Chapter 18

RADIOS

A.) Radio Circuits--Sending Stations:

Note: A simplified circuit for a *radio sending unit* is shown in Figure 18.1. A discussion of its workings is presented below:

1.) Charge flowing up and down an antenna at high frequency creates the following in the vicinity of the antenna:

a.) A rapidly varying (i.e., high frequency) *electric field disturbance* whose direction and magnitude change constantly, and

b.) A rapidly varying (i.e., high frequency) *magnetic field disturbance* whose direction and magnitude change constantly.

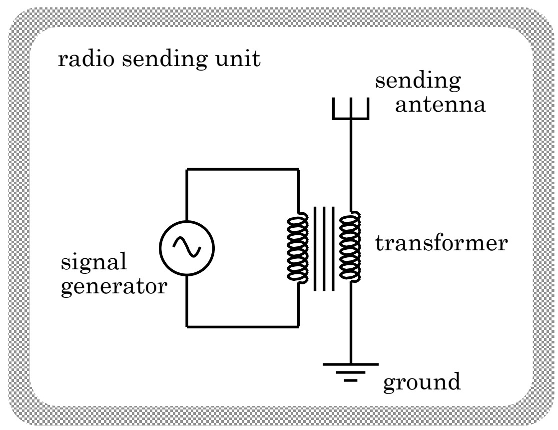


FIGURE 18.1

Note: The rationale for these two assertions should be obvious. *Electric fields* are produced whenever free charge is present. That is the case here as the antenna becomes positively, then negatively, then positively charged. *Magnetic fields* are produced by *charge in motion*--also the case here as charge runs up and down the antenna.

c.) The alternating *magnetic* and *electric fields* around the antenna will be *perpendicular to* and *in synch with* one another. The combination of the two is called an "electromagnetic disturbance."

2.) If the frequency of this electromagnetic disturbance is high enough (over 500,000 hertz), there will not be enough time for the disturbance to collapse back onto the antenna before the next build-up begins. As a result, the disturbance will be forced to "flip off" the antenna and move outward at a speed of 3×10^8 meters per second--the speed of light.

Note 1: Both light and radio waves are electromagnetic waves. The only structural difference between the two is their frequency range. Optical light has a frequency range between $4.3\text{x}10^{14}$ hertz and $7.5\text{x}10^{14}$ hertz while radio radiation has a frequency range between $.5\text{x}10^{6}$ hertz and $1.7\text{x}10^{6}$ hertz.

Note 2: We now have a rational explanation for why light, acting like a wave (i.e., a disturbance moving through a medium), can move through the nothingness of space (a mediumless region) from the sun to the earth.

According to Faraday's Law, *changing magnetic fields* induce *electric fields*. Although we haven't discussed it, it turns out that *changing electric fields* induce *magnetic fields*. In other words, the changing magnetic and electric fields of an electromagnetic wave support one another.

In short, *electromagnetic waves* are their own medium.

3.) Every radio station is given *one frequency* (plus or minus a bit of slop) between 500,000 and 1,700,000 cycles per second to use for its broadcasts (we will talk about how a station puts its programming information on that one frequency later).

Note: If you examine an old-fashioned radio dial (i.e., one that isn't digital), you will find that the dial is marked with the units "10 kHz." If you multiply a station's call numbers by those units, you will get the station's sending frequency.

Example: In L.A., KFWB's call numbers are "Channel 98." Multiply 98 by 10 kHz and you get $98\text{x}10\text{x}10^{3}$ Hz, or 980,000 hertz. That is the *single frequency* the FCC (Federal Communications Commission) has given KFWB for its transmission.

4.) Looking back at Figure 21.10, we see a single frequency oscillator, a transformer for transferring the signal to the antenna, and a grounded antenna (the grounding is needed to allow charge to freely flow *onto* and *off of* the antenna).

This is an extremely simplified schematic. None of the circuitry needed to put information onto the station's single-frequency wave is shown. Nevertheless, it does generally represent the bare-bones circuit of a station's setup.

5.) After flip-off, the EM wave moves out from the station over the countryside.

a.) If sensors are spread out to record the intensity and direction of the electromagnetic wave at various places at a particular instant, the *electric* and *magnetic field* variations will look like the graph shown in Figure 18.2.

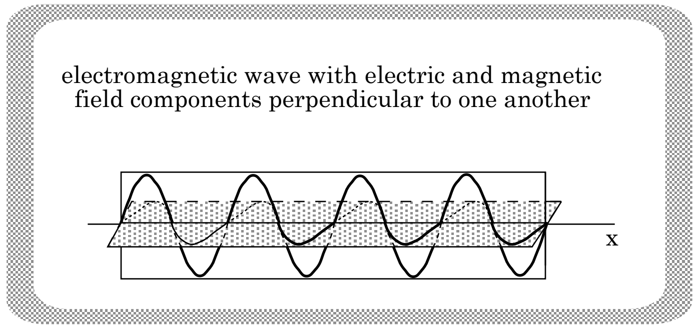


FIGURE 18.2

i.) The *electric field component* will change both *magnitude* and *direction* from place to place as will the *magnetic field component*.

ii.) The *electric* and *magnetic fields* will be *in phase with one another* and *perpendicular to one another*, and the whole mess will be moving away from the radio antenna at the speed of light.

b.) The fun begins when that EM wave comes in contact with the antenna of your radio.

B.) Radio Circuits--the Receiving End:

Note: The circuit for a simple AM radio is shown its workings is provided below:

1.) As the incoming *electromagnetic wave* impinges upon the *receiving antenna* of your radio, the charge carriers in the antenna respond to the varying EM field by oscillating up and down the antenna. The oscillation pattern of these charge carriers will match identically with the oscillation pattern of the charge carriers that produced the EM wave on the sending antenna in the first place.

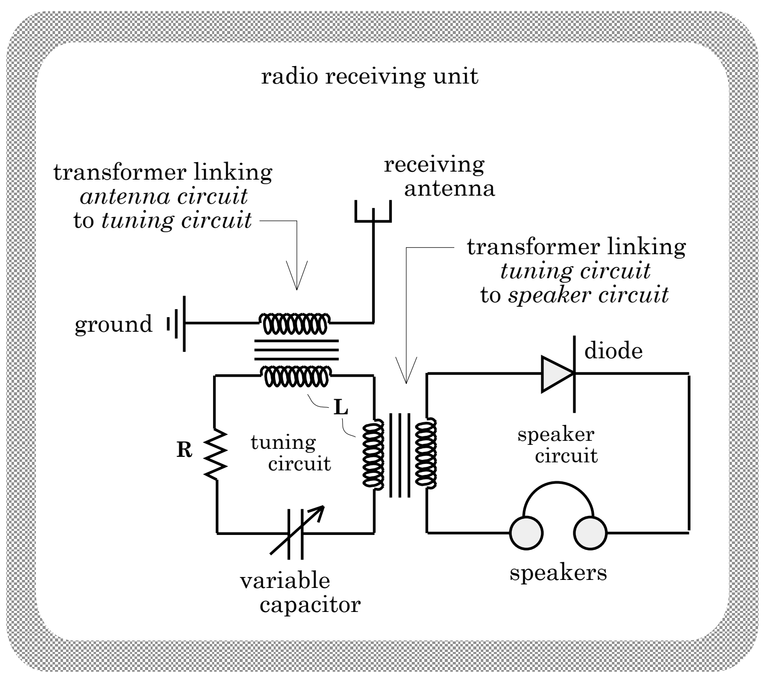


FIGURE 18.3

<u>Bottom line</u>: The *electromagnetic wave* allows us to transfer charge jiggle from a sending antenna to a receiving antenna.

