• *First Steps In Radio*

How Receivers Work

Part 10: The antennas we discussed last month are of little use until we connect a receiver or transmitter to them. Understanding how receivers operate is a basic part of learning to be a radio amateur. Let's see what makes them tick.

By Doug DeMaw,* W1FB

S ome hams lovingly call their receivers "hearing aids." Despite the misnomer being technically incorrect, the term does tell us what a receiver in an amateur station does: It aids us in hearing the other station's message. But, simply hearing signals does not mean we can dicipher them — at least without a good receiver (and some experience and operator skill). After all, many ham bands contain a jumble of radio signals that wax and wane, cover one another up and rattle our earphones or loudspeakers.

A good receiver is not necessarily one that costs $500 or more. Many simple, homemade receivers are capable of good performance if we are willing to do without countless knobs and features that are not essential to separating and copying signals. I think all beginners owe themselves the education and thrill of building at least one receiver. Many a new ham has been known to shout in excitement when that first distant station was pulled in on a homemade receiver. Words can't convey the feeling that goes with that experience. But, in order to pass your Novice exam or build a simple receiver, it is important to understand some fundamentals about receiver circuits.

There are many routes to follow in choosing a station receiver — store bought or made by hand. Let's take a look at some

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receiver concepts and follow briefly the evolution of the communications receiver.

At the Beginning

You may not be old enough to have heard about the "crystal set." Old-time amateurs still have nostalgic conversations about those early receivers. They consisted of a large coil on a readily available coil form, such as a toilet-tissue roll, oatmeal box or other cylindrical insulating form. The other vital element was a crystal and cat's whisker combination, which was used to detect the incoming signal. Earphones completed the package, apart from the antenna and earth ground. The circuit for such a radio is found in Fig. 1. I would like to suggest that you build one of these broadcast-band receivers for the experience. They are not suitable for reception of amateur signals, since they are incompatible with CW, SSB and FM transmissions.

Remembering that by today's standards these radios are very crude, we must accept limitations in performance. They do not separate strong signals very well, they require long antennas if one is not near a broadcast station, and the sound level in the earphones may be low on the weaker stations. But, the detected signal will be crisp and clear — more so than on some expensive receivers. The fidelity of a crystal set is amazing!

The early-day crystal radios used a galena crystal to detect the signal (Fig. 2), and adjustment of the cat's whisker was a

tedious task, indeed. The experimenter had to move the metal whisker about on the surface of the crystal until a "hot spot" was located. The mere act of bumping the table would require readjustment of the whisker, and the really good hot spots were seldom found a second time! The combination crystal and whisker functioned as a modern point-contact diode, which of course has no adjustment (thank goodness!). Tuning capacitors were generally not used. Instead, the insulation along one side of the main coil was bared, and a conductive slider was moved across the exposed turns to change the coil inductance, and hence alter the tuned frequency of the receiver. Other crystal sets had many coil taps that could be selected by means of a tap switch, eliminating the slider mechanism. Enough about the "dark ages." Let's learn what makes so simple a receiver operate before moving to newer things.

The signal is collected by the antenna and flows to ground through coil, L2. The combination of L2 and C1 provides resonance at the desired radio frequency (your favorite station) when you tune C1. The energy flows from the tap on L2, and as it passes through the detector diode it is rectified. This converts the radio energy (RF) from ac to pulsating dc. This dc then flows through the headphones at an audible rate, permitting us to hear the signal.

