Chapter 1: Communication Systems

Chapter 1 Objectives

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

- ∉ Explain the difference between systems and subsystems.
- ∉ Describe the functional blocks in a practical radio communications system.
- ∉ Calculate the *wavelength* of a radio wave and relate it to physical antenna length.
- ∉ Define modulation and explain why it is needed in a radio communications system.
- ∉ List the three steps for troubleshooting systems.

1-1 Communication Systems

Today, every facet of our lives is touched by modern electronics. Being human, we take most of it for granted. It's easy to forget that for the largest part of recorded history, we've lived with no telephones, radios, televisions, or computers. Before the development of electronic communications, the speed of information travel was limited by the physical distance a runner or horseman could cover in a day. During the colonization of America, it was accepted that a letter might take several months to reach its destination across the ocean, and several more months for the reply to return. Today the distance across the globe is measured in fractions of a second.

Have you recently:

Electronic Communications is Everywhere

Watched a TV broadcast or listened to the radio? These are probably the most visible applications of communications technology. Analog television uses very sophisticated electronic techniques. The latest television technology, high-definition television (HDTV), uses complex digital and software technology together with advanced analog circuit techniques. These techniques are readily understood by anyone with a firm grasp of electronic fundamentals.

Used a telephone? Your voice may be sent using many different technologies. Analog transmission carries your conversation to the central office. From there, the signal is converted to digital (digitized). The digital signal is sent (along with thousands of other calls) on a beam of light through fiber-optic cables. The process is reversed at the destination. During the process, your conversation may also travel by radio wave to and from a satellite. Cellular telephones transmit and receive voice signals as streams of digital data over UHF (ultra high frequency) radio-frequency carrier signals.

Used a remote-control for a garage door, TV, or other appliance? Many remote-controls are actually tiny radio transmitters. A small microprocessor encodes digital data onto the transmitted radio wave to represent the user's commands.

Taken a commercial flight? Aircraft use numerous types of communications to ensure flight safety. Both voice and digital (data) communications are used by aircraft. Many of the communications are computer-automated. The Global Positioning System (GPS) is used to help provide accurate navigation.

Used a credit or debit card? If so, the verification was completed electronically. A credit card reader contains a microprocessor and a *modem* (modulator-demodulator). Your individual information record is recorded in three parallel "tracks" which are read from the card's magnetic stripe by the microprocessor. Newer credit cards have a memory chip containing the customer's account information in encrypted form. The modem allows the microprocessor to transmit the data to a host computer operated by the credit card company, typically through an Internet connection, and in some cases, an analog phone line.

Electronic Systems

In your previous electronic studies, you have been primarily concerned with the *theory* of circuits. For example, you might have constructed an amplifier stage with a transistor or op-amp IC (Integrated Circuit). The amplifier you built was studied for its own sake; it didn't fit into anything "bigger." This book will be your first study of *systems*.

A <u>system</u> can be defined as a group of components that work together to complete a job or task.

Many technicians are a little frightened when first asked to learn a new system. Part of this might be a natural fear of the unknown. The technician might wonder if he or she is capable of learning the necessary technical details. The best way to learn a system is to break it down into functional blocks, or *subsystems*. Upon study of these parts, the technician soon recognizes familiar circuits and principles and gains an understanding of how the system actually works.

A <u>subsystem</u> is just part of a system; it helps to complete a task. A subsystem is often shown in a *block diagram.*

Section Checkpoint

1-1 Classify each of the following as a system or subsystem:
- a) A radio transmitter
- b) An automobile
- c) An automatic transmission
- d) A radio transmitter and receiver

1-2 What type of diagram is used to show how systems work?
1-3 How can a technician understand a very complicated system?

1-2 A Simple Radio System

A simple radio system could be constructed as shown in the block diagram of Figure 1-1 below. This system has some severe problems, but it will serve as a good starting point.

