A COURSE IN RADIO FUNDAMENTALS

$1.00

- STUDY ASSIGNMENTS
- EXPERIMENTS
- EXAMINATION QUESTIONS

★

By
GEORGE GRAMMER

★

Based on
THE RADIO AMATEUR'S HANDBOOK

PUBLISHED BY THE AMERICAN RADIO RELAY LEAGUE

A COURSE IN RADIO FUNDAMENTALS

Study Assignments, Experiments and Examination Questions

BASED ON

"The Radio Amateur's Handbook"

By

GEORGE GRAMMER

Technical Director, ARRL and Technical Editor, QST

PUBLISHED BY

THE AMERICAN RADIO RELAY LEAGUE, INC.

NEWINGTON, CONNECTICUT, U.S.A.

Fourth Edition
Fifth Printing

Library of Congress Catalog Card
Number: 55-9760

Published by
THE AMERICAN RADIO RELAY LEAGUE INC.
Newington, Connecticut, U. S. A.

ARRL

☆ CONTENTS ☆

Introduction

THE radio amateur has always been noted for his ability to secure results, in the way of effective communication, far beyond what might reasonably be expected from the equipment he uses. This practical "know-how" has not, however, always been accompanied by an equivalent understanding of underlying principles. It is only natural that those who already have some skill in the art of radio communication should wish to supplement that skill with a foundation of theoretical knowledge — realizing that a good technician becomes a better one by knowing the "why" as well as the "how." Our objective in preparing this course, therefore, was to accent, for the amateur, those principles most frequently applied in actual radio communication.

This volume is a study guide, examination book and laboratory manual. The basic text is *The Radio Amateur's Handbook*. The required subjects usually can be located with ease from the *Handbook* chapter headings, but it may be necessary occasionally to refer to the index to locate specific subjects in the more recent editions.

In the course, the *Handbook* material is divided into thirty-five study assignments; each assignment should represent approximately a week's work, on the assumption that six to eight hours will be available. Certain assignments may call for more time and others for less; those which have no accompanying experiments obviously can be completed more rapidly than those which have a considerable amount of experimental work. With each assignment there is a series of questions designed to bring out the important points in the text. Problems of a numerical nature are included wherever possible, with answers given at the end of the book; in a few cases where more than routine methods are required, the complete solution is given. Also accompanying each assignment, when feasible, are one or more experiments of a nature which, we believe, will not only illustrate the principles being studied but will in many cases throw additional light on the subject under consideration. Information supplementary to that contained in the *Handbook* is frequently contained in the descriptions of the experiments.

As a home-study course, this material was prepared principally for radio amateurs who have already had some practical experience in building and operating radio apparatus. This experience is probably essential for the construction of the various pieces of equipment used. In view of such preknowledge a number of elementary experiments, such as the construction of simple oscillators and receivers, have not been included in the series. The desirability of such experiments for classes which have had no previous radio experience is pointed out at appropriate points in the text.

Experiments and Apparatus

An important part of any technical course of study is experimental work. Outlining a suitable series of experiments for the home worker is always a problem of considerable difficulty, because the cost of the equipment necessarily must be kept to a minimum. Insofar as possible, therefore, the apparatus used in the experiments described herein uses components which can be found in the average amateur station. This inevitably puts some limitation on the scope of the experimental work, but is deemed necessary because the resources of those studying at home frequently are limited.

The experiments outlined all have actually been performed with the equipment recommended, with the results given in the description of each experiment. These descriptions are for the most part fully detailed, emphasizing those factors which tend to cause departures from the theoretically ideal conditions and which, as a consequence, frequently confuse the student who is working without an instructor.

The construction of the various pieces of experimental gear is described as the need for it arises in the course. In addition to these units, it will be necessary to have at least one multipurpose test instrument of the volt-ohm-milliammeter type. All of the experiments have been planned on the basis of using only one such instrument, but the work will be facilitated considerably if voltmeters and milliammeters of various ranges are available so that readings of several quantities can be taken simultaneously. Another necessary adjunct is a communications type receiver, of any make or model so long as it is provided with the frequency calibration which is usually a feature of these sets. A number of miscellaneous small parts — fixed capacitors and resistors, chiefly — also will be needed. They are specified with each experiment as required.

Home Study

Those studying alone usually are inclined to move more rapidly than circumstances warrant. There is frequently a tendency, also, to slight those points about which the student already feels himself fairly well informed. It is a mistake to do either; the only sure way is to omit nothing and to pay as much attention to seemingly simple material as though the work were being done in a formal class.

It is recommended that the set of questions accompanying each assignment be treated as though it were a classroom examination, and that the answers be *written* just as though the paper were going to be marked by an instructor. After answering all questions as completely as possible, the answers should be compared with the *Handbook* text for errors and omissions. This is the only practicable way to check what has been learned, and the whole process promotes the clear thinking which is so essential when there is no instructor at hand to criticize and correct. Reducing a statement to writing spotlights those points about which there is uncertainty, and forces the student to formulate his ideas in such a way that doubt about what is meant is reduced to a minimum. To say "I know the answer but can't express it" is simply a confession that the answer is *not* known. Continual self-criticism is an essential ingredient of successful home study.

Observations taken in the course of the experimental work should be recorded in a notebook kept especially for the purpose. The laboratory notebook should be kept as carefully and neatly as would be required in a regular class, and the observations should be as complete and detailed as possible. It will be helpful, too, to include with the data a written explanation of the phenomena observed and the results secured, including reasons why (when necessary) there is a difference between experiment and theory. Such written notes are invaluable as a means of fixing the principles and practice firmly in mind. Should the subject matter under study suggest further experimental possibilities within the scope of the equipment, the exploration of such possibilities cannot help but be beneficial, if the work is carried out in a methodical way and an attempt is made to provide a logical interpretation of the results.

It is possible to learn, and learn thoroughly, at home — by adopting and preserving the attitude of seriousness toward the work which it deserves.

Part One

ELECTRICITY AND MAGNETISM

THE fundamental facts of electricity and magnetism form the foundation upon which the whole structure of electrical communication rests. The connection between such things as frictional electricity and a radio circuit may frequently seem somewhat obscure, but the concepts of charge and field are basic in both.

Many of the essential ideas can be demonstrated by experiments using apparatus constructed from odds and ends of metal and wood. There is no better way to grasp the principles involved than to perform such experiments, simple though they are.

ASSIGNMENT 1

Study the *Handbook* sections on electric fields, resistance, capacitance or capacity, and capacitors. Perform Exps. Nos. 1, 2 and 3.

Questions

1) What is meant by the electrostatic field, and how is its strength described?

2) Define capacity or capacitance.

3) In what way would you expect the following factors to affect the capacitance of a capacitor? After performing Exps. 2 and 3, what would you give as the reason in each case?

a) area of plates;
b) separation between plates;
c) dielectric material between plates;
d) number of plates, when the capacitor consists of a set of interleaved plates with alternate ones connected together.

4) What is meant by the resistance of a conductor?

5) What is the nature of the force between two electrostatic charges if

a) both are positive;
b) one is positive and one is negative;
c) both are negative.

6) What is the meaning of electromotive force?

7) Name five conductors and five insulators.

8) What is the fundamental particle of electricity?

9) What is the nature of positive and negative electric charges?

10) Name the units for each of the following, giving a suitable definition in each case:

a) resistance;
b) quantity of electricity;
c) capacitance;
d) electromotive force.

11) Explain (a) how an insulated conductor can be charged by contact with a charged body; (b) how such a conductor can be charged by induction.

12) Is capacitance necessarily associated only with a capacitor?

ASSIGNMENT 2

Study *Handbook* section on the electric current.

Questions

1) What is meant by an electric current?

2) How does conduction take place in metals?

3) Describe briefly how an electromotive force is set up by a cell or battery.

4) What is meant by ionization?

5) What other kinds of substances besides metals can conduct electricity?

6) What is the unit of electric current?

ASSIGNMENT 3

Study *Handbook* sections on the magnetic field and inductance, and perform Exps. Nos. 4, 5 and 6.

Questions

1) Describe self-induction.

2) The laws of forces existing between magnetic poles are similar to those governing forces between electrostatically charged bodies. What, then, will be the nature of the force between:

a) a north pole and south pole;
b) two north poles;
c) two south poles.

3) Calculate, from the diameter of each coil and the length of wire, the approximate number of turns on each winding of the electromagnet used in Exp. 4. Using first one battery and then the two in series, measure the corresponding currents through Coil 1 alone, Coil 2 alone, and Coils 1 and 2 connected in series as described in the experiment. Calculate the ampere-turns for each of the six cases. Which of the six should show the strongest magnetic effect? Check experimentally.

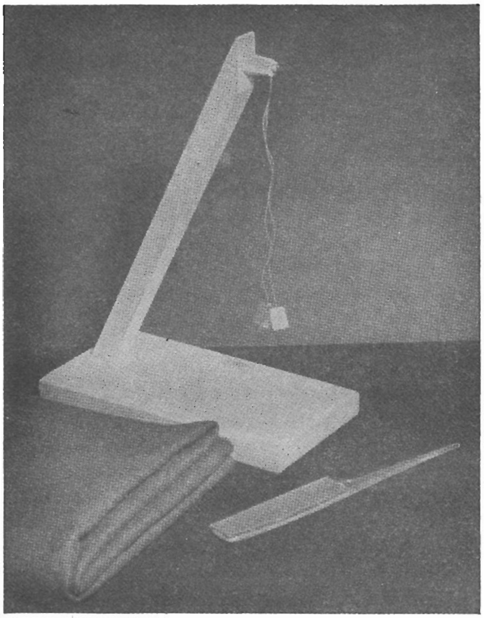


Fig. 1

4) Using the equipment of Exp. 4, connect the two coils in series as described in the experiment and apply the 3 volts from the battery. Observe the magnetizing effect by the attraction for a piece of soft iron. Disconnect the two coils and connect the two "starting" ends of the windings together, applying the battery to the other two ends. How does the magnetizing effect now compare with the original strength? Explain why there is a difference.

5) Under what conditions can a voltage be induced in a conductor?

6) Is inductance necessarily associated only with wire wound in a coil?

7) How is the intensity of a magnetic field described?

8) Name the various units of inductance, and describe their relationship.

9) Explain what is meant by the term permeability?

10) What factors determine the inductance of a coil?

11) What is the direction of flow of an induced current compared to the direction of flow of the current causing the induction?

12) When the current through a coil is broken, is the induced voltage larger or smaller than the voltage induced when the current is started? Why?

13) How is an unmagnetized piece of iron attracted by a magnet?

14) Upon what factors does the strength of the magnetic field set up about an electromagnet depend?

EXPERIMENT 1

Electrostatic Induction

Apparatus: This experiment requires only very simple equipment: a few bits of metal foil, a little thread (preferably silk, which is a better insulator than cotton), a celluloid comb, and a piece of felt on which to rub the comb to work up an electrical charge by friction. Many materials can be substituted for the celluloid and felt; hard rubber (a fountain pen or comb) or glass rods will do very well in place of the celluloid, for instance, and wool cloth in place of the felt.

It is convenient to have a simple mounting for the suspended pieces of foil, as shown in Fig. 1. (The same mounting can be used for the subsequent experiment.) A wooden base about 4 × 8 inches will be adequate. The support is a piece of 1 × 1 wood fastened to the base at an angle of about 60 degrees. A standoff insulator is mounted horizontally at the top of the support, and the threads holding the foil pieces are held under the top screw of the insulator. The insulation should be as good as possible, since even a little leakage will greatly affect the way in which the apparatus responds in the experiment. The insulator should be kept clean and dry, as should also the threads and the wooden support. In humid weather it may be almost impossible to build up a sufficient charge or to retain it for any length of time.

The foil pieces should be about ½ × ½ inch in size, and should be quite thin. The lighter the weight the better, so aluminum foil is to be preferred to tin or lead foil. Thin aluminum foil can be found in cigarette packages or taken from a blown-out tubular paper bypass capacitor. Cut two pieces to size, smooth them out, punch a hole with a needle at one end, and tie on lengths of thread. A seven-inch length is about right. When mounting the foil pieces, make sure that both hang at the same height.

Procedure: Only one foil piece is required for the first step in the experiment. The other may be hung over the wooden support to keep it out of the way. Rub the comb briskly on the felt and bring it near the suspended foil. As the comb is brought nearer the foil will be attracted and will approach the comb edge on. If it is allowed to touch the comb or to approach near enough for a spark to jump, it will immediately be repelled by the comb, and will continue to be repelled so long as both foil and comb retain their charges.

The explanation for this is as follows: When the comb is rubbed on the felt it acquires electrons from the latter and thus becomes negatively charged. When brought near the foil so that the latter is in the electrostatic field of the comb, free electrons on the foil are repelled by the field and collect on the end of the foil farthest from the comb. The foil turns edge on because the forces acting tend to keep the collection of electrons as far from the comb as possible. The movement of electrons on the foil away from the comb causes the far side of the foil to be negatively charged, and since the foil is insulated and no new electrons can enter it, there is a deficiency of electrons on the edge nearest the comb. Thus the near edge is positively charged, and since this charge is opposite in sign to the charge on the comb the near edge is attracted to the comb. The positively charged end, being nearest the comb, is in a stronger part of the comb's field than the far edge, hence the force of attraction is greater than the force of repulsion. Therefore the foil moves toward the comb.

When the foil touches the comb or comes near enough for a spark to jump, a portion of the charge on the comb is imparted to the foil. That is, some of the excess electrons on the comb flow into the foil so that the latter then has an excess of electrons. It has thus acquired a negative charge and is immediately repelled from the comb since both comb and foil now have the same kind of charge. The charges on both will gradually leak off with time, or they may be discharged intentionally by touching them with a grounded conductor or semiconductor. A touch with the finger is usually sufficient, since the human body is large enough to accommodate the excess electrons on the charged objects, and has enough conductivity to allow the charge to be dissipated instantly.

Besides the contact method of charging the foil just described, a charge (and generally a stronger one) may also be imparted to the foil purely by induction. Touch the uncharged foil with the end of a piece of stiff wire several inches long held in the hand. Use the wire to hold the foil so that it cannot move when the charged comb is brought near it. Under these conditions the repelled electrons will flow down the wire to the body, leaving a positive charge on the foil. Now take away the wire and as quickly as possible (but *after* the wire is removed) move the comb away from the foil so that the latter cannot touch it. Removing the wire leaves the foil with an insulated positive charge, and since the foil is then charged oppositely to the comb, the two will attract each other. Should they touch, the foil will again be charged by contact and repulsion will occur. Thus charging by contact gives a charge of the *same* sign as the charge on the comb, while charging by induction gives a charge of *opposite* sign.

In charging by contact the charge imparted depends upon the surface leakage on the comb, and since celluloid is a good insulator only a limited number of electrons can flow into the foil. When charging by induction the field set up by the accumulation of electrons on the comb is used, and electron movement on the comb is not essential. Hence it is frequently possible to impart a stronger charge by induction than by contact under these conditions, particularly when the area of the conductor to be charged is appreciable compared to that of the celluloid comb (or other insulator) which contains the original charge.

Now let both pieces of foil hang freely and bring the charged comb in the vicinity. Observe the sequence of happenings. Explain.

Give both pieces of foil the same kind of charge so they repel each other. Write an explanation for what is observed to happen.

EXPERIMENT 2

Capacitance

Apparatus: The equipment and set-up for this experiment are shown in Fig. 2. The stand used in Exp. 1 supports a 5- or 6-inch length of stiff copper wire (No. 12 or 14) to the lower end of which has been soldered a small piece of very fine bare wire (No. 38 if available) rounded in the form of a hook. Two triangular pieces of thin aluminum foil about ⅜ inch on a side hang on the hook. The holes through which the hook passes can be punched through the foil with a needle, and should be as close as possible to one apex of the triangle. The two "leaves" should be free to move on the hook without interfering with each other. This forms a simple electroscope, or instrument for measuring the intensity of a charge.

On a block of wood about 4 × 6 inches mount a flat metal plate 2½ × 3½ inches, using two standoff insulators as supports. This plate must be well insulated from the wooden base. Attach a length of wire to the plate.

Procedure: First charge the electroscope as strongly as possible by induction, using the procedure outlined in Exp. 1. The best charge can be obtained by holding the charged comb close to and lengthwise with the wire support so that the wire is in the strongest possible field. On removing the grounding wire and comb, the two leaves should spring apart. Since the tops of the leaves are not free to move very far, the leaves will take the position of an inverted V; with a good charge the angle of the V should be about 90 degrees.

Now take the wire from the insulated plate and, handling it with an insulated rod (the comb will serve), touch it on the wire support for the leaves. The leaves will drop toward each other, but will not completely lose their charge. Now remove the wire and the leaves will not change their position. The wire from the plate may be touched on the electroscope again but the position of the leaves will not change. With the wire off, discharge the electroscope with the finger, then touch the wire from the plate to the wire support again. The leaves will once more repel each other, but to a lesser extent than in either of the previous two cases.

In the first case a certain quantity of electricity is placed on the electroscope, the intensity or "potential" being indicated by the extent to which the leaves repel each other. On connecting the plate to the electroscope some of the charge flows into the plate, distributing itself over the surface of the plate as well as over the surface of

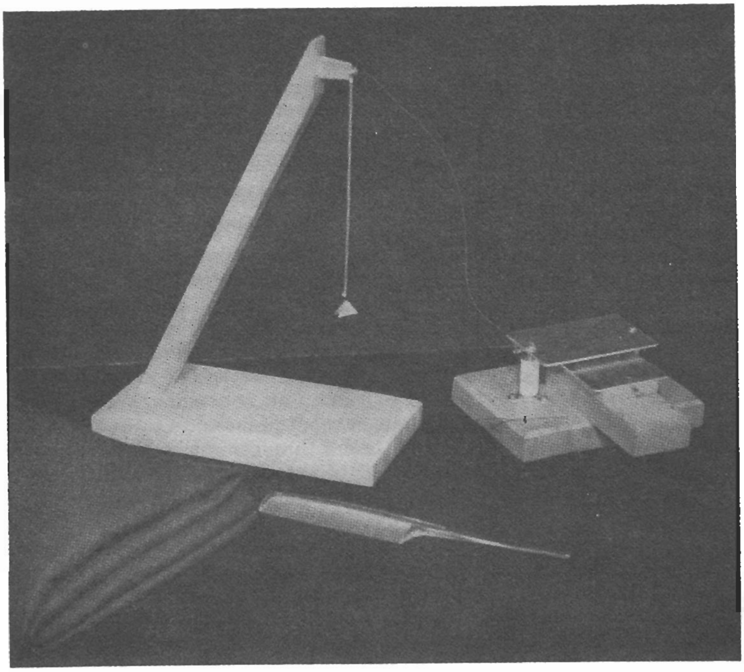


Fig. 2

where C is capacitance, Q quantity and E potential. In practical units C is expressed in farads, Q in coulombs and E in volts. A given quantity of electricity on a high-capacitance conductor will give a smaller potential than the same quantity on a low-capacitance conductor. Or if two conductors of different capacitances are charged to the same potential, the one with the higher capacitance will take the larger quantity of electricity. Under these conditions the quantity of the charge, or amount of electricity stored, will be directly proportional to the capacitance of the conductor.

As a variation, the insulated metal plate alone may be charged and then connected to the electroscope. The leaves will spring apart, the extent of the repulsion indicating the potential of the plate.

the electroscope. Although the total quantity of electricity involved remains the same, the intensity or potential is lowered, as indicated by lesser repulsion between the electroscope leaves, because it is now spread over a larger area. The quantity of electricity distributes itself so that the whole system has the same potential (or voltage), so that reconnecting the plate wire after once removing it causes no further redistribution of charge; both the electroscope and the plate are then at the same potential and hence current will not flow from either one to the other.

With the wire removed and the electroscope discharged, the plate is left with its acquired charge. On connecting the wire once more, some of the electricity on the plate flows back into the electroscope, recharging it — but this time at a lower potential because there is less electricity available than formerly, that part which was drained off the electroscope by discharging it now having disappeared.

The conclusion to be drawn from this experiment is that the system with the larger surface — i.e., the electroscope and plate connected together as compared to the electroscope alone — will have a lower potential, for a given quantity of electricity, than that with the smaller surface — i.e., the electroscope alone. The ratio of quantity to potential is called the capacitance of the system; that is,

$$C = \frac{Q}{E}$$

EXPERIMENT 3

Capacitors

Apparatus: The same equipment is needed as in Exp. 2, with the addition of a 2 × 3-inch metal plate mounted flat on one end of a piece of wood 2 inches wide and 5 or 6 inches long. Add a wooden shim, if necessary, so that when the second plate is slid under the first, as shown in Fig. 2, the two plates will be separated by about ¼ inch. Attach a length of wire to the plate. Provide a piece of clean window glass about 2 × 3 inches in size.

Procedure: Connect the insulated fixed metal plate to the electroscope and charge the system by induction. Connect the wire from the movable plate to ground. (In many cases an actual ground will not be necessary because there will be sufficient leakage through the wood to give the same effect.) Slide the movable plate under the fixed plate, being careful to get no metal-to-metal contact, which will discharge the system. The electroscope leaves will drop toward each other. Raise the movable plate until it is as close as possible to the fixed plate, taking care not to touch the latter and discharge it. The closer the two are to each other, the more the electroscope leaves will drop. Finally, take away the movable plate and the leaves will move apart to their original positions.

The fact that the electroscope leaves indicate a lower potential when the movable plate is inserted shows that the capacitance of the system has been increased ($E = Q/C$) since none of the stored electricity can have escaped from the system. Since the cause of the lowered potential is the presence of the second plate near the first, the two-plate arrangement evidently has larger capacitance than one plate alone. Such a combination is called a capacitor. The further decrease in potential which results when the separation between the two plates is decreased shows that the capacitance increases as the plates are brought closer together. The decrease in potential is the result of the fact that the second plate becomes charged by induction, and since the charge is opposite in polarity to that on the fixed plate, the electrostatic field from the induced charge lowers the potential at the fixed plate. The effect is more marked when the two plates are close together because the fields become more nearly equal in intensity under these conditions. When the movable plate is taken out, the potential of the fixed plate returns to its original value, since the opposing field is no longer present. The electroscope leaves therefore return to their original positions.

Now charge the fixed plate and electroscope once more and insert the movable plate. Slide the piece of glass between the two plates. The electroscope leaves will drop still more when the glass partially replaces the air between the plates, indicating that the potential is lowered more with glass than it is with air. The presence of the glass therefore has increased the capacitance. Evidently there is less drop in electrostatic field strength through glass than through air, since the capacitance can be increased only by lowering the potential, and inserting the glass has the same effect as moving the plates closer together when the medium between them is simply air. The medium is called the *dielectric*, and the ratio of the capacitance with a given dielectric to the capacitance with air dielectrics, all dimensions remaining the same is called the *specific inductive capacity* of the dielectric or, more frequently (in the practical system of units), the *dielectric constant.*

EXPERIMENT 4

Electromagnetism

Apparatus: This experiment requires the apparatus shown in Fig. 3. A homemade electromagnet having two windings is needed, arranged with a removable core. The core should be soft iron, cylindrical and about 3½ inches long. A suitable core can be made from a ⅜-inch diameter bolt having an unthreaded section of the required length, by sawing off the head and threaded portion. Procure or make a cardboard tube of the same length the core and having an inside diameter such that the core will fit in it fairly snugly, but loose enough so that the core can easily be slid in and out. Cut out pieces of thin wood or Masonite and drill them to fit over the ends as mountings, as shown in Fig. 3. Then wind on about 100 feet of No. 28 enameled wire, leaving ends for terminals, cover the winding with tape or paper, and put on a second winding of about 200 feet of wire of the same size. Wind both coils in the same direction (that is, same direction of rotation in winding; the layers can travel back and forth along the coil) and label the terminals so that the "start" and "finish" ends are readily identifiable. The wire should be wound fairly evenly, but perfect layers are not at all essential. Considerable time and effort can be saved by using a hand drill for the winding, mounting the drill in a vise and running a bolt of appropriate size through the cardboard tube and into the chuck so that the tube will turn when the drill handle is turned. A small piece of wood with four machine screw terminals mounted on it makes a suitable base for the coil.

Current can be furnished by a pair of ordinary dry cells connected in series. The current-measuring instrument can be a 0–500 milliammeter or a multirange test set of the general type shown in the photograph. A permanent magnet, either bar or horseshoe, should be provided.

Procedure: Connect one wire from the battery to the smaller coil (Coil No. 1) and insert the iron core in the coil. Hold one end of the permanent magnet near the core, close enough to feel the magnetic pull but not close enough to make the core piece move. Now touch the other battery wire to the remaining terminal of the coil. The permanent magnet will be either attracted or repelled, depending upon the "polarity" — that is, whether the "north" (N) pole or "south" (S) pole of the magnet is closest to the core piece. Repeat, holding the other end of the magnet near the core. If the magnet was repelled in the first

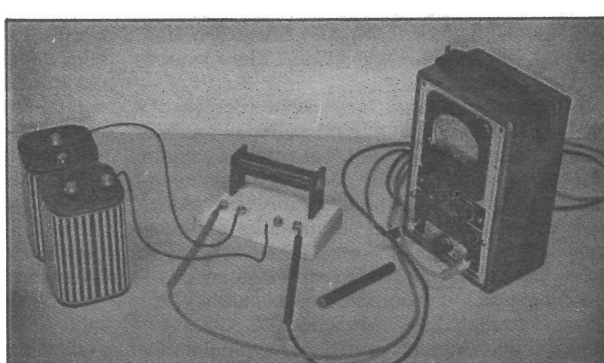


Fig. 3

place, it will now be attracted, and vice versa. Using either end of the magnet, note whether attraction or repulsion takes place when current flows through the coil. Now present the same end of the magnet to the other end of the core. The opposite effect will take place at opposite ends of the core with the same magnet pole. Note that when the current is cut off these effects disappear, and that either end of the core will be attracted equally well by either end of the magnet.

Since the same effects can be observed by going through the same procedure with a permanent bar magnet substituted for the coil and soft-iron core, it is evident that the current flowing through the coil makes the coil and core equivalent to a bar magnet. That is, the current has caused a magnetic field to be set up. Some of the properties of electromagnetism can be demonstrated by continuing the experiment as follows:

Connect one dry cell, the smaller coil (Coil No. 1) and the test set in series, selecting the proper current scale on the latter to read the current in the circuit (the 500-ma. scale, or nearest to that value, will be suitable). Insert the iron core in the coil. Note the current and bring a piece of soft iron (the remainder of the bolt will do) near the core. When the iron is brought close it will be attracted to the core. Open the circuit and the iron is no longer attracted. (If any attraction still exists, the bolt probably is steel instead of soft iron and has retained some of the magnetism imparted to it when attracted to the core. This property is called *magnetic retentivity,* and since it tends to obscure the principles involved in these experiments, soft iron, which has little or no retentivity, is to be preferred.) Now use the two cells in series, which should double the current, approximately, and repeat. The attraction will be noticeably stronger.

Connect the two coils in series, running a wire from the "finish" terminal of Coil 1 to the "start" terminal of Coil 2, and connect the dry cells and meter in series with the remaining terminals. Again bring the iron near the core and note the attraction. Compare this attraction with that which occurs when Coil 1 alone is used with a single dry cell.

The iron is attracted for reasons comparable to those given to explain the attraction of an electrically charged body for one without charge (Exp. 1). In the molecular theory of magnetism the iron molecules are miniature magnets which, in a piece of iron showing no magnetism, are assumed to be in random positions so that on the whole their individual fields cancel out, so far as external effects are concerned. When such a piece of iron is brought near a magnet, the molecules tend to align themselves so that they lie parallel with the lines of force. If the field is from an *N* pole, the *S* poles of the molecules will turn toward the magnet and the *N* poles away from it, since unlike poles attract and like poles repel. Hence the iron becomes a magnet itself, with its *S* pole (in this example) facing the *N*-pole source of the field. The two magnets therefore attract each other, and if the field is strong enough and at least one of the magnets is free to move the two will be pulled together. The same mechanism explains how the iron core becomes magnetized under the influence of the magnetic field set up by the current flowing through the coil. (The coil itself will attract iron and exhibit all the properties of a bar magnet, without the iron core, if the current through it is large enough. With the apparatus described the field without the core is rather weak, so that only small and therefore light pieces of iron will be attracted, but the effect can be clearly observed if a battery of 6 volts or more is used.)

The force of attraction is naturally greater the stronger the field, hence increasing the current through the coil, as is done in the second part of the experiment by increasing the battery voltage applied to Coil 1, must cause a stronger field to be set up, since the attraction is greater with greater current. That the field strength also depends upon the number of turns is shown by connecting the two coils in series. Although the current through the two in series with 3 volts applied is somewhat less than the current through Coil 1 with the single dry cell, the attraction is nevertheless stronger (hence the magnetic field is stronger) with the greater number of turns despite the smaller current. If other dimensions remain the same, the field strength will be proportional to the current for a given number of turns and proportional to turns for a given current. This dual proportionality can be combined in the single expression *ampere-turns,* or product of amperes through the coil times number of turns in it. The number of ampere-turns thus is a measure of the magnetizing force.

EXPERIMENT 5

Electromagnetic Induction

Apparatus: Same as in Exp. 4, with the exception that the permanent magnet is not needed. Set the scale of the test set to use the instrument as a milliammeter having a maximum deflection of 1 milliampere (or the nearest range to 1 ma. provided on the particular test set used).

Procedure: With the core out of the magnet assembly, connect the milliammeter across the terminals of the larger coil (No. 2). Connect one side of the battery to one terminal of the smaller coil (No. 1). Connect a wire to the other side of the battery and touch its free end to the remaining terminal of Coil 1. When the contact is made the milliammeter needle will show a small instantaneous deflection but will quickly return to the zero position. Now remove the wire from the terminal and the needle will deflect in the opposite direction, again returning quickly to zero. The deflections probably will be quite small — less than 0.1 milliampere. Repeat the experiment with only one dry cell instead of two, when it will be found that the deflections are of the same type, but smaller. Note the direction of the deflection on *making* contact and if it is not the same as the normal direction of needle movement, reverse the meter terminals.

Now insert the iron core and close the circuit through Coil 1. The deflection should be of the order of 0.5 milliampere. While the circuit is still closed, reverse the meter terminals. Now open the circuit and the needle will deflect again, this time in the same direction since the meter has been reversed. The purpose of reversing the terminals is to avoid a large deflection in the direction opposite to normal; although this probably will do no harm to the instrument, the needle does not travel very far before hitting the stop and frequently will bounce in the opposite direction (that is, the normal direction of motion) giving the impression that the deflection is in the same direction both on closing and opening the circuit. That this is not the case is easily demonstrated by reversing the meter terminals while current is still flowing through Coil 1.

The observed phenomena can be explained as follows: On closing the circuit a magnetic field is set up by the current flowing through Coil 1. While the field is changing — that is, growing from zero to its final intensity — electrons in Coil 2, which is in the field, are forced to move, causing the current indicated by the milliammeter. Since current can flow only when there is a voltage present to force it to flow, it is evident that the changing magnetic field has caused a voltage to be induced in Coil 2, even though there is no direct connection between this coil and the battery. When the field becomes steady the milliammeter shows no deflection, hence the phenomenon of induced voltage must be associated only with a *changing* field. On opening the battery circuit the field disappears and, in the process of changing from its steady value to zero, again causes a voltage to be induced in Coil 2, as shown by the milliammeter deflection. Since the deflection on opening the circuit is in the opposite direction to that on closing the circuit, the induced voltage must have one polarity when the field is increasing in intensity, and the opposite polarity when the field is decreasing.

Changing the battery voltage, and hence the amount of current through Coil 1, showed that the induced voltage depends upon the strength of the magnetic field, since the field is stronger with greater current, other things being equal. In the last part of the experiment the current remained the same, but much larger deflections were obtained by inserting the iron core. Hence the core must have greatly increased the intensity of the field or, stated another way, many more lines of magnetic force must be set up in iron than in air for the same current flowing in the coil. The ratio of the number of lines of magnetic force which will be set up in a given material to those in air, the dimensions and magnetizing force being the same, is called the *permeability* of the material. The experiment demonstrates that iron has many times the permeability of air.

EXPERIMENT 6

Electromagnetic Induction — (Cont.)

Apparatus: Same equipment as in Exp. 5.

Procedure: Repeat Exp. 5 with the iron core in the coil. Note the direction of current flow in Coil 1, as indicated by the polarities of the battery terminals to which the coil ends are connected. Close the circuit and note the direction of current flow through Coil 2. Remember that the meter indicates normally (pointer deflection to the right) when its positive terminal is connected toward the positive side of the circuit. On opening the circuit the current through Coil 2 reverses, as shown by Exp. 5.

What is the relationship between direction of current flow in Coil 1 and that in Coil 2 on closing the circuit? Trace the current in each circuit by starting at the positive terminal of the source of voltage, going through the part of the circuit to which the voltage is *applied,* and then returning through the other terminal of the source. Remember that the battery is the source of voltage for Coil 1, that Coil 2 is the source of voltage for the meter, and that both coils have been wound in the same direction. What is the relationship between the two currents on opening the circuit? On closing the circuit the induced current flowed in the opposite direction to the current in Coil 1 while the latter current was increasing from zero to its steady value. On opening the circuit the current in Coil 2 reversed its direction, the current in Coil 1 now being decreased from its maximum value to zero. The direction of flow of the induced current is such as to oppose the change in current which caused it. If the original current increases, the induced current will oppose the increase. If the original current decreases, the induced current will oppose the decrease — that is, it will tend to keep the current flowing.

These same effects take place in Coil 1 alone, but cannot be shown conveniently with simple apparatus. However, since both coils are in the same magnetic field it is easy to appreciate that the same effects would be exhibited in both. On closing the circuit a current will be induced in Coil 1 which flows in the opposite direction to the battery current and exists only until the battery current reaches its steady value. The accompanying induced voltage is maximum at the instant of closing the circuit and is practically equal to but opposite in polarity to the battery voltage. It cannot exceed the battery voltage, of course, since a higher induced than applied voltage would mean that electrical energy was being supplied from the coil to the battery, which is obviously impossible. The amplitude of the induced voltage is greatest when the magnetic field is changing most rapidly, which is at the instant the circuit is closed, and decreases as the field builds up until finally it becomes zero when the field is no longer changing. On opening the circuit a voltage of opposite polarity is induced in the coil, and the current accompanying this induced voltage flows in the same direction as the battery current. Under these conditions the polarity of the induced voltage and that of the battery are the same, so that the bucking effect which exists on closing the circuit no longer is present. If the circuit is broken quickly the magnetic field will disappear very rapidly, and since the amplitude of the induced voltage increases with the rapidity of change in the magnetic field, the induced voltage may be very high — hundreds or thousands of times the battery voltage. The energy in the field likewise will have to be dissipated very rapidly, and it is used up in the spark which accompanies the breaking of the circuit. The measure of the voltage induced for a given rate of change of current is called *inductance*. Since for a given current the field is stronger — that is, more energy is stored — with a larger number of turns, as shown in Exp. 4, and also with a core of high permeability, as shown by Exp. 5, the inductance is greater the greater the number of turns and the greater the permeability of the medium in which the field is set up.

If Coil 2 is in the same field, the voltage induced in it will be proportional to the voltage induced in Coil 1, to the ratio of its turns to the turns in Coil 1, and to the proportion of the total field set up by Coil 1 which bathes the turns of Coil 2. In the present case the coils are quite close together, hence are practically in the same field. Since Coil 2 has approximately twice the number of turns of Coil 1, the voltages induced in Coil 2 will be approximately twice those induced in Coil 1. These relationships can be shown in a qualitative way by the "finger test," even though measurement is impossible with this equipment. Disconnect the milliammeter, place two fingers of one hand across the terminals of Coil 2, and close the battery circuit through Coil 1. Since the induced voltage on "make" is quite small, the fingers feel no shock. On opening the circuit, however, there will be a distinct although quite harmless shock, showing that the induced voltage on "break" is quite high. Repeat with the fingers across the terminals of Coil 1; again nothing will be felt on "make," but a small shock will occur on "break." Since part of the energy is dissipated in the spark, it may be necessary to moisten the fingers to feel any effect at all in this second case. A better indication can be secured by holding one finger on the terminal at which the switching is done and keeping the battery wire in contact with the same finger while closing and opening the circuit. The induced voltage on "break" is obviously much larger than the battery voltage, which can give no shock itself, but is not as large as in Coil 2, which has a greater number of turns.

