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ABSTRACT

This instructional guide, intended for student use, develops the subject of radio receivers through a series of sequential activities. A technical development of the subject is pursued with examples stressing practical aspects of the concepts. Included in the minicourse are: (1) the rationale, (2) terminal behavioral objectives, (3) enabling behavioral objectives, (4) activities, (5) resource packages, and (6) evaluation materials. Components of radio receivers are constructed by students. This unit is one of twelve intended for use in the second year of a two year vocationally oriented physics program. (CP)

CAREER ORIENTED PRE-TECHNICAL PHYSICS

Radio Receivers

Minicourse

1974-75

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RADIO RECEIVERS

MINICOURSE

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Bellaire, Texas

1974

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RADIO RECEIVERS

MINICOURSE

Rationale:

This minicourse is designed to test your interest in electronics by building a radio receiver and to help you understand the basic principles of radio receivers.

The basic principles of radio are rather simple. A radio transmitter emits energy in the form of an electromagnetic wave upon which sound wave frequencies of voice or music have been imposed. The initial electromagnetic wave is called the carrier wave. Some of the energy of the transmitted wave is induced in the antenna of the radio receiver. The radio circuit "separates" the sound frequency from the carrier and amplifies this signal which is now a weak pulsating electric current. The speaker transforms this weak electric current into a sound wave again.

In this course you will build a simple radio receiver using vacuum tubes and make it work.

In doing this, you will learn:

(1) what electromagnetic waves are.
(2) how an antenna "picks-up" the electromagnetic wave (the signal).
(3) what resonance is and how a radio receiver is made resonant with an incoming signal.
(4) how the signal is introduced into the receiver circuit.
(5) how vacuum tubes work and what they are used for in receivers.
(6) how transistors work and what they are used for in receivers.
(7) how receivers separate the information (sound) from the carrier wave.
(8) how the receiver amplifies the information.
(9) how speakers work.

In addition you will build a simple radio receiver using transistors.

TERMINAL BEHAVIORAL OBJECTIVE

Upon completion of this minicourse, you will demonstrate your knowledge and skill in radio by;

(a) building a simple transistor radio receiver and demonstrating that it works by tuning in at least two radio stations.

(b) correctly explaining how the radio operates starting with the antenna and working through each component to the speaker.

BEHAVIORAL OBJECTIVE No. 1 Lets find out where you are and get started.	ACTIVITY # 1-1 Read Resource # 1-1 and discuss this with your teacher.	RESOURCE PACKAGE # 1-1
BEHAVIORAL OBJECTIVE # 2 You will construct an antenna for radio receiver.	ACTIVITY # 2-1 Read Resource # 2-1 and erect your antenna.	RESOURCE PACKAGE # 2-1
BEHAVIORAL OBJECTIVE # 3 You will, on completion of this activity, correctly define an electromagnetic wave (radiation).	ACTIVITY # 3-1 If you and your teacher agreed in activity 1-1, you may go on to Activity 5. If not, read Resource 3-1.1 and 3-1.2 and complete experiments 1 & 2.	RESOURCE PACKAGE # 3-1.1
BEHAVIORAL OBJECTIVE # 4 You will, upon completion of this activity, correctly explain the relationship between the electric and the magnetic components of an electro-magnetic wave and the direction of propagation.	ACTIVITY # 3-1.1 Read Resource # 3-1.1	RESOURCE PACKAGE # 3-1.1
	ACTIVITY # 3-1.2 Read the selected readings listed in Resource Package # 3-1.2	RESOURCE PACKAGE # 3-1.2

BEHAVIORAL OBJECTIVE	ACTIVITY	RESOURCE PACKAGE
BEHAVIORAL OBJECTIVE # 5 You will, upon completion of this activity, correctly calculate the length of a dipole antenna to be resonant at a given frequency.	**ACTIVITY # 5-1** Read Resource Package # 5-1.1	**RESOURCE PACKAGE # 5-1.1**
	ACTIVITY # 5-1.2 Read the selected readings listed in Resource Package # 5-1.2	**RESOURCE PACKAGE # 5-1.2**
BEHAVIORAL OBJECTIVE # 6 You will build the power supply circuit of a radio receiver and satisfactorily explain how it converts a.c. line current into a d.c. current.	**ACTIVITY # 6-1** Build the power supply circuit.	**RESOURCE PACKAGE # 6-1** 1 K-50 Kit for 5 tube superhetrodyne radio receiver. * Note: If the K-50 Kit is not available, the same circuit, parts list and circuit description is found on pg. 673 of the RCA Receiving Tube Manual, 1973, RC - 29
	ACTIVITY # 6-2 Read Resource 6-2	**RESOURCE PACKAGE # 6-2**
	ACTIVITY # 6-3 Read the selected readings listed in Resource Package # 6-3	**RESOURCE PACKAGE # 6-3**

*Kit K-50, 5 Tube Superhetrodyne Radio Receiver, STUCTA-KIT Co., 1407 Industrial Blvd. Elk River, Minn.

BEHAVIORAL OBJECTIVE # 7 You will assemble the Pentagrid Circuit of the radio receiver and explain satisfactorily what its function is and how it accomplishes this.	ACTIVITY # 7-1 Assemble the converter circuit.	RESOURCE PACKAGE # 7-1 K-50 Radio Receiver Kit
	ACTIVITY # 7-1.2 Read Resource # 7-1.1	RESOURCE PACKAGE # 7-1
	ACTIVITY # 7-2 Read the selected readings listed in Resource Package 7-2.	RESOURCE PACKAGE # 7-2
BEHAVIORAL OBJECTIVE # 8 You will assemble the i.f. amplifier circuit of the radio receiver and satisfactorily explain what its function is and how it accomplishes this.	ACTIVITY # 8-1.1 Assemble the i.f. amplifier circuit.	K-50 Radio Receiver Kit
	ACTIVITY # 8-1.2 Read Resource 8-1.2	RESOURCE PACKAGE # 8-1
	ACTIVITY # 8-2 Read the selected readings listed in Resource Package 8-2.	RESOURCE PACKAGE # 8-2
BEHAVIORAL OBJECTIVES # 9 You will assemble the diode detector-audio amplifier circuit and satisfactorily explain what its function is and how it accomplishes this.	ACTIVITY # 9-1.1 Assemble the detector circuit.	K-50 Radio Receiver Kit
	ACTIVITIES # 9-1.2 & 9-1.3 Read Resource # 9-1	RESOURCE PACKAGE # 9-1
	ACTIVITY # 9-2 Read the selected readings listed in Resource Package # 9-2	RESOURCE PACKAGE # 9-2

