# LABORATORY MANUAL

for

# Fundamentals of Radio

## PART II

by

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# PREFACE

The experiments contained in this Manual are a continuation of those of Part I and carry the experimental work through the construction, testing, and operation of a complete radio communication system. Each separate component of a transmitter and receiver is constructed, properly adjusted, and operated as a separate unit. Then these units are used to assemble a complete transmitter and a complete receiver. In this manner the student learns the function of each unit of a communication system and how this particular unit functions as an integral part of the complete system.

Several experiments are devoted to the study and the use of equipment for the checking of defective parts, the location of troubles, and the adjustment and alignment of receivers. A thorough understanding of the principles underlying servicing equipment greatly aids the technician in rapidly and effectively servicing radio apparatus.

Ultrahigh frequencies, so important in radio communication today, are also studied in an experimental manner with very simple equipment which is easily constructed.

Some of the experiments, such as the study of a public-address system, require considerable equipment for adequate investigation. The Manual has therefore been prepared in such a manner that experiments of this nature may be performed as a combined demonstration student-participation project. In this manner one set of apparatus serves for the entire class and the instructor can focus the attention of the class on the principle under discussion. The students should be called upon to participate in the experimental work whenever and as often as practicable by being required to read meters, make adjustments, perform calculations, and so on. Experience has demonstrated that this method, under the direction of a competent instructor, is quite as effective as experimental work performed alone by unsupervised students.

The above should not be taken to infer that the experiments of this Manual cannot be performed individually by the student himself. The constants for all parts of each circuit have been included on the circuit diagrams and much additional information has been included in the Appendix to aid in the construction of the apparatus used in the experiments. All of the experimental equipment can be constructed from easily obtainable parts. The experimenter is assured that the equipment for each experiment has been built and operated satisfactorily and is advised, when constructing the apparatus, to follow the circuit diagrams and the pictures which appear in the Appendix.

The author is very grateful to Mr. E. J. Drazy for the competent aid received from him in the preparation of this Manual.

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## EXPERIMENT 16

# A Study of Sweep Circuits for Use with the Cathode-ray Oscilloscope

### APPARATUS REQUIRED

| ITEM | QUANTITY |
|---|---|
| Cathode-ray oscilloscope | 1 |
| Beat-frequency oscillator | 1 |

See Appendix V–10 for sweep-circuit description and determine Parts list from Figures 16–2, 16–6 and 16–7.

In many of the experiments appearing in Part I of this laboratory manual, the cathode-ray oscilloscope has been used to facilitate the study of A.C. voltages. It will be recalled that, in most cases, the manner in which the voltage in question varied with *time* was of interest, and the self-contained linear time-base sweep-circuit of the oscilloscope was employed to provide a time axis for the graph appearing on the oscilloscope screen. It is the purpose of this experiment to study the means whereby a linear time-axis may be produced.

Probably the simplest linear time-base generator is the arrangement illustrated in Fig. 16–1. Here the arm of a potentiometer is rotated by a small electric motor. With the connections shown, the voltage appearing across terminals A–A′ will have the wave form shown in (b) of Fig. 16–1, one cycle corresponding to one revolution of the arm. This voltage, if applied to the horizontal deflecting plates of the oscilloscope, will cause the beam to move slowly (relatively) and at a uniform rate from one side of the screen to the other as the voltage rises from $p$ to $q$, then retrace rapidly as the voltage drops from $q$ to $r$, thus producing the desired linear sweep and quick return.

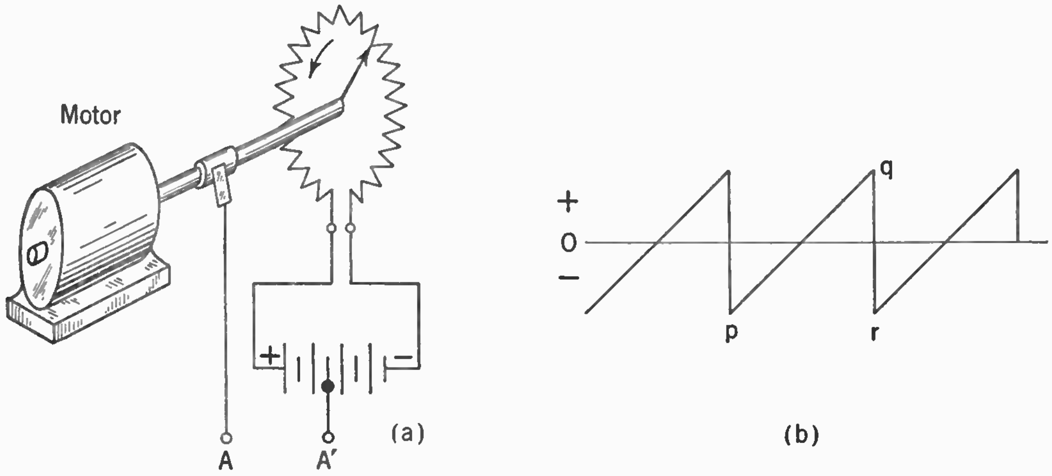


Fig. 16–1. Mechanical Sweep Circuit.

Such a mechanical arrangement is suitable only for slow-speed sweeping, and has the additional disadvantages of bulkiness, noisy operation, being difficult to synchronize with the voltage to be observed, and requiring frequent maintenance. Electronic sweep-circuit oscillators have therefore been devised; these have the advantages of cheapness, noiseless operation, light weight, and a higher frequency range.

A simple oscillator of this type is shown in Fig. 16–2. This oscillator contains a neon tube, which ionizes and becomes conducting only if a voltage greater than approximately 70 v is applied to it. The circuit functions as follows. Upon application of a D.C. voltage to terminals B and B′, the condenser *C* slowly charges, the rate at which it does so being determined by (1) the capacitance of the condenser *C*, (2) the value of the resistance *R*, and (3) the magnitude of the voltage *E*. As the charge of the condenser increases, the voltage across its terminals rises, just as the pressure in an air tank rises as it is "charged" with air, and eventually the voltage becomes great enough to cause the neon tube to ionize or "fire." When this occurs, the condenser is practically short-circuited, and therefore, discharges through the tube. After the condenser has discharged, the voltage across its terminals is too small to maintain an ionized condition of the neon tube, and it therefore is extinguished. The condition of the circuit is now the same as it was when the voltage was first applied, and the cycle repeats itself. The upper frequency limit of this oscillator is determined primarily by the time required for de-ionization of the neon tube after it has fired.

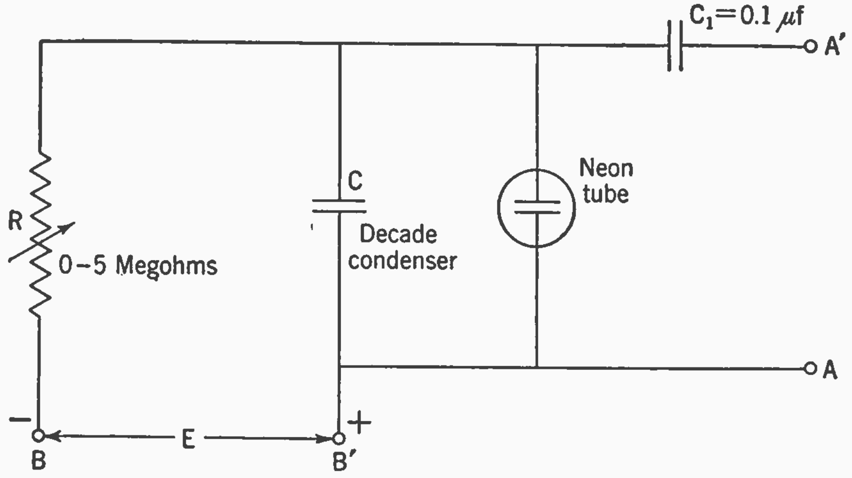
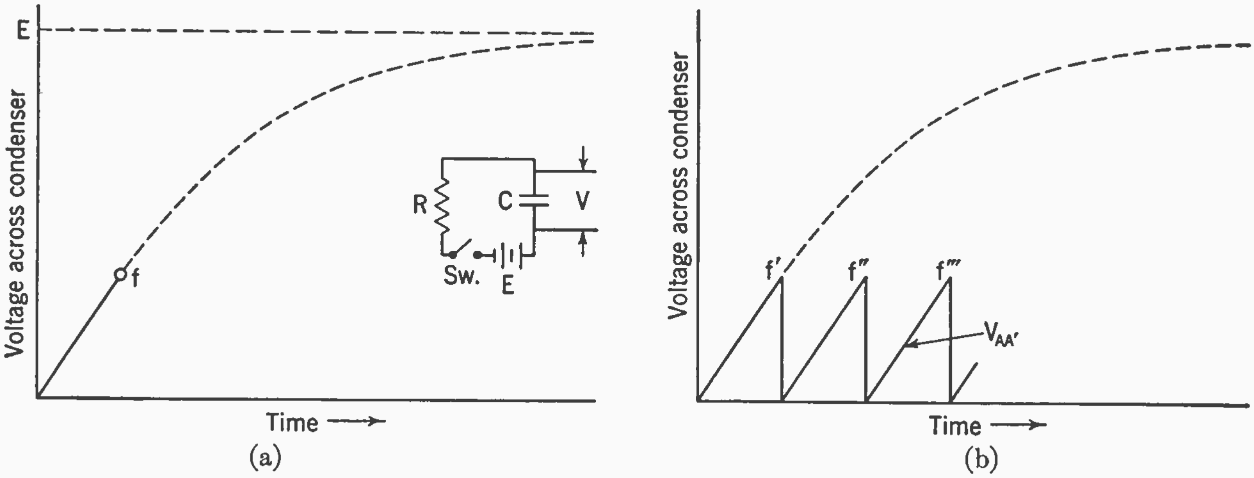


Fig. 16–2. Simple Sweep-circuit Oscillator.

It will be recalled that the voltage across a condenser which is being charged as shown in Fig. 16–2 does not increase directly with time, but instead follows an *exponential* curve, as shown in Fig. 16–3(a).



(a) (b)

Fig. 16–3. (a) Changing Voltage of a Condenser. (b) Output of Circuit, Fig. 16–2.

Since a voltage which increases linearly with time is necessary for a linear sweep, it might at first appear that this type of oscillator would be unsatisfactory. An examination of Fig. 16–3(a) will reveal, however, that *the lower portion of the curve is very nearly a straight line.* Therefore, if the constants of the circuit are so arranged that the tube "fires" before the voltage rises into the curved region, the desired linear relation will be approached very closely. This timing is accomplished by using either a tube that fires at low voltage, or a high charging voltage $E$. The result is illustrated in Fig. 16–3(b). Here the dotted line represents the voltage curve that would be obtained if the charging were not interrupted by the firing of the tube. The frequency is controlled by varying resistor $R$, condenser $C$, or both.

If the charging current of the condenser is maintained constant, it can be shown that a linear rise in voltage will be obtained. An examination of the characteristic curves of a pentode-type vacuum tube (see your text) shows that its plate current is very nearly constant and independent of the plate voltage over a large part of its operating range; it is, therefore, often used as a constant-current element in sweep-circuit oscillators. Figure 16–4 illustrates a circuit containing a constant-current tube. Note that the tube simply replaces the resistor $R$ of Fig. 16–2.

The arrangements of Figures 16–2 and 16–4, although satisfactory for some purposes, have the serious disadvantage that the sweep frequency is difficult to synchronize with the signal to be observed. This difficulty is overcome by replacing the neon tube with a gas triode or *thyratron*. These tubes are similar in appearance to ordinary receiving type high-vacuum triodes, but contain a mixture of inert gases or mercury vapor, and are therefore capable of being ionized. It is found that the plate voltage necessary to ionize or *fire* a thyratron is largely dependent upon its grid bias, so that synchronization may be accomplished if the tube is fired by momentarily lowering its grid bias at just the right instant. Usually, a portion of the signal voltage is applied to the grid through a transformer to supply the necessary synchronizing pulse. A circuit of this type is shown in Fig. 16–7.

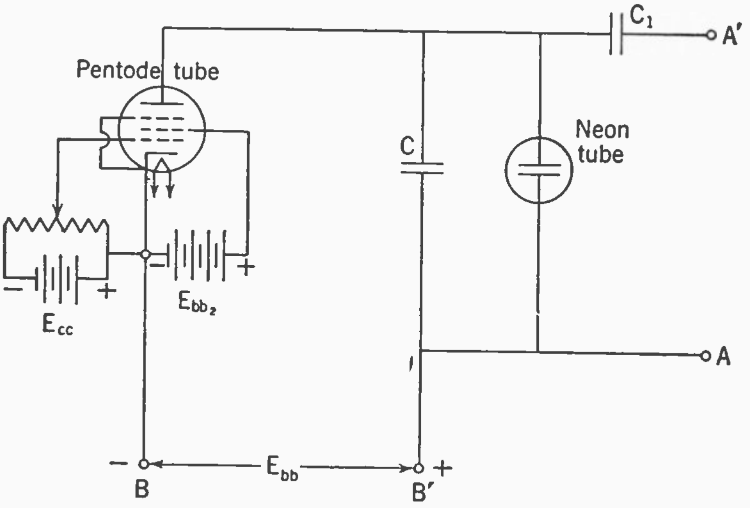


FIG. 16–4. Sweep Circuit with Constant-current Tube.

## Experimental Procedure

**A.** Connect the circuit as in Fig. 16–2 or 16–5. Set the resistor $R$ and condenser $C$ at their maximum values. Apply 250 v to terminals B–B′ and observe the flashing of the neon tube. Reduce $R$ and notice whether the frequency of the flashing increases or decreases. Record observations on the data sheet, in space A.

**B.** **1.** Connect the vertical ($Y$-axis) input terminals of a cathode-ray oscilloscope to terminals A–A′. Apply the highest obtainable voltage (maximum 450 v) to terminals B–B′, and observe the shape of the wave obtained. Sketch this wave in space B–1.

**2.** Reduce the voltage $E$ until the wave form appears similar to that shown by Fig. 16–3(a). Sketch this wave in space B–2, and record the voltage $E$. Note and record whether or not the amplitude of the wave changes as $E$ is varied.

**C.** With the voltage $E$ at a low value, as in part B–2, connect the terminals A–A′ to the horizontal ($X$-axis) input terminals of the oscilloscope, and apply a 60-cycle voltage to the vertical ($Y$-axis) input

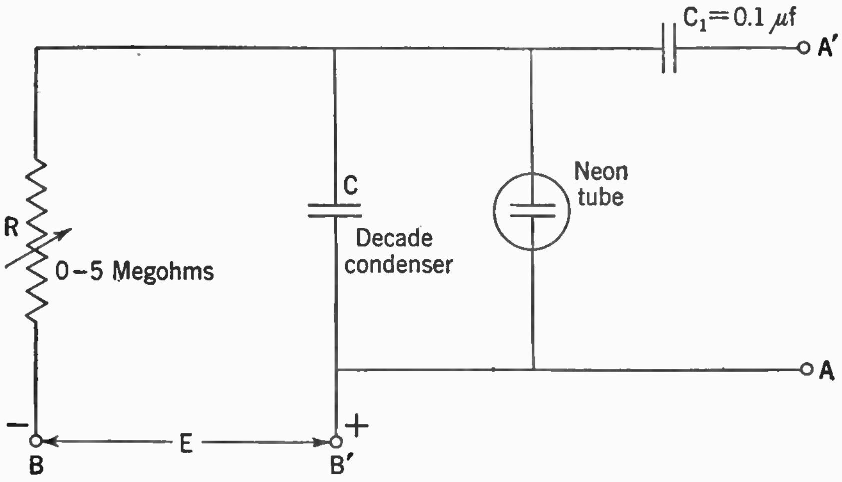


FIG. 16–5. Simple Sweep-circuit Oscillator (same as Fig. 16–2).

terminals. Adjust the resistor *R* and condenser *C* until four complete cycles appear on the oscilloscope screen. Sketch the pattern obtained in space C–1. Raise the voltage *E* to the highest obtainable value (450 v), and readjust *R* and *C* until four complete cycles are again obtained on the screen. Sketch the pattern in space C–2.

**D.** Remove resistor *R* from the circuit, and connect a type 6SJ7 or other pentode into the circuit as a constant-current tube, as shown in Fig. 16–6. Apply the highest obtainable voltage (450 v), connect the vertical (*Y*-axis) input terminals of the oscilloscope to terminals A–A′, and observe the shape of the resulting wave. Sketch in space D–1. Now reduce *E* to the value used in part B–2. Sketch the wave obtained in space D–2, and compare with that obtained in part B–2. Vary the resistor *R′* and notice its effect on the frequency, wave form, and amplitude of the wave obtained. Note that this variation adjusts the grid bias of the pentode tube, which in turn controls the flow of current through the tube and into the condenser.

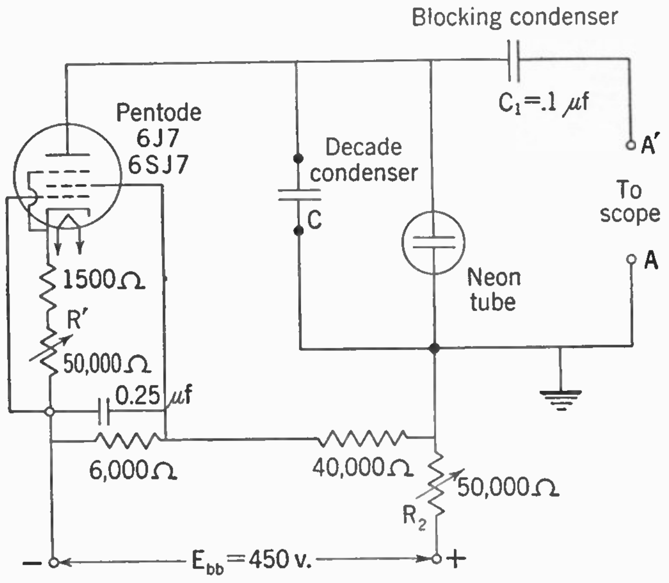


FIG. 16–6.

**E.** Remove the neon tube and its socket from the circuit, and replace with a type 884 (or type 885)* thyratron connected as shown in Fig. 16–7. Connect the horizontal ($X$-axis) input terminals of the cathode-ray oscilloscope to terminals A–A′, and the vertical ($Y$-axis) input terminals to the output posts of an audio-frequency oscillator. Also connect the terminals of the synchronizing transformer to the output of the audio oscillator. Set the oscillator frequency at 1,000 cycles. With the synchronizing control $R_1$ (0.5 megohm) at its minimum value, adjust the output of the oscillator and the vertical gain control of the oscilloscope until a convenient deflection is obtained; then vary the capacitance $C$ and resistance $R'$ of the sweep oscillator until a nearly stationary pattern is obtained on the screen. Advance the synchronizing control until the pattern is observed to lock in and become stationary. By adjustment of $R'$ and $C$, obtain patterns containing four, three, two, and one complete cycles, properly synchronized. Repeat for oscillator settings of 100 cycles and, if possible, 15,000 cycles.

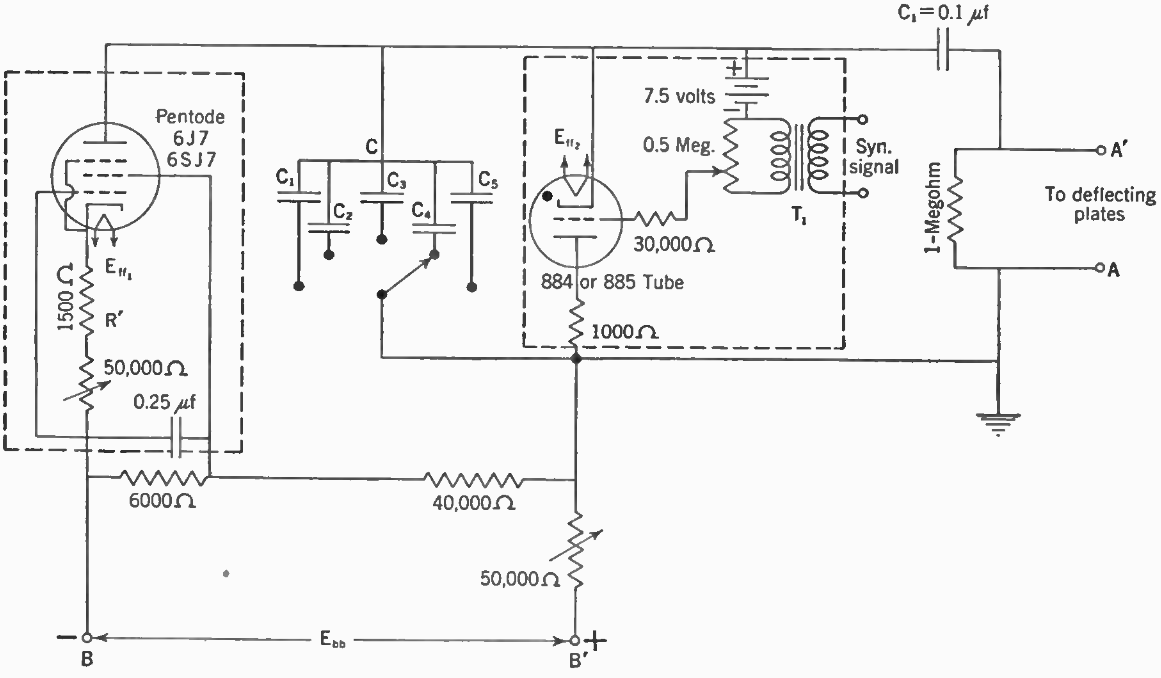


FIG. 16–7. $C_1 = 0.1\ \mu f$; $C_2 = 0.025\ \mu f$; $C_3 = 0.005\ \mu f$; $C_4 = 0.001\ \mu f$; $C_5 = 0.0001\ \mu f$.

**F.** Set the audio-frequency oscillator to 1,000 cycles, adjust the frequency of the sweep-circuit oscillator until a single cycle appears on the screen of the cathode-ray tube, and synchronize the sweep-circuit oscillator with the audio-frequency signal. Now reverse the connections to the synchronizing transformer primary, and notice the result. Sketch the waves in spaces F-1 and F-2.

**References:**

1. Everitt, W. L., *et al.*, "Fundamentals of Radio," pp. 136–137; pp. 206–208.
2. Henney, Keith, "Principles of Radio," 4th ed., pp. 86–91.
3. Hoag, J. B., "Basic Radio," pp. 162–171.
4. Radio Amateur's Handbook, Defense Ed., pp. 236–237.

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* The type 884 requires 6.3 v on its heater and has an octal base; type 885 requires 2.5 v and has a 5-prong base. Otherwise the tubes are identical.

**Name** ________________________ **Date** ________________ **Class** ________________

## DATA SHEET—EXPERIMENT 16

A. ____________________________________________________________

____________________________________________________________

____________________________________________________________

B-1

$E =$ ________ v.

B-2

$E =$ ________ v.

C-1

$E =$ ________ v.

C-2

$E =$ ________ v.

Amplitude ____________________________

D-1

$E =$ ________ v.

D-2

$E =$ ________ v.

F-1

SYNCHRONIZING
TRANSFORMER
NORMAL

F-2

SYNCHRONIZING
TRANSFORMER
REVERSED

**Name** ---------------------------------------- **Date** -------------------- **Class** --------------------

## QUESTION SHEET—EXPERIMENT 16

1. Explain why charging a condenser at constant current yields a linear rise of voltage across its terminals. Use mathematical symbols and equations.

2. Why should the sweep oscillator be synchronized with the signal to be observed?

3. Why is the plate current of the pentode constant-current tube nearly independent of the plate voltage?

4. How does variation of $R'$ (Fig. 16–6) control the sweep frequency?

5. Explain how changing the size of the capacitance $C$ effects the sweep frequency.

### EXPERIMENT 17

# Simple Telephone Circuits

## APPARATUS REQUIRED

| ITEM | QUANTITY |
|---|---|
| Telephone transmitter (carbon-grain) | 1 |
| Telephone receiver (radio headphones satisfactory) | 1 |
| Telephone induction coil | 1 |
| No. 6 dry cells | 4 |
| 1-$\mu$f condenser | 1 |
| Retard coil (audio-frequency choke coil) (per two groups) | 1 |
| Ohmmeter | 1 |
| Cathode-ray oscilloscope | 1 |
| Two-wire cable and connecting wires | — |

Telephone transmission methods are much used in radio systems for conveying broadcast programs to remotely situated transmitters, and for interconnecting the various broadcasting stations of a network system. The methods used in telephony for translating the sounds of speech into electrical impulses are practically the same as those used in radio, the difference being principally that in telephony, *intelligibility* is the prime requisite, whereas in radio broadcasting, *quality* is of paramount importance. An understanding of the principles of telephony is therefore of importance to the radio technician.

From the engineering standpoint, sound consists of a series of waves of pressure in the atmosphere. This can easily be demonstrated by holding a sheet of paper in front of the mouth and shouting loudly—the vibration of the paper, caused by the impinging air waves, can easily be felt by the finger tips. The problem of telephony is thus one of converting these sound waves into electrical impulses, transmitting the electrical impulses through an electrical circuit, and finally reconverting them into sound waves in the air, which may be detected by the ear of a listener.

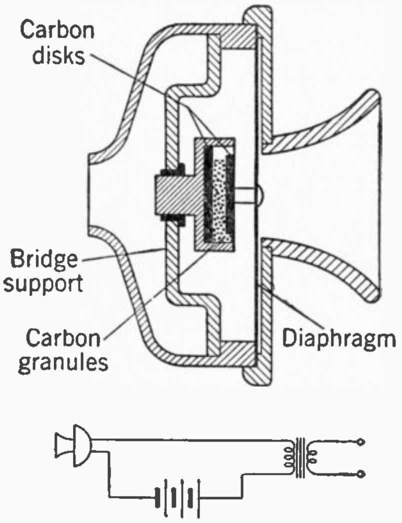

Fig. 17-1. Carbon Microphone.

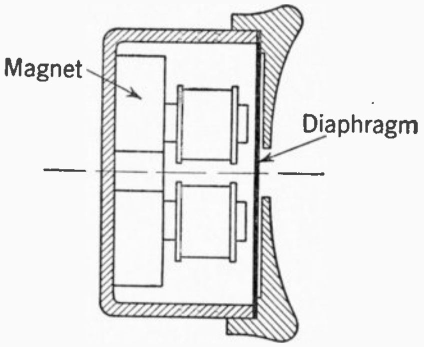

Fig. 17-2. Telephone Receiver.

### The Transmitter

A simplified sectional diagram of a telephone transmitter is shown in Fig. 17-1. A small brass cup, partly filled with carbon granules, is rigidly supported by the bridge. A carbon disk, fastened to the *diaphragm* and free to move plunger-fashion in the cup, compresses the mass of carbon granules whenever a sound wave strikes the diaphragm. This compression results in a decrease in the resistance of the transmitter, and, if it is connected in series with a battery, the current will momentarily rise whenever a sound wave strikes the diaphragm.

### The Receiver

A typical telephone receiver is shown in section in Fig. 17–2. It is seen to consist of a soft iron diaphragm, two small coils of wire, and a permanent magnet. The coils are wound upon the magnet's pole pieces, so that a current sent through the coils either increases or decreases (depending upon the direction of the current) the field produced by the magnet and hence increases or decreases the pull which it exerts upon the iron diaphragm. If the receiver is connected in series with a transmitter and a battery, the momentary increase in current, caused by a sound wave striking the diaphragm of the transmitter, results in an increased pull on the diaphragm, and its resulting motion causes a wave of sound in the surrounding air.

### The Induction Coil

Considerable improvement in the performance of a telephone transmitter may be secured by the use of an induction coil, connected as in Fig. 17–3. The induction coil is simply a transformer, which serves to *step-up* the variations in voltage produced by the transmitter—speaking more technically, it matches the impedance of the transmitter to that of the receiver or line.

The output of the induction coil will, of course, be alternating current. The reason for including a permanent magnet in the receiver now becomes evident. If the magnet were omitted, the diaphragm would be attracted *twice* during each cycle of the current wave—once during the positive half cycle, and once during the negative half cycle. The permanent magnet strengthens the pull during the positive half cycle and weakens it during the negative half cycle; proper operation is thereby obtained.

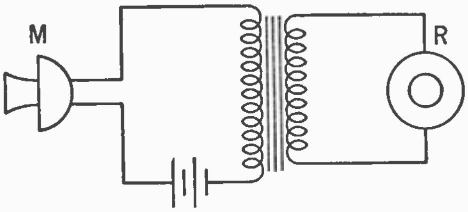

FIG. 17–3. Simple Telephone Circuit.

### Experimental Procedure

**A.** Remove the transmitter from its case and notice its construction. Unscrew the cap from the receiver, carefully remove the diaphragm by *sliding* it off, and notice the manner in which the receiver is made.

With an ohmmeter, measure the resistance of the transmitter and of the receiver. Record in space A of the data sheet. With the ohmmeter connected to the transmitter, very lightly touch its diaphragm, and observe any change in resistance. Touch the diaphragm of the receiver to the pole pieces and notice the amount of force required to remove it. The condition of a receiver may usually be judged by the strength of the magnets if the coils and diaphragm are intact.

