Chapter 21
Broadcasting

The soprano sings at the Metropolitan Opera at Lincoln Center in New York, and the performance is broadcast by National Public Radio. Back at home you take off your Gucci slippers, relax in your hot tub and listen to the performance. How does it work? One thing you know for sure—the sound is not transmitted from the Met to you as an acoustical wave. Instead, the sound is transmitted as a radio wave, a form of electromagnetic radiation.

It is sometimes said that a radio station is "on the air," or that radio broadcasting uses the "air waves." This is a figure of speech; technically it is nonsense. The air has nothing to do with it. Like all forms of electromagnetic radiation, radio waves travel perfectly well through an absolute vacuum. It's a good thing too. All of the energy that we get from the sun arrives here as electromagnetic radiation coming through the vacuum of space. Electromagnetic radiation travels at the speed of light, and therefore the performance from the Met comes to you at the speed of light. The speed of light is

$$c = 3 \times 10^8 \text{ meters per second,} \qquad (21.1)$$

which you will recognize as about one million times faster than the speed of sound.

Practical radio waves have frequencies from about 3,000 Hz to 100 GHz. That is, from 3×10^3 to 10^{11} Hz. You will note that the lowest frequencies are in the audible range. Do not be fooled. These low-frequency radio waves are electromagnetic; they are not acoustical—they cannot be heard. Still, radio waves are indeed waves, and they obey many of the same laws as acoustical waves. For instance, the famous relationship between wavelength and frequency still holds,

$$\lambda = c/f, \qquad (21.2)$$

where in this case, c is the speed of light.

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Another important feature of radio waves that we might anticipate from the study of acoustics is the phenomenon of difference tones, generated in a nonlinear system. We will see that presently.

21.1 Continuous Wave

A radio transmitting system consists of a source of electromagnetic power in the form of a sine wave with a precise frequency in the radio range. The source of power is called a transmitter, and it is attached to an antenna that radiates the sine wave. For instance, the radio wave from Station X might have a frequency of 1.000 MHz. We would say that Station X is broadcasting at a frequency of 1.000 MHz.

A radio receiver has an antenna that intercepts the radiation from the transmitter, as well as the radiation from hundreds of other transmitters sending out signals at other frequencies. At the outset all the transmissions are received together, and it appears to be a hopeless jumble. To solve this problem, the first stage of radio reception is a tuned circuit that precisely selects a desired station. If the tuned circuit is tuned to frequency $f_1 = 1.000$ MHz, then the receiver will pick up Station X. Up to this point, however, no information is being communicated.

To communicate, one needs to make the radio signal audible. To do this, the receiver has a radio-frequency generator of its own (but much less power than the transmitter). Suppose that it generates a signal with a frequency of $f_2 = 1.001$ MHz, and suppose that this is added to the signal from the tuned circuit in a nonlinear device. The nonlinear distortion will create an electrical difference signal having a frequency $f_2 - f_1$, namely 1,000 Hz. This signal is in the audible range and can be converted to a audible signal with a loudspeaker. Out of the speaker comes a 1,000-Hz tone. Wow! Now it is possible to hear radio station X. However, there is still no information being communicated.

Suppose now that the person who is operating the transmitter turns his signal on and off. He might use a telegraph key to do this switching. He can turn it on for a long interval (a "dash") or for a short interval (a "dot"). With a series of dashes and dots the operator can send the letters of the alphabet using Morse code.

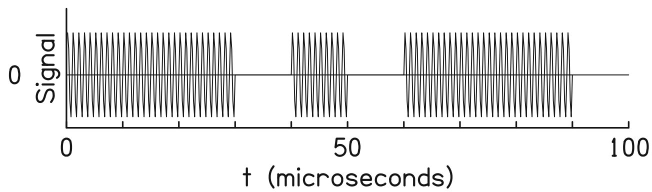

Fig. 21.1 A transmitted 1-MHz radio signal of the type called "continuous wave (CW)" can send Morse code. Shown here is a *dash*, a *dot*, and *another dash*. That makes the letter "K." As shown here, the transmission of *dots* and *dashes* is extremely rapid so that you can see the individual cycles of the carrier