BEHAVIORAL OBJECTIVE # 10 You will assemble the Power Amplifier and Speaker circuits and will satisfactorily explain what the function of each is and how they accomplish their function.	ACTIVITY # 10-1.1 Assemble the power, amplifier and speaker circuits of the radio. ACTIVITY 10-1.2 & 10-1.3 Read Resource 10-1.2 & 10-1.3 ACTIVITY 10-1.4 Enjoy the radio.	K-50 Radio Receiver Kit RESOURCE PACKAGE # 10-1
BEHAVIORAL OBJECTIVE # 11 You will make the measurements on your radio circuit and correctly explain the significance of each.	ACTIVITY # 11-1 Read Resource # 11-1 and make the measurements indicated.	RESOURCE PACKAGE # 11-1
BEHAVIORAL OBJECTIVE # 12 You will correctly explain how diodes rectify an a.c. current, how transistors amplify signals and how transistors detect signals.	ACTIVITY # 12-1.1 Read activity # 12.1.1 ACTIVITY 12-1.2 Visit an Electronics Shop ACTIVITY # 12-2 Read the selected readings listed in Resource #12-2.	RESOURCE PACKAGE # 12.1 RESOURCE PACKAGE # 12.1 RESOURCE PACKAGE # 12-2
BEHAVIORAL OBJECTIVE # 13 You will build a transistorized superhetrodyne radio receiver and will satisfactorily explain how the circuits of this radio compare in function to those of the vacuum tube receiver you built.	ACTIVITY # 13-1 Build a transistorized radio receiver after discussion with your teacher.	Transistorized Radio Rec. Heathkit # GR-1008 The Heath Company Benton Harbor, Mich., 49022

RESOURCE # 1-1

ACTIVITY # 1 Let's build a radio receiver.

We will start building the radio receiver by constructing the antenna. You surely have some idea as to what an antenna is and how it functions. Right! Let's see what you know or can figure out.

From time to time during this minicourse, you will be asked to record your ideas, assumptions and some measurements in your notebook. Have a spiral bound notebook for this purpose and use it. It will serve as a reference for you later on.

For the following questions, answer in your notebook, what you already know and speculate freely. Please write your answers in your notebook for future reference and discuss them with your teacher.

1. Make a list of materials you think that you will need to build the antenna.
2. How do you suppose the sound of voice or music is transmitted from one location to so many distant places as radio programs are?
3. For the antenna you have planned, have you given any consideration to the length?
4. How long should an antenna be?
5. To what should the length of the antenna be related to?
6. A radio receiver must have some "signal" from which to reproduce sound. How in the world does an antenna wire strung in the air get the radio signal?

If you know the answers to each of these questions and understand the principles involved, you probably do not need to complete this activity.

Discuss these with your teacher before proceeding. If you and your teacher are satisfied with your present knowledge, erect your antenna (see below) then go on to Activity #5 on page No. 17. If not, continue the activities in sequence.

Teacher Check [ ]

RESOURCE # 2-1

ACTIVITY 2-1 Erect an Antenna.

To erect an antenna you will need the following:

2 insullators, strain egg insullators are fine, 2 to 3 inches long, glass or porcelain.

2 poles or other means of mounting the antenna outside. The antenna may be on the roof of a building BUT tying the antenna to tree limbs is NOT advisable since the limbs sway in the wind.

21 feet of copper antenna wire, Solid No. 12 copper wire or stranded copper wire are both fine.

- Sufficient copper or galvanized wire to reach from the ends of the antenna wire to the support poles.
- Sufficient insulated copper wire to reach from one end of the antenna wire (after it is mounted) to the receiver location.

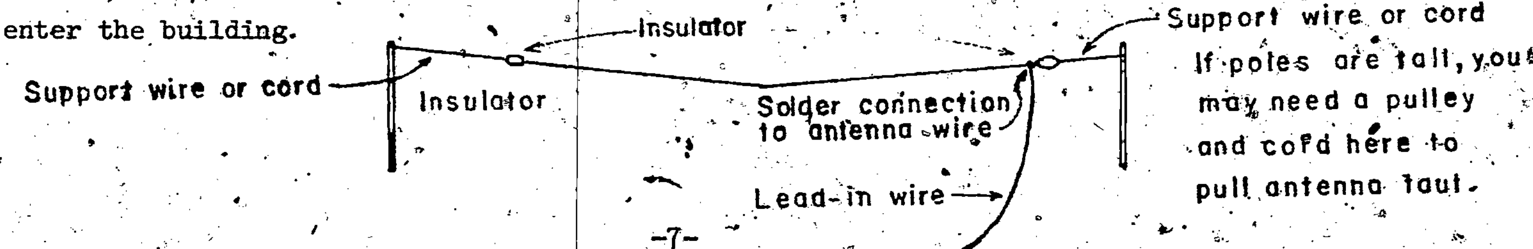
Tools required:

Pliers, knife, soldering iron, rosin core solder and those necessary to mount the support poles.

Procedure

- The antenna should be reasonably high above the ground, 15 - 20 ft., and clear of obstacles such as other buildings, trees, power lines, etc. Mounting the antenna on the roof of a building is usually good.
- Mount the antenna support poles approx. 30 ft. apart and mount the antenna as shown in the sketch below.

Before mounting the antenna, solder one end of the insulated lead-in wire to one end of the the antenna wire. This should be the end nearest the point where the antenna lead-in wire will enter the building.



EXPERIMENT # 3

Purpose: To determine the current in the antenna.

Apparatus: 1 - multitester with very low range a.c. volts and a.c. amperes scales.

CAUTION:

Instruments for measuring electrical properties are delicate and may be damaged easily if used improperly.

WHEN USING A VOLTMETER OR AMMETER, ALWAYS TEST TO BE SURE THAT THE POLARITY OF THE METER IS RIGHT AND THAT THE METER IS NOT OVERRANGED. TEST BY "TAPPING" LIGHTLY AND QUICKLY THE LAST CONNECTION IN THE CIRCUIT. IF THE NEEDLE MOVES THE WRONG DIRECTION, REVERSE THE BATTERY CONNECTIONS. IF THE METER IS OVERRANGED, SELECT A HIGHER READING SCALE OR ANOTHER HIGHER READING INSTRUMENT.

Procedure: Set your multitester on the lowest a.c. volt scale (1-3 volts). Connect the end of the antenna lead-in wire (bare wire) to one instrument lead then tap the other instrument lead to a good ground connection; water pipes are a good ground. Be sure that the pipe is clean, that is, with bright metal showing where you tap it. Repeat with the meter set on the lowest a.c. ampere scale.

Observe and record the meter readings in your notebook.

RESOURCE #3-1.1 RADIO WAVES

ACTIVITY # 3-1

Sound waves lose so much energy as they travel through any transmitting medium they cannot be heard at great distances. Light waves on the other hand do not lose much energy as they travel and light can be seen at great distances. Light waves are one of what we call electromagnetic waves, they and radio waves, are part of the electromagnetic spectrum. See Fig. 1.

