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# METAL DETECTION



One of mans greatest challenges throughout history is to see what cannot be seen, to detect what is hidden, and to reap riches from these treasures. This visit were going to look at some very basic metal-detection circuits. Now don't get me wrong; the circuits we'll share here most likely will never locate a valuable treasure, but they can be put to use performing other more practical applications. However, in the early days of the last century, even the simplest of metal detectors were successful in discovering some very valuable buried treasures. Simplicity often is the best route to take in solving a seemingly difficult task. Never give up on an electronic adventure because you don't have the latest and greatest equipment.

### Woolgathering

The first metal detector ever used by man most likely was a chunk of magnetite. This material is natures rock that is magnetized and attracts other ferrous objects.

House roofers use a modern version of this to pick up wandering nails that just happen to fly off the roof and land on the ground. The roofers tool is a very strong magnet attached to a long handle. Fallen nails stick like glue as the magnet is scanned across the ground. Very powerful magnets are also useful in retrieving ferrous objects lost in lakes and rivers.

### Ferrous Ferrets

Our first example of a ferrous detector is a simple mechanical device shown in Fig. 1. The detector is a modified balanced scale, which indicates ferrous objects and magnetized items. A magnet is attached to one end of the arm and a simple north/south scale is attached at the opposite end. A pivot is located near the magnet end of the arm, and a slide balancing weight is on the opposite end.

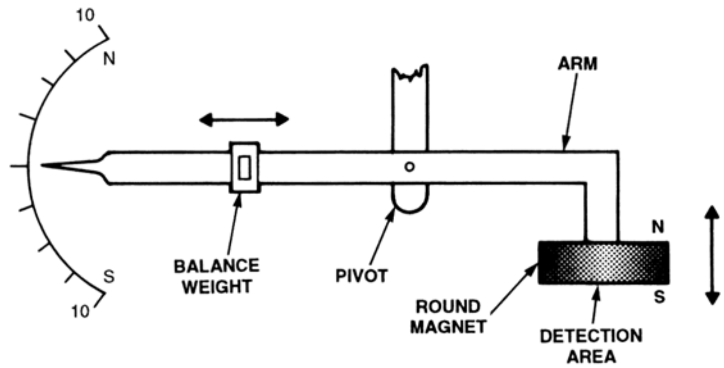


*Fig. 1. This basic detector unit uses mechanics and magnetism principles to detect ferrous objects and magnetic fields. No batteries required!*

**PARTS LIST FOR THE FERROUS FERRETS (FIG. 1)**

1 ⅛-inch round donut ceramic magnet (RadioShack #64-1888) or similar magnet, misc. wood and metal materials

The magnetic scale should be balanced with no ferrous items near by. Any non-magnetized ferrous object positioned below and close to the magnet will cause the pointer to go up due to the magnetic attraction.

A magnetized object with the south pole facing up will cause the pointer to go down, and when the north pole faces up the pointer will rise. This ultra-simple magnetic detector is very sensitive and will easily determine what objects are ferrous and the polarity of magnets.

### Electronic Ferrous Ferret

Our first electronic metal detector circuit, see Fig. 2, uses a Hall Effect sensor to detect weak permanent magnetic fields. Almost all ferrous objects retain some degree of magnetism, and those

