1 INTRODUCTION

The purpose of this introductory chapter is to provide an overview of AM, FM, and FM-stereo receivers and to acquaint the reader with the organization of this text.

1-1 FUNDAMENTAL PRINCIPLES

Radio Waves

We are all vaguely aware of radio waves. After all, that is how the music comes to our radio receiver and how the picture and music together are delivered to the TV set. Amateur radio operators use radio waves to talk over great distances, and a far greater number of CB radio operators use radio waves to talk over short distances. A few CB operators know how to use radio waves to talk over great distances. Radio waves are everywhere, and therefore we do not think about them much.

Strictly speaking, radio waves, television waves, microwaves, and radar waves are all forms of *electromagnetic radiation*. What makes one type different from another is the frequency—the number of waves emitted per second. Radio waves are relatively low-frequency waves; television waves are sort of medium-frequency waves; microwave and radar waves are high-frequency waves.

If we continue upward to even higher frequencies in the electromagnetic spectrum, to the region beyond the realm of electronics, we encounter *infrared* radiation. This consists of radio waves of frequency so high that we perceive it as heat. The warm glow on one's face while standing near a fireplace is due to infrared radiation, a form of electromagnetic radiation.

Going further, until we reach frequencies about 100,000 times as high as that of radar waves, we come to the visible spectrum—light. What our eyes perceive as light is electromagnetic radiation whose frequency is on the order of 10^{14} Hz. Within the visible spectrum, our eyes sense waves of different frequency as different colors. Thus, color is due to frequency. Blue is of higher frequency than red, and green is in the middle.

At only slightly higher frequencies, our eyes cannot respond to the waves. This is the *ultraviolet* region of the spectrum, the so-called black light that makes fluorescent posters glow with a peculiar iridescence. Beyond the ultraviolet region lies the realm of gamma radiation, where the energies are so high and the wavelengths so short that the waves become more like particles than waves. Only people who study nuclear physics need to be concerned about gamma radiation, from the academic point of view, at least.

From all this we conclude that radio waves and light waves are basically the same physical manifestation. All electromagnetic waves travel at the same speed—the speed of light, naturally. They consist of both an electric and a magnetic field and are able to travel through the absolute vacuum of intergalactic space. For our purposes, we need only be concerned with the low-frequency waves that are sent out from radio transmitters.

Transmission and Reception of Radio Waves

At a radio station, high-frequency currents are forced to flow in the transmitting antenna by the power amplifier of the transmitter, which operates at the assigned frequency of the station. Electrons surge back and forth in the antenna, and the accelerations experienced by the electrons give rise to the production of radio waves. When an electric charge is accelerated, an electromagnetic wave is produced. The waves travel outward from the antenna at the speed of light—186,000 miles per second, or one mile in 5.37 microseconds (μs). Thus, high-frequency currents in the transmitting antenna produce radio waves.

When the waves encounter a receiving antenna, they induce currents in the antenna as they pass by. Furthermore, the induced currents are of the same frequency as those in the transmitting antenna, and the strength of the induced currents is directly proportional to the strength of the currents in the transmitting antenna.

Here we have a link established between the transmitting antenna and the receiving antenna, via the radio waves. This link forms the basis for the transfer of information from the transmitter to the receiver, and the information may take the form of voice, music, or in the case of television, a picture.

Tuning

When an inductor is connected to a capacitor, a resonant circuit is formed that produces its maximum response at a particular frequency called the resonant frequency. These circuits form the basis of tuning, the ability to select one transmitter and reject all the others. Without the phenomenon of tuning, there could be only one transmitter on the air at a time, and wars would probably be fought for the privilege of using the transmitter.

Voice Waves

First of all, sound, any sound, is a mechanical vibration of the molecules of the air (or other medium, such as water or wood) through which the sound propagates. The vibrations propagate outward from the disturbance that acts as the source in the form of waves—sound waves. A sound wave entails a variation in pressure, to which our ears will respond.