**B.** Replace the diaphragm and cap on the receiver and hold the receiver cord terminals to a $1\frac{1}{2}$-v dry cell. A sharp click should be heard. Try to determine whether the diaphragm moves toward or away from the magnet poles as the battery is connected. Repeat with the battery connections reversed. Telephone receivers should always be *poled*, or connected so that the diaphragm moves *toward* the magnets when the battery is connected. Usually, one of the receiver cords has a *tracer* thread braided into the covering—this should be connected to the positive battery terminal. Check your receiver to see if it is so connected. Record results of this part in space B of the data sheet.

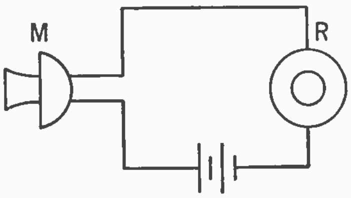

FIG. 17–4.

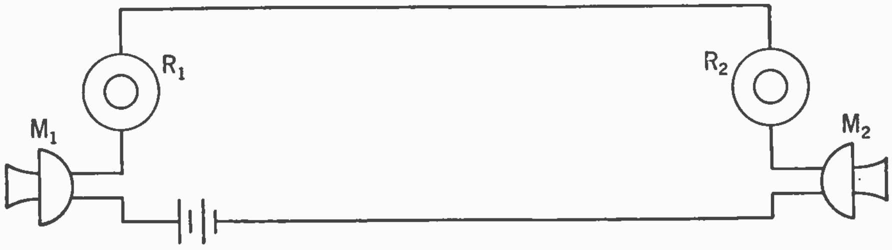

FIG. 17–5.

**C.** Connect the receiver, transmitter, and a 6-v battery in series, as shown in Fig. 17–4. Observe proper poling of the receiver. Have someone speak into the transmitter while you hold the receiver to your ear.

**D.** Connect an induction coil into the circuit, as in Fig. 17–3. Again have someone speak into the transmitter, and compare with the results obtained in part C. Record the results in space C–D of the data sheet.

**E.** Arrange a telephone "line" with a neighboring party by connecting the equipment as in Fig. 17–5. Use this telephone system to carry on a conversation with the neighboring party, noticing in particular the quality of transmission obtained.

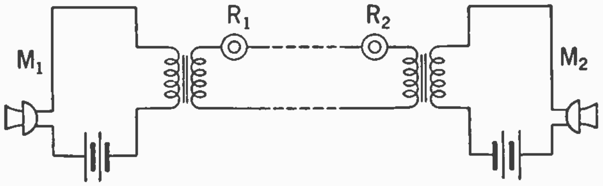

FIG. 17–6. Local-battery Telephone Circuit.

**F.** Connect induction coils into the circuit, as in Fig. 17–6, and compare the transmission with that obtained in part E, using space E–F. This arrangement is called a *local-battery circuit,* since the batteries are located at the telephone sets.

**G.** Reconnect the equipment as in Fig. 17–7. The *retard coil* is simply an audio-frequency choke coil. The primary of a filament transformer may be used here if a regular retard coil is not available.

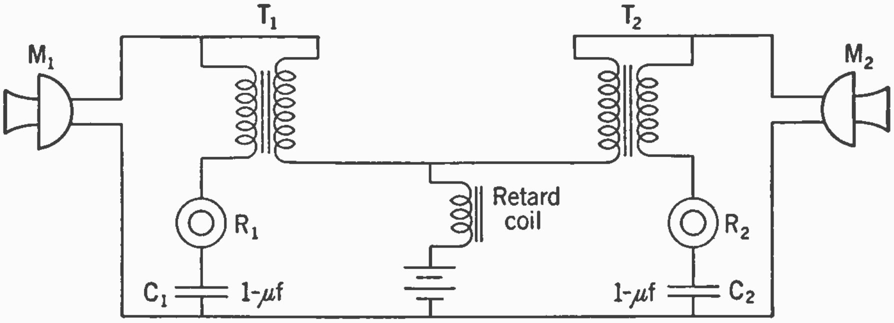

FIG. 17–7.

This circuit is called a *common battery circuit,* because only a single battery is required—it is *common* to several telephone sets, two in this instance. Compare the transmission with that obtained in part F, using space G.

**H.** DEMONSTRATION BY INSTRUCTOR—OPTIONAL. Arrange a transmitter, battery, induction coil, and cathode-ray oscilloscope as in Fig. 17–8. Using a low-frequency linear horizontal sweep (15–20 cycles per second) speak into the microphone and observe the waves obtained. Sing the vowels a, e, i, o, u into the microphone, and observe the wave patterns. If possible, sketch them on the bottom of the data sheet. If the tones can be maintained for a long enough time, it may be possible to synchronize the oscilloscope sweep-circuit with them. Investigate other sounds that may be produced, for example, whistles, hisses, snap of fingers, and so forth.

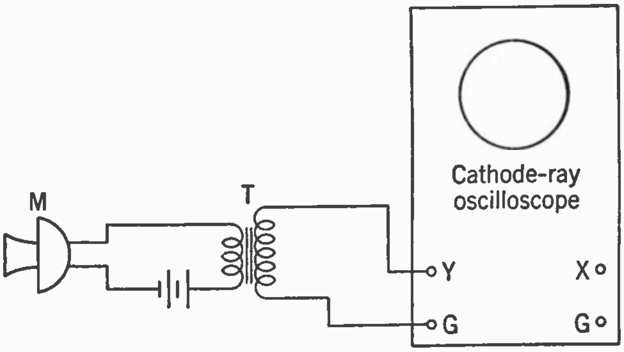

FIG. 17–8.

**Reference:**

1. Everitt, W. L., *et al.*, "Fundamentals of Radio," pp. 153–162.

**Name** ________________ **Date** ________________ **Class** ________________

## DATA SHEET—EXPERIMENT 17

A. Resistance of transmitter = ................ ohms

Resistance of receiver = ................ ohms

B. ........................................

........................................

........................................

C–D. ........................................

........................................

........................................

E–F. ........................................

........................................

........................................

G. ........................................

........................................

........................................

**Name** ---------------------------------------- **Date** -------------------- **Class**--------------------

## QUESTION SHEET—EXPERIMENT 17

1. Why should a telephone receiver always be poled so that the direct current in the coils increases the pull of the magnets on the diaphragm?

2. What are the advantages of the common-battery telephone circuit?

3. What is the purpose of the *retard coil* in the common-battery circuit?

4. Why is it desirable that apparatus used to transmit radio programs be of higher quality (that is, transmit a wider band of frequencies) than that used in ordinary telephone service?

## EXPERIMENT 18

# Public-address System

### APPARATUS REQUIRED

| ITEM | QUANTITY |
|---|---|
| Public-address system, complete with microphone and speaker | 1 |
| Cathode-ray oscilloscope | 1 |
| Beat-frequency oscillator | 1 |
| Output meter | 1 |
| Resistance load (500 or 10 ohms) | 1 |
| Baffles, assorted sizes | 3 |
| Phonograph turntable and pickup (optional) | 1 |

By public-address system is meant an assembly of equipment arranged to supply a volume of sound sufficiently large that musical programs, addresses, and so on, may be heard clearly by large gatherings of people. In addition to their uses for entertainment purposes, public-address systems are much used as paging systems in railroad terminals, airports, factories, and similar places, and for giving orders on shipboard. In short, a public-address system is useful in any location where audition would be difficult without it.

Public-address systems have a wide range in size. Very small units will serve an audience of forty or fifty individuals; monster units are capable of projecting sound to all parts of a huge stadium seating a hundred thousand or so persons. The differences between such units are of size rather than of principle, and much may be learned concerning the proper installation and operation of such equipment by a study of one of the smaller units.

Every public-address system, whether large or small, has at least one of each of the following pieces of equipment:

1. A low-level *transducer* for converting sound (or mechanical) energy into electrical energy. This includes microphones, phonograph pickups, and similar pieces.
2. A *level control* for regulating the volume of the sound amplifier. When there are two or more sources of sound, each is usually provided with an individual level control, so that *mixing* or blending of the sources is possible.
3. A *voltage amplifier*, for increasing the minute voltages produced by the low-level transducer to a value capable of driving the power amplifier.
4. A *power amplifier*, for supplying the large amounts of energy necessary to project the sound.
5. A *high-level transducer*, or *loudspeakers*, for reconverting the electrical energy into sound energy.
6. A *power supply*.

### Low-level Transducers

**A. Microphones.** The microphones most often used in public address work are the crystal, velocity (or ribbon), and dynamic (or moving-coil) types. Any of the above types of microphone is capable of excellent performance, and a choice is usually made on the basis of directional characteristics. The velocity microphone does not pick up sound originating at its sides; this provides a means of preventing unwanted noises from entering the system and being reproduced at great volume. Other types, notably some dynamic microphones, do not pick up sound originating behind them.

**B. Phonograph Pickups.** Phonograph pickups are used whenever phonograph records are to be played over a public-address system. *Crystal* and *magnetic* pickups are available; the former giving good quality at low cost, the latter excellent quality at a somewhat higher cost. Crystal pickups (and microphones) are influenced somewhat by weather conditions; the magnetic pickup is a somewhat better performer in this respect. The output of the pickup is fed directly into the public-address amplifier.

## Level Controls and Mixers

In small public-address installations, the control of *level* or volume is accomplished by a potentiometer or voltage-divider system, exactly as in a radio receiver. The control must be mechanically rugged, since a great deal of use is inevitable, and a noisy control will cause loud crashes. Large public-address systems are usually equipped with *attenuators*.

A very inexpensive type of mixer that is sometimes employed in public-address amplifiers is shown in Fig. 18–1; it provides facilities for mixing inputs from two microphones. With this simple mixer, a change in the setting of one control changes the resistance between the slider of the opposite control and ground, causing a change in its level also. For this reason, the arrangement of Fig. 18–1 is not a very satisfactory one. Figure 18–2 illustrates a much better mixer, of the so-called electronic type. Here individual level control occurs in the grid circuits of the vacuum tubes VT–1 and VT–2, while the actual mixing takes place in their plate circuits. This method eliminates all interaction between the mixer controls.

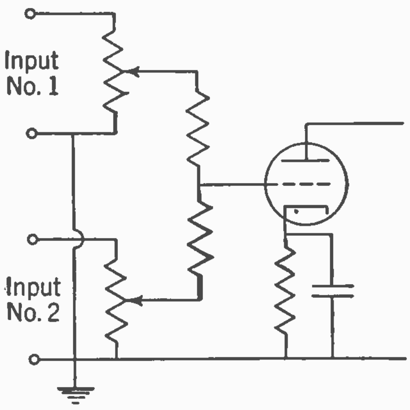

Fig. 18–1. Simple One-tube Audio Mixer.

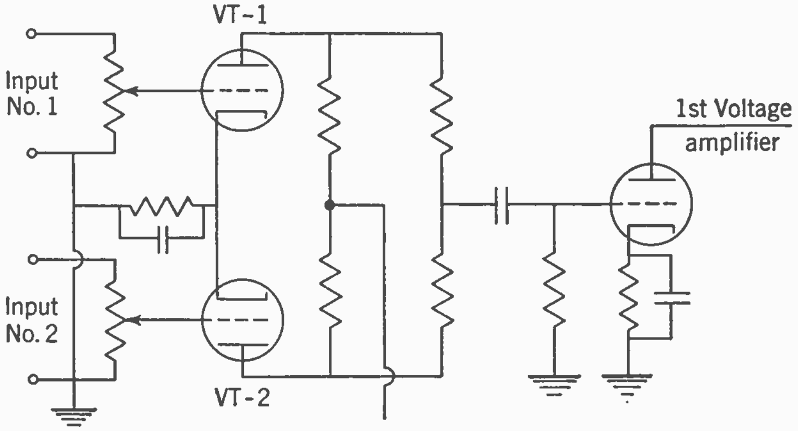

Fig. 18–2. Two-channel Audio Mixer.

Very large and expensive public-address systems frequently are equipped with *T-type* attenuators for mixing. These will be found described in references. The input circuits of a mixer are usually called "channels."

## Voltage Amplifiers

The voltage amplifiers used in public-address systems are much like those used in radio receivers. Elaborate precautions must be taken in the low-level amplifiers to guard against hum, and, since as many as four stages of voltage amplification are often used in large amplifiers, effective means must be provided to eliminate feedback and resultant oscillation. A very wide frequency range is desirable where reproduction of music is required.

When microphones must be situated at a considerable distance from the amplifier, a large part of the rather minute amounts of electrical energy produced by the microphones may be dissipated in the necessary long connecting cables. Furthermore, voltages having a frequency of 60 cycles may be induced into the cables by fields from nearby power wires. If the cables are long, these interfering voltages may be large enough to produce a serious hum if the gain of the main amplifier is increased to compensate for the losses in the cable. For these reasons *preamplifiers* are often used close to the microphone in order to supply relatively large voltages to the long cables. These are simply voltage amplifiers designed to have very low noise and hum levels.

## Power Amplifiers

The power amplifiers used in public-address work may be operated Class A, Class AB, or Class B. Class A amplifiers are most used in indoor installations where high-fidelity reproduction of music is desired. Class AB and Class B power amplifiers are used for out-of-door service where very great amounts of power are necessary and where intelligibility of speech is required, rather than high-quality reproduction of music. In all but the very smallest public-address systems, the power stage is operated in push-pull connection.

Triode power tubes are used in many installations using Class A amplifiers and Class B amplifiers. Many of the amplifiers designed for Class AB operation employ beam power tubes.

## Loudspeakers

There is a great variety of types of public-address loudspeakers. Almost without exception they are of the dynamic or moving-coil type. The necessary magnetic field is often supplied by a massive permanent magnet, although speakers having a field coil are also much used.

Where projection of sound over great distances is necessary, horn or trumpet loudspeakers are used; when these must be used, a sacrifice of fidelity is the price that must be paid for the increased efficiency, except in the largest units.

Most medium and small public-address installations use some form of cone loudspeaker. In this case, the loudspeaker must be provided with a *baffle* if satisfactory low-frequency reproduction is to be obtained. This baffle may be a wood or fiber board three or four feet square (the larger the better) with a hole in the center; behind this hole the speaker is mounted. The baffle board prevents the wave of air produced by a forward motion of the speaker cone from leaking around to the rear of the cone; it does not act as a sounding board, as is sometimes thought. The use of box baffles is undesirable because resonances resulting from reflections of sound waves inside the box often produce an unpleasant boomy tone.

The impedances of the loudspeaker voice coils must be matched to those of the power amplifier tubes for satisfactory operation. If the loudspeakers are located more than about fifty feet from the power amplifier, this transformation should be made in two steps. The output transformer of the amplifier should be wound to match a load of 500 ohms, and the speakers should have transformers to match the 500 ohms to their voice coils. By operating the long speaker lines at the 500-ohm impedance level, excessive line losses are avoided.

## Power Supplies

The power supplies used for public-address work are very much like those used in radio receivers, except for size. In large systems, mercury-vapor rectifier tubes are used. The power supplies for preamplifiers and low-level stages must be extremely well filtered if hum is to be avoided.

The subject of public-address systems is a very extensive one, and, of course, a really adequate discussion cannot be given in the brief space available here. The student is urged to consult the listed references for further information. A study of the catalogs of radio supply companies will supply much valuable information on current practices and equipment for public-address work.

## Experimental Procedure

**A.** Draw on the blackboard a complete circuit diagram of the public-address amplifier. Start with the input terminals, and discuss the function of each stage and its circuits before proceeding to the following stage. Classify the various parts under the divisions given in the discussion. Copy this diagram on the data sheet.

**B.** Connect a load resistor of the proper value across the output terminals of the amplifier,* and to one of its input channels connect the audio-frequency oscillator. Connect the cathode-ray oscilloscope across the load resistor, and, after setting the frequency of the oscillator at 500 cycles, increase the input

---

* If the amplifier has a 500-ohm output, use this value of resistance. If unmarked, disconnect the loudspeaker voice coil by unsoldering its leads and substitute for it a 10-ohm load resistor.

to the amplifier until distortion of the output wave just becomes evident. Measure the voltage across the load resistor at this point, and enter the results in space A of the data sheet. Compute the maximum power output of the amplifier in the space provided.

**C.** Using the cathode-ray oscilloscope, trace the signal through the amplifier stage by stage. Again connect the oscilloscope across the load resistor, and increase the input until a considerable amount of distortion is evident. Trace through the amplifier with the oscilloscope to find the stage where the distortion is originating.

**D.** Connect the oscilloscope across the load resistor, and reduce the input to the amplifier until no distortion is observed.

Set the tone control of the amplifier to "treble," connect the output meter across the load resistor, and measure the output voltage at each of the frequencies listed in Table B of the data sheet, entering the voltages measured in this table. The oscilloscope should be connected across the amplifier input terminals during this test to aid in keeping the input voltage constant.

Repeat the above frequency run with the tone control set to the "bass" position.

Compute the power output for each of the above frequencies, and plot the results on the semilogarithmic graph sheet.

**E.** Reconnect the loudspeaker voice coil. With the input to the amplifier adjusted to give reasonably great volume, determine by listening the effect of adjusting the tone control when the oscillator frequency is set at (1) 100 cycles, (2) 500 cycles, (3) 1,000 cycles, (4) 5,000 cycles. Enter results in Table C.

**F.** Connect the microphone to the proper input terminals. Set the tone control to "treble," and slowly advance the amplifier gain or level control until a howling or "singing" occurs. This is caused by acoustic feedback. Try the effect of moving the microphone and speaker about. Record results in space D.

**G.** Reduce the setting of the gain control until acoustic feedback is eliminated. Speak into the microphone. Determine the effect of the tone-control setting on the intelligibility of speech. Speak the word "Mississippi" with the tone control set to "bass" and then to "treble." Do the hissing sounds come out clearly with the tone control set to "bass"? Note also whether or not the microphone is directional, that is, whether it is less sensitive towards the back and sides. Answer in space E.

**H.** Connect a phonograph pickup unit to another input terminal of the amplifier. Place a record on the turntable, lower the pickup, and advance the amplifier gain control until the music is clearly audible. Now have someone speak or sing into the microphone, and, using the mixers, fade and blend the two signals.

**I.** Remove the loudspeaker from its baffle, and play a musical record, noting the tone quality. While the record is playing, successively place on the speaker a 15-inch-square baffle, then a 36-inch-square baffle, and finally the largest obtainable baffle. The baffles may be of corrugated paper such as is used in packing cases, of wood, or of any other nonmetallic material. Record the results in space F.

**References:**

1. Everitt, W. L., *et al.*, "Fundamentals of Radio," pp. 192–200.
2. Henney, Keith, "Principles of Radio," 4th ed., chap. 11 and Art. 314–322.

**Name** ________________________ **Date** ______________ **Class** ______________

## DATA SHEET—EXPERIMENT 18

AMPLIFIER CIRCUIT DIAGRAM

A. Output voltage = ______________ v Load resistance = ______________ ohms

Maximum undistorted power output $= \dfrac{E^2}{R_L} =$ ______________ watts

### TABLE B

| Frequency, c.p.s. | Tone control "treble" | | Tone control "bass" | |
|---|---|---|---|---|
| | Load, volts | Power output, watts | Load, volts | Power output, watts |
| 50 | | | | |
| 100 | | | | |
| 200 | | | | |
| 500 | | | | |
| 1,000 | | | | |
| 2,000 | | | | |
| 5,000 | | | | |
| 10,000 | | | | |

*Continued on next page*

TABLE C

| Frequency, c.p.s. | Effect of tone-control adjustment |
|---|---|
| 100 | |
| 500 | |
| 1,000 | |
| 5,000 | |

D. ..........................................................................................

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E. ..........................................................................................

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F. ..........................................................................................

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Name ________________________________________ Date ____________________ Class____________________

## QUESTION SHEET—EXPERIMENT 18

1. What steps should be taken to prevent acoustic feedback when the microphone must be located near the loudspeakers?

2. Why should shielded cables always be used for connecting microphones and phonograph pickups to an amplifier?

3. A paging system is located in a noisy factory. Should the amplifier tone control be set to "treble" or "bass" for best results?

4. Explain how the tone control works.

5. The acoustic (sound) power delivered by the loudspeaker is probably not more than 10% of the electrical power delivered to the voice coil. Approximately what is the maximum acoustic power delivered by the unit under test?

## EXPERIMENT 19

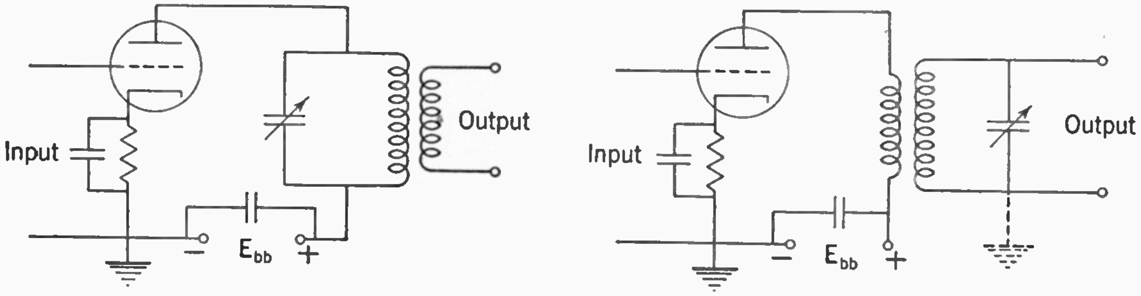
# The Class A Radio-frequency Amplifier

### APPARATUS REQUIRED

| ITEM | QUANTITY |
|---|---|
| Radio-frequency amplifier unit (see Appendix) | 1 |
| Power supply | 1 |
| Radio-frequency signal generator (with internal amplitude modulation) | 1 |
| Cathode-ray oscilloscope (with high-gain, wide-frequency amplifier) or vacuum tube voltmeter | 1 |
| Shielded leads, connecting wires, and so forth | — |

The voltages delivered to the antenna terminals of a radio receiver by the average receiving antenna are very small—of the order of a few thousandths of a volt or less—and therefore require considerable amplification before they can be demodulated or "detected" and applied to the loudspeaker. In previous experiments, the amplification of audio-frequency signals, such as result from the demodulation of radio signals, has been studied. Such amplification can be carried only so far, for serious hum and noise problems arise in the design of high-gain audio-frequency amplifiers. The usual practice in the design of radio receivers is therefore to provide means for amplifying the signal *before* it is demodulated. Amplifiers for this purpose are termed *radio-frequency* or *intermediate-frequency amplifiers*, the distinction being that the radio-frequency amplifier may be easily adjusted to operate at *many* frequencies, whereas the intermediate-frequency amplifier operates at a *fixed* frequency. In other respects the amplifiers are quite similar. In addition to providing a partial solution to the hum and noise problems, the use of radio- and intermediate-frequency amplifiers provides added *selectivity* and *sensitivity* in a receiver.

A radio-frequency amplifier for use in a receiver must be capable of amplifying the applied signal, including the superimposed modulation, without distortion. This means that the output voltage must be exactly proportional to the input voltage. Such performance is secured by operating the tube as a *Class A amplifier*, that is, one in which the plate current flows during the entire cycle of input voltage, and so biased that the grid never becomes positive. This type of operation yields low efficiency and low power output for a given tube, but these are of little consequence in a receiver anyway. Most radio-frequency amplifiers for use in receivers employ *antiresonant* circuits as loads, thereby providing *selective* amplification of signals whose frequencies lie within a narrow band, and eliminating other, unwanted signals. Some amplifiers used in television receivers are designed to amplify a great range of frequencies, including radio frequencies—these are called *wide-band* or *video-frequency* amplifiers.



(a) (b)

FIG. 19–1. Output Circuits for Class A Radio-frequency Amplifiers.

Pentode tubes are used almost exclusively in the radio-frequency stages of modern radio receivers. These are capable of yielding a very high voltage gain per stage, and require no troublesome neutralization, as did the earlier triode radio-frequency stages.

Many arrangements have been proposed and used for coupling radio-frequency amplifiers to their loads or to succeeding stages. Tuned air-core transformers are commonly used for this purpose. Two common arrangements are illustrated in Fig. 19–1. Note that at (a) the primary of the air-core transformer is tuned, while at (b) tuning is accomplished in the secondary circuit. The method shown in (b) permits grounding of one side of the tuning condenser; this is an advantage when several stages are to be tuned simultaneously, for ganged tuning condensers with a common ground terminal can be used.

Radio-frequency amplifiers have been the subject of much study and experiment, and the above discussion contains only the barest rudiments. The student is therefore urged to consult, before attempting to perform this experiment, one or more of the listed references where excellent and easily understood discussions will be found.

## Experimental Procedure

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**A.** Connect the signal generator, radio-frequency amplifier, and cathode-ray oscilloscope as indicated in Fig. 19–2. A good ground should be provided, and shielded leads used wherever indicated. Set the signal generator so as to obtain an *unmodulated* output at a frequency of 300 kc.* Turn the gain control of the oscilloscope and the signal-generator output control to maximum; then, after setting the plate-supply voltage at 250 v, carefully tune the amplifier until maximum response is obtained, reducing the oscilloscope gain as necessary to obtain about a four-inch deflection. Now set the signal generator to obtain a 300-kc *amplitude-modulated* wave, and, using the linear time base of the oscilloscope, stop and synchronize this pattern on the screen. If a symmetrical modulation envelope is not obtained, increase the resistance $R$ of the tuned circuit, then retune the amplifier for maximum response. Sketch the pattern obtained in space A of the data sheet.

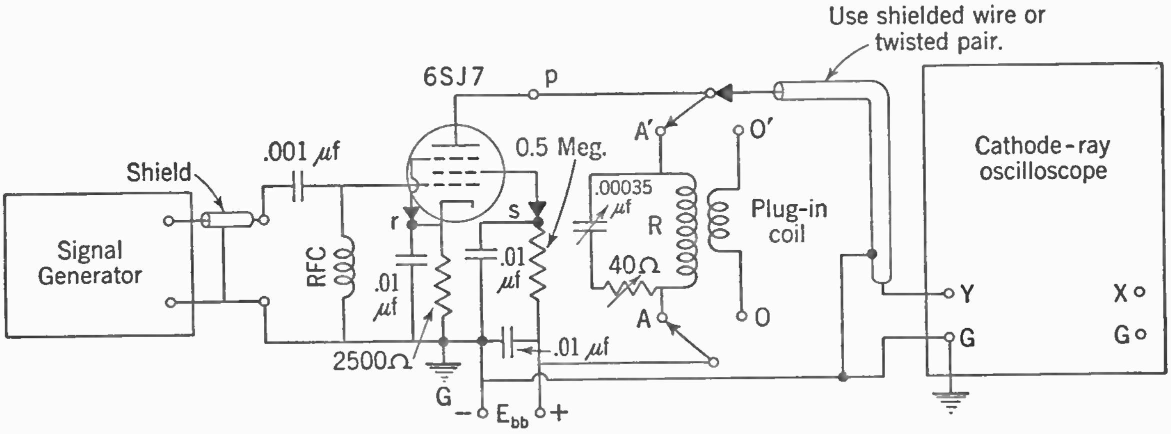

Fig. 19–2. Class A Radio-frequency Amplifier with Apparatus for Testing.

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**B.** Switch off the modulating frequency and turn the coarse frequency control of the oscilloscope to its maximum position and adjust the fine frequency control until a sinusoidal wave pattern is obtained. Note that this is a radio-frequency voltage which is oscillating at many thousands of cycles per second but can be observed by means of the cathode-ray oscilloscope.

Using an *unmodulated* input signal, adjust the gain control of the oscilloscope until a deflection of exactly four inches is obtained when the amplifier is tuned for maximum response. Switch the oscilloscope leads to the input terminals of the amplifier, and leaving the oscilloscope gain control untouched, measure and record in column 2 at the bottom of Table B the deflection obtained. The voltage gain of the amplifier

---

* If the amplifier cannot be tuned to 300-kc, use the lowest possible frequency to which it will tune. The oscilloscope will operate better when a low frequency is used. Set the voltage selector switch (if any) to the high position. This will prevent overloading of the first amplifier and consequent demodulation of the input signal.

is the ratio of the first deflection to the second. Repeat this procedure for input frequencies 2, 4, 6, 8 kc, and so on, *above* and *below* the frequency of maximum response, thus obtaining data for a *response curve* showing the gain of the amplifier as a function of input frequency. Keep the *input* voltage to the amplifier constant during this run by checking with the oscilloscope after each change in frequency or by determining that the output at the signal generator is constant over the range used. On the graph sheet, plot a curve showing *output* (deflection in inches) against *frequency*. Label this curve "B."

**C.** Repeat part B, with the resistance in the amplifier tuned circuit set at its maximum value (40 ohms). Enter data in Table B, column 3. Plot these data on the graph sheet, labeling the resulting curve "C."

**D.** Connect the tube as a *triode* by disconnecting the suppressor- and screen-grid wires at points (r) and (s) and joining them to the plate terminal at point (p). Set *R* at the minimum value consistent with undistorted output, determined as in part A, and repeat part B with this connection of the tube, entering data in Table B, column 4. Plot the response curve on the graph sheet, and label it "D."