2.) Receiving antennas are not selective as to the signals they accept. If there are ten radio stations transmitting in a particular area, the charges on the antenna will respond to the EM waves coming from each of those stations. The net jiggle on your antenna will be the superposition of all the waves impinging on the antenna. We need a way to select out one station only. To do so, we need a *tuning circuit*.

C.) Quick Review of Capacitors, Inductors, and Resistors in AC Circuits:

1.) This is a bit of a side trip, but to understand how tuner circuits work you need to understand how a capacitor, inductor, and resistor will act if made to coexist in series in an AC circuit. Before we can do that, we need a quick review of RL and RC circuits in an AC setting.

2.) For those of you who learned this thoroughly the first time around, the first three lines of the chart presented below summarizes all you know about circuit elements under the influence of an AC source (for now, ignore the last line). For those of you who are still in a cloud, a brief discussion of each element's behavior follows.

element	symbl	units	resistive nature	phase	filter
resistor	R	ohms	resistance R (ohms)	no phase shift	none
inductor	L	henrys	inductive reactance: $X_L = 2\pi \nu L$ (ohms) resistor-like resistance r_L (ohms)	V_L *leads* circuit current by $\pi/2$ radians	low pass
capacitor	C	farads	capacitive reactance: $X_C = 1/(2\pi \nu C)$ (ohms)	V_C *lags* circuit current by $\pi/2$ radians	high pass
RLC circuit	--- --- ---	--- --- ---	impedance: $Z = [R^2 + (X_L - X_C)^2]^{1/2}$ (ohms)	phase shift (ϕ) $= \tan^{-1}[(X_L - X_C)/R]$ (radians)	re-son-ance frequ.

3.) Summary focused on a single resistor *R* in an AC circuit:

a.) The resistive nature of the circuit elements called *resistors* is called *resistance*. Its units are *ohms*.

b.) The current through a resistor is inversely proportional to the size of the resistor and proportional to the voltage impressed across the resistor.

i.) This is summarized in *Ohm's Law* as $V = iR$.

c.) The resistive nature of resistors is *not* frequency dependent.

d.) Resistors do not throw the current through them out of phase with the voltage across them.

4.) Summary focused on an RL circuit in an AC circuit (see Figure 18.4).

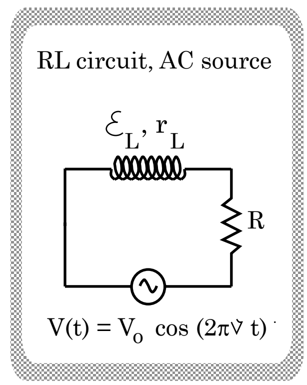


FIGURE 18.4

a.) *Inductors* have resistor-like resistance r_L and frequency dependent resistance associated with them in AC circuits.

b.) The frequency dependent resistance is called *inductive reactance*. It's units are *ohms* and its magnitude is

$$X_L = 2\pi \nu L \quad \text{(ohms)},$$

where the inductance L must be written in terms of *henrys* (versus *milli-henrys* or whatever) and ν is the frequency of the AC source.

c.) Remembering that when the resistive nature is small, large current can flow, a low frequency signal through an inductor will generate a small inductive reactance (i.e., $X_L = 2\pi \nu L$ will be small) and allow large current to flow. In short, inductors pass low frequency signals and dampen out high frequency signals.

5.) Summary focused on an RC circuit in an AC circuit (see Figure 18.5).

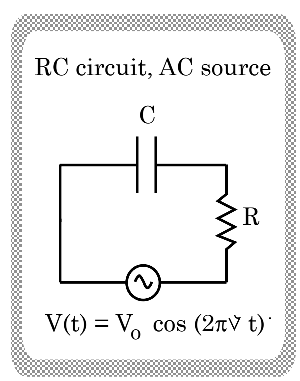


FIGURE 18.5

a.) Unless it is *leaky*, the capacitor in the circuit will have no resistor-like resistance inherent within it. Capacitors do have frequency-dependent resistance in an AC circuit.

b.) The frequency dependent resistance is called *capacitive reactance*. It's units are *ohms* and its magnitude is

$$X_C = \frac{1}{2\pi\nu C} \quad \text{(ohms)},$$

where the capacitance *C* must be written in terms of *farads* (versus leaving it in *microfarads* or whatever).

c.) Remembering that when the resistive nature is small, large current can flow, a high frequency signal through a capacitor will generate a small capacitive reactance (i.e., $X_C = \frac{1}{2\pi\nu C}$ will be small) and allow large current to flow. In short, capacitors pass high frequency signals and dampen out low frequency signals.

D.) RLC Circuits:

1.) If capacitors dampen out low frequency signals and inductors dampen out high frequency signals, what happens when you have a capacitor, inductor, and resistor in the same AC circuit (see Figure 18.6)?

Not what you would expect.

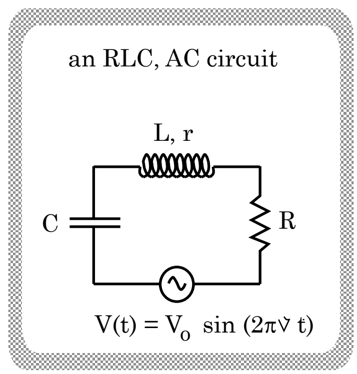


FIGURE 18.6

2.) It turns out that there is one frequency (in a real circuit, this is a small range of frequencies) in which the effect of the capacitor is negated by the effect of the inductor. When this happens, the circuit's net *resistive nature* becomes small and a relatively large current flows.

To determine that frequency, we must first determine an expression for the *net resistive nature* of the RLC circuit. To do that, we could do as we did with the *RC* and *RL circuits*. That is, we could write out Kirchoff's Loop equation for the circuit, solve for the current, then compare that expression with the Ohm's Law relationship *i = V/(resistive nature)* to determine the circuit's net resistive nature.

As mathematically intriguing as this might be, there is another way utilizing what are called *phasor diagrams*.

3.) Phasor diagrams:

a.) For a given frequency, there are three vectors in a phasor diagram:

i.) The magnitude of the first vector is equal to the magnitude of the net resistive nature provided by the elements in the circuit that *do not throw the voltage out of phase with the current at all*. These elements are resistors. Their net resistive nature is denoted by R_{net} (in most cases, this $R_{net} = R + r_L$--remember, there is usually *resistor-like* resistance inherent in the wire making up the inductor coil). This vector will be graphed along the *+x axis*.

Note: In this kind of diagram, circuit elements that leave the voltage in phase with the current are graphed BY DEFINITION along the *+x axis*. Elements that make the voltage *lead* the current by a quarter cycle are graphed at $+\pi/2$ radians from the *+x axis* (i.e., along the *+y axis*), and elements that make the voltage *lag* the current by a quarter cycle are graphed at $-\pi/2$ radians (i.e., along the *-y axis*).

ii.) The magnitude of the second vector is equal to the magnitude of the net resistive nature provided by the elements in the circuit that make the voltage *lead* the current by $\pi/2$ radians. These elements are the inductors. Their net resistive nature is denoted by X_L and it is frequency-dependent. This vector will be graphed along the *+y axis*.

iii.) The magnitude of the third vector is equal to the magnitude of the net resistive nature provided by the elements in the circuit that make the voltage *lag* the current by $\pi/2$ radians. These elements are capacitors. Their net resistive nature is denoted by X_C and it is frequency-dependent. This vector will be graphed along the *-y axis*.