Sound waves are not electromagnetic; they are mechanical. The highest frequency that can be heard by a human ear is about 20 kHz, and the waves travel at about 1100 f/s in air at room temperature.

A microphone is a device—a *transducer*—that converts variations in pressure (sound waves) to variations in voltage—an electrical signal, called an audio signal. The output voltage variation may be observed on an oscilloscope, and the waveform is called a *voice wave*. Here we use the term "wave" to relate to the shape of the trace on the oscilloscope; no new type of wave phenomenon is implied.

Due to the rapid variations of voltage in an audio signal, it assumes the characteristics of an alternating current. However, the waveforms are highly irregular and seldom resemble the smooth sine wave typically associated with an alternating current. The audio spectrum spans the range from 20 Hz to 20 kHz, but most ears will not respond to frequencies much over 15 kHz. The upper-frequency limit of hearing decreases as the age of the listener advances, a normal progression that is not always considered a disadvantage.

The Dynamic Loudspeaker

A truly marvelous and noteworthy device is a common, ordinary speaker. The poorest and best alike consist of a paper cone attached to a small coil of wire (the voice coil) that is suspended in a magnetic field. A current sent through the coil causes a deflection of the paper cone. A voice wave sent through the coil causes the voice to be reproduced. This simple device can reproduce with amazing fidelity the sound of the ocean, a violin, a tuba, an oboe, the human voice, and so forth, ad infinitum.

Respectively, the sounds of a violin, tuba, and oboe are produced by a vibrating string, a brass tube in conjunction with the vibrating lip of the tuba player, and a vibrating reed. The sound of the ocean is produced by splashing water. Is it not just a little bit amazing that a vibrating paper cone can mimic the sounds of these different types of sound sources? Does it not seem that a gadget that can reproduce the sound of an orchestra, for example, should be enormously complex, consisting of strings, reeds, brass tubes, wooden pipes, and perhaps even a few bells?

1-2 AM AND FM (AMPLITUDE AND FREQUENCY MODULATION)

We know that a transmitter can produce radio waves. But radio waves by themselves carry no information. We need a method for transporting a voice wave (or the equivalent) via a radio wave, called the *carrier*. Commercial radio uses two methods for doing this—AM and FM.

In the AM system, the voice wave is used to control, or *modulate*, the amplitude (strength) of the radio waves being transmitted at that instant. The transmitter circuitry that does this is the *modulator*. As the voice wave varies, so does the amplitude of the transmitted waves. As the voice wave becomes more positive, the carrier amplitude increases, and as it becomes more negative, the carrier amplitude decreases. Thus the instantaneous amplitude of the carrier is proportional to the instantaneous voltage of the voice wave—the signal from the microphone, perhaps. In the AM system, the frequency of the carrier does not change.

In the FM system, the amplitude of the carrier always remains the same, but the frequency transmitted at any instant depends on the level of the voice wave at that instant. When the voice wave goes more positive, the carrier frequency goes up. When the voice wave goes more negative, the carrier frequency shifts downward a proportional amount. Thus, the carrier frequency swings back and forth (deviates) about the center frequency as the voice wave alternately goes positive and negative.

Obviously, to receive an AM station, one needs an AM receiver; similarly for FM. Therefore, we find two different types of receivers on the market, AM and FM. In most cases, however, a receiver will have a switch to select either the AM mode or the FM mode. Such a receiver is called an AM-FM receiver.

The broadcast bands for AM and FM are located far apart in frequency. FM frequencies are about 100 times higher than AM, as set up by the Federal Communications Commission (FCC). The AM band ranges from 540 to 1600 kHz with a channel width of 10 kHz. The FM band ranges from 88 to 108 MHz with a channel width of 200 kHz. Thus, an FM station is alloted 20 times as much spectrum space as an AM station. For purposes of comparison, a TV channel is 6 MHz wide—the equivalent of 30 FM channels or 600 AM channels.