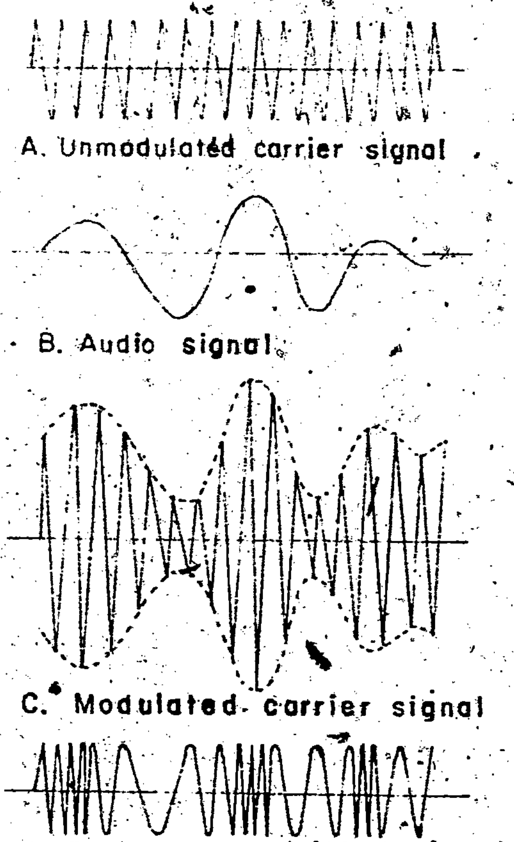
Ray	Electric Rays	Radio	Infrared	Visible	Ultraviolet	X-Rays	Gamma Rays	Cosmic Rays
Source	Produced by Electric Generators	Radio Transmitters	Sun & Heat Sources	Sun-Lights	Sun & UV Lamps	X-Ray Machines	Emitted by Some Radio-Active Elements & Nuclear Reactions	From Space
Wave Length	3×10^{17} Å 3×10^{7} m Very Long	——→ Decreasing Wave Length ——→					3×10^{-7} Å Very Short	
Frequency	Very Low	——→ Increasing Frequency ——→					Very High	
Energy	Very Low	——→ Increasing Energy ——→					Very High	

NOTE: 1 Å = 1×10^{-10} m.

FIG. 1

The basic principle of radio is to impose sound waves on an electromagnetic (radio) wave and let the radio wave "piggyback" the sound wave to the radio receiver where the sound wave component is "separated" and reproduced as a sound wave. Actually the sound wave is converted into a weak electric current which is imposed on the radio wave.

Let's examine for a moment how this works. The radio wave is a wave of fixed single frequency and a wave diagram of it is shown in Fig. 2 A. The frequency of sound waves (voice and music) vary as you know and these same frequencies appear in the weak electric current generated by speaking into the microphone. The amplitude of such a current is represented in the wave diagram in Fig. 2 B. When the sound signal is imposed on the radio wave, it is done in such a manner as to have the sound signal add to and subtract from the amplitude of the radio wave. Since the imposed sound signal alters the amplitude of the radio wave, this process is called "amplitude modulation" or AM. The wave diagram of an AM wave is shown in Fig. 2 C.



A. Unmodulated carrier signal

B. Audio signal

C. Modulated carrier signal

D. Frequency modulated signal

Fig 2

Sound signals may also be combined with radio waves in such a manner as to modulate the frequency of the radio wave. The resulting wave is called "frequency modulation" or FM. A frequency modulated wave is shown in Fig. 2 D.

From the above you see that we should begin our study of radio by examining the properties of electromagnetic waves. If you are going to understand radio operation, you should understand the means by which the signal reaches the radio. The following labs will help you to understand some of the relationships involved.

Now do these two lab experiments, but before you do, a word of caution.

CAUTION AGAIN

Instruments for measuring electrical properties are delicate and may be damaged easily if used improperly.

WHEN USING A VOLTMETER OR AMMETER ALWAYS TEST TO BE SURE THAT THE POLARITY OF THE METER IS RIGHT AND THAT THE METER IS NOT OVERRANGED. TEST BY "TAPPING" LIGHTLY AND QUICKLY THE LAST CONNECTION IN THE CIRCUIT. IF THE NEEDLE MOVES THE WRONG DIRECTION, REVERSE THE BATTERY CONNECTIONS. IF THE METER IS OVERRANGED, SELECT A HIGHER READING SCALE OR ANOTHER HIGHER READING INSTRUMENT.

If you have not done these experiments previously, do them now. Write these up in your notebook.

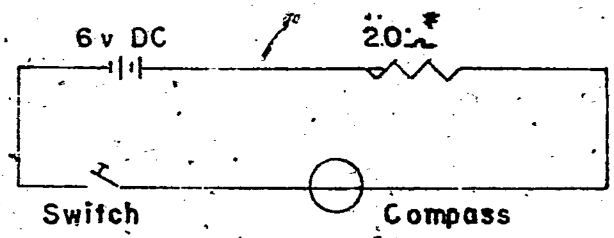
EXPERIMENT 1. Current-Magnetic Fields - Motion.

Purpose: To demonstrate the relationships between electric current (electric charge), magnetic fields and motion.

Apparatus: One galvanometer, 2 bar magnets, 1 6v battery, 1 - 20 * ohm resistor, 1 compass, 1 knife switch and several lengths of copper wire (bell wire).

Introduction: In this experiment, you will observe and report on the relationship between electric current (electric charge), a magnetic field and motion.

Procedure 1. Connect the circuit as shown in the following diagram.



Orient the setup such that the compass needle is pointing to the north and so that the wire

* This resistance should be adjusted to give a very definite movement of the needle.

is directly over the needle. Close the switch momentarily and observe.

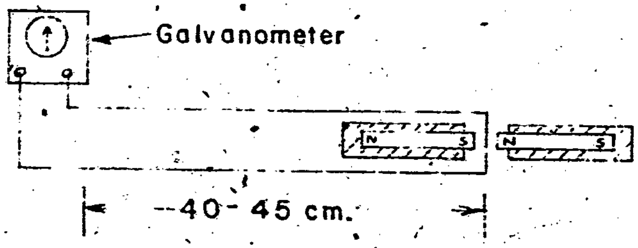
Now reverse the wire leads to the battery. This will cause the current to flow in the opposite direction. Close the switch momentarily and observe.

Orient the setup such that the wire is at right angles to the compass needle when the switch is open. Close the switch momentarily and observe.

Assumptions: Write the assumptions or conclusions you make together with the evidence to support these and turn them in to your teacher.

Teacher Check

Procedure 2. Connect the circuit as shown in the following diagram. You will need a helper for this procedure.



Bar magnets supported 1" - 2" above table top by wooden blocks and the magnets should be separated by a distance of 1.5 - 2 cm.

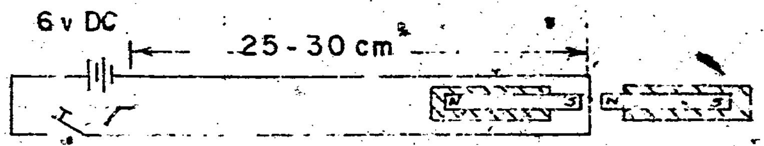
The wire should be shaped as shown so that it will pass between the ends of the magnets. Grasp the wires between the magnets and the galvanometer with one hand on each wire. With a fast motion, pass the wire <u>downward</u> between the two magnets. Your helper should observe the galvanometer as you pass the wire between the magnets.

