Construction of a Beat Frequency Oscillator Metal Detector

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***Abstract* — This paper discusses the design, construction, and testing of a beat frequency oscillator metal detector as a final project submission for ECEN-3400, Electromagnetic Fields and Waves at the University of Colorado, Boulder. The project was completed using approximately $10 worth of parts available from any local hardware and electronics store.**

I. Introduction

In this security-conscience world that we live in today, the ability to detect potentially threatening objects is becoming increasingly more important. In addition, armature treasure-hunters enjoy going out and searching around their favorite parks, lakes, and beaches for valuable lost memories. Solutions to both of these problems have been invented by engineers working in the area of electromagnetic fields and waves. Although there are a variety of methods available today to accomplish this task, all of them work of the principals of induction, flux, and magnetic fields.

Our preliminary research has shown that there are three primary technologies in use by metal detectors today. They are as follows:

VLF Detectors

Very low frequency (VLF) detectors work by producing a relatively low frequency (5-50 kHz) time-varying magnetic field with a large (6-12 inch) inductor. A second, smaller coil, is shielded from detecting any direct fields induced by the first coil, and is tuned to listen for possible fields due to Eddy currents generated by nearby metal objects.

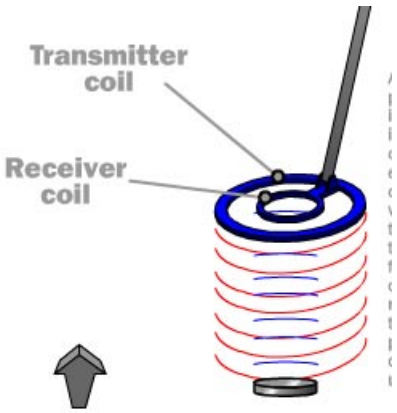

Fig. 1. Operation of a VLF metal detector

Pulse Induction Detectors

Pulse Induction detectors work much like SONAR on a submarine. Electric current is sent in microsecond long pulses through a coil of wire that causes a brief magnetic field to be induced. If this pulse hits a meal object, it is reflected back to the coil of wire, which measures the reflected pulse. While pulse induced detectors aren't very good at determining different types of metal, their effective working depth is much greater than that of a VLF detector.

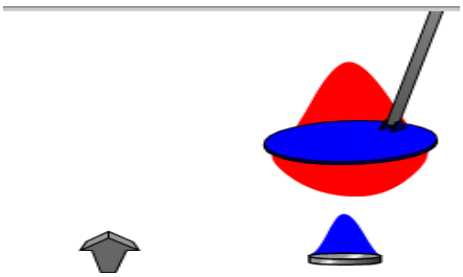

Fig. 2. Operation of a pulse induction metal detector

Beat Frequency Oscillator Detector

A beat frequency oscillator (BFO) style detector works by comparing two different frequency oscillators in order to detect meal objects. The large search head coil is tuned to match the frequency of a reference oscillator, typically located inside the control box. As the head is swept over metal objects, the inductance of the head changes, causing a frequency shift in the oscillating circuit. As the two frequencies change in reference to each other, some simple circuitry alerts the operator that there is nearby treasure.

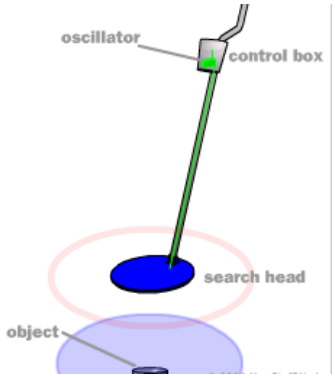

Fig. 3. Operation of a BFO metal detector

Initially, it seems the beat frequency oscillator detector will be the best choice to build due to its relatively simple circuitry, which will allow us to focus more on the electromagnetinc theory during the project.