Fidelity

Everyone knows that FM sounds better than AM, and there are two main reasons why this is so. First, because an FM channel is 20 times as wide as an AM channel, an FM station can transmit more of the audio spectrum—up to 15 kHz. The legal limit for AM is 5 kHz. A wider-frequency response translates directly to higher-fidelity transmission.

Second, electrical noise (static) occurs in the form of amplitude variations, and an AM receiver responds directly to amplitude variations. Hence, we hear static in the speaker of an AM radio, especially when the station is weak. An FM receiver, however, responds only to frequency variations and is therefore immune to static. Indeed, FM receivers use limiters which remove any amplitude variation that might appear at the antenna.

A third reason most FM stations sound better than an AM station is that the majority of FM stations transmit in stereo. FM stereo represents an add-on to the FM system for which there is no counterpart in the present AM system. More is said in regard to FM stereo in the following sections.

1-3 A RADIO RECEIVER

At this point we can identify some of the things a receiver must accomplish without worrying about whether the receiver as AM or FM. We shall see that the overall block diagrams of the two types are quite similar.

First, there must be an antenna to receive the waves from the transmitter. Years ago this was a wire strung as high as possible to a tree in the backyard. Now the antenna is built into the cabinet of almost all AM receivers, and FM receivers use a few tricks to avoid an external antenna. For best FM reception, however, a TV-type FM antenna is still preferred.

Next, we must provide our receiver with tuning capability. *LC* resonant circuits do this to perfection, almost. Tuning is no problem.

The big problem, however, is one of amplification. The signal produced by the antenna is very weak, voltages being measured in the range of microvolts and power levels in the nanowatt range at best. So let us provide about three stages of amplification immediately following the antenna. Because these amplifiers operate at the antenna frequency, we call them *RF amplifiers*—*RF* stands for *radio frequency*. Being clever, we will include tuning circuits in these amplifiers so that we tune and amplify together. We then have the antenna followed by three tuned RF amplifiers.

The output signal of the RF section (called the *front end*) is then delivered to the demodulator, where the voice wave (the audio signal) is recovered from the modulated carrier. The demodulator is sometimes called the *detector*. If our receiver is AM, our demodulator must be an AM demodulator. For FM we must have an FM demodulator. In either case, the output of the demodulator is the much-desired audio signal, the music.

The audio signal produced by the demodulator is usually rather small. In no case could it be applied to a speaker to render an audible volume level. It must be amplified first. To do this, we use an audio amplifier, of course. The audio section may utilize one or two stages of voltage amplification to build up the signal for delivery to the power audio amplifier. The power amplifier is designed to deliver the power required by the speaker. We would incorporate a volume control in one of the voltage amplifiers following the demodulator, and perhaps we would even include a tone control to provide for bass-treble adjustments.

Finally, a power supply must be provided to supply DC voltages to each stage, and the receiver is complete. The block diagram is shown in Figure 1-1. Such a receiver is called a *tuned radio frequency* (TRF) receiver, owing to the three stages of RF amplification following the antenna. This type of receiver will work, and

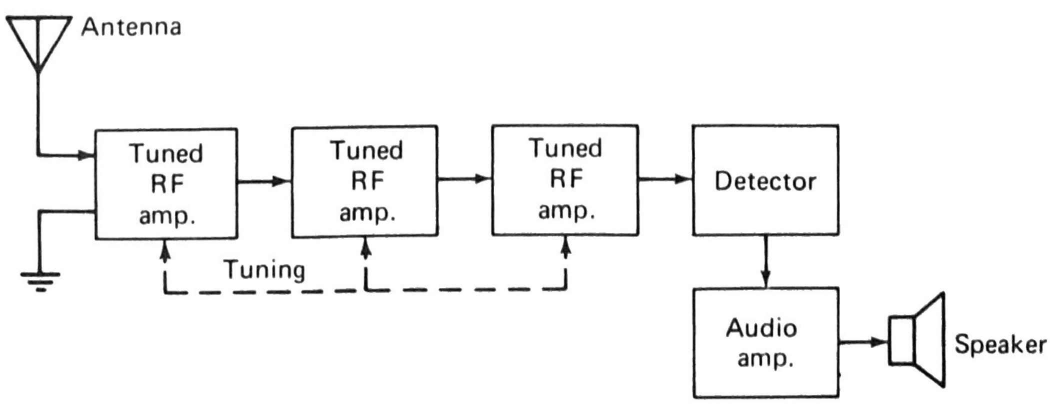

FIGURE 1-1 Block diagram of a tuned radio-frequency (TRF) receiver. (The power supply is omitted.)

millions have been sold. However, it suffers from several disadvantages when compared to the receiver described in the next section.

