"Build these circuits that can amplify, filter, generate white noise, flash lamps, locate hidden metal--and perhaps even detect lies."

Rewritten by Tony van Roon

This last article on bipolar junction transistors (BJT) is a potpourri of circuits. Some are practical and some are not so practical, but they can be great for experiments. With these circuits you can amplify signals, filter high and low frequencies, generate white noise, and flash lamps. You can also boost DC voltage levels, locate hidden metal objects, and detect rising water. One circuit will even demonstrate the fundamentals of lie detection!

More Power Amplifiers:
Today the easiest way to build a low- to medium-power audio amplifier is to pick an integrated circuit (IC) amplifier from a manufacturer's data book and supplement it with additional components recommended in the applications notes in the data book. However, if you just want to learn amplifier principles by experimentation or you have a simple application in mind, you should build the amplifier with discrete transistors.

Figure 1 is a schematic for a general-purpose, low-power, high-gain amplifier based on discrete transistors. A Class-A amplifier, it can drive a load such as a speaker or headset with an impedance greater than 65 ohms. The amplifier draws a quiescent current of about 20 milliamperes. However, this drain can be reduced by increasing the value of R3.
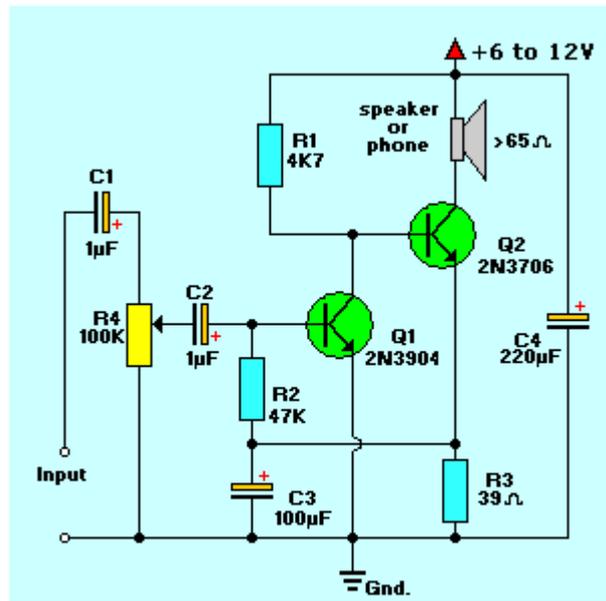
Fig. 1 -- AUDIO AMPLIFIER with two transistors offers high-gain.
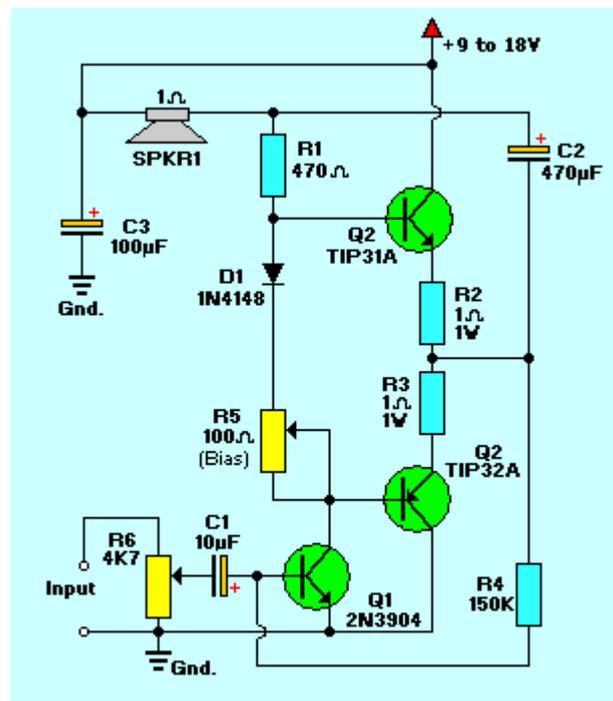
Fig. 2 -- AUDIO POWER AMPLIFIER with three transistors has a 1-watt output.