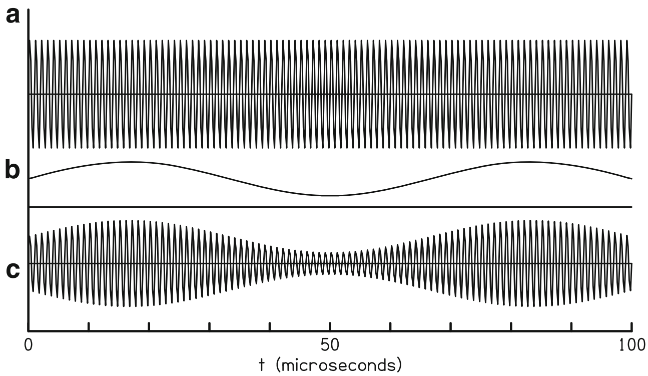

Fig. 21.2 The evolution of an AM broadcast. All the *signals* shown in the figure are voltages, and the *vertical axes* represent volts. Part (**a**) shows a 1-MHz sine wave carrier. In 100 μs there are 100 cycles. When this wave is radiated it will become the electromagnetic radiation of Station X, broadcasting at a frequency of 1 MHz. Part (**b**) shows another electrical wave; it contains the audio information that we desire to transmit using the radio wave. This signal is an audio signal, with a frequency of 15,000 Hz, and it was originally generated from an audible source by the use of a microphone. Part (**c**) shows how the audio signal is transmitted. It is used to modulate the amplitude of the 1-MHz signal. In this way the audible information is incorporated. The process is known as amplitude modulation

At the receiver, the 1,000-Hz tone comes on only when the transmitter is on. If the person at the receiver knows the code, he can decipher what is sent. Now, finally, information can be communicated. This form of broadcasting, called "continuous wave," is the most primitive form. It is illustrated in Fig. 21.1.

21.2 Amplitude Modulation

Modulation makes it possible to transmit more detailed information than simple *on/off* information. With modulation one can transmit speech or music as audio. The concept of modulation begins with the old continuous-wave signal. Quite simply, some aspect of that continuous wave is varied, i.e. modulated, according to the waveform of the speech or music. In amplitude modulation (AM), it is the amplitude of the radio sine wave that is modulated. For instance, Fig. 21.2 modulates a carrier with a 15,000-Hz sine tone as the audio signal.

At the receiving end, the modulation impressed on the signal by the transmitter can be extracted by the AM radio receiver, and the modulation is, of course, the original 15,000-Hz tone that was broadcast. It should now be evident why the 1-MHz radiation is called the "carrier." It acts as a vehicle that *carries* the audio. The frequency of a radio or TV station is the frequency of its carrier. At the receiving end, this carrier is filtered out and only the audio signal is left.

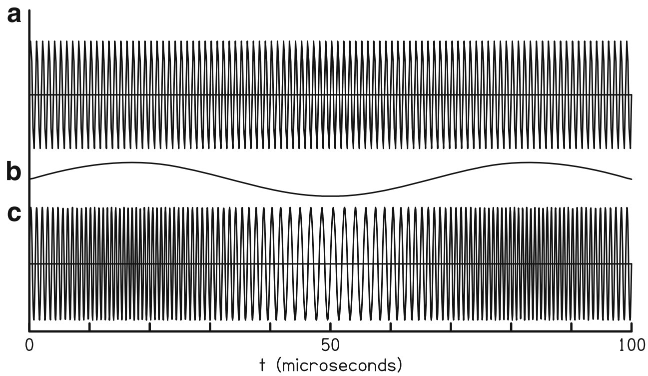

Fig. 21.3 Frequency modulation of a 1-MHz carrier by a 15,000 Hz audio signal. Parts (**a**) and (**b**) are the same as for AM in Fig. 21.2, but the form of the modulation is different

21.3 Frequency Modulation

Figure 21.3 shows a frequency modulated (FM) signal. The FM technique is another means of transmitting an audio signal using radio waves. Now the amplitude is constant. What is modulated is the carrier frequency itself. The carrier frequency is centered on 1 MHz, but the modulation gives this carrier small excursions above and below 1 MHz. The FM receiver has to be different from an AM receiver. Whereas the AM receiver takes variations in the carrier amplitude and converts them to an audible signal, the FM receiver converts carrier *frequency* variations into an audible signal. Receiving information encoded by FM turns out to be less sensitive to static (interference caused by electrical storms); FM provides a better communications channel.

21.4 Bandwidth

The figures above have shown AM and FM signals as functions of time. This time representation is the easiest way to visualize how the modulation affects the carrier. Additional important insight comes from looking at AM and FM from a spectral point of view. At first glance, it would seem that the spectral point of view is very simple. There is a sine wave carrier at 1-MHz. The sine wave has a single spectral component, and so it seems as though the spectrum of the signal would be a single line at a frequency of 1,000,000 Hz. That is actually correct for the continuous-wave signal. However, when a signal is modulated, additional frequencies are added. The additional frequencies are called “sidebands” because