1-4 SUPERHETERODYNE RECEIVERS

With the possible exception of simple demonstration receivers or perhaps very specialized receivers that are dedicated to a specific function, all modern AM or FM receivers utilize the superheterodyne principle and are therefore called *superheterodyne receivers*. Whether a receiver is AM or FM, tube-type or solid state, portable or console, rudimentary or elaborate in design, it is almost a certainty that the superheterodyne principle is employed.

Superheterodyne receivers convert the frequency of the signal received at the antenna to a lower, intermediate-frequency signal that is then amplified by a narrow-band amplifier called the *intermediate frequency* (IF) *amplifier*. The IF amplifier provides a major portion of the amplification that is required to increase the level of the antenna signal to the level required by the demodulator. A generalized block diagram of a superheterodyne receiver, without regard to whether it is AM or FM, is shown in Figure 1-2.

The process of converting the antenna signal to a signal of the IF frequency is called either *heterodyning* or *mixing*, and the stage that performs the frequency conversion may be called either a *converter* or a *mixer*.

Frequency conversion is achieved by mixing two signals of different frequencies to obtain a third signal whose frequency equals the difference between the two original frequencies. Thus, two signals must be applied to the mixer. One comes from the antenna via the RF amplifier, and the other is provided by a *local oscillator* (signal generator) that constitutes a portion of the frequency converter stage. The output of the local oscillator heterodynes with the antenna signal to produce the IF signal, which is then amplified by the IF amplifier.

Because the IF amplifier operates at only one frequency, it can be economically designed to produce a high gain with narrow bandwidth. Further, since the IF frequency does not change as the receiver is tuned across the band, the bandwidth of the IF amplifier remains constant as the receiver is tuned across the band. The

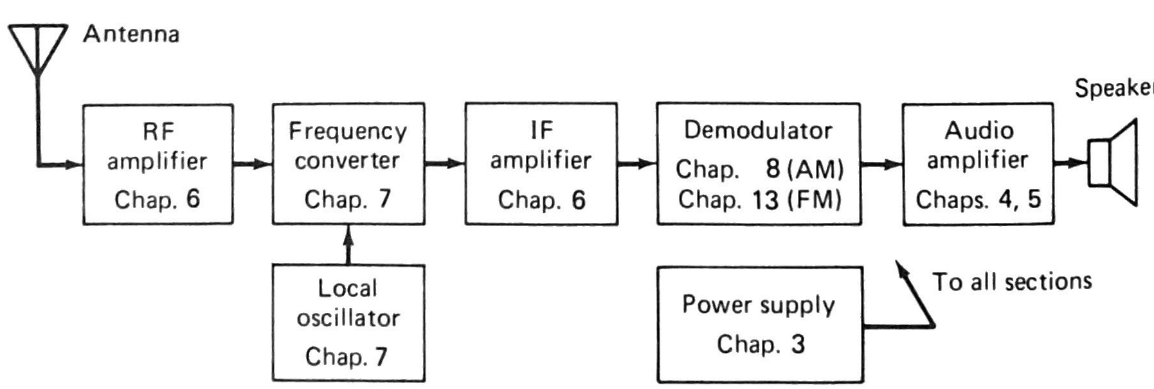

FIGURE 1-2 Generalized block diagram of a superheterodyne receiver. The chapter designations refer to the chapters of the text in which each block is described.

high gain of the IF amplifier contributes to the overall sensitivity of the receiver, and the narrow bandwidth of the IF amplifier contributes to the overall selectivity of the receiver. Since the IF amplifier bandwidth is independent of the receiver tuning, the receiver will exhibit essentially the same selectivity at all portions of the broadcast band.