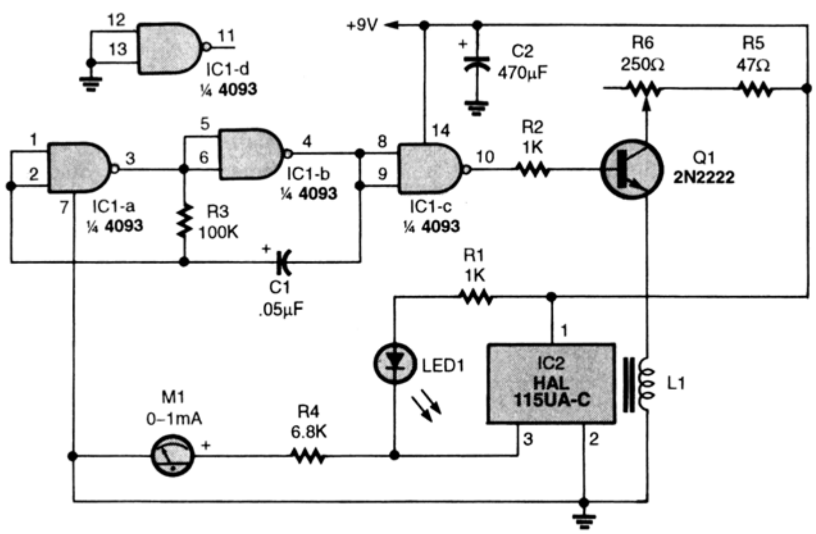


*Fig. 2. The electronic version of the Ferrous Ferret uses a simple Hall Effect IC. Weak magnetic fields can be detected with this easy-to-build device.*

## PARTS LIST FOR THE ELECTRONIC FERROUS FERRET (FIG. 2)

**SEMICONDUCTORS**

IC1–4093B CMOS quad 2-input Schmitt trigger NAND gate
IC2–HAL 115UA-C Hall Effect IC, Digi-Key part HAL115UA-C-ND
Q1–2N2222 NPN transistor
LED1–Light-emitting diode, any color

**RESISTORS**

(All resistors are ¼-watt, 5% units.)
R1, R2–1000-ohm
R3–100,000-ohm
R4–6800-ohm
R5–47-ohm
R6–250-ohm potentiometer

**CAPACITORS**

C1–.05-µF, ceramic-disc
C2–470-µF, 25-WVDC electrolytic

**ADDITIONAL PARTS AND MATERIALS**

L1–#32 enamel-covered copper wire, ¼-inch ferrite rod material (see text)
0-1-mA meter, or digital voltmeter

that do are easily detected with our Hall Effect ferrous-detector circuit.

The HAL 115UA-C IC Hall Effect sensor is the heart of the weak-field detector circuit and is available for less than a buck from Digi-Key. This Hall Effect sensor is a bipolar device that is sensitive to a magnet's north pole on its branded side and to the south pole on the opposite side. The branded side, see Fig. 3, is the side that displays the part number.

The sensor's output (pin 3) is normally low when no external magnetic field is present. Placing a magnet with its north pole facing the branded side of the sensor will cause the output at pin 3 to go high. Placing a magnet with its south pole facing the non-branded side will also cause the output to go high.

Heres how the circuit operates. Two gates of a 4093 quad-, 2-input, NAND Schmitt trigger IC are connected in a low-frequency square-wave oscillator circuit operating at about 100 Hz. The output of gate "C" drives the base of Q1, which is connected in an emitter-follower circuit supplying the 100-Hz signal to L1. Inductor L1's drive level is set by R6. The output (pin 3) of IC2 is

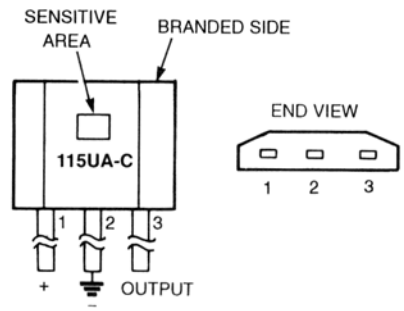


*Fig. 3. Let's get up close and personal with our friend—the HAL 115UA-C. The branded side—where the part number is displayed—is sensitive to a magnet's north pole, while the opposite side is sensitive to a magnet's south pole.*

connected to an LED and a metering circuit.

Inductor L1 supplies a low-frequency AC bias to the backside of the Hall Effect sensor, IC2. This AC bias in effect increases the Hall Effect sensitivity many times over and also allows it to detect both north and south pole magnets from the branded side; however, the circuit is much more sensitive to north pole fields. The arrangement of L1 and the Hall Effect sensor is shown in Fig. 5.

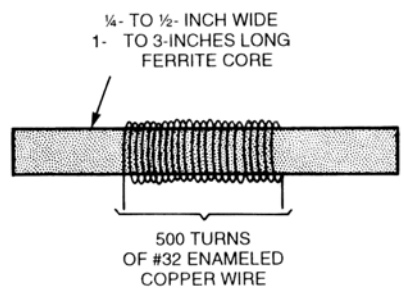


*Fig. 4. Utilizing some skill and patience, inductors can be hand-wound. Here is a simple diagram showing the typical inductor needed for metal-detector circuits.*

The Hall Effects output waveforms are shown in Fig. 6. The waveforms are observed at pin 3 of the Hall Effect IC. Output waveform "A" is set by adjusting R6 for a symmetrical output without any ferrous metals in the pick-up area. If a scope is not handy, a DC voltmeter can be used to set the output to about 4.5 volts. This setting will produce an output waveform very close to the one shown in Fig. 6A. The "B" output waveform occurs when the north pole of a magnet is brought in proximiry of the Hall Effect sensor. The south pole of a magnet produces the output waveform shown in Fig. 6C.