**E.** Reconnect the tube as a pentode, and again tune the amplifier to 300 kc, or to the same frequency that was used in part A. Obtain a four-inch deflection on the oscilloscope by adjustment of its gain control, then switch its leads to terminals O–O′ (see Fig. 19–2). (Point O should be grounded by connecting to point G.) Measure the deflection obtained, and record in Table C. Leave the oscilloscope gain control at the setting used here for use in part F below.

**F.** Connect the plate lead of the tube to point O′, and the $E_{bb}(+)$ lead to point O after ungrounding it. Connect the oscilloscope leads to terminals A–A′, and leaving the oscilloscope gain control unchanged, tune the amplifier for maximum response. Record the deflection obtained in Table C. Switch the oscilloscope leads to terminals O′–G, and record the deflection obtained. Retune for maximum deflection before making a reading. Again apply a modulated input signal, and, using the linear time base, stop the pattern by adjusting the synchronizing control. Study the effect of (1) short-circuiting the self-bias resistor, (2) removing the cathode by-pass condenser, (3) grounding the screen grid of the tube, and (4) removing the screen by-pass condenser. Faults such as these often occur in radio receivers. Record results in space D.

**References:**

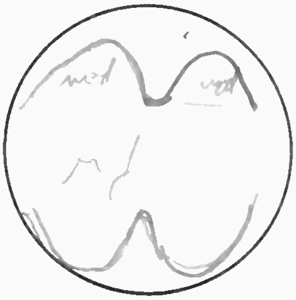
2.6 " high

1. Everitt, W. L., *et al.*, "Fundamentals of Radio," pp. 243–262.
2. Henney, Keith, "Principles of Radio," 4th ed., pp. 323–358.
3. Hoag, J. B., "Basic Radio," chap. 27.

Table "

Name ______________ Date ______________ Class ______________

## DATA SHEET—EXPERIMENT 19



A. MODULATED RADIO-FREQUENCY OUTPUT

TABLE B

| Frequency of signal input, kilocycles | | Deflection, inches | | |
|---|---|---|---|---|
| | | Column 2 Pentode tube | Column 3 Pentode tube | Column 4 Triode tube |
| | | R = 0 ohms | R = 40 ohms | R = 0 ohms |
| 1 | 270 | 26 4 | 8.5 | 17.2 |
| 2 | 272 | 18 | 8.3 | 16.2 |
| 3 | 274 | 13.5 | 8.2 | 14.2 |
| 4 | 276 | 11. | 7.5 | 12. |
| 5 | 278 | 8.5 | 6.8 | 10.5 |
| 6 | 280 | 7.2 | 6.2 | ~~10~~ 9.2 |
| 7 | 268 | 24. | 8.3 | 17. |
| 8 | 266 | 18 | 7.6 | 15.3 |
| 9 | 264 | 13.5 | 7.3 | 13.7 |
| 10 | 262 | 11 | 6.6 | 11.6 |
| 11 | 260 | 8 | 5.8 | 9.6 |
| 12 | 258 | 7 | 5.3 | 8.8 |
| 13 | | | | |
| 14 | | | | |
| 15 | | | | |
| 16 | | | | |
| 17 | | | | |
| Input (inches) | | 1.75 | 1.75 | 1.75 |
| Gain at resonance | | | | |

TABLE C

| Part | Oscilloscope connection | Deflection in inches |
|---|---|---|
| E | A′–G | 26 |
| | O′–O | 26.5 |
| F | A′–A | 26 |
| | O′–G | 26 |

*Continued on next page*

D. 1. ..............................................................................................................

2. ..............................................................................................................

3. ..............................................................................................................

4. ..............................................................................................................

**Name** ________________________ **Date** ______________ **Class**______________

## QUESTION SHEET—EXPERIMENT 19

1. What is the fundamental difference between radio-frequency and audio-frequency amplifiers?

2. What advantages are obtained by using an antiresonant circuit as the plate load of a radio-frequency amplifier?

3. What advantages does the pentode tube have over the triode tube as a radio-frequency amplifier?

4. Why is excessive resistance undesirable in the tuned circuit of a radio-frequency amplifier?

5. (a) What is the purpose of the screen by-pass condenser?

5. (b) What is the purpose of the cathode by-pass condenser?

Name ........................................ Date .................... Class ....................

## GRAPHS—EXPERIMENT 19

Frequency against Output: B, pentode, *R* = .............. ohms; C, pentode, *R* = .............. ohms; D, triode, *R* = .............. ohms.

## EXPERIMENT 20

# The Class C Radio-frequency Amplifier

### APPARATUS REQUIRED

| ITEM | QUANTITY |
|---|---|
| Oscillator–Class-C-amplifier unit (see Appendix) | 1 |
| Power supply | 1 |
| Calibrated wave meter with flashlight lamp | 1 |
| 6–8-v, 0.5-amp lamps and sockets | 2 |
| Resistance (variable) 0–40 ohms, 4-watt | 1 |
| Voltmeter, D.C., 0–10–100–500-v, or multimeter | 1 |
| Milliammeter, D.C., 0–10-ma | 1 |
| Milliammeter, D.C., 0–100-ma | 1 |
| Connecting wires | — |

In order to produce a satisfactory level of signal over its service area, a radio transmitter must be capable of delivering large amounts of power to its antenna—amounts sufficient, in some cases, to light a fair-sized town. It is apparent, therefore, that the power bill of such a transmitter forms quite a large proportion of its operating expense, and it is desirable to use the most efficient means available for converting the low-frequency (60-cycle) energy delivered by the service mains into high-frequency (radio-frequency) energy capable of being radiated as radio waves. This conversion could, of course, be accomplished by a very large tube acting as a radio-frequency oscillator. However, such an arrangement would be very unsatisfactory from the standpoint of *frequency stability*, for the frequency of the oscillator would vary with fluctuations in the supply voltage, with changes in temperature as the oscillator "warmed up"—in fact, with every random change in any part of its circuit. For this reason, it is modern practice to use a carefully compensated and regulated low-power *crystal-controlled oscillator*, and then to *amplify* its output by using radio-frequency amplifiers. Although the Class A radio-frequency amplifier, as studied in Experiment 19, would be capable of serving this purpose, its efficiency as a power amplifier is very low—of the order of only 20%—so that its use would be very uneconomical. A solution to this problem is found in the *Class C radio-frequency amplifier*.

The Class C radio-frequency amplifier differs from the Class A radio-frequency amplifier studied in Experiment 19 *only in the amount of bias and signal voltages applied to the tube.* In the Class A amplifier,

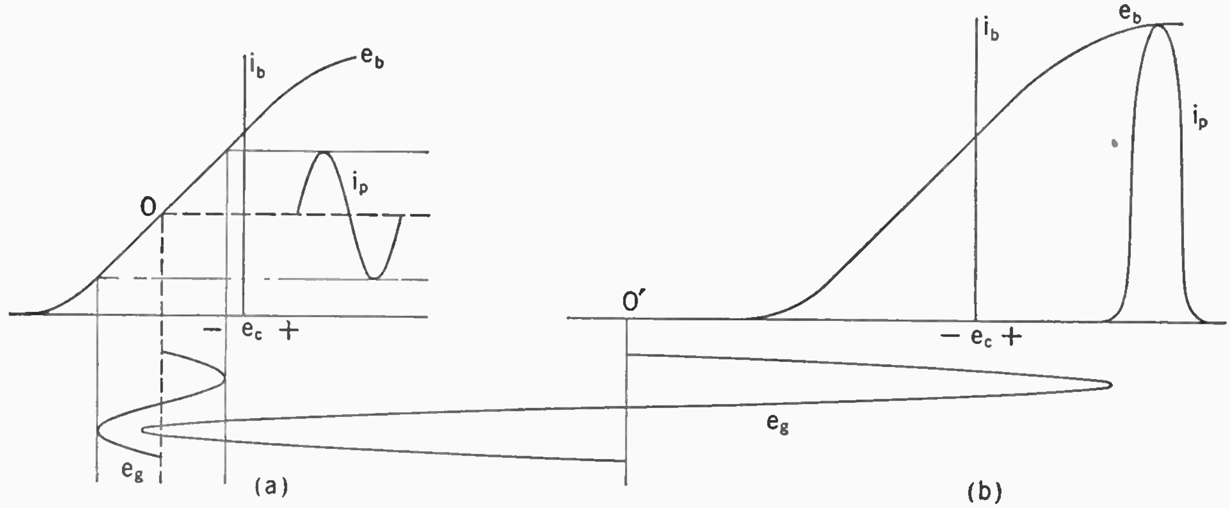


FIG. 20–1. (a) Class A and (b) Class C Amplifier Operation.

the bias is such that D.C. plate current flows even when no signal is applied, and the signal voltage must be small enough so that (1) the plate current is not cut off during the negative half cycle of the signal voltage, and (2) the grid is never driven positive. In the Class C amplifier, on the other hand, the bias voltage is made so great that (1) the plate current is cut off during *most* of the cycle, and (2) the signal voltage is made so great that the grid is driven *considerably* positive. The difference between Class A and Class C operation of a tube is illustrated in Fig. 20–1. The steady plate voltage is the same in each case.

If it is remembered that the *change* in the plate current of a tube determines its useful output, the reason for the high efficiency and output of the Class C amplifier is apparent, for the change in plate current is seen to be several times that obtained in Class A operation, using the same tube and same plate voltage.

It should be noticed that the plate current flows in separate pulses in the case of Class C operation. This pulsating current would result in very severe distortion if a resistance were used as the load; however, if an antiresonant *tank circuit* is used instead of the resistor, it is found that the output of the amplifier is essentially sinusoidal, because the antiresonant circuit tends to maintain a sine wave of current having a frequency equal to its own natural resonant frequency, when excited by a sharp pulse. This property is called the "flywheel effect," and an analogy may be drawn between the Class C amplifier and a one-cylinder gasoline engine, in which the piston receives a sharp pulse of power from the explosion of the fuel, and delivers it to the flywheel, which maintains a comparatively smooth flow of energy to the load during the remainder of the engine cycle.

A Class C amplifier may be made to serve as a *frequency multiplier* by tuning its tank circuit to an even multiple of the input frequency, so that the interval between successive pulses of plate current is sufficiently long for two or more oscillations of current to occur in the tank circuit. This situation is analogous to that existing in gasoline engines which fire only every second revolution of the crankshaft, the flywheel carrying the load between power strokes. Frequency doubling, tripling, and quadrupling are practical, but it is found that the tank circuit "runs down" too much between the pulses of plate current if higher orders of multiplication are attempted.

The problem of *self-oscillation* arises in Class C radio-frequency amplifiers. Referring to Fig. 20–2 (a), which shows the circuit of such an amplifier, it is seen that the internal grid-to-plate capacitance of the tube, plus that of the socket connections (represented by dotted symbols), together form a path through which some of the radio-frequency current flowing in the plate circuit may be diverted into the grid circuit. This current $I$ represents energy, enough of which may be diverted into the grid circuit to cause the amplifier to supply its own driving power and so become an oscillator. If it becomes an oscillator, it will no longer function as an amplifier, and instability and generally poor performance will result. This effect can be eliminated by *neutralization,* as indicated in Fig. 20–2 (b). Here a small *neutralizing condenser* $C_N$ has been connected in such a manner as to permit a current $I'$ to flow which is *equal in magnitude but opposite in direction* to that flowing through the grid-to-plate capacitance $C_{gp}$ of the tube. If Kirchhoff's current law is applied to this circuit, it is found that the net current, and hence the net energy flow, will

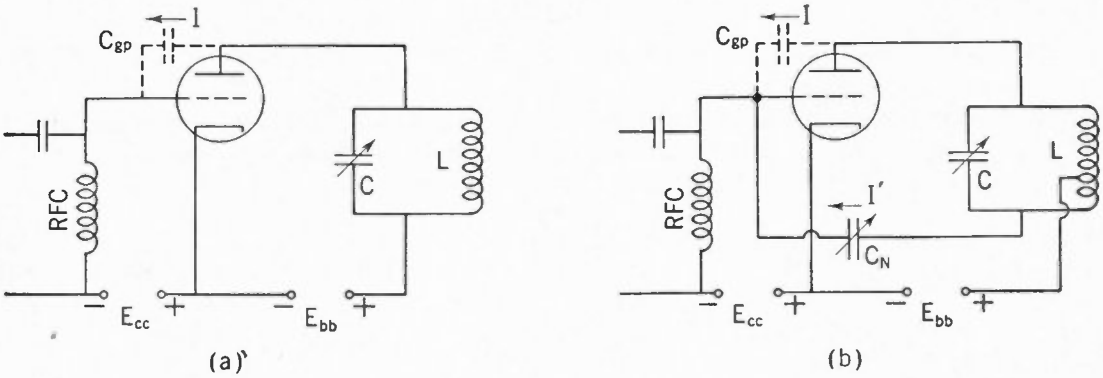


FIG. 20–2. (a) Unneutralized Class C Amplifier. (b) Neutralized Class C Amplifier.

be zero, so oscillation will not occur. Figure 20–2 (b) represent only one of a number of schemes that are used for neutralization.

Since the grid of a Class C amplifier is normally driven quite positive for a part of the cycle, a considerable flow of grid current occurs; this current represents a power loss that must be supplied by the *driver* which is used. Consequently, a Class C amplifier must always be driven by another (though smaller) power amplifier or by an oscillator.

If a resistor is inserted in series with the grid circuit of the Class C amplifier, and the direction of flow of grid current is examined, it will be found that the voltage drop across the resistor is of the correct polarity to supply the grid bias of the tube. This method of obtaining bias voltage, called *grid-leak bias,* is sometimes used, but is hazardous, since if the driver should fail the flow of grid current would be interrupted and the bias lost, resulting in a high value of plate current and possible destruction of the tube. Battery bias, or a linepowered bias supply, is a safer method. A combination of grid-leak and self bias is sometimes used.

## Experimental Procedure

A. Adjustment of the Amplifier and Neutralization. Connect the oscillator–Class-C-amplifier unit, power supply, and cathode-ray oscilloscope as indicated in Fig. 20–3. Disconnect the plate voltage from the Class C amplifier at O–O′. Set the wave-meter dial at a value corresponding to a frequency of 300 kc or some low frequency which can be generated by the oscillator. Turn on the power to the oscillator, loosely couple the wave meter to the oscillator tank, and tune the oscillator for maximum brilliance of the wave-meter lamp.

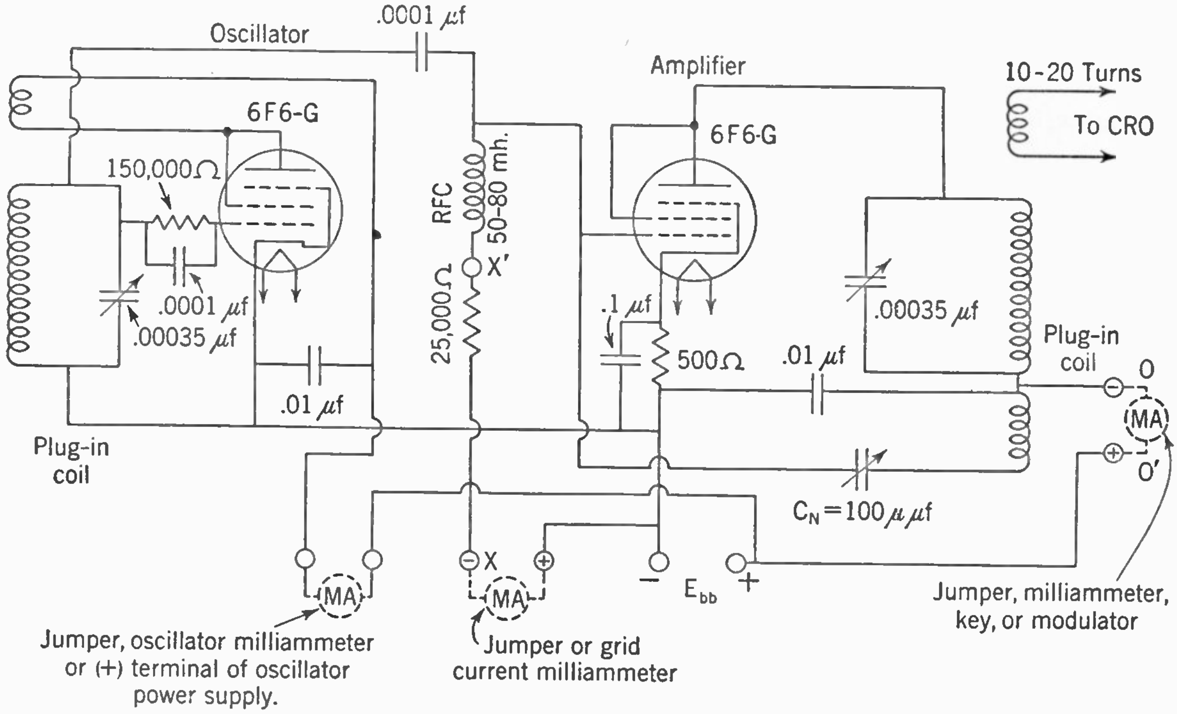


Fig. 20–3. Oscillator-Class-C-Amplifier Circuit.

Neutralizing the Amplifier. With the filament of the amplifier tube heated, radio frequency power applied to its input, and the plate voltage zero, tune the plate tank circuit back and forth through resonance, as evidenced by the rise and fall of the grid current. Adjust $C_N$ until the grid current no longer changes, or shows the minimum change when the tank circuit is tuned through resonance. The circuit is then neutralized for this particular value of frequency but may not be neutralized for values over a wide range. Record the data called for in column 1 of Table A on the data sheet.

After neutralization is complete, set the power supply to obtain about half of the maximum available output voltage, then connect the Class C plate circuit through a milliammeter at points O–O′. Slowly rotate the amplifier tank condenser, while watching the amplifier plate-current meter; tune for *minimum* plate current. Observe whether or not the setting of the tank condenser for *maximum* output voltage, as determined by the oscilloscope deflection, corresponds to the setting for *minimum* plate current. After tuning the amplifier to a minimum of plate current, increase its plate voltage to the maximum obtainable, and record the oscillator plate current, amplifier grid current, amplifier plate current, and oscilloscope deflection in Table A, column 2.

**B.** Loading the Amplifier and Measurement of Radio-frequency Power. Use a lamp in the wave meter[*] of high current capacity but of medium voltage. A 6–8-v .5-amp lamp should prove adequate for low-power oscillators. Arrange a second identical lamp in series with a suitable rheostat and power source (a 40-ohm rheostat and a 6-v source are suitable) and connect as shown in Fig. 20–4. This lamp will serve as a radio-frequency wattmeter by measuring its power input (D.C.) when at the same brilliance as the wave-meter lamp which is being supplied with radio-frequency power. Bring the wave-meter coil near the tank coil of the amplifier, and tune the wave meter for maximum brilliance of the lamp. Find the location of the wave-meter coil for maximum brilliance, and support the wave meter in this position. Bring the comparison lamp near to the wave-meter lamp, and adjust the series resistance until the lamps appear to be equally brilliant. A better comparison can be made by holding a sheet of paper directly on top of and the same distance from both lamps. Record the oscillator plate current, amplifier grid and plate currents and plate voltage, oscilloscope deflection and the current through and voltage across the comparison lamp in Table A, column 3.

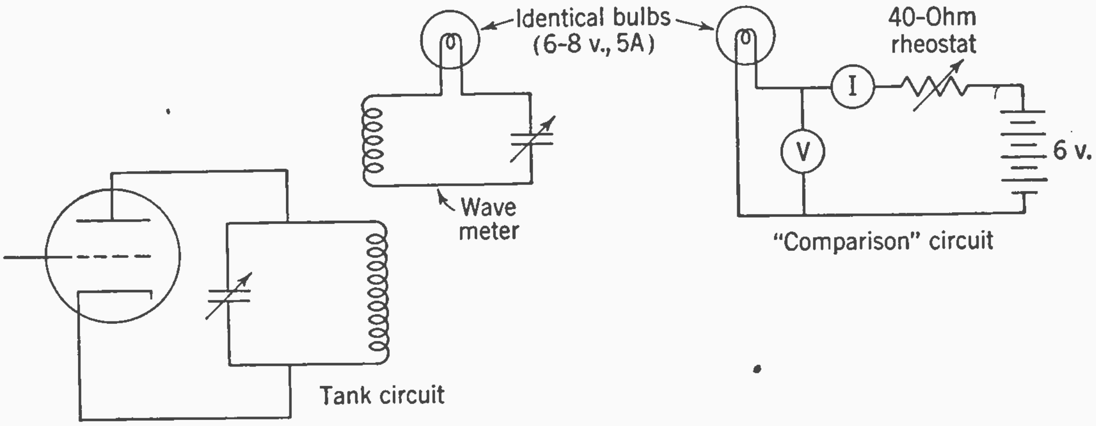


Fig. 20–4. Circuit for Measuring Radio-frequency Power Output of Class C Amplifier.

It should be understood that in actual radio service, the load of a Class C amplifier would be either a transmitting antenna or another and larger Class C amplifier, not a lamp or resistor.

**C.** Reaction of Load on Amplifier—Impedance Matching. With the wave meter still in the same position as for part B, vary the setting of its dial and notice the effect on the amplifier plate and grid currents. Retune the wave meter to resonance, and observe the effect of varying the coupling on the final amplifier plate current and on the brilliance of the lamp. Try to find an optimum value of coupling, where either an increase or decrease of coupling causes a dimming of the lamp. At this point the impedance of the lamp load is *matched* to that of the amplifier by means of the air-core transformer consisting of the tank and wave-meter coils. Record observations in space B.

---

[*] Since the wave meter and lamp are to be used as a load for the amplifier, the resistance of the wave-meter coil should be low and the current capacity of the lamp high. The usual plug-in coil used in radio receivers has too much resistance in it to serve as a suitable coil for the wave meter for this part of the experiment; hence a coil of suitable inductance and of low resistance must be provided. A suitable coil can be procured from an obsolete radio receiver of the tuned radio-frequency or neutrodyne type, or can be constructed by winding sufficient turns of No. 20 or 22 enameled wire on a suitable coil form, which should be large enough to slip over the amplifier tank coil.

D. Frequency Multiplication. Set the oscillator-amplifier at its lowest frequency and by means of the wave meter measure this frequency and record it in Table C. Slowly decrease the capacitance of the tank tuning condenser until the oscilloscope deflection *dips* through a broad minimum, then returns to a fairly high value. Tune for minimum plate current at this point; then measure the frequency, using the wave meter. Again decrease the capacitance until another deflection maximum is found, and repeat the measurement of frequency. If this second point is not found, reset the amplifier tank condenser to maximum capacity, turn off the amplifier power supply, remove the amplifier tank coil from its socket, substitute a smaller coil, and then proceed as above. Find as many resonant points as possible, identifying each with the wave meter. Enter the frequencies obtained in Table C. These should be exact integral multiples of the fundamental frequency—any deviation is probably due to error in the wave meter.

E. Computation of Amplifier Efficiency. In part B, the power input to the loading lamp may be regarded as equal to the input to the comparison lamp—the latter can be calculated from the data of Table A, column 3. This value is thus equal to the power output of the amplifier. The power input to the amplifier is equal to the product of the plate voltage by the plate current.

Compute the power input, power output, and efficiency of this amplifier as operated in part B. Show your computations, and enter in space D.

**References:**

1. Everitt, W. L., *et al.*, "Fundamentals of Radio," pp. 252–253, 257–258, 272–273, 288.
2. Henney, Keith, "Principles of Radio," 4th ed., Art. 261–264.
3. Hoag, J. B., "Basic Radio," Art. 237 and chap. 27.
4. "The Radio Amateur's Handbook," Defense Ed., Art. 4–7 to 4–12.

**Name** ________________ **Date** ________________ **Class** ________________

## DATA SHEET—EXPERIMENT 20

### TABLE A

|  | Column 1 | Column 2 | Column 3 |
|---|---|---|---|
| Oscillator plate current |  |  |  |
| Amplifier grid current |  |  |  |
| Amplifier plate current |  |  |  |
| Amplifier plate voltage |  |  |  |
| Oscilloscope deflection |  |  |  |
| Comparison lamp voltage | ▨ | ▨ |  |
| Comparison lamp current | ▨ | ▨ |  |

B. ................................................................................................

................................................................................................

................................................................................................

### TABLE C

| Wave-meter dial | Frequency, kilocycles | Order of multiplication |
|---|---|---|
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

D. Amplifier power input $= E_{bb} \times I_b$

$= \ldots\ldots\ldots \times \ldots\ldots\ldots$

$= \ldots\ldots\ldots$ watts.

Amplifier power output $= E_{\text{lamp}} \times I_{\text{lamp}}$

$= \ldots\ldots\ldots \times \ldots\ldots\ldots$

$= \ldots\ldots\ldots$ watts.

$$\text{Efficiency} = \frac{\text{Power output}}{\text{Power input}} \times 100$$

$$= \frac{\ldots\ldots\ldots \text{ watts}}{\ldots\ldots\ldots \text{ watts}} \times 100$$

$= \ldots\ldots\ldots$ %.

**Name** ________________________ **Date** ______________ **Class** ______________

## QUESTION SHEET—EXPERIMENT 20

1. Why are Class C amplifiers used in transmitter circuits in preference to Class A amplifiers?

2. Can a Class C amplifier be used as a wide-band amplifier? Explain your answer.

3. What is the value of a frequency multiplier in radio transmission circuits?

4. What is the purpose of neutralizing a Class C amplifier?

## EXPERIMENT 21

# Demodulation—Simple Radio Receiver

### APPARATUS REQUIRED

| ITEM | QUANTITY |
|---|---|
| Demodulating unit complete with rectifier and diode tube (see Appendix) | 1 |
| Mica condenser, 0.01-$\mu$f | 1 |
| Mica condenser, 0.001-$\mu$f | 1 |
| Mica condenser, 0.0001-$\mu$f | 1 |
| Ohmmeter | 1 |
| Audio-frequency oscillator | 1 |
| Signal generator, amplitude-modulated | 1 |
| Cathode-ray oscilloscope (with wide-band high-gain internal amplifier) | 1 |
| Public-address system (Experiment 18) | 1 |
| Wire for antenna and lead wires | Assortment |

The transmission of intelligence by electrical means is usually accomplished by *modulating* an electrical quantity; that is, by causing it to vary in some manner—the variation being controlled by the sound or other impulse to be transmitted. Thus, in the study of the simple telephone system, it was seen that a direct current was varied in accordance with speech sounds; no sound issued from the receiver so long as the current remained steady or *unmodulated.* The steady direct current may thus be regarded as a vehicle, or *carrier,* on which the intelligence is conveyed.

In radio transmission, an alternating current of high frequency is employed as a carrier in place of the direct current of the simple telephone system. In an amplitude-modulated radio system the *magnitude* of this current is varied so as to be at any instant proportional to the pressure of the sound waves striking the microphone; in a television system the variation is proportional to the intensity of light falling on a photoelectric cell. Figure 21–1 represents graphically an unmodulated carrier and the same carrier modulated in accordance with complex speech sounds.

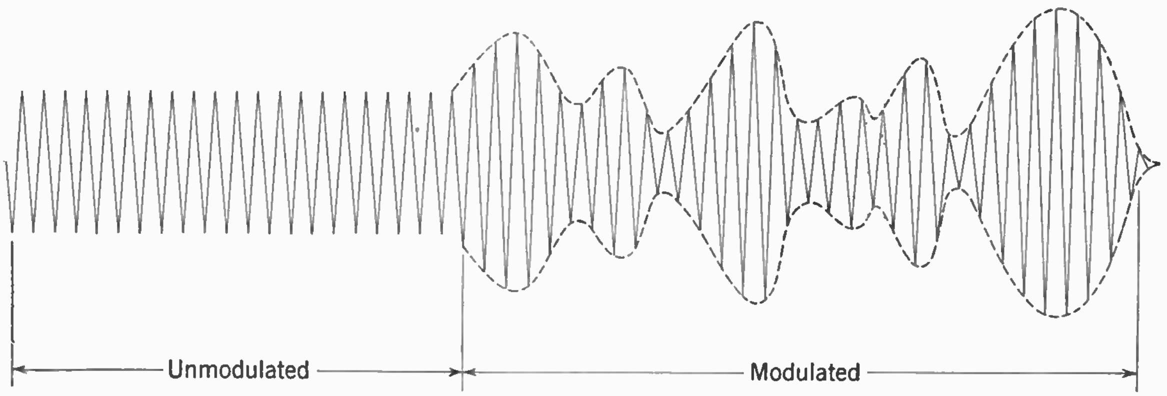


FIG. 21–1. Radio-frequency Carrier, Unmodulated and Modulated.

The mechanism by which modulation of a high-frequency carrier may be accomplished will be demonstrated in a later experiment; in this experiment some methods whereby modulated radio-frequency currents may be reconverted into intelligence will be studied.

Figure 21–2 (a) shows a telephone receiver connected to an antenna and ground system which will be assumed to be situated near a radio transmitter which is sending out a modulated wave, such as that of Fig. 21–1. If the electromagnetic field of the transmitter is sufficiently strong, a radio-frequency current will be produced in the coils of the receiver, the magnitude of which will vary in accordance with the modulation. It might be thought that this arrangement would be capable of *demodulating* the signal, so that it could be heard. However, if the student will recall that, in the study of telephone receivers, it was found that a current flowing through the coils in one direction caused a *pull* on the diaphragm, while one in the other direction caused a *push*, it will be apparent that the arrangement of Fig. 21–2 (a) will result in a succession of pulls and pushes on the diaphragm, each following the other *so rapidly* that the diaphragm will not have time to respond to a pull before a push urges it in the opposite direction. The result is, of course, total silence.

