Chapter 5 Objectives

At the conclusion of this chapter, the reader will be able to:

- Explain the steps necessary in the reception of a radio signal.
- Explain how a diode AM detector works.
- Draw a block diagram of a TRF radio receiver.
- List at least two limitations of TRF radio receivers.
- Draw a block diagram of a superheterodyne AM receiver, explaining the signals at each point.
- Given a carrier and local oscillator frequency, calculate the frequency of the various tuned circuits in a superheterodyne receiver.
- Calculate the image frequency of a signal.
- Given the schematic diagram, recognize the functional blocks and signal flow in a superheterodyne receiver.
- Describe the alignment procedures for AM receivers.
- Given a receiver with a problem, isolate the fault to a particular AF or RF stage.

Chapter 5: AM Receivers

A radio receiver completes a communications system. Without a receiver, a transmitter is useless! Receivers come in many different forms. They can be designed to receive voice, digital data, and many other kinds of signals. Receivers of all types share many common features. The understanding of AM receivers will be an important foundation for the study of more advanced systems.

The Secrets Inside Everyday Objects

Technology and its products surround us, and we're accustomed to being dazzled by the magic inside the latest gadgets. There's nothing flashy about a transistor radio, a digital wristwatch, or a pocket calculator. These products are inexpensive, readily available, and have been around for a long time. But look inside them -- what does it take to *build* a radio, watch, or calculator? Perhaps this question is what led you to the study of electronics.

When we look at the *details* inside such mundane everyday devices, we're overwhelmed. How did anyone ever figure all of this out? There has to be some *magic* in there somewhere. But there isn't; all electronic devices must obey the laws of physics.

There are many years of electronics knowledge built into the humblest widget. Historically men and women have contributed to this store of knowledge for more than a century. No one can learn it all in one night. Don't be intimidated if you don't understand a principle immediately. Most of us need to review and study technical material repeatedly in order for it to "stick." Be persistent. Be patient. You can learn any area of electronics if you apply yourself!

5-1 Receiver Operation

The process of receiving a radio signal can be broken down into a series of five steps. Not every receiver will perform every step, but most do. Figure 5-1 shows this in block diagram form.

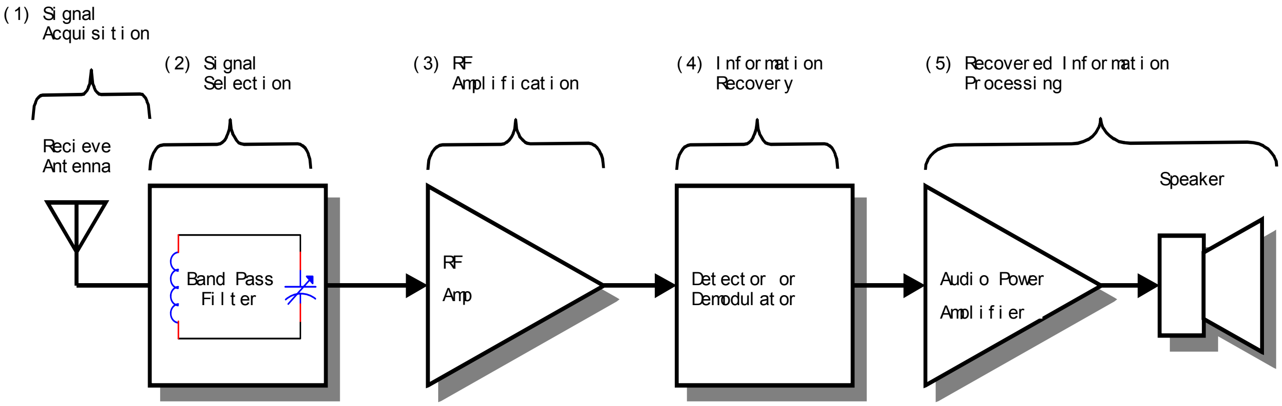

Figure 5-1: The steps in receiving a radio signal

Steps in Reception

1. *Signal Acquisition*: To *acquire* a signal means to get it. Radio signals are in the form of electromagnetic energy traveling through space at the speed of light. In order for a radio signal to be useful in an electronic circuit, it must first be converted back into an electrical signal. This is the job of the *antenna*.