### Winding L1

Inductor L1 (see Fig. 4) is fabricated by jumble winding 500 turns of #32 enamel-covered copper wire on a ¼-inch diameter ferrite rod. The rod's actual diameter and length are not critical, and any size rod material from ¼-to ½-inch in diameter will do. The rod's length can be anything from 1 inch to 3 inches. The rype of rod material suitable for this application can be salvaged from an old AM transistor radio or some older TVs.

If the rod material cannot he located, don't give up 'cause there are other paths to take. A relay coil with a resistance of 10 ohms or greater will generally work for L1. Some miniature audio transformers have straight sections of laminations that can be used in place of the rod material. Most of the rod material I've used and have recommended here is actually designed for much higher frequency use. As a last ditch effort, try a number of small nails taped together as a core for L1 and see what happens. Here's a great place to experiment with various coil core materials and windings to improve or vary the circuit performance. Keep me informed on your efforts.

### Try This One

Something else came to mind after disassembling the circuit, and due to time restraints I was never able to check it out. I would like to challenge you to do so. What if a second Hall Effect IC sensor was added to the circuit but placed beside IC2 with its branded side facing L1's core?

Duplicate IC2's circuitry with the new IC, but leave out the metering circuit. See Fig. 7 for details. Try to get like waveforms from both circuits by adjusting R6 and positioning the two

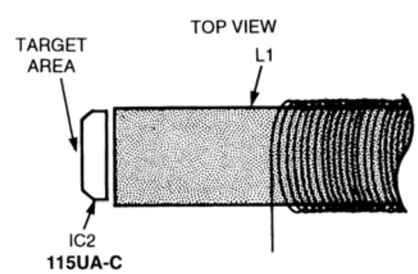


*Fig. 5. The Hall Effect IC works in conjunction with the inductor. A low-frequency AC bias is supplied to the backside of the IC via the inductor.*

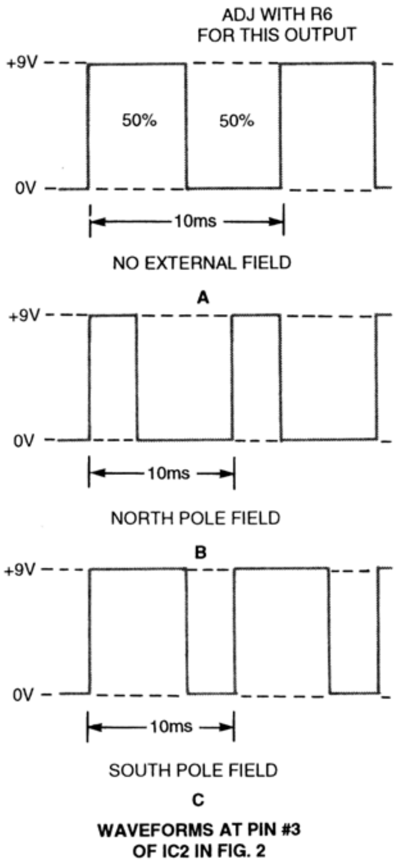


*Fig. 6. Here are the waveforms that might come from pin 3 of IC2. Resistor R6 can be adjusted to calibrate the circuit.*

ICs on the end of L1. Connect one lead of a digital DC voltmeter to pin 3 of IC2 and the other meter lead to pin 3 of the added IC. If I'm correct, the circuit should be as sensitive to the south pole of a magnet as the original circuit was to the north pole. If not, try connecting a DC voltmeter to the output of IC2 and another voltmeter to the output of the added IC. IC2 should remain more sensitive to the south pole of a magnet, and the added IC should be more sensitive to the north pole.

