ELECTRONIC METAL LOCATORS

The mere mention of the term **metal locator** brings to many adventurous minds the exciting thought of prospecting for hidden treasure. This is natural because early electronic metal detectors were offered pointedly as "treasure locators," and many such instruments have been used over the years to search for buried booty — with more or less dubious results, not so much because of inadequacy of the equipment as because of false hopes of sudden wealth having little foundation.

The modern metal locator is more than a casual treasure spotter, however. Its workaday role includes such tasks as locating underground pipes, asphalt-covered railway tracks, electric wiring in walls and under floors, covered sewer tops, buried or submerged firearms, tramp metal (in lumber, foodstuffs, rubber, plastics, paper, hay, confections, tobacco, etc.), metal objects in the intestines of animals, buried military mines, and many other such prosaic applications. Indeed, hunting for buried coins, precious metals, and other ore deposits is only one, glamorous phase of metal locator use.

Locators are in present regular use by electric power companies, water works, electrical contractors, plumbing contractors, food processing mills, tobacco factories, lumber mills, textile plants, and other industrial organizations.

It is interesting to note that, although many changes have been made in metal locator circuitry and components to take advantage of new electronic developments during the past twenty years, the basic principles of their operation have remained substantially the same.

The Editors present a resume of metal locator principles in this article in response to the increased interest in this subject. From this discussion, it will be seen that the locators actually are quite simple both in theory and construction. They are useful and intriguing devices which may easily be built from a technician's own design, or from the circuits given here, often with "parts on hand."

Operating Principle

It is convenient to divide metal locators into two categories: **Class 1** including those units embodying a separate r-f transmitter and receiver and which operate by means of a wave reflected from the transmitter to the receiver by the hidden metal, and **Class 2** including those units consisting of an r-f oscillator which becomes detuned by the metal and generates a beat-note signal. Instruments in each group may be given numerous original modifications.

Class 1. This is perhaps the oldest type of metal locator. It survives in many modern adaptations and has wide use. Figure 1 illustrates the operating principle. Here, a small, battery-operated radio transmitter is in the right-hand box and radiates via the loop antenna mounted perpendicular to the earth's surface. The left-hand box contains a radio receiver operated from a loop antenna mounted parallel to the earth's surface. Transmitter and receiver are tuned to the same, single operating frequency and are mounted as far apart as practicable on opposite ends of a carrying pole.

The right-angle orientation of the two loops minimizes direct pickup of the transmitter signal by the receiver. However, a portion of the radiated energy is propagated downward and penetrates the earth. If a metallic mass lies in the path of these waves, it will reflect a portion of the signal and this component will be picked up by the receiver. This pickup is indicated by a meter deflection, headphone signal, or both. Thus, operation of the receiver in-

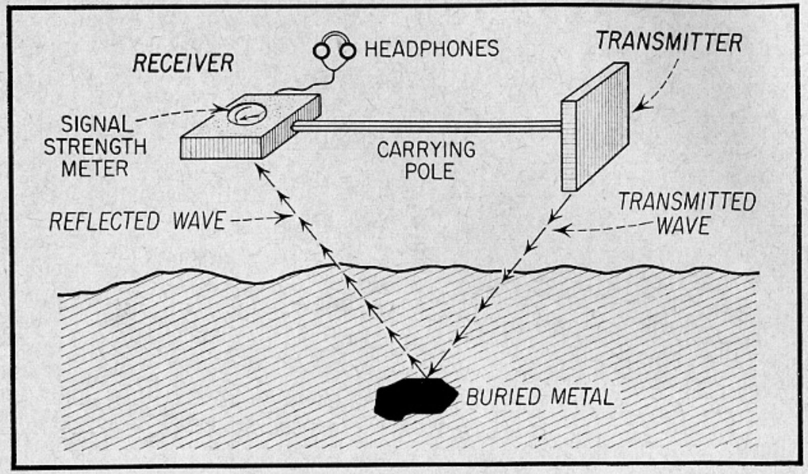

Fig. 1. Operation of Class-1 Locator.

dicates the presence of some metallic body under the locator, while a dead receiver shows the absence of metal.

