A Programmed Lesson on AM Radio Fundamentals

Learn the basics of AM radio in this self-teaching lesson. Modulation, detection, heterodyning, and basic AM diagrams will be discussed, along with other fundamentals.

By Wesley A. Vincent, BSEE, MSE
Electronic Engineer, Motorola Inc.

Today we rely on radio and television for news, music, and entertainment in our everyday living. Communication via radio signals is also used in many other activities wherein man needs to coordinate his actions. These activities include, for example, industrial monitoring known as telemetry, police and fire protection, air and sea navigation, as well as sophisticated deep-space probes.

The basic elements for modern radio communication and broadcasting are shown in figure 1. Radio waves generated by the transmitter are controlled by the information to be transmitted via a key, microphone, or TV camera. These signals are then radiated into space by the transmitter antenna and intercepted by the receiver antenna shown in the diagram. At the receiver, selection and amplification take place so that the desired signals can be detected. After detection, the loudspeaker or picture tube reproduces the original information.

In this lesson, AM radio fundamentals will be discussed. Programmed lessons in future issues will include the basics of FM and digital communication techniques. Start by reading frame 1 and answering the questions at the end of the frame. Go to the frame indicated by your answer. Then continue through the lesson as directed in each frame.

Terms and Symbols Used in This Lesson

AM	— amplitude modulation
E_c	— peak voltage amplitude of modulating signal
E_s	— peak voltage amplitude of carrier signal
F_c	— carrier frequency
F_1	— lowest frequency in the audio spectrum
F_h	— highest frequency in the audio spectrum
F_m	— modulation or information frequency
i-f (I-F)	— intermediate frequency
r-f (R-F)	— radio frequency
m	— modulation index
P_c	— power level of the carrier frequency
P_t	— total AM power
v(t), i(t)	— voltage and current variations with time

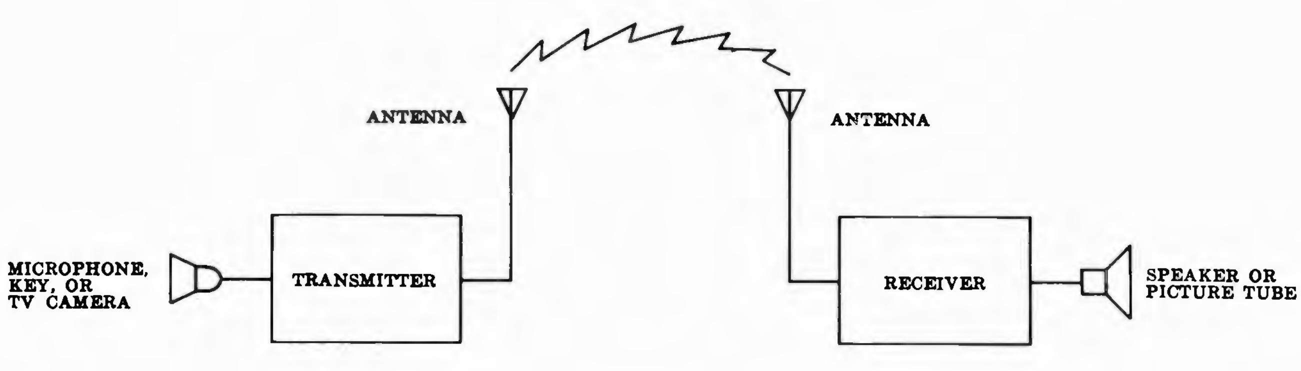


Figure 1
ELEMENTS OF A COMMUNICATION SYSTEM USING RADIO WAVES

1 The process of controlling radio waves for the purpose of transmitting a message is called modulation. Modulation is accomplished by controlling either the (1) amplitude, (2) frequency, or (3) phase of the radio wave known as the carrier. When the carrier is varied in correspondence with the strength of the audio (sound) signal, the radio wave is said to be amplitude-modulated. Hence the term "AM." Figure 2 shows typical signals for a simple sine wave, amplitude-modulating a higher radio frequency (r-f) signal. Of course, voice and other sound signals are much more complex than the sine wave, but this figure illustrates the basic amplitude-modulating process.