### All Metals Detector Circuit

Our next metal detector circuit takes us back into the early years of the last century where tubes were king and semiconductors were only diodes. It was discovered early on that any metal object placed near the tank circuit of an oscillator would shift its frequency either up or down. A tank circuit is the combination of an inductor and capacitor that make up a tuned circuit. Ferrous metals near the inductor of a tuned circuit cause the oscillator's frequency to go down and non-ferrous metals cause the frequency to increase. This is the basic effect that the Beat Frequency Oscillator (BFO) type of metal detector uses to detect all metals. Figure 8 shows a block diagram of the circuits making up a typical BFO detector. A search loop is usually wound in a circular fashion to serve as the inductor in the search oscillator's tank circuit. The reference oscillator is very sinlilar to the search oscillator with a much smaller inductor, which is usually shielded from the search loop. RF signals are taken from both oscillators and fed to a comnmon mixer, where the sum and difference frequencies of the two oscillators are mixed. The sum frequencies are filtered out, leaving only the audible difference frequencies to pass on to the amplifier and headphones.

As a practical example, we'll set the search oscillator up to operate at a frequency of 100,100 Hz, and the reference oscillator to a frequency of 100,000 Hz. The difference frequency between the two oscillators is an audible 100 Hz that is fed to the headphones. The search coil is then moved over a small ferrous metal object causing the oscillator to drop in frequency to about 100,050 Hz. The audible 100 Hz tone drops to 50 Hz

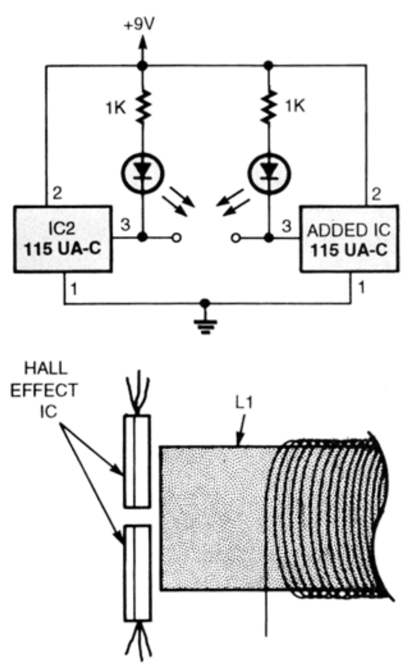


*Fig. 7. Increase your odds at detection with this simple modification. An additional Hall Effect IC is added to balance the circuit's sensitivity to the north and south magnetic poles.*

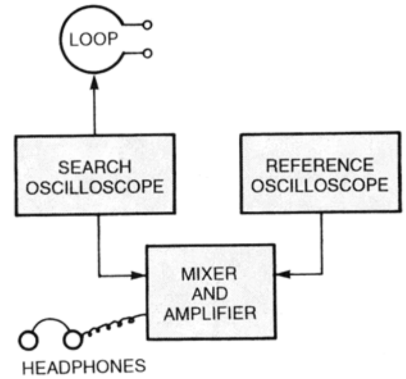


*Fig. 8. The popular loop-detector circuit has been a mainstay for many treasure hunters. A set of headphones allows the user to hear an indication of ferrous material and magnetic fields.*

indicating a metal object is located somewhere near the search loop. A non-ferrous object near the loop will cause the oscillator to increase in frequency and produce a higher audio output tone. A carefully adjusted BFO metal detector can be used to discriminate between ferrous and non-ferrous metals.

### Two-Transistor BFO Detector

One of the simplest BFO metal locators to build is the two-transistor circuit shown in Fig. 9. The circuit may be set up to operate on any frequency between 50,000 Hz to over 1 MHz by selecting the tank circuit components. Just about any good general-purpose NPN transistor suitable for low RF applications will work just fine. The search loop can be as small as a dime or three feet or larger in diameter. A small loop works best for small objects buried shallow and a large loop works best for large objects buried at greater depths. The two oscillator circuits should be separated and shielded from each other to reduce frequency pulling between the two. A really well constructed BFO detector will be able to operate with a difference of less than 100 Hz betveen the two oscillators. The lower the audio output tone the easier it is for the ear to tell a small frequency shift. The detector's maxmum sensitivity is obtained when the two oscillators are operating just a few cycles apart. Believe me, this is not an easy task to accomplish, but one well worth the effort.