Transistors Q1 and Q2 are configured as common-emitter amplifiers; the output of Q1 is directly coupled to the input of Q2. This circuit has an overall voltage gain of about 80 dB. Notice that resistor R3, the emitter load of Q2, is decoupled by capacitor C3 so that the Q2 emitter follows the average collector voltage of Q1.

The base bias for Q1 is derived from Q2's emitter through R2. With this configuration, the bias is stabilized by negative DC feedback. Input potentiometer R4 serves as the circuit's volume control.

Figure 2 is the schematic for a simple, three-transistor, Class-AB complementary amplifier which can drive about 1 Watt into a 3-ohm speaker load. Transistor Q1, which is configured as a common-emitter amplifier, drives a load that is the sum of speaker SPKR1. resistor R1 and potentiometer R5. Its output voltage is *followed* and boosted in power by the complementary emitter-follower stage made up of Q2 and Q3.

The output of the amplifier is fed through capacitor C2 to the junction of SPKR1 and R1 where it provides a low-impedance drive for SPKR1. It simultaneously bootstraps the value of R1 so that the circuit has high-voltage gain. The output is also fed back to Q1's base through R4 so that it produces a base bias through a negative feedback loop.

Carefully adjust trimmer potentiometer R5 to minimize audible signal crossover distortion so that it is consistent with lowest quiescent current consumption that can be measured. To obtain a reasonable value, set the quiescent current from 10 to 15 milliamperes.

Figure 3 shows a more complex audio power amplifier that can deliver about 10 watts into a 8-ohm load when powered from a 30-volt supply. This circuit includes four, high-gain, quasi-complementary output stage (Q3 to Q6). Transistor Q1 functions as an adjustable *amplifier diode* output biasing device in this circuit.
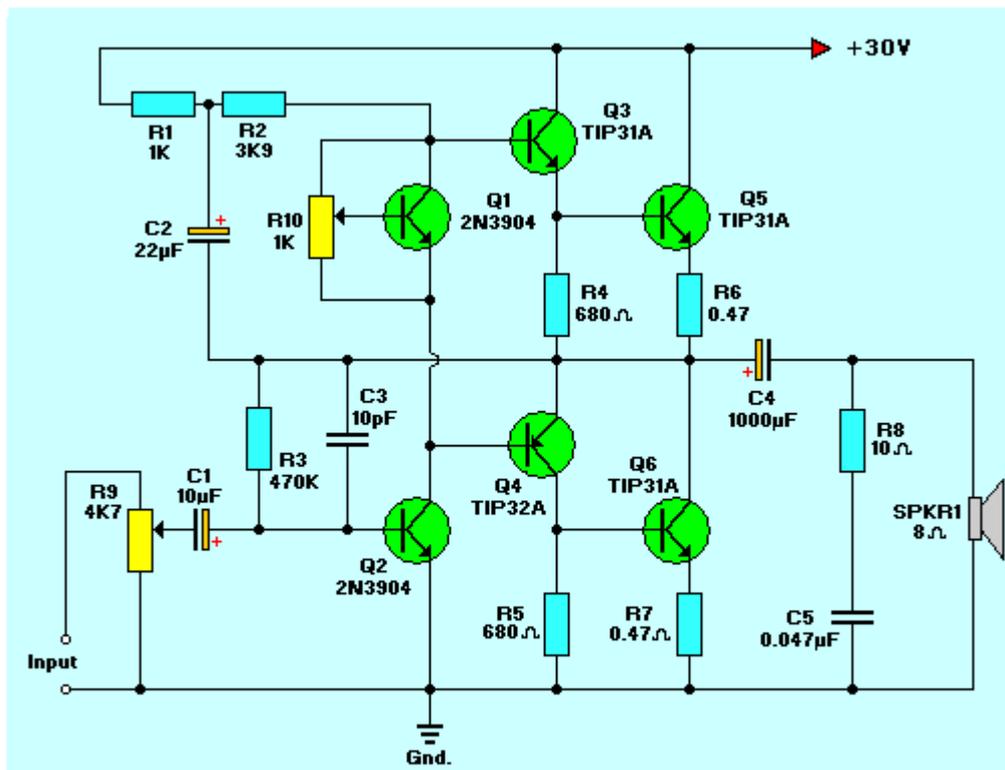
Fig. 3 -- Audio Power Amplifier with six transistors has a 10-watt output.