The process is not unlike that of an ac power supply that uses no filtering after the rectifier. A link winding (L1) is used over L2 when the antenna is long. Were we to
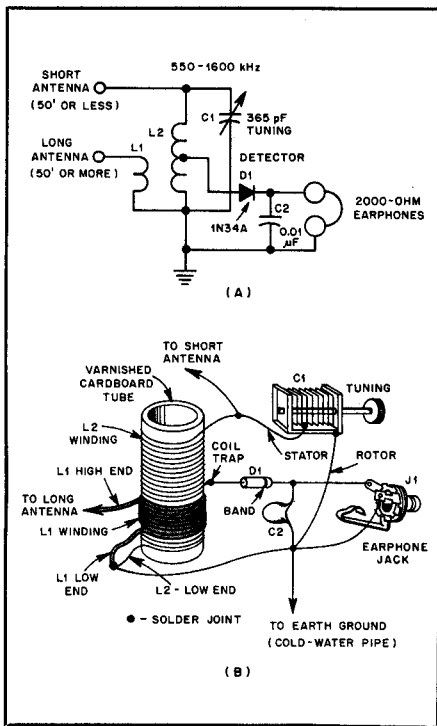
Fig. 1 — The schematic diagram at A shows the simplicity of the first radios, known as crystal sets. C1 was used to tune the stations of the standard AM broadcast band. The pictorial diagram at B illustrates how to connect the component parts of the crystal set. The radio can be built on a piece of wood or Masonite®. C1 is a 365-pF tuning capacitor. The small transistor-radio tuning capacitors are suitable for use at C1 if they have 365 to 400 pF of maximum capacitance. C2 is a disc-ceramic or tubular capacitor. D1 may be a small-signal diode, such as a 1N34A or Schottky diode of the type sold by Radio Shack. J1 is an earphone jack that matches your headphones, which should be 2 kΩ or greater in impedance. Alternatively, you may plug the output of this receiver into the input of your hi-fi amplifier. If so, insert a 0.01-μF capacitor between D1 and J1. L2 can be wound on a toilet-tissue tube. L2 should be about 220 μH in inductance. Use 150 turns of no. 26 enamel wire, close wound. Tap at 50 turns above the ground end. L1 may consist of 40 turns of no. 26 enamel wire, close wound, over the ground end of L2.

connect it directly to the top of L2, it would make the receiver tune very broadly and all of the stations would tend to come in at one setting of C1. In other words, the loading effect of the long antenna would ruin the selectivity of the receiver. The short antenna will not have a serious effect on the performance.

Enter the Vacuum Tube

The vacuum tube came along to help make reception more dramatic and practical. It permitted amplification of the radio signals *before* they were detected. This improved the receiver *sensitivity* immeasurably. Also, tubes could then be used to amplify the audio frequency (AF) after detection. This made loudspeakers practical, and several persons could listen to a radio at the same time. Radios of this class were known as tuned-radio-frequency (TRF) units. They are still used by hi-fi enthusiasts, but contain modern transistors and integrated circuits (IC).

Fig. 3 shows a typical circuit for a TRF radio. Additional RF-amplifier and audio-amplifier stages are used. They greatly increase the level of both the radio-frequency and audio signals, which enables the user to hear weak stations at comfortable volume. A shorter antenna will work reasonably well when the additional amplification is included.

Another popular amateur receiver that came along when vacuum tubes first appeared was known as the *regenerative circuit*. Exceptional sensitivity and selectivity for that era were possible with very few tubes or stages. The detector operated somewhat as an oscillator (just on the brink of oscillation). Part of the oscillator output energy was routed to the input circuit of the state and adjusted to bring the detector to the edge of self-oscillation. This action was called regeneration. It made the detector very sensitive and also aided the selectivity so that stations could be separated easily.

A typical circuit is shown in Fig. 4. The tubes (VT1 and VT2) were, depending on the era, O1As, 6C5s, 6C4s or dual triodes, such as the 6SN7 and 12AT7. Field-effect transistors, such as the MPF102, could be used today for this style of circuit. This kind of radio had a couple of problems. The detector, since it was a self-oscillating stage (like a small transistor), would permit energy to be radiated by the antenna (at the frequency to which the set was tuned). This would cause interference to nearby receivers that were tuned to the same frequency. Also, if the antenna would swing about in the wind, the radio would change frequency, causing the listener to keep his or her hand on the dial to compensate for the slight shift in frequency.
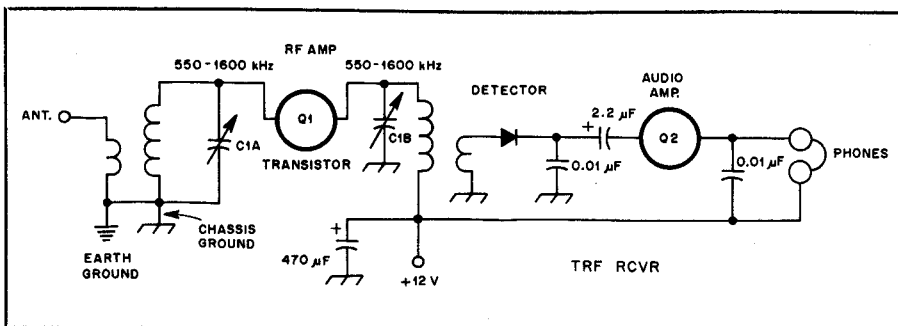

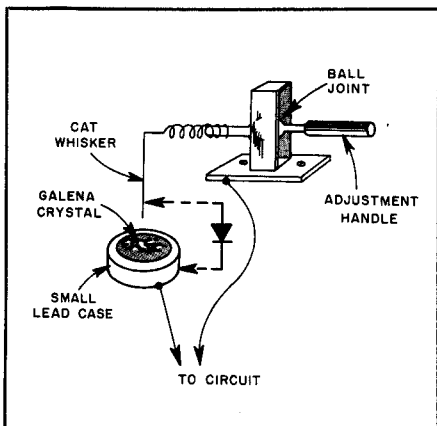Fig. 3 — Block diagram showing how a TRF radio was set up (see text).