For an AM radio signal, the amount of change in amplitude as compared to the original unmodulated carrier amplitude is given by the term "modulation factor (m)." The modulation factor can be computed as $m = \frac{E_s}{E_c}$, where E_s represents the amplitude of the modulating signal and E_c, the amplitude of the carrier.

QUESTION: For the AM signal shown in figure 2, what is the modulation factor?

0.5 . . . go to frame 5

0.33 . . . go to frame 9

1.5 . . . go to frame 12

2 Your answer is incorrect. Note that the audio signal is 400 Hz, not 400 KHz. Return to frame 5 and choose another answer.

3 Your answer is incorrect. The r-f carrier does not need to be known in order to determine the AM bandwidth. The highest modulating frequency will determine the bandwidth, since its resulting upper and lower sideband components will be located furthest from the carrier. In general, the AM spectrum can be visualized as shown in figure 4. Note from this figure that the bandwidth equals twice the highest modulating frequency, independent of the r-f carrier. Return to frame 10 and choose another answer.

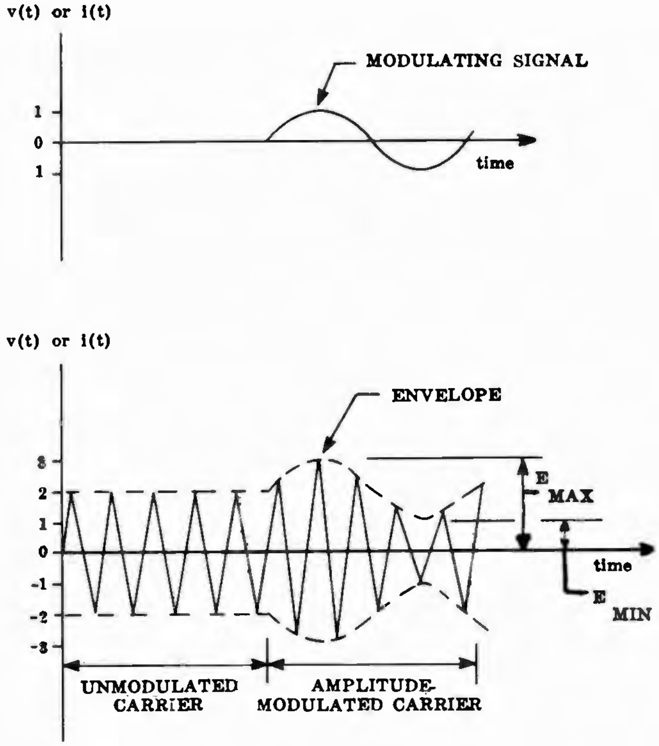


Figure 2
AM WAVEFORM

4 Your answer is incorrect. The function of the tuned circuits is to select the desired signal or radio station while excluding all others. Hence, the tuned circuits determine the receiver's selectivity — not its sensitivity. Return to frame 8 and choose another answer.