The main load resistor R2 of the Q2 common-emitter amplifier stage is bootstrapped by C2 and DC biased by R3. This network should set the quiescent output voltage at about half the power supply value. If it does not, alter the value of R3. The upper frequency response of the amplifier is restricted by C3, which menaces circuit stability. In addition, capacitor C5 is wired in series with R8 across the output of the amplifier to increase circuit stability. The amplifier should be set up initially as was described for the circuit in Fig. 2.

Scratch/Rumble Filters:

Today, with the widespread acceptance of compact discs (CDs/DVDs), records (LP) are long obsolete. However, because of the everlasting popularity of the record (it seems), the last couple years manufacturers have been bringing back the old record player in a new coat. Like myself, many people still own a large collection of these records, and when played on quality record players, they can still provide many hours of listening pleasure.

Back when the records were popular, unless the record player amplifiers were properly filtered, scratch and rumble noise could interfere with reception. This interference was even more evident in the playing of the old 78 rpm records, you know, the old hard and fragile bakelite kind. While scratch and rumble are no longer universal problems, the techniques for eliminating them are still

interesting.

Scratch noise is essentially sound at a frequency greater than 10KHz picked up from the record's surface, while *rumble* is sound at a frequency typically less than 50 Hz caused by variations in turntable drive motor speed. Each of these noises can be effectively eliminated or attenuated by passing the audio output from the record player through a filter that rejects the annoying parts of the audio spectrum.
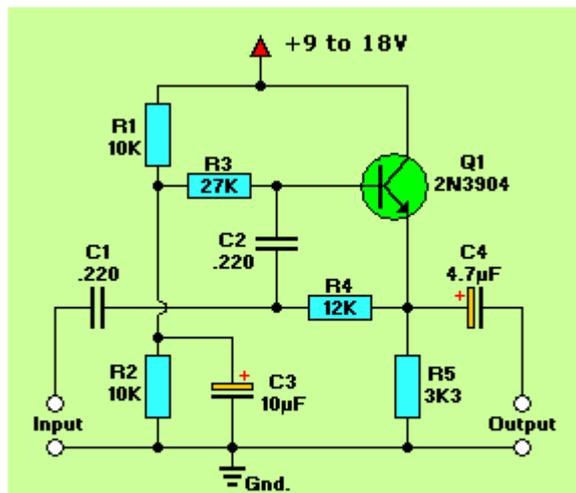
Fig. 4 -- HIGH-PASS Filter emliminates 50-Hz record player "rumble".
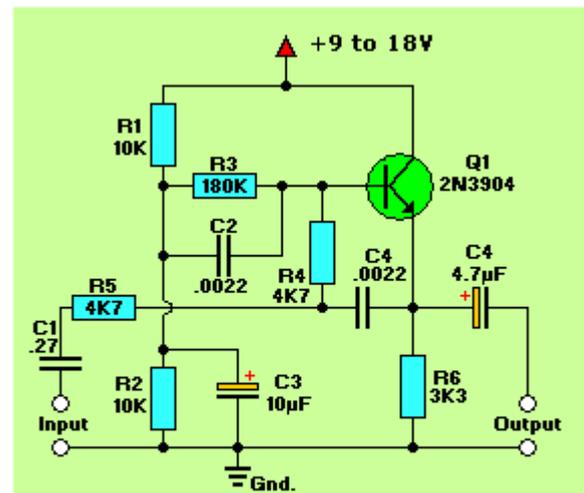
Fig. 5 -- LOW-PASS filtr eliminates 10-KHz record player "scratch" noise.

The rumble filter in Fig. 4 is a high-pass filter that provides unity voltage gain for all frequencies greater than 50Hz. however, it provides 12 dB per octave rejection to all frequencies below 50Hz. For example, attenuation is 40dB at 5Hz. Transistor Q1 is configured as an emitter-follower biased at about half the supply value from the low-impedance junction formed by R1 and R2 in parallel with capacitor C3.