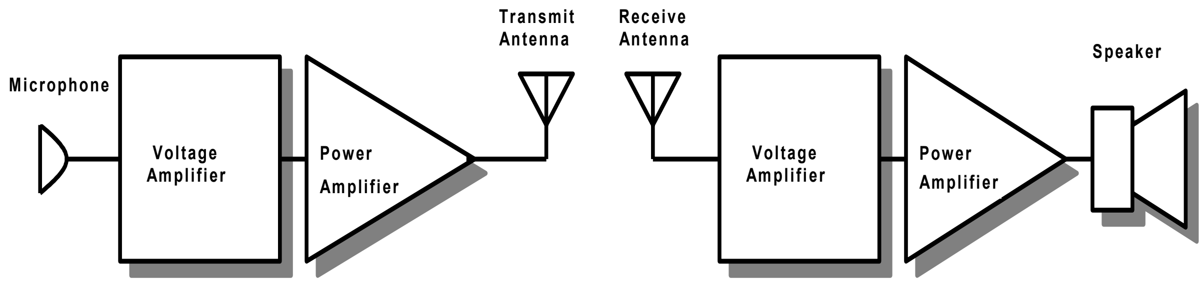
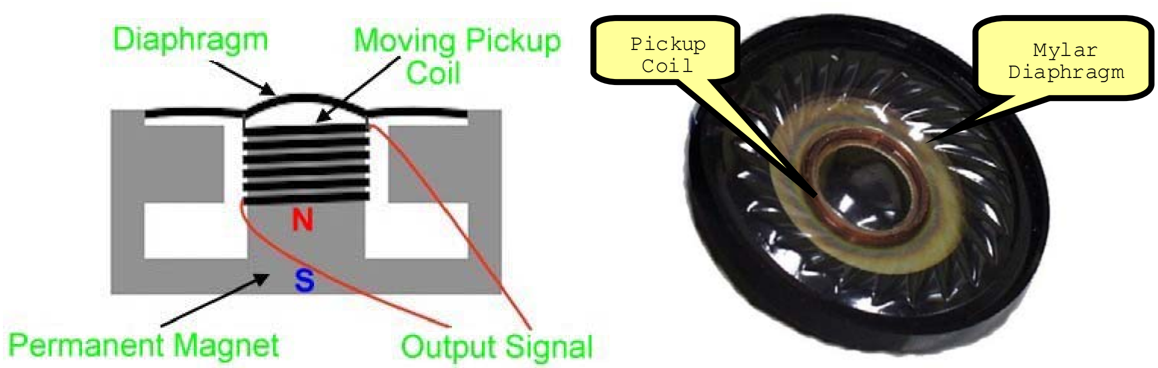


Figure 1-1 - A Simple Radio System

The radio system above begins with a *microphone*. A microphone is a type of *transducer*. It converts the pressure variations in a sound wave (such as from a speaker or musical performer) into electrical energy. A microphone has a thin plastic or paper cone attached to a coil of wire. This coil is placed within the field of a permanent magnet. When sound strikes the cone, it vibrates, moving the coil back and forth within the magnetic field. Thus, a voltage is generated in the coil that is an electrical copy of the original sound wave.



a) Internal Construction b) Typical Unit

Figure 1-2: A Typical Dynamic Microphone Element

We call the electrical signal from the microphone the *intelligence* or *information* signal. The information signal is an electrical replica of the original sound wave.

A transducer is any device that converts one form of energy into another.

The signal from the microphone is quite small. Most microphones produce about 10 mV (millivolts), at a power level of about 40 σW (microwatts). This isn't enough power to cross any significant distance in space, so both voltage and power (current) amplification must take place. The final power level reached at the output of the **power amplifier** depends on how far we need to communicate, and under what conditions. This power level can range from a few milliwatts (personal communications devices such as walkie-talkies) to thousands of watts (military and broadcast communications).

The transmitting *antenna* next converts the amplified information signal into a new form of energy that is capable of traveling through space. This new energy is called *electromagnetic energy*, or a *radio wave*. Electromagnetic energy consists of two fields, a voltage or electric field, and a magnetic field. It travels through space at the speed of light; in fact, visible light is itself electromagnetic energy with a very high frequency.