Repeat except pass the wire <u>upward</u> between the magnets again with a fast motion.

Assumptions: Write assumptions or conclusions you make together with the evidence to support these and turn them in to your teacher.

Teacher Check

Procedure 3 Connect the circuit as shown in the following diagram.



*25 - 35 cm of wire, horizontal or nearly so.

Close the switch momentarily and observe.

Reverse the leads on the battery and repeat.

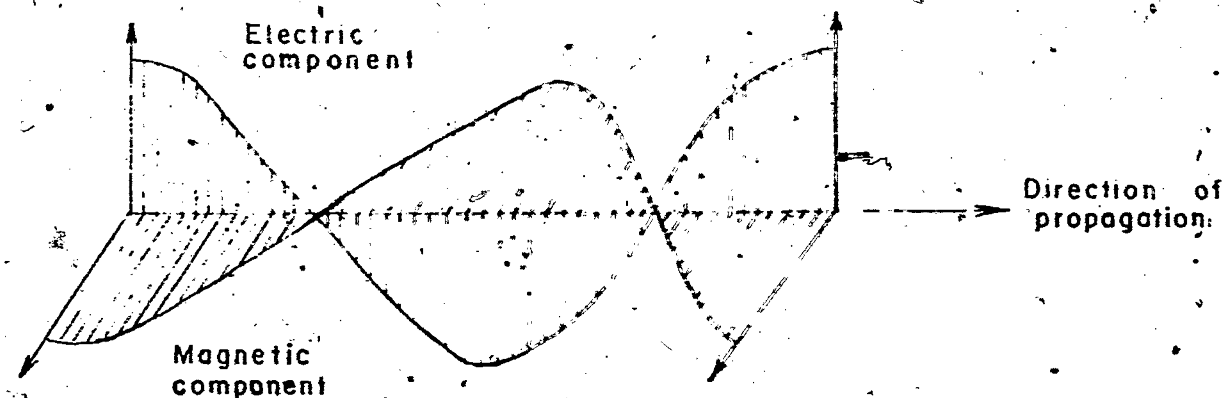
Assumptions: Write assumptions or conclusions you make together with the evidence to support these and turn them in to your teacher.

Teacher Check

A little background information is necessary here so lets look into it.

You will recall that a magnetic field is created by a current flowing in a wire and that the magnetic field is at right angles to the direction of the current flow. In fact, any moving charge creates a magnetic field and any charge, moving or not, creates an electric field about it. These two fields, the electric and the magnetic fields, are at right angles to each other and both represent stored energy. A radio transmitter feeds a high frequency (radio frequency) electric current to the antenna. As this rf current flows in the antenna some of it is radiated as energy into the atmosphere.

The electric energy radiated by an antenna (transmitter) exists in free space (atmosphere) as electromagnetic waves, called radio waves. These waves consist of a magnetic field and an electric field at right angles to each other just as the magnetic field is at right angles to the current flow in a wire. The energy, which is supplied by the transmitter, is equally divided between the two fields and is propagated in a direction at right angles to both. See Fig. 2 below. Being an electromagnetic wave, it is propagated at the speed of light.



In fact, any conductor carrying an alternating current radiates some energy as electromagnetic waves. However, the energy of the radiation is directly proportional to its frequency ie, the greater the frequency, the greater the energy of the radiation*. It turns out that the frequency of house current, 60 cycles per second (cps), the energy of the electromagnetic waves is very low. At radio frequencies, 750 to 29,000 kilocycles per second (kc per sec.), the energy is much greater. Notice however, that radio frequencies are at the low frequency end of the electromagnetic spectrum and that the waves at the higher end of the spectrum (X-ray, gamma & cosmic rays) have much higher frequencies and energies. In fact, while we do nothing to protect ourselves from radio waves, we take elaborate means to protect ourselves from the higher frequency radiations.

The following chart indicates the approximate frequency ranges for radio transmissions. The values are expressed in kilocycles per second (kc).

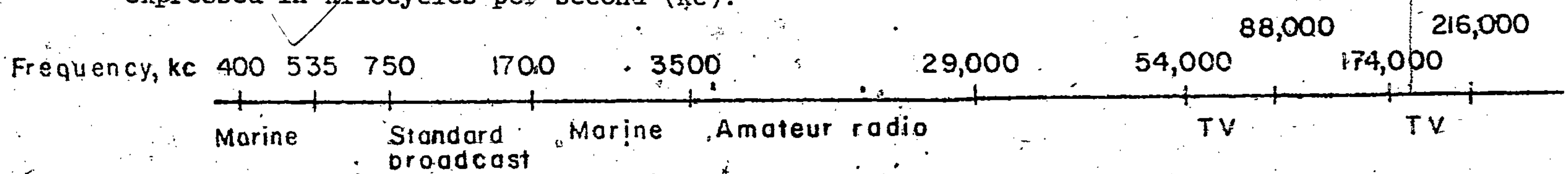


FIG 2

As we have seen, when an antenna is energized as when connected to an operating transmitter, the antenna radiates energy as electromagnetic waves. Conversely, when an antenna not connected to an operating transmitter, is exposed to radio waves, some of the rf (radio frequency) energy is induced in the antenna as the waves move past the antenna. In the receiving antenna, it will have the same frequency and wave-form as it had in the transmitting antenna. However, the induced current in the receiving antenna will be very much weaker than in the transmitting antenna. Because the induced current is weak, antenna length is often important. In the standard broadcast range of frequencies, the length of the antenna is not critical. However, as the frequency increases, the relative length of the wave and the antenna becomes critical.

* For enrichment, look up Plank's Constant and Plank's Quantum Hypothesis.

RESOURCE PACKAGE #3-1.2

Modern Physics: Dull, Metcalf, Williams   Holt, Rinehart & Winston   1964

Selected Readings

Superposition	Pages 289
The Electromagnetic Theory	331-2
The Electromagnetic Spectrum	333
The Quantum Theory	338-9
Electromagnetic Radiation	655-6
Ground & Sky Wave	657

These topics may be found in other Physics texts as well.

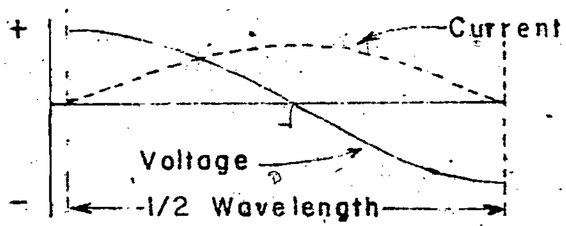
RESOURCE 5-1

The Antenna

In the last activity you found that the radio wave induced in the antenna is of the same frequency, wave length and form as the transmitted wave and that the energy of the wave (the signal) is very low; it is a weak signal. Since the signal is so weak, we must do what we can to enhance it. This is accomplished by adjusting the length of the antenna to correspond to the wave length of the desired signal. The following discussion will help you to understand the reason for this.