However, negative feedback applied through the filter network of R3, C2, C1, and R4 causes an *active* filter response. The rolloff frequency of the circuit can be altered, if desired, by changing the values of capacitors C1 and C2--provided that they are kept equal. For example, if the values of C1 and C2 are reduced 50% from 0.220 to 0.110 microfarads, the rolloff frequency will be double to 100Hz.

The scratch filter circuit in Fig. 5 acts as a low-pass filter that provides unity voltage gain to all frequencies below 10KHz, but it rejects all frequencies above 10 KHz at 12dB per octave. This circuit resembles Fig. 4 except that the positions of the resistors and capacitors are transposed in the network consisting of C2, R4, C4, and R5.

The rolloff frequency of that circuit can be altered, if desired, by changing the values of C2 and C4. For example, if both are increase from 0.0022 microfarads to 0.0033microfards, the rolloff frequency is reduced from 10KHz to 7.5KHz.

The circuits of Fig. 4 and 5 can be combined to make a composite scratch and rumble filter. The output of the high-pass filter is connected to the input of the low-pass filter. If desired, bypass switches can be installed in the individual filter sections so that the filters can easily be switched in and out of circuit. This change is illustrated schematically in Fig. 6.

It's worth noting that if the circuits of Fig. 4 and 5 are built on a single board, three components can be saved by making the biasing network composed of resistors R1 and R2 and capacitor C3 common to both filter circuits.

Noise Circuits:

White Noise is a steady hissing sound obtained by mixing a full spectrum of randomly generated audio frequencies, each having
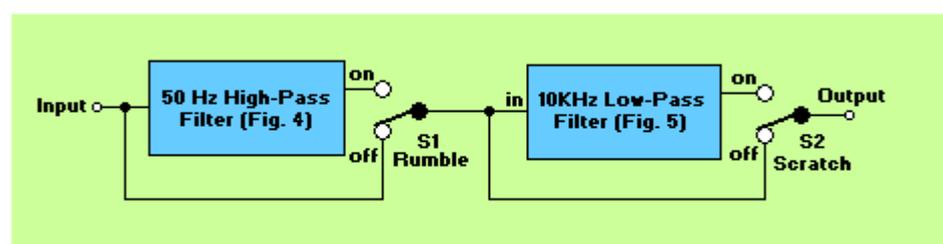
equal sound power when averaged over time. White noise can be heard by tuning an FM radio receiver to that part of the band where no nearby station can be heard. It is intentionally generated for testing audio- and radio-frequency amplifiers. It can also be an effective sleep aid because it masks random background noises from voices, passing vehicles, car horns, closing doors, and other sources.

Figure 7-a is the schematic for a simple but useful white noise generator base on the inherent white-noise generation capability of a revers-biased zener diode. In this circuit, resistor R2 and zener diode D1 form a negative-feedback loop between the collector and base of common-emitter amplifier Q1.
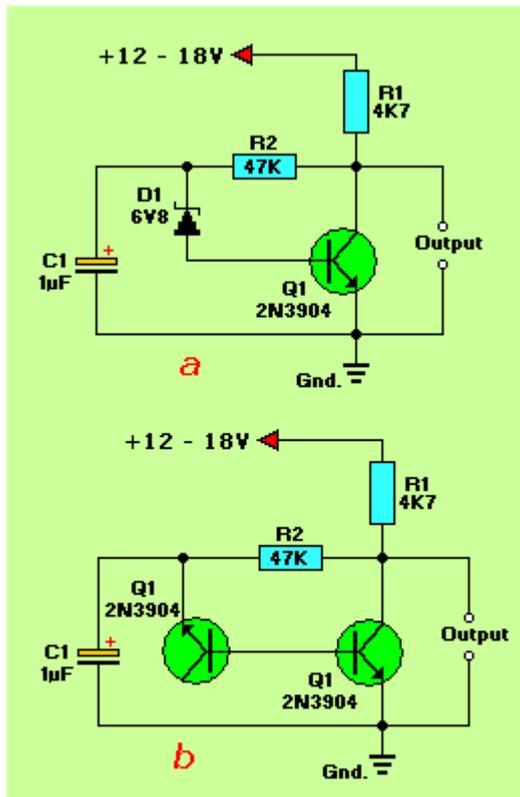
Fig. 7 -- White Noise generators with transistor and zener diode (a) and one with two transistors (b)

This loop stabilizes the DC working levels of the circuit, and capacitor C1 decouples the AC. As a result, D1 becomes a white-noise source in series with the case of Q1, which amplifiers that noise to a useful level of about 1 volt, peak-to-peak.