In operation, the technician grasps the carrying pole near the center of its length and carries the locator over the area of interest, watching for the signal that announces the presence of metal. His body occupies only a small part of the space between the transmitter and receiver.

It is important to consider the problems concerning design and construction of a Class-1 metal locator. The first concerns operating power. For good penetration, the power must be as high as permissible. But since the instrument is highly portable and battery-operated, the power is restricted by weight and current limitations. Moreover, the device must not create radio interference. That is, legally it must satisfy the FCC requirement that the field strength of its transmitter at a distance from the antenna equal to $\lambda/2\pi$ must not exceed 15 microvolts per meter. (Where λ = wavelength in meters.) Since this involves frequency, let us look briefly at frequency requirements and then return to the consideration of power.

Very high frequencies, which admittedly would permit the smallest-sized equipment, tend in general to be reflected by the earth instead of penetrating it to any great depth. They also tend to be radiated great distances from the transmitter, so can cause widespread interference. These factors outlaw their use. The most generally satisfactory frequencies have been found to be the low-frequency r-f group, e.g., 50 to 200 kc. However, useful loop antennas are ungainly in size at the lowest frequencies in this range. Nevertheless, many commercial Class-1 metal locators operate between 80 and 100 kc. Most of these instruments, when home-built, are operated between 100 and 200 kc.

Returning to the consideration of power, simple calculation will show that $\lambda/2\pi$ represents a much greater distance at 50 kc than at 50 Mc, and is greater at 100 kc than at 1000 kc. This is an added recommendation for low-frequency operation. In any event, the transmitter power must be kept low, not only because of the legal requirement but in order to minimize battery drain, reduce the weight of

the instrument, and prevent direct transmission to the receiving loop. Consequently, small receiver-type battery-operated tubes are employed in the transmitter. The plate voltage seldom exceeds 135 v in this application. If headphone operation is desired, the transmitter must be amplitude-modulated.

The receiver must be sensitive, but not so much so that it will pick up troublesome outside interference or direct transmissions from the locator's own transmitter. For this reason, the circuit usually is of the TRF type rather than a superheterodyne. The indicating meter may be operated from a diode detector. Both receiver and transmitter are fix-tuned but are adjustable over a suitable range for alignment purposes.

The receiving loop (and in some applications, the transmitting loop, as well) must be provided with a Faraday shield for protection against the capacitance effects introduced by nearby objects other than the metal of interest, otherwise false indications will be obtained.

The Class-1 instrument is the type of locator seen often in the hands of power company workers and street maintenance crews searching for mains under the street.

Class 2. This type of instrument operates on the beat-frequency principle. Like other beat-frequency devices, it consists of two self-excited r-f oscillators adjusted to zero beat with each other. The tank coil of one of the oscillators is employed as a search coil. When this coil is placed near a metallic body, its inductance will be changed by the latter, detuning the corresponding oscillator and producing a beat note. This beat note may be indicated by either headphones or an output meter operated from a detector or demodulator into which the two oscillator output signals are fed.

Figure 2 illustrates the basic arrangement of the Class-2 locator. A and B are radio-frequency oscillators feeding into the beat-note detector, C. The detector output is presented to an a-f (beat-note) amplifier, D, and thence to the headphones and output meter. The tank coil of oscillator A is supported rigidly outside of the instrument and functions as the search coil. The tank coil of oscillator B is self-contained. The two oscillators ideally are well shielded from each other to prevent interaction and pulling.

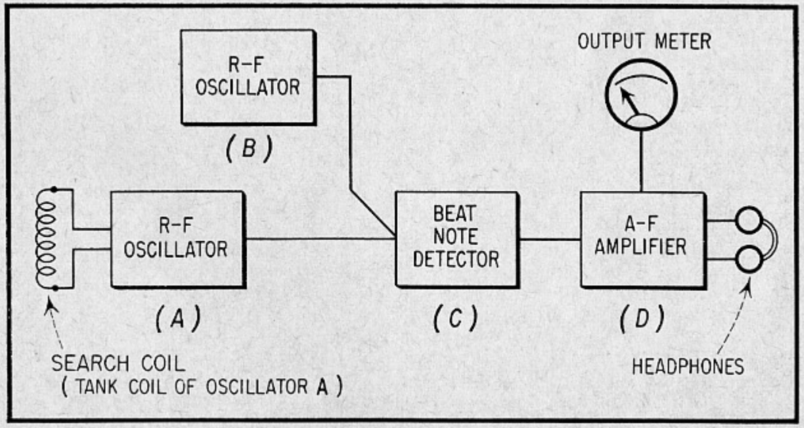

Fig. 2. Basic Arrangement of Class-2 Locator.