The superheterodyne principle and frequency conversion are described in detail in later chapters; indeed, the text is devoted almost entirely to circuits encountered in superheterodyne receivers. More is said in this regard in the following sections of this chapter.

1-5 FM STEREO

The FM-stereo system is an enhancement of the original FM monaural system and is capable of transmitting two independent audio channels via one frequency-modulated RF carrier. FM-stereo receivers receive stereo broadcasts in stereo, and monaural receivers reproduce the same broadcast monaurally with negligible degradation of fidelity in comparison to the reproduction of monophonic broadcasts. In other words, the FM-stereo system is *compatible* with monoaural FM receivers.

In regular monophonic FM transmission, the highest audio frequency transmitted is 15,000 Hz. An examination of the system capabilities, however, reveals that it is possible to transmit modulating frequencies up to 75 kHz. Obviously, the human ear will not respond to frequencies much beyond 15,000 Hz, so modulating frequency spectrum space is available between 15 and 75 kHz that may be (and is) used to transmit the second channel of audio information required for FM stereo transmissions.

The second channel of encoded audio information is placed above the audio spectrum of the main channel by amplitude-modulating (with the carrier suppressed) a subcarrier whose frequency is 38 kHz. The sidebands of the modulated subcarrier are then added to the modulating signal of the main audio channel to form a composite FM signal that contains audio information that the stereo receiver may process to form independent left and right audio channels for stereo reproduction.

An FM-stereo receiver is not radically different from a monaural receiver. The significant difference is that an FM-stereo receiver includes added circuitry for deriving the two independent channels (the left and the right) from the transmitted FM-stereo signal. The RF amplifier, frequency converter, IF amplifiers, and demodulator sections may be almost identical to those of a monaural receiver. The stereo *decoder* comes after the demodulator, and it is the function of the decoder to form the left and right channel signals from the FM stereo composite signal that comes from the demodulator. For stereo reproduction, of course, two independent audio amplifiers and speaker systems are required.

A generalized block diagram of an FM-stereo receiver is shown in Figure 1-3. Further discussion of the FM-stereo system is postponed because of the rather technical and subtle nature of the system. The development of the composite signal and the operation of stereo receivers are described in detail in Chaps. 16 and 17.