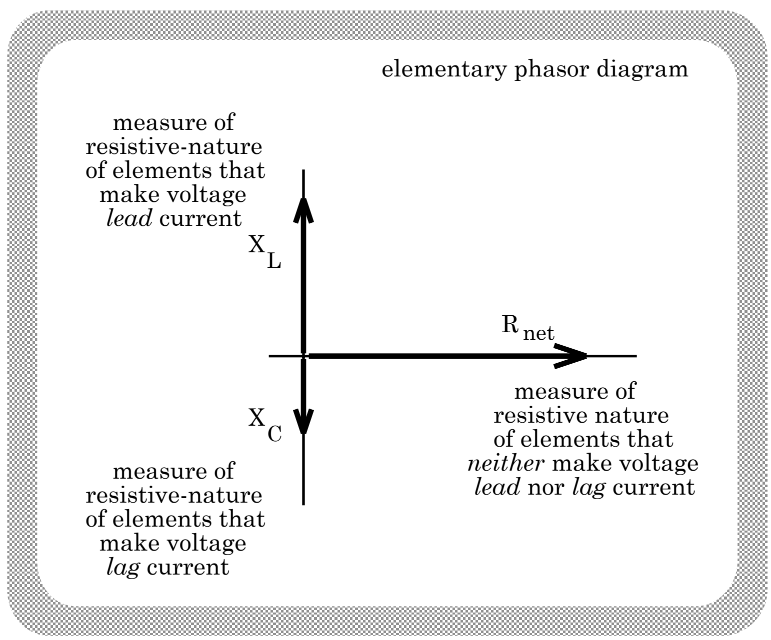


FIGURE 18.7

b.) A typical phasor diagram is shown in Figure 18.7. The vector addition of the two vectors found along the *y axis* is shown in Figure 18.8, and the final vector addition (i.e., the one that produces the resultant *Z*) is shown in Figure 18.9.

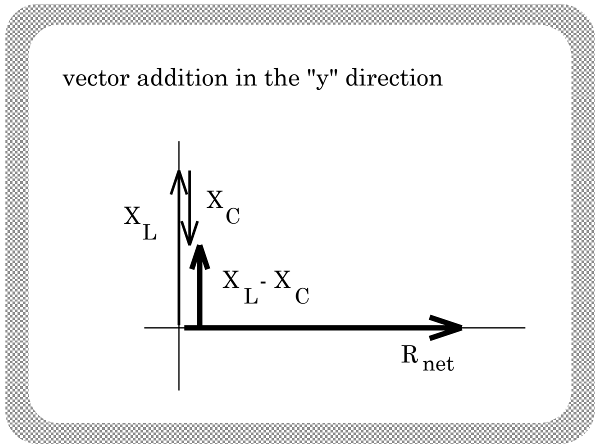


FIGURE 18.8

4.) Impedance:

a.) The resultant of the *phasor diagram* is given a special name--the circuit's *impedance* (its symbol is *Z*). It tells us two things: the *net resistive nature* of the entire circuit and the *phase shift* of the circuit (i.e., the degree to which the voltage *leads* or *lags the current* at a given frequency).

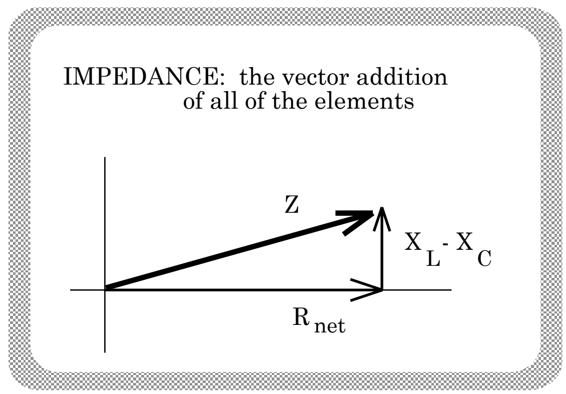


FIGURE 18.9

b.) Algebraically (using the Pythagorean relationship and the diagram), the magnitude of a circuit's impedance equals:

$$Z = [R_{net}{}^2 + (X_L - X_C)^2]^{1/2}.$$

c.) The units of *Z* are *ohms*.

d.) Writing *Z* out in expanded form, we find that it is frequency-dependent:

$$Z = \left[R_{net}{}^2 + [2\pi\nu L - 1/(2\pi\nu C)]^2\right]^{1/2}.$$

e.) Using trig. and the phasor diagram shown in Figure 18.10, the phase shift is found to be:

$$\phi = \tan^{-1}\left[{(X_L - X_C)}/{R_{net}}\right]$$

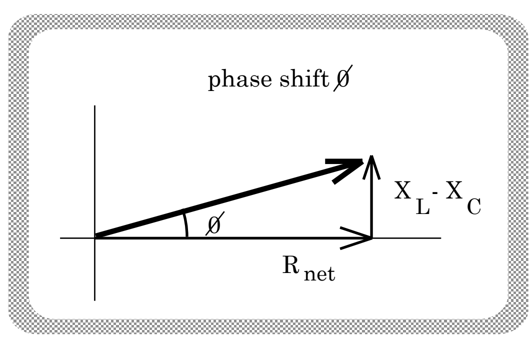


FIGURE 18.10

Note: If the calculated *phase shift* is positive, the voltage *leads* the current. If the *phase shift* is negative, the voltage *lags* the current.

5.) The Resonance Frequency of an RLC circuit: We began this section on RLC circuits by posing a question: "Is there a frequency at which the resistive effects of the inductor and capacitor cancel one another out leaving us with a substantial current flowing in the circuit?"

Our impedance expression gives us the answer.

a.) As both X_L and X_C are frequency-dependent, there must be a frequency at which X_L - X_C equals zero. At that frequency, the net resistive quality of the circuit (i.e., its impedance) will be at a minimum, and a relatively sizable current should flow.

This special frequency is called the *resonance frequency* n_{res}.

b.) Mathematically, the resonance frequency can be found as follows: At resonance,

$$X_L - X_C = 0$$

$$\Rightarrow \quad 2\pi \nu_{res} L - 1/(2\pi \nu_{res} C) = 0$$

$$\Rightarrow \nu_{res} = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}.$$

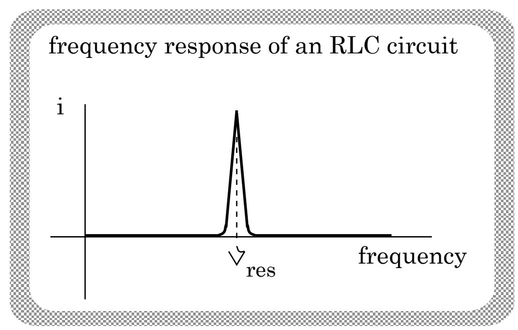


FIGURE 18.11

A graph of the *frequency response* (i.e., *current as a function of frequency*) of an RLC circuit is shown in Figure 18.11.