Initially, the two oscillators are set to zero beat through adjustment of a tank-circuit trimmer in either one, but usually oscillator B. At this point, no headphone signal can be produced and the output meter reads zero. If subsequently a piece of metal comes within the field of the search coil, it will alter the inductance of this coil as long as it remains in the field. This detunes oscillator A, producing a beat note equal to the difference between the two oscillator frequencies. The beat note is amplified, producing a headphone signal and output meter deflection.

In order to obtain a useful de-tuning effect, the oscillator operating frequency is higher than that employed in the Class-1 locator. It usually is of the order of 1 to 2 Mc. This has the added advantage that the coil can be made small in size in hand-held locators employed principally to spot conduit in walls and similar applications. Some operators prefer to set the adjustable oscillator for a continuous beat note (headphone and meter signal), rather than zero beat, an increase in pitch or rise of meter reading then indicating the presence of metal.

The Class-2 type of instrument is sensitive but does not have the penetrating depth of the Class-1 type. The reason for this is that the metallic body must be comparatively close to the coil in order to interact with its magnetic field and alter its inductance. This instrument accordingly is used principally to search out objects lying close to the surface, such as covered car tracks, sewer tops, bolts and nails under plaster, wiring in walls, etc. The beat-note type of operation is employed in some military mine detectors.

Other Types. Additional types of metal detectors not of the r-f variety, which will not be treated in this article, include a-f induction-balance systems and magnetic deflection types for ferrous metals only.

Practical Circuits

Figure 3 shows the complete circuit schematic of a Class-1 metal locator which can be built by the experimenter. This instrument operates on 175 kc and is adapted from a popular earlier design.[3]

In this unit, the receiver employs two stages of tuned r-f amplification (V_1 and V_2), a germanium diode detector (D), and one stage of a-f amplification (V_3). Magnetic headphones are operated from the a-f amplifier, and a 0-100 d-c microammeter, M (as a signal strength indicator) from the rectified output of the diode detector.

The receiver is fix-tuned. Variable capacitor C_2, used as a trimmer, tunes the receiver loop coil, L_1. Capacitor C_2 is shunted by C_1 to bring the circuit capacitance up to the proper value required for resonance at 175 kc. The interstage coupling transformers (T_1 and T_2) are miniature, 175-kc i-f transformers with slug tuning. The capacitors shown across the primary and secondary windings of these transformers in Figure 3 are self-contained in the transformers. The receiver section of the locator is aligned simply by inductively-coupling an unmodulated 175-kc test oscillator or signal generator to the pickup loop (L_1) and adjusting C_2 and each of the i-f transformers for peak deflection of meter M. Increase the resistance setting of rheostat R_1 if the meter "pins."

Tubes V_1 and V_2 in the receiver must be shielded to prevent oscillation. The entire receiver section, including batteries B_1 and B_2, must be enclosed in its own metal box for efficient isolation from the transmitter. The pickup loop, L_1, must be provided with a Faraday shield to minimize capacitance effects. This shield may be constructed of thin sheet metal or foil wrapped around the finished coil. But the wrapping must be slotted, in the usual manner of a Faraday shield, so that it does not form a "shorted turn" around the coil.