2. *Signal Selection*: There are thousands of radio signals in the air at any instant in time. An antenna combines many of them in its electrical output to a receiver. Reception of more than one signal at a time would be annoying to the listener; it would be like listening in a crowded room. How can one signal be extracted from the pile? Right -- every radio transmitter uses a different *carrier frequency*. The receiver's *bandpass filter* is tuned to the frequency of the radio station we wish to receive. Ideally, *only* the desired carrier will get through this filter. In reality, there are problems with this approach; filters are not perfect, and interfering signals can get through.

3. *RF Amplification*: The distance between a radio transmitter and receiver can be very small, or many miles. The transmitted power can be a fraction of a watt, or millions of watts. In general, the signal received at a receiver's antenna is very small. At a receiving antenna, the amplitude of a "strong" received signal is usually 100 μV or less. Many receivers must deal with signals less than 1 μV in size. Before such small signals can be processed, they must be amplified. The RF amplifiers developed in chapter 4 can be adapted and used in receivers as well.

4. *Information Recovery*: The actions in the first three steps resulted in reproduction of the *modulated carrier wave* that was sent from the transmitter. The modulated

carrier wave holds the information; in order to recover the information, we use a *detector* or *demodulator* circuit. Both words have the same meaning. When we detect a signal, we are extracting the information from the modulated carrier wave. The information is saved and used, and the carrier portion of the wave is discarded.

5. *Recovered Information Processing*: This is a general way of saying that we'll be doing something useful with the information the detector extracted. The type of receiver will determine what needs to be done with the information. In a radio receiver, the detected information is an *audio* signal with insufficient voltage and current to drive a loudspeaker. Therefore, the last stage in a radio receiver is an audio power amplifier, which provides the voltage and current needed to operate the loudspeaker. For example, a *television* receiver differs from a radio receiver only in how the detected information (a *video signal* in analog TV, or a *data signal* in digital TV) is processed.

These are the basic steps a receiver needs to perform. In simple radio receivers, some of the tasks can be omitted. For example, you may have built a *crystal radio receiver*. A crystal receiver uses only the energy from the incoming radio wave to produce the sound. A long wire antenna is usually required in order to receive sufficient signal. Figure 5-2 shows the schematic of one type of crystal receiver. There are thousands of different possible crystal receiver designs. Many active enthusiast groups build and study these simple receivers.

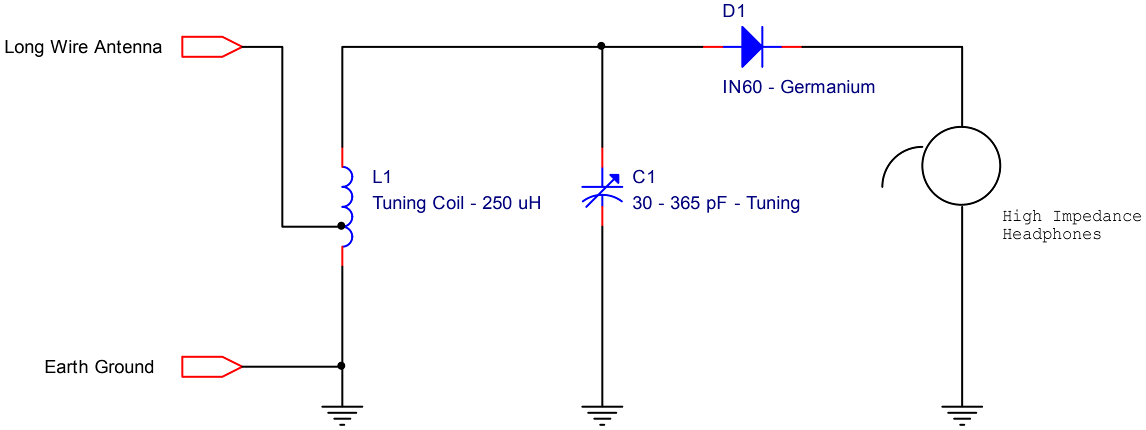

Figure 5-2 A crystal radio receiver

There isn't much to the circuit of Figure 5-2! A *long wire* antenna is connected to the upper input terminal. (A length of wire 50' or longer will work well.) The *earth ground* terminal must be connected to a good earth ground in order to provide an AC return path for the antenna signal. (A ground rod, or metallic cold water pipe could be used.)