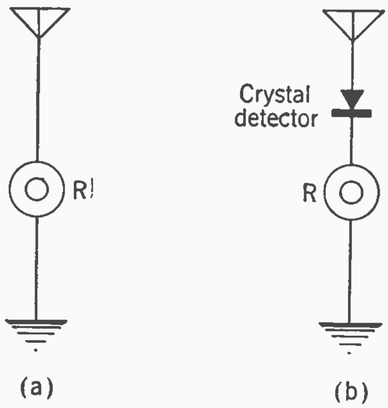


FIG. 21–2. Simple Radio Receiver.

Now let it be assumed that a *rectifier* is connected in series with the receiver, as in Fig. 21–2 (b). The rectifier limits current flow to *one* direction, and, therefore, either pushes alone or pulls alone will be delivered to the diaphragm; motion will result, and sound will be produced. The arrangement of Fig. 21–2 (b) is probably the simplest possible radio receiver.

No means are provided in Fig. 21–2 for the selection of signals of a desired frequency; if, therefore, several stations are operating nearby, all will be heard at once. This interference can be remedied by the use of an *antiresonant* circuit for tuning, as shown in Fig. 21–3 (a), or better, by the use of a tuned air-core transformer, as shown in Fig. 21–3 (b).

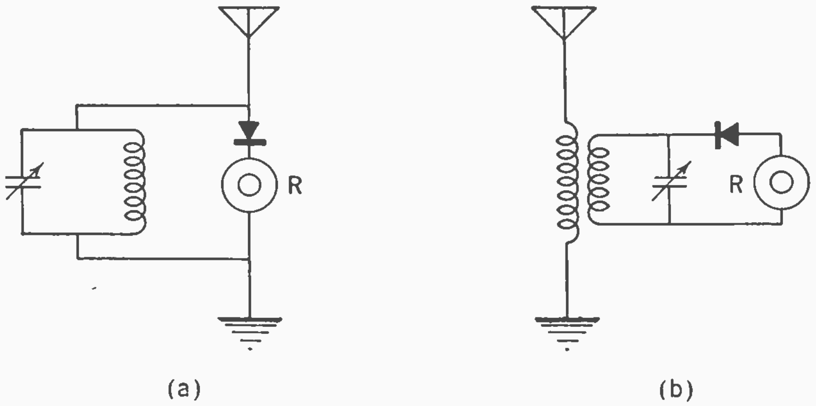


FIG. 21–3. Simple Radio Receiver Using Antiresonant Circuit.

The energy delivered to the telephone receivers in any of the above arrangements is obtained from the radio waves themselves. Since the amount of energy obtainable in this way is very slight, a large amount of amplification is necessary if enough energy to operate the receiver or drive a loudspeaker is to be obtained; in modern radio receivers, therefore, the detector or demodulator is preceded by radio-frequency voltage amplifiers and followed by audio-frequency voltage amplifiers and finally by a power amplifier to drive the loudspeaker.

Audio-frequency voltages for application to subsequent amplifiers are obtained by replacing the telephone receiver of Fig. 21–3 with a *load resistor* and *filter condenser* as shown in Fig. 21–4. The filter condenser aids in smoothing out the pulses of voltage produced by the rectified current, functioning much like a filter condenser in a power supply. It can have a much smaller capacitance, of course, since the frequency is higher and the load much less. Load resistances of 250,000 ohms and filter condensers of 0.0005 $\mu$f capacitance are typical of those commonly used.

In the early days of radio, *crystal detectors* of galena, silicon, iron pyrites, or other mineral substance were found to have rectifying properties and were much used as detectors or demodulators. Figure 21–5 shows a crystal detector. A fine sharply pointed wire of phosphor bronze, called a *cat whisker*, is arranged to bear upon the crystal at a sensitive point, as found by trial. The crystal itself is embedded in a block of alloy metal having a low melting point. This type of detector is again coming to the fore as a demodulator for ultrahigh-frequency signals, where other types of detectors fail. Crystals are not perfect rectifiers, as they permit an appreciable flow of current in the reverse direction. Contrary to popular opinion, the crystal is somewhat inferior to the vacuum tube from the standpoint of distortion produced by its rectifying action.

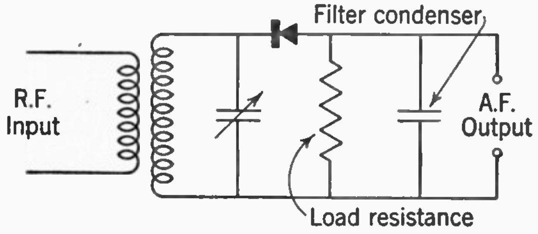


Fig. 21–4. A Dector Circuit.

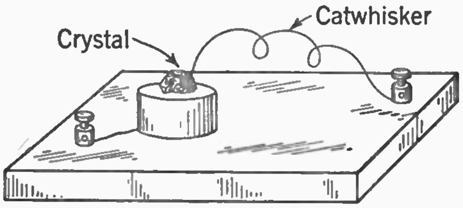


Fig. 21–5. Crystal Detector.

The most common demodulator is the *diode vacuum tube*. This device has been studied in several previous experiments, and so requires little further comment here. Diodes for this purpose are often placed in the same envelope with triode or pentode element assemblies, since the diodes used for demodulation are very small. Such *dual* tubes permit a saving in space and sockets—important in low-priced midget receivers.

Although other types of detectors—some employing triode tubes—have been used, they are of but little importance at the present time. A description of these is contained in the references.

## Experimental Procedure

**A. Crystal Rectification Characteristic.** Connect the crystal detector, 250,000-ohm load resistor, audio-frequency oscillator, and cathode-ray oscilloscope as indicated in Fig. 21–6. With this arrangement, the vertical deflection of the oscilloscope will be proportional to the instantaneous voltage

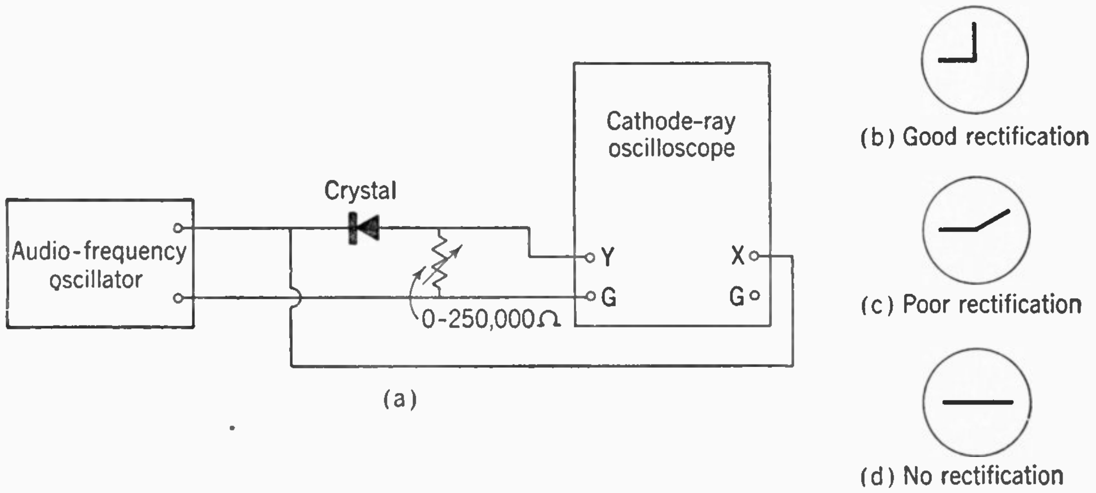


Fig. 21–6. Circuit for Testing the Rectifying Properties of a Crystal.

across the load resistor, while the horizontal deflection will be proportional to the applied voltage. For good performance, a vertical deflection (output of rectifier) should be obtained for positive half cycles of applied voltage and none for negative half cycles, giving a trace as shown in Fig. 21–6 (b). The more nearly the trace approaches a right angle, the better the detector. Set the audio-frequency oscillator at 1,000 cycles, advance the oscilloscope gain controls until convenient deflections are obtained, then proceed to find a sensitive spot on the crystal by moving the cat whisker about. After this point is found, determine the effect on the rectification characteristic caused by varying the output voltage of the oscillator. Sketch the traces for low, medium, and high output in spaces A–1, A–2, and A–3 of the data sheet. Using an ohmmeter, measure the resistance of the crystal alone in one direction; then reverse the leads to the ohmmeter, and measure the resistance in the reverse direction. The ratio of *forward* resistance to *reverse* resistance is called the *rectification ratio;* in a good crystal it will be 15 to 1 or greater. Record measurements in space B.

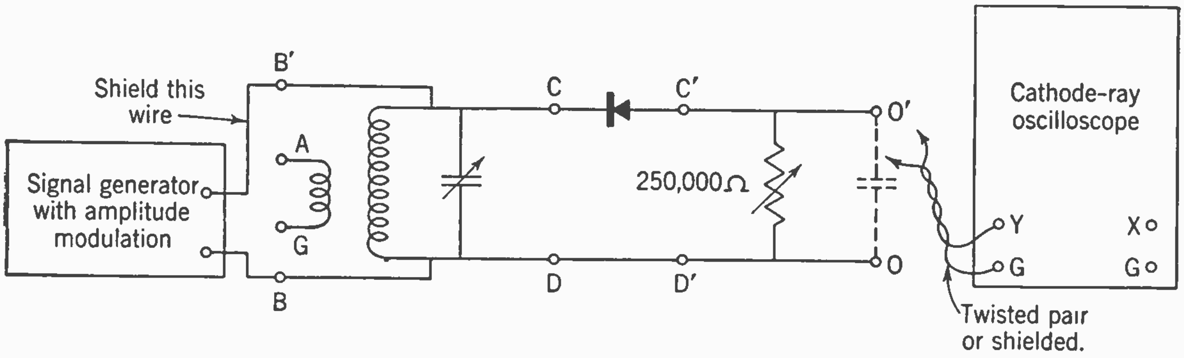


FIG. 21–7. A Study of Demodulation Using a Crystal Detector.

**B.** DEMODULATION OF RADIO-FREQUENCY SIGNALS. Connect the circuit of Fig. 21–7. Set the signal generator to obtain an amplitude-modulated output of 300 kc or the lowest frequency which can be tuned in with the resonant circuit used. Connect the cathode-ray oscilloscope to terminals B–B′, and tune the circuit for maximum deflection. Synchronize the modulation envelope, using the linear time-base sweep circuit. Transfer the oscilloscope leads to terminals O–O′. Note any fuzziness in the wave. Connect a 0.0001-μf condenser across terminals O–O′, and note whether or not the fuzziness of the wave is decreased. If not, use a larger condenser. Sketch the waves in spaces C–1, C–2, and C–3.

**C.** CONVERSION OF AUDIO-FREQUENCY SIGNAL INTO SOUND. Connect terminals O–O′ to one of the

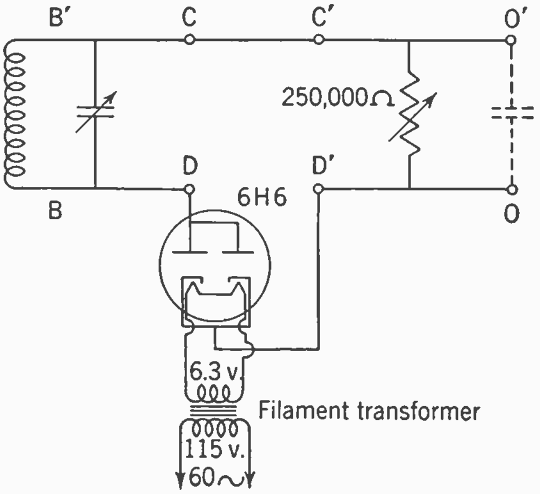


FIG. 21–8. A Study of Demodulation Using a Diode Tube.

input channels of the public-address system used in Experiment 18, and ground terminal O. A shielded lead should be used, and the shield connected to terminal O. Advance the amplifier gain control until the modulation frequency is clearly heard.

**D.** SIMPLE RADIO RECEIVER. Remove the signal generator, and connect terminal A to an antenna, which may be fifty feet or so of wire suspended about the room. Ground terminal G. Using a coil capable of being tuned to broadcast frequencies, proceed to tune in a station. Locate as many stations as possible. Note in particular whether or not the set is selective, that is, whether it tunes sharply. Record the number of divisions on the tuning dial over which the loudest receivable station can be heard. Record any comments you may have in space D.

**E.** Remove the crystal detector, and place a jumper between terminals C–C′. Connect a diode into the circuit, as indicated in Fig. 21–8, between points D–D′. The diode cannot be connected between terminals C–C′ because its cathode must be near ground potential; otherwise hum will result. Repeat part B, using the diode in place of the crystal detector. Record results in spaces E–1, E–2, and E–3.

**F.** Repeat part C, using the diode detector. Record results in space F–1.

**G.** Repeat part D, using the diode detector. Tune in the loudest station, and connect filter condensers of 0.0001, 0.001 and 0.01 $\mu$f capacitance across terminals O–O′. Notice in particular whether the high- or low-frequency response is most affected by large filter condensers. Record results in space F–2.

**References:**

1. Everitt, W. L., *et al.*, "Fundamentals of Radio," pp. 273–283, 317–318.
2. Henney, Keith, "Principles of Radio," 4th ed., chap. 14.
3. Hoag, J. B., "Basic Radio," chap. 17.
4. "The Radio Amateur's Handbook," Defense Ed., Art. 7–3.
5. Ghirardi, Alfred A., "Radio Physics Course," 2nd ed., chapters 16 and 20.

**Name** ________________ **Date** ________________ **Class** ________________

## DATA SHEET—EXPERIMENT 21

A–1
LOW OUTPUT

A–2
MEDIUM OUTPUT

A–3
HIGH OUPUT

B. Forward resistance = .................... ohms. Reverse resistance = .................... ohms.

Rectification ratio = .................... .

C–1
MODULATED
RADIO-FREQUENCY
WAVE

C–2
DEMODULATED WAVE,
NO FILTER
CONDENSER

C–3
DEMODULATED WAVE,

..................-μf
FILTER CONDENSER

D. ....................................................................................................

....................................................................................................

....................................................................................................

*Continued on next page*

E–1
MODULATED
RADIO-FREQUENCY
WAVE

E–2
DEMODULATED WAVE
NO FILTER
CONDENSER

E–3
DEMODULATED WAVE

..................-μf
FILTER CONDENSER

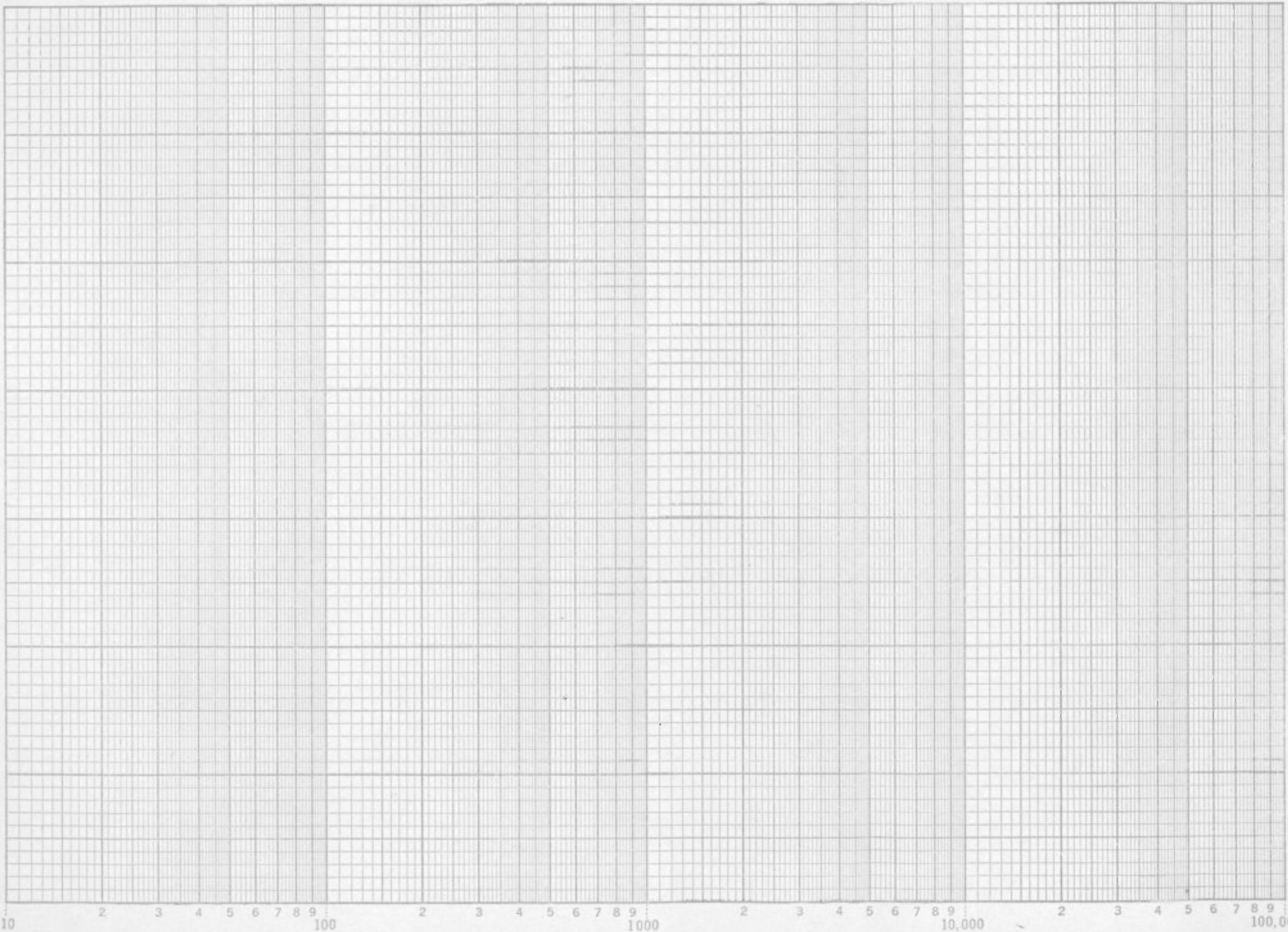
F. 1. ..............................................................................................................................................

F. 2. ..............................................................................................................................................

......................................................................................................................................................

## GRAPHS—EXPERIMENT 18

Power Output against Frequency Response: (a) Treble; (b) Bass



Name ..........................................

Date ..........................................

Class ..........................................

**Name** ________________ **Date** ________________ **Class** ________________

## QUESTION SHEET—EXPERIMENT 21

**1.** List the advantages of the diode as compared to the crystal detector when used as a demodulator.

**2.** Explain the fuzziness of the patterns obtained in parts B and E of this experiment.

**3.** What is the result of using too large a filter condenser with a diode or crystal detector? Why?

**4.** Is the output of the diode alternating current or pulsating direct current? If the latter, is the polarity such as to increase or decrease the magnitude of the bias voltage of a following audio-frequency amplifier tube, if direct coupling is used?

*Continued on next page*

**5.** Sketch a circuit consisting of a diode detector fed by a tuned air-core transformer, and showing (a) how a potentiometer can be used in the circuit as a volume control, and (b) where a blocking condenser would be inserted to prevent changes in the bias of a following amplifier tube by the effect mentioned in Question 4.

## EXPERIMENT 22

# A Study of Amplitude Modulation

### APPARATUS REQUIRED

| ITEM | QUANTITY |
|---|---|
| Oscillator–Class-C-amplifier unit as used in Experiment 20 | 1 |
| Modulator unit (see Appendix)...................... | 1 |
| Power Supplies.................................... | 2 |
| Voltmeter, D.C., 0–100–500 v........................ | 1 |
| Milliammeter, D.C., 0–10–100 ma.................... | 1 |
| Audio-frequency oscillator.......................... | 1 |
| Cathode-ray oscilloscope (with internal wide-frequency, high-gain amplifier)............................. | 1 |
| Connecting wires and so forth....................... | — |

As was pointed out in the discussion accompanying Experiment 21, the transmission of intelligence by radio is usually accomplished by varying the *amplitude* of a high-frequency *carrier* voltage in such a manner that it is at any instant proportional to the amplitude of the sound wave to be transmitted. This process is termed *modulation*, and is the subject of this experiment.

The student should, by this time, have a clear understanding of the way in which a sound wave may be translated into a wave of voltage or current, by the use of microphones and amplifiers. Modulation is accomplished by applying such audio-frequency voltages to a Class C radio-frequency amplifier at the proper point.

### Plate Modulation

It can be demonstrated experimentally that the radio-frequency output voltage of a properly adjusted Class C amplifier is very nearly proportional to its plate-supply voltage. If, then, the plate-supply voltage is caused to vary in accordance with the audio-frequency signal to be transmitted, a modulated radio-frequency output voltage will result. This process is called *plate modulation*, and is the type most frequently used in high-quality broadcast transmitters. The necessary variation in plate-supply voltage is secured by connecting the output of an audio-frequency amplifier (whose input is the audio-frequency signal) in series with the D.C. plate-voltage supply of the Class C amplifier. The D.C. plate-supply voltage must be larger than the crest value of the output voltage of the audio-frequency amplifier, for otherwise, during the negative half-cycles of the modulating voltage, the net plate-supply voltage of the Class C amplifier will become negative, and the amplifier will cease to function. When this condition occurs, the radio-frequency amplifier is said to be *overmodulated*.

An audio-frequency amplifier that is to serve as a plate modulator must function as a power amplifier, with the Class C radio-frequency amplifier as its load.

### Grid Modulation

A modulated radio-frequency output may be obtained by varying the *bias voltage* of a Class C radio-frequency amplifier in accordance with the audio-frequency signals to be transmitted. The usual arrangement is to connect the output of an audio-frequency amplifier in series with the *bias-voltage supply* of the Class C amplifier. In this case, the audio-frequency amplifier functions only as a voltage amplifier.

Grid modulation is characterized by relatively high distortion, and so is used principally in radio telephone service, where intelligibility and economy rather than high quality are of importance.

## Percentage of Modulation

The degree to which a radio-frequency signal is modulated is usually expressed as a percentage. For example, a signal that increases to one and one half times its unmodulated amplitude during modulation *peaks* and decreases to one half its unmodulated value during the *troughs* (see Fig. 22–1) is said to be modulated 50%, since the amount of variation away from the unmodulated value is equal to 50% of this latter value.

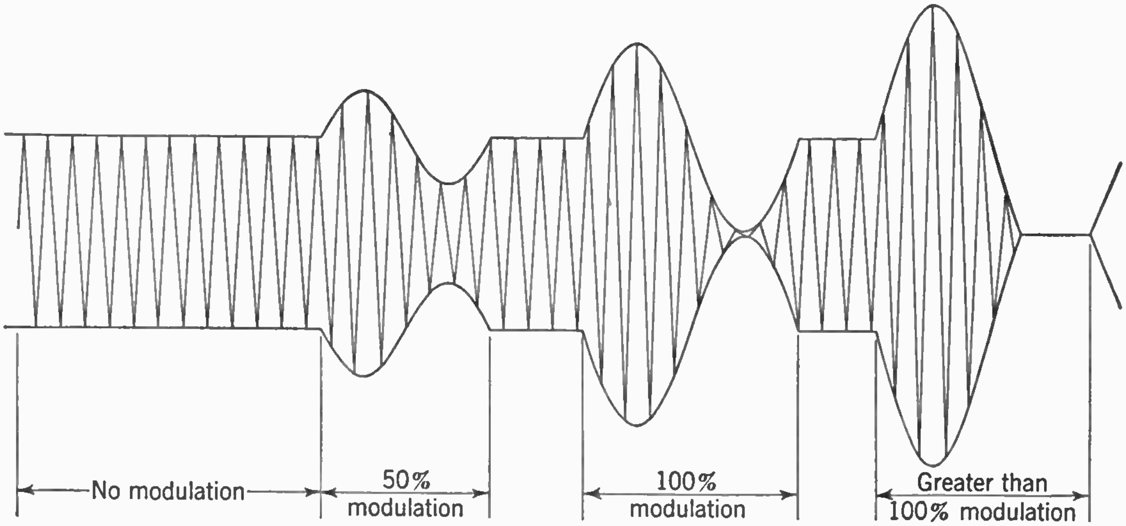


Fig. 22–1. Modulated Carrier Wave.

## Experimental Procedure

**A.** Variation of R.F. Output Voltage with Plate-supply Voltage. Connect the oscillator–Class-C-amplifier, power supplies, and cathode-ray oscilloscope as shown in Fig. 22–2. (Note that separate power supplies are used for the oscillator and Class C amplifier.) The pickup loop should consist of about 10 to 20 turns of insulated wire loosely looped around the amplifier tank coil. Set the oscillator plate-supply voltage at 300 v, and adjust the oscillator condenser to obtain a low output frequency (about 300 kc). Tune and neutralize the Class C amplifier, following the procedure outlined in Experiment 21. Set the amplifier plate-supply voltage at 300 v, turn the vertical ($Y$-axis) gain control of the oscilloscope to maximum, and, using the linear time-base controls of the oscilloscope, either adjust the coupling of the

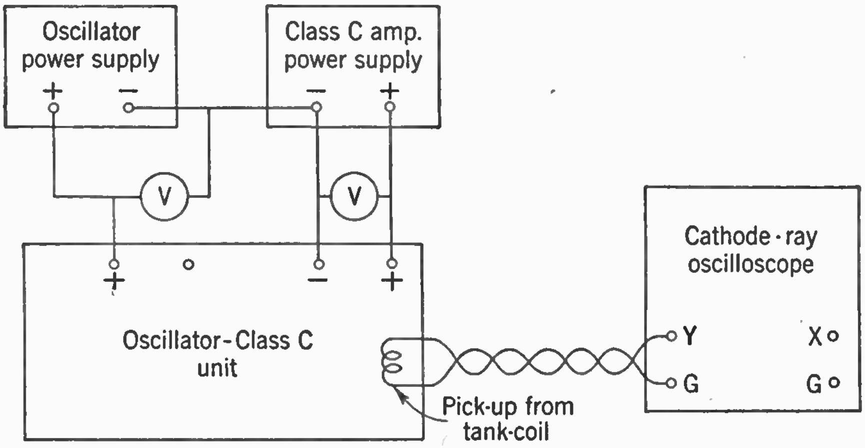


Fig. 22–2. Circuit for Part A.

pickup loop or change the number of its turns until approximately full-screen deflection on the oscilloscope is obtained. The pickup coil should then be firmly supported so its position will not change while data is being taken for Table A of the data sheet.

Vary the amplifier plate-supply voltage from 0 to 300 v in 50-v steps, measuring the deflection of the oscilloscope at each step. Enter the data in Table A, and plot a curve of deflection against amplifier plate-supply voltage on the top half of the graph sheet. (The deflection of the oscilloscope will be proportional to the radio-frequency output voltage of the Class C amplifier.)

B. Plate Modulation. Connect the output of the audio-frequency oscillator to the input terminals of the Class A modulator unit, Fig. 22–3, and connect the output terminals of this unit in series with the plate-voltage supply of the Class C amplifier at points O–O′. (See Fig. 20–3 of Experiment 20.) Use the Class C amplifier power supply as the source of power for the modulator unit. Adjust the audio-frequency oscillator to obtain an output frequency of about 1,000 cycles, and increase the setting of its output control until a change is noticed in the pattern on the oscilloscope screen. Using the linear time-axis and synchronizing controls, *stop* the pattern on the screen. Determine the effect of changing the output voltage and output frequency of the audio-frequency oscillator. Obtain patterns showing about 50%, 100%, and over 100% modulation, and sketch in the spaces of the data sheet. Notice whether or not a distorted *envelope* is obtained when the modulation approaches 100%.