First obtain a standing wave generator and generate a standing wave. Or obtain a piece of light weight rope or a heavy fishing cord, 8 to 10 ft. long. Tie one end to a fixed object and generate a standing wave in the rope by vibrating the other end up and down while adjusting the tension on the rope by pulling. You may want to look up standing waves in a Physics book.

Let us assume a wire one half as long as an rf wave. The electromagnetic radio frequency wave (rf) induces an rf voltage and current in the antenna. If the wave length and the "electrical" length of the antenna are the same, a standing wave results in the antenna and resonance is established. Look at it this way. Refer to FIG.2-1 below.



For this discussion, you must set aside the idea that one must have a closed circuit in order for a current to flow. With radio frequency, a voltage or current impulse will be reflected at the end of the wire much as light is reflected by a mirror.

A system such as a standing rf wave in a wire is known as a resonant circuit although the circuit may not be closed as a lighting circuit. You should recall that the induced rf is composed of a voltage and a current component. Now suppose that we impose an rf voltage at one end of the wire. If at the instant the voltage is applied, it is at the positive peak of its cycle, the voltage at the end of the wire will be at a maximum. A voltage impulse will travel along the wire and upon reaching the end of the wire one half cycle later, two things happen:

a) the voltage impulse is reflected back along the wire, and

b) the voltage of the applied rf will be at its negative peak, since the wire is ½ wave length long.

The result of adding the voltage impulses, those travelling out and those reflected back, will be a standing wave of voltage. It is not a static wave 'per se', but will appear to be static or standing since it is the result of the outgoing and reflected voltage components. If you could measure the voltage along the wire with an rf meter, you would find the voltage to be high at the ends and practically zero at the center. Likewise, if you could measure the current along the wire, you would find it practically zero at the ends and at a maximum near the center of the wire. The current component is also reflected hence it too changes direction once each cycle.

Up to now, you have probably thought of the applied voltage as coming from an rf generator such as a transmitter. Actually, the same kind of a standing wave results from induced energy that results from electromagnetic waves passing an antenna.

The standing wave results because the antenna wire is one half wave length long electrically, hence resonance results. If the wire were significantly longer or shorter, this resonance would not result and the signal transmitted or received would not be as strong.

Now we come to calculating the length of wire that will be one half wave length electrically. First let's examine the relationship between frequency, velocity and wave length of transverse waves.

The relationship is:

velocity = wave length x frequency

$$v = f\lambda \quad \text{or} \quad \lambda = \frac{v}{f}$$

and is true for transverse waves, the consistant units for these variables are:

velocity	in	meters/sec	or	feet/sec
wave length	in	meters	or	feet
frequency	in	cycles/sec	or	cycles/sec

The speed of light & radio waves is approx. 300,000,000 meters/sec.

Calculate the wave length in meters of radio waves having the following frequencies:

900kc/sec 3,800 kc/sec 14,250 kc/sec

NOTE: One kilocycle (kc) = 1000 cycles.

Teacher Check

We make most of our measurements in feet so it would be convenient to have the formula by which we can calculate the wave length in feet. Recalling that a meter is 39.37 inches,

a) calculate the speed of light in feet per second.

Teacher Check

b) calculate the wave length of the three frequencies above in feet.

Teacher Check

The calculations we have made are valid for the rf wave travelling in free space. Since the speed of an rf wave in a wire is a little less than in free space and due to other factors, an adjustment must be made to calculate the resonant length of a dipole antenna. The formula used is:

$$\text{length of half wave antenna (feet)} = \frac{468{,}000}{\text{frequency in kc}}$$

which is the same as

$$\text{length of half wave antenna (ft)} = \frac{468}{\text{freq. Mc}}$$

1 kc = 1000 cycles; 1 Mc = 1,000,000 cycles; 1 Mc = 1000 kc.

Note that in calculating the length of the antenna, we have equated the wave length of the rf with the length of the antenna wire.

Calculate the length of a dipole antenna for the three frequencies mentioned above

Teacher Check

You can now calculate the length of a halfwave, dipole antenna for a radio receiver or transmitter.

RESOURCE PACKAGE # 5-1.2

Understanding Radio	American Radio Relay League		1963
	Selected Reading		
	Antennas & Feeders	Pages 95-96	
Modern Physics	Dull, Metcalf & Williams	Holt, Rinehart & Winston	
	Selected Reading		
	Antennas	Pages 652	
	Dipole Antennas	653	

POST ASSESSMENT

1. Write a definition of electromagnetic radiation.

2. Spacialy, electromagnetic radiation can be described using 3 mutually perpendicular planes. Which components/properties are thought of as being on these planes?

3. Arrange the following electromagnetic waves in order of descending energy.

   a) 14,250 kc. b) 1500 kc. c) 750 kc. d) 28,650 kc. e) light.

4. Calculate the length of the wire necessary to form a resonant dipole antenna for radio waves of:

   a) 14,300 kc. b) 920 kc.

5. Where is the energy thought of as being stored in an electromagnetic wave? How is it divided?

RESOURCE # 6-1

ACTIVITY # 6-1

Now you are ready to start building the radio itself. All radios that operate on house current (115 v, 60 cycle) must have a power supply to change the 115 v a.c. current to a direct current (d.c.) and to change the voltage to the desired levels. This is accomplished in what we call the "power supply". In your radio, the power supply is the circuit involving the rectifier tube type 35W4; on the circuit diagram, it extends from the 115 v a.c. line plug to the connections to the speaker circuit and to the power amplifier tube type 50C5. Note that the filaments (pins 3 & 4) of the other four tubes are connected in this circuit.

From here on you will be reading the circuit diagrams of the radio and in the references. You will become familiar with a number of the symbols used in radio work, but until you do, use the chart of symbols on page 40 of this minicourse.

Assemble this power supply now. In operation, the power supply must have a load in order to function. We will substitute a 2000 ohm resister as the load for testing purposes. If you have not done this kind of work before, you should read pages 119 thru 131 of Chapter 7, Understanding Radio, 1963, published by the American Radio Relay League. In this reference you will be given helpful hints on how to solder, how to prevent damage to components while soldering, how to prevent "hum" in your radio, etc.

Be sure that the leads to the 50C5 and the speaker are connected to a 2000 ohm resistor using alligator clips, not soldered connections, since this is temporary. Double check the wiring to be sure it is as indicated on the diagram. Plug the circuit in to a 115 v a.c. outlet. Now close the switch and open it immediately. (Try to make this opening and closing one motion.) If nothing happens, nothing "blows" or starts smoking, close the switch and observe the power supply.

-Observe the filaments of each of the tubes.