The energy from the radio wave moves outward from the transmitting antenna at the speed of light, which is about 3×10^8 meters/second. It spreads out over space much like an inflating balloon. By the time it reaches the receiver's antenna, its energy is spread thinly. Imagine the thickness of a toy balloon when it is deflated; then imagine the new thickness if the balloon were inflated to a diameter of 10 miles. This is a good way to think about how the energy of a radio wave is distributed. A radio receiver typically receives picowatts (1×10^{-12} watt) or femtowatts (1×10^{-15} watt) of energy from its antenna.

At the receiver, the antenna receives the weak signal. It will typically be just a few microvolts, which is too small for any practical use. Therefore, voltage and current amplification will be needed to bring the signal back up to a useful level. The receiver drives a *loudspeaker*, another transducer (Figure 1-3). The loudspeaker converts the electrical signal back into sound. It works by passing electrical current through a coil (the voice coil) suspended in a strong magnetic field. The electrical current causes the voice coil to become a magnet, and it is then attracted and repelled from the permanent magnet in step with the original information signal. A paper cone attached to the voice coil pushes on the air, which recreates the original sound.

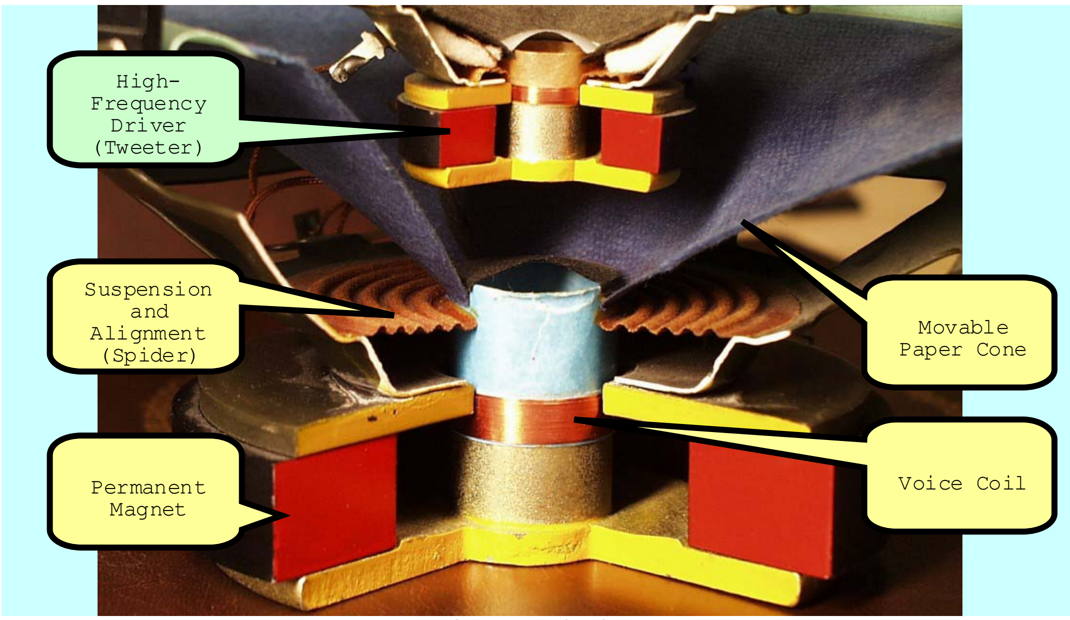


Figure 1-3: Cutaway of a Coaxial Loudspeaker

This is theoretically how a radio system *should* operate. However, there are two practical problems that prevent us from doing it this way! The next section will demonstrate these problems, and how they are avoided.

Section Checkpoint

1-4 What is a transducer?
1-5 Explain the workings behind a microphone and loudspeaker.
1-6 Why must a transmitter use a power amplifier? How is the power level decided?
1-7 What is the *information signal*?
1-8 What are the two types of energy in an electromagnetic wave?
1-9 What types of voltage and power levels are typical at a radio receiver's antenna?
1-10 Answer the following questions about power units:
- a) How much power is a *femtowatt?*
- b) How much power is a *picowatt?*
- c) How many femtowatts in a picowatt? Microwatt? Milliwatt?

1-3 The Need for Modulation

A radio communication system like the one of section 1-2 would not work very well. There are two problems: First, it would be nearly impossible to build a transmitting antenna to work with the system; second, there is no way of having two (or more) transmitters on the air at the same time. There's no way of *separating* individual stations. Let's explore these problems in more detail.