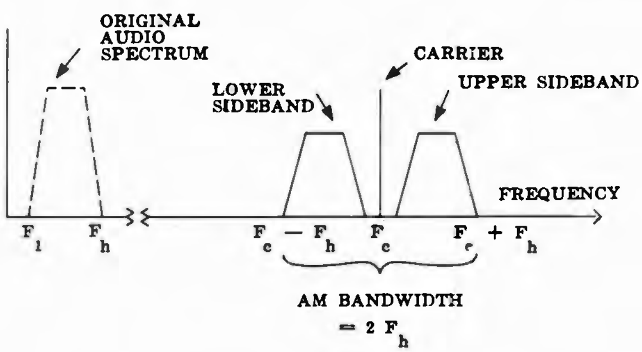


Figure 4
FREQUENCY SPECTRUM SHOWING AM BANDWIDTH REQUIRED TO TRANSMIT A TYPICAL AUDIO SPECTRUM

5 Your answer is correct. Many types of circuits are available to amplitude-modulate a carrier. Generally, the process consists of feeding the carrier and audio signals to a nonlinear device called the modulator. In actual practice, a tube, semiconductor diode, or transistor is used as a modulator when operated in the nonlinear portion of its operating characteristics. Because of this nonlinearity, the output signal contains many frequency components other than carrier and audio frequencies. Harmonics of each of these frequencies and components at the sum and difference frequencies appear. Filtering is necessary so that the final AM signal contains only three components: (1) the carrier frequency (F_c), (2) the upper sideband frequency equal to the sum of the carrier and modulating frequencies ($F_c + F_m$) and (3) the lower sideband frequency equal to the carrier frequency minus the modulating frequency ($F_c - F_m$).

QUESTION: A carrier frequency of 1360 KHz is amplitude-modulated by a pure 400 Hz audio signal. What frequency components exist in the AM signal?

960 KHz, 1360 KHz, 1760 KHz . . . go to frame 2

1359.6 KHz, 1360 KHz, 1360.4 KHz . . . go to frame 10

400 Hz, 1360 KHz, 1359.6 KHz, 1360.4 KHz . . . go to frame 16

6 Your answer is incorrect. The sideband frequencies produced range from $F_c \pm$ 50 Hz to $F_c \pm$ 5 KHz. Therefore, the bandwidth requirement is twice the frequency of the highest modulating frequency. Return to frame 10 and choose the correct answer.

7 Your answer is incorrect. The mixing action is nonlinear and similar to the modulator in the transmitter, but uses a filter to attenuate all but the difference frequency. Return to frame 21 and choose the difference frequency.

8 Your answer is correct. Regardless of type of signal or modulation, modern radio receivers perform the functions illustrated in figure 6. First of all, the antenna intercepts the passing radio signals. Next, the tuned circuits select the desired signal from the many radio signals received by the antenna. Then the usually weak signal is amplified by the r-f amplifier. By the process known as demodulation, the modulating signal is separated or detected from the modulated r-f carrier. Finally, the resulting audio signal is amplified for reproduction by the loudspeaker as shown in the figure.

QUESTION: What section of the receiver is primarily responsible for the receiver's sensitivity?

Tuned circuits . . . go to frame 4

R-F amplifier . . . go to frame 14

Detector . . . . go to frame 19

Audio amplifier . . go to frame 23

9 Your answer is incorrect. The amplitude of the modulating signal is divided by the amplitude of the unmodulated carrier to find m. Either peak amplitudes or peak-to-peak amplitudes can be compared for sinusoidal signals. Return to frame 1 and choose another answer.

10 Your answer is correct. Figure 3 shows the "frequency spectrum" for the AM signal of the previous question. Notice that amplitudes of the upper and low sidebands are related to the carrier by the factor $\frac{m}{2}$. For 100-percent modulation, each sideband has one-half the carrier amplitude.

Most signals such as voice, music, and picture details are complex waves containing many frequencies. Each frequency component produces its own sidebands when mixing with the carrier. Consequently, for typical AM radio signals, a whole band of frequencies exists on either side of the carrier. This band of frequencies, including the carrier, is called the AM bandwidth and is measured in hertz (Hz).

QUESTION: An r-f carrier is amplitude-modulated by music signals with a frequency span of 50-5000 Hz. What bandwidth is necessary to transmit the resulting AM signals?