Pickup loop L_1 consists of 40 turns of No. 22 enamelled wire closewound

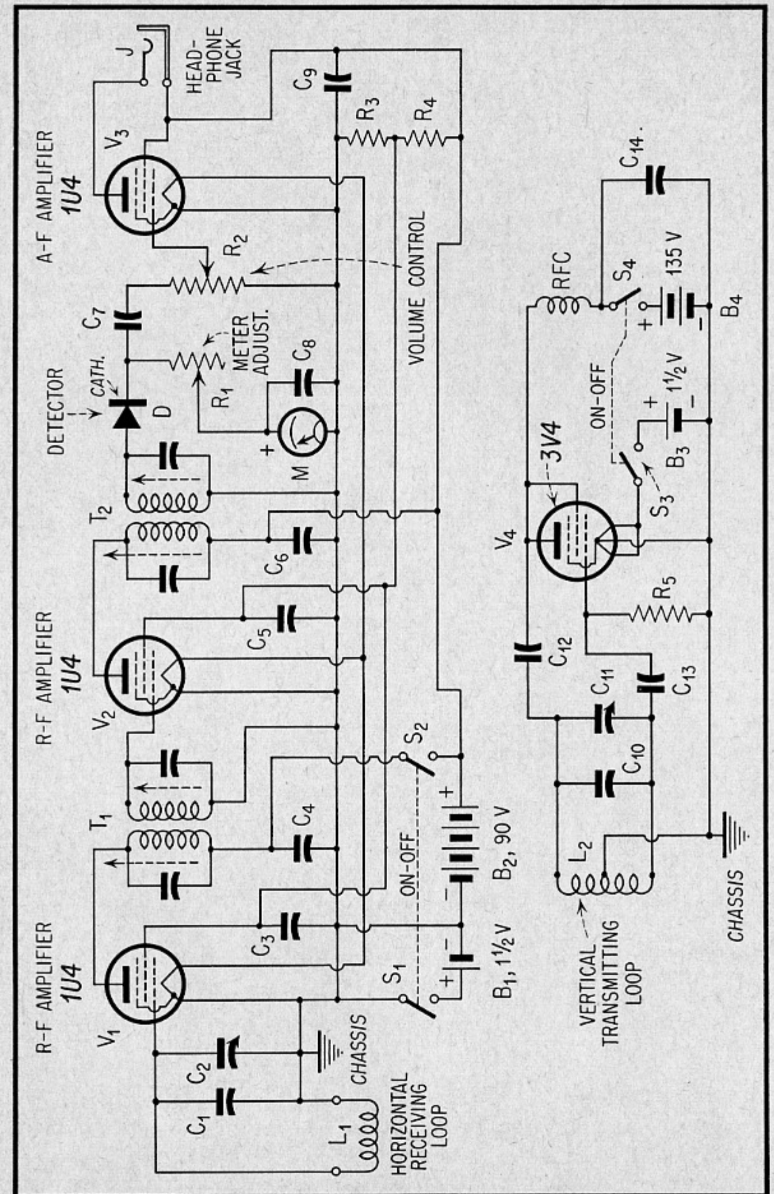

Fig. 3. Complete Schematic, Class-1 Metal Locator.

on a 1-ft-diameter plastic or impregnated-wood hoop.

The transmitter is fix-tuned by means of variable capacitor C_{11}. The latter is shunted by fixed capacitor C_{10} to bring the circuit capacitance up to the value required for 175-kc resonance. A single 3V4 beam-power battery tube is employed in the shunt-fed oscillator-type of transmitter circuit. The transmitter loop, L_2, consists of 40 turns of No. 22 enamelled wire closewound on a 1-ft-diameter plastic or impregnated-wood hoop and tapped at the 12th turn.

The 3V4 is self-modulated at about 450 cycles by the high-resistance grid leak, R_5, which causes blocking action of the oscillator. This is very convenient for operation of headphones in the receiver but does not require a separate modulator stage. The modulation does not interfere with operation of the indicating meter, M. Both meter and headphones may be used simultaneously if this is desired.

The actual numerical value of the operating frequency is unimportant. For this reason, there is no need to set the instrument precisely to 175 kc. Indeed, the transmitter may be set arbitrarily to any frequency within the range of tuning capacitor C_{11}, a length of insulated wire looped around and run temporarily between antenna coils L_1 and L_2 for coupling, and the receiver aligned to this frequency by adjustment of C_2, T_1, and T_2.