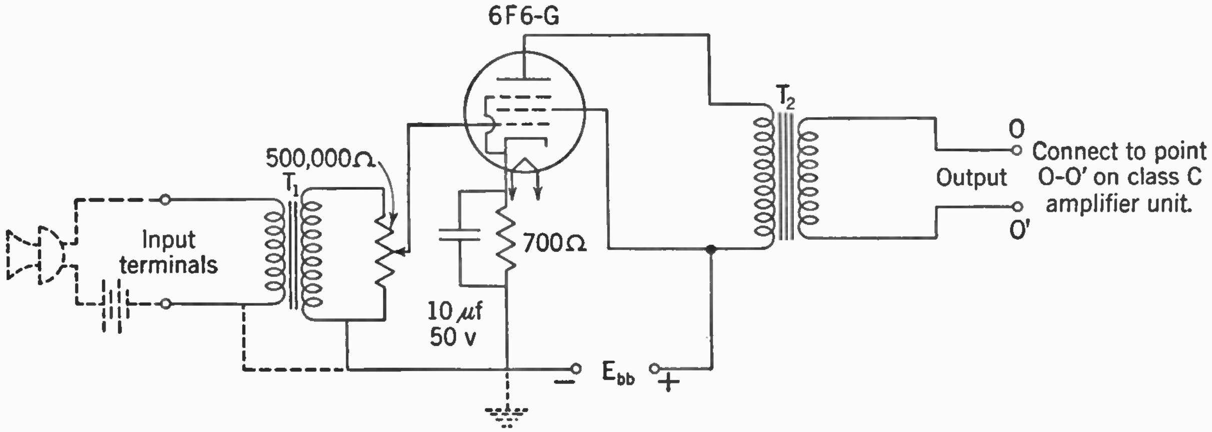
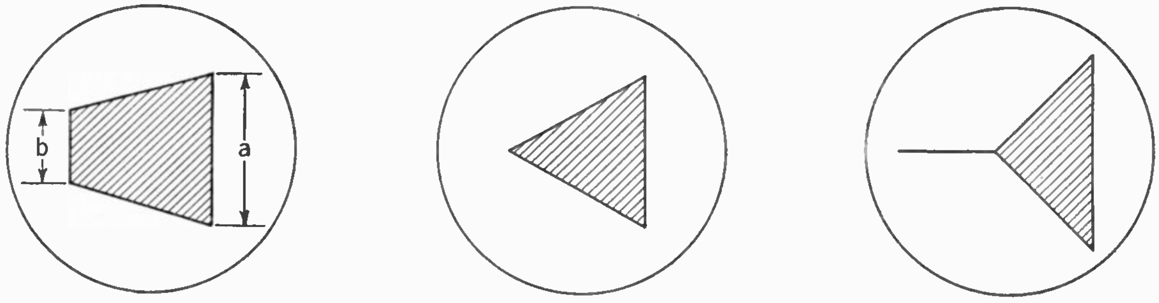


Fig. 22–3. Modulator-amplifier Unit.

C. Modulation Trapezoid. Connect the output of the audio-frequency oscillator to the *X*-input of the cathode-ray oscilloscope and adjust the controls of the oscilloscope so that the output voltage of this oscillator is applied to the horizontal amplifier. Leave the oscillator connected, as in part B, to the modulator input. Observe the pattern obtained. This is a *modulation trapezoid,* and provides an excellent means for continuous monitoring of a radio transmitter to guard against overmodulation. Vary the out-



(a) (b) (c)

Fig. 22–4. Modulation Trapezoids. (a) Less than 100% modulation; (b) 100% modulation; (c) over 100% modulation.

$$\text{Per cent modulation} = \frac{a-b}{a+b} \times 100.$$

put of the audio-frequency oscillator, and observe the effect on the figure. Determine the modulation percentage for several settings of the audio-frequency oscillator output control by measuring the trapezoid and applying the formula of Fig. 22–4. Enter data in Table C, and sketch the figures in the spaces C.

Set the output control of the oscillator to obtain less than 100% modulation and vary the frequency. Any apparent rotation of the pattern is due to *phase shift* in the modulator or oscilloscope amplifiers.

**D.** VARIATION OF R.F. OUTPUT VOLTAGE WITH BIAS VOLTAGE. Turn off all power supplies, and remove the Class C amplifier power supply and the modulator unit. Connect the Class C amplifier and the radio-frequency oscillator so that they both receive their plate power from the same supply. Connect the remaining power supply across the terminals of the grid-leak resistor (points X′–X, Fig. 20–3) of the Class C amplifier to serve as a bias-voltage supply; observe polarity—the grid end of the grid leak should be connected to the negative terminal of the power supply. Connect a D.C. voltmeter (0–300 v) across the bias voltage supply, and set the bias voltage at 200 v. Turn on the oscillator-amplifier power supply, and then vary the bias voltage from 200 to 100 v in 20-v steps, measuring the oscilloscope deflection of the radio-frequency output at each step. Enter these data in Table D; then plot a curve of oscilloscope deflection (which is proportional to the radio-frequency output voltage) against bias voltage on the lower half of the graph sheet.

**E.** GRID MODULATION. Refer to the curve of oscilloscope deflection against bias voltage obtained in part D, and select an operating point in the *middle* of the straight portion. Read from the curve the value of bias voltage corresponding to this operating point, and enter this value in space E. Connect the output of the audio-frequency oscillator in *series* with the bias supply, set the bias voltage to the value read from the curve, turn on the oscillator-amplifier power supply, and advance the output control of the audio-frequency oscillator until a modulated wave is obtained on the oscilloscope screen. Using the linear time-base controls of the oscilloscope, *stop* the pattern on the screen. Vary the setting of the audio-frequency oscillator output control to obtain several different percentages of modulation.

Adjust the output control of the audio-frequency oscillator to obtain a 100% modulated wave, then set the bias voltage 30 v less than the correct operating value as determined from the curve. Sketch the resulting pattern in space F–1. Set the bias voltage 30 v greater than the correct operating value, and repeat, using space F–2. Compare the results of grid modulation with plate modulation.

**References:**

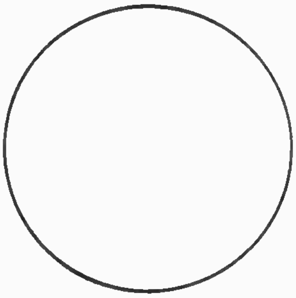
1. Everitt, W. L., *et al.*, "Fundamentals of Radio," pp. 238–240, 209–210, and 291–296.
2. Henney, Keith, "Principles of Radio," 4th ed., Art. 365–369.
3. Hoag, J. B., "Basic Radio," chapters 16, 28, 31.
4. "The Radio Amateur's Handbook," Defense Ed., chap. 5.

Name ______________________ Date ______________________ Class ______________________

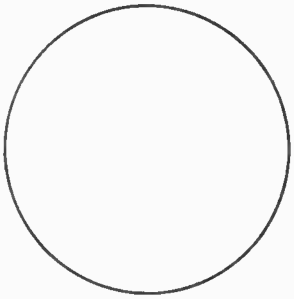
## DATA SHEET—EXPERIMENT 22

TABLE A

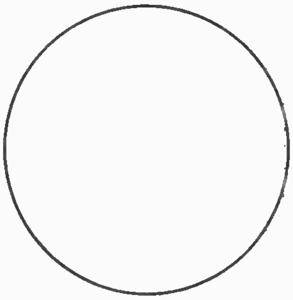
| Plate-supply voltage (volts) | Oscilloscope deflection (inches) |
|---|---|
| 300 | |
| 250 | |
| 200 | |
| 150 | |
| 100 | |
| 50 | |
| 0 | |



B–1. 50% Modulation



B–2. 100% Modulation



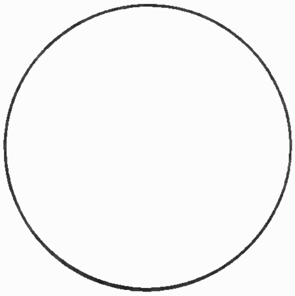
B–3. Overmodulation

*Continued on next page*

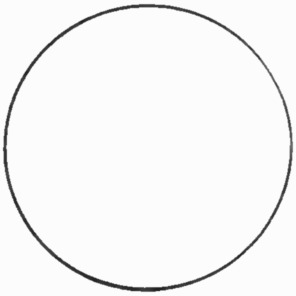
TABLE C

| Output, control setting or voltage | (a)* | (b)* | % Modulation |
|---|---|---|---|
| | | | |
| | | | |
| | | | |

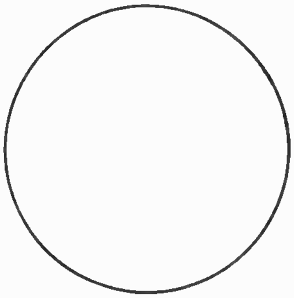
* See Fig. 22–4.



C–1. % Modulation = ..............



C–2. % Modulation = ..............

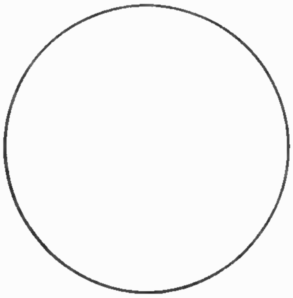


C–3. % Modulation = ..............

E. Operating Bias = .......................... v.

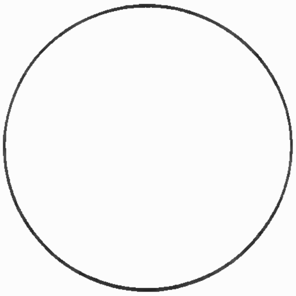
TABLE D

| Grid bias voltage (volts) | Oscilloscope deflection (inches) |
|---|---|
| 200 | |
| 180 | |
| 160 | |
| 140 | |
| 120 | |
| 100 | |



F–1.

Bias Voltage = .................. v.



F–2.

Bias Voltage = .................. v.

**Name** ------------------------------------------ **Date** --------------------- **Class**---------------------

## QUESTION SHEET—EXPERIMENT 22

1. Explain the process of modulation.

2. Compare the two methods of modulation studied on the basis of (a) distortion or quality, (b) power output required from the modulator, and (c) amount of equipment required.

3. Explain the formation of the modulation trapezoid.

4. What should be the peak power output of a modulator in order that it modulate a plate-modulated Class C amplifier 100%?

Name ____________________ Date ____________ Class ____________

## GRAPH SHEET—EXPERIMENT 22

1. Class C Amplifier Plate Voltage against R. F. Output Voltage (deflection).
2. Bias Voltage against R. F. Output Voltage (deflection).

## EXPERIMENT 23

# A Study of Heterodyne Reception of Radio Signals

### APPARATUS REQUIRED

| ITEM | QUANTITY |
|---|---|
| Frequency-converter unit (see Appendix) | 1 |
| Signal generator (with internal amplitude modulation) | 1 |
| Power supply | 1 |
| Demodulator unit (Experiment 21) | 1 |
| Public-address system (Experiment 18) | 1 |
| Cathode-ray oscilloscope | 1 |
| (An output meter or headphones may be substituted for the cathode-ray oscilloscope in this experiment). | |
| Wire for connections and antenna | — |

As the number of radio transmitters in operation increased, a need arose for receivers having sufficient selectivity to tune in a desired signal to the exclusion of all others. The *superheterodyne* receiver was developed to meet this need.

In the superheterodyne receiver, the incoming radio-frequency signals, instead of being amplified as such, are first converted to a lower *intermediate* frequency, which is usually of the order of 450 to 470 kc (150 to 200 kc in older receivers), and nearly all of the amplification other than audio-frequency amplification occurs at this frequency. Among the advantages that accrue from such an arrangement are increased selectivity, greater amplification per tube, and a reduction in the number of circuits which must be retuned each time a new signal is tuned in.

### Frequency Conversion

Frequency conversion is accomplished by mixing two radio-frequency signals in a properly biased vacuum tube. It is found that the output of the vacuum tube contains, in addition to other voltages, one which has a frequency equal to the *difference* between the frequencies of the signals being mixed. Furthermore, this difference-frequency voltage has an amplitude that is proportional to the *product* of the amplitudes of the signals being mixed. If one of these signals is supplied by a *local oscillator* contained in the receiver itself, and the other is a modulated signal from a radio transmitter, the difference-frequency voltage will be modulated *in exactly the same manner as the signal from the transmitter*. The difference-frequency voltage thus may be applied to a radio-frequency amplifier tuned to this frequency, and amplified and demodulated just as any other modulated radio-frequency signal—it becomes the *intermediate-frequency* (abbreviated to I.F.) signal referred to previously.

If the form of the modulation envelope is to be preserved, the converter or mixer tube *must* be biased to operate as a *square-law* detector. (Square-law detectors are described in the text.) The two signals may be applied in various ways; formerly they were applied in series in the grid circuit; but more recent practice is to use a special converter tube having *two* control grids—one for the introduction of the signal from the local oscillator, the other for the introduction of the received signal. Very often the same tube is made to serve both as the local oscillator and the converter.

### The Superheterodyne Receiver

In the modern superheterodyne receiver, the local-oscillator tuning condenser and the tuning condenser for the received-signal input circuit are driven from the same shaft, and either a *series padding* condenser or an oscillator tuning condenser with specially shaped plates is used, so that the local-oscillator frequency always differs from the resonant frequency of the signal input circuit by a constant amount. This difference is the intermediate frequency and is thus *always the same.* This means that the intermediate-frequency amplifiers operate at a *fixed* frequency, and their tuned circuits may be adjusted permanently to this frequency. Consequently, it is feasible to use double-tuned intermediate-frequency transformers, which are (usually) air-core transformers with tuning adjustments for both primary and secondary. Small inexpensive mica trimmer condensers having screwdriver adjustments may be used for tuning the transformers, since once set they require infrequent adjustment.

The arrangement of a superheterodyne receiver is illustrated in the block diagram of Fig. 23–1. A radio-frequency amplifier is included only in the better receivers, and serves to couple the antenna to the converter tube.

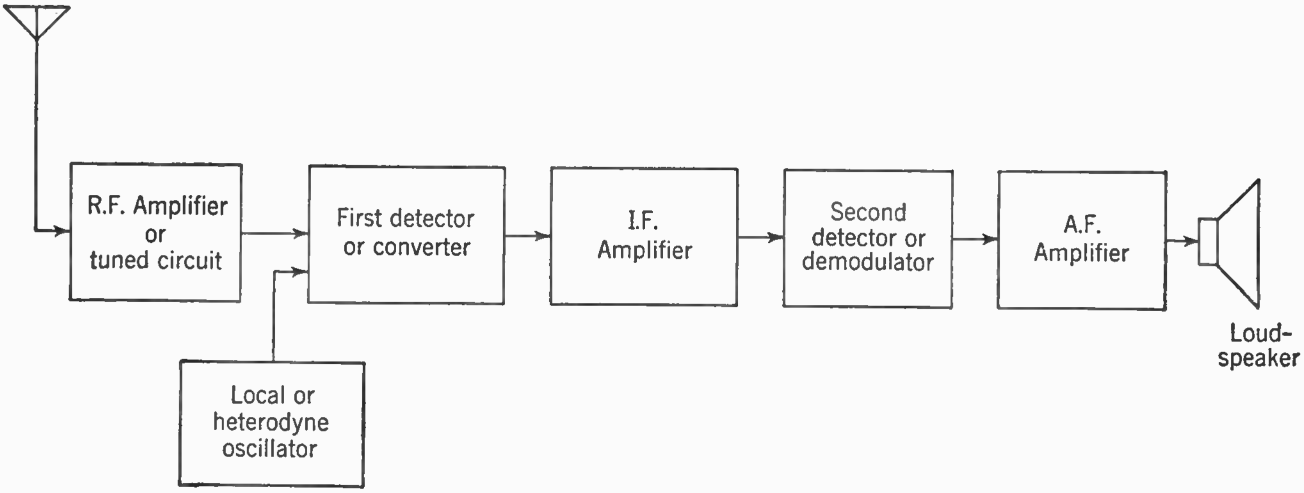


Fig. 23–1. Block Diagram of Superheterodyne Receiver.

### Experimental Procedure

A. Tuning the Intermediate-frequency Transformer. Connect the apparatus as indicated in Fig. 23–2. Set the signal generator controls to obtain a modulated radio-frequency output having the

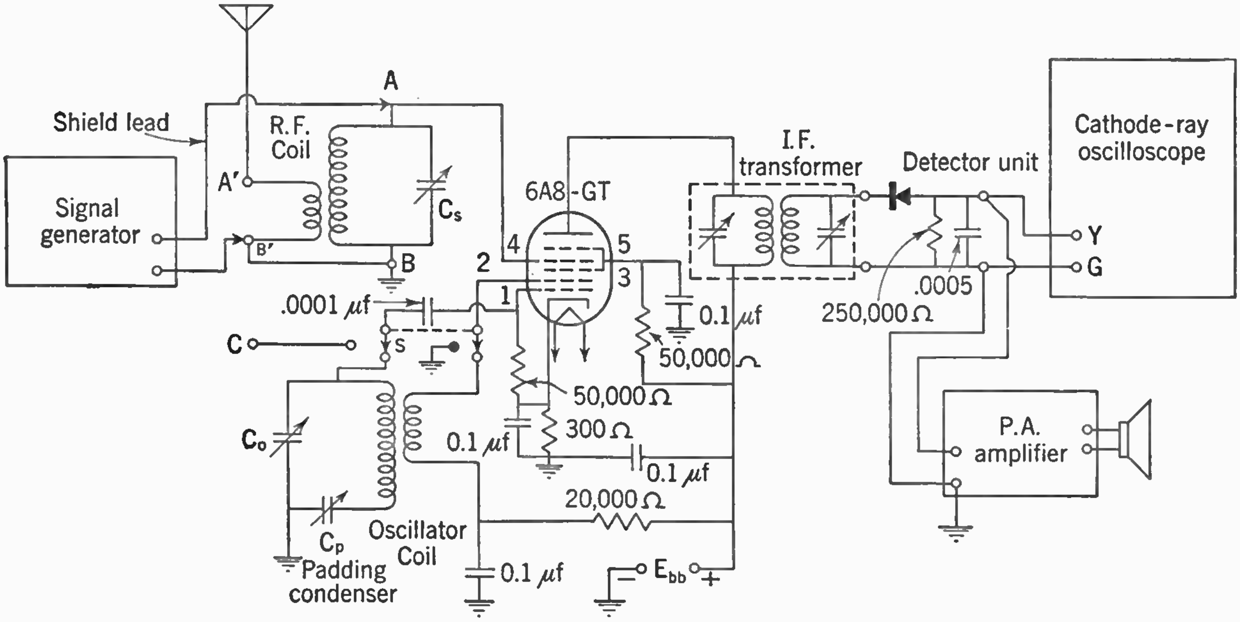


Fig. 23–2. Frequency-converter Unit.

frequency specified by the manufacturer of the intermediate-frequency transformer (this will usually be in the neighborhood of 465 kc—use this frequency if the specifications are not available; enter it in space A of the data sheet); turn the signal generator output to maximum, advance the vertical ($Y$-axis) gain control of the oscilloscope, and turn the adjusting screws of the trimmer condensers in the I.F. transformer until maximum deflection of the oscilloscope is obtained. This process is called *alignment* of the transformer. It is possible to align I.F. transformers by using a pair of headphones, a sensitive output meter, or the public-address system in place of the oscilloscope. The oscilloscope, however, is the better instrument to use for this purpose.

**B.** RECEPTION OF RADIO SIGNALS BY HETERODYNE METHOD, USING THE SIGNAL GENERATOR AS THE LOCAL OSCILLATOR. Remove the *high* lead of the signal generator from point A and connect this lead to post C; then throw the switch S so that the signal from the generator will be applied to grid No. 1 and be *mixed* with that delivered to the tube through the antenna and signal input circuit (grid No. 4). Consult a radio log book, or other source, and determine the carrier frequency of the nearest radio station. To this frequency add the intermediate frequency, and set the signal-generator controls to obtain an unmodulated output of this frequency. Now advance the gain control of the public-address amplifier and tune the signal-input circuit condenser $C_s$ until the station is heard clearly. A good antenna will aid if the signal from the station is weak. Readjustment of the signal-generator dial may be necessary if its calibration is not accurate. Enter the required data in Table B.

Subtract the intermediate frequency from the carrier frequency of the station, and set the signal-generator dial at this value, leaving the other controls unchanged. Vary the frequency setting of the oscillator slightly to obtain maximum volume. See if the station can be identified as the same one heard before. Enter the required data in Table B. Repeat for several other stations if strong enough to be heard.

**C.** HETERODYNE RECEPTION USING A SINGLE TUBE AS COMBINED OSCILLATOR AND CONVERTER. Disconnect the signal generator lead from point C, and throw switch S so that grids No. 1 and No. 2 are connected to the oscillator coils. The circuit is now arranged so that the 6A8 tube acts simultaneously as oscillator and mixer.

Tune in the same stations as in part B by varying the settings of the oscillator and signal-input circuit condensers simultaneously. A little patience may be required here. See if the same "double spot" performance of the oscillator is obtained here as in part B. The oscillator tuning dial may be made to *track* with the input-circuit tuning dial by the proper adjustment of the padding condenser $C_p$. Adjust $C_p$ until satisfactory tracking is obtained over the greater part of the dials. Obtain data to fill in Table C.

**D.** IMAGE RESPONSE. Remove the jumper connecting points B–B′, and connect the output terminals of the signal generator to these points. With the antenna connected to point A′, this arrangement introduces simultaneously two signals into the receiver. With the signal-generator output control set at zero, tune in a local station, using the higher of the two possible local oscillator frequencies. Set the signal generator controls to obtain a *modulated* output having a frequency equal to twice the intermediate frequency plus the local station's carrier frequency. Enter values in Table D. Vary the frequency setting of the signal generator until its characteristic tone is clearly heard. See if the tone from the signal generator disappears when the station is *tuned out* by varying the local oscillator condenser setting. Also see if the relative loudness of the signal-generator tone is increased when the signal circuit tuning condenser $C_s$ is varied. Enter any comments you may have in space E.

This peculiar property of a superheterodyne receiver, of tuning in two signals at once, is called its *image response* characteristic. By completely filling in Table D the reason for this undesirable characteristic of a superheterodyne may be ascertained and information obtained for the answer to question 3.

**References:**

1. Everitt, W. L., *et al.*, "Fundamentals of Radio," pp. 236–240, chap. 13.
2. Henney, Keith, "Principles of Radio," 4th ed., Art. 286–295.
3. Hoag, J. B., "Basic Radio," Art. 32.7–32.8.
4. "The Radio Amateur's Handbook," Defense Ed., Art. 7–8 to 7–12.
5. Ghirardi, A. A., "Radio Physics Course," 2nd ed., chap. 22.

**Name** ________________________ **Date** ________________ **Class** ________________

## DATA SHEET—EXPERIMENT 23

A. Intermediate Frequency = ................ kc.

TABLE B

| Station call letters | Carrier frequency | Input circuit, dial setting | Carrier frequency plus intermediate frequency | Comments on reception | Carrier frequency minus intermediate frequency | Comments on reception |
|---|---|---|---|---|---|---|
| 1. | | | | | | |
| 2. | | | | | | |
| 3. | | | | | | |
| 4. | | | | | | |
| 5. | | | | | | |

TABLE C

| Station call letters | Carrier frequency | Input circuit, dial setting | Oscillator circuit, dial settings | | Comments on reception |
|---|---|---|---|---|---|
| 1. | | | | | |
| 2. | | | | | |
| 3. | | | | | |
| 4. | | | | | |
| 5. | | | | | |

*Continued on next page*

### TABLE D

Station call letters: ........................ Station carrier frequency ........................ kc.

Intermediate frequency × 2 = ........................ kc.

Image frequency = carrier frequency + (2 × I.F.) = ........................ kc = Signal-generator frequency.

Oscillator frequency = carrier frequency + I.F. = ........................ + ........................ = ........................ kc.

Intermediate frequency = oscillator frequency minus carrier frequency = .................. − .................. = ................ kc.

Interfering frequency = image frequency minus oscillator frequency = .................. − .................. = ................ kc.

E. ........................................................................................................................................................................

........................................................................................................................................................................

........................................................................................................................................................................

**Name** ________________________________________ **Date** ____________________ **Class** ____________________

## QUESTION SHEET—EXPERIMENT 23

**1.** Explain why there are two local-oscillator frequencies at which each signal can be heard.

**2.** List some advantages of the superheterodyne receiver over one using tuned radio-frequency stages.

**3.** Explain how image responses arise in a superheterodyne receiver.

**4.** If, in part D, the oscillator frequency had been set to the *lower* of the two possible values, what would have been the image frequency?

### EXPERIMENT 24

# A Study of Test Equipment for Radio Servicing

## APPARATUS REQUIRED

| ITEM | QUANTITY |
|---|---|
| Multimeter | 1 |
| Signal generator | 1 |
| Radio receiver | 1 |
| Audio-frequency oscillator | 1 |
| Receiver analyzer (optional) | 1 |
| Resistor, 500-ohm, 1-watt | 1 |

While a clever radio technician can sometimes accomplish wonders in the way of *trouble shooting* with nothing more than a volt-ohm-milliammeter, his work is nevertheless greatly facilitated by the possession of several additional pieces of test equipment, and *a knowledge of how to use them.*

The student has used many of the essential pieces of service equipment in previous experiments, and has seen others used in demonstrations; however, time did not permit a detailed study of these instruments themselves. This experiment has, therefore, been included to afford the student an opportunity to gain some idea of the construction, proper use, and proper maintenance of this equipment. Obviously, space does not permit even a passing mention of each of the multitude of pieces of equipment available. Instead a combination of discussion and instructions for experimental work is provided for the *basic types* of instruments. These should be supplemented by reference to the manufacturer's instructions for the use of the particular instruments available.

## Experimental Procedure

**A.** Indicating Meters. The most useful indicating meters have been studied and used in previous experiments, and so require no extensive discussion here. Most meters for radio service applications are multipurpose types, combining into one unit a multirange A.C. and D.C. voltmeter, a D.C. milliammeter, and an ohmmeter. Sometimes other measuring instruments such as capacitance and inductance meters are also included with the above.

Remove the multipurpose meter from its case, and notice how the designer has arranged the multipliers, shunts, and other parts to form a compact, durable instrument. Find the rectifier which permits reading A.C. voltages on the D.C. meter. Consult the instruction book to find the ohms-per-volt rating of the meter on the A.C. and D.C. voltage ranges. List all of the electrical quantities which can be measured with the instrument, including ranges, in Table A of the data sheet.

**B.** Signal Generator. A *signal generator* is a refined and well-shielded variable-frequency radio-frequency oscillator. An output *attenuator* is provided which permits a stepless variation in output voltage. A self-contained audio-frequency oscillator is usually provided to amplitude-modulate the radio-frequency output of the signal generator; this audio oscillator can be switched on or off as desired. Some of the more elaborate signal generators have provision for frequency-modulating the output—a process whereby the output frequency is rapidly varied over a band of frequencies centered on the frequency indicated by the dial.

Frequencies above the normal range of a signal generator may be obtained by the use of *harmonics*, which are *integral* multiples of the frequency to which the signal-generator dial is set. These are always present in the output, and are by-products of the oscillator action.

**1.** Using an ohmmeter, measure the resistance between the output terminals of the signal generator with the output attenuator set to obtain zero output, one half of full output, and full output. Enter the values obtained in Table B–1.

**2.** Turn on the radio receiver; connect the *high* terminal of the signal generator to the antenna terminal of the receiver, and its *low* terminal to the ground terminal of the receiver. Set the signal generator to obtain an amplitude-modulated output having a frequency of 1,000 kc and *tune in* this signal on the receiver. Reduce the setting of the signal generator dial until the characteristic tone is heard again—this will occur at a setting of about 500 kc, of which the second harmonic is now being received. Find the setting of the generator (333.3 kc) for reception for which 1,000 kc is the third harmonic, the fourth, fifth, and so on. Notice that a nonharmonic response is also obtained when the signal-generator frequency is equal to a submultiple of the intermediate frequency, if a superheterodyne receiver is used. Enter the generator dial setting for each of the harmonics heard in Table B–2.

**3.** Check the calibration of the signal-generator dial in the broadcast range as follows: Connect an antenna to the receiver, and tune in a station whose carrier frequency is known (see a log book). Couple the signal generator to the receiver by twisting a few turns of insulated wire about the antenna and connecting this wire to the *high* output terminal of the signal generator. Set the generator to obtain an unmodulated output of the same frequency as the radio station. Vary the setting of the generator dial slightly, until a whistle is heard, then move the dial slowly until the *pitch* of the whistle lowers and finally disappears. The signal generator output frequency is now exactly equal to that of the broadcast station.* Enter the generator dial setting, true frequency, and amount of error in Table B–3. Repeat for two other points in the broadcast frequency range. This is the so-called *zero-beat* method of frequency measurement.

**C.** AUDIO-FREQUENCY OSCILLATOR. Audio-frequency oscillators are rather infrequently used in ordinary radio service work, but find application in the testing of audio-frequency amplifiers and public-address systems. Some audio-frequency oscillators operate on the *beat-frequency* principle, in which the desired output is obtained as the *difference* between the frequencies of two radio-frequency signals, in the same manner that the intermediate frequency is obtained in a superheterodyne receiver. Other audio-frequency oscillators generate the signal directly at its fundamental frequency. The advantage of the beat-frequency type lies in its ability to cover the entire audio-frequency range with a *single sweep* of its dial—other types require range-switching—while its chief disadvantage is its tendency to *drift*, or slowly change its output frequency, while in use.

Check the calibration of the audio-frequency oscillator, then, using a copper oxide rectifier voltmeter (or the multipurpose meter), measure its maximum output voltage at a frequency of 1,000 cycles and at the lowest and highest frequencies appearing on its dial. Connect a carbon resistor (500-ohm if available) between the output terminals of the oscillator, and repeat the above measurements. Record in Table C.

Connect the oscillator to the vertical input terminals of the cathode-ray oscilloscope. Switch the linear time-base synchronizing switch of the oscilloscope to the 60-cycle line-frequency position. Adjust the audio oscillator dial until two cycles appear on the oscilloscope screen (do not synchronize), and notice whether or not the pattern *drifts* after a few moments. What does the drifting of the pattern indicate?