10 KHz . . . go to frame 17

100 Hz . . . go to frame 6

Cannot be determined unless

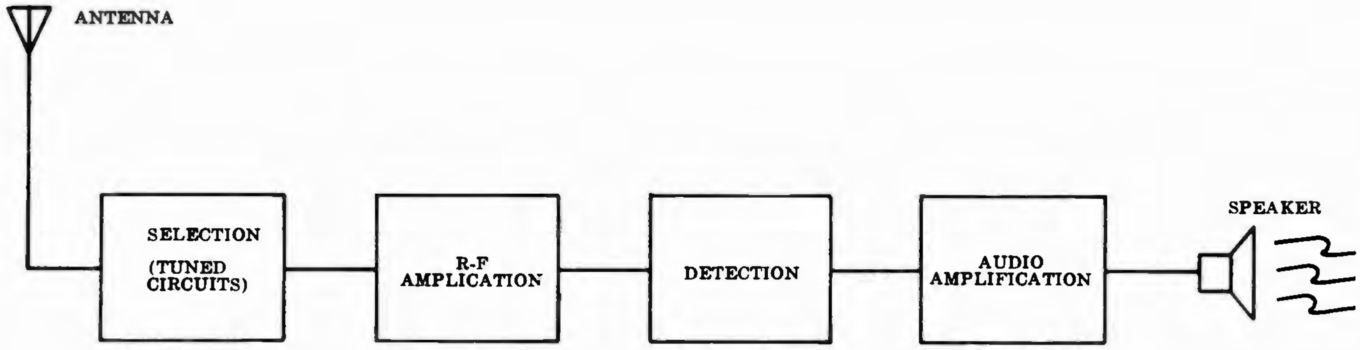


Figure 6
BASIC FUNCTIONS FOR RADIO RECEPTION

carrier frequency is known
. . . go to frame 3

11 Your answer is incorrect. If the RC time constant is long with respect to the period of the audio signal, both i-f and audio frequencies would be shunted to ground. Therefore, the capacitor is chosen so as to respond to envelope variations, but does not allow the circuit to follow the i-f variations. Return to frame 22 and choose another answer.

12 Your answer is incorrect. The modulation factor will always be less than or equal to 1 in order to retain an undistorted envelope. Divide the amplitude of the modulating signal by the amplitude of the unmodulated carrier to find m. An alternate formula for finding m is:

$$m = \frac{E_{max} - E_{min}}{E_{max} + E_{min}}.$$

Recalculate m, using the alternate expression as a check and choose another answer to frame 1.

13 Your answer is incorrect. Did you forget to square the modulation factor when finding the sideband power? A 10-percent modulation level is equivalent to a modulation factor (m) of 0.1. In the expression for sideband power ($\frac{m^2}{2} P_c$), the factor m^2 equals 0.01. Recheck your decimal point and choose another answer to frame 17.

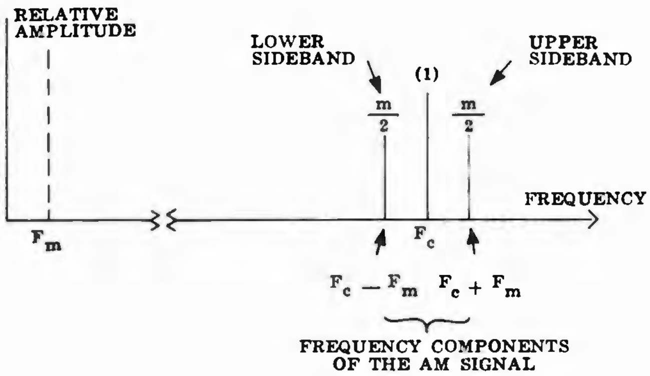


Figure 3
AM SPECTRUM FOR FRAME 10

14 Your answer is correct. Sensitivity is a function of the amount of amplification used in the receiver. The amplification can occur before demodulation in the r-f amplifier or after demodulation in the audio amplifier. Generally, receivers are designed with similar audio amplification so that a receiver's sensitivity rating is mainly dependent on the r-f amplifier. Standard broadcast receivers (540 KHz-1600 KHz), have a sensitivity of about 50 μv (microvolts). Commercial communication receivers may have a sensitivity below 1 μv. Go to frame 21.

15 Go to frame 26.

16 Your answer is incorrect. Only three frequency components exist for this AM signal. They are the carrier frequency and the upper and lower sidebands as discussed in frame 5. Return to frame 5 and choose another answer.

17 Your answer is correct. A block diagram for a standard AM broadcast transmitter is shown in figure 5. This is a simplified version with only the essential blocks shown. The oscillator is the source of the radio waves, since it generates the r-f carrier. Both the r-f carrier and audio signals are amplified and then combined in the modulator to produce the AM signals. These signals are amplified again before being radiated into space via the transmitter antenna.