The process of *selection* is accomplished with L1 and C1, which form a parallel-resonant bandpass filter. The output of the filter is sent to the detector diode, D1. Two types of variable capacitors for receivers are shown in Figure 5-3. The miniature type is very commonly used in portable receivers.

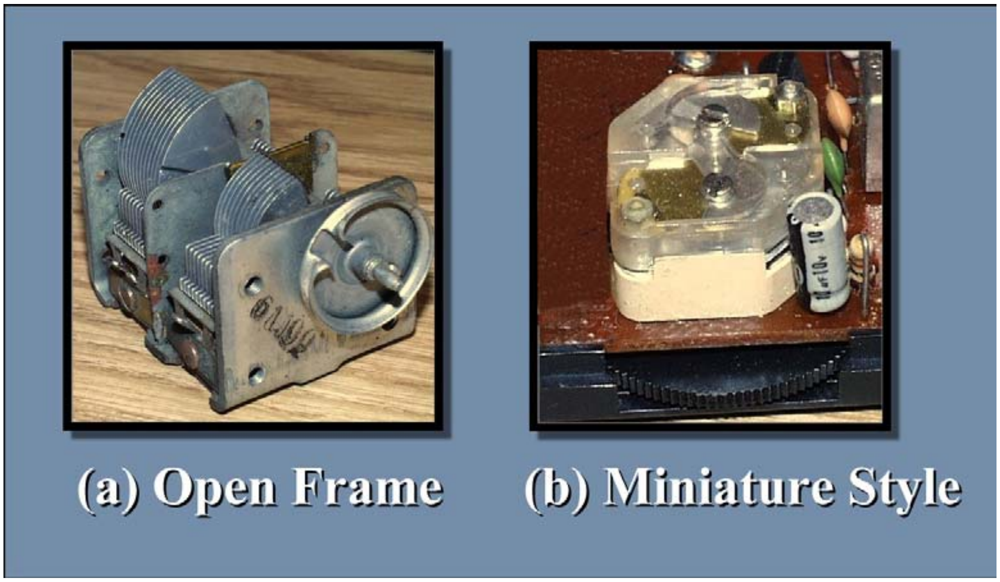

Figure 5-3: Typical receiver variable capacitors

D1 is a *germanium* diode. The use of this type of diode is common in AM detectors. A silicon diode requires a forward bias of 0.7 volt in order to conduct. In contrast, a germanium diode will begin conduction at only 0.2 to 0.3 volts. This greatly increases the sensitivity of the receiver. *The sensitivity of a receiver is its ability to process small input signals.*

The detected signal is a copy of the original information, and leaves the cathode of D1. It consists of a DC component, and two AC components, the AF information, and the RF carrier. The headphones receive this signal, but can only respond to the audio information -- the RF energy changes polarity too quickly for the headphones to respond. Thus, the headphones produce sound that is a copy of the original sound from the transmitter.

Example 5-1

What is the approximate tuning range of the receiver of Figure 5-2?

Solution

L1 and C1 form a bandpass filter. The resonant frequency of this filter controls what carrier frequency the receiver will receive. C1 is a variable capacitor that is adjustable from 30 to 365 pF. This is the tuning control. By setting C1 to its maximum and minimum values, we can find the range of resonant frequencies:

$$f_{\min} = \frac{1}{2\pi\sqrt{LC_{\max}}} = \frac{1}{2\pi\sqrt{(250\mu H)(365pF)}} = \underline{\underline{527kHz}}$$

$$f_{\max} = \frac{1}{2\pi\sqrt{LC_{\min}}} = \frac{1}{2\pi\sqrt{(250\mu H)(30pF)}} = \underline{\underline{1838kHz}}$$

The receiver can tune from 527 kHz to 1838 kHz. This more than covers the AM broadcast band, which runs from 535 kHz to 1620 kHz.