Transmitting Antenna Requirements

In order to be efficient, radio transmitting antennas need to be at least one-quarter of a *wavelength* long. Shorter antennas can be made to work, but they don't radiate energy very well. The term *wavelength* refers to the distance a radio wave travels in one cycle. It is measured in meters, a unit of length. Figure 1-4 represents a radio wave in space. It is traveling into the page.

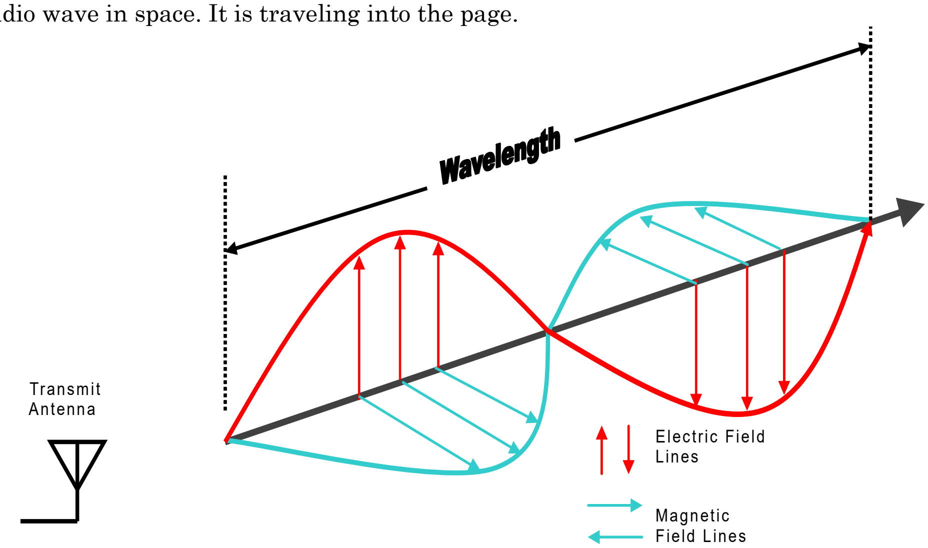


Figure 1-4: A Radio Wave in Free Space

Wavelength can be easily calculated. A standard formula states that to find distance, multiply rate (speed) by time:

$$D = R \times T$$

The speed of a radio wave is the same as the speed of light, and we can give it the letter *v* (for velocity). We also know that frequency and time are *inverses*; f = 1/T. Therefore, we can write:

$$D = v\left(\frac{1}{f}\right) = \frac{v}{f}$$ (Where *v* is the speed of light, 3 x 10^8 meters / second).

It is very common to use the Greek symbol lambda (λ) to stand for the distance of one wavelength. Therefore, we get:

(1-1) $$\lambda = \frac{v}{f}$$

***Wavelength* is the distance that a radio wave travels in one cycle. It is measured between two peaks or two troughs. It is always in distance units (usually meters).**

Back to our problem. The radio system of Figure 1-1 needs to transmit *audio frequencies*. Audio frequencies are those that we can hear. They are from 20 Hz to 20,000 Hz. (Most persons over the age of 15 have great difficulty hearing anything over 15,000 Hz). An audio frequency that is in the "middle" of our hearing range is 1000 Hz, or 1 kHz. Let's calculate the wavelength of a 1 kHz electromagnetic wave.

According to Equation 1-1:

$$\varsigma \mid \frac{v}{f} \mid \frac{3\Delta 10^{8}\, meters/\sec}{1\, kHz} \mid 300{,}000\, m \mid \underline{\underline{300\, km}}$$

300 km is quite a large distance -- about 186 miles! Of course, the antenna doesn't have to be *this* long. It need only be *one-quarter* of this distance, or 75 km (46.6 miles). No big deal, right? Of course, it isn't practical to build an antenna this large. Our system won't work very well. The required antenna length is too long!