-Obtain a multitester and test the following as indicated.

+ Set the meter on an a.c. volt scale that includes 120 v. (0-300 is a good scale for this.)

Touch one meter lead to pin No. 6 of the 35W4 and the other one to one side of the switch.

Read and record the voltage.

+ Set the meter on a d.c. volt scale that includes 150v. Touch the negative lead of the meter to the end of the lead to tube 50C5 and the positive lead to the lead to the speaker circuit. When you first make this connection, just tap the last connection <u>momentarily</u> to check that the polarity of the meter is right. If the meter needle moves the wrong direction, reverse the leads of the meter.

Read the voltage, record it and note that it is now a direct current (read with a d.c. meter).

+ If you have an oscilloscope, connect it to the output of the 35W4 and observe the wave form.

ACTIVITY # 6-1.2

Assumption(s): Based on your observations and recalling that an electric current is a flow of electrons, make an assumption(s) about how the a.c. current was changed into a d.c. current by the tube.

You may use the simplified diagram of the circuit below.

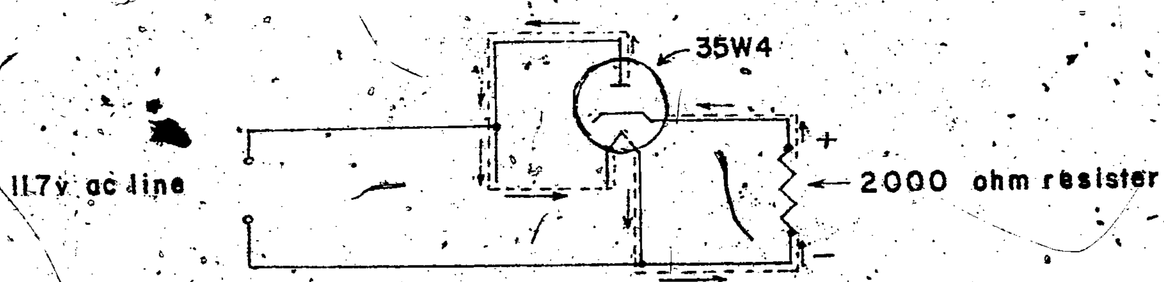


Fig. 6-1

After you have made and recorded your assumptions, discuss these with your teacher.

Teacher Check

ACTIVITY # 6-2

Now let's check your assumption(s).

The tube you used (type 50W4) is known as a diode, which means that is a two (di) element tube. You probably noticed that when you connected the tube to the a.c. current, one element became quite hot. This is the heater; it heats the filament (called the cathode) adjacent to it. Together these two constitute one element; in some tubes the heater itself is the cathode. When the cathode is heated, it gives off electrons creating a cloud of electrons, called the space charge, in the glass envelop of the tube. This phenomonum is known as the Thermionic Emission. The second element in your tube is the plate, usually a metal plate or cylinder placed near the cathode. If the plate is made more positive (not necessarily positive but less negative) than the cathode, some of the space charge will be attracted to the plate and an electric current will flow in the plate circuit. See Fig. 6-2 below.

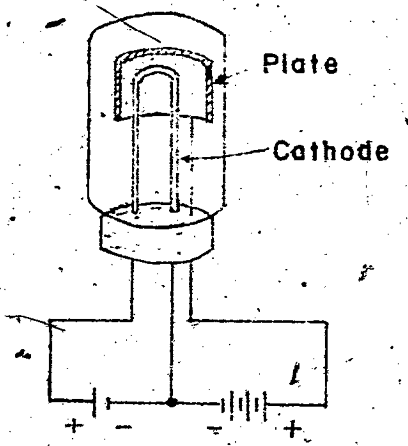


Fig. 6-2

In this figure, the cathode is heated by an electric current flowing from the "A" battery, through the cathode and back to the "A" battery: The plate circuit consists of the plate, the connection to the positive (+) side of the "B" battery, the "B" battery and the wire lead to the negative (-) side of the cathode. Note that the plate is more positive with respect to the cathode since the negative side of the "B" battery is connected to the cathode. Now suppose that the circuit is in operation. The hot cathode creates a space charge of, (negative) electrons. These are more strongly attracted to the plate (the plate being more positive) than to the cathode. As these electrons are captured by the plate they flow as an electric current to the battery and back to the cathode where they replace those that have been emitted.

Now suppose that we reverse the leads on the "B" battery as shown on Fig. 6-3.

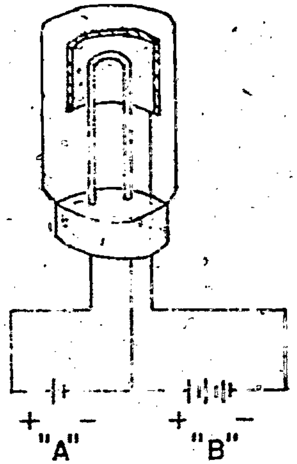


Fig. 6-3

In this case the plate is more negative than the cathode hence the electrons of the space charge will not be attracted to the plate and there will be no current in the plate circuit.

Thus, a current will flow in the plate circuit of a diode only when the plate is more positive than the cathode.

In your power supply, you did ~~not use~~ batteries, you used an alternating current (a.c.) and did find a d.c. current in the output of the tube. The diode tube works in the same manner as described for the direct current from the battery. The a.c. current heats the filament and cathode just as an a.c. current causes an electric space heater to heat. Hence the tube accumulates a space charge. You will recall that the voltage of an ac current changes polarity from positive to negative each cycle. Since the plate of the tube is connected to one side of the ac line, the polarity of the plate will swing from very positive to very negative as the ac voltage does. While it is positive, the tube will pass electrons from the cathode to the plate, but when the plate is negative, no current will flow in the plate circuit. The result is a pulsating direct current. The diagrams in Fig. 6-4 may help you to understand this.

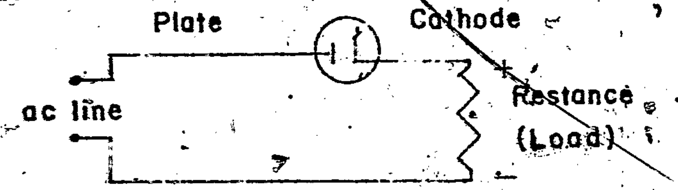
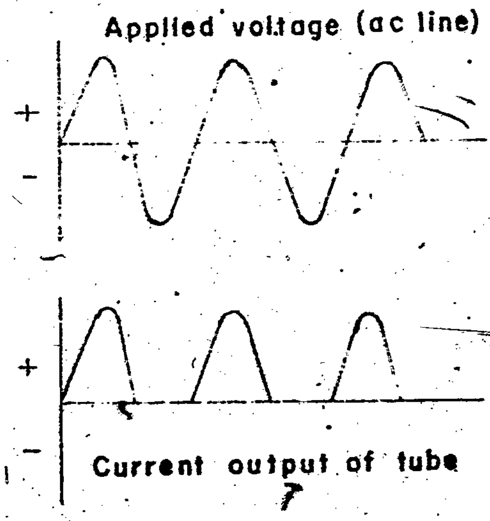


Fig. 6-4

Simplified diagram of a diode rectifier. The heater circuit has been omitted. The current flows only when the plate is positive with respect to the cathode, so that only half cycles of current (dc) flow through the load. Note that the dc current is pulsating.