In construction, the transmitter and receiver boxes must be mounted on opposite ends of the carrying pole. (See Figure 1.) The distance between the transmitting and receiving loops, which are mounted on the outsides of the corresponding boxes, must be

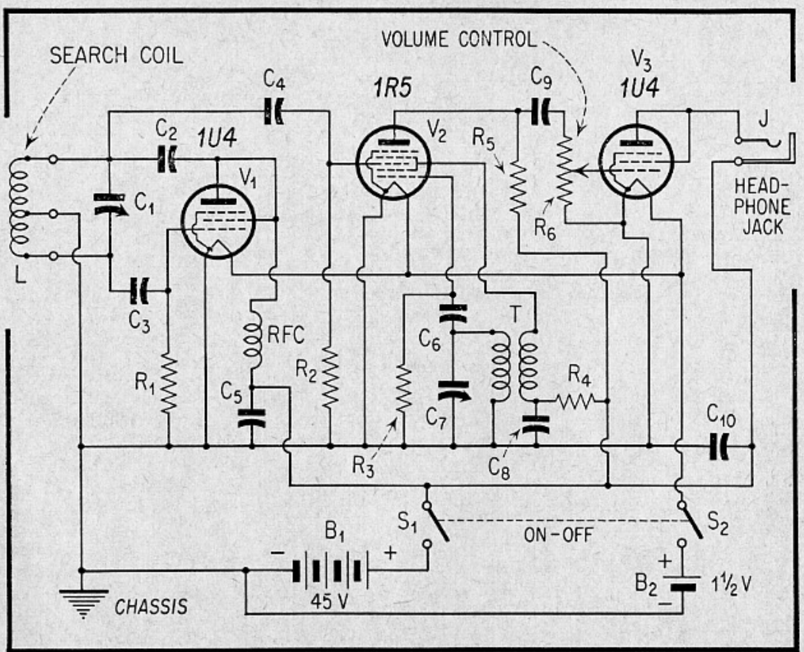

Fig. 4. Complete Schematic of Class-2 Metal Locator.

as great as practicable, never less than 2 feet.

Figure 4 shows the complete circuit schematic of a beat-frequency-type metal locator. In this arrangement, the 1R5 tube (V_2) is employed as a combination r-f oscillator and mixer. The first 1U4 tube (V_1) is the second oscillator. When these two oscillators are operating on the same frequency, V_2 has no output and the headphones are quiet.

The V_1 oscillator circuit contains the search coil, L. This coil is tuned by means of trimmer capacitor C_1, to set this oscillator to zero beat with the 1R5 oscillator tuned by C_7. The 1R5 feedback transformer, T, is self-contained and shielded, while coil L is external to the instrument and may be mounted on the outside of the instrument case or at the end of a pole. This coil consists of 60 turns of No. 26 enamelled wire closewound on a 4"-diameter plastic or cardboard form and tapped at the 20th turn.

When a metallic body enters the magnetic field of coil L, it detunes the 1U4 oscillator by changing the inductance of this coil. The frequency of this oscillator therefore shifts and an audio beat note is delivered by the 1R5 stage to the a-f amplifier (V_3) and headphones. Thus, a beat note signal in the headphones indicates the presence of metal near the search coil. As in the example of the Class-1 locator described previously, the search coil (L) of this unit should be provided with a Faraday shield to minimize capacitance effects.

The higher the operating frequency, the more pronounced will be the detuning introduced by small metal objects in the vicinity of the search coil. However, the frequency ordinarily is kept below 3 megacycles, in order to eliminate undesirable side effects such as radio interference, excessive sensitivity and instability, and susceptibility to body effects. With transformer T, a standard broadcast-receiver oscillator "coil," the operating frequency of the instrument will be approximately 1 to 2.2 Mc.

To set the unit initially: (1) Plug high-resistance magnetic headphones into jack J. (2) Close switch S_1-S_2. (3) With no metal near coil L, set tuning capacitor C_7 near its low-capacitance end. (4) In all probability, you will hear an audible beat note in the headphones at some setting of volume control R_6. (5) Adjust tuning capacitor C_1 for zero beat. (6) Now, bring a small piece of metal near coil L and observe that a beat note is heard as long as the metal is near.