Part Two

OHM'S LAW FOR D.C. AND A.C.

THIS second part of the course deals mainly with the relationships between current and voltage which are included under the general heading of Ohm's Law for both direct and alternating currents. The experimental work largely consists in the measurement of typical simple circuits and the comparison of the measurements with calculations. The experimenter, if he is to get the most from his experimental work, should appreciate the reasons why observed measurements sometimes differ considerably from those calculated for ideal conditions. A coil, for example, has not only inductance but resistance as well, and the presence of the resistance may make the observed measurements differ considerably from the values calculated on the assumption that only inductance is present. And frequently the power consumed in the measuring device may be of the same order of magnitude as that in the circuit being measured.

Results will be affected by inaccuracies in calibration of measuring instruments, and also by lack of precision in reading the instruments. This latter "human factor" can be minimized by taking not one reading but a whole series of them for the given set of operating conditions, then averaging the set of readings to find a "mean" which probably will be nearer the proper value than any one reading alone. For example, the voltage across a circuit element may be read five different times, with the following results.

No. 1 — 24.5 volts
No. 2 — 24.3 "
No. 3 — 25.1 "
No. 4 — 24.4 "
No. 5 — 24.8 "

Unless some extenuating conditions make it possible to say without doubt that one or more of these readings is definitely wrong, the *average* of the five — in this example, 24.6 volts — should be used as the true reading.

ASSIGNMENT 4

Study *Handbook* sections on Ohm's Law, resistance, inductance, capacitance, and time constant. Perform Exps. 7–11, inclusive.

Questions

1) Write Ohm's Law in the three forms to solve for E, I, and R when the other two quantities are known.

2) Define milliampere, microampere.

3) A resistance of 50,000 ohms is connected in parallel with one of 25,000 ohms. What is the resultant resistance?

4) An inductance of 10 henrys is connected in series with one of 15 henrys. What is the total inductance if the fields of the two inductances do not interact?

5) What is the total inductance if the two inductances of Question 4 are connected in parallel?

6) Define time constant.

7) Write the formulas for power dissipated in a d.c. circuit when any two of the three quantities, voltage, current and resistance, are known.

8) What is the unit of power?

9) Compare ohm and megohm.

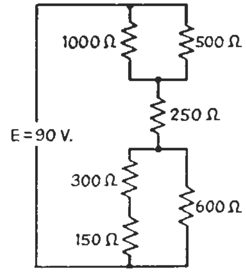
10) Three resistances, 5, 14 and 22 ohms, are connected in parallel. What is the resulting resistance? If 6 volts are applied to the combination, what is the total current, the current through each resistor, and the power dissipated in each?

11) If a current of 350 microamperes flows through a circuit with an applied voltage of 40, what is the resistance of the circuit?

12) What is the time constant of a circuit consisting of a 4-μf. capacitor and a resistance of 150,000 ohms?

13) If two 8-μf. capacitors are connected in series, what is the resulting capacitance?

14) In the following circuit, find the current through each resistor and the voltage across it:



15) A d.c. supply of 250 volts is available, and it is desired to provide voltages of 75 and 125 volts with respect to one terminal of the supply by means of a group of series-connected resistors or "voltage divider." The current drain at the taps will be negligible. What must be the

resistance of each section of the voltage divider if the current through the divider is to be limited to 10 milliamperes?

16) A load taking 5 milliamperes is connected across the 75-volt section of the voltage divider of Question 15, and a load taking 8 milliamperes across the 125-volt section. What will be the actual voltage at each tap with these loads?

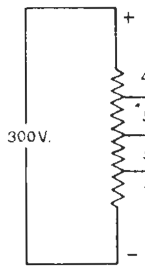
17) If the current through the voltage divider of Question 15 is permitted to be 25 milliamperes, calculate the resistance of each section. If the loads specified in Question 16 are applied, what will be the actual voltage at each tap under load? Is the drop in tap voltage with load as great in this case as with the 10-milliampere divider?

18) Calculate the power lost in the two voltage dividers of Questions 15–17, with and without the load circuits connected.

19) If three resistors, 10,000, 40,000 and 12,000 ohms, are available, how can they be connected to give a total resistance of 20,000 ohms?

20) If the power consumed in a 50,000-ohm resistor is 2 watts, what is the applied voltage? What is the current through the resistor?

21) What are the voltages between the negative terminal and the tap points in the following circuit?



22) What is the unit of electrical energy?

23) What factors determine the resistance of a conductor?

ASSIGNMENT 5

Study *Handbook* section on alternating currents.

Questions

1) Define frequency, cycle, alternation.

2) What is a harmonic?

3) What are the relationships between cycle, kilocycle and megacycle?

4) What is meant by phase?

5) What is meant by the maximum or "peak" amplitude of an a.c. wave?

6) Define effective value. What is the relationship to the peak value in a sine wave?

7) What range of frequencies is considered to be in the audio-frequency spectrum?

8) What is the phase relationship between current and voltage in an inductance?

9) What is meant by the term "sine wave"?

10) What is the average value of an a.c. wave? What is its relationship to the peak value of a sine wave?

11) Is the current through a capacitance leading or lagging the applied voltage? By how many degrees?

12) What is the phase relationship of current and voltage in a resistance?

13) A frequency of 15 megacycles corresponds to how many cycles per second?

14) Convert 1960 kc. to megacycles; cycles.

ASSIGNMENT 6

Study *Handbook* sections on reactance and impedance. Perform Exps. 12–14, inclusive.

Questions

1) What is the reactance of a 250-pf. capacitor at 14 Mc.? At 3.8 Mc.?

2) Write Ohm's Law for alternating current flowing through a resistance.

3) Find the impedance of a circuit consisting of a 2-μf. capacitor in series with a resistance of 40 ohms at a frequency of 60 cycles.

4) What is the impedance at 60 cycles of a 1-μf. capacitor in series with a 1200-ohm resistor?

5) What will be the currents through the two circuits of Questions 3 and 4 if the applied voltage is 115? In each case, what is the voltage across the resistor and the voltage across the capacitor? What is the power factor of each circuit?

6) Find the reactance of an inductance of 15 henrys at 120 cycles. What capacitance will have the same reactance at the same frequency?

7) An inductance of ½ henry and a capacitance of 0.05 μf. are connected in series. What is the total reactance of the circuit at a frequency of 1000 cycles?

8) If a 200-ohm resistor is connected in series with the inductance and capacitance of Question 7, what is the impedance of the circuit? What current will flow if 10 volts is applied to the circuit? What will the current be if the capacitor is short-circuited? If the inductance is short-circuited? If the resistor is short-circuited? Calculate the voltage across the inductance, capacitance and resistance in each case, and also find the power factor in each case.

9) Is power dissipated in a pure reactance?

10) What is the distinction between the impedance in an a.c. circuit and the resistance in a d.c. circuit?

11) If the same current flows through an inductance and a capacitance in series, what is the phase relationship between the voltages across them? What will be the voltage measured across the two in series?

12) If the same voltage is applied to an inductance and a capacitance in parallel, what is the phase relationship between the currents flowing through them? What will be the current measured

in the common lead between the source of voltage and the parallel combination?

13) What are the reactances of the choke coil and fixed capacitors used in Exps. 12 and 13? (L = 30 henrys (actual), C = 0.1, 0.25 and 1 μf. f = 60 cycles.)

14) What is the reactance of a 0.01-μf. capacitor at 30 cycles? If it is in series with a 0.5-megohm resistor across a voltage of 15 at the same frequency, what is the voltage across the resistor? What voltage will appear across the resistor if the frequency is 10,000 cycles?

15) A 5-henry choke and 1000-ohm resistor are connected in series across 115 volts, 60 cycles. What is the power factor of the circuit?

16) In a circuit containing resistance and reactance, how much of the power supplied is dissipated in the resistance and how much in the reactance?

17) Write the formulas for inductive and capacitive reactance. What units must be used in these formulas?

18) If you know only the applied voltage and the current flowing in an a.c. circuit, is it possible to determine the impedance? The power factor? The resistance and reactance present?

ASSIGNMENT 7

Study *Handbook* section on transformers.

Questions

1) If the primary of a filament transformer designed for 115-volt operation has 350 turns, how many turns should be wound on the secondary to give a terminal voltage of 6.3?

2) Assuming that the secondary load on the transformer of Question 1 is to operate at unity power factor and that transformer losses are small enough to be neglected, what size wire should be used for the secondary if the secondary is to deliver 5 amp., allowing 1000 circular mils per ampere? What size wire on the primary?

3) If the transformer of Question 1 is also to have a high-voltage secondary to give 350 volts each side of a center tap (or 700 volts over-all), how many turns will be needed on this winding?

4) Describe the operating principles of the transformer.

5) The secondary load on a transformer having a 5-to-1 primary-to-secondary turns ratio is 300 ohms. What is the impedance looking into the primary from the source of power?

6) How does an autotransformer differ from an ordinary transformer?

7) What are the relationships between turns ratio, voltage ratio, current ratio and impedance ratio in a transformer?

8) If the impedance looking into a transformer primary is 5000 ohms when the secondary load is 7500 ohms, what is the primary-to-secondary turns ratio?

9) A transformer is delivering a current of 10 amperes into a resistance load at a voltage of 10. If the transformer efficiency is 85 per cent, what power is taken from the line? If the primary voltage is 115, what is the primary current, assuming a power factor of 1?

10) A transformer has a primary-to-secondary turns ratio of 1.8 to 1. What will be the impedance looking into the primary when the secondary load is a resistance of 6000 ohms? When the secondary load is 4000 ohms? 12,000 ohms? 200 ohms? 10 ohms?

11) A speaker output transformer is designed to couple a 5-ohm voice coil to a pentode output tube which requires a load of 7000 ohms. What turns ratio is required? If the power delivered to the voice coil is 2 watts, what is the voltage across

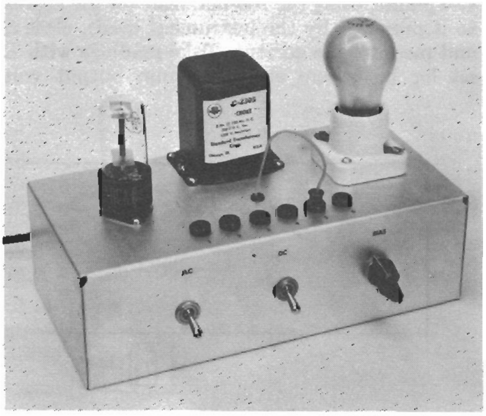


Fig. 1—Transformerless power supply for use in experiments. The circuit diagram of this supply is given in Fig. 2. The metal chassis is 5 × 10 × 3 inches. The 35Z5 rectifier tube is at the left and the filter choke is at the rear center. The six pin jacks along the front are for selecting various d.c. output voltages as required in the experiments; the plug and flexible lead connect to a d.c. output terminal on the right-hand end of the chassis (see Fig. 3).

The supply delivers an adjustable voltage from 0 to about 100 volts d.c. and provision also is made for 115-volt a.c. output. Switches in the a.c. and d.c. lines provide a convenient means for cutting off the voltage when changes or adjustments are made in the associated circuits.

The lamp is used for determining the grounded side of the power line. Before plugging into a power socket, the open side of the lamp terminal, marked "to GND" in Fig. 2, should be connected to ground (water pipe or radiator), then the power plug should be tried both ways in the 115-volt socket. In one position the lamp will light, showing that the common lead is the ungrounded side of the line. When this occurs, reverse the plug so that the common side of the supply will be connected to the grounded side of the line. Since the lamp is not lighted when the proper plug connection is made, for safety's sake *always check by reversing the plug temporarily to make sure that the lamp can be made to light, before turning on the supply.*

The common terminal is the positive terminal of the d.c. supply, this arrangement being used because the supply will be used for bias in later experiments involving vacuum tubes.

the voice coil, the current through it, and the voltage applied to the primary?

12) Can transformers properly be specified in terms of "primary impedance" when the secondary load is not specified?

13) If the secondary load on a transformer has a power factor of 30 per cent, what percentage of the rated power-handling capability of the transformer can be realized? Which is more descriptive of the actual capability of the transformer, a "volt-ampere" or "watt" rating?

14) On dismantling the five-volt secondary winding of a transformer it is found that the winding has 10 turns. If it is desired to put on a winding delivering 7.5 volts, how many turns should the winding have? If the old secondary was rated at 8 amperes, what current can be taken from the new winding without overloading the primary?

15) An autotransformer designed for 115-volt circuits has a 250-turn winding. How many turns should there be between one end and a tap which is to deliver 80 volts?

EXPERIMENT 7

Ohm's Law, Voltage Drops

Apparatus: A source of d.c. voltage variable from zero to about 100 volts is needed for this experiment. The supply shown in Fig. 1 (circuit shown in Fig. 2) is convenient, since it provides for adjustment of the voltage to any value within the range. It is a "transformerless" supply also adaptable to subsequent experiments.

Procedure: The initial adjustment of the taps on the power-supply output resistor or "bleeder," consisting of R_2, R_3 and R_4 in series, illustrates the principle of Ohm's Law. Before making the permanent connection between L_1 and the top end of R_2, insert the milliammeter between these two points, using the 100-ma. scale (or the nearest to it provided by the instrument used), close S_2 and measure the current. Take readings with R_4 set for both zero and maximum output voltage (maximum and minimum resistance, respectively). Remove the milliammeter and make the permanent connection between L_1 and R_2. Now read the output voltage (across the whole bleeder) at the two settings of R_4. With the constants given in Fig. 2, the following readings will be typical:

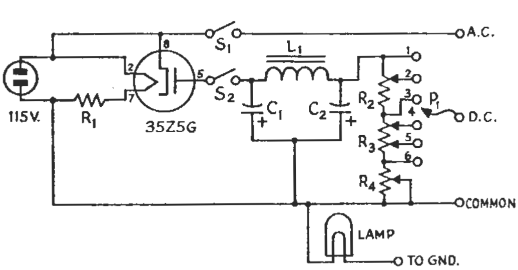
	I	*E*
R_4 at zero resistance	74 ma.	97 volts
R_4 at maximum resistance	71 ma.	99 volts

With the voltmeter between the common lead and point 6, measure the voltage with R_4 at zero and maximum. Note the maximum voltage, turn R_4 to zero and set the first slider on R_3 (point 5) to give the same voltage. Then turn R_4 to maximum, note the new voltage, turn R_4 to zero and set the second slider (point 4) to this voltage. With R_4 at zero, set the slider on R_2 (point 2) to about 75 volts. When this is done a typical tabulation of voltage readings will be as follows:

Between *Common* and	R_4 *Zero*	R_4 *Maximum*
6	0 volts	7 volts
5	7 "	14 "
4	14 "	22 "
3	22 "	28 "
2	70 "	73 "
1	90 "	99 "

In some of the experiments described later different voltages from those listed will be required. In such cases the sliders may be reset to obtain any voltage desired between zero and the maximum available, which is 95 to 100 volts. Note: *Always pull out the power plug before touching any sliders for making adjustments.*

The voltages appearing across the individual resistances constitute voltage drops between points of the complete bleeder circuit, and the sum of these voltage drops must equal the total voltage applied to the bleeder, since the total current flows through each resistor. Thus with R_4 at maximum the drop across it is 7 volts; the drop across R_2 (between points 1 and 3) is 71 volts, and the drop across R_3 (points 3 and 6) is 21 volts. The sum of these three voltages is 99,



Numbered terminals are pin jacks (6 required).
Additional material required includes a 3-terminal strip, octal socket, one single and one double tie-point strip.

Fig. 2—Circuit diagram of the transformerless power supply. No point of this circuit is connected to the metal chassis. The "TO GND" terminal is one of the screw terminals on the lamp socket. Note: If the resistance of L_1 is appreciably different from that specified below, the maximum d.c. output voltage may differ as much as 15 or 20 volts from the nominal 100 volts mentioned in the text. Lower resistance will increase the output voltage.

C_1, C_2—40 μf., electrolytic, 150 volts.
R_1—500 ohms, 10 watts.
R_2—1000 ohms, 25 watts, with slider.
R_3—300 ohms, 25 watts, with two sliders.
R_4—100-ohm wire-wound potentiometer, 4 watts.
L_1—100-ma. filter choke, app. 5 henrys, 300 ohms.
S_1, S_2—S.p.s.t. toggle.
Lamp—115-volt lamp, any convenient size.
P_1—Pin-jack plug.
P_2—115-volt plug and line cord.

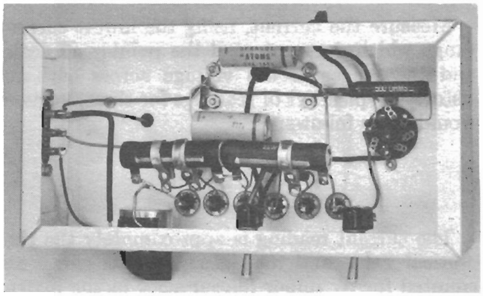


Fig. 3—Inside the chassis of the transformerless power supply. Any convenient layout of components may be used. In this case the two slider-type adjustable resistors, R_2 and R_3, are supported from the pin jacks by stiff leads; in mounting these resistors, leave space between them and the chassis so air can circulate around them for cooling. Use flexible leads from the sliders to the pin jacks to which they are connected, with enough lead length to permit adjustment of each slider.

which is the applied voltage. With R_4 at zero, the voltage across R_3 is 22, and across R_2, 75, totaling 97. These values can be checked by measurement between the appropriate points. The bleeder resistances are very small compared to the voltmeter resistance, so that the current flowing through the latter is small compared with the current through the bleeder. Thus no appreciable error is introduced by the fact that the voltmeter current does not flow through all of the bleeder.

By Ohm's Law

$$R = \frac{E}{I}$$

and the values of the resistances can be calculated from the observed currents and voltages. In the case of the total bleeder, with R_4 at zero

$$R = \frac{97 \text{ volts}}{0.074 \text{ amp.}} = 1310 \text{ ohms}$$

and with R_4 at maximum

$$R = \frac{99 \text{ volts}}{0.071 \text{ amp.}} = 1395 \text{ ohms.}$$

The current must be expressed in amperes when R is in ohms and E in volts, hence the milliampere readings of the meter must be converted to amperes.

Determine the values of the three resistors separately by the same method, using the voltage drops across each for E in the formula, and the values of current corresponding to R_4 at zero and R_4 at maximum. Thus two sets of voltages and currents are available for checking each resistor, and if the measurements are completely accurate the values of resistance found should be identical. The chances are that the two values so found will not be identical, indicating errors in readings and/or the instrument itself. If the differences are more than a few per cent, repeat the measurements of both current and voltage, taking a series of observations and finding averages. Compare the results of this method with the results obtained by the original measurements.

By a similar process, determine the resistance between each pair of taps on the voltage divider. Check the sum of these resistances against the total resistance of the divider.

EXPERIMENT 8

Ohm's Law, Series-Parallel Resistances

Apparatus: Same as for Exp. 7, with the addition of three 10-watt resistors, 1000, 2000, and 5000 ohms. The values need not be exactly as specified, but should be of that order.

Procedure: Connect the resistors as shown in Fig. 4, and apply the full voltage from the power supply. Measure the currents and voltages as indicated. A typical set of data would be as follows:

E = 85 volts
E_1 = 35 volts
E_2 = 50 volts
I = 34.5 ma.
I_1 = 25.0 ma.
I_2 = 9.8 ma.

The sum of E_1 and E_2 should equal E, and the sum of I_1 and I_2 should equal I. Within the limits of measurement error this is the case.

The equivalent resistance of the 5000-ohm and 2000-ohm resistors in parallel can be found by Ohm's Law:

$$R = \frac{E}{I} = \frac{50 \text{ volts}}{0.0348 \text{ amp.}} = 1436 \text{ ohms.}$$

This resistance plus 1000 ohms, or 2436 ohms, is the equivalent resistance of the whole circuit. Checking by Ohm's Law:

$$R = \frac{E}{I} = \frac{85 \text{ volts}}{0.0345 \text{ amp.}} = 2460 \text{ ohms.}$$

By using 0.0348 amp. for the current, the resistance found would be nearer 2440 ohms. Alternatively, the resistance of the "1000-ohm" resistor could be checked by substituting the voltage across it and the current through it in Ohm's Law:

$$R = \frac{E}{I} = \frac{35 \text{ volts}}{34.5 \text{ ma.}} = 1014 \text{ ohms}$$

which value added to 1436 gives a total resistance of 2450 ohms. The measured values can be considered satisfactory, but the observations probably could be improved by taking a series of them and averaging the results.

By the formula for combining resistances in parallel, the resultant resistance of the combination of 2000 and 5000 ohms should be

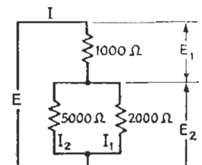


Fig. 4

$$R = \frac{1}{\frac{1}{2000} + \frac{1}{5000}} = 1429 \text{ ohms}$$

which is in very good agreement with the results obtained by measurement.

Rearrange the circuit so that the 1000- and 2000-ohm resistors are in parallel and the 5000-ohm resistor is in series. Measure the applied voltage and calculate the currents and voltages which should result. The step-by-step calculation should be carried through as follows: (1) Find the equivalent resistance of the two parallel resistors; (2) add the equivalent resistance so found to the series resistance (5000 ohms) to find the total resistance; (3) knowing the applied voltage and the total resistance, use Ohm's Law to find the current flowing; (4) using the current so found, determine the voltage drop across the 5000-ohm resistor and across the 2000- and 1000-ohm resistors in parallel; (5) using the voltage drop across the parallel resistors and their known values of resistance, determine the current through each resistor by Ohm's Law. Check the calculated values by measurement. Repeat with the 2000-ohm resistor in series and the 5000- and 1000-ohm resistors in parallel.

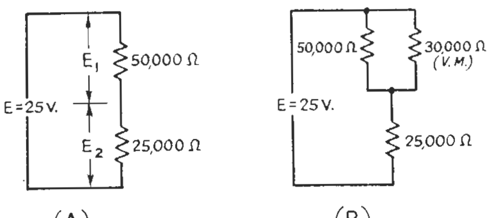


Fig. 5

EXPERIMENT 9

Ohm's Law, Voltage Regulation

Apparatus: Same as for Exp. 8, with the addition of the following fixed resistors: 25,000 ohms, 1 watt; 50,000 ohms, 1 watt.

Procedure: Connect the 25,000- and 50,000-ohm resistors in series as shown in Fig. 5-A and, using the appropriate tap on the power-supply bleeder, adjust the applied voltage to some value just slightly less than the full-scale value on a medium range of the voltmeter. For example, if the instrument has a 30-volt scale a convenient value will be 25 volts. Then by Ohm's Law the current will be

$$I = \frac{E}{R} = \frac{25 \text{ volts}}{75{,}000 \text{ ohms}} = 0.000333 \text{ amp., or } 0.333 \text{ ma.}$$

The voltage drop E_1 across the 50,000-ohm resistor will be

$$E = RI = 0.000333 \times 50{,}000 = 16.67 \text{ volts}$$

and the drop E_2 across the 25,000-ohm resistor

$$E = RI = 0.000333 \times 25{,}000 = 8.33 \text{ volts.}$$

Measure the current, using the lowest current range which does not send the pointer off scale, and then measure the voltage across each resistor. A typical set of readings for the case given would be as follows:

$$I = 0.36 \text{ ma.}$$
$$E_1 = 11.2 \text{ volts}$$
$$E_2 = 5.5 \text{ volts.}$$

The current reading is approximately the theoretical value and the discrepancy is easily accounted for by minor inaccuracies in the instrument, in the rated values of the resistors, and in taking the readings. However, the sum of the voltages across the individual resistors is only 16.7 volts, while the actual applied voltage is 25. The difference is too great to be caused by normal inaccuracies.

The explanation is to be found in the fact that with resistances of this order of value the current flowing through the voltmeter constitutes an appreciable part of the total current flowing through the resistor in series with the meter. Many inexpensive test instruments have a resistance of 1000 ohms per volt on the voltage ranges, which in the case of the 30-volt scale used in obtaining the above data means that the resistance of the voltmeter is 30,000 ohms. When the meter is connected to measure E_1, the 30,000-ohm voltmeter is in parallel with 50,000 ohms so that the circuit now is a series-parallel arrangement, as shown in Fig. 5-B. The resultant resistance of the two in parallel is

$$R = \frac{1}{\frac{1}{50{,}000} + \frac{1}{30{,}000}} = 18{,}750 \text{ ohms.}$$

This resultant resistance is in series with 25,000 ohms, making the total resistance 43,750 ohms. Solving for the current

$$I = \frac{E}{R} = \frac{25 \text{ volts}}{43{,}750 \text{ ohms}} = 0.000572 \text{ amp., or } 0.572 \text{ ma.}$$

The voltage drop across the meter and 50,000-ohm resistor in parallel is therefore

$$E = RI = 18{,}750 \times 0.000572 = 10.7 \text{ volts.}$$

This checks within the limit of error with the value obtained by measurement, 11.2 volts. More accurate results could be secured by determining the value of each resistor separately, using the

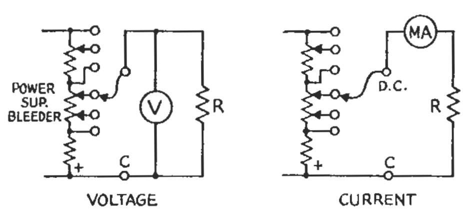


Fig. 6

method given in Exp. 7, and substituting these figures instead of the rated resistances.

Calculate the circuit conditions when the voltmeter is connected to measure E_2, using the method just given. Repeat the experiment using different voltage scales on the instrument, adjusting the applied voltage to an appropriate value each time, and compare the data with the original run, in terms of percentage deviation from the true values. Calculate the circuit conditions for each set of data by the method above.

EXPERIMENT 10

Ohm's Law, E/I Relationships

Apparatus: Same equipment used in Exps. 7, 8 and 9, plus a 15-watt, 115-volt lamp.

Procedure: Set R_4 in the power supply at maximum and measure the output voltages at the various taps. Connect the 5000-ohm resistor to the power-supply output terminals and take readings of current and voltage at various taps on the bleeder. In taking voltage readings, be sure the resistor circuit is closed so that the actual voltage under load is measured. Fig. 6 shows the method. If two instruments are available simultaneous readings can be taken, but equally good results can be secured with only one instrument by shifting from current to voltage ranges. Take similar sets of readings with the 2000- and 1000-ohm resistors, and also with the 15-watt lamp. A typical set of data is given at the bottom of this page. The currents are in milliamperes.

Plot the data so obtained on cross-section paper, as shown in Fig. 7. It is convenient to use half-inch blocks for 10-volt and 10-milliampere intervals. Draw a smooth line through each set of points. Not all the points will lie exactly on the line so drawn, because of slight inaccuracies in measurement, so it is necessary to "average out" the results. If a single measurement is poor, the point obtained from it will lie well out of line with the other points, showing instantly that something is wrong. Such a point should be rechecked by measurement.

In the case of the three resistors, it is obvious that a straight line can be drawn through the plotted points. This indicates that the resistance is constant with varying current; in other words, in such a resistor the ratio between current and voltage is fixed, within the limits of the range of voltages applied. Such a circuit is called "linear" because the plotted curve is a straight line. The *slope* of the line, or the ratio between the number of units covered by the curve in the vertical direction to the number of units moved in the horizontal direction, is constant when the line is straight, and is equal to the resistance. It is expressed in this case in volts per ampere. For example, in the interval between 0 and 10 milliamperes, the curve for the 5000-ohm resistor moves through 50 volts vertically, so that the slope of this curve is

$$\frac{50 \text{ volts}}{0.01 \text{ amp.}}$$

This can be stated as 5000 volts per ampere or as 5 volts per milliampere, and will be recognized as simply another way of expressing Ohm's Law, since $R = E/I$. The more slowly the line rises the lower is the resistance, as illustrated by the lines for 2000 and 1000 ohms.

The curve for the lamp is not a straight line, which means that its resistance is not constant but changes with current. Such a circuit is called "nonlinear," and Ohm's Law cannot be applied as simply as in the case of the linear resistors. The increasing amount of power used in the filament as the current is increased raises the temperature of the filament, and this rise in temperature causes the resistance of the filament to increase. This effect is present in all metallic conductors, but in the case of the ordinary resistors is too small to be noticed over the current range covered by this experiment. The lamp, however, is intended to work with its filament incandescent, hence the change from room temperature to full operating temperature may be several thousand degrees. The resistance at any current will be

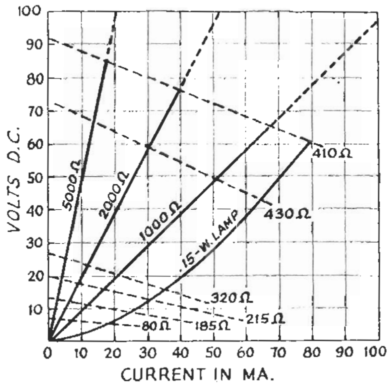


Fig. 7

Tap	No-Load Voltage	1000-Ohm Load E	1000-Ohm Load I	2000-Ohm Load E	2000-Ohm Load I	5000-Ohm Load E	5000-Ohm Load I	Lamp Load E	Lamp Load I
6	6.6	6.0	6.0	6.4	3.3	6.5	1.4	5.1	17.6
5	13.0	11.0	11.7	12.1	6.2	12.6	2.7	9.0	23.0
4	19.5	15.5	16.5	17.4	9.0	18.8	3.9	12.4	31.0
3	26.5	20.0	21.2	23.0	11.9	24.8	6.2	15.7	35.6
2	73.0	48.5	51.1	59.0	31.0	67.0	14.0	42.0	65.0
1	92.5	65.0	67.6	76.0	39.8	85.0	17.6	60.0	80.0

given by Ohm's Law, knowing the voltage across the lamp, but that same resistance value cannot be used for any other current.

Other types of circuits may be nonlinear for different reasons. The vacuum tube is a familiar example, as is also the gas-conduction tube exemplified by the neon lamp. In general, Ohm's Law can be applied directly only to metallic circuits, and then only when temperature effects are taken into account or else are small enough to neglect.

The set of curves in Fig. 7 also shows the effect of internal resistance of the power supply. The current flowing in this resistance causes a voltage drop in the same way as in the external circuit, with the result that the voltage actually applied to the external circuit depends upon the current flowing. The larger the current the greater the internal voltage drop, hence the lower the voltage (generally called the "terminal voltage") available for the load. By connecting the series of plotted points which show the voltages (at a given tap) at no load and with various load resistances, as shown by the dashed lines in Fig. 7, a "regulation" curve is obtained. With this power supply these curves are practically straight lines, indicating that the internal resistance is constant over the range of currents considered. This will not always be true of rectifier-type power supplies, since the internal voltage drop will depend upon the characteristics of the rectifier tube and the filter. However, since the curves in this case are straight, it is possible to determine the effective internal resistance at each tap by taking the slope of the regulation curve at that tap. For example, on the highest tap the voltage changes from 92.5 at no output current to 60 at a current of 80 milliamperes, approximately. The internal resistance is then

$$R = \frac{E}{I} = \frac{92.5-60}{0.8} = 410 \text{ ohms.}$$

The approximate values for other taps are indicated in the graph. From this series of curves it is possible to predict the terminal voltage at any tap for any value of external (or load) resistance, simply by drawing a line, from the origin of the graph, having the proper slope to represent the load resistance. The point where this line intersects the regulation curve gives the terminal voltage at that tap.

EXPERIMENT 11

Time Constant

Apparatus: For this experiment a d.c. source of about 100 volts (the power supply of Fig. 2) and a 0–1 milliammeter are needed. The nearest range to 1 milliampere on the test instrument will be adequate. Several filter capacitors and 1-watt resistors are necessary. Suggested values are 1 μf. (paper), 8 and 16 μf. (electrolytic) with at least 100-volt ratings; suitable resistor values are 1, 0.5, 0.25 and 0.1 megohm. An inexpensive bakelite-insulated pushbutton will be convenient. (These buttons can be obtained at five-and-ten-cent stores.)

Procedure: Connect the apparatus as shown in Fig. 8. The time constant of such a circuit is the product of the capacitance in microfarads and the resistance in megohms, and represents the time in seconds required for the current from the ca-

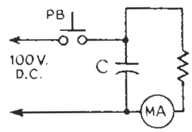


Fig. 8

pacitor to drop to 37 per cent of its initial value when discharging. To check time it is necessary to determine one-second intervals, for which purpose any sort of device which makes a tick or other audible indication once each second can be used, such as a clock or metronome. The standard-frequency transmissions from WWV also provide one-second time ticks. In setting up the apparatus be careful to keep the circuit well insulated, since leakage becomes important when the resistance is high.

Using the 1-μf. capacitor and 1-megohm resistor, close the circuit with the pushbutton and note the current, which should be approximately 0.1 milliampere. Release the pushbutton on the instant of a time tick and count the time in seconds required for the current to drop to 37 per cent of its value with the pushbutton closed. The time cannot be measured with a high degree of accuracy, but it should be obvious that with the constants given a time of about one second is required for the instrument pointer to drop to the 37-per-cent mark. Repeat with the 8- and 16-μf. capacitors. Then substitute lower values of resistors and follow the same procedure in each case. Tabulate the times required for each set of values.

The way in which the current decreases with time is shown in the graph of Fig. 9. The horizontal values in this graph are plotted in terms of time in seconds and the time constant of the cir-

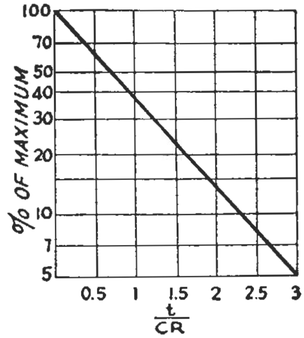


Fig. 9

cuit, the numbers representing the factor by which the time constant should be multiplied to obtain the actual time in seconds. If the time constant is 3 seconds (a 6-μf. capacitor and 0.5-megohm resistor, for instance), the value 2 on the t/CR scale would represent 2×3, or 6 seconds. Therefore at the end of 6 seconds the current from such a combination should have decreased to 14 per cent of its initial value. By choosing integral time intervals the accuracy of time measurement can be increased and the appropriate percentage of maximum current read from the graph.

As an example of experimental use of the graph, suppose that the 16-μf. capacitor and 0.1-megohm resistor are used in the circuit of Fig. 8. On closing the pushbutton the current should be 1 milliampere with 100 volts applied. Open the pushbutton and take a reading at the end of exactly five seconds. Say the current at this instant is found to be 0.1 milliampere. Since this is 10 per cent of the maximum current, the quantity t/CR is found from the graph to be 2.3. Since

$$\frac{t}{CR} = 2.3,\ C = \frac{t}{2.3R}$$

and since $t = 5$, $R = 0.1$

$$C = \frac{5}{2.3 \times 0.1} = 21.7\ \mu\text{f}.$$

The actual capacitance of the capacitor at this voltage is therefore higher than the rated value of 16 μf.

By a similar method, check the capacitances of the other capacitors that may be available.

EXPERIMENT 12

Alternating Current — Reactance and Resistance

Apparatus: This experiment can be performed with the 115-volt line as a source of voltage; provision for connection to the line is made in the power supply of Fig. 2. A multirange high-resistance a.c. voltmeter is needed. This type is provided in the usual multipurpose test instrument such as was recommended for this series of experiments. (The moving-iron type of a.c. voltmeter used for tube filament circuits and for ordinary a.c. measurements has too low resistance to be useful.) Since no a.c.-current scales are provided on most test instruments, this and the following experiment are based on voltage measurements alone, but if an a.c. milliammeter is available it is helpful to measure current as well as voltage. In addition to the meter there should also be provided paper capacitors of 0.1-, 0.25- and 1-μf. capacity, and a filter choke with a rated inductance of 20 to 25 henrys. The 1000-, 2000- and 5000-ohm 10-watt resistors used in the previous experiments will be needed, with the addition of a 10,000-ohm 1-watt resistor.

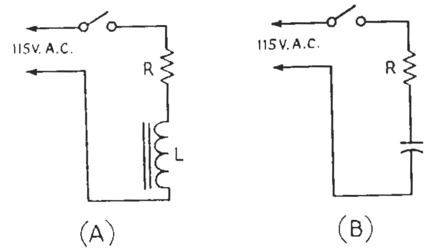


Fig. 10

Procedure: Connect the 1000-ohm resistor in series with the inductance as shown in Fig. 10-A. Measure the voltage across the resistor and that across the inductance. Repeat with the other resistors substituted. A typical tabulation of readings will be as follows (the relative values of voltage measured across the resistor and across the choke can be expected to vary with the type of choke actually used):

Resistance	*Voltage Across Resistance*	*Voltage Across Inductance*
1000 ohms	20	120
2000 ohms	22	118
5000 ohms	40	106
10,000 ohms	68	89

The line voltage was 122 when these data were taken.