In your power supply circuit, note that the plate (pin No.5) is connected to the ac line hence it swings from positive to negative as the ac voltage does. When the plate is positive, a current flows from the plate (pin No.7) of the power amplifier tube, 50C5, through the speaker coil to the cathode of the 35W4, through the space charge and back to the ac line. If you are wondering where all of these electrons come from, note that the cathode of the 50C5 is connected to the other side of the ac line and supplies the electrons that flow in the plate circuits of the 50C5 and the 35W4.

RESOURCE PACKAGE # 6-3

Modern Physics	Dull, Metcalf & Williams	Holt, Rinehart & Winston	1964

Selected Readings

Thermionic Emission	Page 607
Types of Emitters	607-608
Diode Characteristics	608-609
Power Supplies	645-648

The Radio Amateur's Handbook	The American Radio Relay League	1974

Selected Readings

Vacuum Tube Principles	Pages 61-63
Power Supplies:	
Introduction	105
Rectifier Circuits	110-111

RESOURCE # 7-1

ACTIVITY # 7-1.1

Assemble the Pentagrid Converter circuit of the radio receiver, kit K-50. This circuit will include the Ferrite antenna, the oscillator circuit and the coupling transformer between the converter and the amplifier circuits.

ACTIVITY # 7-1.2

Look at the circuit diagram of the converter, the 12BE6 tube. The transformer T_1, and variable condensers C_5 & C_6 form an oscillator, the frequency of which can be controlled. The voltage (rf) output of this oscillator is fed to the grid (pin 1) of the 12BE6 while the rf voltage from the antenna is fed to another grid (pin 7) of the same tube. Thus two (2) frequencies are fed to the tube; a fixed frequency from the oscillator and the rf frequency from the antenna which may contain a number of modulated frequencies.

What do you suppose the purpose of this tube and converter circuit is? In answering this question, please do two things.

a) Study the circuit and think about it in terms of the brief description above and what you now know. Then make an assumption as to what the circuit does (what its function is) and record your assumption. Note: It is not so important at this point that you make the "right" assumption but it is important that you develop the facility to analyze information and make an assumption or model for the phenomonum you study.

b) After you have made your assumptions, look up "Frequency Conversion" or "Intermediate Frequencies" in the references given on page No. 30 and write a brief summary of the function of the converter circuit.

Complete a) and b) above and discuss these with your teacher before you go on.

Teacher Check

Your summary of the function of the converter circuit should express the following ideas:

- Two (2) rf signals are fed to the converter tube (12BE6); one is a single fixed frequency from the oscillator and the other an rf signal from the antenna. The tube "mixes" these frequencies and the output of the tube, the plate current, is a complex mixture which includes:
  + the frequencies of both input signals.
  + a frequency which is the difference of the two input frequencies.
  + a frequency which is the sum of the two input frequencies.
- The tuned circuit in the output of the plate is tuned to select only the beat frequency that is the difference between the two input frequencies. This beat frequency still carries the sound modulation of its amplitude. This selected frequency is the only one that will be coupled or transferred to the amplifier tube. The other frequencies are rejected because they are not of the proper frequency to cause resonance in the tuned circuit.

RESOURCE PACKAGE # 7-2

Modern Physics	Dull, Metcalf & Williams	Holt, Rinehart & Winston	1964

Selected Readings

Triodes Can Amplify — Pages 609-611
Frequency Conversion — 642-643
Pentodes — 619

RCA Receiving Tube Manual	RCA	RC 29	1973

Selected Readings.

Triodes, Tetrodes, Pentodes — Pgs, 7 - 9
Frequency Conversion — 77 - 78

The Radio Amateur's Handbook	The American Radio Relay League	1974

Selected Reading

Triodes (To Power Amplifiers) — Pages 61-67
Screen Grid Tubes — 71-72

RESOURCE # 8-1

ACTIVITY # 8-1.1

Assemble the intermediate frequency (if) amplifier circuit of the radio receiver. This will include the coupling transformer between the i.f. and the diode detector.

ACTIVITY # 8-1.2

From what you have done and read so far, you may have a good idea as to the function of this circuit. Let's see. Study the circuit and the tube and speculate as to what its function is. Record your assumption(s) and discuss these with your teacher.

Teacher Check

Now that you have recorded your assumption, let's examine it. We have a vacuum tube with a cathode, a plate and three grids. This makes it a pentode, five elements. Let's consider first the cathode, the plate and the No. 1 grid, the one connected to the output of the converter. This much of the tube constitutes a triode which will amplify. Recalling that the converter output consists of an ac signal (containing an ac voltage component), and that an ac signal applied to the grid of a triode produces an amplified ac signal of the same wave form in the plate circuit, we see that the circuit merely amplifies the signal which contains the information (that is the sound or audio frequency). The other two grids merely improve the performance of the tube but do not alter its function as an amplifier.

ACTIVITY # 8-2

Read the selected readings listed in Resource Package # 8-2.

RESOURCE PACKAGE # 8-2

Modern Physics — Dull, Metcalf & Williams — Holt, Rinehart & Winston — 1964

Selected Readings

Amplifier Circuits — Pages 630-634

RCA Receiving Tube Manual — RCA — RC-29 — 1973

Selected Readings

Amplification — Pages 24-28
(To Class A Power Amplifiers)

The Radio Amateur's Handbook — The American Radio Relay League — 1974

Selected Reading

Amplification — Pages 64-66
(through Cascade Amplifiers)

RESOURCE # 9-1

ACTIVITY # 9-1.1

Assemble the diode detector- audio amplifier circuit up to the connections to the power amplifier tube 50C5.

ACTIVITY # 9-1.2

The circuit you have just completed is a combination of two functions; detection by a diode and amplification of the audio signal by a triode.

From what you know about radio circuits and what ever help or references you want to look up, make an assumption as to how these two functions are accomplished in one tube. Record your assumptions and discuss these with your teacher.

Teacher Check

ACTIVITY # 9-1.3

When you were building the power supply, you found out how diodes work. The principle here is exactly the same. The difference being that, in this circuit, we have an i.f. ac current on the plate instead of a 60 cycle ac line current. In the 12AV6 tube, there are 3 plates. The plates for the diode section are on pins 5 and 6. One of these is connected to the cathode and does not function in this circuit. The third plate (pin 7) is the plate for the triode section of the tube. As the i.f. output voltage from the preceding tuned coupling circuit oscillates from more to less positive and back, the tube conducts more or less following the i.f. voltage. Since the i.f. voltage variations were caused by the audio frequency (a.f.) current originally used to modulate the rf current, the diode plate voltage is now a replica of the original a.f. current. All we need to do now is to amplify it and change it from an af signal into a sound wave again.