**D.** SIGNAL-TRACING EQUIPMENT. Recent trends in service technique are towards the signal-tracing method, in which the signal is traced and measured in the various circuits of a receiver. As a result, instruments have been devised to facilitate this type of work. Most of these contain several distinct *channels*, each of which is designed to enable measurements to be made in a corresponding channel of the receiver under test. A typical instrument of this type might contain the following channels:

(1) A *radio-frequency–intermediate-frequency channel*, consisting of a *tuned radio-frequency amplifier*, followed by a *vacuum-tube voltmeter*. This channel can be *tuned* to the same frequency as the incoming signal, and the signal *strength* measured in various portions of the R.F. and I.F. channels of the receiver.

(2) An *oscillator channel*, consisting of a low-gain tuned amplifier followed by a vacuum-tube voltmeter to permit measurement of the output *voltage* and *frequency* of the local oscillator in superheterodyne receivers.

(3) An *audio-frequency channel*, consisting of an audio-frequency amplifier and vacuum-tube voltmeter, for the measurement of *signal voltage* in the demodulator output and audio-frequency amplifier circuits.

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* A broadcast station is required by law to maintain its frequency within ±50 cycles of its assigned frequency. Most stations do even better than this, however. They therefore make convenient and accurate frequency standards.

(4) An *electronic* D.C. voltmeter, which makes possible the measurement of D.C. *voltage* in the various circuits without disturbing them. (An electronic voltmeter requires negligible current for its operation.)

(5) A *wattage indicator*, to measure the *power* consumption of a receiver.

If a signal-tracing instrument is available, study the instructions accompanying it to become familiar with its capabilities. Measure the output voltage of the signal generator, using this instrument. Determine the relative strength of the fundamental (1,000 kc) and second-harmonic voltages of the signal generator by tuning the R.F.–I.F. channel of the analyzer or tracing instrument to the proper frequencies.

Measure the power consumption of the audio-frequency oscillator; then, using the audio-frequency channel of the instrument, measure its output voltage at the same frequencies used in part C. Record in the proper spaces in Table C.

Switch the electronic voltmeter to its lowest range, grasp the *chassis* lead of the tracing instrument in one hand, then touch the voltmeter probe to a wristwatch, ring, or other piece of metal in contact with the skin, and measure the existing voltage. Try to do this with an ordinary D.C. voltmeter.

**E. VACUUM-TUBE VOLTMETER.** The vacuum-tube voltmeter is a valuable instrument to the radio technician because it is capable of measuring A.C. voltages of very high (radio) frequency with accuracy, and of doing so with a minimum of disturbance to the circuit to which it is connected. The use of this instrument is demonstrated in the analyzer described under part D. Of course, vacuum-tube voltmeters are available as separate units and have proven to be valuable to the technician for servicing and adjusting receivers and transmitters.

**References:**

1. Everitt, W. L., *et al.*, "Fundamentals of Radio," pp. 116–118, chap. 8.
2. "The Radio Amateur's Handbook," Defense Ed., Art. 12.3.
3. Hicks, H. J., "Principles and Practice of Radio Servicing," chap. 4.
4. Ghirardi, A. A., "Modern Radio Servicing," part 1.

**Name** ---------------------------------------- **Date** -------------------- **Class** --------------------

## DATA SHEET—EXPERIMENT 24

### TABLE A—METER DATA

Name of meter: ............................................................

Ohms-per-volt: A.C. ..................... D.C. .....................

| | Quantity, Ohms, volts, etc. | Range | A.C. or D.C. |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |

### TABLE B—SIGNAL-GENERATOR DATA

1. Resistance between Output Terminals of Signal Generator

Set at 0 = ............................ ohms Half scale = ............................ ohms Full scale = ............................ ohms

2. Signal Generator Dial Setting for Harmonics

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Kilocycles | 1,000 | | | | | | | | | | |
| Order of harmonic | Fundamental | | | | | | | | | | |

Receiver Dial Setting for 1,000 kc = ........................

| 3. Station letters | Station frequency, kilocycles | Signal-generator dial setting, kilocycles | Error, in kilocycles (±) | Error, per cent |
|---|---|---|---|---|
| 1. | | | | |
| 2. | | | | |
| 3. | | | | |

*Continued on next page*

TABLE C

| Audio-oscillator frequency, cycles per second | Output voltage | | |
|---|---|---|---|
| | Without load | With load | Measured with |
| Minimum: | | | A.C. voltmeter |
| 1,000 | | | |
| Maximum: | | | |
| Minimum: | | | Analyzer or vacuum-tube voltmeter |
| 1,000 | | | |
| Maximum: | | | |

Name ________________________________________ Date ____________________ Class ____________________

## QUESTION SHEET—EXPERIMENT 24

**1.** Why should a blocking condenser be connected in series with the *high* lead of the signal generator when it is to be connected to points in a receiver which are at a high D.C. voltage?

**2.** Why is it necessary that the signal generator be well shielded? How is this shielding accomplished?

**3.** What causes the *whistle* in the receiver loudspeaker when the signal generator is tuned to approximately the same frequency as the signal that is being received?

**4.** Why is trouble shooting by the signal-tracing method the most desirable way of locating defective parts in a radio receiver?

## EXPERIMENT 25

# A Complete Radio Communication System

### APPARATUS REQUIRED

| ITEM | QUANTITY |
|---|---|
| Telephone transmitter and battery (Experiment 17) | 1 |
| Oscillator–Class C-amplifier unit (Experiment 20) | 1 |
| Modulator unit (Experiment 22) | 1 |
| Class A radio-frequency amplifier (Experiment 19) | 1 |
| Frequency converter unit (Experiment 23) | 1 |
| Detector or Demodulator unit (Experiment 21) | 1 |
| Public-address amplifier and speaker (Experiment 18) | 1 |
| Power supplies | 2 |
| Cathode-ray oscilloscope | 1 |
| Audio-frequency oscillator | 1 |
| Wave meter (Experiment 20) | 1 |
| Phonograph unit (optional) | 1 |
| Wire for antenna and connections | — |

At one time or another during this course of laboratory work, each of the essential parts of a radio communications system has been studied in some detail as a separate unit. In order to provide a clear understanding of the exact function of each of these units as used in communication service, this experiment has been prepared.

It is assumed that the student remembers—in a general way, at least—the proper procedure for the adjustment and placing in service of each unit, so no extensive instructions will be given. Of course, if any doubt arises as to the proper procedure, reference should be made to the discussion and instructions of the pertinent experiment.

### Experimental Procedure

(It is suggested that the entire task of assembling and adjusting the equipment be left to the students, who may be divided into two groups—one to assemble and operate the transmitter, the other the receiver. No actual wiring diagrams are supplied—only block diagrams, it being left to the students to apply their previously gained knowledge and common sense in wiring up the units, and correcting any errors which may be introduced. The instructor should supply a wiring diagram if, in his opinion, this is necessary.)

A. Assembly and Adjustment of the Transmitter. On one side of the laboratory assemble the proper units to form a radio-telephone transmitter, as indicated in the block diagram of Fig. 25–1. Place

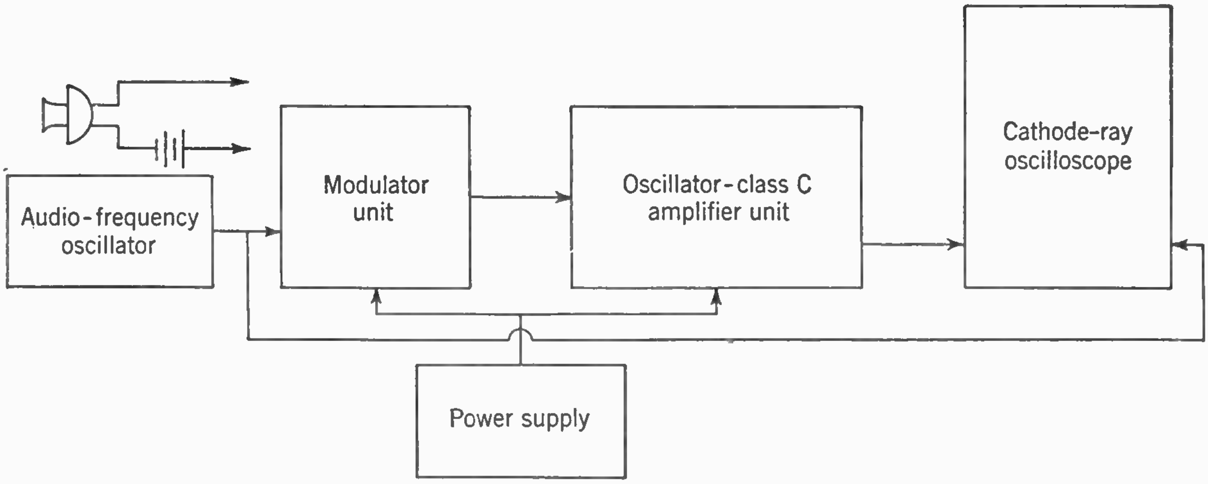


Fig. 25. 1. Block Diagram of Transmitter Unit.

the oscillator in operation and tune it to a frequency of 1,000 kc, after selecting the proper instrument for measurement of the frequency.

Neutralize and tune the Class C amplifier, then apply a 1,000-cycle signal to the modulator unit from the audio-frequency oscillator. Connect the cathode-ray oscilloscope in the proper way to obtain a modulation trapezoid, and inspect the trapezoid to be sure that overmodulation does not occur. Leave the oscilloscope connected here during the remainder of the experiment, so that it may be used to monitor the transmission.

> *Caution: Federal Communications rules forbid connecting an antenna to an unlicensed transmitter—severe penalties are provided for violations to this regulation.* Enough signal intensity for this experiment will be obtained without an antenna.

**B.** ASSEMBLY AND ADJUSTMENT OF THE RECEIVER. Assemble a receiver from component parts as indicated in Fig. 25–2. (The Class A radio-frequency amplifier unit may be omitted if desired. Consult the instructor about this matter.) Use a radio-frequency signal generator to align the intermediate-frequency transformer to its operating frequency, then tune the receiver to the frequency of the transmitter. The 1,000-cycle voltage from the audio-frequency oscillator should be applied to the modulator unit while the receiver is being tuned—it will produce a characteristic tone in the loudspeaker when the tuning is correct.

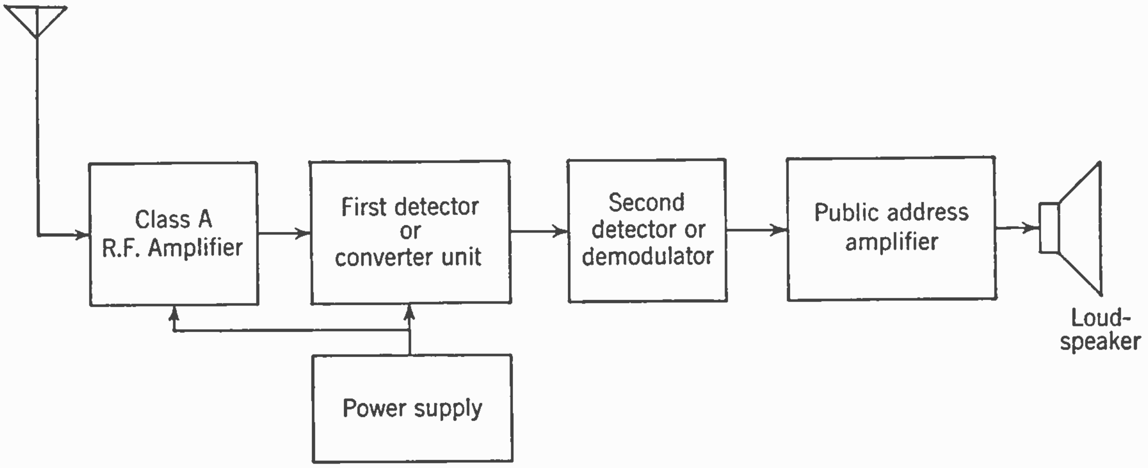


FIG. 25–2. Block Diagram of Radio Receiver.

**C.** Replace the audio-frequency oscillator with a microphone and battery. Speak into the microphone and see if the speech is reproduced by the loudspeaker. One member of the group operating the transmitter should act as *engineer* and constantly monitor the transmission by observing the modulation trapezoid on the oscilloscope. If overmodulation occurs, the setting of the gain control on the modulator amplifier should be reduced.

**D.** (OPTIONAL.) If it is available, a phonograph pickup and turntable unit may be substituted for the microphone, and a musical selection played. Also, if time permits, a simple mixer (Experiment 18), to permit simultaneous speech and music transmission, may be engineered by the students and placed in operation.

**References:**

1. Everitt, W. L., *et al.*, "Fundamentals of Radio," chapters 10–13.
2. Henney, Keith, "Principles of Radio," 4th ed., chapters 13–17.
3. Hoag, J. B., "Basic Radio," chapters 31–32.
4. "The Radio Amateur's Handbook," Defense Ed., chapters 5, 7 and 11.

**Name** ________________________________________ **Date** ____________________ **Class** ____________________

## QUESTION SHEET—EXPERIMENT 25

1. Describe briefly the exact function of each of the component units of the transmitter and of the receiver.

## EXPERIMENT 26

# Construction and Basic Circuits of a Commercial Radio Receiver

### APPARATUS REQUIRED

| ITEM | QUANTITY |
|---|---|
| Radio receiver | 1 |
| Signal generator | 1 |
| Multimeter | 1 |
| Tube manual | 1 |

Although commercial radio receivers are quite similar electrically to those assembled for use in the laboratory (Experiment 25), they differ greatly from the latter in mechanical construction, and in the arrangement of their component parts and wiring. In laboratory-type receivers, visibility and accessibility of parts and flexibility of operation are the qualities desired; in the commercial product, compactness, durability, appearance, ease of control—and most important of all—economy in the use of materials are of prime importance.

Very often the student technician, whose training has been largely theoretical, is somewhat taken aback by the practical difficulties of tracing circuits in and making repairs upon the complex-appearing maze of parts and wires tucked away beneath the chassis of a modern radio receiver. If, however, the student will remember that the maze is an orderly one, and will adopt a systematic method of approach, he will find that the receiver's circuit can be *broken down* into definite sections or *channels*, each type of which has been previously studied as a unit, and with which he should therefore be somewhat familiar.

It is the purpose of this experiment to provide the student with the opportunity to become familiar with the under side of the chassis of a modern type of receiver. Because commercial receivers differ greatly in the details of their construction, no specific instructions can be given—instead a general outline of procedure is provided.

### Experimental Procedure

(If several members of the class have *midget* or other types of small receivers, it is suggested that they bring them to the laboratory. Frequently the circuit diagram will be found somewhere on the cabinet or chassis; if not, a local service man should be consulted to obtain this information. If it is not feasible to provide several receivers in this way, a single receiver may be used for the entire group—however, it is desirable that the students do the actual experimental work themselves.)

A. Circuit Diagram. Copy the circuit diagram of the receiver on the blank page provided. Place values on each part, wherever possible.

Indicate the various channels of the receiver on the circuit diagram by enclosing them in *dotted boxes*, and place a reference number in each *box*. In one corner of the diagram sheet, make a legend, giving the number of each channel and its function. For example: 3–Intermediate-frequency Amplifier.

B. Examination of Receiver. Remove the receiver from its cabinet. Leave the loudspeaker connected and remove it from the cabinet, also, if necessary. Invert the chassis, and support it securely on blocks, so that the tubes will not be damaged. Examine the constructional features of the receiver, and find the answers to questions 1–4 on the question sheet.

C. Measurement of Tube Electrode Voltages. Turn on the receiver, and determine if it is in operating condition; if so, measure the electrode voltages of each of the tubes, using the chassis as a *reference point;* that is, measure the voltage between the chassis and each electrode. Use a 1,000-ohms-per-volt voltmeter for all the D.C. voltage measurements. Enter the results in Table A; if an electrode voltage is negative with respect to the chassis, place a minus sign before it. Be sure to select a suitable meter range for each measurement, as neglect to do so may result in a burned-out meter. Use an A.C. meter to determine the heater voltages and measure between terminals. The socket connections and conventional electrode numberings for each tube will be found in the tube manual.

**D.** Radio- and Intermediate-frequency Channels. If the receiver is a superheterodyne, determine its intermediate frequency by short-circuiting the oscillator tuning condenser, applying a modulated signal from the signal generator to the signal grid of the converter tube, and tuning the signal generator until the characteristic tone of the modulation is heard at maximum volume. Several settings of the signal-generator dial will probably be found where the tone is heard—the *highest* setting is the true intermediate frequency. (The other readings are due to harmonics produced by the signal generator.) Enter the intermediate frequency in space B of the data sheet.

Find the tuning range (broadcast range only) of the receiver from the markings of its dial, and enter this information in space B. Compute the local oscillator frequency range, and enter this information in space B also. (The oscillator frequency is almost invariably *higher* than the signal input frequency in commercial receivers.)

**References:**

1. Everitt, W. L., *et al.*, "Fundamentals of Radio," chap. 13.
2. Henney, Keith, "Principles of Radio," 4th ed., chap. 15.
3. Hoag, J. B., "Basic Radio," chap. 32.
4. "The Radio Amateur's Handbook," Defense Ed., chap. 7.

Name ____________________ Date ____________________ Class ____________________

## CIRCUIT DIAGRAM OF RECEIVER

Name or Maker ____________________ Voltage ____________________ Number of Tubes ____________________

Type ____________________ Frequency ____________________ Power Consumed ____________________

**Name** ________________________ **Date** ______________ **Class** ______________

## DATA SHEET—EXPERIMENT 26

### TABLE A

| | Type of tube | Function of tube in circuit | Electrode voltages measured relative to chassis | | | | | | | | Heater voltage between terminals |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Terminal and voltage | Cathode | Grid | | | | | Plate | |
| | | | | | No. 1 | No. 2* | No. 3* | No. 4* | No. 5* | | |
| 1. | | | Ter. No. | | | | | | | | |
| | | | Voltage | | | | | | | | |
| 2. | | | Ter. No. | | | | | | | | |
| | | | Voltage | | | | | | | | |
| 3. | | | Ter. No. | | | | | | | | |
| | | | Voltage | | | | | | | | |
| 4. | | | Ter. No. | | | | | | | | |
| | | | Voltage | | | | | | | | |
| 5. | | | Ter. No. | | | | | | | | |
| | | | Voltage | | | | | | | | |
| 6. | | | Ter. No. | | | | | | | | |
| | | | Voltage | | | | | | | | |
| 7. | | | Ter. No. | | | | | | | | |
| | | | Voltage | | | | | | | | |
| 8. | | | Ter. No. | | | | | | | | |
| | | | Voltage | | | | | | | | |

*If present.

B. Intermediate frequency = .......................... kc

Tuning range = .......................... kc to .......................... kc

Local oscillator frequency range = .......................... kc to .......................... kc (if superheterodyne).

**Name** ________________________ **Date** ____________ **Class** ____________

## QUESTION SHEET—EXPERIMENT 26

**1.** Is the wiring of the receiver *cabled*, or is it *point-to-point* wiring, or a combination of these? If a combination, is the radio-frequency channel wiring cabled?

**2.** Are the pigtails of small parts (condensers, resistors, and so on) connected directly to the hook-up wires or are they first joined to terminal lugs or the socket terminals for mechanical support?

**3.** Is a multigang variable condenser used for tuning the receiver? Are its rotor or stator plates *grounded* to the chassis? Are all sections of the variable condenser alike?

*Continued on next page*

4. What has been done to prevent undesired *magnetic* and *electrostatic* coupling between the various coils in the radio- and intermediate-frequency channels of the receiver?

5. How do the tubes in this receiver obtain their bias voltage?

6. If the loudspeaker has a field coil, how is it energized? If it has none, what supplies the magnetic field?

7. By what means is volume control accomplished in this receiver?

8. Is there a tone control incorporated in the receiver? If so, how does it function electrically?

## EXPERIMENT 27

# Alignment of Superheterodyne Receivers

### APPARATUS REQUIRED

| ITEM | QUANTITY |
|---|---|
| Radio receiver (superheterodyne) | 1 |
| Signal generator (with amplitude and frequency modulation) | 1 |
| Output meter or A.C. copper-oxide voltmeter with a 1- or 2-$\mu$f condenser and a 5,000-ohm, 5–10-watt resistor | 1 |
| Mica condenser (.001- to .01-$\mu$f) | 1 |
| 3-v battery | 1 |
| Aligning tool or insulated screwdriver | 1 |
| Soldering iron | 1 |
| Cathode-ray oscilloscope | 1 |
| Connecting wires | — |

In very nearly all modern radio receivers a system of *single-dial* tuning is employed, which permits selection of any desired signal either by the turning of but *one* dial or the pushing of a button. In tuned radio-frequency receivers, this requires that all of the tuned radio-frequency transformers be *identical*, and also that all of the tuning condensers be *ganged* on the same shaft, so that the tuned circuits of which they are parts will *track* or be tuned to the same frequency when the dial is set at any given point.

In superheterodyne receivers, the situation is somewhat more complicated, for, although the intermediate-frequency transformers need not be retuned when a new signal is selected, the signal input and oscillator circuits do require retuning, and must be designed and adjusted so that the oscillator frequency always differs from the resonant frequency of the signal-input circuits by a *fixed amount*, equal to the intermediate frequency. This is sometimes accomplished by making the oscillator section of the tuning condenser smaller than the sections which tune the signal-input circuits. More often, however, a *series padder* or *tracking condenser* is used, as shown in Fig. 23–3, to increase the resonant frequency of the oscillator tank circuit. If this is done, all of the sections of the ganged tuning condenser may be identical. It can be shown mathematically that the difference between the oscillator and signal-input circuit frequencies can be made *exactly* correct only for *three* settings of the tuning dial, and that a small *tracking error* exists at other settings of the dial. By proper proportioning and adjustment of the oscillator inductance, tuning capacitance, and series-padding capacitance, this error can be reduced to a negligible amount.

To summarize the above—the following conditions must be fulfilled for proper operation of a single-dial superheterodyne:

1. The intermediate-frequency transformers must all be tuned to the correct intermediate frequency.
2. When the dial is set to receive a signal of a certain frequency, all of the tuned circuits of the signal-input channel must be made to resonate simultaneously at this frequency.
3. The oscillator frequency must automatically be adjusted to a value equal to the sum (or difference) of the signal and intermediate frequencies.

Before it leaves the factory, a receiver is always *aligned* so that the above conditions are fulfilled for every setting of its dial. However, rough mechanical treatment, changes in temperature, variations in humidity, natural aging, and replacement of tubes or other parts often cause a *drifting* of the adjustments, and insensitiveness in the receiver is the result. It often happens, therefore, that the technician is called upon to realign a receiver. This task is not a difficult one, but a *systematic order* of procedure must be followed if the results are to be satisfactory. Like many other operations, this one is best learned by doing, and so the order of operations is given in the experimental procedure.

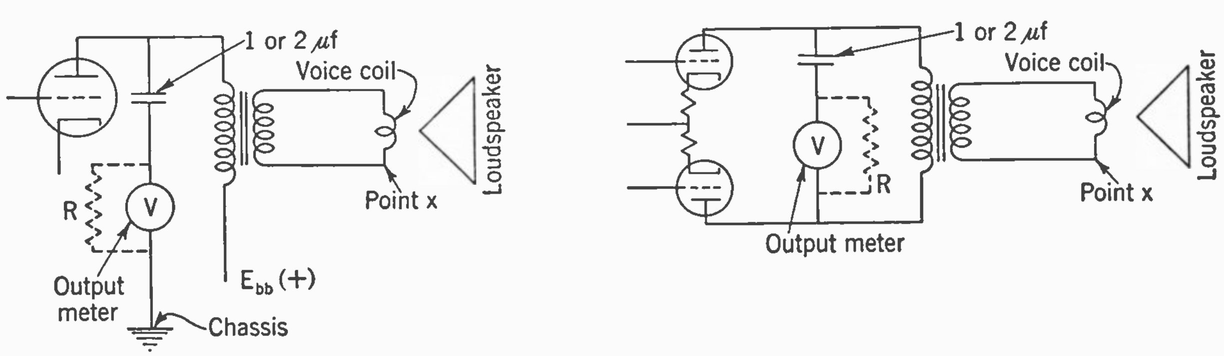
It should be emphasized that many different designs of superheterodyne receivers are in use—each requiring a slightly different alignment procedure for *peak* performance. In particular, receivers employing *image traps* present special problems. Obviously, all of these special cases cannot be considered here—instead, a procedure is described which will be useful in aligning perhaps nine out of ten receivers in use at present.

## Experimental Procedure

(It is suggested that two or three members of the class who have superheterodyne receivers bring them to the laboratory for alignment. In this way, receivers having different arrangements of parts will be available. A local serviceman will probably have information about the intermediate frequencies used in these sets.)

A. Examination of Intermediate-frequency Transformer. Remove the receiver from its cabinet, leaving the loudspeaker connected; then remove the intermediate-frequency transformer from its shield can (or the shield can from the transformer). Notice the arrangement of the coils, and, in particular, whether the core is composed of a wooden dowel, a plastic tube, or compressed powdered iron. See if there is a copper *damping ring* between the coils, to reduce the coupling, yet allow the coils to be placed close together to conserve space. Are mica-dielectric compression-type trimmer condensers used, or are small variable air-condensers used as trimmers? Is the transformer a tuned-primary–tuned-secondary or a single-tuned type? At what frequency is the transformer designed to operate? Answer these questions on the question sheet.

B. Alignment of Receiver, Using an Output Meter. 1. *Preparation of Receiver for Alignment.* Connect an *output meter*,* in series with a 1- or 2-$\mu$f blocking condenser, into the audio-frequency power-amplifier output circuit, as shown in Fig. 27–1(a) if the receiver has a single-ended output circuit, or as shown in Fig. 27–1(b) if a push-pull power amplifier is used. If no output meter is available, a copper-oxide voltmeter, shunted by a 5,000-ohm, 5- or 10-watt resistor, as indicated by the dotted lines of Fig. 27–1, may be substituted. Disconnect the loudspeaker voice coil by unsoldering its connection, as at point *x* in Fig. 27–1.



(a)

(b)

Fig. 27–1. Connection of Output Meter.

If the receiver has automatic volume control, this should be rendered inoperative by disconnecting the automatic-volume-control lead or *bus* (ask the instructor about this) and connecting a 3-v battery between the intermediate-frequency transformer side of the broken A.V.C. connection and the chassis, to provide a steady D.C. bias for the controlled tubes. If a *selectivity* or *fidelity* control is present, it should

---

* An output meter is simply a copper-oxide voltmeter calibrated in *decibels* and provided with a self-contained load resistance. A capacitor is sometimes incorporated in the meter to prevent direct currents from flowing through it. If the meter used contains an internal condenser, no external series condenser is necessary.

be set at the high-selectivity (low-fidelity) position. The receiver should now be turned on and allowed to warm up for at least ten minutes before proceeding.

2. *Alignment of Intermediate-frequency Stages.* Short-circuit the oscillator section of the main tuning condenser, and connect the *high* output terminal of the signal generator to the signal-input grid of the converter tube (consult a tube manual for socket connections) through a small (.001–.01-$\mu$f) blocking condenser. Set the controls of the signal generator to obtain a modulated radio-frequency output having the intermediate frequency specified by the manufacturer. With an aligning tool (insulated low-capacitance screwdriver) adjust the trimmer condensers of the *output* or *last* intermediate-frequency transformer for maximum deflection of the output meter. After this transformer is properly tuned, go to the next preceding one, always working backward toward the first intermediate-frequency transformer, which should be tuned last. Always adjust for maximum output on the meter. Do not overload the tubes with an excessive signal at any time.

3. *High-frequency Alignment of Oscillator and Signal-input Circuits.* Remove the signal-generator connection from the signal grid of the converter tube and connect it to the antenna terminal of the receiver. Remove the short circuit from the oscillator condenser and set both the signal-generator and receiver dials to 1,400 kc (or the high alignment frequency specified by the manufacturer, if known). With the aligning tool, turn the adjusting screw of the oscillator *parallel trimmer* condenser (this will usually be found mounted on the tuning-condenser frame, and may be distinguished from the signal-input circuit trimmers because its adjustment is *much more critical.* Note that this is *not* the oscillator *series-padder* condenser). Set this trimmer for maximum deflection on the output meter, then adjust the trimmers of the signal-input and radio-frequency stage (if one is used) tuning condensers for maximum output. Do not overload the tubes with an excessive signal during this process.

4. *Low-frequency Alignment of Oscillator Circuit.* This is the procedure for receivers having a series-padder condenser or adjustable iron-core oscillator coil. Set the signal generator and receiver dials to their 600-kc positions (or to the low alignment frequency specified by the manufacturer). Place the aligning tool on the adjustment screw of the oscillator *series-padder* condenser. (This is usually a compression-type mica condenser, and will probably be found beneath the chassis with a hole provided for adjustment. Ask the instructor if in doubt about its location.) Slowly *rock* the receiver tuning dial back and forth between the 550- and 650-kc positions, while turning the padder-condenser adjusting screw. In this way, find the combination of padder-condenser adjustment and dial setting that gives maximum deflection of the output meter. If an iron-core oscillator coil is used, proceed in the same manner by adjusting the oscillator-coil core. The dial setting of the receiver should agree with that of the signal generator; if it does not, this situation may indicate that the receiver dial is not calibrated accurately.