Section Checkpoint

5-1 What are the five steps in the reception of a radio signal?
5-2 What type of circuit is used for *selection* of a signal?
5-3 Why are RF amplifiers necessary in receivers?
5-4 What steps of reception are performed in the circuit of Figure 5-2?
5-5 Why are germanium diodes used in AM detectors?
5-6 How does the end user control the frequency of the bandpass filter in the receiver of Figure 5-2?

5-2 AM Detection

There are several types of AM detectors in use. The most common of these is the *diode detector* of Figure 5-4. The diode detector generates some distortion of the information, but is the simplest and least expensive approach. A diode detector works because a diode is a nonlinear device. In general, a nonlinear device is required to both *modulate* and *demodulate* (detect) AM signals.

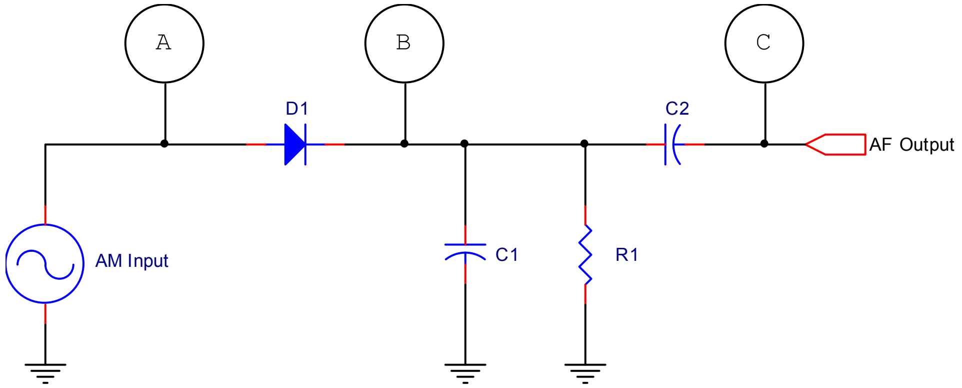

Figure 5-4: The diode detector

The waveforms for the diode detector are shown in Figure 5-5. The primary action that takes place in a diode detector is *rectification*. The AM detector is very similar to a half wave power supply in this regard. When the AM signal is applied to the input, the diode cuts off the negative half cycles, since it can only conduct when it is forward biased.

The third waveform of Figure 5-5 illustrates this action. This waveform would be obtained at test point *B* if capacitor C1 were removed from the circuit. Although it doesn't look like it, there are actually *three* primary frequency components in the half-wave rectified signal at test point *B*. They are the *modulated AM carrier signal and sidebands*, the *information frequency*, and a *DC level.*

Time Domain Analysis

The rectified waveform from D1 is passed to capacitor C1, which charges up to the voltage of each positive peak of the rectified RF wave. Resistor R1 is a bleeder resistor. Without R1 to continually discharge C1, C1 would just charge up and hold the highest positive DC level! The time constant of R1 and C1 is designed to be as short as possible so that the voltage on C1 will follow the AM envelope as closely as possible.

The jagged shape of the recovered information is due to the charging and discharging of C1. A capacitor cannot change its voltage instantaneously. When the envelope is *falling* (getting smaller), the voltage on C1 can fall only as fast as the RC time constant of R1 and C1 permits.

The bottom waveform in Figure 5-5 contains the information and a DC component. The DC component is useful as a *signal strength* indicator, and can be used to operate the automatic gain control (AGC) circuit in a receiver. The DC component is *not* useful for audio amplification, so it is removed by capacitor C2.

Frequency Domain Analysis

The detector's operation can also be explained in the frequency domain. The signal at test point *B* contains the AM carrier (an RF signal), the information frequency (an AF signal), and a DC level. We desire to recover the information frequency and discard the AM carrier signal. This job is performed by a *low-pass filter* built with C1 and R1. The low pass filter works because the carrier frequency is much higher than the information frequency.

For example, the receiver might be tuned to 810 kHz with an information frequency of 4 kHz. The low-pass filter can easily reject the 810 kHz (carrier) component and pass the 4 kHz (information) component. The bottom waveform results. The jagged shape of the recovered information is a result of imperfect filter action. A small amount of the 810 kHz carrier signal gets through the filter and shows up as a high-frequency ripple in the detected output.