The base-emitter junction of any silicone transistor can function as a noise-generating zener diode if its junction is reverse-biased to tits breakdown level. This breakdown typically occurs in a 2N3904 small-signal BJT at about 6 volts. Figure 7-b shows the schematic of a two-transistor, white-noise generator. In this circuit Q1 acts as a zener diode.

Audio noise can be annoying, especially if you are trying to listen to a very weak broadcast station. You might find that the peaks of unwanted background noise completely swamp the broadcast signal, making it unintelligible. It is possible to overcome this problem with the *noise-limiter* circuit shown in Fig. 8.

In this circuit, both the signal and the noise are fed to amplifier Q1 through potentiometer R3. Transistor Q1 amplifies both waveforms equally, but diodes D1 and D2 automatically limit the peak-to-peak output swing of Q1 to about 1.2 volts. If R3 is adjusted so that the signal output is amplified to this peak level, the noise peaks will not exceed signal output. Therefore, the receiver signal will be far more intelligible.

Astable Multivibrators:

The *astable multivibrator* or *square-wave generator* circuit is versatile. Figure 9, for example, shows how it can flash two light-emitting diodes (Led) about once per second. Its flash rate is controlled by the time constant values of resistive-capacitive combinations of R4 and C1 and R3 and C2.

The Leds are in series with the collectors of transistors Q1 and Q2, and they flash on and off symmetrically out-of-phase with each other. The flash rate can be changed by altering the values of either R4 and C1 or R3 and C2. You can also replace one of the Leds with a short circuit to make a one-Led flasher.
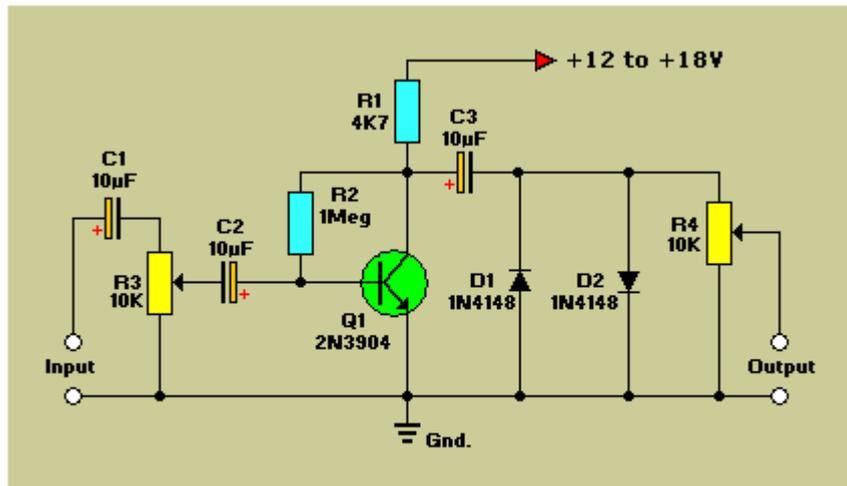
Fig. 8 -- *Noise Limiter Circuit improves the reception of weak broadcast stations.*
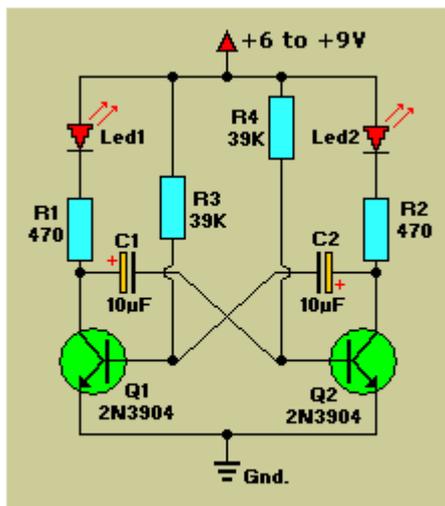
Fig. 9 -- *Two-Led Flasher circuit can attract attention.*
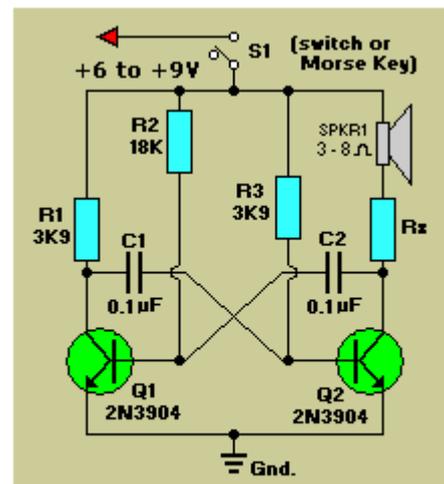
Fig. 10 -- *Morse-Code Practice oscillator is a multivibrator with a telegrapher's key.*