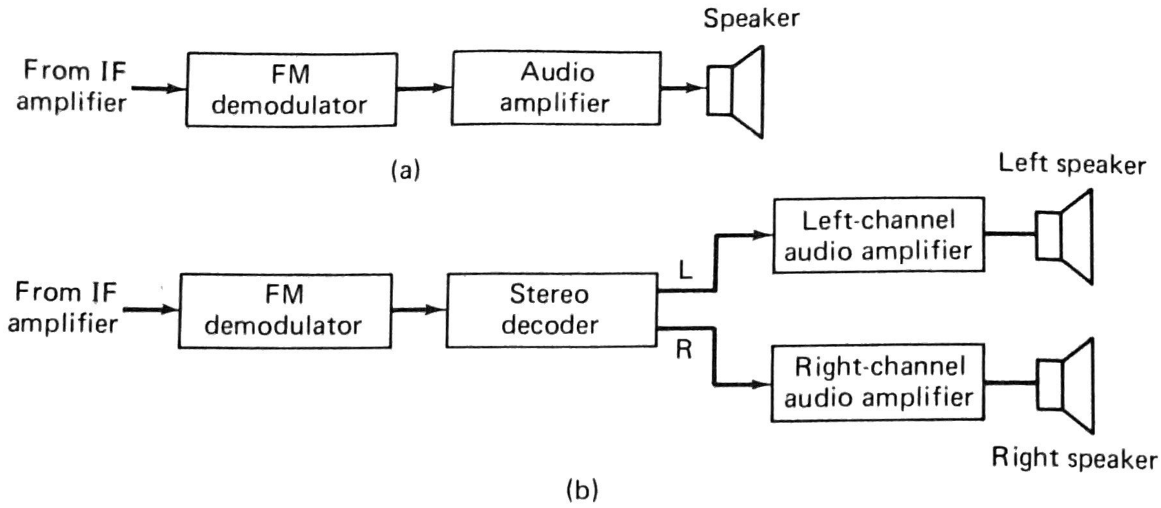

FIGURE 1-3 Block diagrams of the FM demodulator and audio section (a) of a monaural FM receiver, and (b) of a stereo FM receiver.

1-6 ORGANIZATION OF THIS TEXT

This text is divided into four main sections, as shown in the block diagram of Figure 1-4. The first section provides a description of active devices—tubes, transistors, field-effect transistors, and operational amplifiers—and a description of the circuits commonly encountered in AM, FM, and FM-stereo receivers. This includes audio amplifiers of various types, RF amplifiers, frequency changers, and power supplies. The first section forms a base of information that is used extensively in later sections.

The second section is devoted to AM receivers, to the fundamentals of troubleshooting, and to the troubleshooting of AM receivers. The principles of AM systems are given in Chap. 8, and actual receivers are analyzed in Chap. 9. Note that the fundamentals of troubleshooting and the basic troubleshooting procedure are introduced immediately after a complete system (an AM receiver) is analyzed.

The third section parallels the second, being devoted to FM receivers. The principles of FM transmission are given, followed by an analysis of receivers and troubleshooting.

The fourth section is devoted to FM stereo. A complete, detailed explanation of the FM-stereo system is given in Chap. 16. This is followed by the analysis of FM-stereo decoders; the final chapter deals with the troubleshooting of FM-stereo receivers.

1-7 LOOKING AHEAD

A person who is just beginning to study electronic servicing may tend to be impressed by the amount of material that he is required to master, and, indeed, the volume of material is considerable. But, as the longest journey begins with the first step, the devoted student should make rapid progress—even though the amount of progress may not at first be clearly evident. Electronic servicing is a big field,