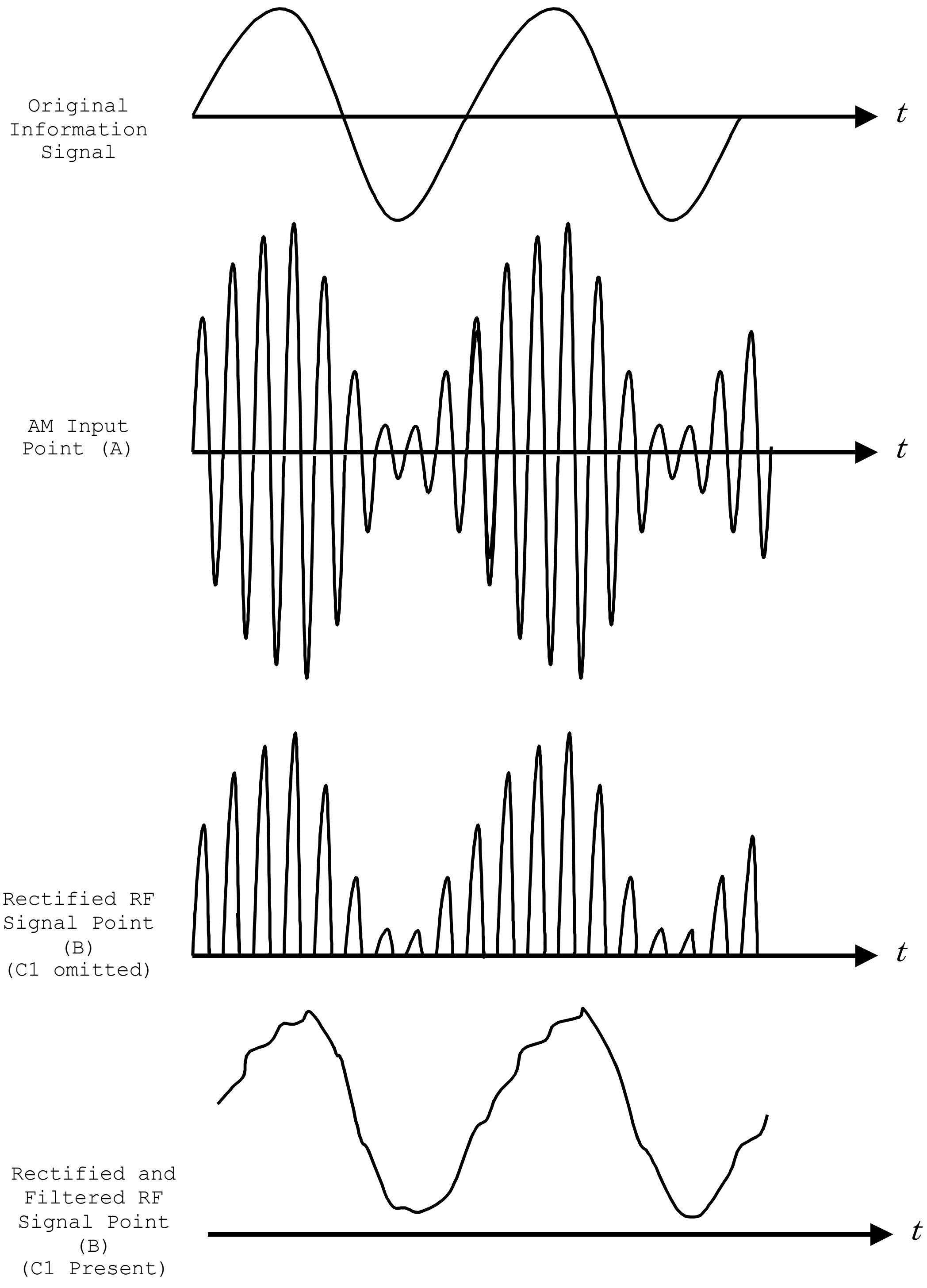

Figure 5-5: Waveforms for the diode detector

Distortion in the AM Detector

A diode AM detector doesn’t produce a perfect copy of the information. C1 can't discharge (through R1) rapidly enough to keep up when the envelope falls rapidly. The recovered information is distorted as a result.