Figure 10 is a simple variation of the Fig. 9 astable multivibrator. This circuit generates an asymmetrical waveform at about 800 Hz, which is fed to speaker SPKR1 and limiting resistor Rx in the collector circuit of Q2. A monotone audio signal is generated when switch S1 is closed.
This circuit becomes a simple sound generator if S1 is a simple on-off switch, or it can be a Morse-code practice oscillator if a telegrapher's key is substituted for S1. The frequency of the generated tone can be changed by altering the values of either or both capacitors C1 and C2.
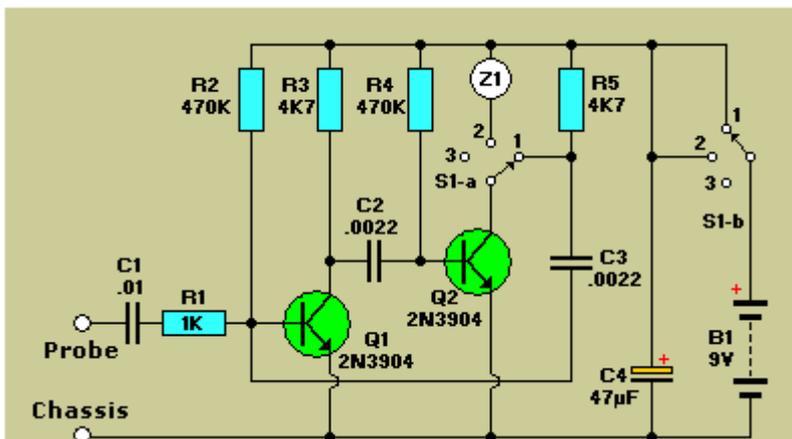
Figure 11 shows how an astable multivibrator can act as a signal injector-tracer for testing radio receivers. When S1 is in the *inject* position 1, transistors Q1 and Q2 are configured as a 1KHz astable multivibrator. With that setting, a sharp squarewave signal is sent to the *probe* terminal through R1 and C1.
That waveform, which is rich in harmonics, will produce an audible

output through a radio's loudspeaker if it is injected into any audio- or radio-frequency stage of an amplitude modulated radio. By selecting a suitable injection point, the injector can help in troubleshooting a defective radio.

When S1 is switched to *Trace* position 2, the circuit is configured as a cascaded pair of common-emitter amplifiers. The *Probe* input feeds the base of Q1 and Q2's output driving headphone Z1. Consequently, any weak audio signal fed to the *Probe* will be amplified directly and heard in the headphone.