In operation, capacitor C_1 or C_7 may be tuned to set the circuit to zero beat. Often, it will be necessary to re-zero as the instrument is "walked" over a varying terrain, and especially where rocks, vegetation, or water appear at intervals.

The beat-frequency instrument has considerably less sensitivity than the transmitter-receiver type. However, it is particularly useful for searching out nearby objects for that very reason. Furthermore, the beat-frequency-type locator can be constructed to a much smaller size than the transmitter-receiver type.

Technique

The person who plans to use a metal locator of any type for whatever purpose must recognize that this instrument is incapable of making distinctions or of correlating and appraising the data which it senses. In short, it is only a tool and the role of interpretation is exclusive with the operator.

The locator cannot tell one kind of metal from another, although some locators (especially the beat-frequency type) sometimes can be adjusted so as to give an upward indication of an output meter with ferrous metals and a downward indication with non-ferrous ones. Nor can most locators distinguish between a mass of metal and a large pocket of highly-conductive water.

A great deal of skill is acquired by the operator strictly through the "feel" that comes with long practice in handling the instrument. The alert and observant operator learns many peculiarities of his metal locator and, by the strength and quality of its output indications plus his familiarity with the environmental conditions under which he uses the instrument, he can tell many things about the detected metal — such things as probable size, depth of location, whether metal or water, etc.

REFERENCES

1. Harold S. Renne, ELECTRONIC METAL LOCATORS (Howard W. Sams & Co., Inc., Indianapolis, Ind., 1956).

2. C. R. Shafer, **Choosing Industrial Metal Detectors,** ELECTRONICS, June, 1951.

3. Rufus P. Turner, **A Modern Metal Locator,** RADIO & TELEVISION NEWS, March, 1955.

PARTS LIST FOR FIGURE 3

B_1, B_3—1½-volt cells

B_2—90-volt B-battery

B_4—135-volt B-battery

C_1, C_{10}—0.001 ufd silvered mica — (C-D 1R5D1)

C_2, C_{11}—140 uufd midget variable — (Hammarlund APC-140)

C_3, C_4, C_5, C_6, C_7, C_9—.01 ufd disc ceramic — (C-D BYA10S1)

C_8—0.002 ufd mica — (C-D 1W5D2)

C_{12}, C_{13}—0.004 ufd mica — (C-D 1W5D4)

C_{14}—0.01 ufd mica — (C-D 1D3S1)

D—Germanium diode — (Sylvania 1N34)

J—Open-circuit, insulated phone jack

L_1, L_2—Loop antenna coils — See Text

M—0-100 d-c microammeter

R_1—2000-ohm wirewound potentiometer

R_2—0.5-megohm poteniometer

R_3—47K 1-watt carbon

R_4—10K 1-watt carbon

R_5—2.7 meg ½ watt carbon

RFC—80 mh r-f choke — (Meissner 19-2709)

S_1-S_2—Dpst toggle switch

S_3-S_4—Dpst toggle switch

T_1—175-kc i-f input transformer — (Miller 012-K2)

T_2—175-kc i-f output transformer — (Miller 012-K4)

PARTS LIST FOR FIGURE 4

B_1—35-volt B-battery

B_2—1½-volt cell

C_1—100 uufd midget variable

C_2, C_3—0.002 ufd mica — (C-D 1W5D2)

C_4—30 uufd mica — (C-D 5W5Q3)

C_5, C_8—0.01 ufd mica — (C-D 1D3S1)

C_6—50 uufd silvered mica — (C-D 22R5Q5)

C_7—Midget 365 uufd variable

C_9, C_{10}—.01 ufd disc ceramic — (C-D BYA10S1)

J—Open-circuit, insulated midget phone jack

L—Search coil — See Text

R_1—1 meg ½ watt carbon

R_2—0.5-megohm ½ watt carbon

R_3—100K ½ watt carbon

R_4, R_5—15K 1-watt carbon

R_6—0.5-megohm potentiometer

RFC—16 mh r-f choke — (Meissner 19-1995)

S_1-S_2—Dpst toggle switch

T—Broadcast oscillator coil — (Miller 71-OSC)