As the carrier frequency is modulated, the power levels of the sideband frequencies increase with the degree of modulation. The carrier itself is unaffected so that there is no change in the carrier power level. Expressed mathematically, total carrier and sideband power is

$$P_t = P_c + \frac{m^2}{2} P = P \left(1 + \frac{m^2}{2}\right).$$

In this expression, P_t is used to represent the total AM power and P_c, the carrier power level.

QUESTION: A 20-Kw r-f carrier is modulated to a level of 10 percent. How much sideband power is required?

100 watts . . . go to frame 8

120 watts . . . go to frame 24

1 Kw . . . . . go to frame 13

18 Your answer is correct. The difference frequency is still an AM radio signal with modulation, but shifted down to a lower frequency. Because it lies between the original carrier and audio frequencies, it is called the intermediate frequency (i-f). Since no tuning is required in the i-f section, it is designed for maximum amplification with high selectivity. The i-f frequency normally used in broadcast receivers is 455 KHz.

QUESTION: AM transmitters use a bandwidth of 10 KHz centered about the r-f carrier. What bandwidth is required in the receiver i-f section so that no distortion occurs?

The i-f bandwidth is a function of the r-f carrier frequency
. . . go to frame 26

Much less than 10 KHz
. . . go to frame 15

10 KHz . . . . . go to frame 22

19 Your answer is incorrect. The primary purpose of the detector is to separate the audio component from the r-f component. Generally, receiver sensitivity is limited by other sections of the receiver. Return to frame 8 and choose another answer.

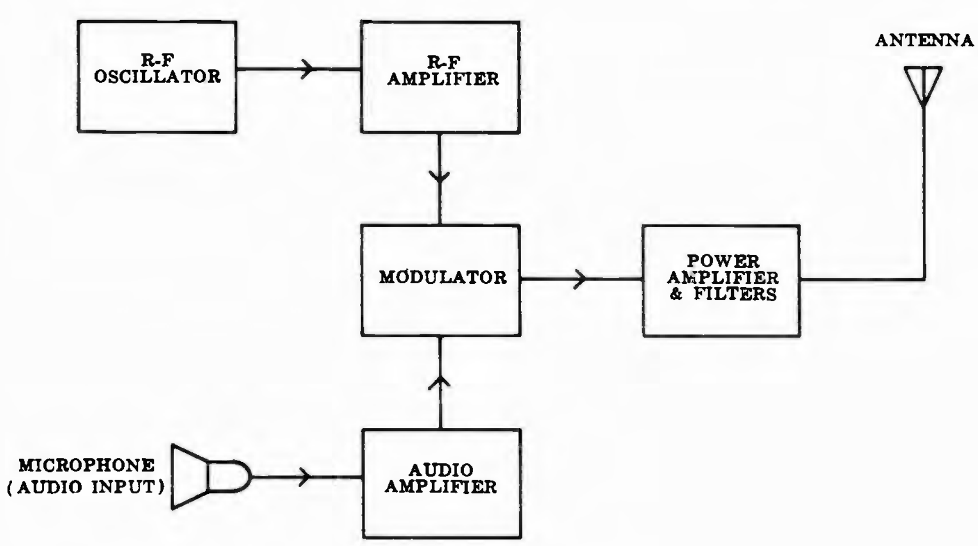


Figure 5
STANDARD BROADCAST TRANSMITTER

20 Your answer is incorrect. The primary purpose of the detector is to separate the audio component from the r-f component. Generally, receiver sensitivity is limited by other sections of the receiver. Return to frame 8 and choose another answer.

21 The earliest type of AM receiver was the crystal radio now considered a toy. Later, the tuned radio-frequency (trf) receiver achieved more gain and better selectivity by using several tuned LC tank circuits.