Similarly, any amplitude-modulated radio-frequency signals that are fed to the Probe will be demodulated by the non-linear response of transistor Q1, and the resulting audio signal will be amplified and heard in the earphone. If the *Probe* is connected at suitable test points in a radio, the tracer can troubleshoot faults.
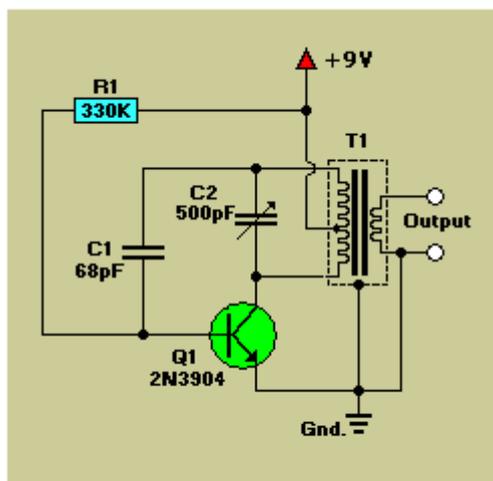
Fig. 12 -- Broadcast Band Signal generator/beat frequency oscillator.
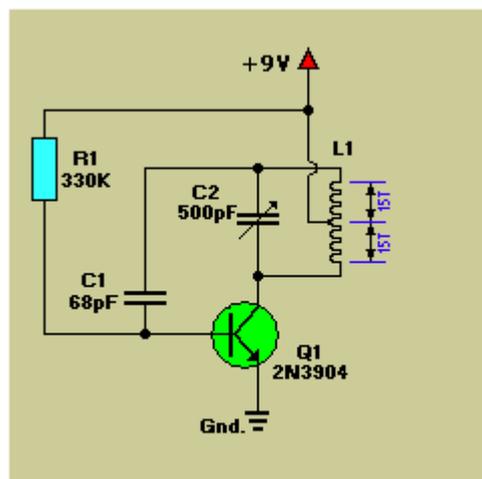
Fig. 13 -- Metal Object locator can hunt for hidden metal pipes or wires.

LC Oscillators:

Many applications can be found for inductance-capacitance (L/C) oscillators in test equipment and practical circuits. Figure 12 is a *local oscillator Beat-Frequency Oscillator (BFO).* Transistor Q1 is configured as a conventional Hartley Oscillator with modified 465 KHz Intermediate Frequency (IF) transformer as its collector load.

If the internal tuning capacitor of the transformer is removed, variable capacitor C1 becomes the tuning control of a variable-frequency oscillator. The output frequency can be varied from well below 465 KHz to well above 1.7MHz.

Any radio capable of receiving broadcast band frequencies will detect the oscillation frequency if it is placed near the signal generator circuit. If the signal generator is tuned to the intermediate frequency of a radio, a beat note can be heard. This will permit continuous-wave or sinus-sideband transmissions to be detected.

Figure 13 is a modification of Fig. 12 without a transformer secondary. When the circuit is functioning with a nearby radio receiver acting as a detector and amplifier, it becomes a simple metal object locator. Oscillator coil L1 is made by winding 30 turns of wire tightly on a 3- to 4-inch diameter plastic core or bobbin about 1 inch long. It becomes a *search head* or *sensing coil* when it it is connected to the circuit with a 3-wire cable.
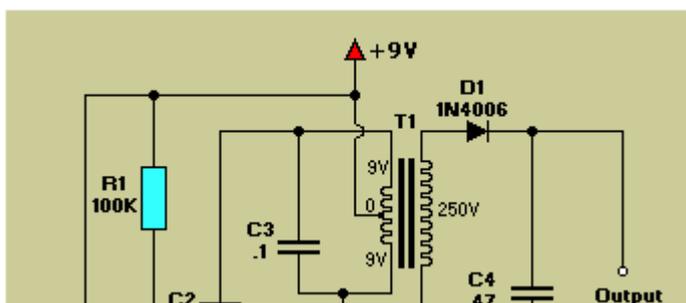
The searching head or sensor can be mounted at the end of a long wooden or plastic handle if you want to use the circuit as a classic ground-sweeping metal detector. Similar circuits can detect buried treasure of military mines that include at least some metal parts. However, the complete circuit can be housed in a

handheld case if you want to locate metal pipes or wiring that are hidden behind walls that are made of brick, wood, or plasterboard (gypsum/drywall).