You found out earlier that triode tubes would amplify a signal. The ac signal is the plate current from the diode plate via the coupler, resistors and condenser to the grid of the tube. The amplification takes place just as it did in the i.f. amplifier (12BE6) tube and the amplified af signal is fed through a condenser to the grid of the power amplified tube.

RESOURCE PACKAGE # 9-2

Modern Physics	Dull, Metcalf & Williams	Holt, Rinehart & Winston	1964
	Selected Reading		
	Detection	Pages 643-644	
RCA Receiving Tube Manual	RCA	RC-29	1973
	Selected Reading		
	Detection	Pages 19-20	
The Radio Amateur's Handbook	The American Radio Relay League		1974
	Selected Reading		
	Detection and Detectors	Pages 237-242	

RESOURCE # 10-1

ACTIVITY # 10-1.1

Assemble the power amplifier and speaker circuits but do not place the chassis in the cabinet yet. We will do some testing first. DO NOT CONNECT THE RADIO TO A SOURCE OF POWER YET.

Take the assembly instructions furnished by the manufacturer and check each step of these instructions to be sure that you have the entire circuit correctly connected.

ACTIVITY # 10-1.2

Examine the power amplifier circuit and, based on what you now know about radio and tubes, make an assumption as to what the function of this circuit is. Also find out what you can about how this amplifier differs from the previous amplifier stage.

Discuss your assumption(s) and findings with your teacher.

Teacher Check

ACTIVITY # 10-1.3

Please complete Activity 10-1.2 before you go on.

The purpose of the power amplifier tube is to deliver a relatively large amount of power to the speaker. In the previous amplifier (12AV6), the tube was designed to maximize voltage amplification, not power output. In this amplifier, the design of the tube sacrifices voltage gain to increase power output. If the speaker is to produce sound, energy (power) is required and this must come from the input signal to the speaker. It is true that the power amplifier tube does amplify the voltage to a degree, but this is incidental to the power amplification function.

ACTIVITY # 10-1.4

After you have completed the circuit check using the manufacturers instructions, plug the power cord into a 115 v ac outlet and have some fun with your radio for a while. Don't put the chassis in the cabinet yet though. CAUTION. Although most of the circuits in the radio are low voltage, there are some peak voltages in excess of 200v. Do not touch bare wire or connections in handling the set while it is plugged in.

RESOURCE # 11-1

ACTIVITY # 11-1.1

Turn the chassis on its side, plug in the radio and let it warm up. Tune in a strong station and perform the following measurements using a multitester.

The measurements you make on the radio with the multitester will not be accurate since the meter is not designed for rf but they will be relative.

A. Set the multitester on an ac volts scale including 150 v and test the voltage between the plate of each tube (except the 35 W4) and the chassis. Record the voltages and explain the results in your notebook.

B. If you have an oscilloscope, connect it to the plate of each tube (one at a time) and observe the wave form for each paying particular attention to the amplitude of each wave form. Sketch the wave forms in your notebook and explain the differences in terms of the function of ~~the tube.~~

C. The radio you have built has a built-in ferrite antenna. In this experiment, we will use the external antenna that you built in addition to the built-in antenna.
Place the completed chassis in the cabinet. Plug-in the radio near the antenna lead-in and tune in a station. Adjust the volume to a low but comfortable level.

1) Now without changing the orientation of the radio and with it playing, wrap several turns of the end of the lead-in wire around the radio case in the vacinity of the ferrite antenna. Note the effect of adding each additional turn.
2) You have noticed how the volume of portable radios vary as the orientation of the radio is changed. Remove the external antenna and adjust the volume of your radio to a low level then rotate it in the horizontal plane until the volume diminishes to its lowest point, then rewrap the external antenna lead-in. Note the difference.
3) During these experiments, the external antenna has not been connected directly to the radio but merely wrapped around the radio cabinet.

Your problem now is to figure out how or why rf energy is transferred from the wire wrapped around the radio to the radio's antenna system. Think about it using what you now know, look up references, ask people you know and finally discuss it with your teacher.

Hint. What, electrically speaking, does the wire wrapped around the cabinet constitute?

RESOURCE # 12-1

Solid State Devices-Diodes & Transistors

ACTIVITY # 12-1.1

In the radio receiver you have made, vacuum tubes were used for the following function: 1) to rectify an ac current, 2) to produce an intermediate frequency, 3) to amplify the signal, 4) to detect (separate) the information from the carrier signal and 5) to supply the a.f. signal with enough power to operate the speaker. In transistorized radios, diodes (solid state diodes) and transistors perform all of these functions. In a subsequent activity, you will build a transistorized radio receiver so we need to 'bone-up' a bit on transistors.

Before you go any farther, write a brief summary of all you know about transistors. Answer such as:

- What they are used for.
- What they are made of.
- What the advantages of transistors vs vacuum tubes are.
- Relative size of transistors and vacuum tubes.
- How transistors work.

Go ahead and speculate freely using all that you have learned.

ACTIVITY # 12-1.2

Having prepared your summary, you are now prepared to ask some questions and to find out more about transistors. Go to an electronics store or an electronics repair shop (or to some one you know who is skilled in electronics especially radio) and find out all you can about transistors. Make notes of what you find out then discuss with your teacher.

Teacher Check ☐

ACTIVITY # 12-2

After you have discussed your knowledge of diodes and transistors with your teacher, obtain the references and do the selected readings listed in Resource 12-2. These are arranged in order of increasing difficulty and detail. If this is your first 'brush' with transistors, you probably will want to start with the first one and continue on until you achieve the level of understanding that suits you. The first two are recommended as a minimum.

RESOURCE PACKAGE # 12-2

Modern Physics	Dull, Metcalf & Williams	Holt, Rinehart & Winston			1964
		Selected Readings			
		Crystals Are Used as Diodes	Pages	620	
		Transistors		620-621	
		P-and-N Semicounductors		621-622	
		The P-N Junction		622-623	
		Two Types of Junction Transistors		623-624	
		Transistor Amplification		624	
RCA Transistor, Thyristor & Diode Manual	RCA	SC-15			1971
		Selected Readings			
		Materials, Junctions & Devices	Pages	3-11	
		Bipolar Transistors		12-20 (to Biasing)	
		Detectors		89-90	
The Radio Amateur's Handbook	The American Radio Relay League				1974
		Selected Readings			
		Semiconductor Devices	Pages	79-83	
		Transistors		83-91	
		Detection & Detectors		237-238	

Filmstrip: How Transistors Work.

RESOURCE # 13-1

ACTIVITY # 13-1

Build a transistorized radio.

Heathkit #GR-1008 is suggested as a good one and one that is comparable to the vacuum tube set you have built.

SYMBOLS USED IN RADIO