Let's now discuss the operating principles of the most widely used AM receiver called the superheterodyne receiver. This type of receiver is used in just about all standard AM radios today. It offers better selectivity, sensitivity, and stability than the trf receiver. A block diagram of the basic superheterodyne receiver is shown in figure 7. The first block is an r-f amplifier capable of being tuned over the entire broadcast band. The key to the superheterodyne action occurs in the mixer and local oscillator blocks. The output of the mixer is the difference frequency between the r-f signal and the oscillator frequency. This is possible because the oscillator frequency is variable but always a fixed amount higher than the resonant frequency of the r-f stage. Since nonlinear mixing occurs in the mixer similar to a modulator, filtering is required to suppress unwanted frequencies. The frequency conversion process is also known as frequency translation or heterodyning.

QUESTION: A modulated carrier of 945 KHz is fed to a mixer together with an oscillator frequency of 1400 KHz. What frequency or frequencies exist at the output of the mixer stage?

455 KHz . . . . . go to frame 18

455 KHz and 2345 KHz
. . . go to frame 25

455 KHz, 945 KHz, and 2345 KHz
. . . go to frame 7

22 Your answer is correct. The detector stage receives the output of the i-f amplifier, removes the i-f signal, and leaves only the audio signal. One common type of detector, known as an envelope detector, consists of a half-wave diode rectifier followed by an RC filter as shown in figure 8. The i-f signal is rectified by the diode and then filtered by the RC circuit so that only the audio signal results. Typical signals showing the detection process are also included in this figure. After detection, the audio signal is stepped up by the audio amplifier whose output drives the speaker.

The resistor in the envelope detector actually represents the equivalent input resistance of the audio amplifier, but must be considered in filtering action. The RC product has dimensions of time and is known as a time constant. Signals with a shorter period