In no case does the sum of the voltages across the resistor and inductance equal the line voltage. This is because the voltage across the resistor is in phase with the current, while the voltage across the inductance is 90 degrees out of phase with the current. Hence the r.m.s. voltages (which are indicated by the instrument) cannot be added directly, but the phase difference must be taken into account. Because of the 90-degree phase difference the voltages are, so to speak, at right angles to each other and must be combined by the law relating the sides of a triangle. This relationship is shown in Fig. 11-A, where E_R represents the voltage across the resistance, E_L the voltage across the inductance, and E the total or applied voltage, all drawn to scale. Since the length of the hypothenuse of a right triangle is equal to the square root of the sum of the squares

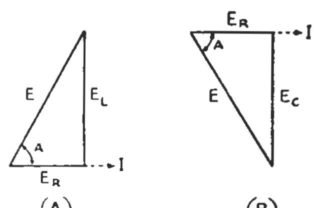


Fig. 11

of the lengths of the other two sides, the total voltage is given by

$$E = \sqrt{E_R^2 + E_L^2}$$

Solving this equation for E with the observed voltages substituted gives the following results:

Resistance in Circuit	*Calculated Total Voltage*
1000 ohms	122
2000 ohms	120
5000 ohms	113
10,000 ohms	112

with an actual applied voltage of 122. The discrepancy is caused chiefly by the fact that the choke has resistance as well as inductance, so that the voltage across it is not exactly 90 degrees out of phase with the voltage across the resistor. For the present purpose this factor can be neglected and the assumption made that the effects of losses in the choke are negligible.

Take a set of such data, using the highest voltmeter scale which will permit reasonably accurate reading (to keep down the voltmeter current) and calculate the total voltage as described above.

Since in a resistor the current is in phase with the voltage, a line representing the current can be drawn on top of the line E_R representing the resistance voltage. The voltage E_L is 90 degrees out of phase with the current and is drawn upward from the current line to indicate that it leads the current by 90 degrees (which is the same as saying that the current lags the voltage by 90 degrees). The angle A then represents the phase angle between the applied voltage and the current in the circuit. The phase angles for the observations above are 80.6, 79.5, 69.3 and 52.6 degrees, respectively. Construct such triangles to scale, using the observed data, and determine the phase angle between the calculated total voltage and current either by measurement with a protractor or by the use of tables of trigonometric functions.

Using the circuit of Fig. 10-B, take readings of voltage across the resistance and capacitor, using the series of resistors with each of the three capacitance values. In the case of the 0.1-μf. capacitor it will be difficult to get accurate resistor voltage readings when the resistance is less than 5000 ohms because the voltage drop is small, so the 2000- and 1000-ohm resistors may be omitted in this case. Tabulate the data and compute the applied voltage from the readings. In a capacitor the current leads the voltage by 90 degrees, so that the same triangular relationship between resistance voltage, capacitor voltage and total voltages applies, and the same formula may be used for computing the total voltage. In this case, however, the triangle is drawn as in Fig. 11-B with the capacitor voltage extending downward from the resistance voltage to indicate that the voltage lags behind the current, which is in phase with the resistance voltage. The angle A is the phase angle between the applied voltage and the current when the voltages are drawn to scale. Draw the triangles and measure or compute the phase angle for each of the pairs of readings.

The voltage drops are caused by the resistance in the case of the resistor, by the reactance in the case of the inductance or capacitance, and by the impedance, which is the combination of resistance and reactance, in the case of the complete circuit. That is,

$$E_R = IR$$
$$E_X = IX$$
$$E = IZ$$

Since the current is the same in all elements in a series circuit, the voltages in such a circuit will be proportional to R, X and Z. Hence the triangles of Fig. 11 show the relationship between resistance, reactance and impedance in series circuits when Z is substituted for E, X for E_L or E_C and R for E_R, in the drawings. Inductive reactance is indicated by a vertical line drawn upward from the horizontal resistance line and capacitive reactance by a vertical line drawn downward, to indicate the phase relationships. Thus the impedance of a series circuit also can be solved by the triangle formula, or

$$Z = \sqrt{R^2 + X^2}$$

From the triangles previously constructed from voltage measurements, compute the reactance and impedance in each case by taking the length of the resistance voltage line equal to the resistance in ohms and measuring the reactance and impedance to the same scale. This also can be done without measurement by taking the ratio of the voltages and multiplying by the resistance used. For example, with 2000 ohms in the circuit the data above give 118 volts across the inductive reactance and 20 volts across the resistor, with the computed total voltage being 120.

Then

$$\frac{E_L}{E_R} \times 2000 = \frac{118}{20} \times 2000 = 11{,}800 \text{ ohms for } X_L,$$

and

$$\frac{E}{E_R} \times 2000 = \frac{120}{20} \times 2000 = 12{,}000 \text{ ohms for } Z.$$

The value of reactance so computed may vary by several per cent in the different cases because of measurement inaccuracies, but should be approximately the same for all values of resistance that are at least several times the resistance of the choke, in the case of inductive reactance, and that are large enough to result in voltages at least one fifth as large as the voltage across the capacitor, in the case of capacitive reactance.

EXPERIMENT 13

Alternating Current — Series Circuits Containing Resistance, Inductance and Capacity

Apparatus: The same equipment is required for this experiment as for Exp. 12.

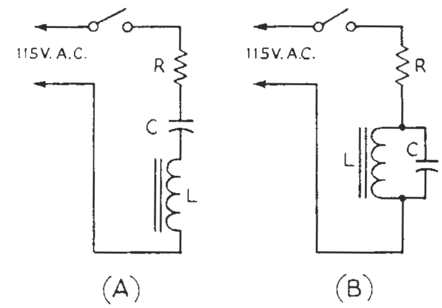


Fig. 12

Procedure: Connect the choke coil, 0.1-μf. capacitor and 1000-ohm resistor in series as shown in Fig. 12-A. Read the voltages across the resistance, capacitance, inductance, and across the capacitor and inductor in series. Substitute the 2000-, 5000- and 10,000-ohm resistances one at a time in place of the 1000-ohm unit and again take voltage readings. Repeat the same procedure with the 0.25-μf. capacitor replacing the 0.1-μf. unit, and finally repeat again with the 1-μf. capacitor.

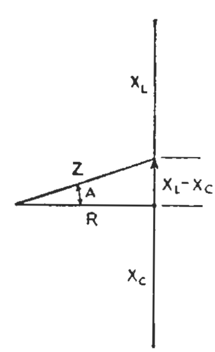
The following tabulation will be typical of the observed data, when the inductance is approximately 30 henrys (a representative value of actual inductance of a choke rated at 20 to 25 henrys for d.c. use in power-supply filtering, but when used in a purely a.c. circuit such as this) and the frequency 60 cycles.

	Resistance, Ohms			
	1000	*2000*	*5000*	*10,000*
When C = 0.1 μf.:				
Voltage across R	7	14	40	67
" " C	218	212	190	153
" " L	115	112	105	90
" " CL	121	119	106	82
When C = 0.25 μf.:				
Voltage across R	52	72	90	97
" " C	443	313	161	92
" " L	428	313	176	115
" " CL	73	51	32	27
When C = 1.0 μf.:				
Voltage across R	10	22	52	78
" " C	38	34	27	18
" " L	153	148	126	97
" " CL	119	116	100	79

The line voltage was 122 when the above data was taken.

Since the voltage across an inductance leads the current by 90 degrees and that across a capacitor lags the current by 90 degrees, the voltages across an inductance and capacitance in series (where both carry the same current) have a phase difference of 180 degrees. In other words, one voltage reaches its positive maximum at the same instant that the other reaches its negative maximum. At every part of the cycle the polarity of one is opposite to the polarity of the other. Hence the total voltage across the inductance and capacitance in series is the *difference* between the voltage appearing across each one. Since the same current flows through all in a series circuit, the same relationships hold between resistance, reactance and impedance. This is shown graphically in Fig. 13, where (as in Fig. 11) the resistance is represented by a horizontal line, the inductive reactance by a vertical line drawn upward to the same scale of ohms, and the capacitive reactance by a vertical line drawn downward. The net reactance in the circuit is the difference between the inductive and capacitive reactances, and is shown as $X_L - X_C$ on the diagram. The impedance is found by using the resistance and net reactance in the triangle relationship. If X_C had been larger than X_L the net reactance would be drawn downward, since the X_C line would be longer than the X_L line and the difference would be in its favor. In such case the phase angle, A, would be leading since the impedance line would be below the resistance line (remembering that the lines can indicate voltage as well as resistance, reactance or impedance and that the current always is in phase with the voltage in a resistance). In the case illustrated in Fig. 13 the phase angle is lagging. Lead or lag is always taken with the voltage as a reference unless otherwise specified, so that a lagging phase angle means that the current is lagging behind the voltage, and a leading phase angle means that the current is leading the voltage.

Fig. 13



When the inductive and capacitive reactances are equal, the net reactance is zero and the impedance is simply equal to the resistance. When this condition exists in a series circuit the circuit is said to be *resonant*, and the current is the same as it would be if only the resistance were present. This current, nevertheless, flows through the inductance and capacitance, and because of the reactances of these elements voltages of considerable amplitude can be developed across them. In the above data the circuit is approximately resonant when the 0.25-μf. capacitor is used, and with the lowest value of resistance the voltage across either C or L is several times the line voltage. If the choke coil had no resistance or other losses, the voltage across CL would be zero at resonance. In the actual data the voltage is not zero, and its value is a measure of the effective resistance of the choke. The term "effective" is used to indicate that the resistance operating is not just the d.c. resistance of the winding, but includes power losses in the iron. In this special case the voltage across CL and the voltage across R both represent resistance voltages, hence these voltages are in phase and should add arithmetically to give the applied voltage. That this is so can be checked by adding the voltages for each case, when it will be found that the sum is approximately equal to the applied voltage.

Calculate the applied voltage from the observed data when $C = 0.1$ μf. and when $C = 1.0$ μf., using the triangular relationship as shown in Fig. 13. Using the resistance as a reference, calculate the impedances, or find them graphically from scale drawings of the voltages (the method was described in Exp. 12). Neglect choke resistance and assume that the calculated applied voltage is correct. The effective resistance of the capacitor is very low and may be neglected without appreciable error.

EXPERIMENT 14

Alternating Current — Inductance and Capacitance in Parallel

Apparatus: The same equipment is required as for Exps. 12 and 13.

Procedure: Arrange the circuit as shown in Fig. 12-B. Using the 1000-ohm resistor at R, take voltage readings across R and across the parallel inductance and capacitance, using successively the 0.1-, 0.25- and 1-μf. capacitors. Substitute the 2000-, 5000- and 10,000-ohm resistances and repeat the procedure in each case. Following is a typical set of data, taken with the line voltage at 123 volts:

	Capacitance, µf. 0.1	0.25	1.0
When R = 1000 ohms:			
Voltage across R	6.3	3.5	37
" " LC	121	121	118
When R = 2000 ohms:			
Voltage across R	12	7.5	61
" " LC	120	120	105
When R = 5000 ohms:			
Voltage across R	25	16.5	103
" " LC	114	114	66
When R = 10,000 ohms:			
Voltage across R	43	30	116
" " LC	102	103	35

Since L and C are connected together in parallel, only one voltage can appear across them. The current in L may differ considerably from that in C, however, since these currents will depend upon the voltage and the reactance of the particular element considered. That is,

$$I_C = \frac{E_{LC}}{X_C} \text{ and } I_L = \frac{E_{LC}}{X_L}$$

neglecting the effect of resistance and losses in the inductance. These two currents combine to form the current ("line" current) which flows through R and the source of voltage. In the capacitor, the current leads the voltage by 90 degrees and in the inductance the current lags the voltage by 90 degrees. Therefore the line current is the difference between the two branch currents, just as in the series case (Exp. 13) the total voltage was the difference between the separate voltages across capacitor and inductor. In other words, the impedance of the parallel circuit ($Z = E/I$) is higher than the reactance of either branch alone since the total current is less than the current in either branch. Should I_C and I_L have the same value the line current under ideal conditions would be zero, indicating that the impedance of the parallel circuit is infinite. In practice this is impossible, since the actual phase relationship between current and voltage in the two branches is not exactly 90 degrees because of the internal resistance present, particularly in the inductive branch. Hence complete cancellation of currents, even when the reactances are equal, does not occur, since such cancellation would require a phase difference of exactly 180 degrees between the two currents. The effect of the internal resistance on line current is relatively small if the reactances of the two branches differ considerably (and if the resistance itself is small compared to the reactance) but becomes more and more pronounced when the two reactances approach equality; that is, when the circuit is near resonance.

With only an a.c. voltmeter available, it is not possible to measure the various currents in such a circuit. The voltage measurements do, however, give a clue to the way in which the impedance of the parallel circuit changes when the capacitive reactance is changed. The lowest voltage drop across the series resistor is obtained when the capacitance (0.25 μf.) which is nearest to series resonance (Exp. 13) is used, showing that the line current is low and hence the impedance of the capacitance and inductance is high. This is just the opposite of the case when the inductance and capacitance are in series, since in the series circuit (Exp. 13) the current is highest when the reactances are equal. With other values of capacitance the resistance voltage increases, which indicates an increase in line current and hence lower impedance in the parallel circuit.

Part Three

Resonant Circuits

In performing experiments on resonant circuits, it is necessary to have a source of radio-frequency voltage. For this purpose a combination crystal and self-controlled oscillator is used. This in turn must have a source of power for the heater and plate of the tube. The units shown in the photographs differ only in a few details from similar equipment to be found in practically every amateur station, and if an oscillator and power supply already are available there is nothing to prevent their being adapted to the purpose.

Ordinary voltmeters and milliammeters cannot be used for radio-frequency measurements, so it becomes necessary to devise an instrument which will be suitable. A vacuum-tube voltmeter, useful for r.f. voltage measurements, is relatively simple to build. One which is adequate for the purposes of these experiments can be constructed from a few resistors and capacitors, in addition to a small receiving triode. Power for the voltmeter can be taken from the oscillator supply.

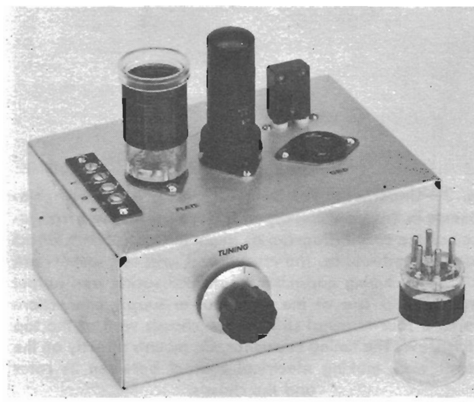


Fig. 1—Oscillator for generating r.f. signal used in measurements on resonant circuits. It may be used either with crystal or grid coil, so that either fixed or variable frequency may be obtained. Separate sockets, right, are provided for the crystal and grid coil, but only one is used at a time. The oscillator output terminals are at the left. The plate coil, L_1 (Fig. 2) is between the terminal strip and the 6F6 oscillator tube.

Oscillator

The oscillator shown in the photograph, Fig. 1, is a conventional pentode circuit when crystal is used, and is converted to a self-excited oscillator by plugging in a grid coil in place of the crystal. The plate tuned circuit of the oscillator is parallel fed, which is advantageous in that no d.c. voltage appears on either the coil or capacitor. The plate coil specified in Fig. 2 should be about the right size for most of the experimental work, but in one or two cases shunt capacitance of leads may reduce the tuning range to the point where a slightly smaller coil would be desirable. It is therefore suggested that the coil be tapped about 10 turns from one end and provision made for shorting out the 10 turns when required. Alterna-

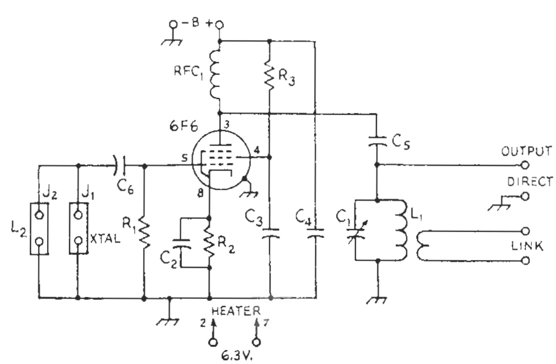


Fig. 2—Oscillator circuit.

C_1—100-pf. variable.
C_2, C_3, C_4—0.01-μf. disk ceramic.
C_5—0.002-μf. mica.
C_6—470- or 500-pf. mica.
R_1—0.1 megohm, 1 watt.
R_2—400 ohms, 1 watt.
R_3—10,000 ohms, 10 watts.
L_1—40 turns No. 24 enameled, spaced to occupy a length of 1¼ inches on 1¼-inch diameter form.
L_2—No. 30 enameled close-wound to length of 9/16 inch on 1¼-inch diameter form.
RFC_1—2.5-mh. r.f. choke.
Additional material required: 5 × 7 × 3 inch aluminum chassis, 2 5-prong sockets, 1 octal socket, 1 crystal socket for FT-243 type crystal holder, 2 4-terminal strips, 2 (or 3—see text) 5-prong coil forms, 1¼ inch diameter (Amphenol 24-5P).

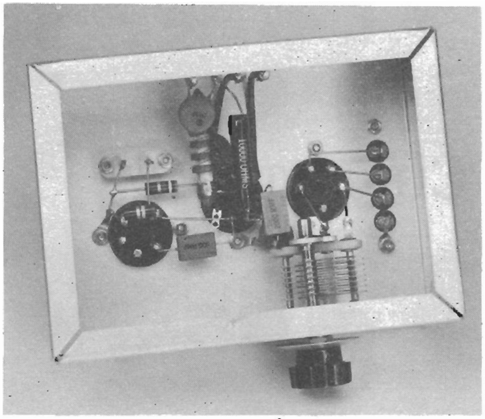


Fig. 3—Underneath the oscillator chassis. Layout of components in this view corresponds closely with the arrangement of the circuit diagram as given in Fig. 2. Short, direct leads are advisable. The crystal and grid coil sockets are at the left; tuning capacitor, plate-coil socket and output terminal strip are at the right. Power-supply connections are to a four-terminal strip on the chassis wall at the top in this view. The tuning capacitor, C_1, mounts directly on the chassis wall, making electrical contact between its rotor and the chassis.

tively, a separate coil having 30 turns spaced to make the length 1¼ inches may be used. A pair of output terminals is connected directly across the tank for set-ups which require a fairly high r.f. voltage. Provision also is made for link output.

For crystal control, any crystal in the 3.5–4-Mc. band can be used. For tuned-circuit frequency control, the "untuned" grid coil replaces the crystal. The number of turns on this coil

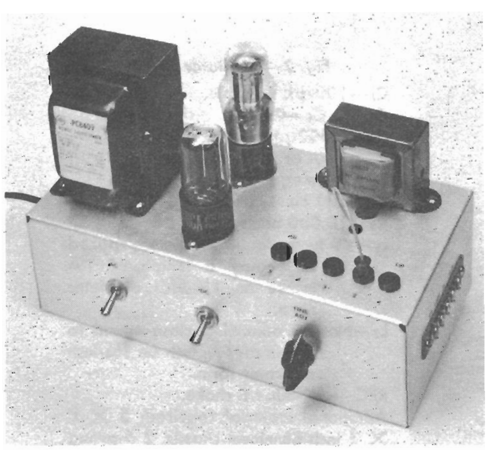


Fig. 4—The power-supply unit. Mounting of parts closely follows the circuit diagram of Fig. 6, with the power transformer at the left, rectifier (front) and voltage regulator tubes alongside it, filter choke at the rear right and pin-jack voltage taps at the right front.

should be adjusted so that the oscillator output voltage is substantially uniform (without load) over as much of the 3.5–4-Mc. band as possible. Other wire sizes may be used provided this requirement is met.

Power Supply

The power supply, Figs. 4, 5 and 6, uses an ordinary replacement-type power transformer with a 5Y3GT rectifier and capacitor-input filter. Any supply which delivers about 250 to 300 volts at 75 to 100 milliamperes will do. The voltage divider incorporated in this supply enables continuous adjustment of the output voltage from zero to the maximum voltage of which the supply is capable. The output filter capacitor is connected to the output terminals rather than to the voltage divider so that the capacitor can act as a

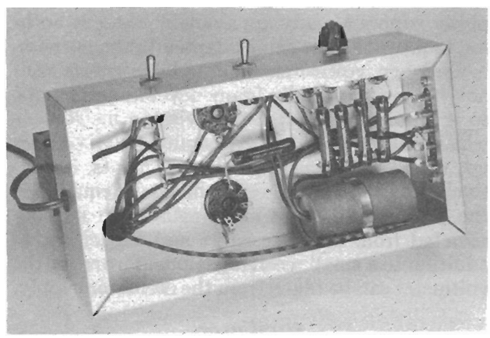


Fig. 5—The filter capacitors (two units in one case) and voltage divider resistors are underneath the chassis in the power-supply unit. Output terminals are at the right.

bypass when the supply is used for audio work. A similar divider can be added to any existing supply, of course. A regulated tap, using an 0D3-VR150 regulator tube and delivering 150 volts under loads varying from zero to about 20 milliamperes, is included. A switch is provided in the rectifier output so that the d.c. voltage can be shut off when adjustments are made, while keeping filaments hot.

V.T. Voltmeter

The vacuum-tube voltmeter need not be accurately calibrated, since absolute values of voltage need not be known. However, it is essential to know *relative* voltage values, and a preliminary voltage calibration therefore is necessary It is desirable to have a voltmeter with a scale as nearly linear as possible, and also one which has high input impedance since the accuracy of measurement of voltages in resonant circuits will be impaired if the voltmeter takes appreciable energy. For these reasons a feedback-type triode voltmeter is used. Selection of the proper cathode resistor sets the voltage range; in the present case

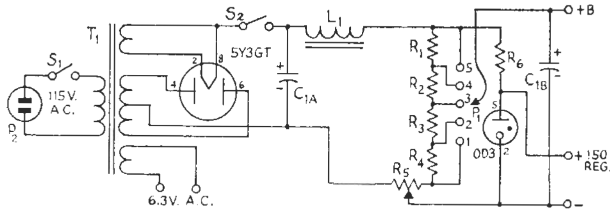


Fig. 6—Power-supply circuit.
C_1—Dual 16-μf. electrolytic, 450 volts, with separate negatives.
L_1—10 to 15 henrys, 80 to 100 ma.
P_1—Pin jack plug.
P_2—A.c. plug and line cord.
R_1, R_2, R_3, R_4—5000 ohms, 10 watts.
R_5—5000-ohm wire-wound potentiometer, 4 watts.
R_6—10,000 ohms, 10 watts.
S_1, S_2—S.p.s.t. toggle.
T_1—Replacement or similar transformer to deliver 250 to 300 volts d.c. from filter at 100 ma. (350 volts a.c. each side center-tap); with 5-volt and 6.3-volt filament windings (such as Stancor PC8409 or Thordarson 24R04).
Additional material required: 5 × 10 × 3-inch chassis, 5 pin jacks, 1 5-terminal strip, 1 4-lug tie strip, 2 octal sockets.

approximate ranges of 10, 30 and 100 volts are provided when the plate-circuit milliammeter has a full-scale range of 1 milliampere. The universal test instrument can be used for measuring the plate current.

The circuit of the v.t. voltmeter is shown in Fig. 8. It is simply a tube biased nearly to cutoff so that the positive cycle of an a.c. voltage applied to the input circuit will cause the plate current to increase. Under ideal conditions the increase in plate current will be proportional to the applied voltage, and in practice this linear relationship is very nearly achieved. Some initial fixed bias is applied to the grid by means of the voltage divider consisting of R_5 in series with R_6; R_6 is in the cathode circuit and the drop across it biases the grid negatively. Additional bias is provided by the cathode resistors R_2, R_3 and R_4. The lower the resistance used here the greater the sensitivity — that is, the higher the plate-current reading for a given voltage applied to the grid. The higher the resistance, the greater the input-voltage range which can be handled; the linearity also is improved with high resistance.

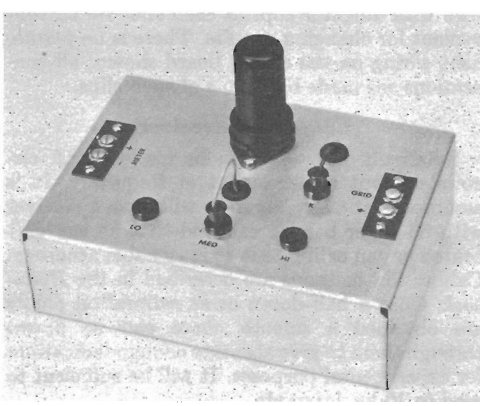


Fig. 7—Vacuum-tube voltmeter for r.f. measurements. It has three ranges, 10, 30 and 100 volts. The pair of terminals at the left is for a 0-1 d.c. milliammeter; signal-input terminals are at the right. The three ranges can be selected by means of the pin jacks and plug at the front. The jack marked "K" is for connecting a 1-μf. capacitor across the cathode resistor (Fig. 8) when making measurements at low frequencies.

The voltmeter should be calibrated against a d.c source. The transformerless supply described in Part 2 is quite suitable for this purpose. Connect its negative output terminal to the ground terminal of the v.t. voltmeter input and the positive terminal to the grid side, then vary the output voltage over a suitable range and take readings of the voltmeter-tube plate current for each applied voltage. The test instrument can be used to measure both current and voltage by switching it back and forth from the plate of the voltmeter tube (where it should be used as a 0-1 milliammeter) to the input terminals of the v.t. voltmeter (where it should be used as a d.c. voltmeter of appropriate range). When enough data have been taken, plot curves showing plate current against grid voltage for all three values of cathode resistance. A typical chart is shown in Fig. 10. The calibration is linear on the two higher ranges except near the low end of the scale, where

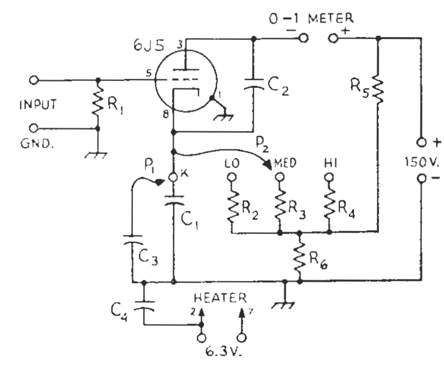


Fig 8—V.t. voltmeter circuit.
C_1, C_2, C_4—0.01-μf. disk ceramic.
C_3—1-μf. paper, 200 volts working.
P_1, P_2—Pin-jack plug.
R_1—5 megohms.
R_2—3000 ohms, 1 watt (10-volt scale).
R_3—25,000 ohms, 1 watt (30-volt scale).
R_4—0.1 megohm, 1 watt (100-volt scale).
R_5—50,000 ohms, 2 watts.
R_6—3000 ohms, 1 watt.
Additional material required: 4 pin jacks, 2 2-terminal strips, 1 4-terminal strip, 1 octal socket, 1 4-plug tie strip, 1 chassis, 5 × 7 × 2 inches.

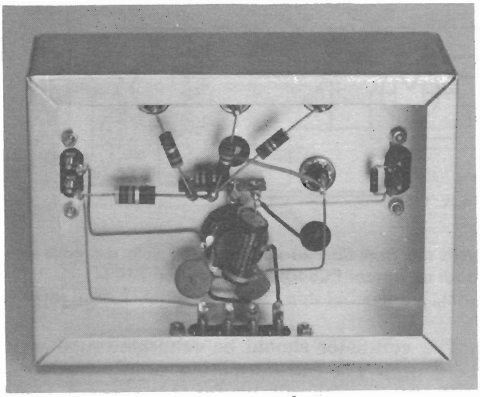


Fig. 9—Below-chassis view of the v.t. voltmeter. The principal consideration in wiring this unit is to keep the lead from the grid of the tube to the input terminal clear of other leads, and to bypass the cathode to ground (through C_1) with short leads. C_1 can be grounded to one of the screws holding the tube socket in place. The "GND" input terminal should be connected to the chassis at the adjacent mounting screw for the terminal strip.

there is a small departure from a straight line.

The value of the bias resistor R_6 may require some modification for tubes of slightly different characteristics. Its resistance should be high enough to bring the plate current almost, but not quite, to zero when no voltage is applied to the input terminals. Should the plate current be zero at first trial, R_6 should be reduced in resistance until the plate milliammeter shows a small indication — between zero and a few hundredths of a milliampere.

Changing the plate voltage has the effect of shifting the curve up or down on the graph, but if the *increase* — not the actual value — in current with applied input voltage is considered, the

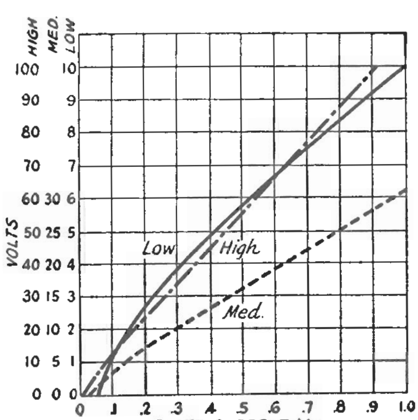


Fig. 10—Typical d.c. calibration curves for the vacuum-tube voltmeter of Fig. 8.

calibration is not changed appreciably. However, with higher plate voltage the plate milliammeter may go off scale near the upper end of the range, while lower plate voltage will cut down the maximum grid input voltage which it is possible to handle without overloading. The regulated tap on the power supply of Fig. 6 provides a constant voltage of suitable value.

Capacitors C_1 and C_2 are r.f. bypasses and tend to build up the plate current to a value which indicates the peak voltage of an applied r.f. wave. C_3 is a similar bypass for audio frequencies across the cathode circuit. Whether or not the instrument reads peak voltage is not important in the present application, since relative voltages are of chief interest. In making r.f. measurements it will be sufficient to assign the measured voltage a value equal to the d.c. voltage which gives the same plate-current reading. C_4 is an r.f. bypass on the heater circuit.

Circuit Board

It is convenient, although not wholly necessary, to have a "circuit board" arranged somewhat as shown in Fig. 11. Variable capacitors can be fastened solidly to it, as can also one coil. The other coil is left free for varying coupling when both are used. In the unit shown in the photograph, the coils are wound on ordinary mailing tubes and are mounted on small pieces of Presdwood or thin wood (so the free coil will sit still and not topple over) by miniature standoff insulators. The variable capacitors should have a maximum capacity of 250 pf. or more to give ample experimental range; old broadcast capacitors will do quite nicely. The small variable at the left is for capacitive coupling when needed.

A half-dozen or so 6- to 8-inch lengths of flexible wire with alligator clips at each end will be convenient for changing circuits. There is no permanent wiring on the circuit board shown; all connections are made by means of such clips.

Calibrated Receiver

Relatively few tests can be made on r.f. circuits without measurement of frequency. It is assumed that every amateur will have a receiver with 80-meter bandspread and that he has calibrated or can calibrate it to reasonable accuracy. Calibration methods are described in the *Handbook*. Once a half-dozen or so calibration points are obtained a smooth curve can be drawn through them to give accurate enough indications for experimental purposes. It will be sufficient to read to 10-kc. intervals.

ASSIGNMENT 8

Study *Handbook* section on r.f. tuned circuits. Perform Exp. 15.

Questions

1) If a current of one ampere flows through a

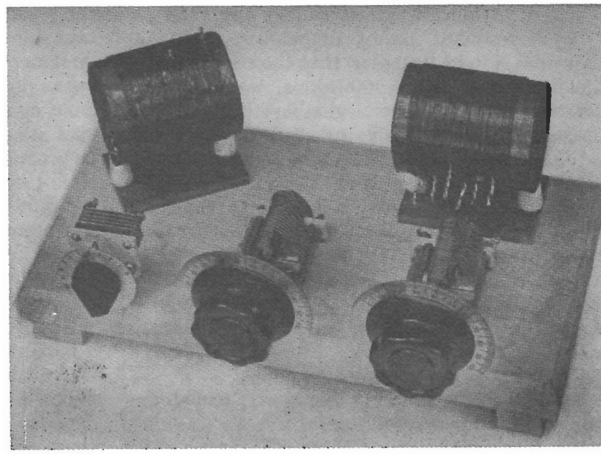


Fig. 11—A circuit board such as this is convenient for making up various types of resonant circuits. The tuning capacitors are 250-pf. units; any capacitors having this or higher capacitance will be satisfactory. The coils, wound on mailing tubes of 2¼-inch outside diameter, have 35 turns each, tapped every 5 turns, with turns spaced to occupy a total length of 2 inches. The wire is No. 18. The small capacitor at the left is for coupling purposes and may have a maximum capacitance of 25 to 50 pf.

series-resonant circuit having a resistance of 10 ohms and inductive and capacitive reactances of 500 ohms each, what is the applied voltage? What voltage appears across the terminals of the inductance? Across the terminals of the capacitor?

2) When is an ordinary radio circuit resonant?

3) Describe the operating characteristics of a series-resonant circuit; of a parallel-resonant circuit.

4) Define the quantity Q.

5) An inductance of 10 microhenrys is used in a parallel-resonant circuit tuned to 7 megacycles. If the coil has a resistance of 3.5 ohms at this frequency, what is the Q of the circuit? Losses in the capacitor may be neglected. What is the parallel-resonant impedance of the circuit?

6) A resistance of 5000 ohms is connected across the circuit of Question 5. What is the new value of circuit Q? What is the equivalent resistance introduced in *series* with the coil by the shunt resistor?

7) How may the Q of an unloaded circuit (one in which all the energy supplied to the circuit is consumed in the circuit itself) be increased? If the circuit is parallel-resonant and is shunted by a fixed value of resistance, how may the circuit Q be increased?

8) In the circuit of Questions 5 and 6, what values should the inductance and capacitance have, to give a circuit Q of 25 when the circuit is loaded by the shunt 5000-ohm resistance?

9) Plot a curve showing the different values of inductance required to tune to 3.5 megacycles with any value of capacitance between 50 and 250 picofarads.

10) Neglecting coil resistance, plot a curve showing the variation in Q of the circuit in Question 9 as the L/C ratio is varied, when a resistance of 10,000 ohms is connected across the circuit. Plot in terms of the capacitance in use. Plot a similar curve for a resistance value of 5000 ohms.

11) What is the resonant frequency of a circuit consisting of a coil of 30 microhenrys and a capacitance of 60 pf.?

12) A resonant circuit is formed by a 50-pf. capacitor and a coil of 10 microhenrys. The latter has a resistance of 2 ohms at resonance.

a) What is the resonant frequency of the circuit?
b) What is the Q of the circuit?
c) What is the parallel-resonant impedance of the circuit?
d) If one volt at the resonant frequency is applied in series with the circuit, what voltage will appear across either the coil or capacitor?
e) If 250 volts at the resonant frequency is applied in parallel with the circuit, what is the equivalent series voltage, corresponding to the series voltage in (d), acting in the circuit? What then is the current circulating in the parallel-resonant circuit? What is the line current (see Exp. 14)? What is the ratio of circulating current to line current, and what circuit quantity does it equal?
f) A resistance of 8000 ohms is connected across the parallel-resonant circuit. Find the new value of circuit impedance. (Use the ordinary formula for resistances in parallel, since the impedance of the tuned circuit alone is a resistance at the resonant frequency.) If the impedance of the tuned circuit alone were neglected in determining the new impedance, would the error be appreciable? What would be the per cent error caused by neglecting the impedance of the tuned circuit alone if the inductance and capacitance had the same values but the coil resistance was 40 ohms?
g) If 250 volts at the resonant frequency is applied across the circuit with the 8000-ohm resistor in shunt (assuming the original coil resistance of 2 ohms) what is the circulating current in the circuit? What is the line cur-

rent? What is the new value of circuit *Q*?

13) A resonant circuit to operate at 14,200 kilocycles is to be loaded so that the effective parallel impedance will be 4000 ohms. Assuming that the coil resistance will be negligible (that is, nearly all the energy will be dissipated in the load, not in the coil itself) what inductance and capacitance should be used to give a *Q* of 15?

14) If a voltage of lower frequency than the parallel-resonant frequency of a circuit is applied, which branch of the circuit carries the greater current, the inductance or capacitance? What are the conditions when the applied frequency is higher than the resonant frequency? Compare with a series circuit.