Another Problem

As if the inability to build a suitable antenna weren't enough, another serious problem exists with the system of Figure 1-1. Imagine that somehow, practical antennas were invented to work at audio frequencies. We'll want to operate several stations at the same time; having just one broadcaster "hogging" the airwaves just won't do! Do you see the problem? Yes! *All the stations will be sharing the same frequencies (the audio frequencies).* It will be impossible to separate different stations at the radio receiver, since they'll all be on the same group of frequencies.

You can see that the system of Figure 1-1 is hardly practical. Can you think of a way to make it work? How could we get the antennas to be shorter?

Making it Shorter

Equation 1-1 gives a clue about how to proceed. It tells us that wavelength is velocity divided by frequency. We can't change the velocity -- that's the speed of light in free space. But we can easily change the *frequency* of the wave. If we increase the frequency, the wavelength will get *shorter*. This looks promising!

Increasing frequency always decreases wavelength. Decreasing frequency always increases wavelength.

Let's try changing to a 10 kHz wave. What will the wavelength be? How long will the antenna have to be? By using equation 1-1 again, we get:

$$\varsigma \mid \frac{v}{f} \mid \frac{3\Delta 10^{8}\, meters/\sec}{10\, kHz} \mid 30{,}000\, m \mid \underline{\underline{30\, km}}$$

This is much better! *The wavelength got 10 times shorter*. The minimum antenna length would be one-quarter of a wavelength:

$$L_{\min} \mid \frac{\varsigma}{4} \mid \frac{30\, km}{4} \mid \underline{\underline{7.5\, km}}$$

The antennas are still too long to build. If we continue to increase the frequency further, the wavelength will get even smaller. For example, many mobile FM radio units operate near 150 MHz. At this frequency:

$$\varsigma \mid \frac{v}{f} \mid \frac{3\Delta 10^{8}\, meters/\sec}{150\, MHz} \mid 2\, m$$

And:

$$L_{\min} \mid \frac{\varsigma}{4} \mid \frac{2\, m}{4} \mid \underline{\underline{0.5\, m}} \mid \underline{\underline{19.7''}}$$

Antennas of this type are very practical. You can often estimate the frequency of a transmitter by "eyeballing" the antenna. The longer the antenna, the longer the wavelength -- and you guessed it, the lower the operating frequency.

Radio Frequencies

Frequencies above the range of hearing are called *radio frequencies.* Any frequency above 20 kHz is considered a radio frequency. This is an arbitrary definition that's used by the FCC, the US government agency that regulates radio communications.

Example 1-1

What is the wavelength of a 710 kHz AM broadcast signal? What is the minimum height of the antenna tower in *feet* if it is one-quarter of a wavelength long?

Solution:
Equation 1-1 calculates wavelength:

$$\varsigma \mid \frac{v}{f} \mid \frac{3\Delta 10^{8}\, m/s}{710\ kHz} \mid \underline{\underline{422.5\ m}}$$

The tower need not be a full 422.5 meters high. In fact, a quarter of that length will do just fine:

$$\frac{\varsigma}{4} \mid 422.5\ m \Delta \frac{1}{4} \mid 105.6\ m$$

So the tower height will really be 105.6 meters. However, the answer was requested in *feet*, so we need to convert:

$$L_{feet} \mid 105.6\ m \Delta \frac{3.28\, ft}{1\ m} \mid \underline{\underline{346.6\, ft}}$$

The physical height of the tower will be close to 346.6 feet. This is very typical of AM broadcast installations.

Example 1-2

An quarter-wave (ς/4) whip antenna measures 108". What is the approximate operating frequency of the transmitter?

Solution:
By manipulating equation 1-1, we get:

$$f \mid \frac{v}{\varsigma}$$

We know *v* since it is the speed of light, but not ς (the wavelength). We have been given the dimension of *one-quarter of a wavelength* in inches. This needs to be converted into *meters* to be useful to us:

$$\frac{\varsigma}{4} \mid 108'' \Delta \frac{1m}{39.37''} \mid 2.74m$$

This figure is one-quarter of a wavelength (ς/4) in meters. The wavelength must be equal to:

$$\varsigma \mid 4\Delta(\varsigma/4) \mid 4\Delta 2.74m \mid 10.97m$$

Now with this answer in hand, we can plug back into the manipulated equation 1-1:

$$f \mid \frac{v}{\varsigma} \mid \frac{3\Delta 10^{8}\, meters/\sec}{10.97 meters} \mid \underline{\underline{27.3MHz}}$$

This frequency is in the middle of the class-D citizens band.