6.) One might wonder what is really happening conceptually at resonance. The answer is interesting. To answer it, consider the following:

a.) Assume a capacitor in an *LC circuit* is initially charged (see Figure 18.12--there is resistance in the circuit but we will ignore it for now). There is *no power supply* in the circuit, so when the switch is

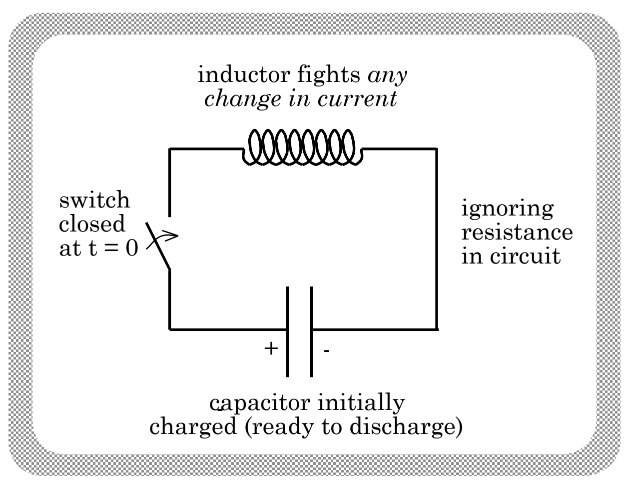


FIGURE 18.12

thrown at $t = 0$ the capacitor begins to discharge through the inductor.

b.) As a coil, the inductor produces a back-EMF which fights the increase of current in the circuit. As such, the current rises more slowly than would otherwise have been the case (though it does still rise).

c.) Sooner or later, the free charge on the discharging capacitor begins to run out. As this occurs, the current in the circuit declines prompting the inductor to produce an induced EMF that fights *that* change.

d.) Bottom line: Charge continues to flow in the circuit even after the capacitor is completely discharged.

e.) As current continues to flow, the capacitor begins to recharge *going the other way* (i.e., what was the positive terminal becomes the negative terminal and vice versa). When the induced current finally dies out, we find ourselves with a charged capacitor all ready to discharge, starting the whole process over again.

f.) If there is no resistance in the circuit (i.e., if the system's wires are superconductors), this oscillating AC charge flow will continue forever. With resistance in the circuit, the amplitude of the current will diminish with time but the charge/discharge frequency will not change (see Figure 18.13).

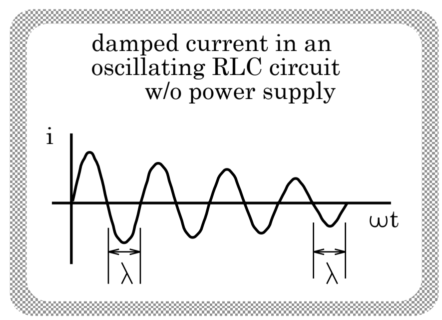


FIGURE 18.13

g.) The natural frequency of this discharge, charge, discharge process is related to the size of the inductor and capacitor. Specifically, the system's natural frequency is $\frac{1}{2\pi}\sqrt{\frac{1}{LC}}$.

h.) It shouldn't be hard to imagine what will happen if a power supply is placed in a circuit.

i.) If the frequency of the power supply does not match the natural frequency of the (R)LC combination, the charge/discharge frequency will fight the alternative voltage provided by the out-of-step power supply, and the net current in the circuit will be very small if not zero.

ii.) On the other hand, if the frequency of the power supply is just right (i.e., $\frac{1}{2\pi}\sqrt{\frac{1}{LC}}$), its voltage will resonate with the charge/discharge cycle and the amplitude of the net current in the circuit will grow large.

iii.) That frequency at which the signal proliferates is the resonance frequency for the (R)LC circuit. At that frequency the current will be as large as it ever can be.

E.) Radios and the Tuner Circuit:

1.) So look at the receiving circuit shown in Figure 18.3. In it, a transformer is used to transfer signals picked up by the antenna from the antenna circuit to the *tuner circuit*. And how does the tuner circuit work? Consider:

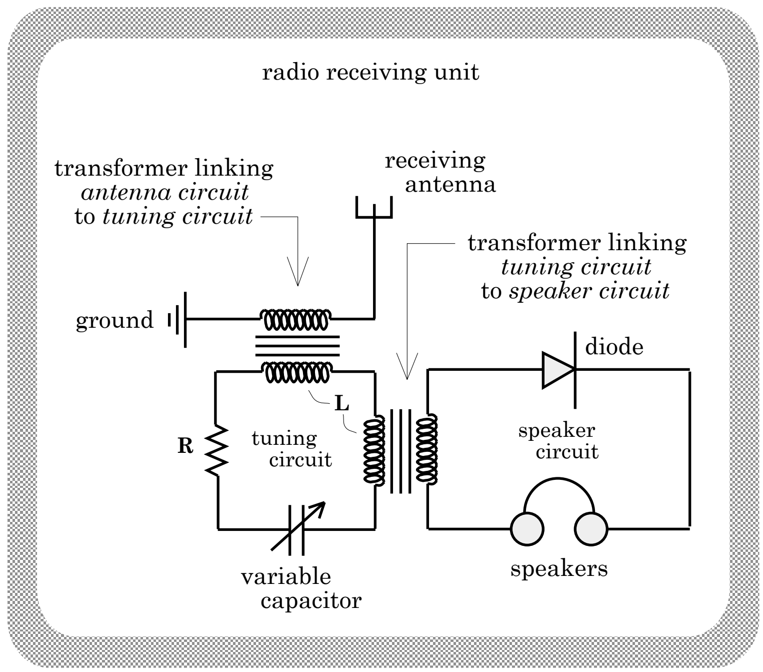


FIGURE 18.3

a.) A driven RLC circuit (i.e., an RLC circuit in which there is some source of power in the circuit) has the peculiar characteristic of allowing only one frequency to oscillate freely within it. That frequency is called the *resonance frequency* and is mathematically equal to:

$$\nu_{res} = (1/2\pi)\,(1/LC)^{1/2}.$$

b.) Consider for a moment a radio signal that is transmitting at some frequency *other than* the natural frequency of the (R)LC combination in the radio's *tuner circuit*.

i.) The signal impinges on the antenna causing charge to oscillate in the antenna circuit at the station's sending frequency.

ii.) When the signal is transferred from the antenna circuit to the tuner circuit, the transformers acts like a power supply in the tuner circuit. That is, the transformer is the power-providing agent in the circuit.

iii.) For this situation (i.e., if the tuner circuit's resonant frequency and the station's sending frequency don't match), the signal will die in the tuner circuit.

iv.) Why? Because the transferred signal will be out of step with the natural charge/discharge pattern of the (R)LC combination in the circuit.

v.) The bottom line is that the signal does not proliferate in the tuner circuit and, hence, dampens out.

c.) Now consider a radio signal that is transmitting at the same frequency as the natural frequency of the (R)LC combination in the radio's *tuner circuit.*

i.) In that case, the frequency of the signal being transferred in via the transformer will match the resonant frequency of the tuner circuit and the charging/discharging action of the RLC circuit will help the signal intensity to build on itself.

d.) In other words, because the *tuner circuit* only allows one frequency (or, in real life, a small range of frequencies) to proliferate within its bounds, all signals from all stations that don't match that resonant frequency will be dampened out by the tuner circuit while the signal from the station the radio has been tuned for will come through with gusto.

e.) By varying the capacitance of the capacitor in the tuner circuit (the capacitor symbol in Figure 18.3 is that of a *variable* capacitor), the natural frequency of the *tuner current* changes and different stations can be "tuned in."

f.) Bottom line: From the many signals impinging on our antenna, the *tuner circuit* selects one frequency to pass on to the next part of the radio circuit, the *speaker circuit.*

F.) Speakers and the Speaker Circuit:

1.) To understand the speaker circuit, we need to discuss two separate topics. The first is, "How is information put on a radio station's *single, high-frequency, electromagnetic wave*?"

a.) Let's assume we have a radio station that wants to send out *middle C* over the airwaves (middle C is a 256 hertz *sine wave*). The station has a single, high-frequency signal--say 1,000,000 cycles per second--to work with (Figure 18.14 shows both waves).

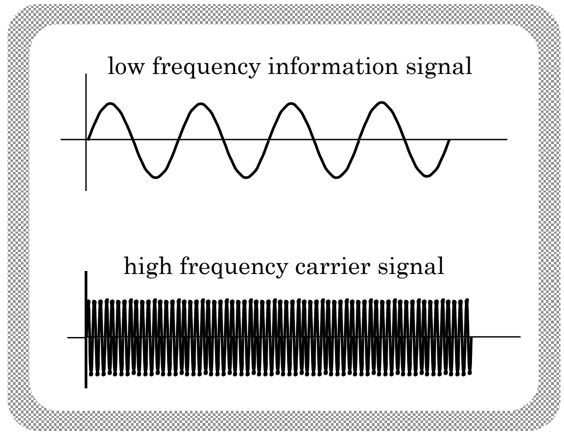


FIGURE 18.14

b.) In AM radios, information is put on the station's *single, high-frequency signal* (called the *carrier wave*) by a technique called *amplitude modulation.*

i.) The *amplitude* of the high frequency carrier wave is *modulated* (varied) so that the *envelope* (i.e., the outline of the high-frequency wave) exactly matches the waveform to be sent (in this case, a 256 hertz sine wave). For clarification:

c.) As has already been pointed out, Figure 18.14 shows both the low frequency *information signal* (the 256 hertz *middle C* sine wave) and the station's high-frequency *carrier wave*;

d.) Figure 18.15 shows the station's carrier-wave *amplitude modulated* so as to conform to the outline of the information-signal.

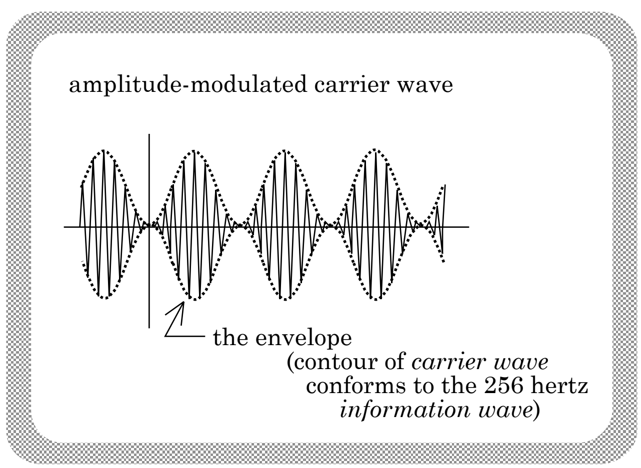


FIGURE 18.15

2.) Speech and music have more complex frequency wave forms, but the *amplitude modulation* approach still works. That is how AM stations put information on their carrier signal. It is also why AM stations are called AM--the letters stand for *Amplitude Modulation*.

Note: Although we will not be looking at the circuitry for such systems, FM stations encode their information by modulating not the *amplitude* of their sending wave but by modulating their *sending frequency* over a band-of-frequencies registered to them by the FCC (FM frequencies are typically in the 10^8 hertz range).

An example of a frequency-modulated wave and the decoded message is shown in Figure 18.16.

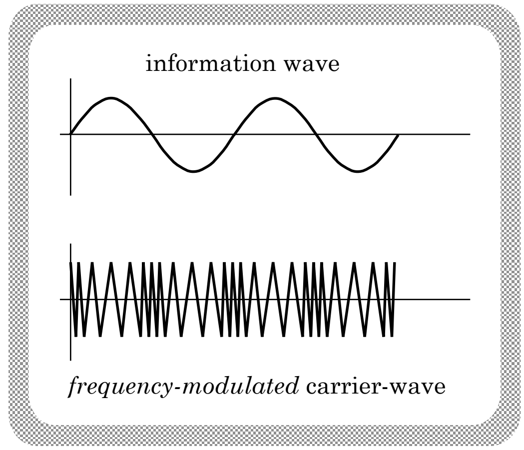


FIGURE 18.16

5.) Speakers: As shown in Figure 18.17, a speaker is comprised of a fixed magnet and a coil attached to a cardboard cone that is itself attached to a rigid frame at its edges (this attachment is not shown in the sketch).

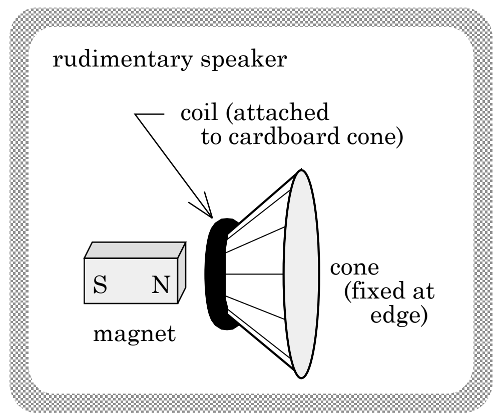


FIGURE 18.17

a.) At low frequency (i.e., in the audio range between 20 and 20,000 cycles per second), an AC signal produces an alternating current in the coil. From the chapter on magnetic fields, we know that a current flowing in a coil produces a magnetic field down its axis which, in turn, makes one side of the coil's face into a *North Pole* and the other side into a *South Pole*.

b.) Looking at Figure 18.18, assume the current in the coil makes the *cone-side* of the coil into a *South Pole* and the *magnet-side* of the coil into a *North Pole*. At that instant, the magnet's *North Pole* and the coil's magnetic field will repulse one

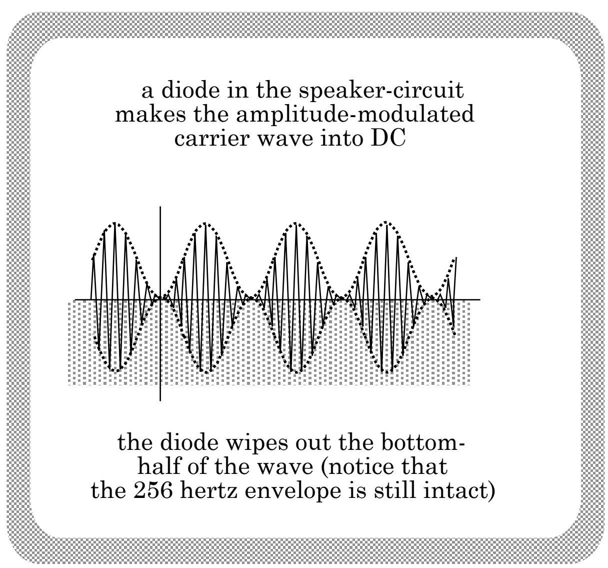


FIGURE 18.18

another, pushing the coil and cone *outward* away from the magnet.

c.) The AC polarity changes. The current in the coil flows in the opposite direction. The current in the coil now makes the *cone-side* of the coil into a *North Pole* and the *magnet-side* of the coil into a *South Pole*. At that instant, the magnet's *North Pole* and the coil's magnetic field will attract, pulling the coil and cone *inward*.

d.) As the current in the coil alternates at the power source frequency, the cone vibrates back and forth at that frequency producing *compression* and *rarefaction regions* in the air pressure around the speaker. Those pressure variations move out into the room.

As these pressure ridges pass your ear, hairs in the ear vibrate due to the pressure changes, electrical impulses are produced, and your brain senses sound.

6.) The scenario outlined above works fine as long as the frequency of the current is low enough for the cone to respond (cardboard cones do fine in the audio range). Unfortunately, speakers do not respond to million hertz AC signals--a cardboard cone is too massive and, hence, sluggish to vibrate at that rate--so putting a 1,000,000 hertz signal through a speaker will yield no net motion and, hence, no sound at all (even if it did produce sound, your ears would not be able to pick it up).

7.) The Speaker Circuit: The problem outlined in *Part 6* above is circumvented ingeniously with the use of a diode. The diode in the *speaker circuit* (Figure 18.3) turns the high frequency AC signal into a DC signal (see Figure 18.19). It is lumpy DC, but it is DC nevertheless. As such, the speaker now has a chance of dealing with the information placed on the carrier wave:

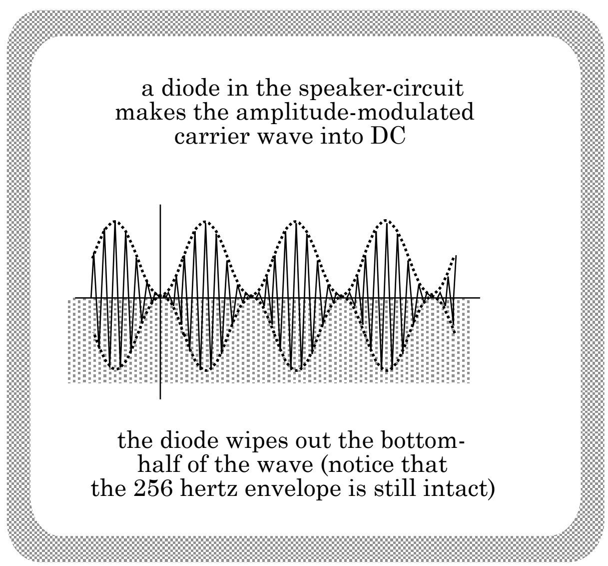


FIGURE 18.19

a.) Current will flow through the speaker's coil in *one direction only*, which in turn means the *fixed magnet* side of the *coil* will always have the same magnetic polarity. Let's assume, for this situation, its polarity is always *North*.

b.) The *coil* and *cone* cannot respond to every change in the varying current provided by the signal--the frequency is still too high for that--but it can follow *general trends of current flow*. That is, as the *average current* becomes larger and larger, the *northness* of the coil's face, on average, increases. This creates a larger and larger average repulsion between the coil and the fixed magnet and the cone pushes outward.

c.) As the average current decreases, the *northness* of the coil's face lessens. The repulsion between the coil and the fixed magnet becomes smaller and smaller, and the cone relaxes, pulling back inward toward its equilibrium position.

In other words, the cone *pulls in* or *pushes out* in conformity to the general current trend of the signal. This trend exactly conforms to the envelope of the carrier wave--to the very waveform we are trying to decode from the carrier signal.

d.) In short, the half-wave-rectified, high-frequency, amplitude modulated *carrier wave* generates in the speaker a slowly varying DC signal that exactly matches the 256 hertz signal we wanted to send in the first place. Our speaker, coupled with a diode, has acted as a decoder.

G.) Radio Circuit--Summary/Nutshell:

1.) At the station: A single, high-frequency carrier wave is *amplitude modulated* so that its *envelope* exactly matches the signal-to-be-sent (i.e., the information wave). A transformer transfers the signal to the *sending antenna* where an amplitude-varied electromagnetic wave is formed and sent out at the speed of light.

2.) The wave impinges on the receiving antenna of your radio. That wave, along with signals from every other radio station in the area, is transferred via transformer from the *antenna circuit* to the *tuner circuit*.

A signal whose frequency matches the resonance frequency of the variable (R)LC *tuner circuit* is the signal that thrives in the tuner circuit. All others die. This selected signal is transferred to the speaker circuit via a transformer.

The signal enters the *speaker circuit* as a high frequency AC voltage/current source. A diode eliminates half the signal making it into DC. This DC current flows through the coil in the speaker making the speaker's coil a variable-magnitude, *permanent-pole* magnet.

As the average current increases and decreases, the variations in the current cause variations in the polarity of the coil. This causes motion in the coil which, in turn, causes cone vibration. The resulting frequency of cone-vibration is the frequency of the *envelope of the signal* (i.e., that of the *information wave*). In doing so, we have successfully manipulated the incoming radio wave into audible sound.

H.) Amplification:

1.) The radio receiver circuit shown in Figure 18.3 uses no batteries. The speaker in such circuits is a tiny, single, ear-plug type. All the power needed to drive it is provided by the electromagnetic wave impinging on the receiving antenna. If a larger speaker is required, the signal needs to be amplified. (Some of this is going to be review, some not.)

2.) If you will remember back, the semi-conductor arrangement shown in Figure 18.20 is that of an *npn transistor*. In the circuit shown, it will not allow current to pass in either direction.

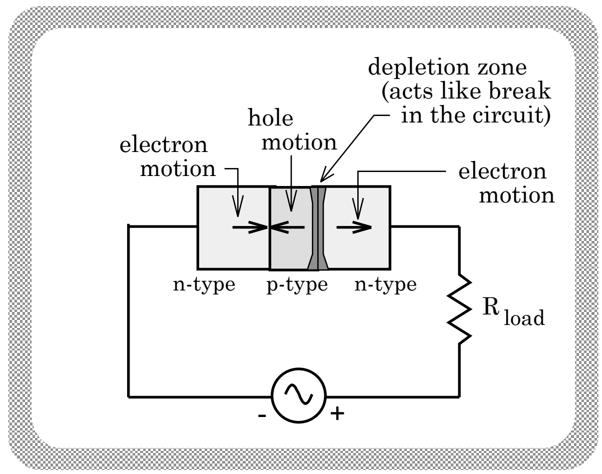


FIGURE 18.20

3.) Clever manipulation of this device will create a circuit that acts like an amplifier.

4.) Figure 18.21 shows the above arrangement with three modifications: a large DC power supply replaces the AC power source, a lead has been attached to the mid-section semi-conductor, and names have been given to the three transistor terminals.

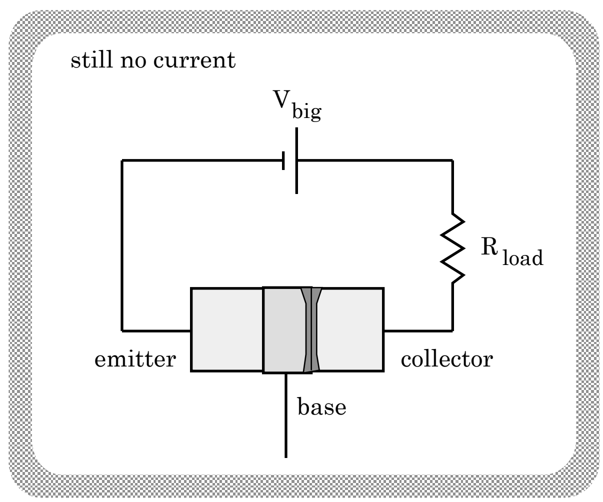


FIGURE 18.21

a.) You have already had experience with transistors as switches. This is similar but different.

b.) When the *base* of an *npn transistor* is made positive, the depletion zone diminishes as expected and some current flows.

c.) What is different in this case is that if the base is made just a little positive, the depletion zone will be diminished only slightly and the resulting current in the circuit will be small. If the base is made quite positive, the depletion zone will diminish greatly and the current in the upper circuit will be large. In other words, the amount the depletion zone is diminished governs the amount of current that flows through the transistor. There are two additional observations to note:

i.) If the positiveness of the base is somehow made to vary, the current in the upper circuit will vary accordingly.

ii.) Devices like this are extremely sensitive to base/emitter voltage variations. That is, a very small change in the base voltage will make a very big change in the circuit current (hence, a big voltage variation across the load resistor). In other words, if we are clever, we should be able to use this device to amplify a small signal into a large signal.

5.) Having established what happens when the *base* is made positive, consider the circuit shown in Figure 18.22.

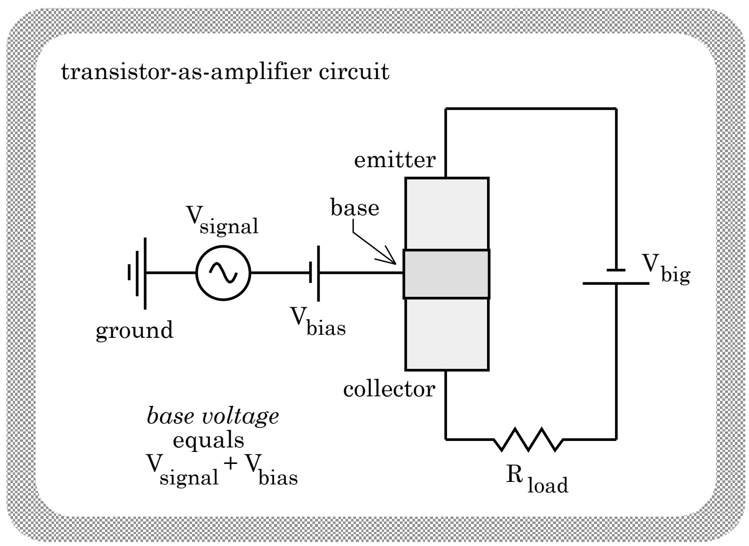


FIGURE 18.22

a.) In it, a very large DC battery (i.e., V_{big}) is placed in the upper circuit along with a load resistor (a speaker).

b.) A bias battery V_b is connected to the *base terminal* in series with a small, AC signal V_s (this is the signal to be amplified).

i.) V_b is greater than V_s so that when V_s goes negative, the sum of the two will stay *positive* thereby always making the *base* positive.

ii.) If this is not clear, look at Figure 18.23. Note that it has been rotated for easier viewing and that the graphs of the signal voltage V_s, the bias voltage V_b, the net base voltage V_{base}, and the net voltage across the load resistor V_R are all shown in the sketch.

6.) Examining the graphs in Figure 18.23 tells the story.

a.) The AC signal voltage V_s adds to the bias voltage V_{bias} to produce the *base voltage*. As the bias voltage is always larger than the signal voltage, the base voltage is always positive.

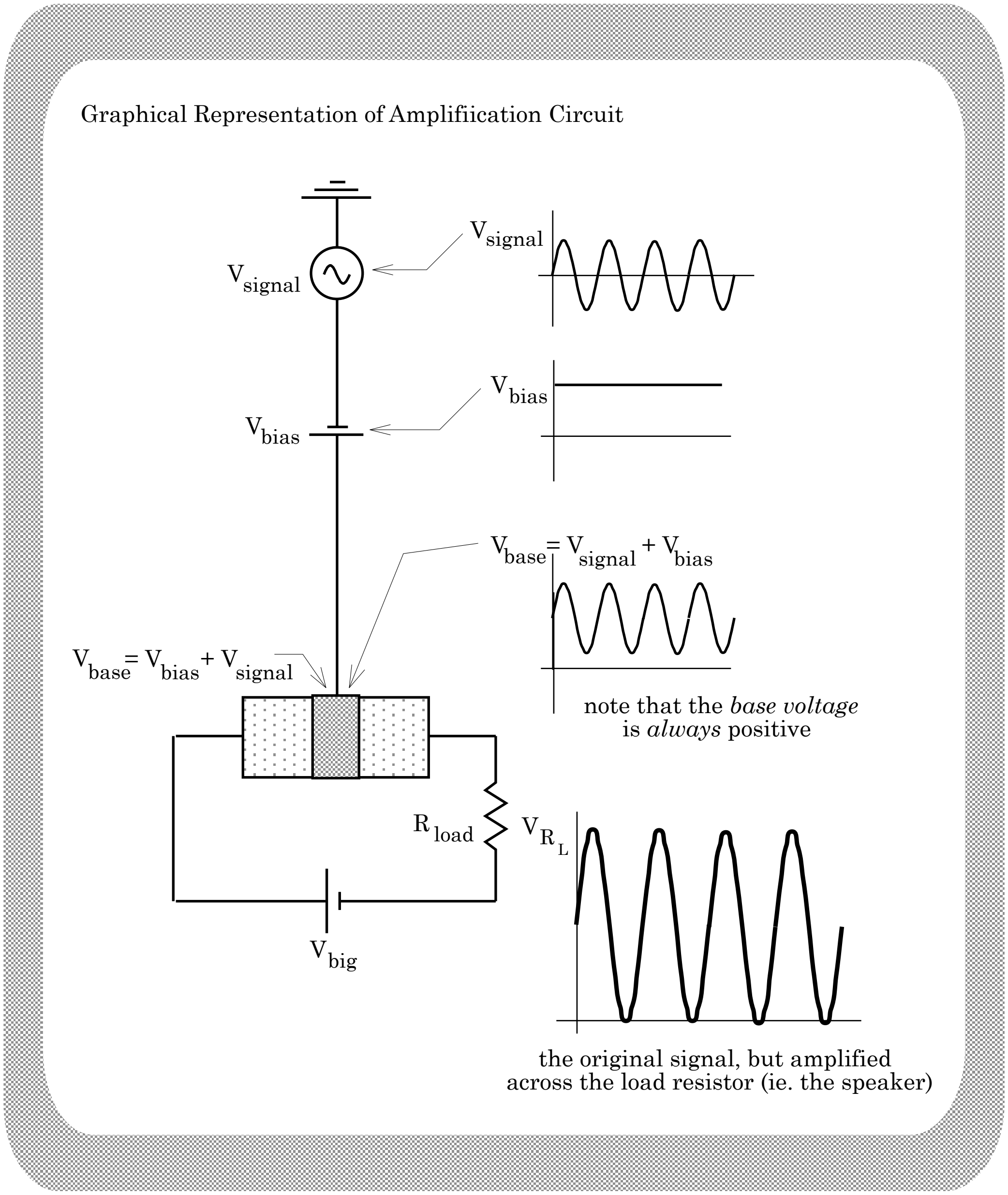


FIGURE 18.23

b.) As the signal voltage increases, the base voltage increases. This diminishes the size of the depletion zone allowing a large current to flow through the load resistor.

c.) As the signal voltage decreases, the base voltage decreases. This increases the size of the depletion zone cutting down current in the upper circuit and, hence, cutting down current through the load resistor.

d.) In all cases, the ups and downs of the signal at the base controls the ups and downs of the potentially large current through the load resistor. As such, a small signal (V_s) is reproduced and amplified across the load.

7.) Bottom line: In our radio circuit, the signal provided by the radio station is ushered into the amplifier-inclusive speaker circuit via the transformer between the tuner circuit and the transistor. Treating that transformer's secondary coil as though it were a signal source V_s, we end up with a radio receiver circuit with amplification (see Figure 18.24).

