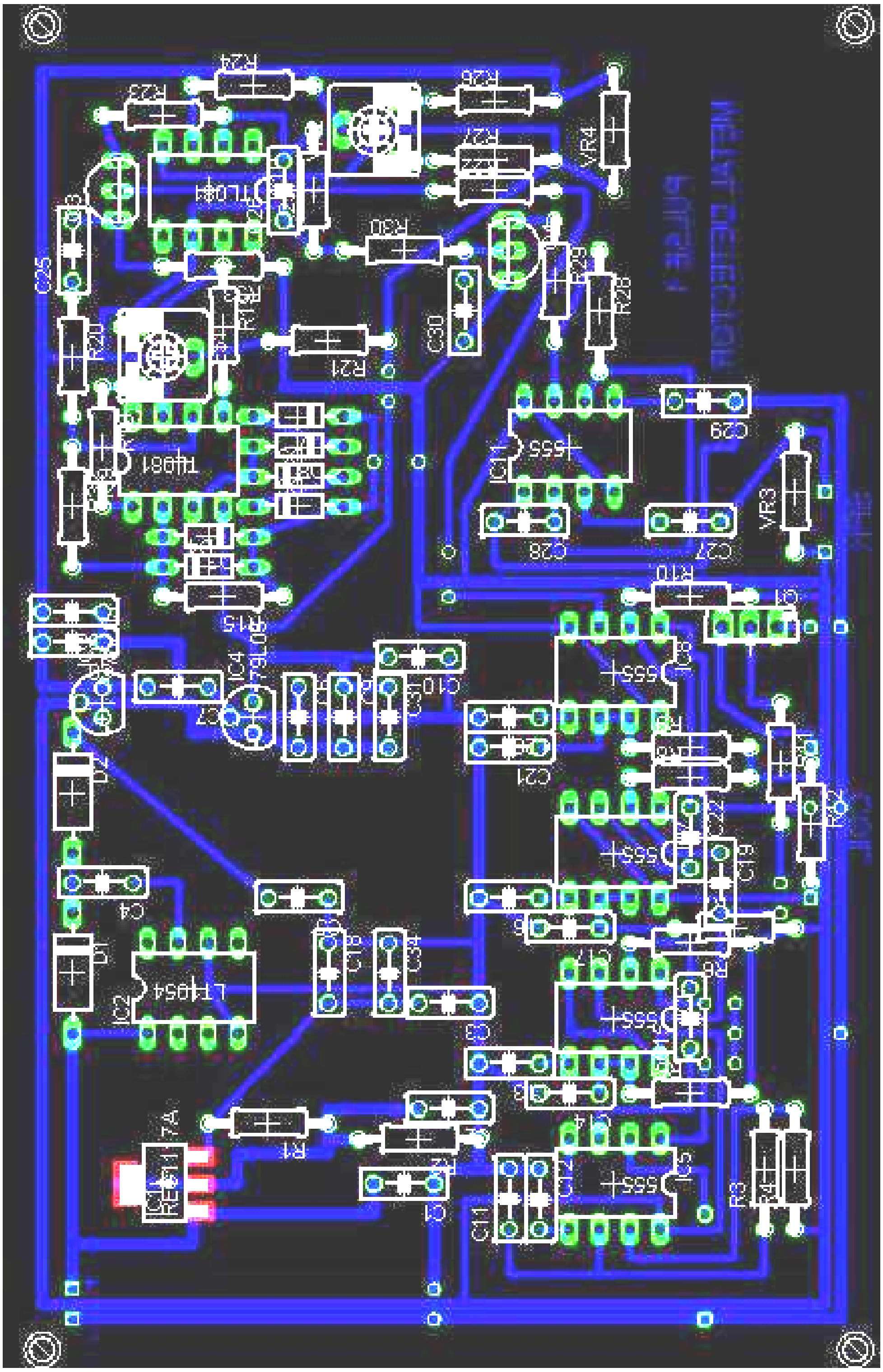
Ouput from IC10, L = 100uH

Decay time in the 100uH case is increased.



Input to speaker.

APPENDIX C



Screenshot of completed PCB layout file in EAGLE.