II. DESIGN AND CONSTRUCTION

Two inductors that are used to detect the presence of a metal. One inductor is used as a reference coil with specific known inductance. This was constructed by winding a 120 turns of 34 AWG wire around a ½ wooden dowel. When placed in an RLC circuit, it will oscillate at a given frequency. A second inductor (the search coil) is used to detect the presence of metal. Our search coil consisted of a 12 inch non-conducting loop wrapped with 8 turns of 34 AWG wire.

This search coil's inductance and resonant frequency is found by circuit theory to be

$$\omega = \frac{1}{\sqrt{LC}}$$

This frequency is then closely matched with the reference coil by the fine tuning of the reference coil; it is tuned by screwing or unscrewing a metal washer around the reference coil until the frequencies are about the same. Once there are two oscillating RLC circuits, closely matched, one can slightly alter the search coil's inductance then compare the difference between them.

Altering the search coil's inductance is accomplished by placing a large metal object near the search coil; this will in turn change the frequency at which this RLC circuit is oscillating. Now that the two circuits are oscillating at different frequencies, this frequency difference can be analyzed, stepped down and amplified into an audible tone utilizing a high impedance speaker or headphones. If there is a large difference between the frequencies, this will produce a higher frequency on the audio output. However, when the frequencies are still very close together, a small beat, or no beat will be output to the audio.

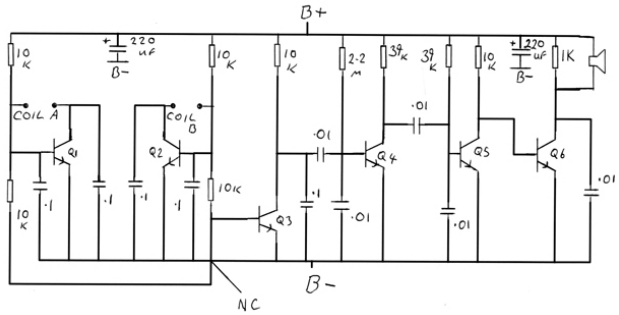

Fig. 4. RLC resonator circuit and beat detection audio driver. All resistor values are given in ohms and all capacitor values are given in microfarads.

Using this method, there will always be a tone produced regardless of the presence of metal. This is due to the fact that these two circuits will never be exactly the same because it is very, very difficult to practically match the inductors completely, so they will be oscillating at slightly different frequencies. There will always be a slight difference between the two resonant frequencies regardless of how closely one tries to match them. However, if the frequencies change noticeably, then so will the tone being produced. So, while there will always be a small tone being produced, a noticeable changing tone means there is metal being detected.

When analyzed on an oscilloscope, the audio output is seen to be periodic spikes in voltage when a frequency difference is present in the two RLC circuits. The larger the difference between the frequencies, the wider the pulse becomes. However, this spike's width is rather small because the frequencies never change considerable around any small piece of metal, which makes this pulse rather difficult to hear using a speaker or headphones.

III. DISCUSSION

Our original design goals were to be able to detect a small piece of metal, such as a coin, buried under approximately two inches of dirt. Unfortunately, after construction and initial testing, it was found that our metal detector was simply not that sensitive. In fact, it took a noticeably large amount of metal (on the order of 1-2 kg) in order to change the search coil's inductance enough to produce a noticeable beat. A variety of search coils were tested, ranging from 7 inches to 12 inches, and ranging in inductance values from 12 nH 108 nH. Unfortunately, the B-field produced by these inductors was simply not large enough to induce any eddy currents in small pieces of metal.

Our final circuit model oscillated at 104kHz. Bringing a large piece of metal close to the search coil resulted in an inductance that changed the coil's resonance to 107 kHz, producing a 3 kHz beat. Unfortunately, the audio driver portion of our circuit didn't perform as well as could have been hoped, so we found it much more functional to use an oscilloscope to observe the beat change. Perhaps we could have used a simple LPF integrator circuit to drive a needle-point meter as a better way to alert the user as to the presence of metal

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