The Need for Modulation

A 150 MHz signal may transmit just fine, but there's one more problem. We can't hear a 150 MHz signal; it's too high in frequency (our hearing is limited to audio frequencies, which are 20 Hz to 20 kHz). However, there is a solution; it's called *modulation*. When we modulate a wave, we place a low-frequency information signal onto it. The low-frequency signal is just along for the ride. It is, in effect, "carried" on top of the high-frequency signal. The high-frequency signal is therefore called the *carrier* signal.

There are three ways we can impress information onto a carrier. We can change the voltage (or power) of the wave in step with the information. This is called *amplitude modulation*, or AM. We can alter the frequency of the wave with the information; this is called *frequency modulation*, or FM. Finally, we can change the phase of the carrier wave. This is called *phase modulation*, or PM.

Section Checkpoint

1-11 What are two problems with the system of Figure 1-1?
1-12 How is the wavelength of a radio wave calculated?
1-13 Why are high frequencies used for carrier waves?
1-14 What is meant by the term *modulation*?
1-15 What are three ways a carrier can be modulated?
1-16 What is the lowest *radio frequency*?

1-4 A Practical Radio System

An actual radio system looks very much like the diagram of Figure 1-5:

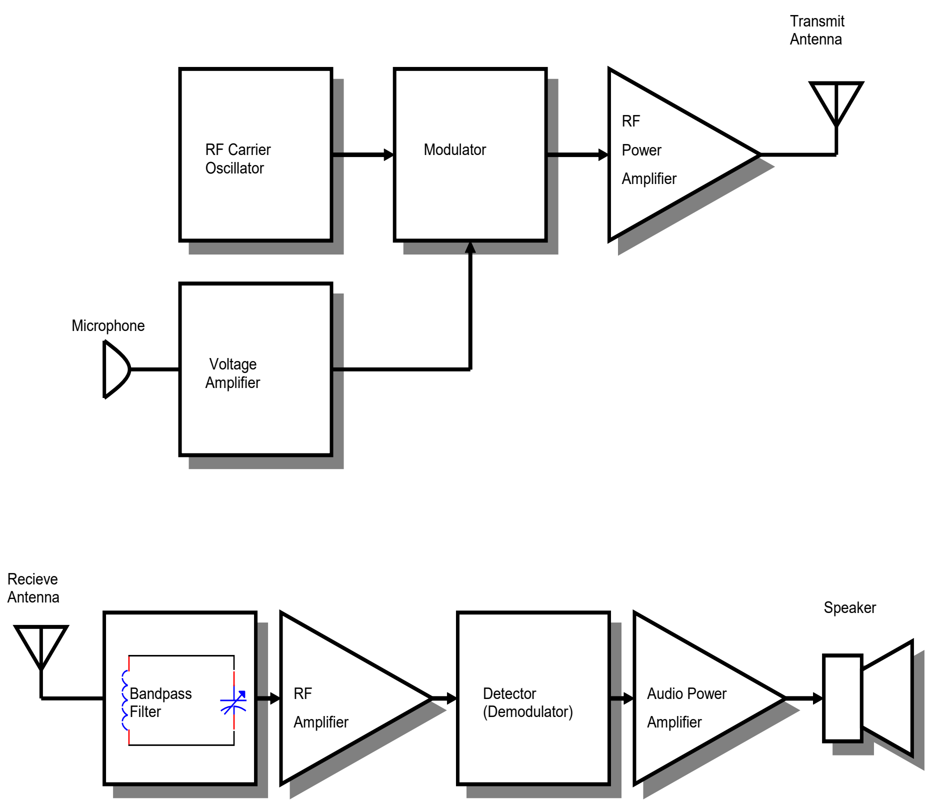


Figure 1-5: A Practical Radio System

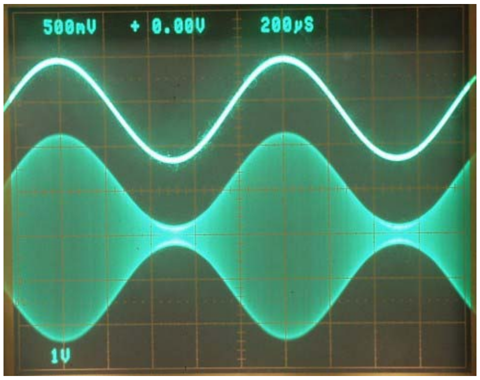
Transmitter Components

Every radio transmitter is assigned to operate on a specific *carrier frequency*. The job of the carrier oscillator is to generate this frequency. From your electronic fundamentals coursework, you'll recall that the purpose of an oscillator is to convert the DC from the power supply into an AC signal. The output of the carrier oscillator is a nearly-pure sine wave. The sine wave from the carrier oscillator carries no information at this point.

The modulator stage is a little unusual -- it has *two* inputs! One of the inputs is the radio-frequency sine wave from the carrier oscillator. The other is the *information* signal. The modulator combines the carrier and information in a special way. The output of the modulator is a *modulated carrier wave.* You might wonder why a voltage amplifier is needed between the microphone and modulator. Right! The microphone produces very little voltage or power, so its signal still needs a little "boost" before it can modulate the carrier.

The output from the modulator drives the radio frequency (RF) power amplifier. The signal at the modulator's output is too small to cover any significant distance, so additional amplification is needed. RF amplifiers use circuit techniques a little different from the low-frequency amplifiers you might have studied in fundamentals courses. These techniques are necessary because of the high frequencies involved.