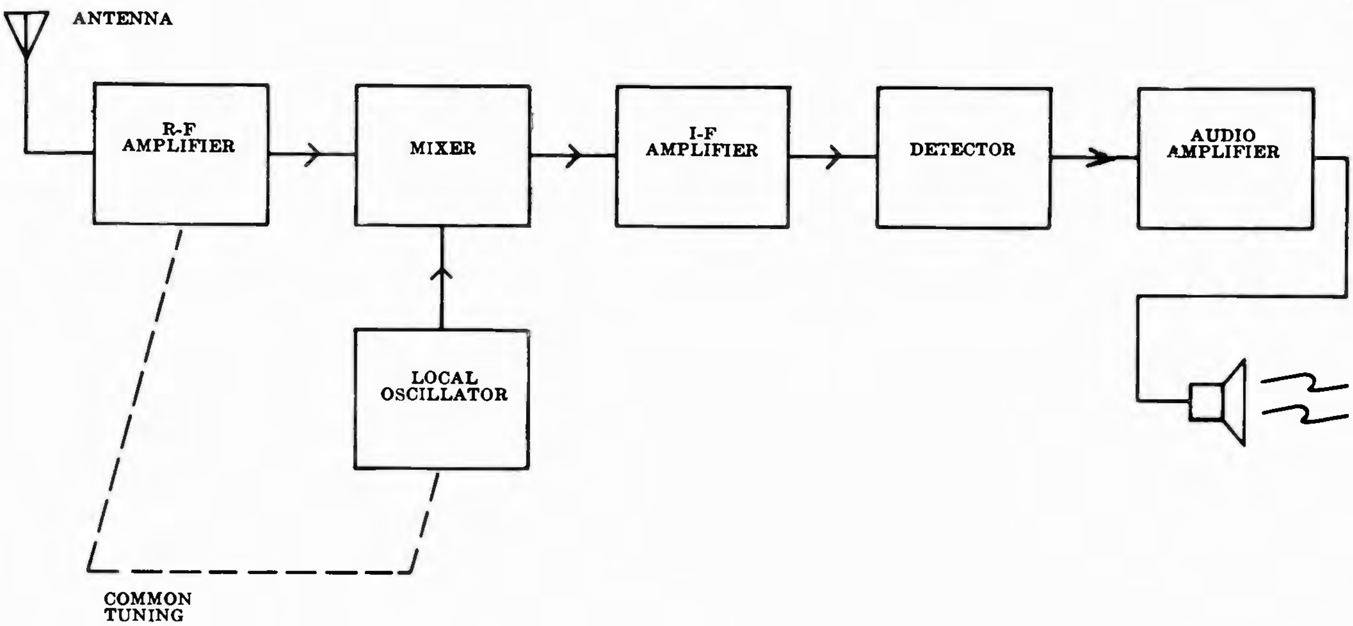


Figure 7
BLOCK DIAGRAM FOR THE SUPERHETERODYNE RECEIVER

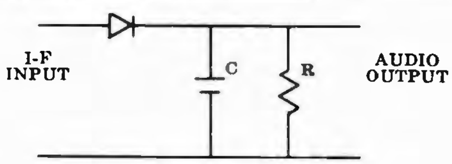
than the time constant are shunted to ground. Signals with a longer period pass through. (Remember, the period of a signal measured in time is equal to the inverse of its frequency.)

QUESTION: The RC time constant associated with the detector should have which of the following characteristics?

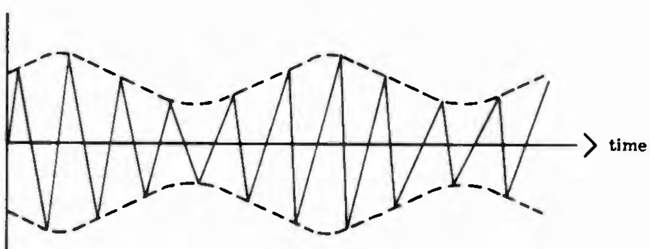
Should have a long time constant with respect to the period of the audio frequency
. . . go to frame 11

Should have a short time constant with respect to the period of the i-f frequency
. . . go to frame 20

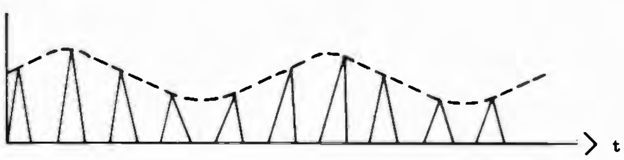
Should have a time constant intermediate between the period of the i-f frequency and the audio frequency . . . go to frame 27



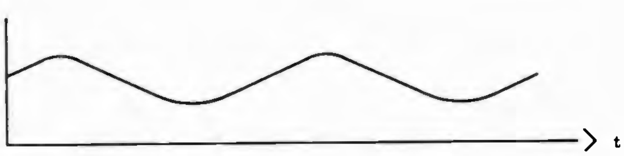
ENVELOPE DETECTOR



I-F SIGNAL



RECTIFIED I-F SIGNAL



AUDIO SIGNAL

Figure 8
ENVELOPE DETECTION PROCESS

23 Go to frame 14.

24 Your answer is incorrect. The power level in both sidebands is equal to $\frac{m^2}{2}P_c$. A modulation factor (m) of 0.1 is equivalent to the 10-percent modulation level. Recalculate the sideband power using the above expression and choose another answer to frame 17.

25 The frequency conversion process produces both the sum and difference frequencies as indicated by your answer. Actually, many other frequencies including harmonics of the sum and difference frequencies are produced by the nonlinear action of the mixer. Filtering occurs in the mixer, however, so that its primary output is the difference frequency. Return to frame 21 and choose the difference frequency.

26 Your answer is incorrect. During frequency conversion, the bandwidth associated with the r-f carrier is translated to the lower i-f region. Hence, the r-f and i-f bandwidths are the same. Return to frame 18 and choose the correct answer.

27 Your answer is correct. The RC circuit bypasses i-f frequencies to ground, while allowing audio signals to pass to the audio amplifier.

This completes our discussion of the superheterodyne receiver and introduction to AM radio. From an understanding of the basic theory presented in this lesson, you are now better prepared to understand the variations and refinements described in texts on this subject. In our next lesson, principles of FM communications will be presented and compared with the basic AM fundamentals from this lesson.