Here's how the simple BFO detector operates. Transistor Q1 along with its associated components make up a Col-

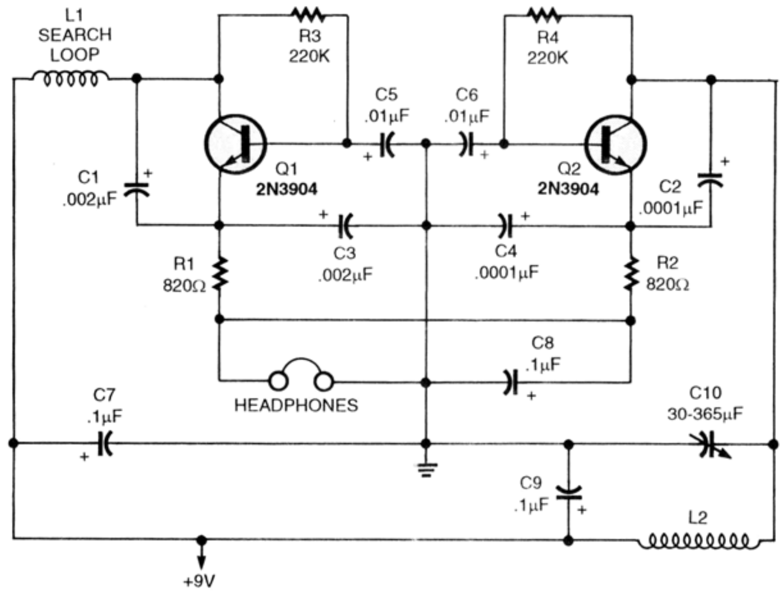


*Fig. 9. This is the schematic for a Beat Frequency Oscillator metal-detector. Two transistors are used as the oscillators in this circuit.*

**PARTS LIST FOR ALL METALS DETECTOR CIRCUIT (FIG. 9)**

**RESISTORS**
(All resistors are ¼-watt, 5% units.)
R1, R2–820-ohm
R3, R4–220,000-ohm

**CAPACITORS**
C1, C3–.002-µF, mylar, or similar type capacitor
C2, C4–.0001-µF, mylar, or similar type capacitor
C5, C6–.01-µF, ceramic-disc
C7, C8, C9–.1-µF, ceramic-disc
C10–365-pf, variable capacitor

**ADDITIONAL PARTS AND MATERIALS**
Q1, Q2–2N3904 NPN transistor
Low-impedance headphones
Loop form, wire, plastic pill bottle, etc. See text.

pitts oscillator circuit with the search loop, C1 and C3 forming its tuned circuit. Transistor Q2 with its associated components make up another Colpitts oscillator circuit with L2, C2, and C4. forming the tuned circuit. The emitters of Q1 and Q2 are coupled together through R1, R2, and the low-impedance headphones. This circuit arrangement functions as a simple RF mixer circuit. The audio frequencies are fed to the headphones, and the RF frequencies are bypassed to ground through C8.

### Winding And Scrounging

The loop may be wound on almost any round insulated non-metallic form, such as wood or plastic. Inductor L2 can be an old ferrite rod antenna coil removed from an AM transistor radio, or one can be made by winding a coil on a round insulated form. Let me offer the following winding suggestion to get you going on buildling the BFO circuit. Locate a 10- to 12-inch wood or plastic hoop that's about 3/4-inches wide and close wind ten turns of #18 to #22 enamel-covered copper wire evenly around the forms. Tape over the wire with plastic electrical tape and connect to the circuit with a length of two-wire zip cord. If an antenna coil cannot be found for L2, then close wind about 80 turns of #22 enamel-covered copper wire on a 1-inch plastic pill bottle or plastic pipe.

One important thing to do in selecting the two inductors is to be sure that the reference oscillator can tune to the same frequency as the search oscillator. If a frequency counter is available then the chore will be super easy. If not, some experimenting with dlifferent pairs of capacitors (Cl and C3 or C2 and C4) will he necessary to bring both oscillators to the same frequency.

Fellow Circuiteers, we've just ran out of space and time; so meet me back here next month, and we'll continue on our metal dectector journey. I want to thank Ken, in Texas, for suggesting this months subject.