Fig. 2 — Example of a galena crystal and a cat's whisker, as used for detecting signals during the crystal-set era.
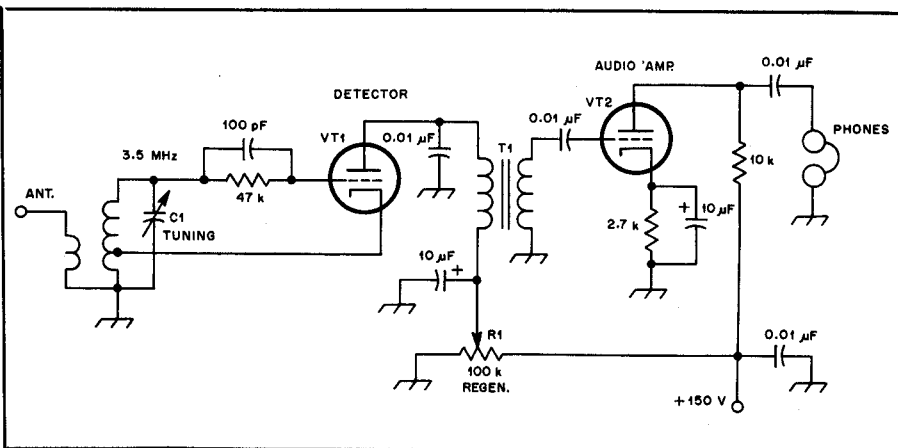

Fig. 4 — A regenerative receiver circuit. C1 was adjusted to the desired listening frequency, and R1 was set so the detector was on the verge of self-oscillation.

Clearly, something better was needed for reliable reception.

The Superheterodyne Receiver

It is not my intent to saturate you with nostalgia, for as the saying goes, "What is past is past." But, the evolution of the radio is important in terms of background if we are to understand how our present-day receivers operate.

About five decades ago, we were blessed by the invention of the superheterodyne receiver concept. Strangely, it has remained the standard circuit ever since, but with improvements and frills. Many of the circuits found in early receivers are common to today's circuits. The primary advancement is the use of semiconductors in place of vacuum tubes. The solid-state parts are, in general, more efficient: They operate cooler and last longer.

What is a superheterodyne radio (often called a "superhet")? The general scheme of the critter is shown in Fig. 5. At the left, we find an RF amplifier. It builds up the signal level from the antenna and helps to separate the stations by way of *selectivity* of the tuned circuits. If the receiver includes an RF gain control (R1), it is used to vary the gain of Q1. Next, the signal, say, 3.7 MHz, is routed to the mixer, Q2. The signal from Q1 is *mixed* with the one from our local oscillator, Q7. The output from the mixer can be either the sum of the two frequencies (9 MHz) or the difference (1.6 MHz). For reasons beyond this discussion we have chosen the higher intermediate frequency (IF). The local oscillator can be thought of as a tunable low-power transmitter that creates a CW carrier. In reality, it is not a signal unless intelligence is contained on it — at least by definition. If we were to be precise in describing the local-oscillator output energy, we would call it RF voltage.

Now that we have mixed our two frequencies in Q2, we have a 9-MHz IF. To ensure that this energy is pure and free of other frequencies (including the difference IF of 1.6 MHz), we have included FL1. This filter contains four or more quartz crystals that permit the passage of the desired frequency (9 MHz) while greatly attenuating or rejecting frequencies above and below 9 MHz. Depending on the design goals for the filter, it may pass only a narrow band of CW frequencies (250 Hz), or it may be wide enough to permit SSB or AM signals to pass (2 to 3 kHz). An FM filter will pass a much wider band of frequencies (15 kHz for many modern amateur FM transceivers).