15) What is the piezoelectric effect?

16) What is meant by the term "loaded circuit"?

17) Two coils, one having an inductance of 15 microhenrys and a resistance of 5 ohms, and the other an inductance of 9 microhenrys and a resistance of 3 ohms, are available for use in a circuit to operate at 7500 kc. Which will give the greater selectivity?

18) If the *Q* of a coil having an inductance of 100 microhenrys is found to be 125 at a frequency of 2000 kc., what is the effective r.f. resistance of the coil?

19) What capacitance is necessary to tune the coil of Question 18 to 2000 kc., and what will be the parallel impedance of the circuit?

ASSIGNMENT 9

Study *Handbook* section on coupled radio-frequency circuits. Perform Exps. 16–20, inclusive.

Questions

1) Name three methods by which radio-frequency energy may be transferred from one resonant circuit to another.

2) What is meant by "critical coupling"?

3) What happens to the effective series resistance of the primary circuit when the coupling to the secondary circuit is increased? What is the effect of increasing coupling on the parallel impedance of the primary circuit? On the over-all selectivity of the two circuits?

4) What is mutual inductance?

5) On increasing the coupling between two circuits it is found that the primary is thrown off tune. What is the cause?

6) Define coefficient of coupling.

7) A 600-ohm load is connected to a resonant circuit which in turn is coupled to the tuned plate circuit of a transmitter operating at 7100 kc. If the secondary circuit must have a *Q* of 10 to obtain sufficient energy transfer, what values of inductance and capacitance must be used (assuming negligible losses in the coil itself) in the secondary circuit if the inductance, capacitance and load are connected in series? Would these values be practicable at this frequency? If the secondary circuit is parallel-resonant and is shunted by the 600-ohm load, what values of inductance and capacitance should be used to obtain the required *Q*? Suppose only half this capacitance was available; what could be done to obtain sufficient coupling?

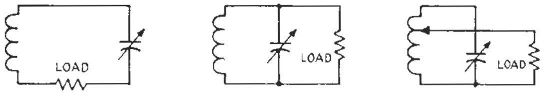
8) Assuming that a variable capacitor having a maximum of 300 pf. and a minimum of 30 pf. is available to tune the secondary or load circuit, indicate which of the circuits, A, B, or C in the diagram (below) should be used to couple to the primary (at 7100 kc.) if the secondary circuit must have a *Q* of 10 for adequate energy transfer, when the load resistance has the following values: 10, 20, 70, 150, 600, 2000, 5000 ohms. Find the value of capacitance which should be used in each case, and also the value of inductance necessary to tune to resonance in each case.

9) What is the purpose of shielding? What type of shield eliminates or reduces electrostatic coupling?

10) What materials are satisfactory for magnetic shielding at audio frequencies? At radio frequencies?

11) What happens to the inductance of a coil when it is enclosed in a shield? What is the effect on the *Q* of the coil? What determines the magnitude of these effects?

12) How would you arrange two coils to obtain the highest possible mutual inductance?



(A) (B) (C)

ASSIGNMENT 10

Study *Handbook* section on circuit details.

Questions

1) What beat frequencies are produced when currents having frequencies of 2000 kilocycles and 2450 kilocycles are mixed in a circuit suitable for the production of beats? What beats are produced if the two frequencies to be mixed are 3900 kilocycles and 1500 cycles? 7150 kilocycles and 7149 kilocycles?

2) What is meant by ground potential?

3) When are bypass capacitors necessary?

4) What requirement must a bypass capacitor meet to function properly?

5) What is the purpose of a choke coil, and what requirements must it meet with respect to the characteristics of the circuit in which it is used?

6) A bypass capacitor is to be used to shunt r.f. current at a frequency of 14.15 megacycles around a circuit having an im-

pedance of 6000 ohms. Determine what value of capacitance would be suitable.

7) A 500-ohm resistor is to be effectively bypassed for 100-cycle alternating current. What value of capacitance is required?

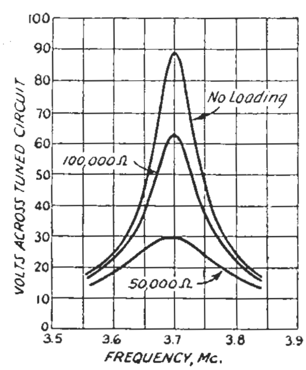
8) A 15-henry inductance is being used as a choke coil through which direct current is being fed to an alternating-current circuit which has an impedance of 4000 ohms at 500 cycles. Would you judge this value of inductance to be adequate? Would it be adequate if the frequency were 60 cycles?

EXPERIMENT 15

Resonant Circuits

Apparatus: The oscillator, power supply, vacuum-tube voltmeter, test instrument, circuit board and the calibrated receiver are needed for this experiment, together with two 1-watt re-

Fig. 12



sistors, 50,000 and 100,000 ohms. Use the full voltage of the supply (250 to 300 volts) on the oscillator, which is operated with the coil in the grid circuit to give variable frequency.

Procedure: Connect a capacitor and coil on the circuit board in parallel, and connect the input terminals of the v.t. voltmeter across the parallel circuit. Set the oscillator frequency to about 3700 kilocycles as determined by the receiver calibration (keep the gain low so that the signal is weak enough to give a good zero-beat indication) and bring the oscillator and tuned circuit near enough to each other to get a good v.t. voltmeter indication when the circuit is tuned through resonance. A reading of nearly full scale (on either the 30- or 100-volt scale) should be obtained when the circuit is resonant at the oscillator frequency. Once the relative positions of oscillator and circuit to give such a reading have been determined, do not move either unit. Should one or the other be accidentally moved, recheck to obtain the same maximum reading at resonance before going ahead.

Using all the turns in the coil, set the capacitor to resonance. Then vary the oscillator frequency in steps of about 20 kc., taking readings on the v.t.v.m. each time, until the frequency is sufficiently far from resonance to bring the v.t.v.m. reading down to the low end of the scale. Do not touch the tuned circuit in the meantime. Take readings on both the low- and high-frequency sides of resonance. Then connect the 100,000-ohm resistor across the tuned circuit and repeat the measurements over the same frequency range. Finally, follow the same procedure with the 50,000-ohm resistor across the circuit. When the run is complete, convert the plate-current readings to volts by means of the v.t.v.m. calibration curve and then plot a curve showing the voltage across the circuit against frequency.

Typical results of such measurements are shown in Fig. 12. The voltage is highest at resonance, dropping off with frequency on either side at a rate determined by the losses in the circuit. These losses are highest with the lower values of parallel resistance, hence the resonance curves of the loaded circuit become progressively less sharp as the loading is increased (parallel resistance lowered). Since the coupling to the oscillator is not changed during the run the voltage induced in the circuit remains unchanged, but the voltage rise at resonance decreases with loading, indicating that the Q of the circuit is decreasing.

Using a smaller number of turns on the coil, repeat the experiment, plot the data, and compare the curves with those obtained with the whole coil. Take a series of such data with different values of inductance. Whenever the inductance is changed, change the position of the coil, if necessary, to get the same maximum value of voltage at resonance without load, or else convert the new readings to the original scale by multiplying each value by the ratio of the original maximum voltage to the new maximum voltage.

If some low-resistance 1-watt units are availa-

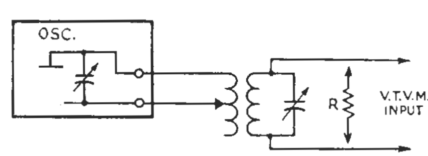


Fig. 13

ble (50 to 200 ohms) the experiment can be varied by taking readings similar to those described above, but with the low-resistance units connected in series with the coil and capacitor instead of in parallel. In such case connect the v.t.v.m. across the capacitor. When plotted, these readings can be compared with the curves obtained with the parallel resistors, in which case it will be observed that the higher values of series resistance give curves comparable to those obtained with the lower values of parallel resistance. If the losses in the circuit itself are small compared with the loss in the connected resistor, the relationship between parallel resistance and equivalent series resistance can be found from the formula

$$Z = \frac{X^2}{R}$$

where Z is the resistance actually connected in parallel and R is the equivalent series resistance. Conversely the impedance of the circuit can be found when the series resistance R is known. Calculate the values from the experimental data obtained.

EXPERIMENT 16

Inductively Coupled Circuits

Apparatus: Same as for Exp. 15, with the addition of 25,000- and 10,000-ohm 1-watt resistors.

Procedure: Set up the oscillator for crystal operation, but remove the plate coil and connect the free coil on the circuit board in its place, using flexible leads. Set the plate-voltage tap on the power supply for about half voltage (between R_2 and R_3, Fig. 6). Connect the fixed coil on the circuit board in parallel with the nearest variable capacitor, using all the turns on the coil. Connect the v.t. voltmeter across this circuit. The general arrangement is shown in Fig. 13.

This experiment involves varying the coupling between the two coils, so it is convenient to make a scale to indicate the degree of coupling. The simplest way to do this is to rule a line on the board to serve as a guide for the movable coil so that its axis always will coincide with that of the fixed coil, and then mark off half-inch intervals along the guide line. Zero spacing will simply be the closest possible spacing between the coil bases on the board, and need have no reference to the actual separation between the turns. This method of measuring coupling is purely

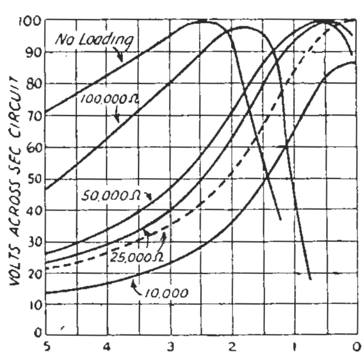


Fig. 14

arbitrary, but will serve the purpose satisfactorily. At the very close spacings, quarter-inch intervals on the guide line will be desirable.

At the start, set the coils at the maximum possible separation on the circuit board. This is about 5 inches in the arrangement shown in Fig. 11. No loading resistor is used in the first run. Use about 25 turns of the movable coil for the crystal-oscillator plate tank, or whatever number of turns brings the setting for oscillation at or above half capacitance on the oscillator tank capacitor. Tune down a bit from the setting of the plate capacitor which gives maximum output so that the oscillator operation will not be critical with loading. Move the coil a half inch at a time toward the fixed coil, taking readings at each interval. If the readings show rapid variation with spacing, reduce the interval to a quarter inch in the critical region. The secondary circuit should be adjusted for maximum voltage (resonance) with the loosest coupling between the two coils and then left alone while the coupling is increased.

The same procedure should be followed with parallel resistance loads of 100,000, 50,000, 25,000 and 10,000 ohms. After a run is complete, reduce the number of turns on the secondary coil and repeat. Do this for as many taps as is possible with the tuning capacitance available. Make certain that the "ground" end of each circuit is connected to the facing ends of the coils to minimize capacitive coupling, and in changing taps keep the active turns in the facing ends. Convert the data into voltage readings and then plot on cross-section paper. A typical set of curves so obtained is shown in Fig. 14. This series of curves was taken with 20 turns in the secondary coil with the exception of the dashed curve, which was taken with 35 turns.

This experiment illustrates the effect of the Q of the secondary circuit on coupling. In the case of the no-load curve, critical coupling — maximum output — is reached when the coils are separated about 2½ inches on the arbitrary scale. When the Q is reduced by the addition of the 100,000-ohm resistor in parallel across the secondary it is necessary to increase the coupling to about 1¾ inches for critical coupling, and as the loading is increased still more by shunting lower values of resistance across the secondary the coupling must also be increased to secure maximum energy transfer. It can be seen that critical coupling can be just about reached with the 10,000-ohm resistor in parallel, and with much lower values of resistance it would not be possible to get tight enough coupling for maximum output. Assuming that the losses in the circuit alone are negligible in comparison to the power in the resistor, the Q of the circuit is

$$Q = \frac{Z}{X}$$

and since the reactance of the 20-turn coil is calculated to be approximately 500 ohms, the circuit Q is 10,000/500, or 20. In this particular case, therefore, the secondary circuit must have a Q

of the order of 20 at least if maximum energy is to be transferred. This is confirmed by the dashed curve, which was taken with 35 turns in the coil and the 25,000-ohm resistor in shunt. Using the new value of coil reactance represented by the larger number of turns the Q again works out to be approximately 20, and in this case the maximum energy transfer also is secured with the coupling distance at zero on the arbitrary scale. (At this "zero" there is still about ¾-inch separation between the actual ends of the coils, so that with other construction tighter coupling could be possible.)

From the data accumulated in the experiment, determine the cases where critical coupling is reached with minimum separation between the coils, and calculate the Q by the method above for these cases. The inductance can be calculated by means of the formula in the *Handbook* or by a *Lightning Calculator.** The effect of dead ends in the tapped coil can be ignored for the purpose of this approximate calculation.

After completing a run, go back and repeat any typical one, this time observing the effect on output voltage of varying the secondary tuning capacitance at various degrees of coupling. It will be observed that with the coupling less than critical the output voltage will go through a resonance curve much like those in Fig. 12, becoming broader as critical coupling is approached, but that with coupling tighter than critical the secondary curve will have two humps, one on either side of the point where the circuit actually is resonant. The amplitude of the humps is approximately the same as the amplitude of the output voltage at critical coupling and is greater than the voltage at actual resonance (with greater than critical coupling) which drops off as shown by the curves. The tighter the coupling the greater the separation between the humps.

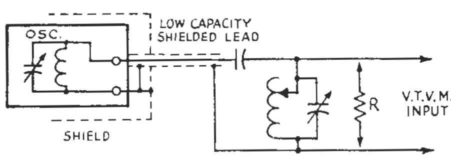


Fig. 15

EXPERIMENT 17

Capacitive Coupling

Apparatus: Same equipment as for Exps. 15 and 16.

Procedure: Use the grid coil in the oscillator for variable-frequency operation (operate the oscillator at half voltage) and set up the fixed coil and tuning capacitor on the circuit board as in the previous two experiments. Because stray coupling between the oscillator and tuned circuit will mask the effects the experiment is intended to illustrate, it is necessary to provide sufficient shielding to reduce stray coupling to the point where it does not cause more than a volt or so to appear across the unloaded circuit. This can be accomplished by placing a large metal can, such as a household sugar can, over the oscillator components on top of the chassis and connecting the can to the oscillator chassis. Reasonable separation between the oscillator and tuned circuit, and keeping the power leads bunched together where they run from the power-supply unit to the oscillator and v.t.v.m., respectively, also will help. Connect the v.t. voltmeter to the circuit, set on the lowest range, and try different positions of the apparatus until not more than a volt or so appears across the unloaded circuit when it is tuned to resonance with the oscillator. An additional baffle shield judiciously placed near the oscillator (and also connected to the oscillator chassis) may help.

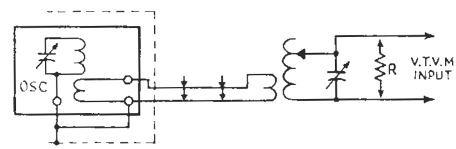


Fig. 16

In this experiment coupling between the oscillator and tuned circuit is by means of a small capacitance. The circuit arrangement is shown in Fig. 15. The lead from the "hot" side of the oscillator tank circuit connects to one side of the small coupling capacitor on the circuit board, and must be shielded for its entire length to prevent stray pick-up. A loosely fitting piece of shield braid over insulated wire will be satisfactory. A tight-fitting shield is not recommended since the capacitance of such a wire will be high. Coaxial cable made for r.f. use is good if available. In any event the lead should not be more than a foot long, to prevent the shunting capacitance across the oscillator tank circuit from becoming too high. It will probably be necessary to use the smaller oscillator plate coil.

Stray capacitance between the coupling capacitor and the tuned circuit will provide enough coupling for the first attempt. Set the oscillator frequency to about 3700 kc., and, using all the turns on the tuned-circuit coil, adjust the circuit to resonance with the oscillator. Vary the oscillator frequency as described in Exp. 15 and take voltage readings. Connect a wire to the "hot" side of the circuit and bring it near the coupling capacitor, again varying the frequency and taking a set of readings. Try various positions of the wire and finally connect it to the other set of plates on the coupling capacitor. (This will probably result in overcoupling and a double-

* Available from ARRL, 225 Main Street, Newington, Conn. 06111, for $1.50 each.

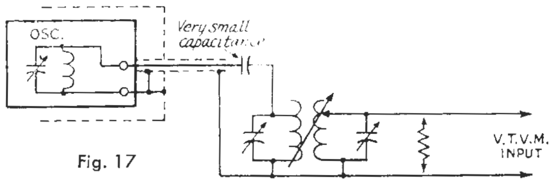


Fig. 17

humped resonance curve with the unloaded tuned circuit.) Shunt the various values of resistance across the tuned circuit and repeat the measurements, noting approximately how much coupling capacitance is required each time for maximum energy transfer. In all cases the capacitance will be quite small.

When the data are taken and curves plotted, the similarity between capacitive coupling and inductive coupling will become apparent, even though the two experiments were not performed on exactly the same basis.

EXPERIMENT 18

Link Coupling

Apparatus: Same as for Exp. 17.

Procedure: The circuit is shown in Fig. 16. The shielding described under Exp. 17 will be required, and stray coupling must be minimized. The link line connecting the two circuits should be twisted and both wires should be the same length. The link coils in both cases are temporary, consisting of a few turns wound around the ground end of the oscillator plate coil and the corresponding end of the tuned-circuit coil. The link for the latter may be arranged to be pushed in and out of the coil to vary the coupling. Start with about 5 turns on each link coil and successively reduce the number of turns, observing the effect on the output voltage. The oscillator and tuned circuit should be returned to the original frequency each time a change is made. It will be found that, with fixed coupling (link wound around the coil) changing the number of turns on either link has relatively little effect so long as a turn or two is retained.

Make runs in the same ways as in Exp. 15, varying the loading over the range of available resistors and taking a run at each tap on the tuned-

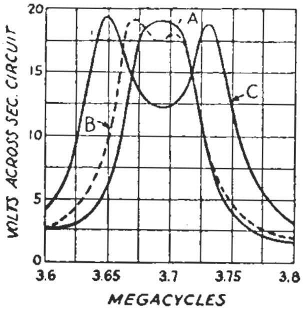


Fig. 18

circuit coil. Repeat for varying degrees of coupling at either end of the link circuit. Compare the results with the information obtained in the experiment on inductive coupling (Exp. 16) with respect to the effect of secondary-circuit Q on the energy transfer. For the cases where maximum energy transfer is just attainable with maximum coupling between the link coil and the tuned-circuit coil, calculate the minimum Q necessary to secure critical coupling.

EXPERIMENT 19

Coupled Resonant Circuits

Apparatus: Same equipment as for preceding experiments.

Procedure: The object of this experiment is to show the effect on selectivity of operating two resonant circuits in cascade. Set up the oscillator for tuned-circuit frequency control as in Exp. 17, checking stray pick-up to make certain that not more than a volt or so is present on the tuned circuit on the circuit board. Connect each coil to a variable capacitor, using all the turns in both cases. The general circuit arrangement is shown in Fig. 17. Very loose coupling must be used between the oscillator and the first tuned circuit, the coil in which is movable with respect to the coil in the secondary circuit. No special coupling capacitor is necessary; enough coupling can be secured by bringing a wire from the hot side of the primary circuit on the board to within a quarter inch or so of the end of the wire projecting from the shielded lead (described in Exp. 17) from the oscillator. Do not allow more than a half-inch of wire to project from the shield, and fasten the two wires securely so the capacitance cannot change during the experiment. Set the oscillator frequency to about 3700 kc. and adjust the coupling capacitance to a value which permits the coupled circuit (the primary in this experiment) to be tuned through resonance without changing the oscillator frequency by more than a few hundred cycles. The secondary circuit should be disconnected when this check is made. If the frequency change is appreciable, the capacitance must be reduced, since overcoupling (which is very easy to get) will greatly affect the measurements.

With the oscillator frequency at about 3700 kc., tune the primary circuit to resonance. The resonance point can easily be observed with the receiver (the beat oscillator should be on) or can be checked by bringing the hot lead from the v.t. voltmeter near (but not touching) the circuit and using the low range for measurement. The v. t. v. m. should not be connected directly to the circuit because its capacitance will change the setting of the tuning capacitor, hence the circuit will be out of resonance when the v.t.v.m. is shifted to the secondary circuit where the actual measurements are to be made. With the primary resonant, connect the v.t.v.m. to the secondary circuit and tune the latter to resonance. Move the primary coil away from the secondary until a reasonably high indication is obtained on the medium range — about 20 volts is satisfactory. Then reduce the coupling still more, check the tuning of the two circuits to make sure they are exactly resonant, and vary the oscillator frequency over a range of about 100 kc., either way from the resonant frequency, taking readings at 10-kc. intervals. Then, without touching the tuning of either circuit, increase the coupling and repeat. Follow the same procedure with progressively closer coupling until a quite pronounced double-humped resonance curve is obtained.

On plotting the data the curves can be expected to look something like those shown in Fig. 18. Curve *A* in this group was taken with quite loose coupling, the primary coil being at its maximum distance and its axis turned slightly to give a further reduction in coupling. Nevertheless the slightly flattened top on the curve, as well as the fact that the maximum amplitude is practically the same as that of the largest hump in each of the other two curves, indicates that the coupling is very near the critical value. Curve *B* is with "4-inch" coupling and shows a double hump, indicating that the coupling is greater than critical. Curve *C*, with "2-inch" coupling, shows considerable overcoupling and very pronounced double humps. In general, these curves will not be exactly symmetrical, either theoretically or practically. Slight inaccuracies in setting the circuits to resonance will have some effect on the symmetry, and an important cause of dissymmetry is overcoupling between the oscillator and the primary circuit. It is of first importance to make this coupling the loosest possible if reasonably good curves are to be obtained.

After completing a run with no loading on the secondary circuit the same procedure should be followed with the 100,000-ohm resistor connected in parallel with the secondary, and then again with the 50,000-ohm resistor in parallel. Plot the data and compare the curves with those obtained with no loading. It will be found that tighter coupling is necessary for maximum secondary voltage, and that the new maximum will be lower than in the no-load case. The resistance loading also tends to flatten the tops of the overcoupled curves, making the double humps less pronounced.

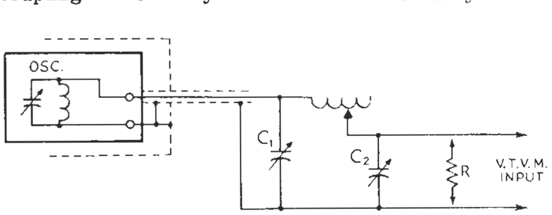


Fig. 19

Compare the set of curves obtained in this experiment with those secured in Exp. 15. How do the curves with corresponding loading compare near resonance? How do they compare at frequencies removed by 100 kc. or so from resonance? To make this comparison it will be necessary to convert the voltage readings to the same scale by plotting selected curves, representing typical sets of conditions, in terms of percentage of the maximum voltage obtained. Suggested curves to plot in this fashion are three corresponding to those shown in Fig. 12, and one set of three (less than critical coupling, critical coupling, and moderate overcoupling) for each condition of loading (no load, 100,000 ohms, and 50,000 ohms) as obtained in the present experiment. Note the "band-pass" effect — rather uniform output over a comparatively wide range of frequencies — of a pair of overcoupled circuits with appropriate resistance loading.

An electrical filter is a circuit using inductance and capacitance in combination to obtain a desired type of frequency-response curve. Three types of filters, *high-pass*, *low-pass*, and *band-pass*, are frequently used in radio work. A high-pass filter is one that passes all frequencies above a selected frequency called the *cut-off frequency* with little or no loss, but has greatly reduced response to all frequencies below the cut-off frequency. A low-pass filter is the opposite type; it passes frequencies *below* the cut-off point and attenuates or "holds back" frequencies *above* the cutoff frequency. A band-pass filter is one that passes all frequencies between two selected limits and attenuates all frequencies outside those limits. The loaded and overcoupled circuits used in the preceding experiment represent a simple type of band-pass filter. A filter must be designed to work into a definite value of load resistance. Both the load and the type of filter circuit determine the values of in-

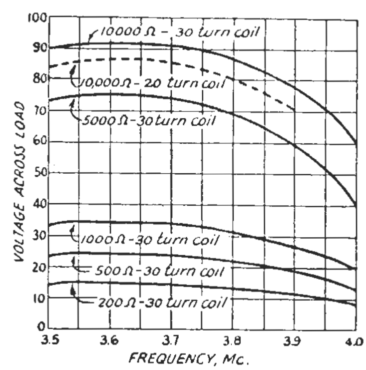


Fig. 20

ductance and capacitance that must be used.

A low-pass filter of the "pi-section" type — so called because its circuit diagram resembles the Greek letter π — is sometimes used to couple a transmitter to an antenna or transmission line. The same type of circuit is also very commonly used as a combined tank circuit and antenna-coupling system in transmitting amplifiers. This type of filter is studied in the present experiment.

EXPERIMENT 20

Pi-Section Filter Operation

Apparatus: Same as used for preceding experiment, with the following values of 1-watt resistors: 10,000, 5000, 1000, 500 and 200 ohms.

Procedure: The operating characteristics of the pi-section filter are investigated in this experiment. The circuit arrangement is shown in Fig. 19, the two capacitors being connected with one of the coils on the circuit board to form a low-pass filter. The input side of the filter is connected directly across the oscillator tank circuit. A blocking capacitor of about 0.001 μf. should be connected in series with the hot lead if the oscillator plate circuit is series-fed; this capacitor is not necessary with the circuit of Fig. 2. The v.t. voltmeter is connected across the filter output to measure the voltage developed across the load. Make sure stray pickup is minimized.

With the filter disconnected from the oscillator, set the frequency of the latter to about 3700 kc. Then, without touching the oscillator tuning, connect the filter, using an output load of 10,000 ohms. Rotate the input capacitor, C_1, until the oscillator frequency returns to its original value. Then try different settings of C_2, the output capacitor, until maximum output voltage is obtained. Each time the capacitance of C_2 is changed, reset C_1 to bring the frequency back to the original value. When the maximum possible output voltage is obtained in this fashion, vary the oscillator frequency on both sides of the original frequency, taking v.t.v.m. readings simultaneously, until most of the 3.5–4-Mc. band has been covered. It will be satisfactory to take readings at 40- or 50-kc. intervals. Do not touch the tuning capacitors in the filter while this frequency run is being made. When this series of data is complete, substitute the next lower value of resistance and repeat the whole procedure. Continue until all the resistance values specified have been used. Plot the data as illustrated in Fig. 20.

In taking the data it will be observed that as the value of load resistance is lowered the capacitance required in C_2 for maximum output voltage progressively increases. It is by this means that the "impedance-matching" function of the filter is realized, and this characteristic compares to the use of more capacitance in a parallel-tuned circuit to maintain sufficient Q when the load resistance is lowered. By comparing the relative power (E_2/R) delivered to the various values of load resistance it can be seen that the output is approximately the same over the range of loads shown in Fig. 20, illustrating the ability of such a coupling circuit to provide proper impedance matching over a wide range of load resistances.

The low-pass characteristic of the filter can be observed from the curves, although there is no sharp cutoff. However, the output drops continually on the high-frequency side of resonance, while it is nearly constant for a 200-kc. frequency range on the low-frequency side. The heavy vertical line represents the initial frequency (3700 kc.) at which the filter was adjusted for maximum output.

Continue the experiment by taking a new value of inductance and repeating the original procedure with various loads. Plot curves and compare them with those obtained with the full 35 turns in the coil. Still larger values of inductance also may be used by connecting part of the second coil in series with the first. Changing the L/C ratio of the filter may result in a better impedance match with certain values of load resistance, less inductance and more capacitance being required for low-resistance loads. This corresponds to the effect of a similar change in L/C ratio on coupling in an ordinary resonant circuit with the load connected in parallel.

The operation of the filter with loads having a reactance as well as resistance component, a condition frequently met when a pi-section filter is coupled to an antenna or transmission line, can be investigated by connecting various values of capacitance or inductance in series with the load resistance. Useful information about the tuning capabilities of the filter can be obtained by observing the limits of reactance which can be compensated for by the filter, for various values of load resistance. The reactance values can be computed from the calculated or known values of inductance or capacitance inserted in the load circuit.

Part Four

VACUUM-TUBE FUNDAMENTALS

EXPERIMENTS designed to show comprehensively the operation of the vacuum tube as an amplifier require a fairly elaborate array of test apparatus. Finding the gain-frequency characteristic of an audio amplifier, for example, requires the use of a calibrated source of variable frequency over the audio-frequency range, plus a calibrated attenuator and a means for measuring voltages, with readings independent of frequency. Distortion cannot readily be observed without an oscilloscope. Such equipment is relatively expensive and satisfactory substitutes cannot readily be constructed at home.

However, simple experiments designed to show the properties of vacuum tubes readily can be performed with the gear described in the preceding experiments. As a convenience in setting up apparatus, a tube chassis such as is shown in Fig. 1 can be added. It consists simply of an aluminum chassis, 5 × 7 × 2 inches, on which an octal tube socket, a single-pole single-throw toggle switch, and a few terminal strips are mounted. Connections from the socket pins, except Nos. 2 and 7 which are for the tube heater, are run to the five-terminal strip mounted alongside the tube socket. The three-terminal strip on top of the chassis provides negative-B (ground), plus 150-volt, and plus-B screw-terminal outlets which may be connected as required to various terminals on the five-terminal strip by means of jumpers made from short lengths of wire. These three terminals, along with pins 2 and 7 on the tube socket, connect to the five-terminal strip on the side wall of the chassis. Leads from the power supply are brought to the latter strip. The two terminals of the toggle switch connect to the two-terminal strip mounted beside the switch; thus the switch can also be connected into any tube-element circuit as required. Principally, it will be used for closing the plate (or screen) circuit when the milliammeter in the test instrument is being used for other measurements.

In using the plate power supply with its variable voltage divider it should be remembered that only a limited current can be taken through the divider taps for more than very short periods of time. The variable resistor, in particular, is rated at only a few watts, and if the output current is more than 15 milliamperes or so the time during which current flows must be kept to a minimum. Since a reading can be taken in a matter of seconds this is no handicap, but if the supply is used for continuous output the resistor arm should be set at the end connected to the transformer center tap (see Fig. 5, p. 29), or else a switch should be provided for shorting between the negative output terminal and the wire connected to the center tap of the power transformer.

Tube Characteristics

Some amplification of the *Handbook* material dealing with tube constants may be helpful in connection with the experimental work. In the paragraph on "Characteristics," for instance, plate resistance is explained to be the ratio of a change in plate voltage to the plate-current change it causes. This can be written in the form of an equation:

$$r_p = \frac{\Delta E_p}{\Delta I_p}\ (E_g \text{ constant})$$

where r_p stands for plate resistance, ΔE_p for the change in plate voltage, and ΔI_p for the corresponding change in plate current. The sign Δ indicates that we are concerned not with one value but with the *difference between two values*. (In other respects the equation is simply the familiar statement of Ohm's Law.) The other two constants, amplification factor and mutual conductance, also can be defined in formulas instead of words:

$$\mu = \frac{\Delta E_p}{\Delta E_g}\ (I_p \text{ constant})$$

$$g_m = \frac{\Delta I_p}{\Delta E_g} (E_p \text{ constant})$$

By simple substitution in these formulas it is

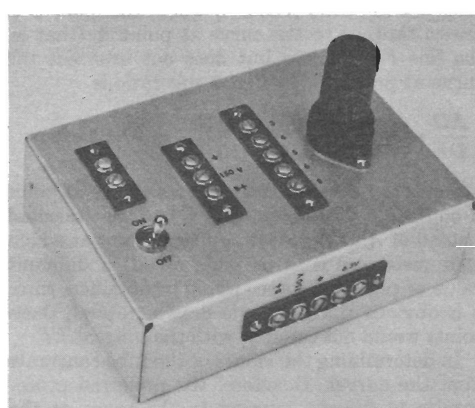


Fig. 1 — Chassis for taking tube characteristic curves.

found that the three constants are related in this way:

$$g_m = \frac{\mu}{r_p}.$$

The values of the constants can be found by plotting characteristic curves and measuring the change which occurs in one quantity when the other is changed any arbitrary amount. However, this method must be used with some caution when the characteristic curve does not turn out to be a straight line. If the line bends, the "constant" is not actually always the same, but varies with the point on the curve at which it is measured. For example, suppose that Fig. 2 represents a curve showing the variation of plate current as the plate voltage is varied, and from it we want to determine the plate resistance. We arbitrarily select A as the point from which to start and, also arbitrarily, decide to make the plate current change, I_p, 2 milliamperes. A 2-milliampere increase brings us to point B on the curve. Then the corresponding change in plate voltage, E_p, is the difference between the plate voltages which cause 1 and 3 milliamperes to flow. Thus $E_p = 70 - 30 = 40$ volts. Then

$$r_p = \frac{\Delta E_p}{\Delta I_p} = \frac{40}{0.002} = 20{,}000 \text{ ohms}.$$

Suppose that instead of 2 milliamperes for I_p we had selected 1 milliampere. This would bring us to point C on the curve, and now $E_p = 53 - 30 = 23$ volts. Substituting these new values in the equation gives us

$$r_p = \frac{23}{0.001} = 23{,}000 \text{ ohms}.$$

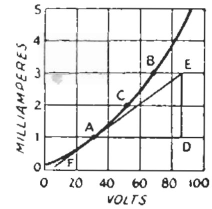
Because of the curvature of the characteristic the value of the "constant" r_p as measured by this method will depend considerably upon the value of Δ selected. As the value of Δ is made smaller and smaller the value of the ratio $\Delta E_p/\Delta I_p$ approaches the ratio AD/DE, where the line FE is drawn tangent to the curve at point A (that is, the line FE touches but does not intersect the curve at point A). In Fig. 2 this ratio is

$$\frac{AD}{DE} = \frac{85 - 30}{0.003 - 0.001} = \frac{55}{0.002} = 27{,}500 \text{ ohms}$$

which is the value of the plate resistance at point A on the curve. If point B or C had been selected instead of A as the starting place (point at which plate resistance is to be determined) a different value of plate resistance would be obtained, since it is obvious that tangents drawn through these points would not coincide with the tangent EF.

In determining the values of the tube constants from the curves, therefore, the preferred procedure is to draw a tangent to the curve at the point at which the value of the constant is to be measured, and then use the tangent line as a basis for measurement of ΔE_p and ΔI_p (or whatever pair of quantities is represented by the curve). While there is bound to be some inaccuracy in drawing the tangent, in general the results will

Fig. 2



be nearer the truth than if two points on the curve itself are selected. Of course if the curve is straight the curve and its tangent coincide, so that in the special case of a straight-line curve points can be taken directly from the curve.

Caution!

In the diagrams of the various set-ups for the experiments to follow, milliammeters and voltmeters are indicated where measurements are to be made. If enough separate instruments are at hand, they may be used as shown. However, if only the single combination test instrument is available for measuring currents and voltages, extreme care should be used to see that the proper range is selected before making voltage measurements. In particular, if the instrument is set on the 0–1 ma. range for use with the v.t. voltmeter, and then connected across a high-voltage part of the circuit while inadvertently left on that range, burn-out or other serious damage to the meter movement is almost certain to result. It is important to form the habit of checking the setting of the range switch on the instrument before making any change in connections.

ASSIGNMENT 11

Study *Handbook* sections on vacuum tubes and amplification. Perform Exps. 21, 22 and 23.

Questions

1) How does conduction take place in a thermionic vacuum tube?

2) What is the space charge?

3) What is the purpose of the grid in a triode?

4) Name the three fundamental tube characteristics and define them.

5) Why is a "load" necessary if a vacuum tube is to perform useful work?

6) What are tube characteristic curves?

7) Why is amplification possible with a triode tube?

8) What is meant by the term "interelectrode capacitance"?

9) What is a dynamic characteristic curve?

10) In what form is the power supplied to the plate-cathode circuit of a tube dissipated?

11) What is the purpose of tube ratings?

12) What is meant by the term "plate-current cutoff point"?

13) What is grid bias, and why is it used?

14) Define saturation point.

15) What is rectification?

ASSIGNMENT 12

Study *Handbook* sections on amplification, amplifier types, amplifier operation, and the decibel. Perform Exp. 24.

Questions

1) Name three forms which the plate load for a triode amplifier may take.

2) Define voltage amplification; power amplification. What is the essential difference between amplifiers designed for the two purposes?

3) What determines the choice of operating point for an amplifier?

4) What is harmonic distortion and how is it caused?

5) Describe Class-A amplifier operation.

6) What is feedback? What is the result of application of positive feedback? Of negative feedback?

7) How is the input capacitance of a triode amplifier affected by its operating conditions?

8) What is driving power?

9) In an amplifier having a resistance load what is the phase relationship between the alternating voltage applied to the grid and the amplified voltage which appears in the plate circuit?

10) What is the effect of the value of load resistance on the voltage amplification obtainable with a given tube?

11) If a certain power-amplifier circuit delivers 3.5 watts when a signal voltage of 20 peak volts is applied to the grid, what is the power sensitivity of the amplifier?

12) Describe Class-B amplifier operation.

13) What is the definition of a decibel?

14) If the power level at one point in an amplifier is 0.25 watt and at a later point is 4 watts, what is the gain in db.?

15) What is the difference between parallel and push-pull operation?

16) A certain circuit provides an attenuation of 15 db. What is the ratio of power levels in the circuit?

17) If a signal of 0.6 volt is applied to an amplifier having a voltage amplification of 125, what is the output voltage?

18) In a certain amplifier an input voltage of 0.01 volt produces an output voltage of 50 across 500 ohms. The input resistance of the amplifier is 0.1 megohm. What is the gain of the amplifier in db.?

ASSIGNMENT 13

Study *Handbook* sections on screen-grid and special tube types, biasing methods. Perform Exp. 25.

Questions

1) What is the purpose of the screen grid in a tetrode or pentode tube intended for use as a radio-frequency amplifier?

2) Does the shielding afforded by the screen grid have to be as complete in a tetrode or pentode designed for audio-frequency amplification as in one designed for radio-frequency amplification?

3) Describe secondary emission.

4) How may the effects of secondary emission be reduced in a screen-grid tube?

5) What is the difference between a "variable-μ" and a "sharp cutoff" tube?

6) Why is a mercury-vapor rectifier preferred to a high-vacuum rectifier when the rectifier tube must handle a considerable amount of power?

7) How does a mercury-vapor grid-control rectifier differ from a high-vacuum triode? Could such a "gas triode" be used for amplification in the ordinary sense of the word?

8) Identify five general types of multipurpose tubes.

9) What is a beam tube?

10) Name the two general types of cathodes used in thermionic vacuum tubes.

11) What is the advantage of the unipotential cathode?

12) What is the purpose of center-tapping the filament supply of a tube whose cathode is heated by alternating current?

13) A certain r.f. power amplifier requires a negative grid bias of 200 volts for Class-C operation. The d.c. grid current is to be 16 milliamperes under operating conditions. If the bias is to be obtained entirely from grid-leak action, what value of grid-leak resistance is required?

14) A triode amplifier requires a negative grid bias of 30 volts, at which bias the plate current is 45 milliamperes. What value of cathode resistance will give the required bias? If the amplifier is to be used at audio frequencies as low as 100 cycles, what value of bypass capacitance should be shunted across the resistor to minimize negative feedback, assuming that the capacitor reactance should not exceed 10% of the cathode resistance?

15) What value of cathode bias resistance should be provided for a 6F6 used as a Class-A pentode audio amplifier with 250 volts on the plate? (Use published operating conditions.) What value of bypass capacitor should be used to prevent negative feedback at frequencies down to 80 cycles?

16) A push-pull r.f. power amplifier requires 400 volts bias and a d.c. grid current of 15 milliamperes per tube under rated operating conditions. If 130 volts of fixed bias is to be provided by batteries, what grid-leak resistance should be used?

ASSIGNMENT 14

Study *Handbook* sections on oscillators and circuit details. Perform Exp. 26.

Questions

1) How may a vacuum-tube circuit be made to generate self-sustained oscillations?

2) Can oscillations be set up in a circuit in which the feedback is negative?

3) What is negative resistance?

4) Define series feed; parallel feed.

5) Draw two circuits utilizing magnetic feedback.

6) How can the amount of feedback be controlled in the Colpitts circuit?

7) Draw a simple triode crystal-oscillator circuit. Which of the ordinary oscillator circuits does it resemble most closely?

8) Name four factors which can affect the frequency of oscillation.

9) How can the effect of plate-voltage variations on frequency of oscillation be minimized?

10) Draw three oscillator circuits with capacitive feedback, and describe how the feedback may be controlled in each.

11) What is the usual method of obtaining grid bias in an oscillator circuit? Why is it used in preference to other methods?

12) How can frequency drift in an oscillator be reduced?

13) A 25-microhenry coil is available for use in an oscillator circuit which is to operate at approximately 2000 kc. What capacitance will be required to tune the coil?

ASSIGNMENT 15

Study *Handbook* sections on the cathode-ray tube and oscilloscope.

Questions

1) What is a fluorescent screen?

2) Describe the construction and operation of a simple cathode-ray oscilloscope tube.

3) By what methods may an electron beam be deflected?

4) How is the intensity of the fluorescent spot controlled?

5) What is the purpose of the sweep circuit in an oscilloscope?

6) Name two common forms of sweep. What are the advantages and disadvantages of each?

7) What is an electron gun?

8) Why should the time of the return trace in a linear sweep circuit be as short as possible?

9) Explain the method by which patterns are formed on the fluorescent screen. Construct a pattern, using a linear sweep with return trace time equal to 1/20 of the total time of the sweep cycle, for two cycles of a sine wave applied to the vertical plates. Construct a pattern, using the same two sine-wave cycles applied to the vertical plates, but with a single sine wave for the horizontal sweep. Compare with the linear sweep.

EXPERIMENT 21

Diode Characteristics

Apparatus: This experiment uses the plate power supply, tube chassis, test set, vacuum-tube voltmeter, and three 1-watt resistors, 25,000, 50,000 and 100,000 ohms. The circuit arrangement is shown in Fig. 3. Measurements must be made of the voltage applied to the tube and the current flowing in its plate-cathode circuit; the single test instrument can be used for both purposes by being shifted back and forth for each pair of readings. However, the small current consumed by the instrument when used as a voltmeter will cause the actual output voltage to be lower when the voltage is being measured than when the instrument is shifted to read plate current. Unless a separate voltmeter which can be left permanently in the circuit is available, it is advisable to use the v.t. voltmeter, thus avoiding the loading effect. The test instrument is therefore shifted between the plate circuit of the tube being tested and the plate circuit of the voltmeter tube.

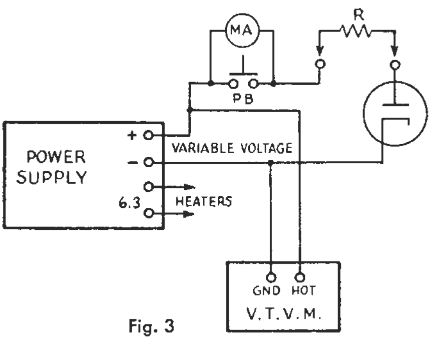


Fig. 3

The tube to be tested may be a 6H6, the diode section of a combination diode-amplifier tube, or simply a small triode such as the 6J5 with the grid and plate connected together to act as a single plate.

Procedure: The object of the experiment is to plot characteristic curves, plate voltage *vs.* plate current, for the tube alone (static characteristic) and with various values of load resistance in series with the plate circuit (dynamic characteristics). Starting at zero plate voltage, increase the plate voltage in small steps, taking plate-current readings at each voltage step. With no load resistor in the circuit, take readings at intervals of voltage which will give current intervals of about 1 milliampere so that enough points will be secured to give a smooth curve when the points are plotted. In the case of the 6H6 tube, using one plate and cathode only, one-volt intervals are suitable. Proceed similarly when the load resistance is inserted in the circuit; in this case larger voltage intervals (5-volt steps, for instance) can be used.

In using the single test set for all measurements, the push-button should be closed while the voltage measurement is being made so that the voltage can be adjusted to the proper value with plate current flowing. If the plate circuit is not closed at the time the voltage is adjusted, the voltage will drop when the milliammeter is connected in the plate circuit of the tube to measure plate current. It is not necessary to make provision for closing the plate circuit of the v.t.v.m. when the meter is being used elsewhere.

The observed data should be plotted in the fashion shown in Fig. 4, which gives characteristic curves taken on a 6H6. With no load the current is quite high, reaching 10 milliamperes with about 7.5 volts applied. Other types of tubes may give considerably different plate-current values without load, but should approximate the load curves given since the current which flows at a given voltage is principally determined by the load resistance rather than the tube. As is to be expected, the current decreases, at a given applied voltage, as the load resistance is increased.

If the no-load curve is inspected carefully, it will be observed that it is not a straight line, particularly near the low-voltage end. The lamp in Exp. 10 was another example of a nonlinear circuit, although for a different reason. In the present case, the nonlinearity arises from the fact that the number of electrons drawn to the plate is not strictly proportional to the voltage applied between plate and cathode. The *d.c. resistance* of the diode at any voltage is equal to that voltage divided by the current which it forces through the tube. In practice the behavior of the tube when an alternating voltage is applied is of more interest, in which case the a.c. plate resistance, or resistance effective to small *changes* in applied voltage, is important. The value of this plate resistance is found as described in the introduction to this chapter.

When a load resistance is inserted in the plate circuit the linearity of the circuit consisting of the resistance and the tube is better than that of the tube alone. This improvement, which increases as the load resistance is increased, is because the load resistor tends to reduce the effect of variations in the resistance of the tube. For example, if the resistance of the tube varies between 1000 and 3000 ohms with a certain range of applied voltage the resistance change is 2000 ohms, or an increase of 200 per cent, using the smaller number as a base. If a 10,000-ohm resistor is connected in series, the minimum resistance becomes 11,000 ohms and the maximum resistance 13,000 ohms, so that the increase in resistance is now only 2000/11,000, or 18 per cent. With 100,000 ohms in series, the increase is from 101,000 to 103,000 ohms, so that the percentage increase is now 2 per cent. In the curves of Fig. 4 the addition of the load resistance makes all the points fall on a line which is practically straight except at the low voltage end where the tube resistance has its highest value. The higher the load resistance the less marked does this slight curvature become.

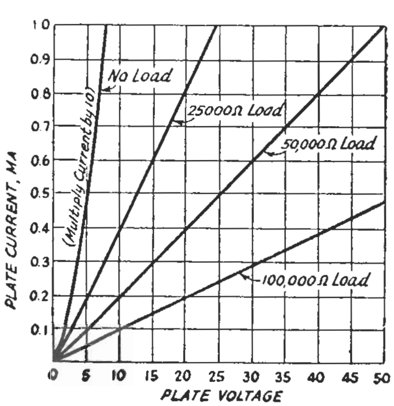


Fig. 4

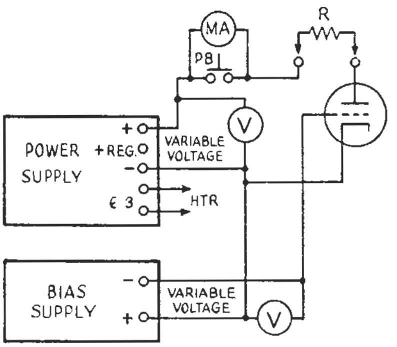


Fig. 5

In taking data it will be observed that a small current flows in the plate circuit even at zero plate voltage. This current is the result of the fact that some electrons are emitted from the cathode with sufficient velocity to reach the plate even though there is no positive charge on the plate to attract them. For complete cutoff of plate current it would be necessary to make the plate a volt or two negative with respect to the cathode, thus repelling these high-energy electrons from the plate. Since the current in any case is very small — a very small fraction of a milliampere — it can be neglected in most applications of the tube. However, in flowing through an external load resistance of high value a volt or two may be developed across the load, which may need to be taken into account in some cases.

EXPERIMENT 22

Triode Static Characteristics

Apparatus: The set-up for this experiment is shown in Fig. 5. Insofar as the plate circuit of the triode is concerned, the arrangement is practically the same as that used for diode measurements, Fig. 3, except that the plate voltage is measured with the test instrument rather than with the v.t. voltmeter. This is possible because larger

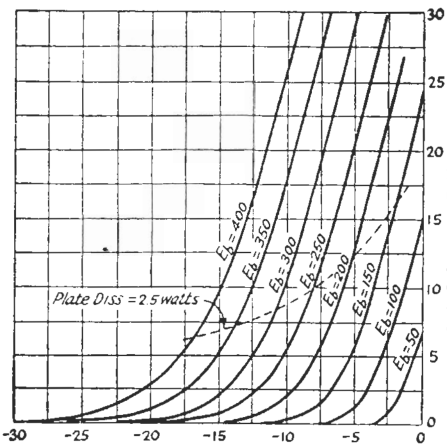


Fig. 6

plate-voltage steps may be used so that a high range (500 volts or the nearest provided on the test instrument), which will have a resistance of a half megohm or so, will give sufficient accuracy for all measurements. The bias supply is incorporated in the set-up to provide variable grid bias, and its voltage output also may be measured by the test instrument on the condition that the voltmeter resistance is 25,000 ohms or more (25-volt scale on a 1000-ohms-per-volt instrument). Be sure that the positive output terminal of the bias supply is connected to the grounded side of the 115-volt line, using the lamp provided for checking as described in Part 2. In using a single instrument in place of the three indicated, the pushbutton should be closed each time the plate voltage is measured so that the voltage will be that existing when plate current flows.

The resistor R shown in Fig. 5 is not needed in this experiment, so the pushbutton may be connected directly to the plate

Procedure: The object of the experiment is to determine the relationship between plate voltage, plate current and grid voltage of a small triode. One quantity is held constant throughout a run, the second is varied, and corresponding measurements of the third are made. A receiving triode such as the 6J5 is suitable. Three sets of characteristics can be taken. The first, with the plate voltage held fixed while the behavior of plate current with varying grid voltage is observed, is called the "grid voltage-plate current" characteristic. When a series of such data is taken with several fixed values of plate voltage, a "family" of curves results. A typical grid voltage-plate current family taken in this way on a 6J5 is shown in Fig. 6. The plate voltage was set at 50-volt intervals from 50 to 400 volts (the maximum output voltage of the power supply described in Part 3), enough points being taken at each plate voltage to permit smooth curves to be drawn. Notice that for each value of plate voltage the curve bends at the higher values of negative grid voltage (as the plate current decreases toward the cutoff point) but that the curvature decreases as the grid bias becomes less negative. The curves eventually straighten out and become practically parallel, and the distances between the 50-volt intervals also approach equality. The dashed line shows the value of plate current at which the plate dissipation (plate voltage multiplied by plate current) is equal to the maximum rated value for the tube; at any point above this line the plate dissipation is exceeded.

The "plate family," shown plotted from experimental data in Fig. 7, is obtained by holding the grid bias constant at selected values and measuring the plate current as the plate voltage is varied. These curves show the same general tendency to bend when the plate current is near cutoff, and to straighten out at higher values of plate current. The plate family is frequently more useful than the set of grid voltage-plate current curves represented by Fig. 6.

When the remaining quantity, plate current, is held constant while the grid voltage is varied (the plate voltage being adjusted for each value of grid bias to give the selected value of plate current) the set of curves shown in Fig. 8 results, again plotted from experimental data on a 6J5. These "constant-current" curves show the relative effect of grid voltage and plate voltage on plate current. The curves are nearly straight lines for all except very small values of plate current, showing that the amplification factor is practically constant for a given plate-current value regardless of the plate and grid voltages. With the exception of the curve for a plate current of 0.1 milliampere, the curves are very nearly parallel, indicating that the amplification factor also is nearly independent of the plate current so long as the latter is not near the cutoff point.

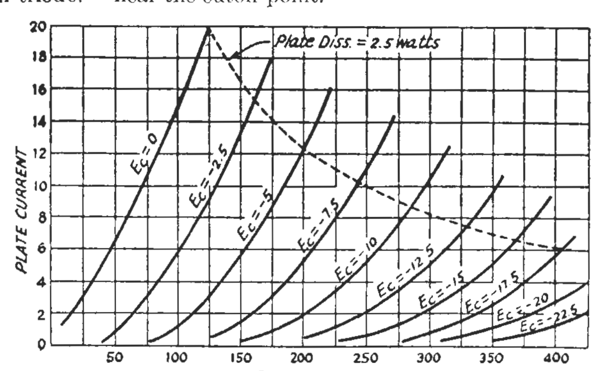


Fig. 7

The values of amplification factor, μ, plate resistance, r_p, and mutual conductance, g_m, can be measured from these three sets of curves. The mutual conductance, $\Delta I_p/\Delta E_g$, can be found from the curves of Fig. 6 since these curves show the relationship between grid voltage and plate current. The plate resistance, $\Delta E_p/\Delta I_p$, can be measured from the curves of Fig. 7, which relate

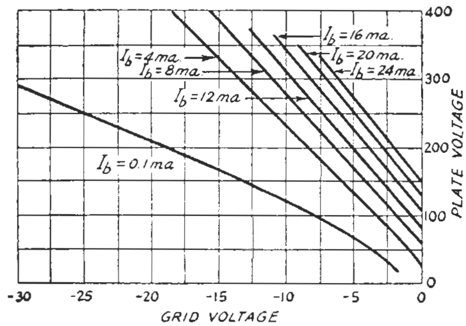


Fig. 8

plate current to plate voltage for various values of grid bias, while the amplification factor, $\Delta E_p/\Delta E_g$, can be taken from the curves of Fig. 8. The method of making these measurements is described in the introduction to this chapter. Since these "constants" are a function of three variables a large number of graphs would be required to give their behavior even partially completely, but one special case is shown in Fig. 9. This graph shows the variation in μ, r_p and g_m as a function of grid bias when the plate voltage is held constant at 250 volts, the normal rated operating voltage for the tube, and is a plot of values measured at 250-volt points on each of the three sets of curves in Figs. 6, 7 and 8. It is plain that the amplification factor changes relatively little compared with the changes in the other two quantities. Increasing negative grid bias causes the mutual conductance to decrease, which means that the amplification obtainable from the tube also decreases since amplification is proportional to mutual conductance, other things being equal. On the other hand, the plate resistance increases with increasing negative grid bias. As a check on the accuracy of measurement, the three curves should satisfy the relationship

$$g_m = \frac{\mu}{r_p}$$

within reasonable limits of accuracy, for any given value of grid bias.

If published average curves for the type of tube measured are available, it will be of interest to compare them with the curves determined experimentally. Exact duplication of the published curves is not to be expected, of course, because of slight variations in tubes.

EXPERIMENT 23

Triode Dynamic Operation

Apparatus: Same equipment as for Exp. 22, with the addition of the following resistors: 5000, 10,000, 25,000, 50,000 and 100,000 ohms. Resistors of 1-watt rating will be satisfactory.

Procedure: The object of this experiment is to plot dynamic grid voltage-plate current characteristics for representative values of plate load resistance. Using a fixed value of plate-supply voltage, insert a resistor at R, Fig. 5, and measure the plate current as the grid bias is varied in steps of 2.5 volts or so. Each time the grid bias is changed, readjust the plate-supply voltage (measured across the supply terminals, not from plate to cathode of the tube being investigated) with the pushbutton closed so that the voltage under load will be the actual value selected. The voltage will need to be reset as the plate current increases, because of voltage drop in the power supply. When a complete set of data has been obtained with one value of plate load resistance, change to another value and take another run. When finished with all values of resistance, plot the data in the form of curves showing plate current against grid bias.

A typical set of such curves, taken on a 6J5 with the plate voltage constant at 300, is shown in Fig. 10. As the plate load resistance is made larger the maximum plate current (at zero grid bias) becomes smaller, as is to be expected. The plate-current cutoff point, however, occurs at approximately the same value of negative grid bias in each case, since the plate voltage is fixed and at zero current there is no voltage drop in the load resistor. As in the case of the diode which was the subject of Exp. 21, increasing the value of load resistance has the effect of straightening out the

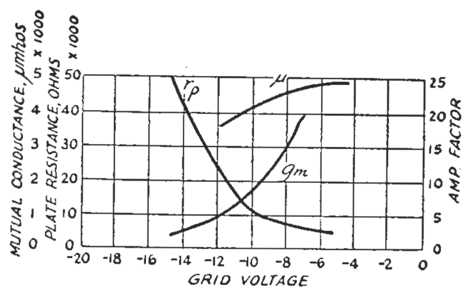


Fig. 9

curve, so that the curves taken with high values of load show less bending than curves with no load or small values of load resistance.

The effect of the load resistance on the amplification obtainable from the tube, and also the distortion it introduces, can be found graphically from curves such as these. In Fig. 11, as an illustration, the curve for R = 10,000 ohms has been plotted singly for the purpose of showing the re-

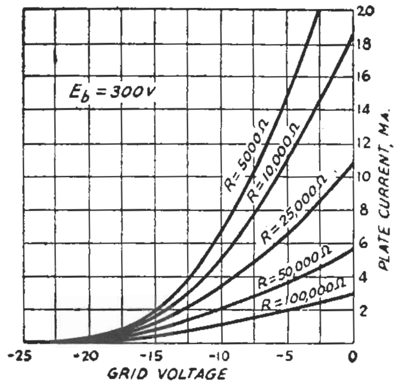


Fig. 10

lationship between varying grid signal voltage and the corresponding variations in plate current. An operating point should be chosen somewhere near the middle of the relatively straight part of the curve, such that the product of the plate current by the voltage between plate and cathode will not exceed the rated plate dissipation of the tube. In Fig. 11 the operating point selected is the point *A*, at −7.5 volts grid bias, making the no-signal plate current slightly less than 8 milliamperes. The dashed line extending downward from *A* is the axis of grid voltage, and the line extending to the right is the axis of plate current. On the grid-voltage axis a sine wave is plotted as the assumed signal voltage (the actual shape of the signal wave is not highly important, but the sine wave is representative of a single frequency) as a function of time, one complete cycle being represented. In Fig. 11 the signal has a maximum amplitude of 5 volts, so that the instantaneous grid voltage swings between the limits of −2.5 volts and −12.5 volts about the fixed grid bias of −7.5 volts. A corresponding time scale is applied to the plate-current axis so that the plate current corresponding to the grid voltage at a given instant can be plotted.

At zero time (beginning of the cycle) the grid voltage is −7.5 and the plate current 7.8 ma., approximately. One-eighth cycle later (point *B*) the grid signal voltage has risen to 71 per cent of its maximum value so that the instantaneous grid voltage is −4 volts. The plate current, *C*, at that same instant is 12.3 milliamperes, and this value is plotted at *D*, one-eighth cycle from zero time on the plate-current axis. Points for other instants are similarly obtained until enough are plotted to permit drawing a smooth curve. When the cycle is complete it can be compared for shape with the original grid signal. As Fig. 11 shows, the two halves of the plate-current cycle are not exactly the same shape, as they were in the grid signal. This difference in shape represents distortion, and the greater the difference the more distortion there is present. As is obvious from the drawing, the distortion is caused by the curvature of the tube characteristic, since if the characteristic were perfectly straight the plate current would be proportional to the grid voltage. Plotting similar graphs from dynamic curves taken with different values of load resistance readily will show the effect of the load resistance on distortion.

The gain of the tube as an amplifier can also be found from the graph of Fig. 11 or from the curves of Fig. 10. Referring to Fig. 12, it can be seen that with fixed plate-supply voltage, E_b, the current flowing in the plate circuit will cause a voltage drop across the load resistance, this drop being equal to I_pR, where I_p is the value of the plate current and R the resistance. The voltage actually between plate and cathode of the tube is the plate-supply voltage minus the voltage drop in the resistance. When an a.c. signal is applied to the grid, the plate current varies at the same frequency, hence a corresponding a.c. voltage is developed across the load resistor. This a.c. voltage is the useful output of the tube. The maximum drop in the resistor occurs when the plate current is maximum, corresponding to the most positive value of instantaneous grid voltage, and the minimum drop occurs when the plate current is minimum, corresponding to the most negative value of instantaneous grid voltage. In Fig. 11 these plate-current values are 14.5 milliamperes for an instantaneous grid voltage of −2.5, and 3.0 ma. for a grid voltage of −12.5. Since the plate load resistance is 10,000 ohms, the maximum voltage drop is 0.0145 × 10,000, or 145 volts, and the minimum drop is 0.003 × 10,000, or 30 volts. The difference, 145 − 30, or 115 volts, is the total change in voltage across the load corresponding to a total change in grid voltage of 10 volts. Hence the voltage gain is 115/10, or 11.5. The same in-

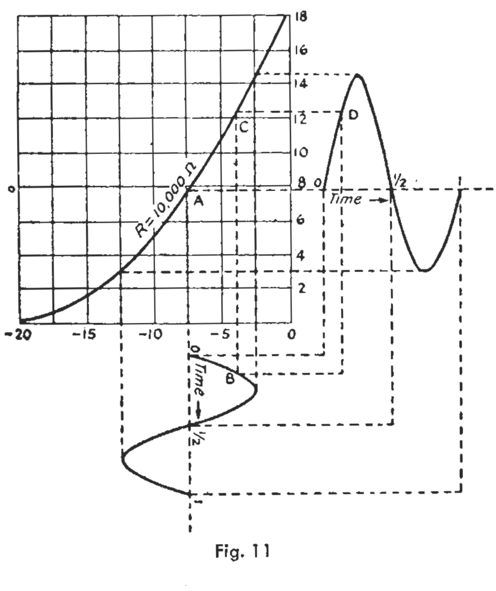


Fig. 11

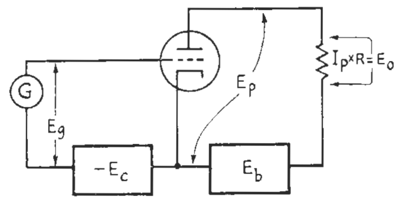


Fig. 12

formation could be obtained from the curves of Fig. 10 by finding the currents corresponding to any chosen change in grid voltage, and then proceeding as above to find the voltage output. From such information a curve can be plotted showing the variation of amplification with load resistance.

EXPERIMENT 24

Class-A Amplification

Apparatus: The power supply, bias supply, v.t. voltmeter and tube chassis are used in this experiment, together with a potentiometer or volume control and the resistors specified in Exp. 23. Almost any potentiometer resistance may be used, although values higher than about 100,000 ohms should be avoided if possible. The circuit arrangement is shown in Fig. 13. The heater voltage for the tubes is used as a source of a.c. voltage for the grid of the tube being tested, the value of voltage applied to the grid being adjusted by means of the potentiometer. The a.c. voltage in either the grid or plate circuit is measured by the vacuum-tube voltmeter, the input circuit of which is connected to the circuit being measured through the 0.01-μf. capacitor. This capacitor blocks the d.c. voltages present and permits only the a.c. to be measured.

Before performing the experiment the v.t. voltmeter should be calibrated on a.c. A source of variable a.c. voltage can most conveniently be obtained by making a slight change in the bias supply so that its voltage divider can be connected directly across the a.c. line. Referring to Fig. 2, page 18, Part 2, disconnect the top end of R_2 from the filter and connect it to the a.c. output terminal. Then proceed to calibrate the voltmeter by the same method used in making the d.c. calibration, using the 0.01-μf. blocking capacitor in the "hot" voltmeter lead. Connect the 1-μf. capacitor, C_3, to the cathode of the voltmeter tube (Fig. 6, page 29, Part 3). The calibration will be in terms of r.m.s. voltages, since the test-set calibration is r.m.s. The a.c. calibration will resemble that taken on d.c., except that the curve above about 40 volts on the high range may show considerable departure from linearity. If so, use only the linear part of this scale. This effect is attributable to the fact that with a capacitance of only 1 μf. at C_3 the time constant of the circuit is too small at 60 cycles to permit the cathode bias to build up to a value sufficient to prevent grid current from flowing at the higher applied voltages. In performing the experiment, care should be taken to keep the maximum voltage to be measured within the linear part of the high-range curve.

Procedure: The purpose of this experiment is to confirm by measurement the results of the gain calculations carried out as described in Exp. 23. Adjust the grid bias (restore the voltage-divider connection to the filter after completing the a.c. calibration) and plate voltage to the values used in the calculations, using the same tube. These were −7.5 and 300 volts respectively in our example, using a 6J5. Set the potentiometer so that the voltage applied to the grid is about 2 volts r.m.s. as measured between grid and cathode (Fig. 13). Insert a resistor in the plate circuit of the tube at R, and adjust the plate-supply voltage to the selected value (300 in this illustration) with plate current flowing (pushbutton closed). Shift the v.t.v.m. to the plate circuit and measure the a.c. output voltage, keeping the pushbutton closed. Repeat for various values of plate load resistance, using two resistors in series to make up values intermediate to those available in the single units. The results of a typical set of measurements are given below, for 2 volts r.m.s. applied to the grid:

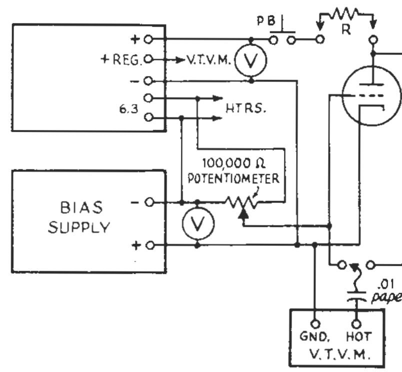


Fig. 13

Plate load resistance, ohms	*Output voltage*
5000	21.5
10,000	27
15,000	29
25,000	31
50,000	34
75,000	34.5
100,000	35

The gain of the amplifier will be equal to the output voltage divided by the input voltage, or just half (input voltage = 2) the figures above. Plot the data in the form of a curve, as shown in Fig. 14.

Note that the gain rises as the plate load resistance is increased, but eventually a point is reached where a considerable increase in load resistance causes only a negligibly small increase in gain. The gain obtainable is proportional to the amplification factor and also to the ratio of the plate load resistance to the sum of the plate load resistance and the a.c. plate resistance of the tube, and when the plate load resistance is large compared to the tube resistance this ratio changes very slowly. Hence the amplification tends to level off as the plate load resistance is increased. From the curves of Fig. 9 the tube plate resistance is seen to be about 7500 ohms. When the plate load resistance is about 5 times the plate resistance, or approximately 40,000 ohms, the amplification increases very slowly with further increases in load resistance. Hence a load in the vicinity of 50,000 ohms is a suitable value.

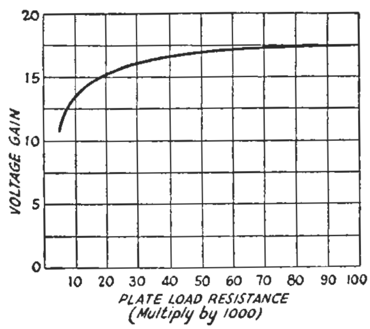


Fig. 14

At 10,000 ohms, the value used in the illustration of Exp. 23, the measured gain is about 13.5 as compared to the calculated value of 11.5. The discrepancy lies in the fact that the v.t. voltmeter reads essentially the amplitude of the positive half of the a.c. wave, while the calculated amplification was based on the *total* amplitude measured from the negative peak to the positive peak. In Fig. 11 the positive current swing is from 7.8 to 14.5 ma., or 6.7 ma., so the plate voltage swing in the positive direction is $0.0067 \times 10{,}000 = 67$ volts. Since it was caused by a 5-volt grid swing, the calculated amplification *for this half-cycle only* is $67/5 = 13.4$.

EXPERIMENT 25

Pentode Characteristics

Apparatus: The apparatus set-up used in this experiment is shown in Fig. 15. The power supply, bias supply, tube chassis and test instrument are required. In taking one set of data it is necessary to maintain the screen grid at constant voltage, preferably the rated value, and for this purpose an 0C3/VR105 is substituted in the power supply for the 0D3/VR150 previously specified. The tube tested can be a small receiving pentode such as the 6J7.

In making voltage measurements, the highest

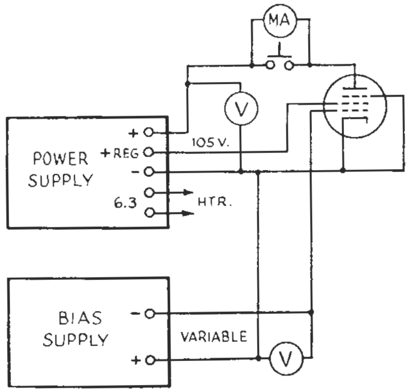


Fig. 15

voltage range on the test instrument which will permit reasonably accurate reading should be used so that the effects of voltage regulation will be minimized. The 500-volt scale for plate voltage and 25-volt scale for grid voltage will be satisfactory (or nearest equivalent ranges provided on the actual instrument).

Procedure: In this experiment curves equivalent to those plotted for the triode (Exp. 22) are to be obtained, for the purpose of determining the relationships between plate current and grid and plate voltages in a pentode. It is advisable to take data for the plate voltage-plate current family first. Using a 6J7, first set the grid bias at zero and then vary the plate voltage, taking plate-current readings at each value of plate voltage selected.

From a plate voltage of 100 up to the maximum available from the supply (about 400), 50-volt steps will be satisfactory. Below 100 volts it is suggested that readings be taken at 10, 25, 50 and 75 volts. Each time the plate voltage is adjusted

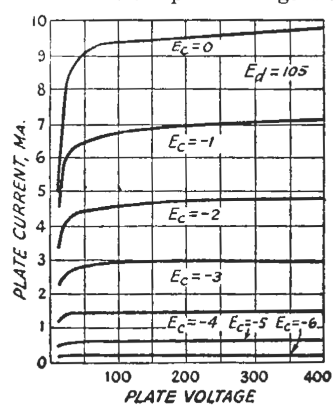


Fig. 16

be sure the pushbutton in the plate circuit is closed so that the voltage will be set to the proper value with plate current flowing.

When a set of measurements has been made with zero grid bias, increase the bias to 1 volt negative and repeat. Continue at 1-volt intervals in bias until a set of measurements has been taken for −6 volts. At higher bias the plate current will be cut off, or else so small in value as to be negligible. Plot the data in curves such as are shown in Fig. 16.

Comparing these curves with the equivalent triode family in Fig. 7 shows a tremendous difference in the behavior of plate current with varying plate voltage. In the triode case (Fig. 7) the plate current is very markedly dependent upon the plate voltage. On the other hand, except for the region of plate voltage lower than the screen voltage, the plate current of the pentode is practically unaffected by the plate voltage. The curves begin to droop as the plate voltage is reduced below 100, but the drop-off is not really marked until the plate voltage is quite low. The fact that the plate voltage has relatively little effect on plate current while the grid voltage has a very great effect indicates that the amplification factor, $\Delta E_p/\Delta E_g$, is very high.

The cause of this behavior is the screen grid. Since the screen grid is an electrostatic shield, it prevents the electric field set up by the plate from

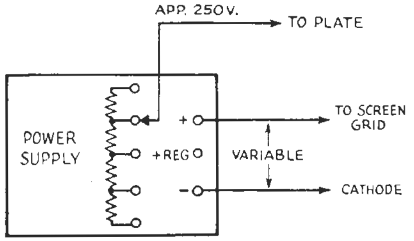


Fig. 17

penetrating to the region occupied by the cathode and control grid, hence electrons in this region are unaffected by the plate potential. The control grid, however, has just as much effect on the electron stream as it does in a triode. Electrons passing through the control grid are attracted to the screen because the latter is operated at a positive potential, but many of them have sufficient velocity to pass between the screen-grid wires without being caught by the screen grid itself. These electrons then come under the influence of the electric field set up by the plate and are attracted to it, forming the plate current. Since the plate can attract only the electrons which get through the screen, it is obvious that the plate current will be determined almost wholly by the screen potential and the structure of the screen grid.

The effect of the screen grid on plate current can be found by holding the plate voltage at a fixed value and varying the screen voltage (for a fixed value of grid bias) while observing the plate current. A slight modification of the experimental set-up of Fig. 15 is necessary. Connect the screen grid to the variable tap on the power supply as shown in Fig. 17, and tap the plate connection on the power-supply voltage divider so that the plate voltage will be about 250 volts. The first tap below maximum will be satisfactory. If the plate voltage varies slightly during a run no harm will be done since the plate current is only slightly

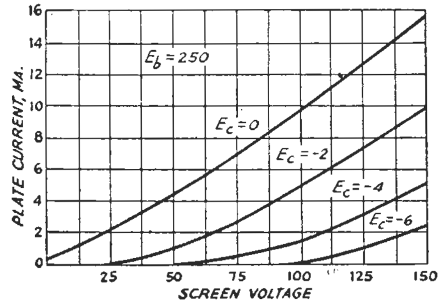


Fig. 18

affected by the plate voltage so long as it is appreciably higher than the screen voltage. Vary the screen voltage in small enough steps so that smooth curves can be plotted from the data. Do this for several values of grid-bias voltage. Typical experimental curves obtained by this method are shown in Fig. 18, taken on a 6J7. These curves have essentially the same nature as the curves of Fig. 7, which is to be expected from the explanation of the operation of the screen-grid tube given above.

Since the plate voltage has relatively little effect on the plate current, a single grid voltage-plate current curve will suffice for practically all plate voltages above the screen voltage, so long as the latter is not changed. Such a characteristic

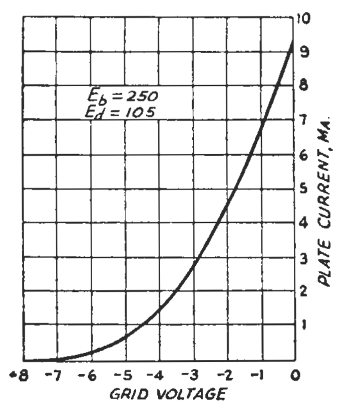


Fig. 19

can be taken by holding the plate and screen voltages fixed, reading plate current while varying the grid bias. An experimental curve on a 6J7 is shown in Fig. 19. Although in the triode case the corresponding curves (Fig. 6) had to be drawn for several values of plate voltage, in this case such a series would lie so close together as to merge into one curve, for all practical purposes. It can be seen, however, that the curve has the same general characteristics as those typical of triodes, and if the mutual conductance is measured it will be found to be approximately the same as for a triode of the same size. The plate resistance is obviously high, since a large change in plate voltage is required to make a comparatively small change in plate current. Both plate resistance and amplification factor are very difficult to measure with any reasonable accuracy because in each case the ratio of the two quantities involved is so high that the probable error in measuring the smaller of the two reflects a large error in the ratio.

Further experimental work may be done with the tube by plotting a series of grid voltage-plate current curves for different values of screen voltage. Also, the effect of secondary emission may be investigated by running a series of plate voltage-plate current curves, corresponding to those of Fig. 16, but with the suppressor grid connected to plate instead of cathode. The characteristics of a variable-μ tube of the same general type, such as the 6K7, also may be taken and compared with the sharp cut-off 6J7.

EXPERIMENT 26

Oscillator Operation

Apparatus: The power supply, v.t. voltmeter and tube chassis are needed for this experiment, together with the additional parts indicated in the diagram of Fig. 20. The Hartley oscillator circuit is indicated in this diagram, with parallel feed in both plate and grid circuits. The radio-frequency chokes are 2.5-millihenry pie-wound units, and the blocking capacitors are 0.001-μf. midget mica or disk ceramic. Provision should be made for changing the grid-leak resistance and for using different values of load resistance. The 1-watt resistors used in previous experiments will be satisfactory in both cases.

Procedure: The object of this experiment is to show the effect of grid-leak resistance on oscillator plate current, grid current, and r.f. output voltage, the plate voltage being fixed at some convenient value and other circuit conditions left

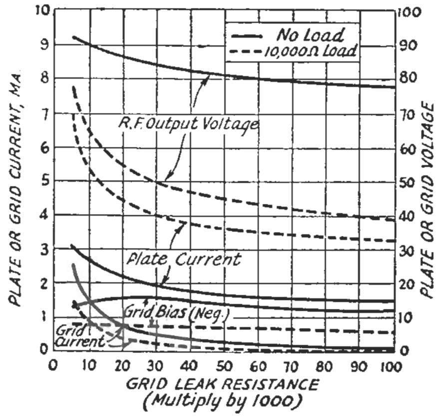


Fig. 21

unchanged. In the circuit of Fig. 20 the tuned circuit is formed by one of the capacitors and coils on the circuit board, the whole 35-turn coil being used with the cathode of the oscillator tube (a 6J5) tapped on the coil 10 turns from the grid end. The v.t. voltmeter is connected between the cathode and plate of the tube (through the plate blocking capacitor) to measure the r.f. plate voltage. The 1-μf. bypass capacitor in the v.t.v.m. cathode circuit (C_3) should not be used.

With the plate voltage at some value which prevents excessive plate current, such as 100 volts, insert a 5000-ohm resistor as a grid leak and measure the plate current, grid current, and r.f. plate voltage. Adjust the plate voltage to the chosen value with the plate circuit closed so that the tube draws plate current. There should be no load on the oscillator on the first run. Change the grid leak to 10,000 ohms and repeat, then continue with successively higher values of grid-leak resistance up to 100,000 ohms. Connect a 25,000-ohm resistor across the v.t.v.m. input circuit as a load and repeat the measurements. Continue with lower values of load resistance until the circuit refuses to oscillate. The data may then be plotted in graphic form.

Typical results of such measurements are shown in the curves of Fig. 21. Curves for no load and for a load of 10,000 ohms are shown for comparison, although if several values of load resistance are used it would be better to use separate sheets for each, to avoid confusion. With no load the variation in r.f. output voltage over the whole range of grid-leak resistance is relatively small. The plate current is low and decreases somewhat as the grid-leak resistance is increased. The grid current at the lowest grid-leak resistance is relatively high, but decreases with increasing grid-leak resistance. The grid bias — product of grid current by grid-leak resistance — shows comparatively little

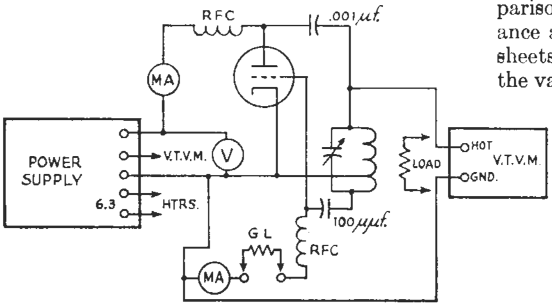


Fig. 20

variation, indicating the self-regulating properties of the oscillator stage in this respect; that is, the grid current regulates itself so as to develop about the same bias over a wide range of grid resistance.

When the circuit is loaded the plate current shows a pronounced increase. This is partly because the load reduces the Q of the tuned circuit, thus lowering its parallel impedance and hence allowing more plate current to flow, much in the same way that the plate current increased in the curves of Fig. 10 with lower load resistance for a fixed value of grid bias. At the same time the r.f. output voltage decreases while the internal voltage drop in the tube increases. This effect is comparable to the decrease in amplification with lower load resistance which was observed in Exp. 24. The plate-current increase is exaggerated in the case of the oscillator because the decrease in r.f. plate voltage is accompanied by a proportional decrease in r.f. grid voltage, since the r.f. grid voltage is obtained from the plate circuit. Hence the grid bias also decreases, if the grid-leak resistance and feedback coupling are fixed. With lower grid bias more plate current will flow, and to some extent the amplification increases so that the r.f. output voltage tends to become greater. Thus two tendencies working in opposite directions are present, but with the net result that there is a decrease in both r.f. output voltage and grid bias and an increase in plate current. Increasing the value of grid-leak resistance again results in self-regulating action with respect to grid bias, while r.f. output voltage and plate current decrease together.

The experiment can be extended by making a similar set of observations with a new value of feedback obtained by changing the position of the cathode tap on the coil. It is also of interest to compare the operation of the various oscillator circuits which can be made up from the coils and capacitors on the circuit board.

Part Five

Radio-Frequency Power Generation

The experiments in this chapter do not require any equipment additional to that already used in the preceding work. Much of the useful practical knowledge of the operation of the various parts of transmitters comes from actual construction and use, and the average amateur, for whom this course is intended, usually has acquired a fair fund of such knowledge. Supplementary to the experiments, the beginner can get a great deal of practical benefit from building up various basic circuits shown in the *Handbook* and observing their operation. This additional work also is recommended as part of a classroom program. The experiments devised for this chapter have for their purpose the focusing of attention on points which ordinarily are somewhat obscure to the practicing amateur and which, because of their basic nature, form a good background for understanding otherwise puzzling phenomena which arise occasionally in the course of adjusting a transmitter.

ASSIGNMENT 16

Study *Handbook* sections on self-controlled and crystal-controlled oscillators. Perform Exp. 27.

Questions

1) Why is it general practice, on frequencies below 60 megacycles, to use multistage transmitters in preference to the much simpler arrangement of an oscillator coupled to an antenna?

2) What is a buffer amplifier?

3) What are the advantages and disadvantages of a self-controlled oscillator as compared with the crystal-controlled type?

4) What requirement must be met by the oscillator tank circuit to give the highest frequency stability? How can this be accomplished in practice?

5) How should an oscillator be adjusted and operated to secure a high order of frequency stability? What constructional precautions should be observed?

6) Draw an electron-coupled oscillator circuit, using a tube having an indirectly heated cathode, with tuned output.

7) Draw a crystal-oscillator circuit using a pentode tube.

8) If a crystal oscillator refuses to function, what are some of the possible causes?

9) Compare the triode with a tetrode or pentode as a crystal-oscillator tube.

10) What determines the frequency at which a crystal will oscillate?

11) Show a crystal-oscillator circuit that will give output at a harmonic of the crystal frequency.

12) Describe the behavior of the plate current of a crystal oscillator as the plate tank circuit is tuned through resonance.

13) What is the correct method of adjusting a Tri-tet oscillator?

14) What determines the safe power input to a crystal-oscillator circuit?

15) What precautionary measures can be taken to prevent fracturing a crystal from excessive r.f. voltage?

16) What is the effect on r.f. crystal voltage of taking power output from a crystal oscillator?

ASSIGNMENT 17

Study *Handbook* sections on r.f. power-amplifier circuits and interstage coupling. Perform Exps. 28 and 29.

Questions

1) Draw a circuit diagram showing link coupling between a single-ended driver stage and a push-pull amplifier Indicate series-fed plate supply for the driver and series-fed bias supply for the amplifier.

2) When is it desirable to use link coupling between driver and amplifier stages?

3) If the effect of shunting capacitances can be neglected, as at low frequencies, would you expect the same coupling efficiency to be obtained with capacitive and with link coupling, assuming optimum adjustments in each case?

4) Draw a circuit diagram showing capacitive coupling between a single-ended driver and single-ended amplifier. Indicate a method for obtaining optimum energy transfer ("impedance matching").

5) To what part of the tank coil should a link winding be coupled in order to minimize capacitive coupling?

6) Why is neutralization necessary in a triode r.f. amplifier?

7) If, when adjusting a link-coupled driver-amplifier circuit, it is found that the amplifier excitation is insufficient even though the driver power output capability is known to be ample, what is the probable cause? How may the condition be remedied?

8) What precautions must be taken to prevent self-oscillation in screen-grid r.f. amplifiers?

9) Draw a circuit of a plate-neutralized single-tube triode amplifier using a split-stator plate tank capacitor. Show a driver stage with capacitive coupling to the amplifier.

10) Draw a cross-neutralized push-pull triode-amplifier circuit, with a link-coupled single-ended screen-grid driver. Use split-stator or balanced capacitors in the amplifier plate and grid tank circuits.

11) Why is it possible, as a general rule, to obtain more complete neutralization of a push-pull than a single-ended amplifier?

12) Draw a circuit of a grid-neutralized amplifier using a single-ended or unbalanced grid tank condenser. Show link coupling to a plate-neutralized driver stage.

13) Describe the procedure used in neutralizing an amplifier, using a milliammeter in the grid circuit as an indicator.

14) If it is found impossible to neutralize an amplifier completely, how would you test for coupling (external to the tube) between the input and output circuits?

15) What is the principle of inductive neutralization?

16) If the impedance in the plate circuit of a 3.5-Mc. amplifier is 2000 ohms, what value of bypass capacitance will be suitable in the plate circuit if series feed is used?

17) A certain amplifier exhibits a grid impedance of 4000 ohms under normal operating conditions. If the driver stage requires a load of 6000 ohms for optimum efficiency, what means can be used to secure optimum power transfer with capacitive coupling? If the operating frequency is 7 Mc., what values of coupling capacitance will be satisfactory?

18) If the amplifier of Question 17 is link-coupled to the driver stage, and a Q of 10 is necessary in both the driver plate tank circuit and amplifier grid tank circuit to assure sufficient coupling, what values of inductance and capacitance should be used in each circuit?

ASSIGNMENT 18

Study *Handbook* sections on r.f. power-amplifier and frequency-multiplier operation. Perform Exp. 30.

Questions

1) Of what order of value is the optimum Q (with load) of a plate tank circuit constructed in accordance with good design principles? Why is it necessary to set a lower limit for Q?

2) Given a fixed value of load resistance, how may the Q of a tank circuit be adjusted to a desired value?

3) Of what order is the plate efficiency of a properly operated r.f. amplifier? Is this the same as the ratio of actual useful power output to d.c. input?

4) How may the load on an r.f. power amplifier be adjusted?

5) A Class-C amplifier is operating on 3600 kc. with a plate input of 120 milliamperes at 750 volts. What tank capacitance should be used for a Q of 12 if the plate circuit is single-ended? What capacitance is necessary if the circuit is balanced and uses a split-stator or balanced tank capacitor?

6) A push-pull amplifier operating on 7200 kc. is loaded so that the plate current is 250 ma. The applied plate voltage is 1500. What value of inductance should be used in the tank circuit if the Q of the circuit is to be 12?

7) Describe the behavior of plate current with plate tank tuning of a Class-C amplifier.

8) Why is the plate current of a Class-C amplifier least when the plate tank circuit is tuned to resonance with the frequency of the r.f. grid voltage? Why is the plate dissipation also minimum at this point?

9) On coupling an antenna circuit to a Class-C amplifier it is found that it is necessary to retune the plate tank circuit. What is the cause?

10) Why is it necessary to supply more driving power to a Class-C amplifier than that actually consumed in heating the grid?

11) What is the purpose of a dummy antenna? Describe a circuit arrangement suitable for the purpose.

12) Why do you think it desirable that an r.f. power amplifier initially be tuned up with low plate voltage?

13) If the plate current of a Class-C stage rises continually after a period of steady operation, what is the likely cause?

14) In what way does a frequency multiplier differ from a straight-through amplifier?

15) Why is frequency multiplication necessary in high-frequency transmitters?

16) Why is the frequency doubler the most common type of frequency multiplier?

17) Can a push-pull circuit be used satisfactorily for frequency doubling?

18) How do the operating conditions for frequency doubling compare with those for straight amplification?

19) What is a parasitic oscillation? Why is such an oscillation undesirable?

20) Describe two forms of parasitic oscillations and the means for suppressing each type.

21) Explain how you would go about testing an amplifier for parasitic oscillations. How could a parasitic be distinguished from oscillation resulting from improper neutralization of a triode amplifier or insufficient screening in the case of a screen-grid amplifier?

EXPERIMENT 27

Crystal-Oscillator Operation

Apparatus: The power supply, vacuum-tube voltmeter, test instrument and crystal oscillator are used in this experiment. The circuit arrangement is shown in Fig. 1. The plate voltage for both oscillator and v.t.v.m. is taken from the 150-volt regulated tap in the power supply. The pushbutton on the tube chassis can be used to close the plate-supply circuit of the oscillator when the milliammeter is used with the v.t.v.m., in case the test set is used for all current measurements.

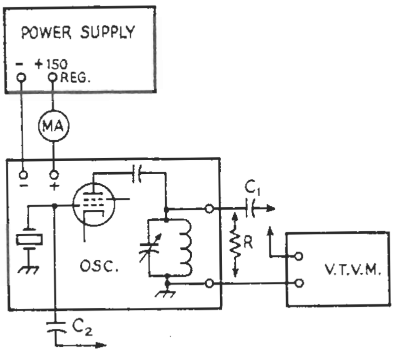


Fig. 1

The v.t. voltmeter is coupled to the output circuit of the oscillator through a small capacitor, C_1, as shown in Fig. 1, or to the grid of the oscillator tube through a second capacitor, C_2. (Complete oscillator connections are not shown; only the parts of the circuit to which the v.t.v.m. should be coupled are indicated.) These capacitors must be adjusted so that the v.t.v.m. reads half to full scale on the medium range. It will be convenient to use a 30-pf. trimmer for C_1. The same type of capacitor can also be used at C_2, although a fixed capacitor of about 5 pf. can be substituted.

Procedure: The object of this experiment is to determine the operating characteristics of a crystal oscillator with respect to plate current, r.f. grid voltage and r.f. output voltage. While the actual r.f. voltages cannot be determined accurately with the simple equipment available, the relative voltage in either the plate or grid circuit of the oscillator can be determined with sufficient accuracy for the purpose. The d.c. calibration of the v.t.v.m. may be used. The setting of the plate tank capacitor of the oscillator is used as an arbitrary reference in the experiment. If the oscillator does not already have a tuning dial which can be read to a division or so on a 100-division scale, such a dial or scale should be provided.

Using the 6F6 in the oscillator, connect the v.t.v.m. to the plate circuit and set the oscillator in operation. Adjust C_1 to give a suitable reading near full scale on the medium range of the voltmeter. Starting with the oscillator tank capacitor at maximum, reduce the capacitance until the oscillator just starts, as indicated by a reading on the v.t.v.m. (a receiver may be used for monitoring the oscillator signal) and take voltmeter readings as the capacitance is decreased to minimum. In the region immediately after oscillations begin it will be necessary to take readings at quite small intervals of capacitance in order to get enough points to plot a smooth curve. Take care not to disturb the leads to the v.t.v.m. once the run is started, because variable stray pick-up will make the readings inconsistent. If a second milliammeter is available, take simultaneous readings of plate current; if not, the procedure may be repeated for the plate-current readings, leaving the v.t.v.m. connected to the plate circuit.

When these data have been taken, the v.t.v.m. should be connected to the grid of the oscillator and C_2 adjusted, if necessary, to give a maximum reading between half and full scale. Observe the dial setting at which oscillations start, and if it differs from that noted previously, connect C_1 across the tank circuit and adjust it to make oscillations begin at the same tank capacitor setting. This compensates for the capacitance of the v.t.v.m. tube which was shunted across the circuit in the first run. Repeat the run, taking readings of the r.f. grid voltage. When this is completed, connect a 5000-ohm 1-watt resistor across the tank circuit, as shown at R in Fig. 1, and repeat the whole procedure. It may be necessary to readjust C_1 and C_2 to get suitable readings, or to shift to the low-voltage scale on the v.t.v.m. when reading the r.f. grid voltage.

To get a proper comparison between the no-

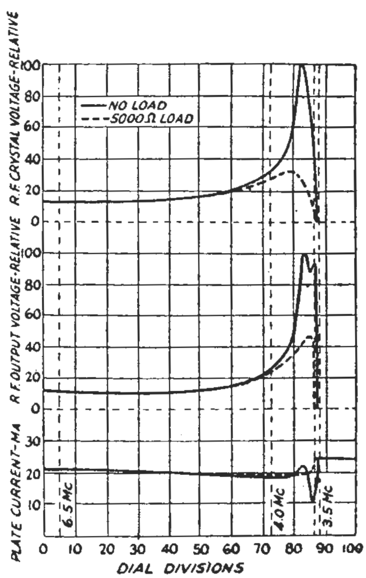


Fig. 2

load and load conditions, the following procedure is advisable: With no load on the oscillator, connect the v.t.v.m. to the grid and adjust C_2 to give a reading of half to full scale on the medium voltage range. Adjust the oscillator tuning for maximum r.f. grid voltage and note the value. Then, without moving the connecting wires, connect the load resistor to the plate tank and retune the oscillator capacitor for maximum r.f. grid voltage. The latter figure divided by the former gives the ratio of load voltage to no-load voltage. Similar readings should be taken of the r.f. plate voltage with and without load to determine the load/no-load ratio in the plate circuit.

In plotting the data the form shown in Fig. 2 is recommended. The r.f. grid voltage is plotted in terms of percentage of the maximum grid voltage observed in the no-load condition; the load data are also in terms of percentage of the maximum voltage observed, but reduced by the ratio of load to no-load voltage found as described above. The same method is used in plotting the r.f. plate voltage. The plate-current values shown are the actual values measured.

The curves of Fig. 2 give the results of experimental measurements on a 6F6 oscillator. As additional information, the vertical broken lines indicate the frequency to which the tuned circuit is resonant at that setting of the tuning capacitor. The line just to the left of the 3.5-Mc. line is the frequency of the crystal used, 3550 kc. As the tuning capacitance is continuously decreased from maximum, oscillation starts at approximately the capacitance which makes the tuned circuit resonant at the crystal frequency. The plate current immediately drops to about half its nonoscillating value, goes through a minimum and then rises again to a maximum. This is followed by a relatively small decrease to a broad minimum and then a slow rise. Oscillation continues throughout the remainder of the capacitor range, so that the nonoscillating value of plate current does not recur on the low-capacitance side of resonance. The r.f. plate voltage rises rather abruptly once oscillations start, and goes through a maximum at a capacitor setting somewhat below actual resonance in the plate circuit. The r.f. grid-voltage curve is similar, but reaches its maximum at a still lower setting of the capacitor.

This behavior is the result of the necessity for adjusting the tank circuit tuning to maintain the proper phase relationship between the feedback voltage in the grid circuit and the generated r.f. voltage in the plate circuit. This requires that the plate circuit show inductive reactance; that is, the plate circuit must be tuned slightly to the high-frequency side of resonance with the crystal frequency. The tank-circuit impedance decreases as the circuit is detuned. The plate current is lowest near resonance, where the tank impedance is highest, and there is also a small maximum in the r.f. plate voltage at this point. However, this tuning condition is not that which gives strongest oscillation. With slightly lower capacitance the r.f. plate voltage reaches a peak, but the tank is detuned and its impedance decreases, hence the plate current rises. Further detuning gives the phase relationship which results in maximum feedback, as shown by the peak of r.f. grid voltage, but there is some decrease in actual output at this point because the tank circuit is now detuned still farther from resonance. The peak of r.f. grid voltage is accompanied by a maximum in the d.c. plate current, corresponding to high grid excitation with a detuned tank circuit. With further detuning the feedback decreases, causing the plate current to drop once more, while the r.f. output (plate) voltage drops rapidly because the tank circuit is no longer near resonance. There is relatively little change in the three quantities when the tank circuit is considerably off resonance and the oscillations are weak. The net operation is thus the result of several conflicting factors, since there is no one setting of the tank capacitor which will give, simultaneously, maximum output, maximum feedback voltage, and minimum plate current.

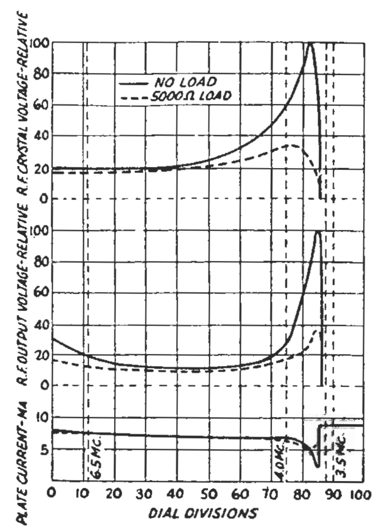


Fig. 3

When the oscillator is loaded, oscillations commence at a slightly lower capacitor setting than in the unloaded case; that is more feedback is needed to cause oscillations to begin. Since the impedance of the loaded tank is lower than in the case without load, the minimum plate current is considerably higher than without load. Thus the d.c. plate input to the tubes rises as the power consumption in the tank and load increases. For the same reason the r.f. plate and grid voltages are lower than in the unloaded case, and the maxima are fairly broad as compared to the solid curves. This shows the result of lowering the Q of the tank circuit by loading; the selectivity of the tank is decreased to such an extent that the sharp humps are smoothed down, and the double-hump effects observed in the case of the plate current and the r.f. plate voltage disappear completely. With these modifications, the operation is similar to that without load.

To compare the operation of a triode with that of the pentode, substitute a 6J5 for the 6F6 (the 6J5 will fit in the same socket and no circuit changes are necessary) and repeat the procedure described above for the pentode. Plot a second set of curves in the same manner. A typical set for a 6J5 is shown in Fig. 3. Note that the double-hump effects are not present with this tube in the unloaded case; this is because the effective Q of the tank circuit is lower since it is shunted by the comparatively low plate resistance of the triode, whereas the plate resistance of the pentode is so high that the selectivity of the tank circuit is affected very little. The no-load curves for the triode resemble in shape, although not in amplitude, the load curves for the pentode. The effect of loading is similar in both cases. Once the oscillator tuning is well on the high-frequency side of resonance the voltages and currents are about the same with or without load, illustrating that the effect of loading a tuned circuit is largely confined to the region near resonance.

Near minimum on the tuning capacitor scale the r.f. output voltage rises, although neither the plate current nor r.f. grid voltage show any particular change. The reason for this is that the plate circuit is nearing resonance at the second harmonic of the crystal frequency, with the result that the impedance for the second-harmonic component of the plate current is increasing, hence a larger voltage appears across the tank circuit. The effect is also present, although not so marked, in the pentode curve for r.f. plate voltage.

EXPERIMENT 28

Interstage Coupling

Apparatus: This experiment requires the crystal oscillator, power supply, bias supply, tube chassis and test instrument. The circuit arrangement is shown in Fig. 4. Power for the oscillator is taken from the 150-volt regulated tap on the power supply so that the plate voltage will stay constant as the r.f. power taken from the oscillator is varied. (Should the regulator tube cease to glow at any time during the experiment, the dropping resistor in the power supply in series with the 0D3/VR150 should be decreased in value until the tube glows under all conditions. The 10,000-ohm resistor recommended in Fig. 6, page 29, Part 3, may be shunted by a 15,000-ohm unit to accomplish this.)

The coil L is the movable coil from the circuit board. C_1 is a small fixed mica capacitor; a capacitance of 100 pf. is satisfactory, but larger values may be used without affecting the results of the

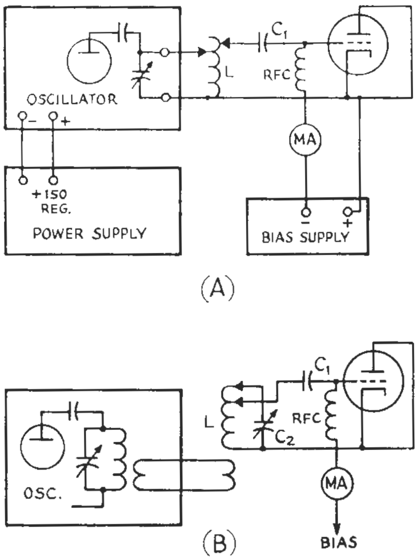


Fig. 4

experiment. RFC is a 2.5-millihenry choke coil and C_2 is one of the tuning capacitors (250 pf.) on the circuit board. The tube used in the experiment should be a 6J5 or 6C5.

Procedure: Capacitive coupling may be checked by means of the set-up shown in Fig. 4-A. The plug-in tank coil is removed from the oscillator and the coil L is connected across the tank capacitor in its place, using a clip connection at the ungrounded end so that the number of turns can be varied. The coil is set up on the tube chassis near the tube socket and connected to the tube as shown. The plate of the tube is connected to the cathode to prevent its acquiring a charge by collecting stray electrons. The bias should be adjusted to about 50 volts.

Connect the two clips to the end of the coil, putting all 35 turns in circuit, and rotate the oscillator tank capacitor to obtain oscillation. It will be helpful to monitor the oscillator by a receiver set to the crystal frequency. The shunting capacitance of the tube, together with the large inductance, may make it impossible to set the circuit to resonance with the crystal, so if oscillation does not take place move the taps down to 30 turns and try again. Using the equipment previously described, 30 turns was the maximum number permissible with this circuit and a crystal having a frequency of about 3550 kc. When the largest usable value of inductance has been found, leave the oscillator plate tap set and take grid-current readings as the grid clip is moved down one tap at a time. Each time the tap is changed, readjust the oscillator plate capacitor to obtain maximum grid current. Then move the oscillator plate clip down one tap (5 turns) toward the ground or cathode end of the coil and repeat, starting at the end of the coil with the grid tap. Move the plate tap down another 5 turns and repeat, continuing in this way until the plate tap is carried down at least to the 15th turn from the bottom end of the coil. The data so obtained may then be plotted in the form of curves showing the relationship between rectified grid current and number of turns included in the grid circuit of the tube.

A typical set of such curves, taken with a 6J5, is shown in Fig. 5. The number on each curve indicates the number of turns in use in the oscillator plate circuit.

Note that maximum output (maximum rectified grid current) is obtained when the grid tap includes fewer turns than are in use in the oscillator plate circuit. If the curves are inspected carefully it will be found that maximum current occurs when the grid circuit has approximately 70 per cent as many turns as the oscillator plate circuit, in each case. This indicates that the load represented by the grid-cathode circuit of the 6J5 has a lower value of resistance than the value required by the oscillator tube for maximum output. The tapped coil is thus used as an autotransformer for the purpose of transforming the actual load resistance into the value required by the tube. Since practically the same turns ratio is required in each case the operation is evidently quite independent of the constants of the tuned circuit. Actually, the maximum rectified current

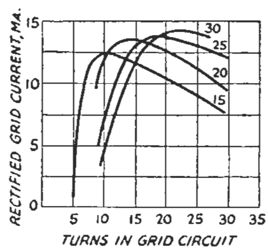


Fig. 5

obtainable decreases as the number of turns in the plate circuit of the oscillator is made smaller. This is because the decreasing L/C ratio is accompanied by an increase in the r.f. current circulating in the tank (the Q of the loaded circuit is raised) causing the internal losses of the tank circuit to increase. Hence a somewhat smaller proportion of the power developed by the oscillator tube is available for the load. If the L/C ratio could be decreased without increasing the tank losses the output current would be the same in each case. In the experimental set-up some of the loss undoubtedly is "dead-end" loss in the unused turns of the coil, caused by current circulating through the distributed capacitance of the unused turns.

The effect of a change in load impedance can be observed by changing the bias on the tube and following the experimental procedure just described. As the bias is increased the impedance of the grid-cathode circuit increases, since a considerably larger r.f. grid voltage must be applied to overcome the bias and cause the same or less grid current to flow. The curves of Fig. 6 show the results of such a run, using four different values

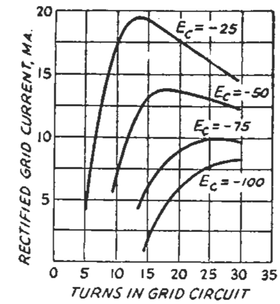


Fig. 6

of negative grid bias, 25, 50, 75 and 100 volts. In all four cases the oscillator plate was tapped on the coil at the 25th turn. At the highest bias, 100 volts, the grid current is just reaching maximum with 30 turns in the grid circuit; that is, a step-up impedance ratio is required, showing that the grid impedance is higher than the value required by the oscillator tube for maximum output. With 75 volts bias the maximum current is secured with the same number of turns in the grid circuit as in the plate circuit. The curve for $E_C = -50$ is simply a repetition of the corresponding curve in Fig. 5. With -25 volts bias the grid circuit must be tapped across approximately half the number of turns used in the plate circuit, indicating that the impedance has decreased very considerably. The resistance (or impedance) of the grid circuit therefore depends not only on the characteristics of the tube but also on the conditions under which it is operated. If the tube had been actually operating as an amplifier, still different conditions would obtain and the curves would show maximum points at different turns ratios than those indicated. In such a case the effect of the plate voltage would be to attract some of the electrons which in the experimental set-up are drawn to the grid, and this would tend to reduce the grid current and thus raise the grid impedance, since less current would flow for the same applied r.f. grid voltage.

In the second part of the experiment link coupling is investigated. The circuit arrangement is shown in Fig. 4-B. The regular plug-in tank coil is returned to the oscillator circuit, and is provided with an output link winding of three turns or so wound close to the "ground" end of the coil. The coil L is connected to C_2, one of the variable capacitors on the circuit board, as shown. As a preliminary experiment, wind about 10 turns at the ground end of L, and connect C_2 and the grid tap to the other end of the coil so that the full 35 turns is used. Using about 50 volts bias, adjust

C_2 and the oscillator tank capacitor for maximum rectified grid current. There may be some interaction between the two capacitors, so "rock" C_2 back and forth while adjusting the oscillator tank capacitor until it is certain that maximum output is secured. Take one turn off the link and again adjust for maximum grid current; continue in this way until only one link turn is left. The result of such an experimental procedure is shown in Fig. 7, where the number of link turns on L is plotted against grid current in terms of percentage of the maximum current obtainable. Note that there is a broad maximum to the curve, the output showing negligible variation with links having from 2 to 5 turns. The value for one turn

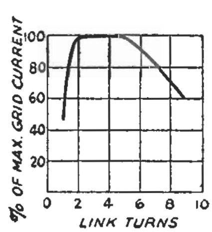


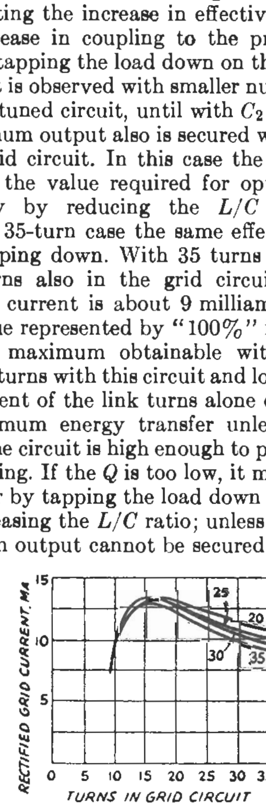
Fig. 7

is probably low, since the turn was not held very tightly to the coil form. Obviously the number of turns is not critical. The maximum output is in the region where the link coil has enough turns to give a sufficiently high coefficient of coupling without having enough reactance to limit the flow of r.f. current in the link circuit.

Using a link of about three turns on L, set the tap from C_2 at the end of the coil (35 turns) and tap the grid on the same spot. Adjust C_2 and the oscillator plate capacitor for maximum grid current, then move the grid clip down one tap (30 turns) and again adjust the two capacitors for maximum grid current. Continue moving the grid clip down the coil. As the tap approaches the bottom end the loading on the oscillator increases and may cause the oscillator to stop. The best procedure is to keep the oscillator tank capacitor well on the low-capacitance side of resonance, then rock C_2 back and forth through resonance while carefully increasing the oscillator capacitor setting until it is set just below the point where oscillation ceases when C_2 goes through resonance. (Monitoring the oscillator in a receiver will be helpful.) This point usually will result in maximum output. When the run is completed, move the clip from C_2 down one tap and repeat. Continue until the tap from C_2 has been moved down to the 15th or 20th turn. Plot the data in the same way as in the case of capacitive coupling.

A set of experimental data so obtained is shown graphically in Fig. 8. The tube and grid bias were the same as in Fig. 5. There is quite a marked difference between these curves and those of Fig. 5, showing that more than simple autotransformer action is involved. Maximum grid current is secured with approximately the same number of turns between grid and cathode in all four cases shown (the numbers on the curves indicate the number of turns across which C_2 is connected). This is because in the link-coupled case — link coupling is equivalent to inductive coupling — the coupling depends very largely on the effective Q of the secondary circuit, the constants of the primary circuit being fixed. With a fixed value of load resistance, represented by the grid circuit of the tube, the Q of the circuit depends on the L/C ratio and/or the ratio of turns in the tuned circuit to turns in the load (grid-cathode) circuit. Using 35 turns in the tuned circuit, maximum output is secured with about 15 turns in the grid or load circuit, illustrating the increase in effective Q — and hence increase in coupling to the primary — afforded by tapping the load down on the coil. A similar effect is observed with smaller numbers of turns in the tuned circuit, until with C_2 across 20 turns maximum output also is secured with 20 turns in the grid circuit. In this case the Q has been raised to the value required for optimum coupling solely by reducing the L/C ratio, whereas in the 35-turn case the same effect was secured by tapping down. With 35 turns across C_2 and 35 turns also in the grid circuit, the maximum grid current is about 9 milliamperes. This is the value represented by "100%" in Fig. 7, and is the maximum obtainable with *any* number of link turns with this circuit and loading. Hence adjustment of the link turns alone cannot result in maximum energy transfer unless the effective Q of the circuit is high enough to provide optimum coupling. If the Q is too low, it must be increased either by tapping the load down on the coil or by decreasing the L/C ratio; unless this is done, maximum output cannot be secured.

Fig. 8



Note that the maximum grid current obtainable with link coupling is less than with capacitive coupling. The difference is attributable to the additional losses in the second tuned circuit used in link coupling. Other considerations, such as the effect of too-high shunt capacitance, may result in a reversal of this situation at higher frequencies, but at the frequency used in this experiment (3550 kc.) these effects are negligible.

EXPERIMENT 29

Neutralizing an Amplifier

Apparatus: The set-up for this experiment is shown in Fig. 9. Equipment required includes the

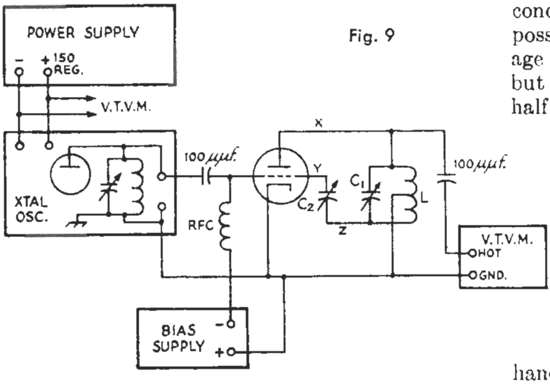


Fig. 9

power supply, bias supply, crystal oscillator, vacuum-tube voltmeter, tube chassis, circuit board, and test instrument. The tube used is a 6J5 or similar small triode. The coil L is the fixed coil on the circuit board and capacitor C_1 is the variable capacitor associated with that coil. C_1 should be connected across 30 turns of L, with the tap to ground placed at the 15th turn on the coil. C_2 is the smaller capacitor (25 to 50 pf. maximum capacity) on the circuit board. The 100-pf. capacitors are small fixed mica units. *RFC* is a 2.5-millihenry r.f. choke.

The connections X, Y and Z preferably should be flexible leads with clips at both ends so that they can be connected and disconnected conveniently. The crystal-oscillator plate voltage can be taken from the 150-volt regulated tap on the plate power supply. The bias on the tube under test should be set to about 75 volts.

Procedure: This experiment is an exercise in neutralizing an r.f. amplifier. Connect the circuit as shown, omitting for the moment the leads X, Y and Z. Set the crystal oscillator in operation and, with the tuned circuit LC_1 in about the position it will occupy (near the tube), tune C_1 for maximum deflection on the v.t. voltmeter. If the deflection is more than a flicker on the low range, move the tuned circuit as far as possible from the oscillator, while still keeping within reasonable distance of the tube so that long connecting leads will not be necessary. It should be possible to get the v.t.v.m. reading down to less than 1 volt without much difficulty. When this has been done, connect the leads X, Y and Z, set C_2 to minimum capacitance, put the v.t.v.m. on the high range, and adjust C_1 for maximum v.t.v.m. deflection. Increase the capacitance of C_2 slightly and again tune C_1 for maximum deflection. Continue this process, observing that the deflection decreases as the capacitance of C_2 increases, until a point is reached where an increase in capacitance causes the deflection to increase again. The setting of C_2 which gives minimum output voltage is that at which the tube is neutralized as well as the circuit conditions will permit. In most cases it will not be possible to adjust the circuit so that the r.f. voltage disappears completely from the plate circuit, but it should be possible to get it down to around half scale on the low range of the v.t.v.m.

It will be observed that hand-capacitance effects are quite evident in adjusting both capacitors. This is partly because the hand adds a small amount of capacitance which detunes the circuit, since the shafts of both capacitors are above ground for r.f., and partly because the body picks up some r.f. voltage from the oscillator and couples it to the circuit when the hand is brought near either capacitor. This effect can be eliminated by dispensing with the ordinary tuning knobs and, instead, sawing slots in the ends of the capacitor shafts, the capacitors then being turned by means of an 8- or 10-inch length of wooden rod (any other insulating material will do) cut at one end to fit the slots.

Connect the test instrument as a milliammeter in series with the grid-bias lead to the amplifier and repeat the experiment, using grid current as a neutralizing indicator. Disconnect the v.t.v.m. in this case. Adjust the neutralizing capacitor, C_2, so that there is least change in rectified grid current as C_1 is tuned through resonance. It should be possible to neutralize well enough so that there is the barest flicker, or none at all, in grid current. How does this method compare in sensitivity with the v.t.v.m. method?

EXPERIMENT 30

Class-C Amplifier Operation

Apparatus: This experiment uses the apparatus set-up shown in Fig. 10. It resembles quite closely the circuit used in the preceding experiment except that provision is made for applying plate voltage to the amplifier tube and for connecting a load resistance in the plate circuit. The 0.001-μf. blocking capacitor in the plate circuit replaces the direct ground used in Exp. 29; this is necessary to prevent short-circuiting the plate-supply voltage. The crystal oscillator again gets its plate power from the 150-volt regulated tap on the power supply.

Procedure: The object of this experiment is to observe the behavior of a Class-C amplifier under different load conditions. A small tube such as a 6J5 will be suitable. Set the variable resistor on the power supply so that only the bleeder current flows through it (arm to the left end in Fig. 6, page 29, Part 3) since the current drawn will exceed a safe value for this resistor. The plate voltage for the amplifier may be adjusted to a suitable value by tapping the output clip on the divider at a point which gives 250 to 300 volts.

With the amplifier plate-voltage tap disconnected, neutralize the amplifier by the grid-current method described in the preceding experiment. Set the bias at 30 volts so that the tube is biased well beyond the cutoff point for that plate voltage. With the 6J5 cutoff bias is approximately 15 volts, neglecting the "tailing-off" effect associated with the change in amplification factor near the cutoff point (see Exp. 22). Although the plate current may not actually reach zero until the bias is 20 volts or more, the plate current in the region between the cutoff bias calculated on the assumption that the amplification factor is constant (E_b/μ, in this case 300/20) and the actual cutoff point is so small that its influence on the operation of the tube as a Class-C amplifier is practically negligible. Adjust the oscillator tuning so that the grid current is approximately 10 milliamperes with no plate voltage on the amplifier.

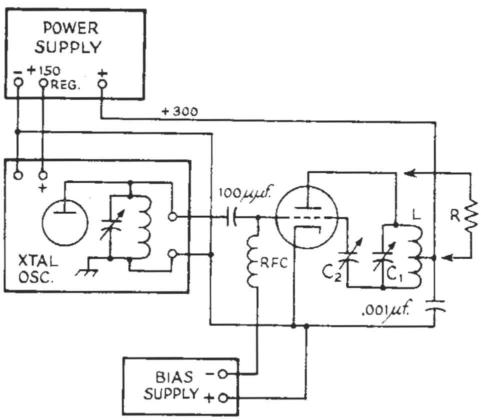


Fig. 10

After neutralization, apply plate voltage and measure the amplifier plate current. If the tank circuit is not set at resonance with the crystal-oscillator frequency the plate current probably will be in the vicinity of 30 milliamperes. Carefully tune the amplifier tank circuit, observing that at resonance the plate current drops to a comparatively low value — well below 10 milliamperes. The resonance point should be quite sharp. The plate current is minimum at resonance because at this point the impedance of the tank circuit is highest to r.f. current of the frequency generated by the crystal oscillator, and tuning to resonance is equivalent to connecting a high value of load resistance in series with the amplifier plate circuit. Hence there is a large r.f. voltage drop in the tank circuit and the average voltage acting to cause plate current to flow is reduced. The d.c. plate current is likewise reduced. When the tank circuit is off resonance its impedance to the crystal frequency is low and the r.f. voltage drop is negligible, hence practically the full d.c. plate voltage is continuously applied to the tube and the plate current is high. It is higher than in Class-A applications because the r.f. grid voltage drives the grid considerably positive with respect to the cathode over a part of the r.f. cycle. The variation in r.f. tank voltage can be observed by touching a neon bulb to one side of the tank capacitor. The bulb will glow brightly when the tank is tuned to resonance but goes out when the capacitor is detuned.

Note also that the grid current drops when the plate voltage is applied to the amplifier. When there is plate voltage on the tube some of the electrons which formerly were attracted to the grid go to the plate instead. The number thus diverted depends upon the effective plate voltage, which in turn depends upon the tuning of the tank circuit for the reasons mentioned above. With the tank circuit tuned to resonance the drop in grid current is slight, but if the tank is detuned the grid current may drop to as little as half its value with the plate voltage off.

Connect a 25,000-ohm 1-watt resistor between the plate of the tube and the positive plate voltage lead as shown at R in Fig. 10. Apply plate voltage and observe the plate current as the plate tank circuit is tuned through resonance, leaving the excitation the same as before — that is, adjusted to give a rectified grid current of about 10 ma. with no plate voltage on the amplifier. In this case the resonance point will not be quite as sharp and the minimum plate current will be higher than without load. Note that the off-resonance plate current is the same as before, showing that the off-resonance impedance of the tank circuit is so low that the presence of the load resistor does not affect it At resonance, however, the tank impedance is reduced by the load resistor and the r.f. voltage drop consequently is less. Hence the average plate voltage causing plate current flow is higher and the plate current also is higher. The grid current also shows a greater drop, at resonance, with the load resistor connected, because the effective plate voltage is higher and more electrons are diverted from the grid to the plate.

The same procedure should be followed with 10,000- and 5000-ohm 1-watt resistors as loads, when it will be found that the greater the loading, i.e., the lower the load resistance, the higher the plate current and the lower the grid current. As the load resistance progressively decreases the tank impedance also decreases, resulting in a lower r.f. voltage drop and consequently higher average plate voltage during the part of the cycle when plate current flows. If the tank circuit is detuned off resonance, however, the presence of the load resistor has relatively little effect on the impedance and the off-resonance conditions are practically the same regardless of load resistance.

Observations on Class-C amplifiers can be carried farther by using the v.t. voltmeter to measure the r.f. output voltage. For this purpose the voltmeter may be connected to the plate circuit as shown in Fig. 9, using a very small value of coupling capacitance so that the indication will come on the medium range of the v.t.v.m If care is taken not to disturb the v.t.v.m. position or leads when changing load resistors, the relative variation of r.f. tank voltage with changes in load can be measured. It is also of interest, with a fixed value of load resistance, to measure the variation in r.f. tank or output voltage as the excitation is changed; the rectified grid current can be used as a measure of the excitation. Since power output is proportional to the square of the radio-frequency output voltage, a series of such observations can be plotted in terms of relative power output *versus* grid current, for a fixed load resistance and grid bias.

Part Six

MODULATION AND KEYING

THIS section deals with various methods for modulating a radio-frequency carrier. The experimental work consists of determining the modulation characteristics of r.f. amplifiers, using the point-by-point method, under different conditions of operation. The influence of various factors on the linearity of a modulated amplifier is the chief subject investigated.

Contrary to what might be anticipated, the experiments outlined do not involve actual modulation of a carrier. Unless an oscilloscope is available for depicting actual operation with modulation, the use of a modulating signal would add comparatively little to the instructional value of the experiments. Those who do have an oscilloscope and an audio amplifier suitable for modulating the experimental amplifiers can, of course, extend the work. The obvious direction for such an extension to take is in comparing oscilloscope patterns with the performance curves obtained as described in the experiments.

ASSIGNMENT 19

Study *Handbook* sections on modulation principles and plate modulation. Perform Exps. 31 and 32.

Questions

1) What is meant by the term "modulation"?

2) What is the function of the microphone in a radiotelephone system?

3) Name the three fundamental methods of modulating a radio-frequency current.

4) What is the "carrier"?

5) In present-day practice, what requirements must be met by the carrier in radiotelephone transmission on communication frequencies?

6) Why is a "buffer" amplifier necessary?

7) Define percentage of modulation.

8) What is meant by "linearity" of a modulated amplifier?

9) Define modulation capability.

10) An unmodulated carrier produces a current of 2.5 amperes in an antenna system. When modulation is applied it is found that the maximum instantaneous amplitude of the current is 4.3 amperes. What is the percentage of modulation, assuming that the modulated amplifier is linear?

11) What is the ratio of average power in a 100 per cent amplitude-modulated wave to the power in the carrier alone, assuming sinusoidal modulation?

12) What is meant by the term "modulation envelope"?

13) What are sidebands?

14) If the modulation applied to a carrier is unsymmetrical, how should the modulation percentage be computed?

15) Describe overmodulation. Why should overmodulation be avoided?

16) A 3900-kc. carrier is modulated by a sinusoidal signal having a frequency of 1600 cycles. What are the sideband frequencies?

17) The audio-frequency output of the modulator of a certain radiotelephone transmitter contains substantially no audio frequencies higher than 4200 cycles. With channel width is required for the modulated output of the transmitter?

18) A transmitter is modulated by a 1000-cycle tone which has pronounced harmonics up to the fifth. If the carrier frequency is 28,650 kc., what are the frequency limits of the channel occupied by the signal?

19) What are spurious sidebands?

20) Name three systems used for amplitude modulation.

21) What is the average ratio of power in speech waveforms to power in a sine wave? How does this affect the required power capacity of the modulator, when plate modulation is used?

22) Define modulating impedance of a Class-C plate-modulated amplifier.

23) A Class-C amplifier is operating at a plate voltage of 2000 and is adjusted so that the plate current is 150 milliamperes. How much audio power is required for plate modulation of the amplifier, for a modulation percentage of 100, assuming that the modulating signal is sinusoidal?

24) What is the modulating impedance of the amplifier in Question 23?

25) Draw a circuit diagram showing plate modulation of a neutralized-triode Class-C amplifier.

26) An amplifier having an audio-frequency power output of 130 watts is available for plate-modulating a transmitter If the modulation is to be 100 per cent, what is the maximum possible power input to the Class-C modulated amplifier?

27) How can the power input to a Class-C plate-modulated amplifier be adjusted to the proper value for 100 per cent modulation?

28) How may plate modulation be applied to a tetrode or pentode Class-C amplifier? Draw a circuit diagram.

29) Describe the method of using choke coupling between the modulator and modulated amplifier. Why is this system seldom used?

30) Does the d.c. plate current of a properly operating Class-C amplifier change when the amplifier is plate-modulated? Why?

31) A screen-grid Class-C plate-modulated amplifier operates under the following conditions; plate voltage, 2500 volts; plate current, 125 ma.; screen voltage, 400 volts; screen current, 30 ma. If the screen current is to be taken from the plate supply, what value of screen dropping resistor is required, and what is the modulating impedance of the amplifier? How much audio power is necessary for 100 per cent modulation?

32) Why is it necessary to neutralize a triode amplifier as completely as possible when the amplifier is to be modulated?

33) Describe the general operating conditions necessary if a Class-C amplifier is to have a linear modulation characteristic.

ASSIGNMENT 20

Study *Handbook* sections on grid modulation and cathode modulation. Perform Exp. 33.

Questions

1) What are the advantages and disadvantages of grid modulation as compared with plate modulation?

2) Describe the essential principles of grid modulation.

3) Why should the source of fixed bias used with a grid-bias modulated amplifier have low internal resistance?

4) A tube having a rated plate dissipation of 80 watts is to be used as a grid-modulated amplifier. What is the approximate carrier power output obtainable? How much power could be secured from the same tube if plate modulation were used?

5) In a grid-modulated amplifier, what is the effect of linearity of adjusting for too-high carrier efficiency?

6) Draw a circuit diagram of a Class-C amplifier arrange for screen modulation.

7) Describe the operating principles of suppressor-grid modulation. How does this method compare with grid modulation?

8) Why is it necessary that the r.f. stage driving a control-grid-modulated amplifier have good output-voltage regulation? How can good regulation be secured?

9) Describe a method of adjusting a grid-modulated amplifier for proper operating conditions.

10) Why should the d.c. plate current of a properly operated grid-modulated amplifier be constant under modulation? What is the permissible tolerance in this respect? Is constant plate current a certain indication that the amplifier is operating linearly?

11) What is the effect of load resistance on the carrier power output obtainable from a grid-modulated amplifier, assuming that the amplifier is adjusted for linear operation?

12) What is the effect of excitation voltage on the linearity of a grid-modulated amplifier, assuming that load resistance, d.c. grid voltage, etc., are fixed?

13) Explain the operating principles of cathode modulation.

14) Two tubes each having a plate dissipation rating of 60 watts are to be used in push-pull as a cathode-modulated amplifier. If a modulator having an audio-frequency power output of 80 watts is available, what is the maximum carrier output power obtainable if the modulation percentage is to be 100 per cent? If the plate voltage on the modulated amplifier is 1500, what is the modulating impedance?

15) How should a cathode-modulated amplifier be adjusted for linear operation?

ASSIGNMENT 21

Study *Handbook* sections on speech amplifiers and modulators.

Questions

1) Why is a Class-B type audio amplifier generally used for plate modulation of a Class-C amplifier?

2) Why is it necessary to have good regulation of the output voltage of the stage driving a Class-B amplifier?

3) What design precaution should be taken to ensure good output voltage regulation of the driver stage?

4) A Class-C amplifier taking a plate current of 180 ma. at a plate voltage of 1250 is to be plate-modulated. How much audio-frequency power is required? If the Class-B modulator requires a plate-to-plate load of 10,000 ohms, what is the proper turns ratio of the coupling transformer, assuming that the transformer losses are negligible?

5) Why is it necessary to use a voltage source having low internal resistance to supply grid bias for a Class-B amplifier?

6) Is it safe to operate a Class-B modulator without load?

7) What is the result of overdriving a Class-B modulator?

8) What requirements should be met by the plate supply for a Class-B modulator?

9) What is meant by the terms "sensitivity" and "frequency response" when used in connection with microphones?

10) Describe the principle of operation of four types of microphones and show suitable circuits for connecting them to an amplifier.

11) About what order of output voltage can be expected from a crystal microphone under normal conditions — that is, speech of average intensity — and from single-button carbon, double-button carbon, and velocity microphones, when provided with appropriate coupling transformers?

12) What is meant by "stage gain"?

13) What is the general function of a speech amplifier in a modulation system?

14) Why is resistance coupling generally used in voltage-amplifier stages? Under what conditions is resistance coupling inapplicable?

15) What determines the response characteristic of a resistance-coupled amplifier? Over what frequency range is it necessary to have "flat" amplification for satisfactory speech transmission?

16) What is a decoupling circuit, and why is it used?

17) What considerations determine the point in the circuit at which the gain control is placed?

18) An amplifier is to deliver an audio power output of 2 watts when excited by a crystal microphone having a peak output voltage of 0.02 volt with normal speech. Using the tube characteristic tables and the table of resistance-coupled voltage-amplifier data in the *Handbook*, select a suitable tube line-up and draw a circuit diagram, marking proper values on the components. Indicate proper plate voltages on the circuit diagram.

19) Describe the operation of a phase inverter. For what purpose is such a circuit used?

20) What precautions should be taken to minimize hum in a speech amplifier?

ASSIGNMENT 22

Study *Handbook* section on checking phone-transmitter operation. If an oscilloscope is available, use it in conjunction with Exps. 31, 32 and 33, making connections as described in the *Handbook*. Compare the oscilloscope patterns with the data obtained by measurement and plotted graphically. A suitable modulating voltage must be available for this purpose; 60-cycle a.c. will be quite satisfactory if the voltage can be adjusted to the proper value. A transformer having suitable turns ratio should be used between the modulated amplifier and the 115-volt a.c. line.

Questions

1) What is the difference between the "wave-envelope" and "trapezoidal" patterns used in checking modulation?

2) What connections are necessary between the transmitter and oscilloscope to obtain the wave-envelope pattern?

3) Show a method of connecting the oscilloscope and transmitter for securing a wedge pattern. What precautions are necessary in making these connections?

4) How can percentage of modulation be measured with the oscilloscope?

5) If the voice waveform is found to be unsymmetrical, what can be done in the speech amplifier to insure that "splatter," or spurious sidebands, will be minimized on occasional voice peaks which cause overmodulation?

6) Why is it frequently desirable to connect a tuned circuit to the vertical-plate terminals of the oscilloscope, coupling through a link circuit to the transmitter?

7) In using the wedge pattern, from what part of the audio system should the audio voltage for the horizontal sweep be taken?

8) How can the oscilloscope be used to check the linearity of a phone transmitter? Which type of pattern is preferable?

9) If indications of a carrier appear on the oscilloscope screen when the plate current of the modulated amplifier is completely cut off but the transmitter is otherwise operating, what are the possible causes?

10) What is the effect on the modulation pattern of the presence of a radio-frequency voltage on the horizontal plates of the oscilloscope? What can be done to prevent such a voltage from reaching the horizontal plates?

11) Describe a method of checking for spurious sidebands.

12) Name some possible causes for an upward shift in plate current with plate modulation; with grid-bias modulation.

13) If the carrier is found to have excessive hum modulation, how can the cause be localized?

14) What is the common indication of the presence of r.f. in the audio system? What precautions are necessary to prevent such r.f. pickup?

15) Name some possible causes of a downward shift in plate current with plate modulation; with grid-bias modulation.

ASSIGNMENT 23

Study *Handbook* sections on frequency-modulation principles and operation. Perform Exp. 34.

Questions

1) How does frequency modulation differ from amplitude modulation?

2) Define frequency deviation and deviation ratio.

3) In what two respects does frequency modulation have distinct advantages over amplitude modulation? What is the chief disadvantage of frequency modulation from a practical communication standpoint?

4) Why is a frequency-modulation system less sensitive to natural static and other electrical noises than an amplitude-modulation system?

5) Describe the operating principles of a simple type of reactance modulator.

6) What is meant by the "sensitivity" of the modulator?

7) A reactance modulator used in conjunction with an oscillator adjusted to a mean or carrier frequency of 3.58 megacycles is capable of causing the frequency to deviate linearly 1 kc. on either side of the carrier. If the output of the transmitter is to be in the 28-Mc. band, what is the output carrier frequency, and the output frequency deviation? What is the deviation ratio if the upper limit of audio frequencies to be transmitted is 4000 cycles?

8) What is meant by linearity of a frequency-modulation system?

9) Why is it desirable to stabilize the d.c. voltages applied to a reactance modulator and its associated oscillator?

10) An f.m. transmitter to operate on 144.8 Mc. is to have a deviation ratio of 5, based on an upper audio-frequency limit of 4000 cycles. If the oscillator and reactance modulator are to be operated in the 7-Mc. band, over what frequency range should the modulator operate linearly? What is the maximum frequency deviation required at the fundamental frequency?

11) What is the effect on the sensitivity and linearity of a reactance modulator of varying the circuit constants of the r.f. voltage divider across the oscillator tank circuit?

12) Describe a method of using a selective receiver to check frequency deviation of a reactance-modulator system.

13) What is the effect on linearity of excitation voltage and plate-circuit loading in the r.f. stages of a frequency-modulation transmitter?

14) How do the sidebands generated by frequency modulation compare with those set up in amplitude modulation?

ASSIGNMENT 24

Study *Handbook* chapter on keying.

Questions

1) What are key "clicks"? Why are key clicks undesirable?

2) What is the cause of key clicks?

3) Name three requirements which should be met by a keying system.

4) What is a "back wave"? What causes it?

5) What is meant by "break-in" operation and what are its advantages?

6) Name three methods of keying and draw simple circuit diagrams showing how each method is accomplished.

7) How does a filter circuit function in reducing key clicks? Describe a representative circuit.

8) Why is it frequently necessary to use an r.f. filter at the key?

9) Give the advantages and disadvantages of oscillator keying and amplifier keying.

10) What is a keying "chirp," and how is it caused?

11) Describe two general methods for obtaining break-in keying without keying the oscillator.

12) What are the advantages of a vacuum-tube keyer circuit as compared with ordinary keying?

EXPERIMENT 31

Plate-Modulation Characteristics of Class-C Amplifier

Apparatus: The circuit diagram for this experiment is shown in Fig. 1. Equipment required includes the power supply, bias supply, crystal oscillator, tube chassis, circuit board, vacuum-tube voltmeter, and multirange test instrument. A neutralized-amplifier circuit similar to that shown in Exp. 30 is used. The grid circuit of the amplifier is coupled through the 100-pf. fixed capacitor to the plate tank circuit of the oscillator. Bias for the amplifier is taken from the bias supply through the 2.5-millihenry r.f. choke, *RFC*. L_1 is the fixed coil on the circuit board, with 30 turns in use; the plate voltage lead is tapped on the coil at the 15th turn. C_1 is the 250-pf. capacitor on the circuit board and C_2 is the small capacitor (about 50 pf. maximum capacitance) used in this case as a neutralizing capacitor. In wiring the amplifier circuit keep the leads as short as the physical conditions permit, and use enough separation between the crystal oscillator and the amplifier tank circuit, C_1L_1, to reduce the inductive coupling between the two to a negligible amount

The v.t. voltmeter is inductively coupled to the amplifier tank circuit through the movable coil, L_2, from the circuit board. Place the coil so that it is not intimately associated with the amplifier wiring. To do this it will probably be necessary to remove it from the circuit board entirely, setting it up off the board so that it can be coupled to the

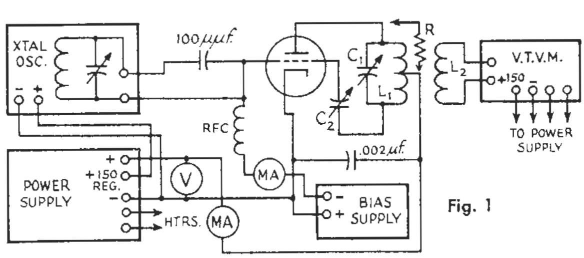


Fig. 1

outer end of L_1 (assuming that the construction illustrated in Fig. 11, page 31, Part 3, is used).

Separate milliammeters and voltmeters are shown in Fig. 1, but, as in the previous experiments, the single test kit can be used for all measurements if provision is made for closing those circuits through which current must flow — the amplifier grid-bias circuit and d.c. plate circuit — when the instrument is used elsewhere. Plate-voltage measurements should be made with the highest-range meter scale which will give reasonably precise readings — at least a 500-volt scale.

For the resistor R shown in the diagram use 1-watt composition resistors having values of 5000 and 10,000 ohms. Ordinary wire-wound resistors cannot be used. The two resistors may be connected in series to give a total resistance of 15,000 ohms. These three values will suffice for the experiment.

In using the plate power supply in this experiment, set the variable resistor (R_5, Fig. 6, page 29, Part 3) to give maximum output voltage; that is, so that none of the load current flows through it. The currents to be drawn exceed the safe ratings of the ordinary small volume-control type wire-wound resistors. Sufficient voltage variation can be secured by means of the output taps.

Procedure: The purpose of this experiment is to show, on a small scale, the effect of load resistance on the linearity of a plate-modulated Class-C amplifier. Since the output voltage of the power supply is limited to somewhat less than 400 volts, it will be assumed that this voltage is the maximum that would be applied to the Class-C amplifier at the modulation peak. The plate voltage for the carrier alone therefore will be one-half this value, or 200 volts.

As explained in the *Handbook*, the plate efficiency of a plate-modulated Class-C amplifier must remain constant throughout the modulation cycle — that is, over the complete range of plate voltage from zero to twice the carrier plate voltage — if the amplifier is to be modulated 100 per cent. To meet this condition, it is necessary that the operating angle of the amplifier be not greater than 180 degrees at the modulation peak, since the plate efficiency decreases rather rapidly when the operating angle is increased beyond 180 degrees. Therefore the grid bias must be at least the value which will give plate-current cutoff, under static conditions, at the *peak* plate voltage. This accounts for the customary rule that the grid bias for a Class-C amplifier should be "twice cutoff" at the carrier plate voltage (In practice it is more likely that the grid bias would be set to a value which gives an operating angle of 150 degrees or less under carrier conditions. This leads to a grid-bias value considerably larger than twice cutoff if the tube has a fairly high μ, but gives higher plate efficiency.) Using a 6J5 as an amplifier, the minimum grid bias required is approximately 400/20 (E_b/μ) or 20 volts. To be on the safe side a little higher bias, say 25 volts, may be used.

Set the bias to approximately 25 volts, disconnect the d.c. plate-voltage lead to the amplifier, and apply power to the crystal oscillator, using the 150-volt regulated tap as the plate supply. Neutralize the amplifier circuit by one of the procedures described in Exp. 29, having first adjusted the oscillator output (by means of the oscillator tank capacitor) to give an amplifier grid current between 5 and 10 milliamperes. Neutralize as completely as possible. If reasonable care has been used in separating the oscillator and amplifier tank circuits there should be no difficulty in neutralizing well enough so that the grid current will show no more than a barely perceptible change as the amplifier plate capacitor is tuned through resonance. After neutralizing, apply plate voltage to the amplifier and set the plate tank capacitor to resonance, as indicated by the setting that gives minimum plate-current reading.

Now connect the 15,000-ohm load resistance between the "B+" tap and the plate of the amplifier tube, as shown in Fig. 1. Set the plate voltage to the maximum available, check the setting of C_1 for resonance, adjust the oscillator tank

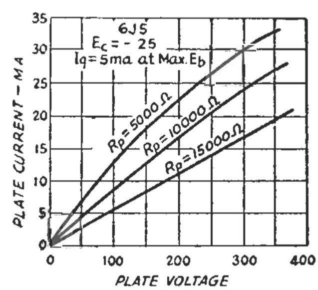


Fig. 2

capacitor to give an amplifier grid current of 5 milliamperes, and then adjust the coupling between L_2 and L_1 so that the v.t.v.m. reads nearly full scale on its lowest range. All 35 turns of the coil L_2 may be used. Once the proper coupling is found, do not disturb the two coils during a run. Take the following readings: plate current, grid current, plate voltage, and v.t.v.m. current. Change the plate voltage to the second tap and repeat, continuing in this way until readings have been taken at all five taps (or at intervals of 50 to 75 volts in case a different type of power supply than that described in Part 3 is used; in such case the maximum plate voltage should be limited to 350 or 400 volts). Change the load resistance, R, to 10,000 ohms and repeat, then take a similar set of data once more with 5000 ohms at R. In each case adjust the grid current to 5 milliamperes with the highest plate voltage on the amplifier and with the plate tank circuit tuned to resonance.

When the load resistance is lowered the r.f. plate voltage will decrease, hence the v.t.v.m. readings will be smaller. The coupling between L_2 and L_1 may be increased to compensate for this drop in voltage, if desired; the readings are only relative and the values for different runs need not be compared. When the data have been obtained, plot the plate current against plate voltage as shown in Fig. 2, drawing a smooth curve through each set of points. Fig. 2 is a typical set of curves taken on a 6J5, and Fig. 3 shows the corresponding variation of r.f. output voltage, plotted in terms of percentage of the maximum value in each case. The curves do not all end on the same ordinate because the maximum plate voltage was subject to small variations with changes in the plate current taken by the amplifier with different load resistances. The d.c. calibration of the v.t. voltmeter may be used for obtaining the relative r.f. voltages. Similar plots could be made of the rectified grid current; it will be observed that the grid current rises as the plate current falls, for the reasons explained in Exp. 30.

These curves show the behavior of d.c. plate current and r.f. output voltage with varying plate voltage, and hence show how the amplifier will operate with plate modulation. For distortionless modulation the plate current and r.f. output voltage should be directly proportional to the plate voltage; that is, the curves showing the relationship between these two quantities and plate voltage should be straight lines. With the particular tube used in these tests the "modulation characteristic," as such a curve is called, is linear (straight) with the 15,000-ohm load resistance, but shows curvature with the lower values of load resistance. In each case the r.f. output voltage, shown in Fig. 3, has approximately the same shape as the corresponding plate-current curve.

The modulation characteristic must be linear for distortionless modulation for the same reason that the grid voltage-plate current characteristic of an amplifier tube must be linear (Exp. 23, Fig.

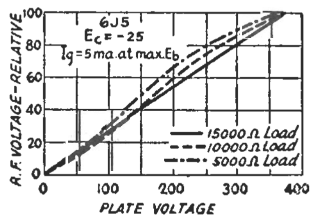


Fig. 3

11). If the modulation characteristic is not linear, the envelope of the modulated wave will not be a true reproduction of the audio-frequency voltage applied to the plate circuit of the modulated amplifier, hence distortion will be introduced in the modulation process. In addition, the relationship between plate voltage and d.c. plate current must be linear so that the modulator can work into a constant load resistance. The load resistance represented by the Class-C amplifier is equal

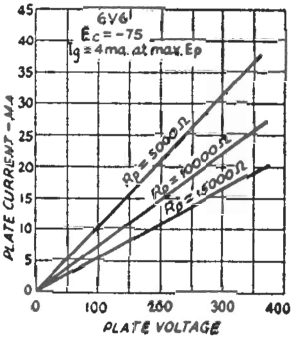


Fig. 4

to the slope of its plate voltage-plate current curve and is measured as described in the introduction to Part 4. Since the slope, and hence the resistance, is constant only when the modulation characteristic is straight, a curved characteristic indicates that the load resistance varies over the audio-frequency cycle. In Fig. 2 the slope at the lower end of the 5000-ohm curve is more than twice as great as at the upper end, which means that the load resistance into which the modulator works varies in a ratio of more than 2 to 1 over an audio cycle, when the amplifier is modulated 100 per cent. Since the audio output voltage of the modulator depends upon the value of load resistance into which the modulator is delivering power, a load resistance which varies will cause the waveshape of the modulator output voltage to differ from the waveshape of the signal applied to its grid. Hence, even though a curved Class-C amplifier plate voltage-plate current characteristic could conceivably result in a fairly straight-line relationship between plate voltage and r.f. output voltage (if the plate efficiency of the Class-C amplifier should vary in such a way as to compensate for the curvature) nevertheless distortion would be introduced because of the varying load on the modulator.

The curvature of the characteristics in Fig. 2 for loads of 10,000 and 5000 ohms is chiefly the result of insufficient cathode emission. That is, the tube is being worked beyond its capabilities at the lower values of load resistance, where the peak currents reach high values. This can be shown by substituting a tube having a cathode which takes more power. There is no octal-based triode of heavier construction comparable to the 6J5 in general characteristics, but a 6V6 can be used by connecting its screen and plate together to make the tube into a triode. The amplification factor in this case is approximately 6 (this can be determined by measurement, using the procedure outlined in Exp. 22), so that for plate-current cutoff at the highest plate voltage available the fixed bias on such a tube should be at least 400/6, or 67 volts. The curves of Fig. 4 were taken on such a tube, using the procedure described earlier but with the grid bias set at 75 volts (slightly above cutoff) and the grid current adjusted by means of the oscillator plate tank capacitor to 4 milliamperes when the tube was operating at maximum plate voltage. The curves are straight lines, showing that this particular tube is capable of maintaining a linear relationship between input and output under conditions which resulted in considerable nonlinearity when the 6J5 was used. The r.f. output voltage should be plotted in the same way as in Fig. 3, when it will be found that the curves are practically straight lines.

EXPERIMENT 32

Effect of Grid Bias and Excitation Voltage on Linearity

Apparatus: Same equipment and set-up as in Fig. 1, Exp. 31.

Procedure: In this experiment the investigation of the factors affecting the linearity of a plate-modulated Class-C amplifier is continued. Using the 6J5 as an amplifier tube, set the grid bias at approximately −50 volts and repeat the measurements described in Exp. 31. Plot the data in the same form as in Exp. 31. Fig. 5 shows the results of such measurements. It can be observed that there is no marked improvement in linearity at the lower values of load resistance as compared to the curves shown in Fig. 2 for a grid bias of −25 volts.

Using a load resistance of 10,000 ohms and a grid bias of −50 volts, adjust the grid current to 7 milliamperes with the amplifier tube operating at the highest plate voltage, check the amplifier tank circuit tuning to make sure it is at resonance, and again measure plate current, plate voltage, grid current and r.f. output voltage as the plate

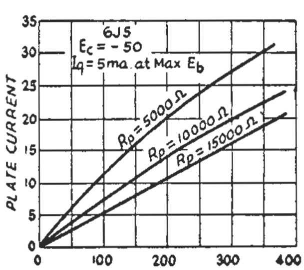


Fig. 5

voltage is decreased one tap at a time on the power supply. When the run is complete, repeat the procedure with the grid current set to 3 ma., and then repeat once more with the grid current set at 1 ma. with the amplifier operating at the highest plate voltage. Plotting the plate voltage-plate current data should give a set of curves resembling those of Fig. 6, taken on a 6J5 in such an experimental set-up. Increasing the amount of excitation, as measured by the d.c. grid current,

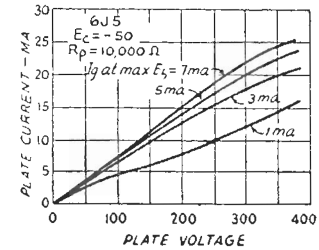


Fig. 6

improves the linearity, particularly at the higher plate voltages. The curve for a grid current of 1 milliampere does not conform to what might be expected from an inspection of the other three curves; the tendency for the slope of the curve to rise rather than to continue decreasing at the higher plate voltages is chiefly the result of a small amount of regeneration attributable to less-than-complete neutralization. In this case the grid current did not show the usual increase with decreasing plate voltage but was practically constant over the whole range of plate voltage. This regenerative effect is masked in the other curves because in those cases the regenerative voltage is small in comparison with the driving voltage from the oscillator.