Figure 1-6 shows typical waveforms used to test an AM transmitter. The top waveform is the *information*; a sine wave is often used as a convenient test signal, since it's available from most benchtop signal generators. The bottom waveform shows the resultant AM signal at the modulator stage output.



1 kHz Information Signal

Modulated Carrier Wave

Figure 1-6: Intelligence and AM Carrier Waves

Receiver Concepts

The receiver of Figure 1-5 reverses the steps taken in the transmitter. After the incoming signal is received from space by the antenna, it is fed into a bandpass filter. Recall that a bandpass filter rejects frequencies above and below its design frequency. Most receivers use an LC resonant circuit as the bandpass filter. This filter is tuned to the *carrier frequency* of the transmitting station. There are thousands of signals reaching the receiver's antenna at any given instant, yet the receiver must reproduce only one of them. That is a tall order! Because each incoming carrier signal has a different frequency, it is possible to separate them by using a frequency-selective circuit. In other words, we use a filter to do the job of "selecting" the appropriate station.

You might have noticed the variable capacitor in the filter of Figure 1-5. Yes, that's the receiver's tuning control. The tuning knob on a receiver is coupled to a variable capacitor, which is part of the bandpass filter. The resonant frequency of the filter changes as the variable capacitance varies. When a user is tuning in a radio station, he or she is actually adjusting the resonant frequency of a tank circuit.

After selection of the appropriate carrier frequency, we will still have a very weak signal. Several stages of **RF amplification** are needed to bring the modulated wave up to a level that is useful.

The **detector** or **demodulator** stage does exactly the *opposite* of the modulator stage. It takes the incoming modulated carrier waveform and strips away the carrier frequency, leaving a copy of the original information signal. The output of the detector will look very much like the original information signal from the microphone. This is the *recovered information* signal.

The recovered information is still too weak to drive a loudspeaker (or other device), so an **audio power amplifier** is used to boost the signal's voltage and current. In most modern radio receivers, the audio power amplifier is likely to be on a single integrated-circuit (IC) chip. The loudspeaker completes the process, converting the amplified information signal back into sound.

Section Checkpoint

1-17 What is the purpose of an *oscillator* circuit?
1-18 How does an RF amplifier differ from an AF amplifier?
1-19 What is the purpose of the *modulator* circuit?
1-20 How many radio signals can be expected in the antenna circuit of a receiver?
1-21 How does a radio receiver "select" one signal from thousands?
1-22 What happens in a *detector* circuit?