The procedure differs for receivers having no series-padder condenser. If one section of the receiver's tuning condenser is smaller than the others, it is likely that no series-padder condenser is used. In this case, the oscillator must be aligned at the low-frequency end by setting the signal-generator dial at 600 kc, tuning the receiver for maximum deflection of the output meter, then loosening its dial indicator and turning it upon the shaft to make it read 600 kc. The signal input circuits are made to track by bending the end plates of their tuning condensers, which are usually slotted to facilitate doing this.

5. *Rechecking the Alignment.* After low-frequency alignment is complete, the high-frequency alignment should be rechecked as in part B–3, to see that it has not been disturbed. If it has, realign, following the same procedure.

The receiver is now properly aligned, and its automatic volume control should be reconnected and the receiver replaced in its cabinet.

C. ALIGNMENT OF RECEIVER—VISUAL METHOD (DEMONSTRATION BY INSTRUCTOR—OPTIONAL). A very convenient and accurate method of aligning a receiver is to use a signal which is *frequency modulated*, or *swept through* a range of frequencies centered on the intermediate frequency or the chosen high or low alignment frequency. The output of the receiver's demodulator is applied to the vertical ($Y$-axis) deflecting plates of a cathode-ray oscilloscope whose horizontal deflection is synchronized with the *rate of sweep* of the signal-generator output. The resulting pattern is a *frequency-response curve of the entire receiver*, made by varying the input frequency rapidly and continuously, instead of step by step. Thus the selectivity of the receiver and its band-pass characteristics may be estimated at the same time alignment is accomplished. Many commercial signal generators are arranged to provide a frequency-modulated output if this is desired, and external modulators or *wobbulators* are available that will frequency modulate the output of any signal generator.

Connect the frequency-modulated signal generator and cathode-ray oscilloscope to the receiver, following the instructions accompanying the signal generator, and align the receiver by the method recommended therein. Try to obtain a symmetrical response curve by the proper adjustment of the tuned circuits.

**References:**

1. Hoag, J. B., "Basic Radio," Art. 32.8.
2. "The Radio Amateur's Handbook," Defense Ed., Art. 7–17.
3. Ghirardi, A. A., "Modern Radio Servicing," chapters 24–25.
4. Hicks, H. J., "Principles and Practice of Radio Servicing," pp. 204–210.
5. The instructions accompanying the signal generator.

**Name** ________________ **Date** ________________ **Class** ________________

## QUESTION SHEET—EXPERIMENT 27

1. Intermediate-frequency Transformer Data:

(a) Operating frequency = ................................ kc

(b) Core material: ................................

(c) Is damping ring present? ................................

(d) Type of trimmer: ................................

(e) Single- or double-tuned? ................................

2. If a receiver has automatic volume control, why should this be rendered inoperative during alignment?

3. Why is the visual aligning method better than one using an output meter?

4. In aligning the oscillator, the parallel trimmer condenser was adjusted at a high frequency and the series-padder condenser at a low frequency. Explain why this sequence could not be reversed.

## EXPERIMENT 28

# Tube and Condenser Checking

### APPARATUS REQUIRED

| ITEM | QUANTITY |
|---|---|
| Tube-testing unit (see Fig. 28–1) | 1 |
| Condenser-testing unit (see Fig. 28–2) | 1 |
| Power supply | 2 |
| D.C. voltmeter, 0–5 v, 0–10–100 v, 0–100, 500 v, each | 1 |
| Milliammeter, 0–10–100 ma | 1 |
| (A multimeter may be substituted for the above meters, if desired.) | |
| Audio-frequency oscillator | 1 |
| Ohmmeter | 1 |
| Headphones | 1 |
| Assortment of tubes and condensers to test | — |

Taken together, defective tubes and condensers probably account for about three fourths of all radio receiver troubles. It is apparent, therefore, that tube testers and condenser testers are among the *indispensables* of the radio technician's equipment, and an understanding of their operation is desirable.

### Tube Testers

There are several criteria by which the condition of a vacuum tube can be judged, but probably the most important are (1) its *total cathode emission* and (2) its *transconductance.*

As a tube ages, the number of electrons emitted from its filament gradually decreases, until finally there are too few to provide sufficient plate current for proper operation. The total emission of a tube can be measured by connecting all of its electrodes—other than the cathode—together to form a single anode. Enough voltage is then applied between the cathode and anode to produce voltage saturation (the student will recall that this is the condition where *all* of the electrons emitted by the cathode are attracted to the anode) and the total emission current is read on a milliammeter inserted in the plate circuit. A lower than normal value of current indicates that the tube has reached the end of its useful life. In this type of test, all tubes are tested as *diodes.*

Though it gives an indication of the condition of the cathode, which is the element of a tube subject to wear, the emission test does not indicate defects arising from displaced elements, such as might result from mechanical abuse or vibration encountered in automotive and aviation applications. Displaced elements within a tube will almost always cause a change in the transconductance; in addition, lowered cathode emission will cause the transconductance to be somewhat less than normal. A measurement of transconductance therefore gives an indication both of the condition of the cathode and of misplaced elements.

The student will recall that the transconductance of a tube is given by

$$g_m = \frac{\Delta i_b}{\Delta e_c} = \frac{\text{any small change in plate current}}{\text{change in grid voltage to produce } \Delta i_b.}$$

In many commercial tube testers, a switching system connects all tube elements other than the control grid and cathode together to form a single anode (thus all tubes are tested as triodes). Proper voltage is applied to the plate and the correct bias voltage is applied to the control grid. By pressing a button, the grid bias voltage is changed by a small amount (usually 1 v) and the resulting change in plate current is read on a milliammeter. For this reason, transconductance testers are often called *grid-shift* testers.

Most commercial testers of this type have special circuits which enable the operator to *buck out* the steady plate current in the milliammeter *before* the bias voltage is shifted. When the bias is changed, the meter reads the *change* in plate current directly, and if the amount of grid shift is kept constant for all tubes, the meter may be calibrated directly in micromhos.

Provision is made in commercial tube testers of all types for testing the tube for *interelectrode shorts.* This should be done before the quality test is made, in order to safeguard the meters and other parts of the tube tester itself. In some tube testers, circuits are included which permit tests for *gas*, *leaky insulation*, and *tube noise.* A number of sockets are provided to accommodate tubes having different basing arrangements, and the proper connections are made by switching systems, which are often quite complex. A tapped filament transformer supplies the various heater voltages for different types of tubes.

## Condenser Testers

Condenser failures usually fall into one of the following classes: (1) shorts (breakdown of the dielectric); (2) open circuits (leads disconnected from the electrodes); (3) leaks (condenser passes direct current). A good condenser tester should indicate *all* of the above faults, in addition to giving an indication of the *capacitance* of good condensers. Commercial condenser testers are available that can make all of the tests outlined above. Many of these use the *Wheatstone bridge principle* for the measurement of capacitance and employ a neon-lamp arrangement for the other tests. A very simple tester of this type, capable of yielding results of sufficient accuracy for all service applications, will be described in the experimental procedure.

## Experimental Procedure

At least one good tube and several defective ones of various types should be available for testing. Tetrode and pentode types should be selected which have their characteristics *when connected as triodes* published in tube manuals. The manufacturer of tube testers can obtain this information for *any* type of tube by actual measurements on a large number of tubes of each type, but such measurements would not be practical here. Defective tubes and condensers for testing will probably be obtainable at a local radio service establishment.

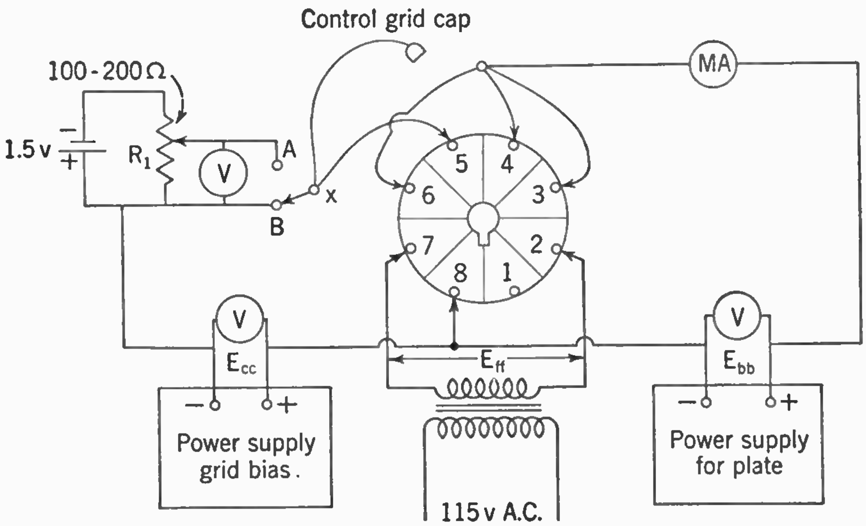


FIG. 28–1. A Transconductance of Tube Tester.

A. TRANSCONDUCTANCE TUBE TESTER. Connect the apparatus as indicated in Fig. 28–1. Consult a tube manual to find the socket connections for a type 6F6 tube. All electrodes except the cathode and control grid should be connected together—the control grid should be connected to point $x$. From the tube manual obtain the plate-supply voltage and grid-bias voltage recommended for *triode* operation of the tube. Set the plate-supply and bias voltages at these values, and enter them on the data sheet. Connect a voltmeter between points A and B (Fig. 28–1) and adjust $R_1$ so that a voltage of *exactly* 1 v is obtained. Turn the switch to point A, insert a good 6F6 tube into the socket, and after the cathode has reached operating temperature carefully read and record the plate current. Now turn the switch to point B, and again carefully read and record the plate current. The transconductance of the tube is given by the equation

$$\begin{aligned} g_m &= \text{change in plate current (in milliamperes)} \times 1{,}000 \\ &= \text{transconductance in micromhos.} \end{aligned}$$

Compare this figure with that given in the tube manual; then repeat this procedure for the other tubes supplied. If the measured transconductance of any tube is less than 75% of that specified in the tube manual, the tube should be laid aside as a reject.

**B. A Condenser Tester.** Figure 28–2 shows a simple condenser tester which is extremely useful. Condensers are tested for shorts and leakage by connecting them to terminals *x–x* and throwing the switch $S_1$ to the right. A leaky condenser is indicated by a *soft* glow in the neon lamp, a shorted condenser by a *brilliant* glow. Capacitance is measured by throwing the switch to the left and adjusting the potentiometer and switch $S_2$ for minimum volume of sound in the headphones. The capacitance of the unknown condenser is given in microfarads by the expression

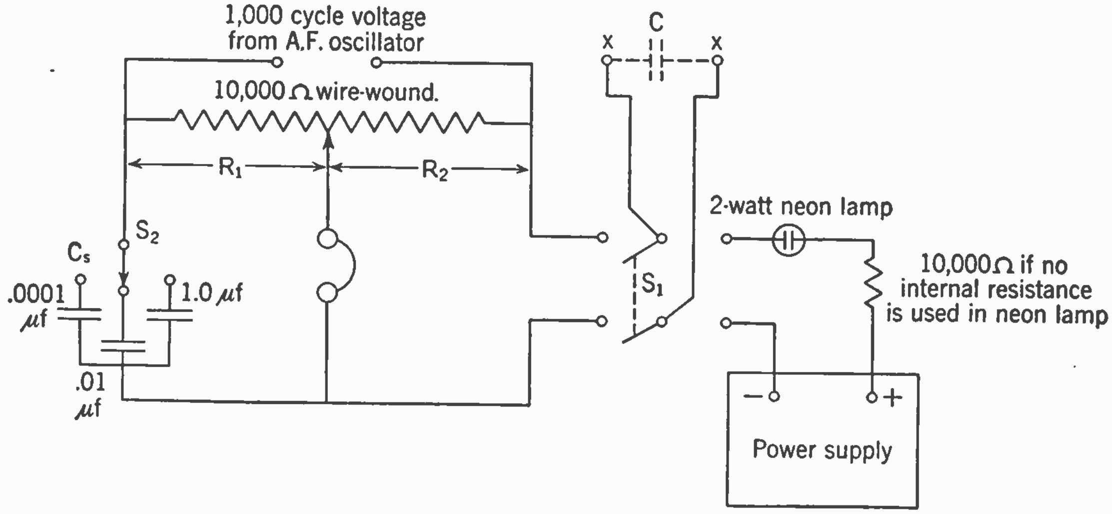


Fig. 28–2. A Capacitance Tester.

$$C = C_s \frac{R_1}{R_2},$$

if $C_s$ is given in microfarads, $R_1$ and $R_2$ being as shown, and $C_s$ being the capacitance to which $S_2$ is set. The potentiometer can be provided with a dial marked with values of $R_1/R_2$ for various settings. The instrument then becomes direct reading, if the values of $C_s$ are chosen equal to powers of 10 as shown.

Assuming that the potentiometer is linearly wound, provide a paper scale for it and place the following marks at the correct points on the scale: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. Note that 1 occurs at the midpoint of the winding and 10 where $R_1 = 10R_2$. Also note that the scale is logarithmic and that the same spacings may be used to lay out the scale from .1 to 1.0. Mark the scale from 0.1 to 10.

Wire up the condenser tester and use it to check several condensers, testing each for leakage and shorts, then measuring the capacitance of each if in good condition. Record the data in Table B.

**References:**

1. Everitt, W. L., *et al.*, "Fundamentals of Radio," pp. 118–119.
2. Henney, Keith, "Principles of Radio," Art. 34, 81–85, 165.
3. "The Radio Amateur's Handbook," Defense Ed., Art. 12–4, 12–9.
4. R.C.A. Tube Manual, RC–14, pp. 195–197.

**Name** ______________________ **Date** ______________ **Class** ______________

## DATA SHEET—EXPERIMENT 28

### TABLE A. TRANSCONDUCTANCE TEST

| Tube type | Bias voltage | Anode voltage | Anode current (milliamperes), switch on | | Transconductance (micromhos) | | Good | Bad |
|---|---|---|---|---|---|---|---|---|
| | | | A | B | Measured | Tube manual | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

### TABLE B. CONDENSER TEST

| Nominal capacitance (microfarads) | $R_1$ (ohms) | $R_2$ (ohms) | $R_1/R_2$ | $C_s$ | Measured capacitance (microfarads) | Leaky or shorted? |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

**Name** ________________________ **Date** ____________ **Class** ____________

## QUESTION SHEET—EXPERIMENT 28

**1.** Draw a diagram showing an emission-type tube tester capable of being operated from alternating current, in which the tube under test acts as a rectifier for the meter.

**2.** Show that, in a transconductance tester, if $\triangle e_c$ is made to be 1 v, then the transconductance is given by:

$$g_m = \triangle i_b(\text{ma}) \times 1{,}000 \text{ micromhos.}$$

**3.** Draw the capacitance-measuring portion of the condenser tester as a Wheatstone bridge circuit, and prove that at balance

$$C = C_s\frac{R_1}{R_2}.$$

## EXPERIMENT 29

# Trouble Shooting in Radio Receivers

### APPARATUS REQUIRED

| ITEM | QUANTITY |
|---|---|
| Radio receiver with circuit diagram | 1 |
| Multirange tester (V-O-M) | 1 |
| Signal-tracing analyzer (with instructions) | 1 |
| Soldering iron | 1 |
| Defective parts, connecting wires, and | — |

An obvious procedure in dealing with an inoperative or poorly-performing radio receiver would be to remove its parts one by one and test each one with suitable instruments until the defective one was found. However, when the large number of parts contained in even the smallest of commercial receivers is considered, it becomes evident that this process would be entirely too laborious and time-consuming to be practical. For this reason, systematic methods have been devised that enable the technician to locate the defective part within a single portion of the receiver. Only the parts of this portion need then be tested individually—and usually the systematic checking process gives important clues as to the location of the particular part that has failed.

There are three methods of testing which are most used, either alone or in combination. These are:

1. Voltage-current analysis;
2. Resistance analysis;
3. Signal tracing.

### Voltage-current Analysis

The voltage-current analysis method of receiver testing is predicated upon the principle that a defect in a receiver is often indicated by a voltage or current greater or less than normal in the vacuum tube of the stage containing the defect. The socket voltages of all of the tubes in the receiver are measured and tabulated, likewise the currents flowing to the tube electrodes. A comparison is then made, either with similar measurements made on a receiver of the same type which is performing properly, or better, with the values of voltage and current specified as correct by the manufacturer of the receiver. Any wide variation in either voltage or current from the specified values indicates a defective stage. A set analyzer (see Experiment 24) is used to facilitate breaking into the circuits for measurement of currents. Voltages are usually measured between the chassis and the electrode concerned.

### Resistance Analysis

The resistance-analysis method of testing consists of measuring the resistance between all of the vacuum-tube socket connections and the chassis of the receiver; an ohmmeter is commonly used for these measurements. The defective part is usually found in the circuit whose resistance differs from the value specified as correct. This method has the advantage that, if the manufacturers' specifications of resistance are not available, the correct value can be computed from the values given on the circuit diagram.

### Signal Tracing

The signal-tracing method of receiver testing is the surest and most rapid of all. In this method, a signal is applied to the receiver, and traced from its input through the various circuits until a point is found where it disappears or becomes seriously weakened—the defective stage is the one containing this point.

Instruments for signal tracing are quite specialized, and contain channels for measurements in each of the corresponding channels of the receiver. Thus, a typical signal-tracing instrument contains the following channels:

1. A *tunable vacuum-tube voltmeter*, which can be tuned to the frequency of the applied signal. The voltmeter feature permits measurement of the amplification of the signal as it passes through the various stages.
2. A second *tunable vacuum-tube voltmeter*, which can be tuned to the frequency of the local oscillator, and used to measure its frequency and magnitude at all points between the oscillator tank coil and the oscillator grid of the converter tube.
3. An *audio-frequency voltmeter*, which is used to measure the magnitude of the signal after demodulation, and in its course through the audio-frequency channel of the receiver.
4. An *electronic D.C. voltmeter*, which has an extremely high ohms-per-volt factor (about 2,000,000 ohms per volt on the low-voltage range) and can therefore measure the voltage at any point in the receiver without interfering with its normal operation.
5. A *wattage indicator*, to give an indication of the power consumed by the receiver.

The signal tracing method of testing is a *dynamic* one, in that the receiver is tested while in operation, and the signal—which is the important thing anyway—is the subject of measurement. Many defects which cannot be located by other methods of test are found rapidly and easily by signal tracing; furthermore, it can be determined whether or not the signal is *leaking* into portions of the receiver where it should not be.

Before concluding this discussion, it might be well to remark that experience and common sense are valuable assets for successful servicing. Each receiver presents new problems, but the student will find that after he has gained a little experience he will acquire a *knack* for rapidly proceeding to the seat of the trouble. It is, of course, impossible to include a complete discussion of service procedure here. Excellent books on this subject are available, and should be consulted by the student.

## Experimental Procedure

A circuit diagram should be available for each receiver to be tested. It is suggested that common and easily found faults be introduced into *good* receivers by the instructor, for otherwise such obscure troubles may be present as to discourage the student. Defective condensers can probably be obtained from a local service shop and used to replace the good condensers in the receiver to introduce faults. *Open* resistors can be made by changing the color of the dots on high-resistances to make them appear to be lower in value.

If only one complete set of test equipment is available, this experiment may be conducted as a group participation project, in which the actual measurements are made by the students, and the results tabulated on the blackboard for consideration by the class.

**A.** VOLTAGE-CURRENT ANALYSIS. Turn on the receiver, and tune in a station to be sure the set is operating properly. If a tube tester is available, test all of the tubes for quality and shorts. Measure and tabulate all of the chassis-socket terminal voltages, using a suitable multirange voltmeter. If a set analyzer is available, use this to measure the electrode currents, tabulating them also. Compare the voltages and currents measured with those given in the tube manual.

Have the instructor put the receiver out of order; then try to locate the defective part by the voltage-current analysis method. Record the defect found and briefly describe how it was located on the data sheet.

**B.** RESISTANCE ANALYSIS. Remove the line cord of the receiver from the socket, then measure and tabulate all resistances as measured from tube-socket terminals to chassis.

Have the instructor introduce a fault, then try to locate the defective part by the resistance-analysis method. Refer to the circuit diagram of the receiver for guidance. Record as above on the data sheet.

C. Signal Tracing. Refer to the instructions accompanying the signal-tracing unit to learn something of its operation. Have the instructor put a fault in the receiver; then connect the signal generator to its antenna and ground terminals, and proceed to trace the signal through the receiver until the defective stage is found. Do not fail to measure the power-supply voltage, and to be sure that the oscillator is functioning if the receiver is a superheterodyne. Do not forget that the signal-tracing instrument must be tuned to the intermediate frequency when the I.F. stages are being tested. Record the complete results of the test on the data sheet.

**References:**

1. Hicks, H. J., "Principles and Practice of Radio Servicing," chap. 13.
2. Ghirardi, A. A., "Modern Radio Servicing," chapters 12, 20, 21, 22.
3. Rider, J. F., "Servicing Superheterodynes," chapters 6–7.
4. Instruction books accompanying receiver analyzers.

**Name** ---------------------------------------- **Date** -------------------- **Class** --------------------

# DATA SHEET—EXPERIMENT 29

## A. VOLTAGE–CURRENT ANALYSIS

## B. RESISTANCE ANALYSIS

## C. SIGNAL–TRACING ANALYSIS

LABORATORY MANUAL, PART II, FOR FUNDAMENTALS OF RADIO, COPYRIGHT, 1942, BY PRENTICE-HALL, INC.

Name ______________________ Class ______________ Date ______________

## QUESTION SHEET—EXPERIMENT 29

**1.** Can open-circuited condensers be located by a voltage-current analysis? By resistance analysis? By signal tracing? Explain each answer.

**2.** Why should the tubes in a receiver be checked before making a voltage-current analysis?

**3.** Faulty tubes and condensers are responsible for a large percentage of defective receivers. Explain why these two are more subject to faults than other parts of a receiver.

## EXPERIMENT 30

# Standing Waves on Wires

### APPARATUS REQUIRED

| ITEM | QUANTITY |
|---|---|
| Ultrahigh-frequency oscillator (see Appendix) | 1 |
| Power supply | 1 |
| Two-wire transmission line with shorting bar | 1 |
| Traveling detector with milliammeter | 1 |
| Neon tube (smallest size available) | 1 |
| Meter or yard stick | 1 |
| Connecting wires | Assortment |

It can be demonstrated experimentally that if an A.C. voltage is applied to a two-wire transmission line, such as the one shown in Fig. 30–1, the voltage travels along the line in the form of waves, which are propagated with approximately the speed of light. Thus, if the voltage wave applied to terminals A–A′ goes through its maximum positive value at a certain instant, the voltage appearing across points B–B′ will not rise to a maximum until a later instant, and that across C–C′ at a still later time. If the frequency of the applied voltage is high enough—or the line long enough—it may happen that the alternating voltage across terminals A–A′ has decreased to a negative maximum before that at C–C′ has reached its first positive maximum. A still further increase in frequency will result in the existence of several successive waves of voltage on the line, all traveling with the velocity of light.

Fig. 30–1.

It is found that electrical waves traveling along a line are *reflected back* toward the source if the line is either short-circuited or open circuited at its terminals. In the former case, the voltage wave is reflected with a polarity *opposite* to that of the initial wave, while in the latter the reflected wave has the *same* polarity as the initial wave.

At any point along a transmission line upon which there are traveling waves, the *instantaneous* voltage is equal to the *algebraic sum* of the initial and reflected waves. Referring to Fig. 30–2, which represents an open-circuited transmission line at successive instants of time, upon which both types of wave are traveling, it is seen that there are certain points along the line where the sum of the two waves is *always zero*. These points are called *voltage nodes*, and can be found by connecting a suitable voltmeter across the line and moving it along to locations where no voltage is indicated.

It is also seen from Fig. 30–2 that there are points where the two waves add to yield voltage *maxima*, points where the voltage is greater than at other locations along the line. The resultant wave, obtained by adding the initial and reflected waves, is one that is stationary upon the line, and is therefore called a *standing* wave.

A *Lecher-wire system* is a length of transmission line arranged so that standing waves may be produced upon it by applying high-frequency A.C. voltages to the system. The Lecher-wire system is often used as a wavemeter in ultrahigh-frequency work, for the wave length of the standing waves can be measured with a yardstick or other rule, and the frequency determined by the equation:

$$f_{cps} = \frac{3 \times 10^{10}}{\lambda_{cm}}$$

where $\lambda_{cm}$ is the wave length of the standing waves in centimeters.

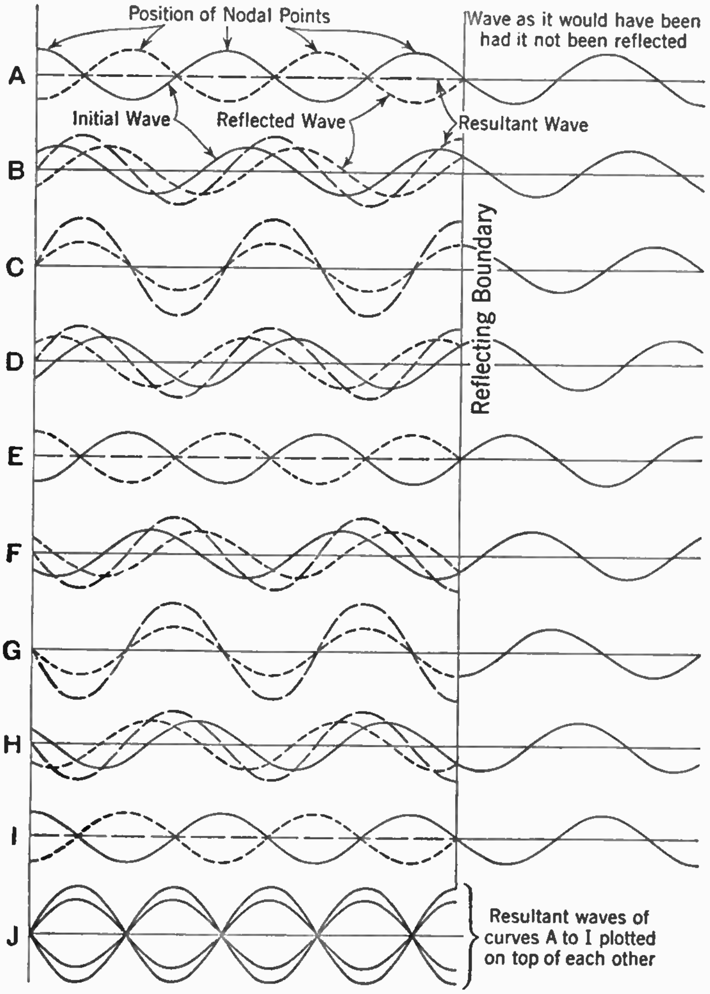


FIG. 30–2. Reflection of a Wave at a Boundary, Showing Addition of Initial and Reflected Waves to Give Standing Waves.

The foregoing discussion of the subject of standing waves is necessarily a very brief and incomplete one. The student is therefore urged to consult one or more of the references before proceeding with the experimental work.

## Experimental Procedure

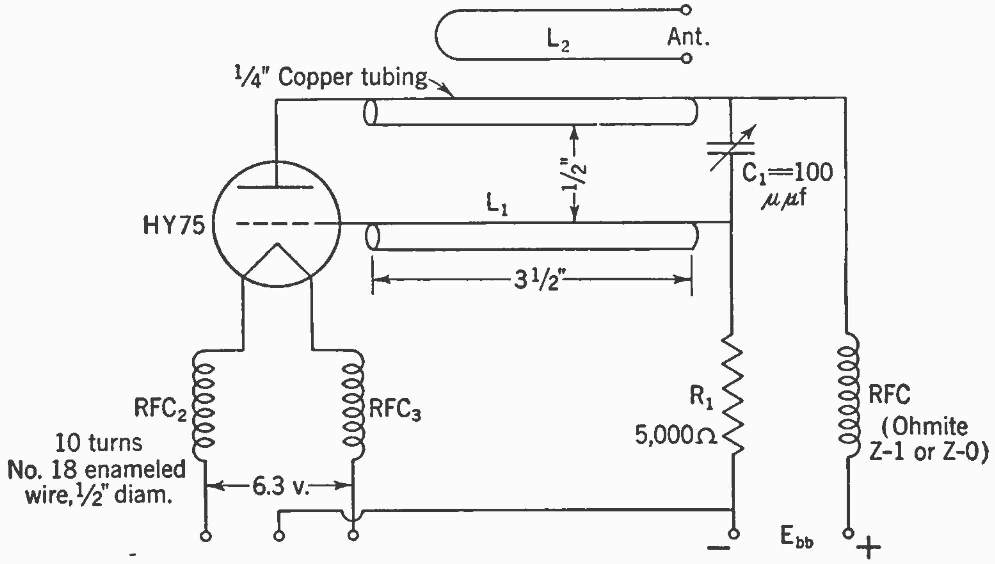
**A.** GENERATION OF ULTRAHIGH-FREQUENCY VOLTAGES. Because of the very great velocity at which electrical waves travel along a transmission line, it is necessary to apply the successive waves of voltage to the line very rapidly if several waves are to be obtained simultaneously upon a reasonably short length of line—this is equivalent to stating that the applied voltage must be of extremely high frequency.