The operation of the object locator circuit in Fig. 13 depends on the presence of a metal object that will interfere with coil L1's electromagnetic field. The presence of the metal object can be detected by a battery-portable broadcast band radio held close to the locator circuit. It senses the frequency shift and gives out an audible screech.

To detect a hidden metal object, first tune the radio to a local station, and then adjust C1 so that a low-frequency *beat* or chirp is heard from the radio's speaker. This beat note will change significantly if the locator circuit is placed near the hidden metal object.

Figure 14 shows the Hartley oscillator used as a DC-to-DC converter. It is capable of converting the output of a 9-volt battery to 300-volts DC. TransformerT1 is a 9-0-9 to 250-volt transformer. Its primary forms the inductance (L) part of the oscillator.

The supply voltage is stepped up to a peak of about 350 volts at T1's secondary. This waveform is rectified by half-wave rectifier diode D1, and it charges capacitor C4. With a permanent load, the output falls to about 300 volts at a load current of a few milliamperes.

Caution: Without a permanent load across C4, the capacitor can deliver a powerful but non-lethal shock to the unwary!

Conductive Water Switch:

A relay switch in a circuit that can be activated when a pair of probes come in contact with water can be very useful around the home or on a boat. It might, for example, indicate flooding of a basement, or water in the bilges of a boat. Figure 15 is a conductive-water-operated relay. Transistors Q1 and Q2 are a Darlington pair configured as a common-emitter, and relay coil RY1 is the collector load.

Fig. 15 -- Relay Circuit is activated when probes are immersed in water.

The circuit relay is normally open (NO), but it is activated when the probes are placed across a resistance path that has a value generally less than several megohms. Most potable tap water has a bulk resistances below this value, so this circuit will work as a water-level relay switch. Relay RY1 can activate a pump or alarm (or both). However, the presence of salt in theater (or sea water) has higher conductivity, and it can enhance the effectiveness of the detection circuit.

Because the conductivity of human shin has about the same resistance range as ordinary tap water, placing the probes in contact with human skin can also serve to activate the relay.

Lie Detector:

Figure 16 is simple Wheatstone bridge "lie-detector". However, because of the possible errors in the output of this circuit, its use should be confined to games or informal experiment. The circuit's operation is based on the knowledge that the resistance of human skin changes as a result of changes in the emotional state of the subject.

The bridge of this detector circuit is formed by resistor R1 and R3 in a second arm. T4 in a third arm, and transistor a probe in its base circuit) in the fourth arm.

A milliammeter with its zero point at the cent of the scale is connected across the bridge. It serves as a bridge-imbalance detector. Resistor R2 in series with the second probe is attached to the junction between Q1's collector and the low side of potentiometer R5. Large bare copper bards or silver spoons can be used to make suitable probes.

The probes should be taped or strapped directly to the skin on the subject's hand or arm, separated by at least several inches. When the subject is relaxed and his or her skin resistance reaches a stable value, adjust potentiometer R5 to obtain a null on milliammeter M1. The subject can then be questioned about the truth or falsity of emotionally loaded or embarrassing subject--in fun of course.

The subject's skin resistance will change in response to questions of that kind if they are phrased correctly. The bridge should be unbalanced if the subject reacts emotionally to the questions. Experiments of this kind are often performed by students taking college-level experimental psychology lab courses, but the equipment that they use is usually more sophisticated and sensitive than this circuit.

Professional lie detectors typically factor in changes in the subject's respiration and pulse rate measured by other sensors to supplement the skin-resistance changes. The output of the machine is in the form of pen traces on a moving pater strip. Nevertheless, you might be surprised with the results you get experimenting with this simple circuit.

Suggested Reading:

- "The Early History of the Transistor".
- "A History of Engineering and Science in the Bell System:", Physical Sciences (1925-1980). S. Millman, Editor.
- "Revolution in Miniature:", The History and Impact of Semiconductor electronics.
- "Crystal Fire", by Michael Riordan and Lillian Hoddeson
- "Transistorized!", Morgan Sparks interview.
- "How we Built the Transistor" by William Shockley. New Scientist December 1972.
- "The Improbable Years," Electronics (19 February 1968)
- "They Had Eight Days to Learn About Transistors"

Copyright and Credits: