Chapter 21

SEMI-CONDUCTORS AND RADIOS

A.) Semiconductors--"p-types" and "n-types":

1.) By themselves, Germanium (Ge) atoms bond in the same way all insulators do--covalently. Each Germanium atom has four valence electrons which are shared with four Germanium neighbors. See Figure 21.1.

2.) A curious thing happens when Gallium (Ga)--a five valence electron atom--is introduced into a structure whose atomic composition is made up of Germanium.

a.) Each Germanium atom around the Gallium shares a single electron with its oddball neighbor (the Ga), leaving the Gallium with one electron more than would have been the case if a Germanium had occupied the spot (see Figure 21.2a).

Note: Placing impurities into an otherwise pure insulator is called "doping."

b.) Because Gallium's valence shell holds only eight electrons, this extra electron doesn't fit into the valence orbital and has to occupy an energy orbital further out. In so doing, it is

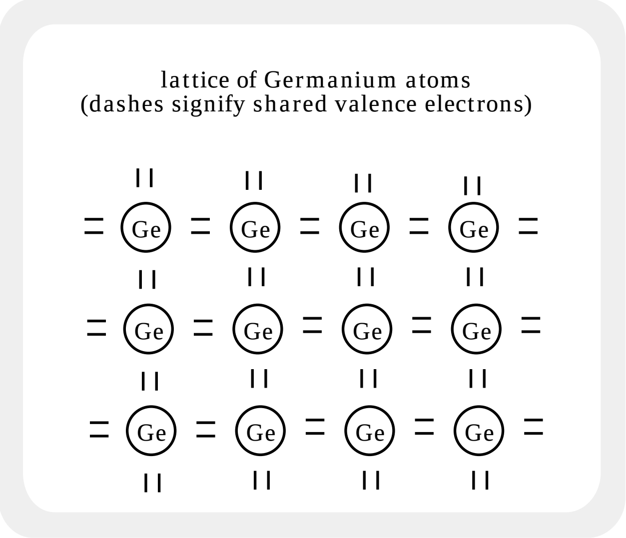


FIGURE 21.1

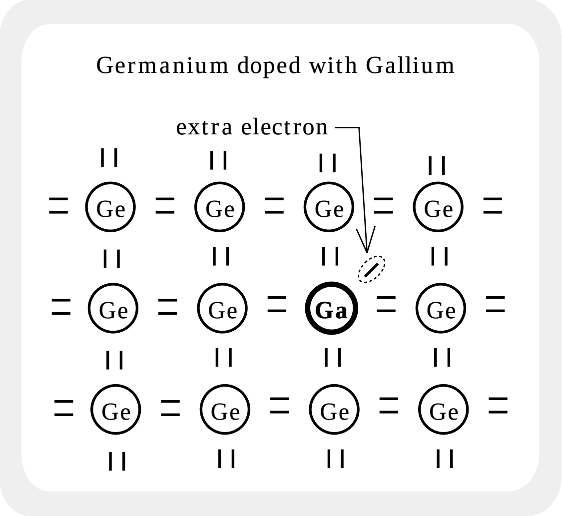


FIGURE 21.2a

only loosely bound to the positive Gallium nucleus.

c.) Due to this loose attraction, a small external electric field is all that is needed to break the extra electron away from its host atom. Once free, the electron can migrate through the structure just as do electrons in conductors (see Figure 21.2b).

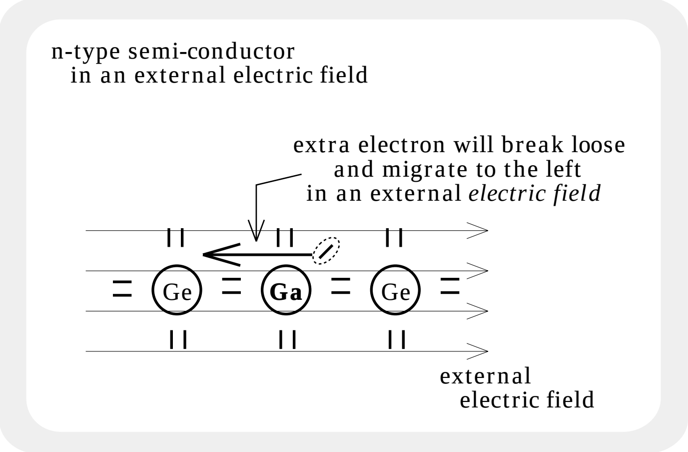


FIGURE 21.2b

d.) Bottom line: If we take an insulator (Germanium for example) and place the right impurities in it (Gallium in this case), we will end up with an insulator that has conductor-like characteristics--a material through which free charge can migrate if an electric field is applied.

3.) A doped insulator like this is called a semi-conductor. In the case outlined above, negative charges (electrons) move through the material. As such, the material is called an n-type semi-conductor.

4.) A positive-charge-version of the semi-conductor can be generated using Arsenic (As) as the impurity. Arsenic has three valence electrons. Introducing it into a structure whose atomic composition is made up of Germanium yields the following:

a.) Each Germanium atom around the Arsenic wants to share a single electron with its oddball neighbor (the As). After doing so, though, the Arsenic still has one less electron than would have been the case if a Germanium had occupied the spot.

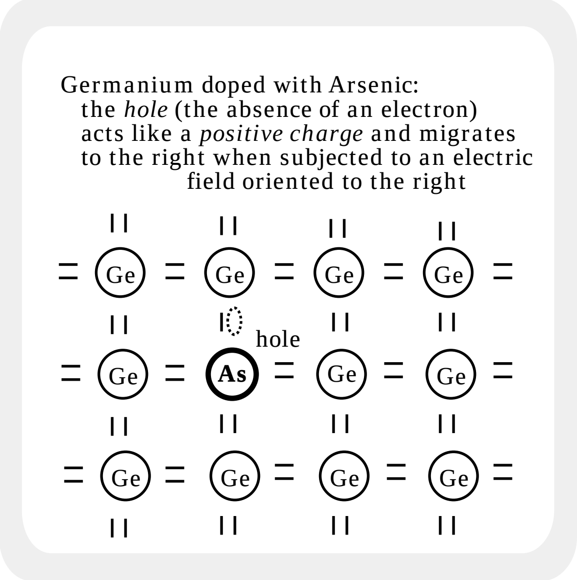


FIGURE 21.3a

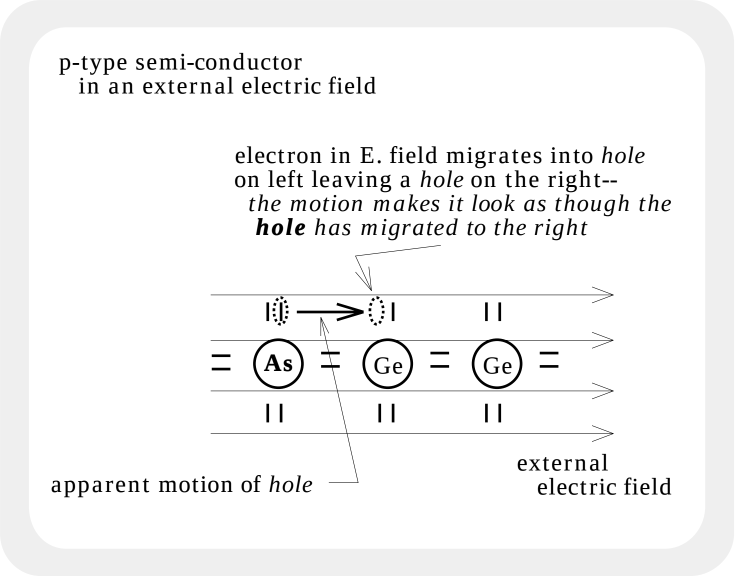


FIGURE 21.3b

In other words, there is a hole where an electron should be (see Figure 21.3a).

b.) Placing a small electric field across this structure (Figure 21.3b) motivates electrons from neighboring atoms to migrate up-field into the vacancies.

c.) When an electron leaves a Germanium atom to fill a hole, it leaves a hole of its own behind. That new vacancy makes the area around that Germanium less negative--hence, MORE POSITIVE--than otherwise would have been (there is one less electron present).

Put another way, holes act like <u>positive</u> charges in the sense that where a hole exists, the area around it is more positive than it would otherwise have been.

d.) <u>Bottom line</u>: When an electric field is applied to this kind of semi-conductor, holes move through the structure. As such, the charge carriers are called holes, they are associated with positive charge, and the material is called a p-type semi-conductor.

B.) Diodes and the Production of DC from AC:

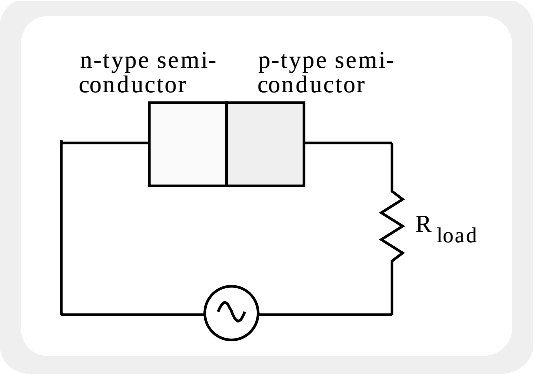


FIGURE 21.4

1.) If a p-type and an n-type semi-conductor are joined together and placed in an AC circuit as shown in Figure 21.4, the following occurs:

a.) When the <u>right terminal</u> of the power supply is positive (see Figure 21.5a on the next page), the holes in the p-type semi-conductor move to the left and the electrons in the n-type semiconductor move to the right. At the junction between the two semiconductors, the holes and electrons combine and neutralize one another.

b.) As there is no appreciable voltage drop at the junction, the entire voltage drop in the circuit occurs across the resistor. As such, the voltage versus time graph for the power supply and the voltage versus time graph for the resistor look similar, as shown in Figure 21.5a.

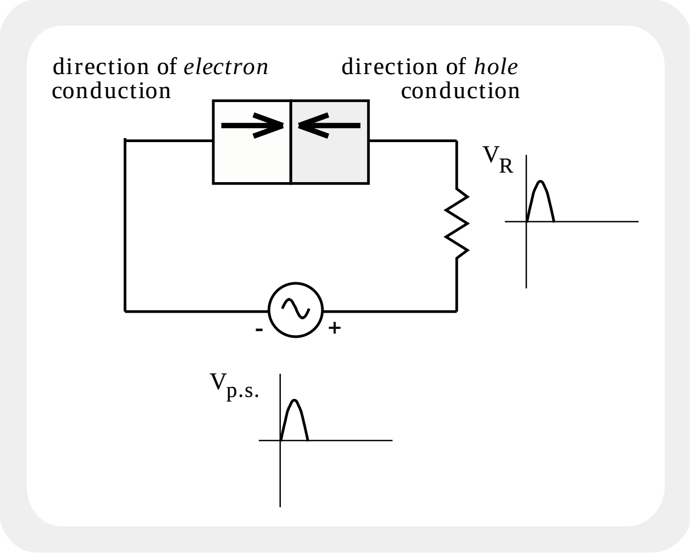


FIGURE 21.5a

The current through a resistor is proportional to the voltage across the resistor. This tells us there will be a current in the circuit for this part of the power cycle.

c.) During the second half of the power supply's power cycle, the left terminal reverses polarity and becomes positive (see Figure 21.5b). Holes in the p-type semi-conductor move to the right and electrons in the n-type semi-conductor move to the left. This separation of charge carriers (holes going one way, electrons going the other) creates a depletion zone at the junction between the two materials.

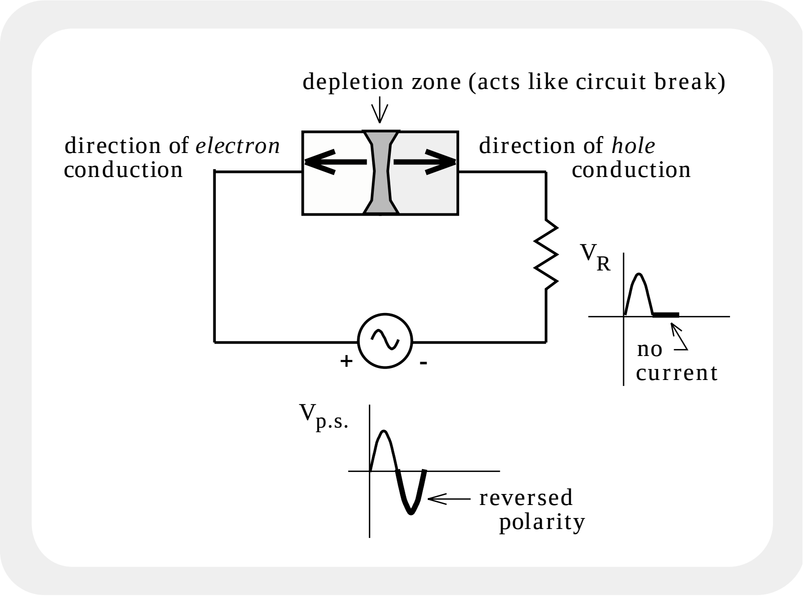


FIGURE 21.5b

d.) In this case, a large voltage drop will exist across the depletion zone with virtually no voltage drop across the resistor. That means no current flows in the circuit (remember, the voltage drop across a resistor is proportional to the current through the resistor).

Note: In simple terms, a depletion zone acts like a break in the circuit.

e.) Putting everything together, when the AC power supply exhibits one polarity, we see current in the circuit. When the polarity changes, the current stops.

f.) Bottom line: Diodes allow current to flow in one and only one direction. That is, they make DC out of AC. The graphs in Figure 21.5c summarize this.

Note 1: A reminder: In an AC circuit, charge carriers jiggle back and forth as the alternating voltage that drives them switches polarity across the power supply. In a DC circuit, on the other hand, the current flows in one direction only.

The DC generated by a single diode is lumpy, but it is still DC--current is still flowing in one direction only.

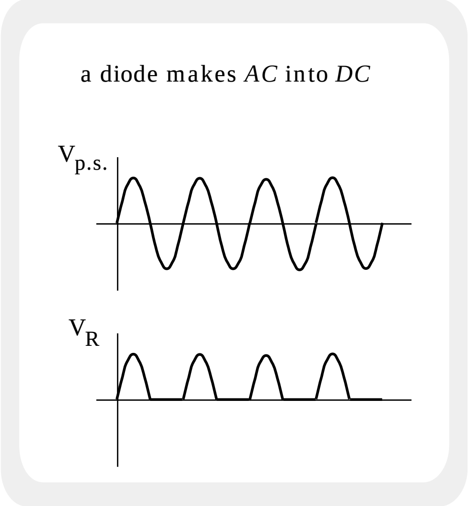


FIGURE 21.5c

Note 2: The circuit symbol for a diode is shown in Figure 21.5d. The arrow points in the direction that current (i.e., positive charge flow) can pass.

Note 3: A single diode in an AC circuit is sometimes called a half-wave rectifier because it keeps only half the AC signal as it makes DC.

2.) The Diode Bridge: DC generated by a single diode is inadequate for two reasons: 1.) current flows only during half of the power cycle (consequence--half the power available to the circuit is lost), and 2.) the DC is lumpy. To correct these problems:

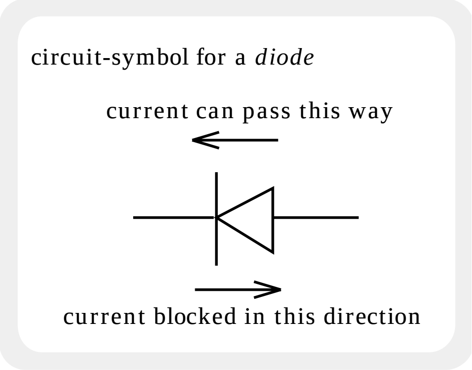


FIGURE 21.5d

a.) Consider the diode bridge and power supply shown in Figure 21.6 on the next page. With the voltage polarity such that the + terminal is on the upper side of the power source (this polarity is shown on the inside of the circuit diagram), the current in the circuit flows through the load resistor from left to right.

Note: By load resistor, we are talking about any device that requires electrical power. It could be a light bulb, a Skill saw, or a toaster. Do not be thrown by the word resistor in this context. It is simply a general term used to cover all possibilities.

b.) With the power supply polarity such that the + terminal is on the lower side of the power supply (this is shown on the outside of the circuit diagram), the current in the circuit again flows through the load resistor from left to right.

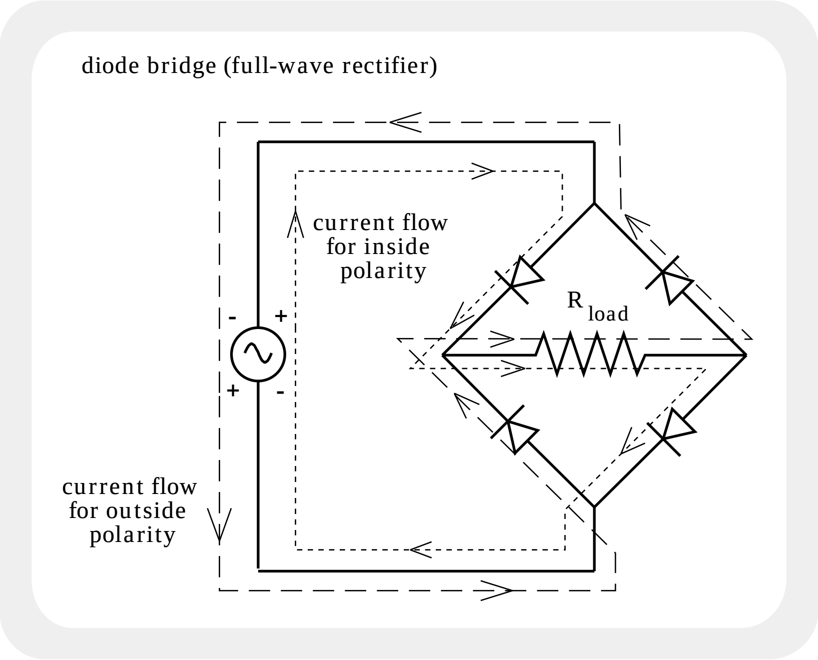


FIGURE 21.6

c.) Bottom line: Current flows through the diode bridge in the same direction no matter what.

d.) A graphical representation of both the voltage across the power supply as a function of time and the voltage across the load resistor as a function of time is shown in Figure 21.7. Notice that the voltage across the resistor is still lumpy-DC, but we are no longer losing half our power in the process.

Diode bridges that flip half an AC wave over (versus blotting half the wave out altogether) are called full wave rectifiers.

3.) To get rid of the lumpiness:

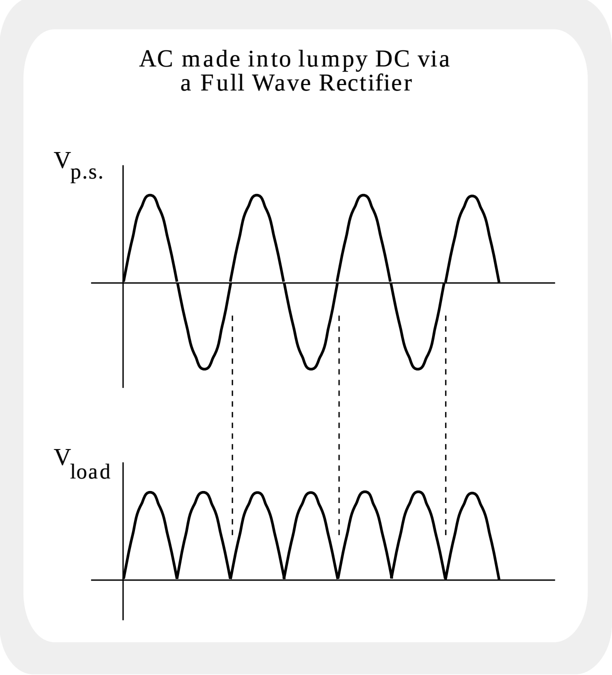


FIGURE 21.7

a.) A capacitor must be placed across the load resistor (see Figure 21.8). When the power is first turned on, the current in the circuit will rise and the capacitor will charge up. The voltage sooner or later reaches its maximum and begins to decrease. As it does, the charged capacitor begins to discharge through the load resistor.

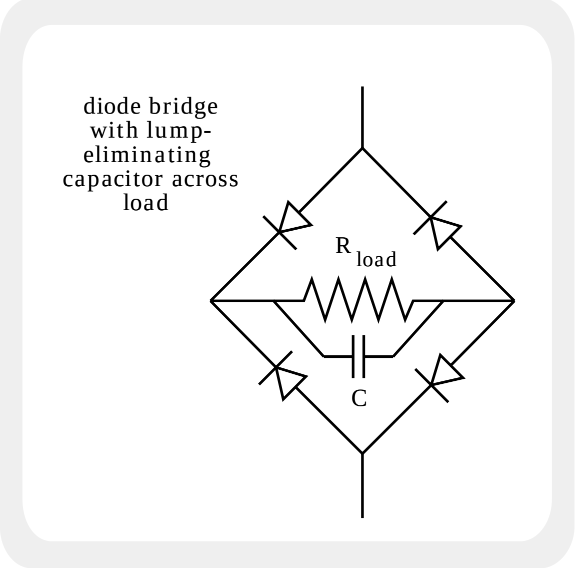


FIGURE 21.8

b.) With extra current flowing through the load resistor due to the discharging capacitor, the voltage across the load resistor stays higher than would normally be expected, dropping only slightly with time as the charge on the capacitor diminishes.

c.) After a time the power cycle returns to higher voltages whereupon the voltage across the resistor increases. At that point, the capacitor also begins to re-charge and the cycle begins all over again. A graph of the superposition of all the voltages affecting the resistor is shown in Figure 21.9.

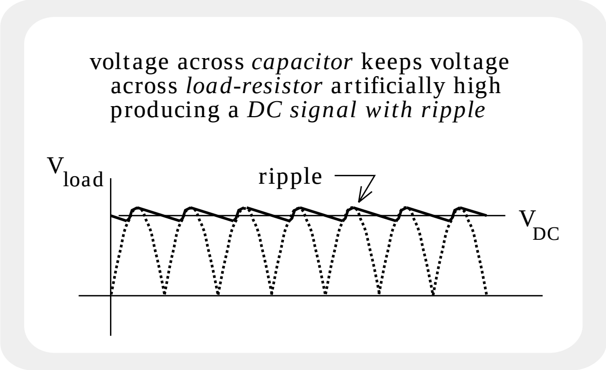


FIGURE 21.9

d.) Note that the net voltage across the load resistor shown in Figure 21.9 is not completely constant. This variation in AC generated DC is called ripple.

A good power supply will have less than 2% ripple with cheaper power supplies having ripple as large as 8%. In both cases, the variation is comparatively little--so small, in fact, that it is not normally evident even when viewed on an oscilloscope.

e.) Summary: A laboratory power supply generates DC by taking the 110 volt RMS voltage provided by the wall socket, using a transformer to step the voltage up or down depending upon the need, and passing the signal through a diode bridge (full wave rectifier) coupled with a capacitor wired in parallel to the output terminal (i.e., the terminal into which the load is to be plugged). The output DC voltage will have some ripple, but it will be relatively lumpless.

C.) Radio Circuits--Sending Stations:

Note: A simplified circuit for a radio sending unit is shown in Figure 21.10. A discussion of its workings is presented below:

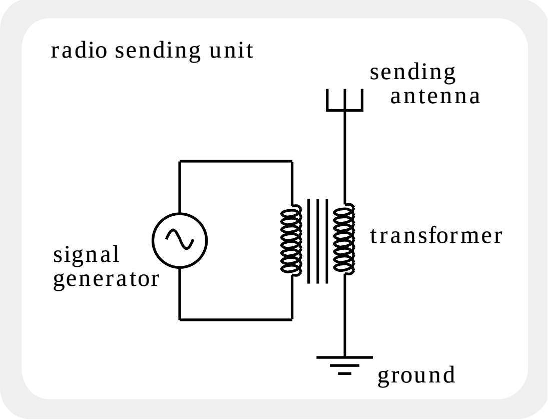


FIGURE 21.10

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.

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 $3x10^8$ meters per second--the speed of light.

Note 1: Both light and radio waves are electromagnetic waves. The only structural difference between the two are their frequencies. Optical light has a frequency range between 4.3×10^{14} hertz and 7.5×10^{14} hertz while radio radiation has a frequency range between $.5 \times 10^{6}$ hertz and 1.7×10^{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 $98 \times 10 \times 10^{3}$ 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 21.11.

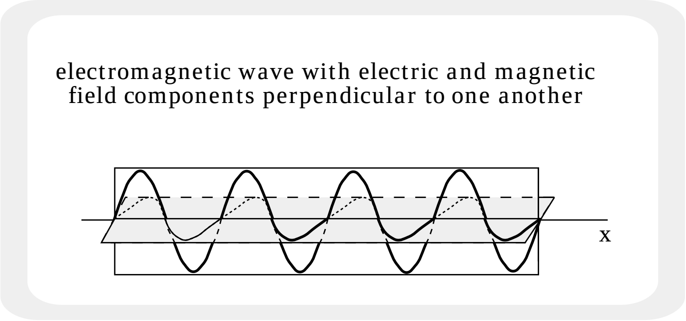


FIGURE 21.11

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.

D.) Radio Circuits--the Receiving End:

Note: The circuit for a simple AM radio is shown in Figure 21.12. A discussion of 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. <u>Bottom line</u>: The electromagnetic wave allows us to trans-

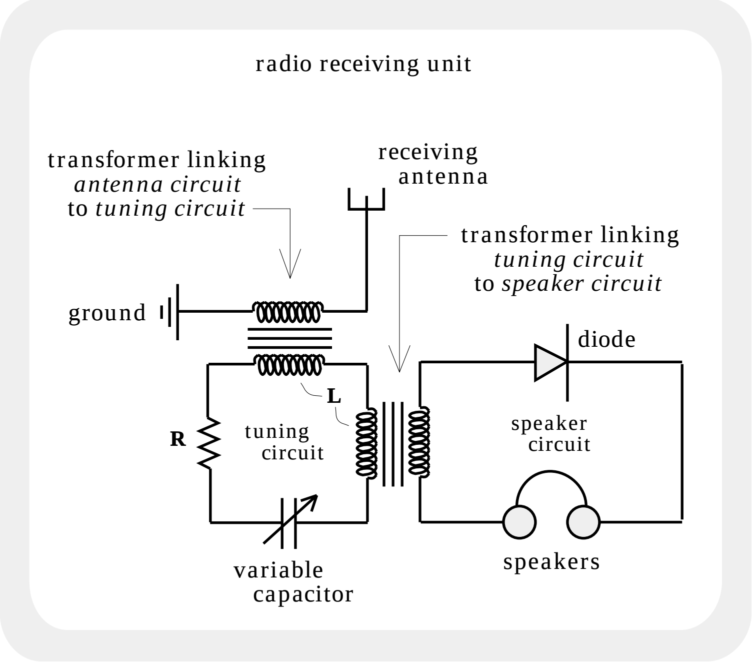


FIGURE 21.12

fer 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, consider the tuning circuit.

3.) A transformer is used to transfer signals picked up by the antenna from the antenna circuit to what is generally called the tuner circuit. The basis for the tuner circuit is as follows:

a.) From the last chapter, 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. If you will remember, 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. The signal will be transferred via the transformer from the antenna circuit to the tuner circuit where it will die. Why? Because the signal will be out of step with the natural charge/discharge pattern of the (R)LC combination in the circuit (if this is not clear, go back to the end of the AC Circuits chapter and re-read the Note concerning "what is really happening with ν_{res}").

On the other hand, a signal that has exactly the same frequency as the (R)LC's natural frequency will build freely within the tuner circuit. In other words, the tuner circuit effectively selects one frequency that will flourish while damping out all others.

By varying the capacitance of the capacitor in the tuner circuit (the capacitor symbol in Figure 21.12 is that of a variable capacitor), the natural frequency of the tuner current changes and different stations can be "tuned in."

c.) <u>Bottom line</u>: 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.

4.) 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 21.13a shows both waves).

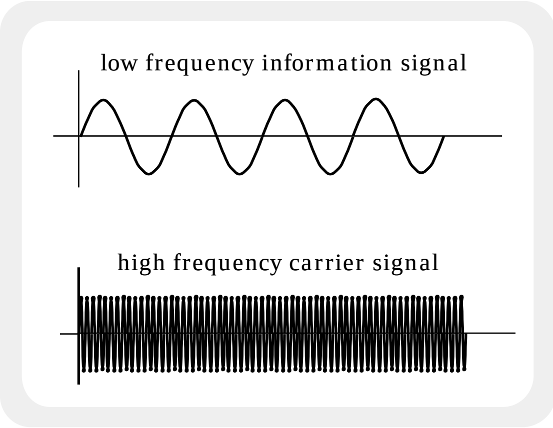


FIGURE 21.13a

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.

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:

i.) As has already been pointed out, Figure 21.13a shows both the low frequency information signal (the 256 hertz middle C sine wave) and the station's high-frequency carrier wave;

ii.) Figure 21.13b shows the station's carrier-wave amplitude modulated so as to conform to the outline of the information-signal.

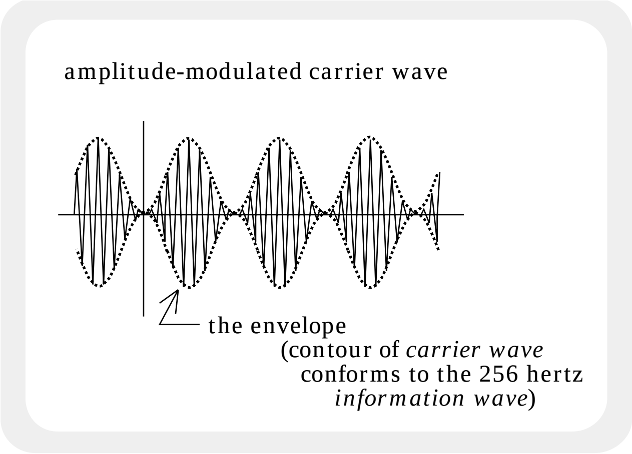


FIGURE 21.13b

c.) 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 21.14.

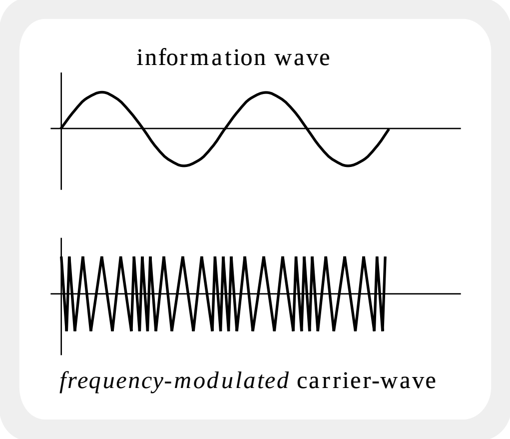


FIGURE 21.14

5.) Speakers: As shown in Figure 21.15, 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).

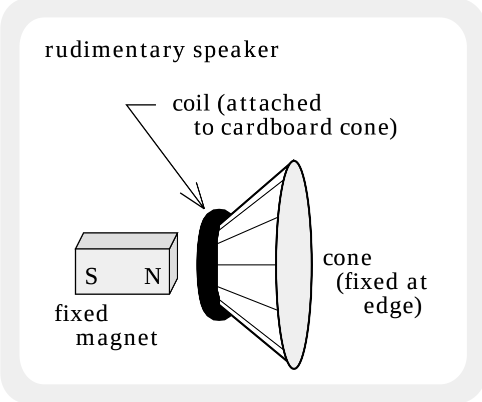


FIGURE 21.15

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

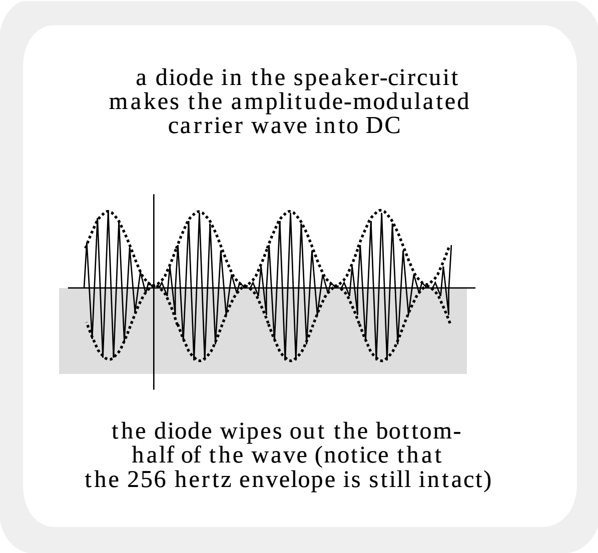
c.) The AC polarity changes. The current in the coil flows in the opposite direction. The current in the coil now makes the cone-side of the coil into a North Pole and the magnet-side of the coil into a South Pole. At that instant, the magnet's North Pole and the coil's magnetic field will attract, pulling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

d.) As the current in the coil alternates at the power source frequency, the <u>cone</u> 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 21.12) turns the high frequency AC signal into a DC signal (see Figure 21.16). 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:


a diode in the speaker-circuit makes the amplitude-modulated carrier wave into DC

the diode wipes out the bottom-half of the wave (notice that the 256 hertz envelope is still intact)

FIGURE 21.16

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 <u>speaker</u>, coupled with a diode, has acted as a decoder.

E.) 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.

F.) Amplification:

1.) The radio receiver circuit shown in Figure 21.12 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.

2.) The semi-conductor arrangement shown in Figure 21.17 is essentially that of two diodes back-to-back. Called a transistor, the arrangement will not pass current in either direction.

Why? Given the polarity shown in the sketch, the electrons in the n-type semi-conductors will move to the right and the positive holes in the p-type semi-conductor will move to the left. That means electrons and holes will combine across the left semi-conductor junction, but a depletion zone will be created along the right junction. The depletion zone acts like a break in the circuit, stopping current from flowing altogether. The exact opposite will occur when the power supply polarity changes--in that case the depletion zone will be along the left junction.

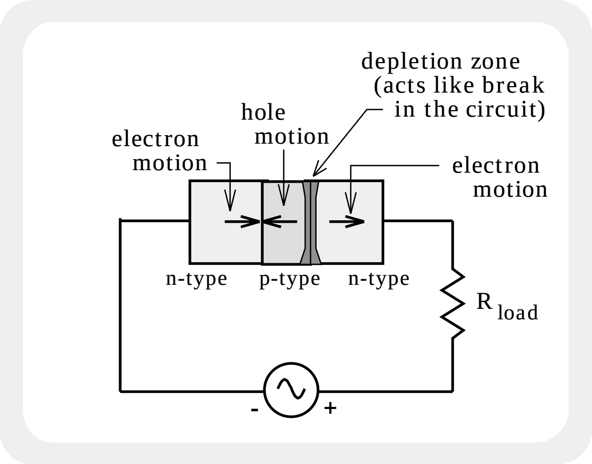


FIGURE 21.17

3.) As unlikely as it might seem, clever manipulation of this device will create a circuit that acts like an amplifier.

4.) Figure 21.18a 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.

a.) What happens when the base is made positive?

b.) In Figure 21.18b (next page), the base has been made positive. Holes near and to the right of the base-connection in the p-type semi-conductor will

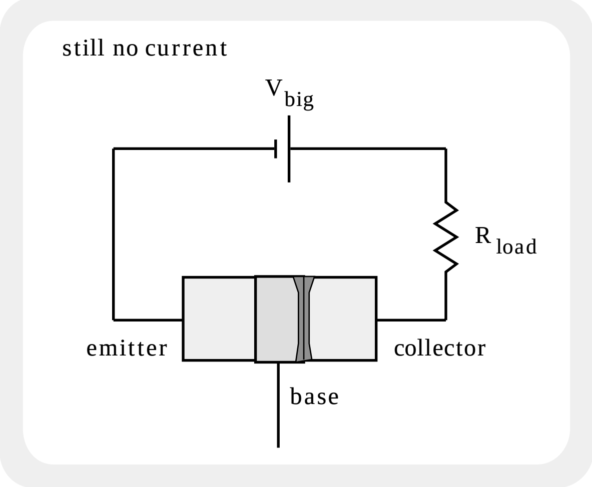


FIGURE 21.18a

be repulsed by the positive base and will migrate to the right. Electrons near the base in the right-side n-type semiconductor will be attracted to the positive base and will migrate toward the left. The holes and electrons will meet at the junction and the depletion zone will be compromised.

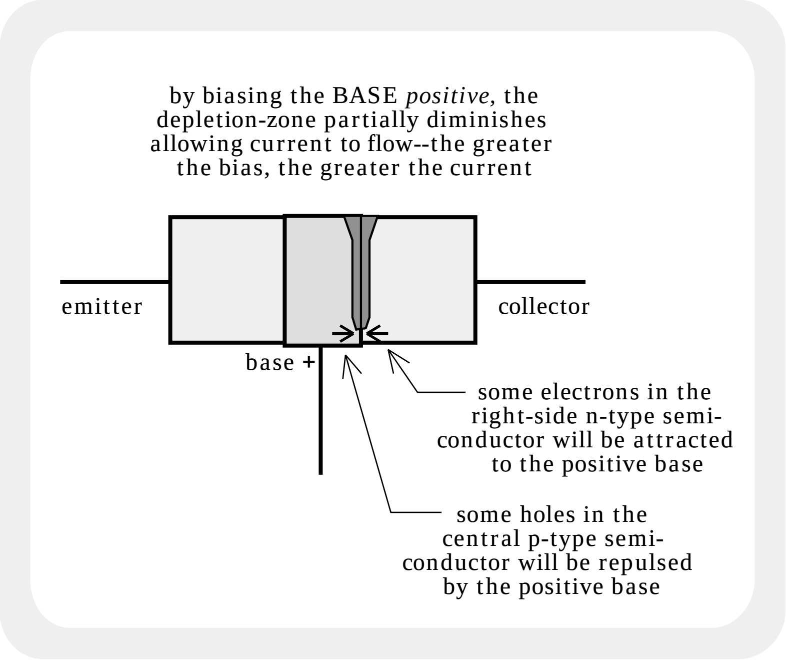


FIGURE 21.18b

c.) 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. 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-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 21.18c on the next page.

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

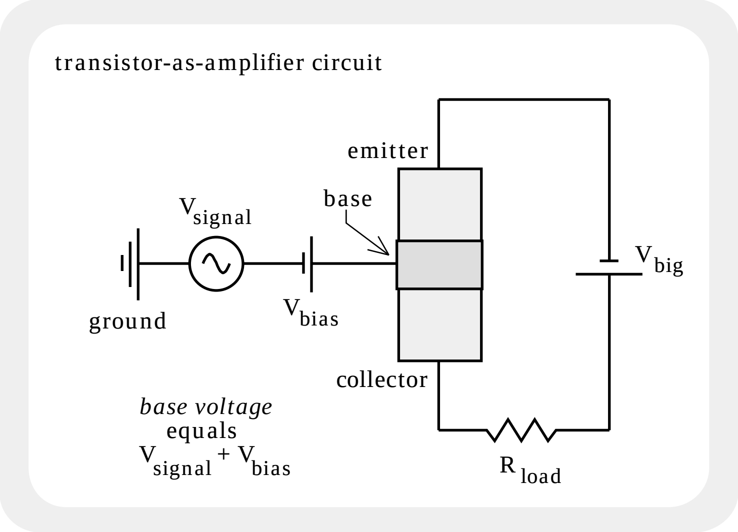


FIGURE 21.18c

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). V_b is made greater than V_s making the base voltage (the sum of V_b and V_s) always positive (if this is not clear, look at Figure 21.18d--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}, as well as the net voltage across the load resistor V_R, are all shown in the sketch).

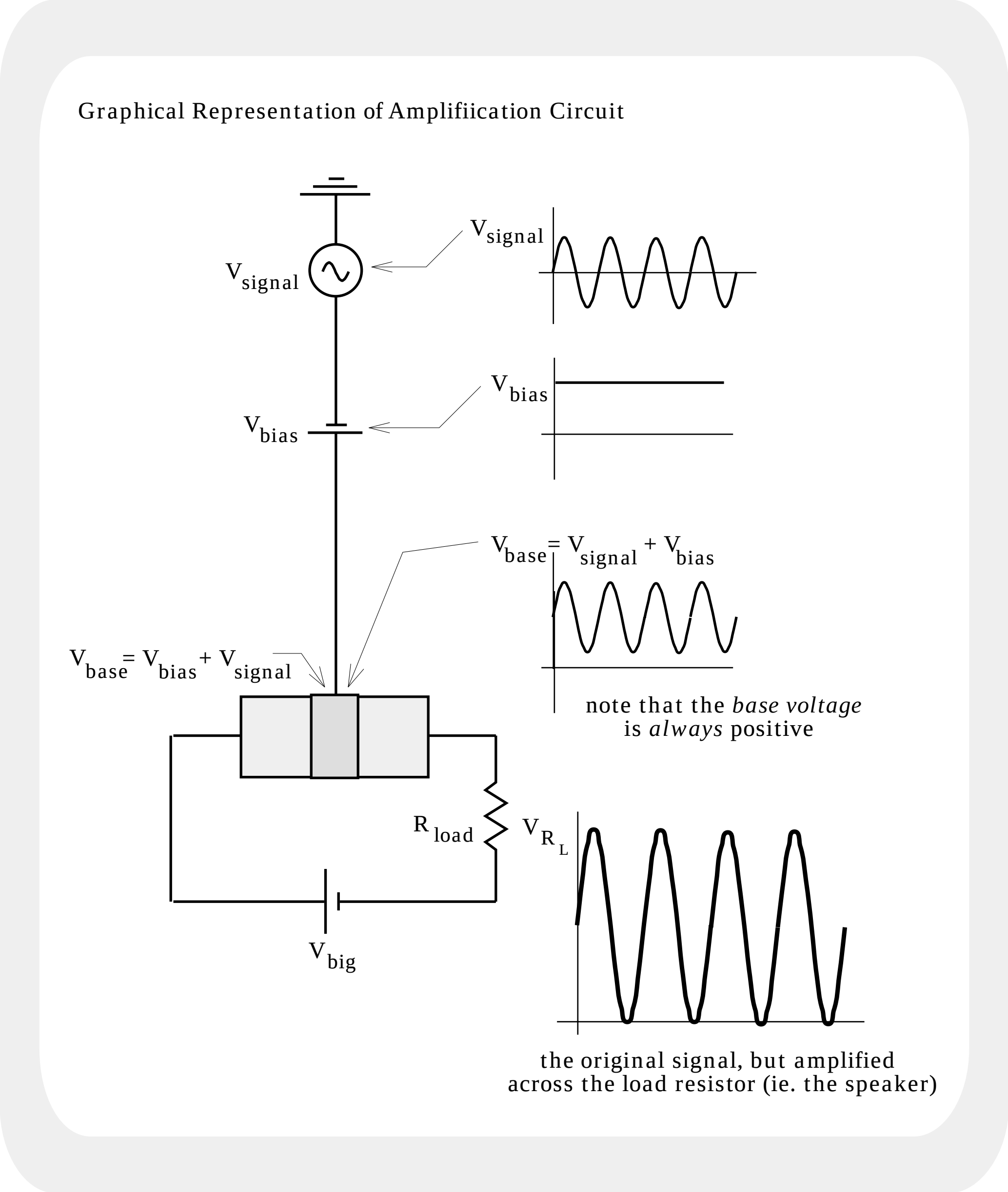


FIGURE 21.18d

c.) Examining those graphs tells the story. 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.

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.

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

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

6.) This type of transistor is called an n-p-n transistor--"n-p-n" because its structure looks like a p-type semi-conductor sandwiched between two n-type semi-conductors. Its symbol is shown in Figure 21.19.

Note: We could as well have made our transistor a p-n-p type (the symbol for a p-n-p transistor is the same as shown in Figure 21.19 but with the arrow pointing in the opposite direction). The final setup for the amplifier circuit would have been a little different, but the end result would have been the same.

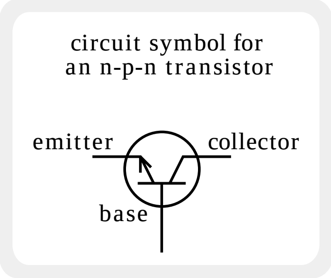


FIGURE 21.19

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 (see Figure 21.20a). 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.

Note 1: If you will remember, a diode in the speaker circuit does two things: it exposes the

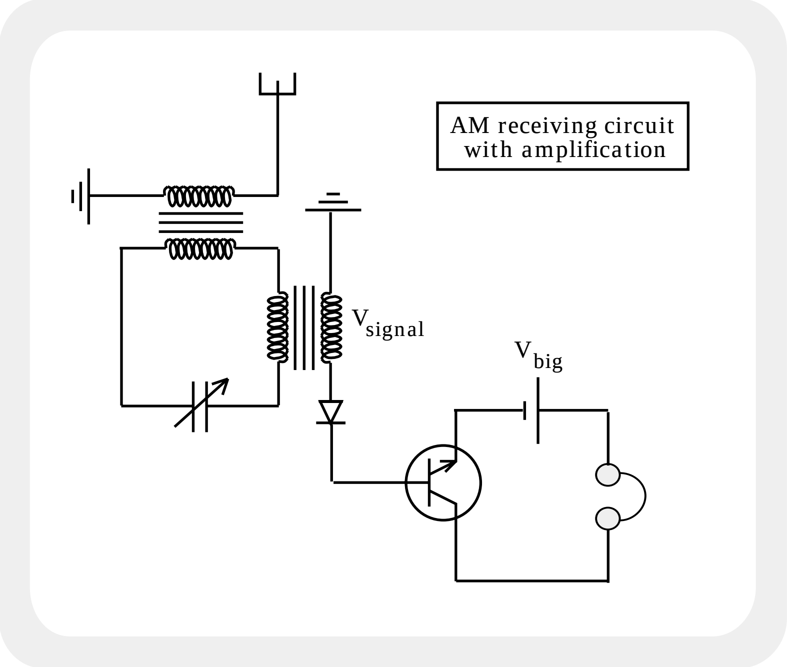


FIGURE 21.20a

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 21.20b. 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.

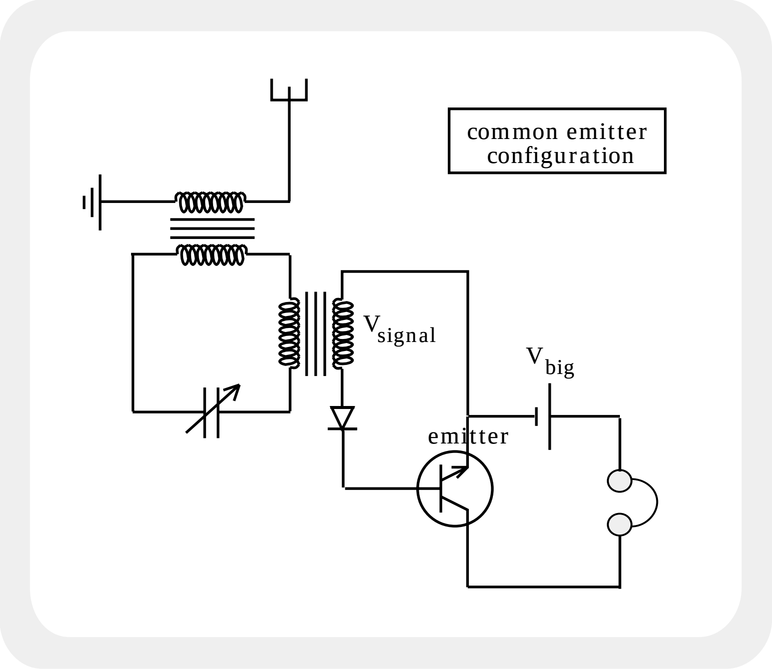


FIGURE 21.20b

QUESTIONS

There are no quantitative problems to be solved in this chapter as the chapter is predominantly a qualitative discussion of the radio. In studying for the radio part of the test, you should be able to concisely explain the following:

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)?