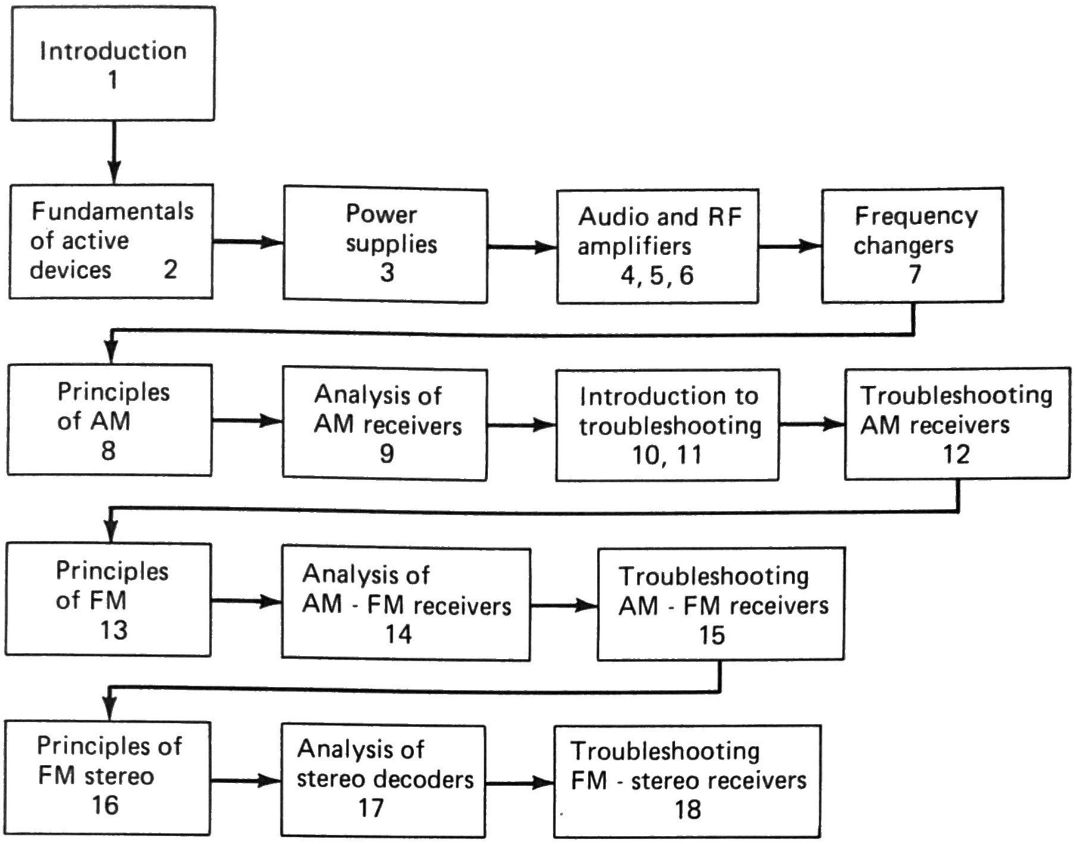

FIGURE 1-4 Block diagram illustrating the organization of this text.

and it is one that can never be mastered in its entirety—partly because the technology is advancing so rapidly and partly because of the tremendous number of devices on the market. Consequently, electronic servicing requires continued study in order to keep up with the technology and to constantly improve and increase one's abilities.

An objective of this text is to emphasize troubleshooting by procedure and to emphasize a systematic approach to troubleshooting rather than to present a collection of symptoms and the probable causes of each. As a technician gains experience, however, he will be increasingly able to recognize a symptom and to pinpoint the defect. However, many receivers exhibit unusual symptoms that can be misleading or deceptive and rather difficult to assess; such receivers are known affectionately as "dogs." With such receivers, only a carefully executed systematic approach is likely to be productive.

In real life, troubleshooting is never as straightforward and forthright as a text on the subject makes it appear that it should be. It is likely that this text is no exception. The defects assumed for purposes of illustration have been carefully selected to illustrate applicable procedures, and, indeed, many, if not most, stem from specific troubleshooting situations experienced by the authors. No defects have been included that have not been encountered in practice.

It is usually very beneficial for the beginning technican to acquire an assortment of junk receivers in order to become familiar with the physical aspects of the circuitry. Such a practice is even more beneficial if service information can be obtained for the receivers. As the technican gains experience, attempts can be made to repair the receivers—there is no better way to learn than by doing. However, it is generally not a good idea for a novice technician to accept service jobs for hire until he has acquired considerable experience on "noncritical" receivers.

In the face of a rapidly advancing technology, a concern naturally arises that any text on troubleshooting is obsolete or soon destined to become so. To some extent this must be true, but many elements of troubleshooting have remained essentially constant for a long time. The basic block diagram of superheterodyne receivers has remained unchanged for decades, as have the basic techniques of signal tracing, signal injection, and voltage-resistance analysis. Although the details of implementation may change or require modification, procedures remain essentially unchanged even as the technology undergoes transitions from vacuum tubes to transistors and onward to an increasing use of monolithic integrated circuits. Another consideration is that, to some extent, an electronic service technician must look not only to the future, but must also be concerned with what has gone before. Millions of older sets utilizing outdated technology by present standards are still in use and will require servicing for years to come.

It is probably true that in most specialized service organizations, the major effort is toward TV servicing. Although this text is not directed toward TV servicing, many of the techniques and procedures elaborated upon here are applicable not only to many sections of TV receivers, but also to citizen's band tranceivers and commercial two-way communications equipment. This text provides a good background for almost any area of electronic servicing.

Electronic servicing is a challenging endeavor that can be very satisfying and rewarding. Frustrations often arise, but the satisfaction derived from conquering a particularly stubborn problem more than compensates for the attendant frustrations.