There is always some signal loss (insertion loss) through a filter, for in order for it to be a filter it must have that characteristic. The typical loss through a filter will range from 5 to 10 decibels (dB). If the station to which we are listening is running 100 W of power, a 10-dB filter loss would be equivalent to that station re-
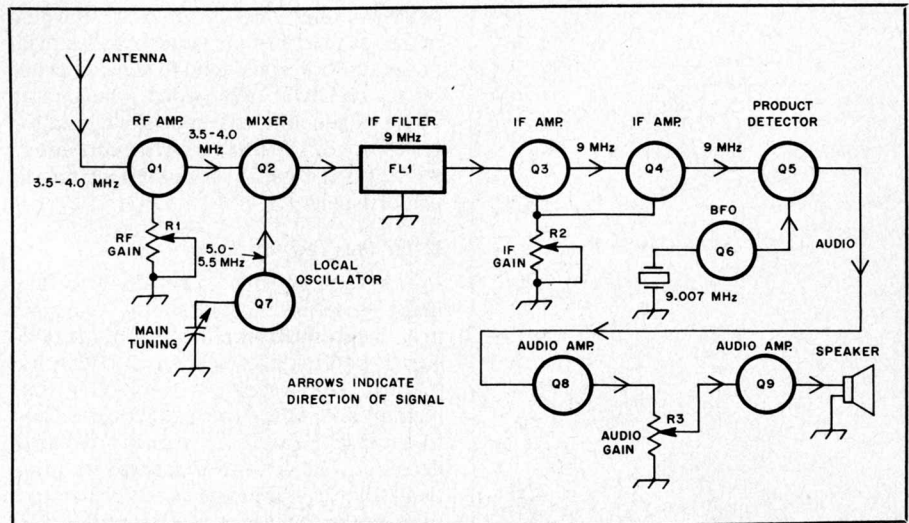

Fig. 5 — Block diagram that shows the lineup of a single-conversion superheterodyne receiver. The function of the stages is treated in the text.

Glossary

AGC — automatic gain control. An electronic circuit that lowers the receiver gain as the incoming signal becomes stronger.

BFO — beat-frequency oscillator. It generates an RF voltage that is beat or mixed with the IF signal to produce an audible voltage or signal.

decibel — (dB) — a unit of relative power measurement.

demodulate — the process of removing signal energy from an RF or IF signal and changing it to an audio frequency.

filter — a circuit used to pass desired frequencies while rejecting unwanted frequencies.

IF — intermediate frequency, as related to superheterodyne circuits.

local oscillator — generally considered the circuit in a radio receiver or transmitter that controls the operating frequency. It is adjustable by the operator from the front panel of the equipment.

regeneration — a state that exists when the output energy from a stage (amplifier) is routed to the stage input, intentionally or otherwise. It causes the stage to self-oscillate.

selectivity — the ability of a circuit to select the desired frequency while rejecting other frequencies.

sensitivity — the ability of a receiver to extract weak signals from the internal noise of a receiver to make them discernible or readable. Based on the ratio of the inherent receiver noise to the level of a received signal.

S meter — a panel instrument on a receiver that provides visual observation of received signal levels on a relative basis.

TRF radio — a nonsuperheterodyne receiver that has tuned RF amplifiers, a detector and audio amplifiers.

ducing its power to only 10 W. Therefore, we must build up the IF signal by means of IF amplifiers (Q3 and Q4).

Our ability to separate the signals has come through the selectivity of the RF amplifier stage and the filter, FL1. Therefore, the IF amplifiers do not need to have a high degree of selectivity, since the job has already been done. In fact, if we chose to use no tuned circuits between the IF amplifiers, we could design our circuit that way. Most IF tuned circuits are used to provide an impedance match between stages, rather than to increase the selectivity.

Now that we have increased the signal level from FL1, we are ready to detect or *demodulate* it. This brings us to the product detector, Q5, of Fig. 5. Generally speaking, it functions as does the mixer, Q2. The major difference is that the IF of this stage is at audio frequency rather than at RF. Therefore, the local oscillator (BFO Q6) is offset in frequency by an audio amount. For CW reception it is usually between 700 and 1000 Hz, depending on the designer's philosophy. Thus, our BFO crystal can be 700 Hz above or below the 9-MHz IF for CW reception. The offset is about 1.5 kHz for SSB reception. No BFO is needed for AM or FM reception, but special detectors are required. A product detector can be used for AM reception, however, if the AM signal is tuned in as one might tune in an SSB signal (tuned until no whistle from the AM carrier is heard). A wider IF filter is desirable for AM reception so that better fidelity will result.