Ultrahigh-frequency oscillators differ greatly in mechanical construction from the low-frequency oscillators previously studied. Great care must be taken in their design to keep all wiring as short as possible. Coils are frequently absent from such oscillators—lengths of transmission line being used instead. Special tubes having small elements and top-connections to reduce lead lengths and interelectrode capacitances are ordinarily required. Some idea of the problems encountered in the design of such equipment can be had when it is considered that the *tank condenser* often consists of the grid-to-plate capacitance of the tube, while the *tank coil* is a straight length of wire just long enough to connect the plate to the grid (with a blocking condenser to prevent the flow of direct current).

Examine the ultrahigh-frequency oscillator. Notice that the tank circuit is composed of a length of transmission line terminated in a condenser, rather than the usual coil-condenser arrangement. The circuit diagram of the oscillator appears in Fig. 30–3.*

Connect the oscillator to the power supply, set the plate voltage at the highest value obtainable (450 or less) and test for oscillation by grasping the neon lamp by its glass portion and holding one of its contacts against the plate connection of the tube.

B. PRODUCTION OF STANDING WAVES ON A TRANSMISSION LINE. Tightly couple the oscillator to the transmission line by placing it directly under the line wires at their short-circuited end—the tank line (copper tubing) of the oscillator should be *parallel* to the wires. Support the oscillator so that it just clears the transmission line.



Courtesy of A. R. R. L.

FIG. 30–3.

Suspend the neon lamp from the line wires somewhere near their mid-point—one terminal of the lamp on each wire—then place the short-circuiting bar across the line at the end opposite from the oscillator and *tune* the line by sliding the shorting bar along the line until the neon lamp is seen to glow. (If no glow can be obtained, try a different position of the lamp—about 20 cm either way from its former position.) Adjust the shorting bar for maximum brilliance of the lamp, then, with a stick of wood or other insulating material, carefully slide the lamp along the line. Determine positions along the line where the lamp refuses to glow (voltage nodes) and other points where it glows with maximum brilliance (voltage loops). Measure the distance between the points of maximum brilliance, and record and compute the average distance as indicated in Table A of the data sheet.

C. STANDING-WAVE PATTERNS ON LINES HAVING OPEN- AND SHORT-CIRCUIT TERMINATIONS. Move the oscillator from the shorted end of the line to a point nearer its center, and place the shorting bar on the line near the short-circuited end. (See Line Diagram No. 1 on the data sheet.)

Suspend the neon lamp from the line near the open-circuited end, then slide the shorting bar along until the line is tuned, as indicated by maximum brilliance of the lamp. Readjust the position of the

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* Reprinted by permission of the American Radio Relay League from "Radio Amateur's Handbook," 1942 edition.

oscillator along the line to obtain a further increase in brilliance, then slide the lamp all along the line, finding the points of maximum brilliance, and the points where the lamp is extinguished. On Line Diagram No. 1 on the data sheet, place a *circle* at the points of *maximum brilliance*, and a *cross* at the points where the lamp is *extinguished.*

Now short-circuit the line at the end which was formerly open-circuited (see Line Diagram No. 2), place the neon lamp about 30 cm from the far (right) end of the line, and retune the line with the shorting bar. Readjust the position of the oscillator to obtain maximum brilliance of the lamp, then slide the lamp along on the line, finding the points of maximum brilliance and the points where the lamp is extinguished. Enter these on Line Diagram No. 2, marking the voltage loops (points of maximum brilliance) with a circle, and the points of extinction with a cross.

D. MEASUREMENT OF ULTRAHIGH FREQUENCIES, USING THE LECHER-WIRE SYSTEM. Couple the oscillator to the line loosely at the short-circuited end, connect the traveling detector to the milliammeter, and place it on the line near the center. Put the shorting bar on the line at the open-circuited end, then slide it along the line until maximum deflection of the milliammeter is obtained.* Adjust the position of the detector to obtain maximum sensitivity, then readjust the position of the shorting bar on the line. Move the shorting bar along the line until the reading of the meter drops to zero or to a minimum value, then returns to a maximum. The distance between the successive maximum points should be measured—it is equal to one half a wave length. Enter data in Table C, and repeat for other settings of the oscillator tuning condenser. Compute the oscillating frequency, as indicated.

**References:**

1. Everitt, W. L., *et al.*, "Fundamentals of Radio," chap. 9.
2. "The Radio Amateur's Handbook," 1942, 19th ed.

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* If no deflection is obtained, reverse the meter leads, and move the detector along the line about 20 cm or so.

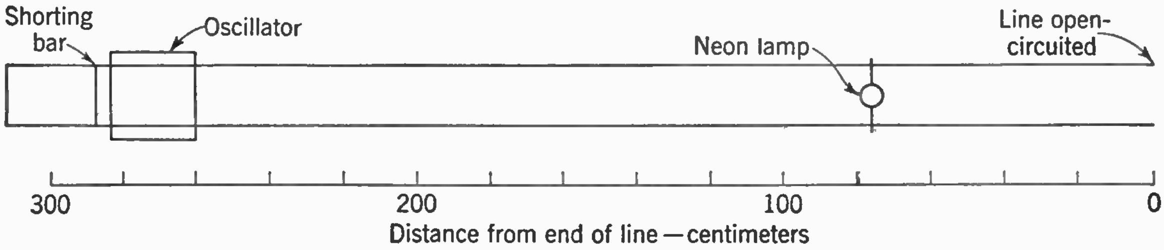
**Name** ________________ **Date** ________________ **Class** ________________

## DATA SHEET—EXPERIMENT 30

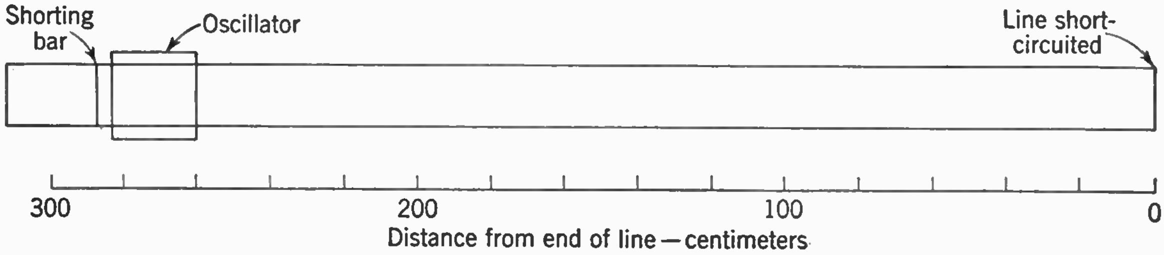
### TABLE A—DISTANCE BETWEEN VOLTAGE LOOPS

| Reading | Inches | Centimeters |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| Average | | |

### DIAGRAMS B



Line Diagram No. 1



Line Diagram No. 2

### TABLE C

| Oscillator condenser setting | Distance between voltage loops | Wave length, centimeters | Frequency, megacycles |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

Name ________________________ Date ____________ Class ____________

## QUESTION SHEET—EXPERIMENT 30

1. Why are choke coils used in the filament leads of the vacuum tube?

2. Why are a few turns of wire an effective choke coil at ultrahigh frequencies?

3. Explain why the circles and crosses on Line Diagram No. 1 do not occur at the same places on Line Diagram No. 2.

# APPENDIX

## CONSTRUCTION OF APPARATUS *

10. **Linear Time-base Sweep Circuits.** It has been found, for demonstration purposes, that the mounting of parts and drawing the circuit diagram on a spread board is a very satisfactory method of presentation. The picture of Fig. 15 shows the complete circuit diagram of Fig. 16–6 on such a board. Each component part of the circuit is mounted beside its symbol in the circuit diagram. Pin jacks are provided at many points in the circuit in order that various voltages and currents may be measured or their wave form observed on a cathode-ray oscilloscope. The power supply is assembled at the lower center of the panel, but its wiring diagram is omitted. The panel is 24 × 36 inches and is made of $\frac{3}{16}$-inch masonite covered with white cardboard and mounted in a 4-inch wooden frame.

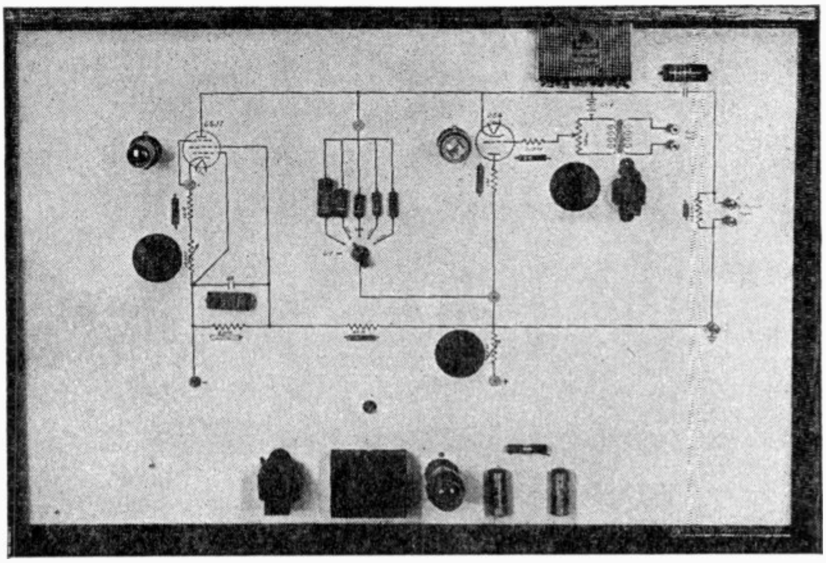


Fig. 15. A Linear Time-base Sweep Circuit.

As it is desirable to begin with a simpler and more fundamental circuit than that shown in the picture, provision has been made to hang cardboard pieces (see dotted lines of Fig. 16–6) over the pentode tube and its associated circuits and the thyratron and its circuits. On the former of these is the symbol for the resistor $R$, which is a variable resistance of 0–5 megohms and is mounted in a discarded tube base so it can be plugged into the pentode tube socket and used for the current-limiting device as shown in Fig. 16–2. The circuit of the thyratron can be covered by the second card, which has the symbol for a simple two-element neon lamp on it. The neon lamp is mounted in an octal tube base and can be substituted for the thyratron tube. With both cards in place the circuit shown on the board is that of Fig. 16–2.

If we remove the 0–5 megohm resistor and its card and substitute the pentode tube, the circuit of Fig. 16–5 results. Removal of the second card and the use of the thyratron tube in place of the neon lamp converts the circuit into that shown by Fig. 16–6.

The above is applicable only when the circuits described are arranged spread-board fashion. The sweep-circuit will operate even more satisfactorily if mounted in a more compact manner on a metal or wooden chassis. All the different circuits mentioned in Experiment 16 may be constructed and used in this manner.

Attention is called to the point of the circuit which is grounded. The grounded terminal of the output posts must be connected to the G terminal of the oscilloscope. It may be necessary with some makes of oscilloscope to reverse the leads to the deflecting plates in order to make the saw-tooth pattern appear as desired on the screen of the cathode-ray tube. A good ground connection should be made at the point indicated and it will aid in removing 60-cycle interfering voltages which may be induced into the circuit.

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* A continuation of Appendix V, Laboratory Manual for Fundamentals of Radio, Part I.

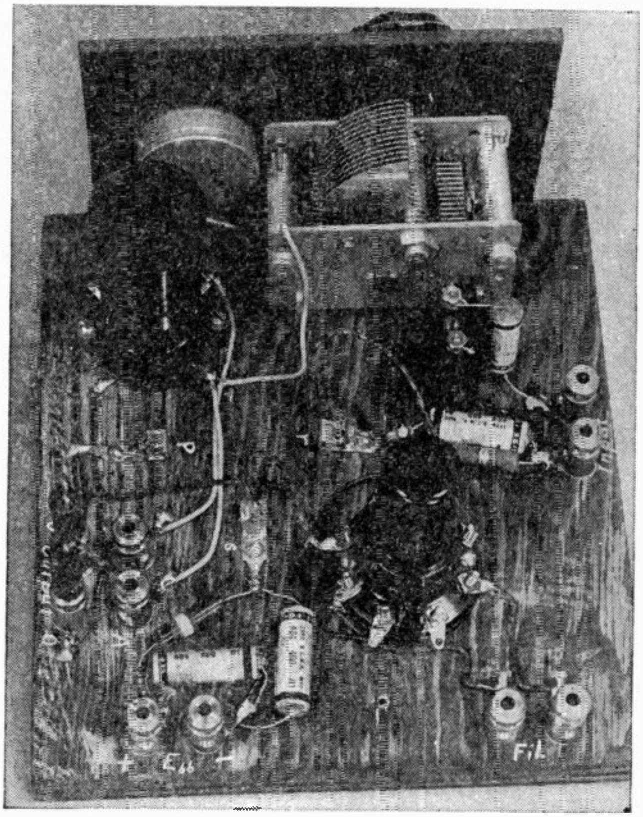

FIG. 16. A Class A Radio-frequency Amplifier Unit.

**11. THE CLASS A RADIO-FREQUENCY AMPLIFIER UNIT.** The picture of Fig. 16 shows the arrangement of parts for the circuit of Fig. 19–2. The experimenter is urged to follow a similar arrangement when constructing this circuit, as radio-frequency units operate more satisfactorily when the connecting wires are as short and as direct as possible.

Attention is called to the manner in which the tube connections are easily changeable so that the unit may be operated either as a triode or as a pentode amplifier, also to the plugging arrangement which

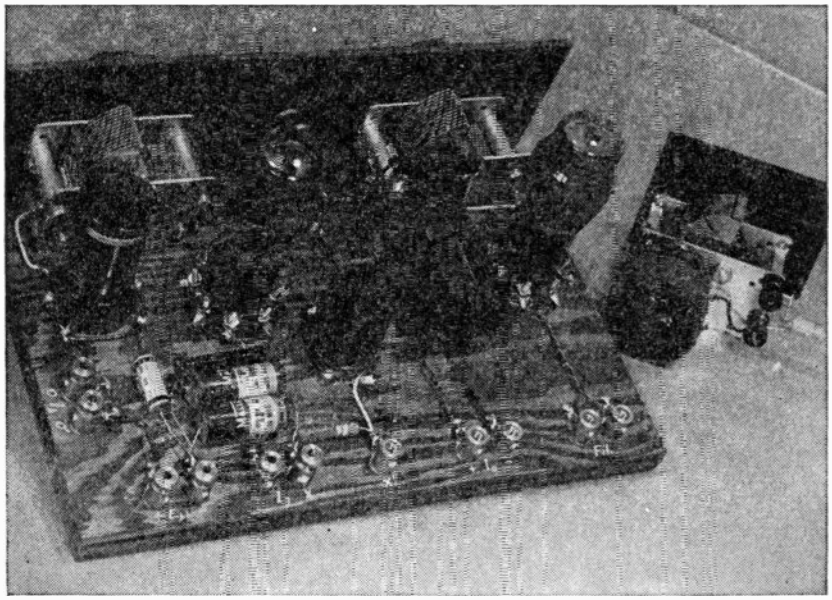

FIG. 17. Radio-frequency Oscillator and Class C Amplifier Unit and a Wave Meter.

readily permits changing the output circuit into which the tube works. The variable 40-ohm resistor is shown mounted on the front panel beside the tuning condenser. A plug-in coil is shown in the picture, but any radio-frequency antenna coil from a discarded radio receiver will serve equally well.

To prevent the picking up of unwanted 60-cycle voltages the leads from the signal generator to the amplifier should be shielded and the leads from the pick-up coil to the oscilloscope should also be shielded or a twisted pair should be used.

If trouble is experienced in obtaining a uniform pattern of the modulated output from the amplifier, the input voltage to the oscilloscope may be too high. Try changing the input connections to accommodate a high input voltage. If this does not produce the correct wave pattern, connect the pickup-coil terminals directly to the vertical plates of the oscilloscope. This will prevent rectification from taking place in any amplifier of the oscilloscope, a condition which sometimes occurs and causes the side bands of the modulation envelope to appear to be in phase with one another.

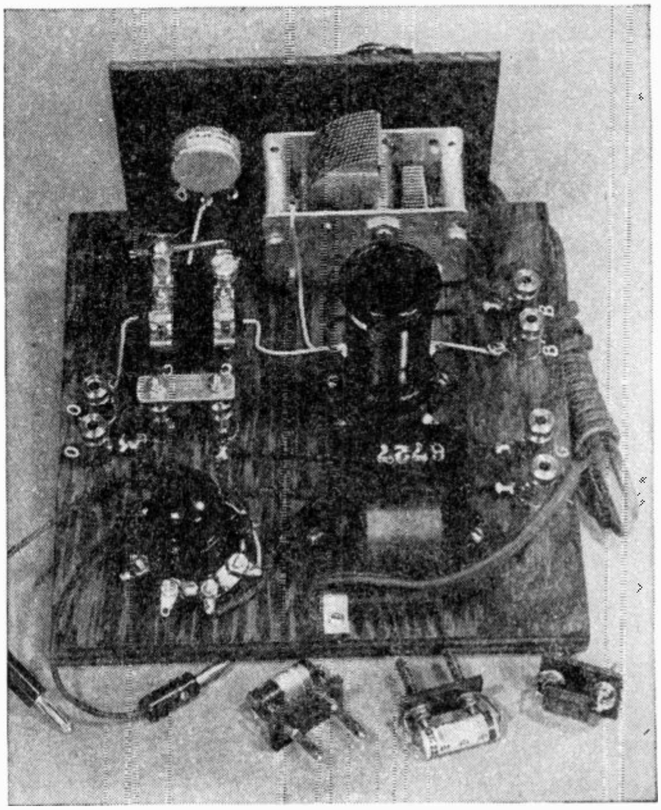

FIG. 18. The Demodulator or Detector Unit.

**12. THE OSCILLATOR–CLASS-C-AMPLIFIER UNIT.** The driving oscillator is constructed with the Class C amplifier as an integral part of it. This feature is desirable since the efficiency of operation of a Class C amplifier depends upon the magnitude of the input signal. With this arrangement the input to the Class C amplifier can be fixed after it is adjusted to the correct value. The complete unit is shown in the picture of Fig. 17, which represents the circuit diagram of Fig. 20–3.

The oscillator is the unit nearest to the wave meter in the picture, and has the oscillator coil mounted with its axis in the horizontal plane to minimize magnetic coupling with the amplifier tank coil. The neutralizing condenser is mounted on the front panel between the oscillator and amplifier tuning condensers. Plug-in coils are used for tuning inductances because they are easily obtained, but coils wound from wire of a larger size would be more satisfactory for oscillator and amplifier service.

Attention is called to the large number of binding posts mounted around the edge of the baseboard. These are placed in the circuit so that the characteristics of the unit may more easily be studied. Provision is made for the measurement of the plate current for either unit and the grid current for the Class C amplifier, also two posts (X–X′) are provided for the external grid bias supply and modulating signal when control-grid modulation is desired. See the circuit diagram (Fig. 20–3) for the location in the circuit of these points.

The circuit of the Class C amplifier uses a combined grid-leak and cathode-bias arrangement to obtain its grid-biasing voltage. The cathode resistor will prevent damage to the amplifier tube should the driving voltage be removed while plate voltage is still applied to the amplifier tube.

The wave meter is composed of a condenser, coil, and pilot lamp. The coil form should be large enough to slip over the amplifier tank coil and the coil should be wound from fairly large wire (No. 20 to No. 24) in order that when the wave meter and lamp is used as a tunable load for the amplifier there shall be no significant $I^2R$ loss in the wire of the coil. A bakelite coil form of 2-inch diameter is recommended.

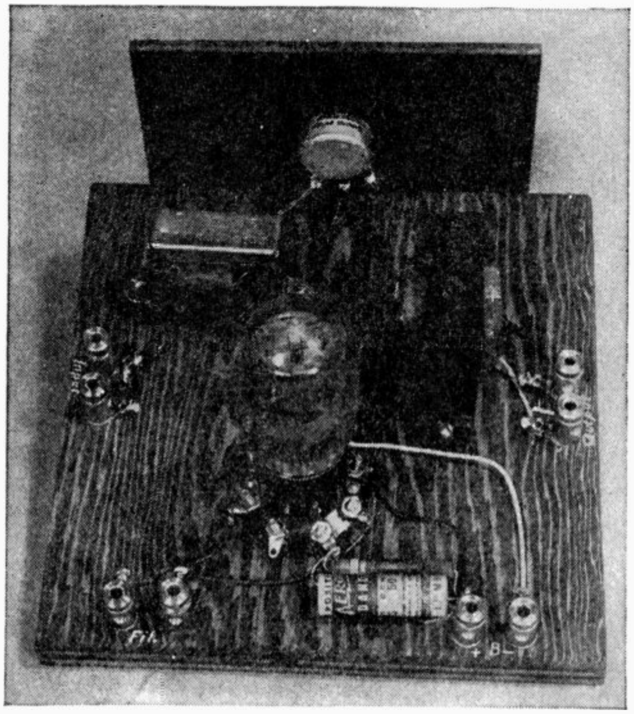

Fig. 19. The Modulator Unit.

The inductance of this coil should be comparable to that of the oscillator and amplifier coils if the size of the condenser is similar to that of the tuning condenser of the oscillator or amplifier. The lamp should be a 6–8-v, 0.5-amp pilot lamp or one of similar power rating for this type of oscillator-amplifier unit. It may be necessary to use two lamps either in series or parallel to absorb the power output of the amplifier.

**13.** THE DEMODULATION OR DETECTOR UNIT. The demodulator or detector unit pictured in Fig. 18 is constructed so that it can easily be converted from a crystal detector to a diode detector using a 6H6 tube. This is accomplished by a plug-in arrangement as shown in the picture which represents the circuit diagrams of Figs. 21–7 and 21–8.

The load for the detector to work into is a 250,000-ohm variable resistor mounted on the front panel along with the tuning condenser. The secondary of the tuning coil, as well as the primary, is available from terminals along one edge of the base board. Three different sizes of condensers, mounted as shown, are available for plugging across the output (O–O′) of the detector to by-pass any radio-frequency signal which may have passed through the detector itself.

It is desirable that the diode be located in the *low* side of the line to reduce 60-cycle interference; the crystal operates better in the *high* side. The plug-in arrangement provides for this change.

**14.** THE MODULATOR UNIT. The modulator unit pictured in Fig. 19 is a simple Class A audio-frequency power amplifier, like that shown by the circuit diagram of Fig. 22–3. The input feeds into a single-button microphone transformer, but almost any type of interstage transformer would operate in this position. The gain control, mounted on the front panel, is across the secondary of this transformer. The output transformer is chosen to *match* the load, which is the Class C amplifier, to the plate circuit of the modulator tube. The plate load desired for a pentode (6F6) power tube is approximately 7,000 ohms and the load presented by the Class C amplifier can be approximated as the product of $I_b \times E_{bb}$ for the amplifier. Modulation transformers with tapped windings are available and are recommended, since the experimenter may wish to operate the Class C amplifier with various loads which will require the modulation transformer to have different impedance ratios.

**15.** THE CONVERTER UNIT. The circuit of Fig. 23–2 is shown in the picture of Fig. 20. A study of the picture will reveal the arrangement of parts. The right-hand condenser (in the picture) is the input-signal tuning condenser and tunes the radio-frequency coil which is shown directly in front of it in a shield can. The other condenser tunes the oscillator coil, which is mounted between the two air condensers. The switch that permits operation with either the local or an external oscillator is placed between the tuning condensers. The padding condenser is located in an accessible place as shown, and the intermediate-frequency transformer in the square can is arranged so that the shield may be removed for inspection.

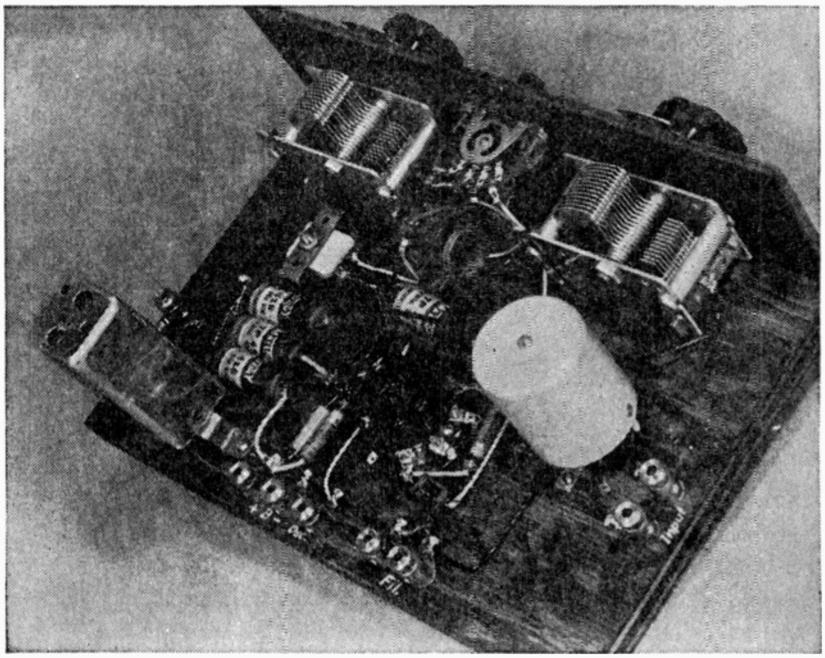

FIG. 20. The Converter Unit.

The parts for this unit may be obtained from any discarded superheterodyne receiver or may be purchased as new apparatus.

**16.** THE ULTRAHIGH-FREQUENCY OSCILLATOR AND TRAVELING DETECTOR. Figure 21 shows two pieces of equipment used in Experiment 30: the ultrahigh-frequency oscillator unit and the traveling detector. The oscillator is designed around a HY75 tube which is especially constructed as an ultrahigh-frequency tube. Note that the plate and grid leads emerge from the top of the tube and are connected to two short lengths of a transmission line (copper tubing) which constitute the tank coil for the oscillator. The tuning condenser is mounted directly across the end of the tank coil with very short leads. The antenna coupling is the loop of wire connected to the two binding posts on the top of the panel. This loop may be dispensed with if the oscillator is to be used only for the work of Experiment 30. The binding posts seen on the end of the mounting base are for the filament and $E_{bb}$ connections. The necessary choke coils and resistors are mounted under the top panel.

The detector unit is used with the oscillator and the Lecher-wire system to measure the oscillator frequency or wave length. It consists of two lengths of bus wire terminated at one end in a fixed crystal detector unit with a small (.0001-$\mu$f) fixed mica by-pass condenser and a sensitive milliammeter (0–.5 ma). The other ends of the wires are fastened to a piece of high-frequency insulating material (polystyrene) which is slotted to fit the wires of the Lecher-wire system. The slots are made so the wires of the detector unit will terminate very close to, but not touch, the transmission-line wires. The coupling between the transmission line and the detector unit is capacitive. The length of the wires for the detector unit should be equivalent to a quarter wave length of the oscillator output, but this distance is not critical and a length of 8 to 12 inches will be satisfactory.

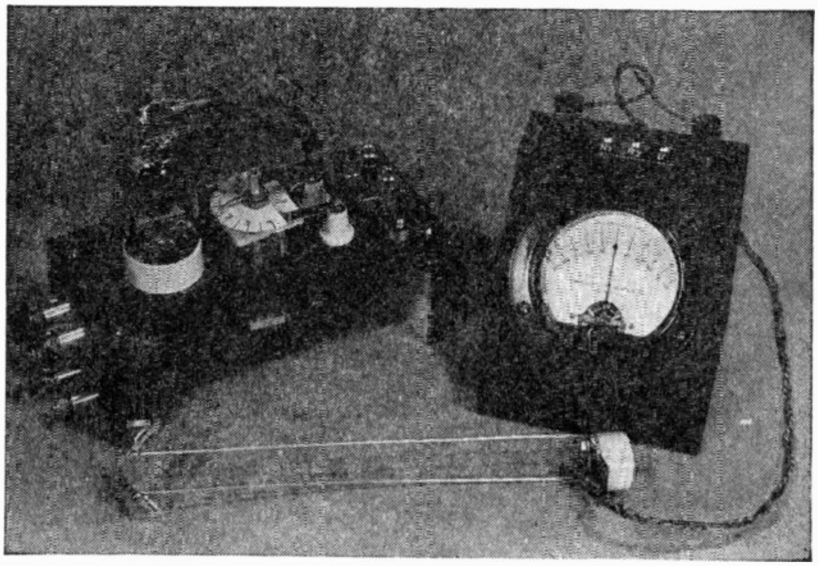

FIG. 21. The Ultrahigh-frequency Oscillator and Traveling Detector.

The Lecher-wire system as described in Experiment 30 consists of two copper wires (No. 16) about 10 to 12 feet long, spaced 1 inch on centers. These wires must be mounted so they can be tightly stretched to prevent vibration, which would cause erratic results in the measurements. A turnbuckle can be used to tighten the wires. The wires are shorted together at one end but open at the other and a sliding shorting bar is provided to place a short on the line at any chosen point.

The most satisfactory neon lamp to use as a voltage indicator on the transmission line is a baseless one of type T–2, .3-ma, whose terminal wires may be formed into hooks so it can be supported from the transmission line and can slide along from point to point.