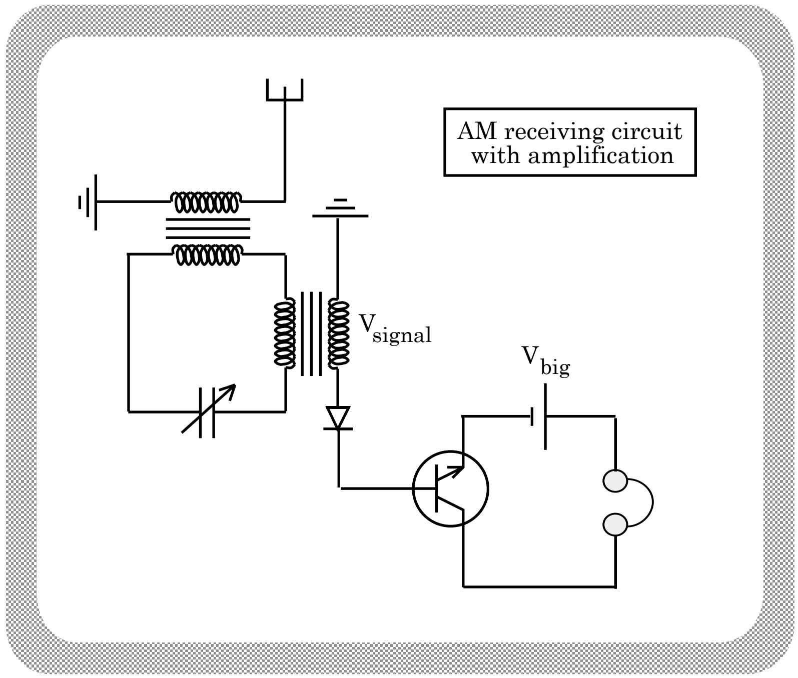


FIGURE 18.24

Note 1: If you will remember, a diode in the speaker circuit does two things: it exposes the envelope of the carrier wave, and it makes the signal DC. We still need the diode to expose the envelope, but because the diode makes the signal DC, we no longer need the bias voltage source that normally goes with the transistor (the base will always be positive with the diode-generated DC signal). That is why the original amplification circuit looks different from the amplification circuit shown in the radio system.

Note 2: A circuit like this is usually drawn with its ground leads connected as shown in Figure 18.24. In such a case, the emitter is common to both the speaker and the amplifier circuit. When connected this way, the transistor is said to be in a *common emitter* configuration.

QUESTIONS & PROBLEMS

Note: The answers to *Problems 18.1* and *18.2* are scattered throughout the chapter. As they are not analytical, problem solving questions but, rather, research and memory oriented questions, I won't be supplying solutions.

18.1) There are a bunch of conceptual questions associated with an AM radio. Here are some to chew on.

a.) What is a semi-conductor and how are semi-conductors used to make:

i.) Diodes?

ii.) Transistors?

b.) How is a diode used in an electrical circuit, why does it act as it does, and what is its circuit symbol?

c.) What are electromagnetic waves and how are they produced?

d.) What does a simplified radio-station circuit look like (be able to draw it)?

e.) How does a radio station put information onto its single, high-frequency carrier signal?

i.) What is the difference between AM and FM?

ii.) Why are there no radio waves below 500,000 hertz?

f.) What does a simple radio receiving circuit without amplification look like (be able to draw it)?

g.) How does a radio capture radio waves?

h.) How does a radio select a particular radio station frequency to listen to (i.e., how does the tuner circuit work)?

i.) How does a speaker work?

j.) How does a radio decode a radio station's signal (i.e., how does the speaker circuit work)?

k.) How does a transistor affect amplification and what is its circuit symbol?

l.) What does a radio-receiving circuit with amplification look like (be able to draw it)?

18.2) Concerning RLC circuits:

a.) What happens when a capacitor and an inductor are put in the same AC circuit. That is, if a low frequency signal (i.e., current) is blocked by the cap, and a high frequency signal is blocked by the inductor, is there *any* frequency at which current will flow?

b.) What does the phase shift tell you? Is the phase shift ever truly a quarter cycle (i.e., $\pi/2$ radians)?

c.) What does the impedance of a circuit tell you? Also, what are its units and how is it calculated?

d.) Is the impedance of a circuit frequency dependent? If so, how so?

18.3) An RLC circuit incorporates a 12 ohm resistor, a 60 mH inductor, and a 12 μf capacitor hooked in series across a power supply whose time-dependent voltage is *140 sin (1100 t)*.

a.) Determine the frequency of the power supply's signal.

b.) Determine the capacitive reactance at this frequency.

c.) Determine the inductive reactance at this frequency.

d.) Determine the impedance of the circuit at this frequency.

e.) Determine the phase shift at this frequency. Is the voltage leading or lagging the current?

f.) Determine the power supply's RMS voltage.

g.) Determine the RMS current in the circuit at this frequency.

h.) Determine the resonance frequency for this circuit.

18.4) You have an old, analog radio (i.e., not electronic) in which there exists a fixed 25 mH inductor. Unfortunately, the little arrow thingie that points to the station numbers on the face of the radio has broken off, so you can't just turn the dial until it points to the station number you want. You do, though, have access to the guts of the radio, and you have an impedance bridge (i.e., a meter that measures inductance or capacitance or resistance). You would *like* to listen to KFWB, channel 98 (x10 kHz). To get that station, what must you do. Be complete, and include any numerical values needed to execute your plan.

18.5)A circuit driven at 240 hertz has 27 ohms of impedance when a 12 ohm resistor is connected in series with an inductor whose internal resistance is 8 ohms and a 25 μf capacitor. The circuit's power source provides 70 volts RMS.

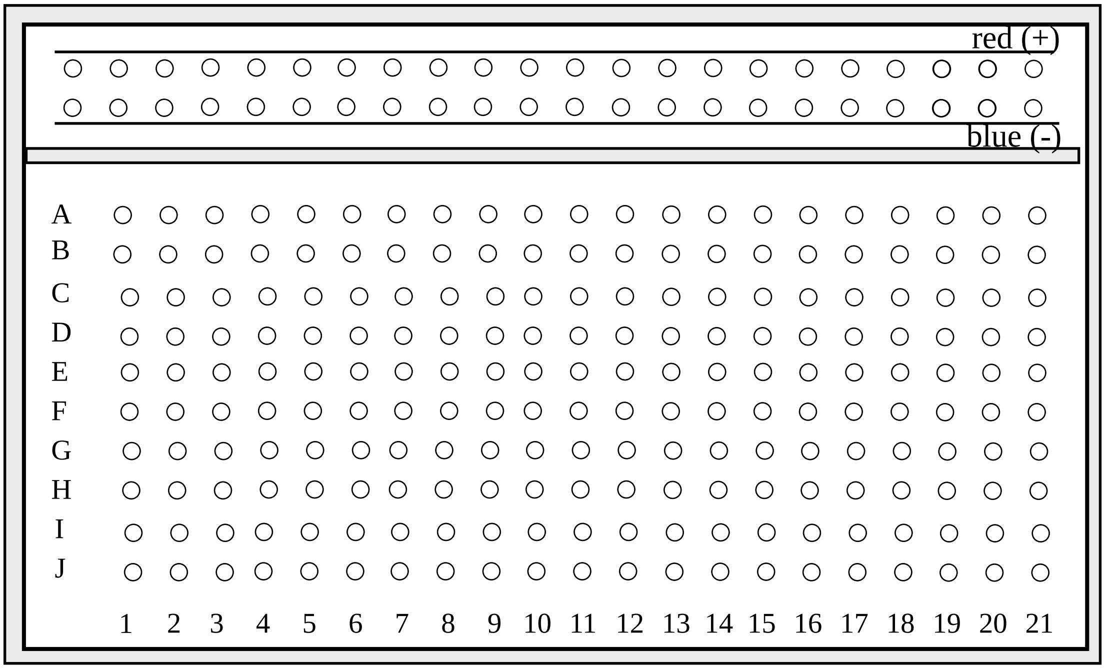
a.) What is the inductive reactance at this frequency?

b.) Determine the circuit's impedance at 1000 hertz.

c.) Determine the circuit's RMS current at 1000 hertz.

d.) What is the resonant frequency for this circuit?

18.6) Use the breadboard provided (next page) to show how you would wire the amplified radio circuit pictured in Figure 18.24.


red (+)
blue (-)
A
B
C
D
E
F
G
H
I
J
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21