Now that we have detected the signal, all that remains is to build it up (at audio frequency) until it is strong enough to operate headphones or a speaker. An audio-gain control (R3) is included for setting the level for comfortable listening. Some receivers use an IF-gain control (R2) for varying the IF gain.

The circuit of Fig. 5 is that of a single-conversion superheterodyne receiver. Double- and triple-conversion receivers are common as well. They offer some advan-
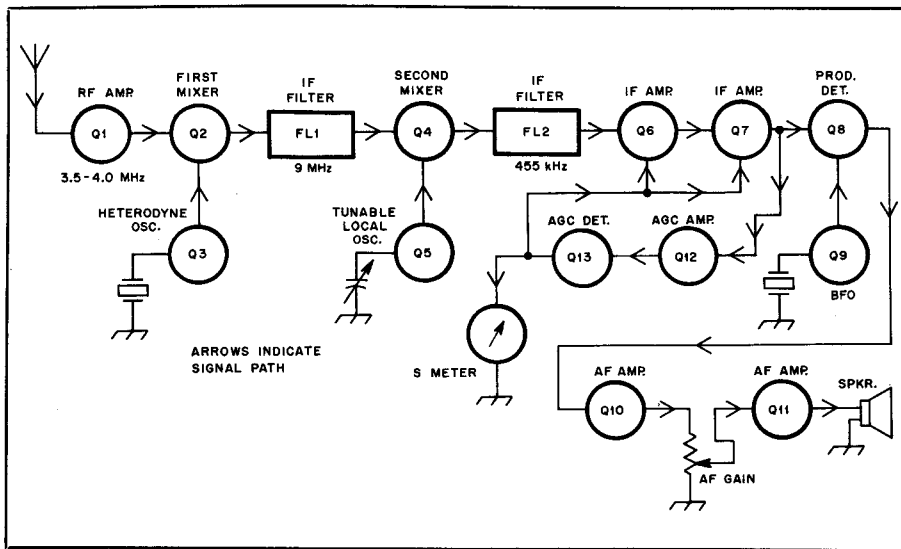
Fig. 6 — Block diagram of a double-conversion superheterodyne receiver. The function of the circuit, plus the addition of AGC and an S meter, are discussed in the text.

tages that we won't get involved with here, but Fig. 6 shows how they differ from a single-conversion receiver.

Practically, we have two receivers in series. There are two local oscillators (Q3 and Q5), two mixers (Q2 and Q4) and two IF filters (FL1 and FL2). What we are doing is converting the signal frequency from our antenna to 9 MHz, then converting it again to a lower frequency (455 kHz). The lower frequency is known as the second IF, while the 9-MHz frequency is the first IF. A triple-conversion receiver would have three local oscillators, three mixers and perhaps another IF filter. Fig. 6 shows the most fundamental method for realizing a double-conversion receiver. Modern receivers are substantially more esoteric than the example we have examined.

AGC and S Meters

Today's radios have automatic gain control (AGC) and relative signal-strength indicators (S meters). The technique for obtaining these features can be seen in simple form by returning to Fig. 6. Some IF energy is sampled at the output of the last IF amplifier, routed to an AGC amplifier (just another IF amplifier, actually), which is Q12 in our circuit, then it is rectified at Q13. The resultant dc voltage is sent back to the two IF amplifiers (Q6, Q7) for the purpose of changing their gain as the incoming signal from the antenna changes in amplitude.

The stronger the received signal, the greater the AGC voltage, and hence the lower the IF amplifier gain. This helps to keep the signal at the speaker from changing in volume, even though the received signal may vary considerably in strength. Some of the rectified AGC voltage may be used to operate an S meter, which gives us a visual indication of the relative strength of the received signal.

Today's receivers feature many additional frills, such as digital frequency readout, passband tuning, notch filters (for removing interference) fast and slow AGC response and frequency memories. But, the basic circuit is of the type shown in Figs. 5 and 6.

What Have We Learned?

If we are to summarize this lesson about receivers, we can say that the superheterodyne receiver is the common circuit today. It grew from the simple crystal detector of yesterday through a long period of evolution that brought performance landmarks step by step. A knowledge of how our receivers function is important if we are to pass the FCC license examination. It is vital also if we are to service our equipment or experience the thrill of designing and building a homemade receiver. If you wish to learn more about receivers I suggest you obtain a copy of *Understanding Amateur Radio.* There is an additional wealth of information on this subject in *The Radio Amateur's Handbook,* also available from the ARRL.