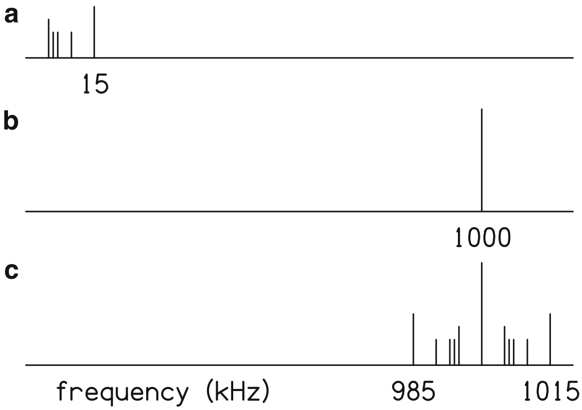

Fig. 21.4 (**a**) An audio signal with components at 5, 6, 7, 10, and 15 kHz. (**b**) A radio frequency carrier with a frequency of 1 MHz (1,000 kHz). (**c**) An AM signal—the 1-MHz carrier is amplitude modulated by the audio signal. Because the audio signal has a frequency as high as 15 kHz, the modulated signal in part (**c**) extends from 985 to 1,015 kHz. Therefore, the bandwidth of the signal is 30 kHz

they appear to the left- and right-hand sides of the carrier frequency. Specifically, when a 1-MHz carrier is modulated by a 15,000-Hz signal there is a component at 1 MHz + 15,000 Hz (the upper sideband) and a component at 1 MHz – 15,000 Hz (the lower sideband).

Of course, the 15,000-Hz tone is a very simple modulation. In practice we would like to broadcast audio with all frequencies from 0 to 15,000 Hz. Therefore, instead of having single discrete sideband components, we get a smeared out spectral region, extending plus and minus 15,000 Hz, either side of the carrier frequency. The total bandwidth is, therefore, 30,000 Hz as shown in Fig. 21.4.

If we wanted to transmit a television signal the bandwidth would have to be much greater. That is because the TV signal includes both the audio and the video information. More information requires greater bandwidth. A conventional analog TV signal has a bandwidth of 6 MHz. Obviously it would not be possible to transmit a TV signal using a carrier of 1 MHz. The sidebands would extend to negative frequencies, and this would greatly distort the signal. Therefore, TV stations broadcast with carrier frequencies that are high, about 100 MHz for VHF, and 500–800 MHz for UHF. The broad bandwidth required for analog TV is the reason that governments worldwide are encouraging digital TV. In fact, they are insisting on it because the information in TV signals can be compressed in the digital domain by eliminating redundancy. Less redundant information means that signals can have a narrower bandwidth. Narrower bandwidth, in turn, means that more TV signals can be squeezed into any given range of frequencies.

21.5 Carrier Frequencies

Worldwide, the transmission of radio signals is regulated. There are specific rules about which radio frequencies may be used, and where, and when. It has to be that way. Otherwise, signals from competing stations would pile on top of one another and communication would be chaotic. It is rather like cars on the street. Only one car is allowed to occupy a given patch of street at any given time. Particular frequency bands have been assigned to particular kinds of broadcasting. In the USA, AM broadcasting is done with carriers in the range from 550 to 1,600 kHz (or 1.6 MHz). FM broadcasting is done with carriers in the range from 98 to 106 MHz. Because the AM range is so narrow (only about 1 MHz) AM radio stations are limited in bandwidth. In fact, it would be illegal for an AM station to broadcast a signal with a bandwidth of 30 kHz as in the example above. However, an FM station is allowed to broadcast a signal that wide.

Analog TV broadcasting takes place in several frequency ranges. Channels 2–6 are found between 54 and 88 MHz. Channels 7–13 are found between 174 and 216 MHz, and channels 14–69 are found between 470 and 806 MHz.

Exercises

Exercise 1, Frequency and wavelength revisited

(a) AM radio broadcasts at frequencies of about 1 MHz, i.e. 10^6 Hz. Show that the wavelength is about 300 m. (b) Microwaves have frequencies as high as 10^{11} Hz. Show that the wavelength is 3 mm.

Exercise 2, AM radio

Draw the spectrum of a 1-MHz carrier amplitude modulated by a 15,000-Hz audio signal.

Exercise 3, The bandwidth cost of video

How many times greater is the bandwidth of an analog TV signal compared to the 30,000-Hz bandwidth of an FM signal?

Exercise 4, FM vs AM

Why do you suppose that FM transmission is less susceptible to static than AM transmission? Consider static to be a noise that is added to the electromagnetic radiation on its way to the receiver.

Exercise 5, Who hears it first?

The back row of the opera house is 150 ft away from a singer on stage. The broadcast microphone may only be 2 ft away. Who hears the singer first? Is it the person in the audience sitting in the back row at the opera, or is it you, sitting in the hot tub perhaps several thousand miles away? [Hint: Remember that the broadcast comes to you at the speed of a radio wave, namely the speed of light.]

Exercise 6, Bandwidth, information and economics

What is the connection between bandwidth and the amount of information that is transmitted? Is bandwidth scarce? Must it be regulated?

Exercise 7, Static

The antenna of a radio receiver not only picks up all the radio transmitters within range, but it also picks up noise (called "static" in radio communications terminology) from electrical storms all around the world. The input tuning of the receiver helps reduce this noise. How do you think that this works?

Exercise 8, TV broadcasting

The text says that TV signals have a bandwidth of 6 MHz. (These were the USA standard—NTSC—signals prior to digital TV.) Is this bandwidth consistent with the assignment of frequency ranges for TV channels given in the section called "Carrier frequencies?"

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