The effect of improper grid bias can be demonstrated by using the 6V6, connected as triode with the screen grid and plate tied together. As explained in Exp. 31, the grid bias required for plate-current cutoff at a plate voltage of 400 is approximately −67 volts. Using a bias of −75 volts, follow the same experimental procedure and take the same data as before, then repeat with the bias set at −100 volts. Finally, set the bias to about −33 volts, the cutoff value for a plate voltage of 200, so that the amplifier is operating Class-B under carrier conditions, and repeat the measurements. Fig. 7 shows a set of curves obtained in this way. The curve for $E_C = -75$ is straight, as is also the curve for $E_C = -100$. The grid currents at maximum plate voltage were 4 and 2 milliamperes, respectively, for these two curves. With a bias of −100 volts a grid current of 2 ma. was approximately the maximum obtainable from the oscillator under the conditions of the experiment. The curve for −33 volts was taken with the grid current set at 4 milliamperes at the maximum plate voltage.

With the bias set at −33 volts the amplifier operates under conditions intermediate between Class B and Class A when the plate voltage is above 200 volts. Thus the plate efficiency shows a marked decrease as the plate voltage increases.

However, the amplification ratio increases as the Class-A condition is approached, so that the r.f. output-voltage curve is quite straight. Nevertheless, the nonlinearity of the plate voltage-plate current curve would introduce considerable distortion in such a system because of the variation, with plate voltage, of the load resistance represented by the Class-C amplifier plate circuit. The effect of such variation on the modulator operation was described in the preceding experiment.

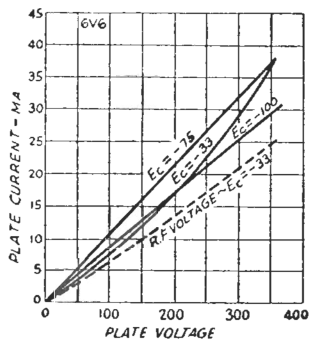


Fig. 7

As shown by the curves, once the bias is at the cutoff value for the maximum plate voltage to be applied to the tube under modulation, the modulation characteristic of the amplifier will be quite linear provided the excitation voltage is large enough. Increasing the bias beyond this value will improve the efficiency and may also improve the linearity. The latter effect is too small to show on the graphs, but was detectable in the measurements. Fig. 8 shows the result of choice of suitable operating conditions with a tube having ample cathode emission. Notice that the grid current varies as the plate voltage is changed, for the reasons explained in connection with Exp. 30. This same variation will occur during an audio modulating cycle, so that the load on the driving stage also varies when the Class-C amplifier is modulated. This audio-frequency variation of driver loading is one reason why it is desirable to use a buffer amplifier between the oscillator and modulated amplifier, since a change in load will usually cause some shift in oscillator frequency and hence frequency modulation will occur if the modulated amplifier is excited directly by the oscillator.

EXPERIMENT 33

Grid-Bias Modulation Characteristics of Class-C Amplifier

Apparatus: The equipment and circuit arrangement are the same for this experiment as for Exps. 31 and 32, except that the voltmeter is transferred to the grid-bias supply.

Procedure: The object of this experiment is to determine suitable operating conditions for grid-bias modulation of a Class-C amplifier. With this type of modulation the plate efficiency and d.c. plate current both are varied in accordance with the modulating voltage, but the d.c. plate voltage is constant. At the modulation peak the amplifier should reach its maximum plate efficiency and the d.c. plate current should be twice the carrier value of plate current. The amplifier can be adjusted for normal Class-C efficiency (about 70 per cent) at peak modulation; the operating angle therefore should be 180 degrees or less (grid bias at cutoff or higher) at the modulation peak. The minimum bias under modulation, at the instant when the modulating signal has its maximum positive value, therefore should not be less than the cutoff value for the tube and plate voltage used.

The 6J5 is a suitable type of tube for use in the experiment. The plate voltage should be the maximum available from the power supply — between 350 and 400 volts. At this plate voltage the negative grid bias required for plate-current cutoff is approximately 400/20 (E_b/μ), or -20 volts. Because of the tendency of the amplification factor of the tube to decrease near the cutoff point it is more satisfactory to use -25 volts as the cutoff value. The taps on the bias supply should be adjusted to give steps of 10 to 15 volts, starting with 25 volts and going to higher values. During the course of the experiment it will be necessary to reset the slider on R_2 in order to obtain the various voltages needed; if desired, the sliders on R_3 can be placed on R_2 temporarily to provide additional tap positions. A small range of voltages will be available at each tap by adjusting R_4.

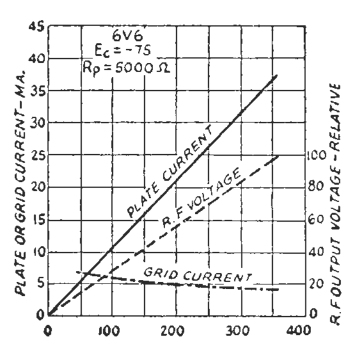


Fig. 8

The measurement procedure is similar to that used in Exps. 31 and 32, except that the plate voltage is fixed and the grid bias is varied. First measure the plate voltage, then set the bias at approximately −25 volts, adjust the oscillator tuning to give a d.c. grid current of 10 ma., and measure the plate current, grid current, and v.t. voltmeter current. Adjust the coupling to the v.t. voltmeter to give nearly a full-scale reading on the low range. Then increase the bias one step at a time, recording the readings at each step as above, until the plate current is reduced to zero. Use the 10,000-ohm 1-watt resistor as a load, and before starting the series of measurements tune the plate tank circuit of the amplifier to resonance, as indicated by minimum plate current. The readings should be taken fairly quickly, since the load resistor will overheat at the lower values of grid bias. As in the previous two experiments, set the variable resistor in the power supply so that the output voltage is maximum — that is, so that no part of the resistor is in the load circuit of the power supply.

When the measurements are completed, take a new set with an initial d.c. grid current of 8 milliamperes, then take similar sets with initial grid currents of 6 and 4 milliamperes. Plot the measured data against grid-bias voltage. A typical set of such curves is shown in Figs. 9, 10, 11 and 12. These show the effect of excitation voltage, as indicated by the value of grid current for a given bias voltage, on the input, linearity and grid bias. In each of these cases the values at minimum grid bias (approximately −25 volts) can be taken as representing conditions existing at the modulation peak. For carrier conditions the bias would be set midway between the minimum bias and that required to cut off plate current completely; for example, in Fig. 11 the plate-current curve reaches the zero axis at a bias of −70 volts; the difference between this and the minimum bias (−25 volts) is 45 volts, which represents the

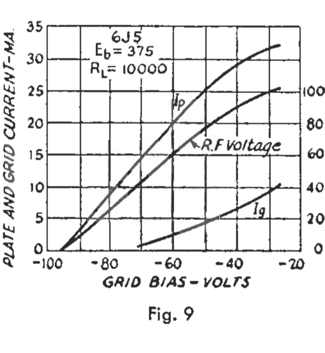


Fig. 9

total voltage swing required from the modulator for 100 per cent modulation. Half of 45 volts, or 22.5 volts, is the peak value of the modulating voltage on one side of its axis, and since the minimum instantaneous grid bias must not be less than the static cutoff value, this amount of voltage must be added to the cutoff bias to find the operating bias under carrier conditions. The carrier operating bias therefore would be 25 + 22.5, or −47.5 volts. At this bias the plate current is 13 milliamperes — half of the maximum value, which occurs at the minimum bias of −25 volts.

The r.f. output voltage at E_C = −47.5 also is half its maximum value, so that the power output (which is proportional to the square of the r.f. voltage) is ¼ its maximum value. Since the d.c. plate voltage is constant, the d.c. plate power input is half its maximum value (375 × 0.013 compared with 375 × 0.026). The proportionally greater reduction in power output therefore must be the result of a decrease in plate efficiency; in fact, the efficiency must have decreased to half its value under maximum conditions.

If the same value of fixed grid bias, −47.5 volts, is used for carrier conditions with other values of excitation voltage, serious distortion will result. In Fig. 9, for example, this value of

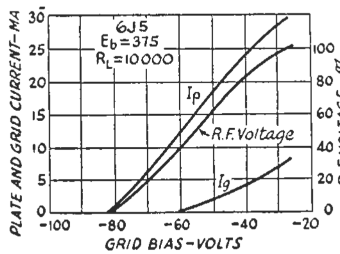


Fig. 10

bias would give a carrier plate current of 25 milliamperes. If the modulating voltage swings the instantaneous bias plus and minus 22.5 volts about the carrier bias (the conditions of operation which give 100 per cent modulation in the case of Fig. 11) the modulation peak will occur at −25 volts and the valley at −70 volts. The grid bias-plate current characteristic is badly curved in the peak region, hence the modulated wave will be distorted. Also, the plate current and r.f. voltage do not go to zero at 70 volts bias, hence the modulation is less than 100 per cent. The same state of affairs exists in Fig. 10, although to a lesser extent. In Fig. 12, the same carrier bias and modulating voltage would result in overmodulation, since the plate current is zero at approximately −65 volts bias. Hence a negative swing to −70 volts would completely cut off the output for an appreciable period of time, giving a modulated wave that is badly flattened on the down-peak. It is evident, therefore, that for a given value of carrier bias and a specified modulating voltage, there is, in general, only one value of excitation voltage which will permit linear 100 per cent modulation. This is subject to the further restriction that the peak positive swing of the modulation voltage should not cause the instantaneous grid bias to reach a value lower than that necessary to cut off the plate current (without excitation). This restriction is necessary because bias less than cutoff

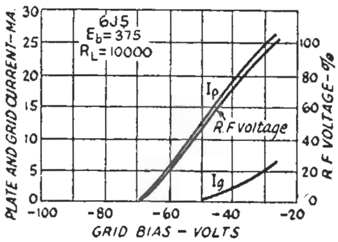


Fig. 11

would increase the operating angle to more than 180 degrees, with the result that at the modulation peak the plate efficiency would not be increasing at the proper rate. In grid-bias modulation the efficiency must reach its highest value at the modulation peak.

Further inspection of the curves of Figs. 9–12 shows that, with the same tube and plate voltage, a large number of operating conditions all capable of giving linear 100 per cent modulation can be chosen. It is in fact only necessary to restrict the operation to the straight portion of any of the curves, choosing a modulation voltage such that the total swing (total voltage from positive peak to negative peak) will confine the plate-current variations to a straight part of the curve. The carrier grid bias can be selected so that the plate current and output will just be reduced to zero when the modulation voltage reaches its negative peak. For example, the characteristic in Fig. 9 is obviously straight from the zero point, which occurs at a grid bias of −95 volts, to the 20-ma. point, where the grid bias is −60 volts. The total bias change and hence the total swing of the modulating voltage, is then 95 − 60 = 35 volts. The peak value of the modulating voltage is half the total swing, or 17.5 volts. On the negative swing of the modulating voltage the instantaneous grid bias must just reach 95 volts, hence the carrier grid bias will be equal to the maximum instantaneous grid bias minus the peak negative swing of the modulating voltage, or 95 − 17.5 = 77.5 volts. It is not necessary to utilize *all* of the straight portion of the characteristic to realize linear 100 per cent modulation. For instance, if the modulating voltage has a peak value of 10 volts the carrier bias would be 95 − 10 = 85 volts and the amplifier output still would be modulated 100 per cent. However, the carrier power output would be smaller in the latter case, since the plate current would be 6 milliamperes as against 10 for the first example, the plate voltage remaining the same. The plate efficiency also would be smaller, since the new carrier operating point is farther down on the grid bias-plate current curve.

The upper ends of the characteristics in Figs. 9 and 10 show curvature because the excitation voltage is large enough to "saturate" the amplifier — that is, maximum instantaneous grid voltage and minimum instantaneous plate current are near equality — before the bias is reduced to cutoff. When this is the case the efficiency is high and changes rather slowly with changes in either excitation voltage or bias. As a result, the plate current and power output also change slowly and the curve is no longer linear. The object in adjusting a grid-bias modulated amplifier is to attain maximum efficiency at the modulation peak without operating in the curved region of the characteristic. When this is accomplished the carrier efficiency will have its highest possible value, resulting in the greatest possible carrier power output from the tube or tubes used, consistent with linear 100 per cent modulation. Since the maximum efficiency is in the vicinity of 70 per cent, the carrier efficiency (which is half the maximum efficiency) will be approximately 35 per cent when optimum operating conditions are attained. The permissible power input to the tube can be calculated on this basis (power dissipated by the tube equals 100 − 35 = 65 per cent of the d.c. plate power input, carrier conditions) and a set of operating conditions worked out so that this carrier input can be used. The 6J5 used in the experiment has a rated plate dissipation of 2.5 watts so that the permissible carrier input is 2.5/0.65 = 3.85 watts. At the plate voltage used in the measurements described, 375 volts, the permissible carrier plate current is therefore 3.85/375 = 10 milliamperes, approximately. The 10-milliampere point on the curve of Fig. 9 shows that the fixed (carrier) grid bias should be −77.5 volts and the peak modulating voltage 95 − 77.5 = 17.5 volts, the same operating conditions selected before. In Fig. 10

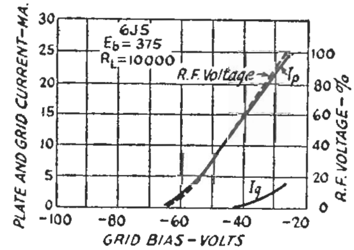


Fig. 12

the 10-milliampere point on the curve occurs at a bias of 64 volts and the plate current and output are cut off at 82 volts. The peak modulating voltage required for 100 per cent modulation therefore is 82 − 64 = 18 volts. The modulation peak will occur at 64 − 18 = 46 volts, which is still on the straight portion of the curve. The corresponding operating conditions for the curves of Figs. 11 and 12 can be worked out similarly. It will be observed that in no case does the positive peak of the modulating voltage carry

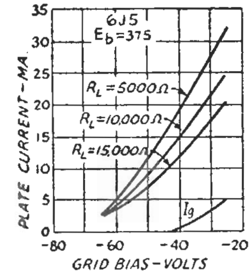


Fig. 13

the minimum instantaneous grid bias into the curved region of the characteristic. This indicates that optimum conditions will not be secured with this particular set of curves since the efficiency at the modulation peak will not be as high as is permissible. In Fig. 9, for example, the curvature of the characteristic is negligible up to a bias of about −45 volts, so that it is at approximately this point that the efficiency begins to "level off" at its maximum permissible value of about 70 per cent. If the bias can be swung to −45 volts by the modulating signal the total swing required for 100 per cent modulation will be 95 − 45 = 50 volts and the carrier bias therefore should be set at −70 volts. This will give optimum carrier efficiency, but the plate current is 14 ma. and d.c. plate-power input will be in excess of the tube ratings.

Since in every case the efficiency is too low at the modulation peak when the power input is limited to the value set by the tube ratings, a new set of operating conditions must be found which will result in higher peak efficiency. Higher efficiency can be secured by raising the value of load resistance. Take a new set of data with a 15,000-ohm load substituted for the 10,000-ohm load used in the previous measurements, plot the data, and compare the curves to those secured with the 10,000-ohm load (Fig. 13). Work out the operating conditions on the basis of the permissible power input as described above. The set which results in operating slightly into the curved region of the characteristic at the modulation peak will be optimum.

Study of the curves of Figs. 9 to 12 will show that the characteristic becomes more linear in the low-plate-current region when the grid bias is large and the excitation voltage (as indicated by the value of grid current at cutoff bias) also is large. For this reason it is advisable to operate a grid-bias-modulated amplifier in such a way that the minimum instantaneous grid bias is higher than the static cutoff value; that is, the operating angle should be less than 180 degrees at the modulation peak.

EXPERIMENT 34

Operation of Reactance Modulator

Apparatus: The circuit arrangement for this experiment is shown in Fig. 14. The equipment required includes the power supply, bias supply, oscillator, tube chassis, test instrument, and a calibrated receiver. The reactance tube is a 6J7. The oscillator should be self-controlled, using the self-resonant grid coil. Coil L is the movable coil from the circuit board and is substituted for the regular plug-in oscillator plate coil, which should be removed from its socket. The oscillator and the 6J7 screen should be operated at approximately 100 volts; this voltage preferably should be taken from the regulated tap on the power supply, substituting a 0C3 for the 0D3 normally used. The 6J7 plate voltage, which should be 250 volts approximately, is applied to the tube through a 2.5-millihenry r.f. choke.

C_1 is a midget variable capacitor of about 50-pf. maximum capacitance; the small capacitor on the circuit board may be used. The bias for the 6J7 is applied to the grid in series with a 2.5-mh. choke which provides a d.c. path to the grid. The various by pass capacitors, C_2 to C_6, inclusive, may be small mica or ceramic units of 0.001-μf. capacitance or larger; the values are not critical. C_2 and C_6 are blocking capacitors to prevent short-circuiting the plate and bias voltages through L; the other capacitors confine the r.f. currents to the proper paths.

In setting up the circuit keep the r.f. leads short, and separate the plate and grid wiring of the 6J7 as much as possible.

Procedure: In this experiment the effect of circuit constants and operating conditions on the sensitivity and linearity of a reactance modulator is investigated. The frequency change is measured by means of a calibrated receiver. Although the exact frequency need not be known precisely there should be enough bandspread in the receiver to give a fairly open calibration curve, since the experiment can be performed more satisfactorily if a frequency difference of the order of one kilocycle can be measured or estimated with fair accuracy. If a few points of known frequency can be spotted on the receiver dial it will suffice to draw a smooth curve through them and assume that the calibration is correct; this will give satisfactory *relative* readings, which is all that is needed for the experiment.

As a preliminary step, disconnect lead A from the coil and take the grid voltage-plate current characteristic of the 6J7 (Exp. 25). This is used for comparing the static plate current, at a given value of negative grid bias, to the operating plate current under different conditions of operation. Allow the receiver and oscillator to warm up thoroughly so that frequency drift will not affect the measurements. Set the receiver (with the beat oscillator on) to some value of frequency selected as a reference, such as 3600 kc. Reconnect lead A, set C_1 at maximum capacitance, use a 50,000-ohm 1-watt resistor at R, and set the bias on the 6J7 to some high value (30 volts or more) which will insure that its plate current is cut off. Using 25 turns in the coil L, set the oscillator plate tuning capacitor to bring the oscillator frequency to zero beat with the receiver. Under these conditions the reactance tube is not functioning, since its plate current is zero, but the tube and circuit capacitances are shunted across the oscillator tuned circuit and hence play their normal part in determining the frequency of oscillation.

Now set the grid bias to zero and measure the new frequency. Increase the bias to one volt and again measure the frequency; continue in this fashion at 1-volt intervals until the frequency has returned to its original value. When this run is complete, set C_1 at half capacitance and repeat. Finally, set C_1 at minimum capacitance and take a similar set of readings. Plot the data in the form of curves showing frequency as a function of grid-bias voltage applied to the reactance tube.

Fig. 15 shows the result of such a procedure, curve A being for maximum capacitance (50 pf. in this case), B for half capacitance and C for minimum capacitance. The reactance of C_1 increases with decreasing capacitance, but since the reactance in any case is small compared with the resistance of R the current in the circuit formed by R and C_1 changes relatively little. Hence the voltage across C_1 is approximately proportional to the reactance of the capacitor, and increases as the capacitance is made smaller. Since this voltage is applied to the grid of the reactance tube the r.f. component of plate current also increases when C_1 is made smaller, for a given value of grid bias. As a result, the shift in frequency also is larger.

All three curves have a straight portion in the middle, with curvature at both ends. In using the tube for frequency modulation only the straight portion would be used. In the case of curve A, the straight portion extends from approximately -3 volts to -6 volts. The operating point would be set in the middle of this region — that is, the fixed grid bias would be set at -4.5 volts — and linear modulation would be secured with a peak audio grid voltage of 1.5

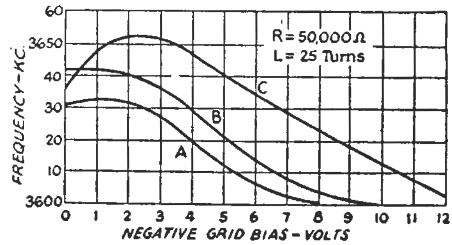


Fig. 15

volts. The total frequency swing is then 22 kilocycles, from a frequency of 3628 kc. at -3 volts bias to 3606 kc. at -6 volts bias. The frequency deviation, which is half the total swing, is thus 11 kilocycles. In curve B the approximately straight portion lies between the limits of -3 and -7 volts, so that the operating bias would be -5 volts and the peak audio voltage would be 2 volts. The deviation in this case is 14.5 kc. Curve C has a much longer straight portion — from -3 to -12 volts, giving a deviation of 24 kc. at the maximum permissible audio modulating voltage.

In some respects the reactance tube operates in much the same way as a grid-bias-modulated amplifier; that is, the amplification is a function of the grid bias, the amplitude of the r.f. voltage applied to the grid being fixed. The curvature of the characteristics below -3 volts in Fig. 15 is partly caused by saturation effects similar to those observed with grid-bias-modulated amplifiers when the grid bias is made too small (Exp. 33) and partly because the resistance of the grid circuit decreases rapidly when the grid is driven into the positive region. In the case of the reactance modulator this grid resistance is in parallel with C_1. When the grid resistance approaches the reactance of C_1 in order of magnitude, the phase angle between voltage and current in the circuit formed by C_1 and the grid resistance decreases. As a result, the r.f. component of plate current does not lag exactly 90 degrees behind the voltage across the tank circuit, and consequently the effectiveness of the tube as shunt inductance across the tank is reduced. If the grid resistance becomes comparatively low, the combination of the two effects can result in a reversal of the normal trend of frequency with changing grid bias. This is evident in the left-hand portion of curve C.

The curvature at the high-bias ends of the characteristics is the "tailing-off" effect usually encountered with variation in bias near the plate-current cutoff point, and is attributable to the change in tube amplification factor in this region.

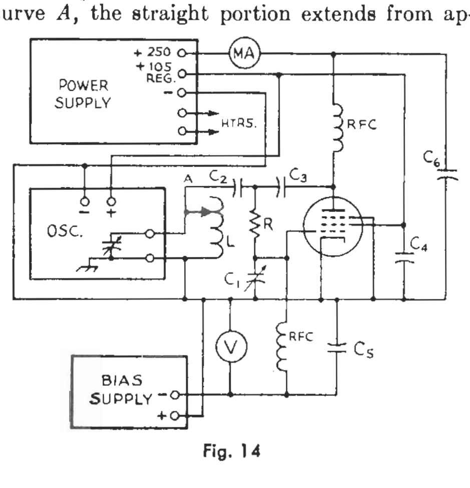


Fig. 14

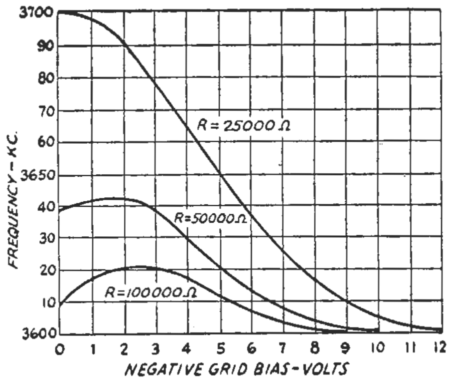


Fig. 16

For the second part of the experiment, set C_1 at about half capacitance and take readings similar to the above, but with 100,000 ohms substituted for the 50,000-ohm resistor first used at R. When this run is finished, substitute a 25,000-ohm resistor at R and repeat. Plot the data in the same form as before. Fig. 16 shows the results of a typical run of this type. For a fixed value of capacitance at C_1, the current through RC_1, and hence the voltage across C_1, is dependent upon the value of resistance used at R, smaller values giving larger current and vice versa. This is clearly shown by the experimental curves, since the frequency shift, which is proportional to the r.f. voltage across C_1, increases with decreasing resistance at any given value of grid bias. In other respects the curves have the same general nature.

The effect of the L/C ratio of the tank circuit on frequency deviation can be observed by repeating the first set of measurements, using 15 turns in L instead of 25. The sensitivity of the modulator can be expected to decrease; that is, the same change in bias voltage should give a smaller change in frequency, other conditions remaining the same. For a given value of r.f. voltage at the grid of the reactance tube the r.f. component of plate current of the tube will be the same (provided the tank-circuit impedance has not changed greatly) regardless of the L/C ratio. However, the smaller the L/C ratio the greater the tank current. When the fixed reactance tube r.f. plate current is added to a small tank current its effect on the resultant phase angle, and hence on the frequency, is greater than when it is added to a large tank current. Hence the frequency swing for a given change in modulator bias is less when the L/C ratio is small.

The experimental measurements will show this. Fig. 17 is a typical set of curves, which may be compared directly with those of Fig. 15. It can be seen that the frequency deviation has been halved, approximately, by using 15 turns in the tank coil in place of the 25 used in securing the data plotted in Fig. 15.

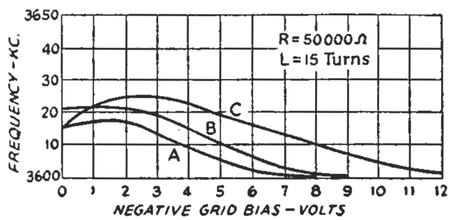


Fig. 17

In each set of measurements it is useful to measure the d.c. plate current of the 6J7 and compare it to the static plate current at the same value of grid bias. The operating plate current in general will be larger. The increase over the static plate current gives an indication of the amplitude of the r.f. voltage applied to the grid of the reactance tube.

Part Seven

Receivers and Power Supply

The subject of receiving is one for which a great many experiments could be outlined. Really comprehensive ones, however, would require far more elaborate equipment than has been used for the previous work. Consequently the experiments to be outlined are based on the measuring equipment already used.

Simple experiments, such as the construction of small receivers or amplifiers, are highly beneficial to beginners and are strongly recommended to those who have never built any of their own receiving equipment. Various designs are available in the constructional section of the *Handbook*, and they can be copied as given or can have such variations introduced as the experimenter thinks desirable, based on his study of receiver principles. Those who are conducting radio courses will find it helpful to include a bit of simple receiver construction and also to work in an experiment which involves alignment of a superhet receiver of conventional design. In many formal courses it is likely that the requisite test equipment will be at hand. The details of such experiments are rather obvious and need no special comment.

ASSIGNMENT 25

Study *Handbook* sections on receiver characteristics and detection. Perform Exp. 35.

Questions

1) Why is it necessary to "detect" radio signals?

2) What types of amplification are used in a receiver?

3) How can code signals be made audible in a receiver?

4) What is meant by the sensitivity of a receiver?

5) How is the bandwidth of a receiver specified?

6) What determines the selectivity of a receiver?

7) How are selectivity and signal-to-noise ratio related in a receiver?

8) What is a selectivity curve?

9) Name some factors affecting the stability of a receiver. Define "stability" as the term is applied to receivers.

10) What is receiver fidelity?

11) Name the three most common types of detectors.

12) Draw a circuit diagram of a simple diode detector and explain the operation.

13) What is meant by the linearity of a detector?

14) Define sensitivity as applied to receiver detectors.

15) Describe the operation of the plate detector. Why is the plate detector more sensitive than the diode detector? Why is it less sensitive than the grid-leak detector?

16) Explain the working of an infinite-impedance detector.

17) In what respect does the grid-leak detector resemble a diode detector? Describe the operation of the grid-leak detector and draw a representative circuit diagram.

18) Compare the diode, grid-leak, and plate detectors in the following respects. (a) sensitivity; (b) impedance; (c) linearity; (d) signal-handling capability.

19) What is a regenerative detector? Why is its sensitivity greater than that of a nonregenerative detector?

20) Draw a regenerative detector circuit of the tickler type, indicating audio-frequency output connections.

21) Name two methods of controlling feedback in a regenerative detector circuit.

22) Describe the method of tuning a regenerative detector for both code and phone signals. What setting of the regeneration control gives greatest sensitivity?

23) Why does a regenerative detector have greater effective selectivity than a nonregenerative detector?

24) Why is the sensitivity of a superregenerative detector greater than that of an ordinary regenerative detector?

25) If a regenerative detector circuit exhibits hand-capacitance (body-capacitance) effects, what are the probable causes?

26) What is tunable hum? Explain how it is caused.

27) Why are "dead spots" likely to occur when a regenerative or superregenerative detector is coupled to an antenna?

ASSIGNMENT 26

Study *Handbook* sections on receiver amplifiers, audio and radio, and tuning methods. Perform Exp. 36.

Questions

1) Why is audio-frequency amplification needed in a receiver?

2) What is the purpose of a "tone control"? Draw a simple tone-control circuit.

3) How is grid bias ordinarily secured for amplifiers used in receivers?

4) Draw a circuit diagram of a typical radio-frequency amplifier using a pentode tube. Show a method of controlling the amplification.

5) Why is it necessary to use screen-grid tubes in r.f. amplifiers?

6) What precautions must be taken to prevent self-oscillation in the r.f. amplifier stage?

7) What is thermal-agitation noise? Upon what factor does its value depend in a tuned circuit?

8) What is the normal cause of noise originating in a vacuum tube?

9) What design considerations must be followed to secure a good signal-to-noise ratio?

10) Why is the first tube in the receiver the most important one from the standpoint of signal-to-noise ratio?

11) Why is it necessary to sectionalize the tuning range of a receiver into bands?

12) What is meant by "bandspread"? Describe three methods which may be applied to tuned circuits for accomplishing bandspreading. Give the relative advantages and disadvantages of each method.

13) Using the parallel-capacitor bandspread circuit, what should be the capacitance variation available in the bandspread capacitor to spread the band 7000–7500 kc. over its tuning dial if the coil has an inductance of 10 microhenrys? At what value of capacitance should the bandsetting capacitor be set to give this bandspread?

14) A coil having an inductance of 10 microhenrys is tuned by a capacitor having a maximum capacitance of 100 pf. If a bandspread capacitor having a maximum of 20 pf. and a minimum of 5 pf. is shunted across the main tuning capacitor, what tuning range can be covered with the bandspread capacitor when the main capacitor is set at 25 pf.? at 50 pf.? At 100 pf.?

15) The following values are used in the series-capacitor bandspread circuit: inductance, 35 microhenrys; bandspread capacitor, maximum 200 pf., minimum 30 pf.; series padding capacitor, 50 pf.; parallel padding capacitor, 25 pf. What is the tuning range of the circuit?

16) Assuming that the variation of the bandspread capacitor in Question 15 is linear with respect to dial settings, plot a curve showing the resonant frequency of the circuit as a function of the dial setting. (Assume a dial having 100 divisions.)

17) In the parallel-capacitor bandspread circuit, if the bandspread capacitor has a maximum of 20 pf. and a minimum of 5 pf., what bandsetting capacitance is required and what inductance should be used in a tuned circuit which is to have bandspread tuning over the 3500-4000-kc. range?

18) Plot a curve showing resonant frequency as a function of dial setting for the circuit of Question 17, assuming a 100-division dial and linear variation in the bandspread capacitance. Compare its shape with the graph of Question 16.

19) What is meant by "tracking"? In the case of tuned-r.f.-amplifier stages, what requirements must be met for correct tracking?

20) How is it possible to compensate the effects of tube and stray capacitances in circuits which are to be tracked?

ASSIGNMENT 27

Study *Handbook* sections on the superheterodyne. Perform Exp. 37.

Questions

1) Describe the operating principles of the superheterodyne receiver. Draw a block diagram showing the various sections of such a receiver.

2) What are the advantages of the superhet over other types of receivers?

3) What is image response? Name some other "spurious" signals that may be encountered in a superhet receiver.

4) A superhet receiver having an intermediate frequency of 455 kc. is to be adjusted to receive a signal on 13,540 kc. To what frequencies can the high-frequency oscillator be set to give a beat signal at the intermediate frequency? What will the image frequency be in each case?

5) What is a double superheterodyne? What is the purpose of this type of circuit?

6) What is the function of the first detector or mixer in a superheterodyne?

7) Define conversion efficiency as applied to mixers.

8) What is "pulling"? What requirements with respect to oscillator voltage should be met by a mixer?

9) Draw a circuit diagram of a typical mixer circuit, indicating the point at which oscillator voltage should be injected.

10) Why is it desirable to use separate mixer and oscillator tubes rather than to perform both functions in one tube?

11) What is meant by "tracking" in the case of gang-tuned mixer and oscillator circuits?

12) A mixer-oscillator circuit is to tune over a signal range of 4000 to 8000 kc. If the intermediate frequency is 455 kc., what frequency range must be covered by the oscillator if the oscillator frequency is to be higher than that of the mixer?

13) What requirements must be met by the high-frequency oscillator of a superhet receiver for optimum receiver stability?

14) Draw a representative oscillator circuit, showing the point from which injection voltage for the mixer may be taken.

15) What considerations dictate the choice of an intermediate frequency in a superhet receiver?

16) Describe the construction of an intermediate-frequency transformer. How are the gain and stability of the transformer affected by the types of coils and capacitors used?

17) What is the "single-signal effect"?

18) Draw a circuit diagram of a typical intermediate-frequency amplifier. What precautions are necessary to prevent self-oscillation?

19) What benefits result from making an i.f. amplifier regenerative? What are the disadvantages?

20) Why does a properly designed crystal filter greatly increase the selectivity of an i.f. amplifier?

21) What is the function of the "phasing capacitor" in a crystal-filter circuit? Draw a typical crystal-filter circuit, indicating the phasing capacitor and the selectivity control.

22) What is the function of the second detector in a superhet receiver? What type of detector is commonly used?

23) What is the purpose of the beat-frequency oscillator? What design considerations are necessary to prevent its causing spurious responses in the receiver?

ASSIGNMENT 28

Study *Handbook* sections on intermediate-frequency amplifiers.

Questions

1) Show by a simple circuit how voltage for automatic volume control can be secured from a diode detector and applied to the control grids of r.f. amplifiers. Indicate filter circuits. Describe the operation of the circuit.

2) What is meant by "delayed a.v.c."?

3) What considerations determine the selection of the time constant for the a.v.c. filter circuit? What is the effect if the time constant is too small? If too large?

4) What is the purpose of a tuning indicator? Draw a representative circuit and describe its operation.

5) Name two advantages resulting from the use of tuned r.f. amplification preceding the mixer stage in a superhet receiver.

6) What are the advantages and disadvantages of regeneration in a preselector stage?

7) Describe the general principle upon which devices intended to reduce impulse noise operate.

8) What is a noise limiter? Why are such devices most satisfactory when used in receivers having a comparatively broad resonance curve?

9) Outline the differences in operating principles between a limiter of the type used with second-detector circuits and the i.f. noise silencer.

10) What is the proper method of setting the frequency of the beat-frequency oscillator in a superhet receiver? Why should the b.f.o. not be tuned exactly to the intermediate frequency, especially when a crystal filter is used?

11) How is it possible to recognize an image signal in a superhet receiver? How can other spurious responses be identified?

12) Describe the general method of aligning the intermediate-frequency amplifier of a superhet receiver, using a test oscillator.

13) In aligning the r.f. to the mixer stage in a superhet receiver it is found that, after resonating the r.f. stage at the high-frequency end of the range by means of the trimmer capacitor, on tuning to the low-frequency end of the range the r.f. trimmer capacitance must be reduced to obtain maximum response. If the tuning capacitors in the two stages are identical, what must be done to bring about proper tracking?

14) How does oscillation in r.f. or i.f. circuits manifest itself? Name some possible causes and remedies.

ASSIGNMENT 29

Study *Handbook* section on frequency-modulation reception. Perform Exp. 38.

Questions

1) In what way does a receiver for frequency modulation differ from one for amplitude modulation?

2) What is the function of the limiter in an f.m. receiver?

3) Why is it necessary to have a great deal of r.f. gain in the part of the receiver preceding the limiter?

4) Is it possible to receive frequency-modulated signals with an amplitude-modulation receiver? If so, describe how the receiver is adjusted.

5) Draw a simple limiter circuit and describe its operation. In what respects does the operation of the circuit differ from that of an r.f. amplifier?

6) Compare the requirements for the detection of frequency-modulated signals with those for amplitude-modulation detection.

7) Describe briefly the operation of the ordinary type of f.m. detector or "discriminator."

8) What audible effects indicate proper and improper tuning of a frequency-modulation receiver?

9) How can it be determined that the limiter circuit of an f.m. receiver is functioning properly?

10) Why is f.m. reception effective in reducing interference from impulse-type noise?

ASSIGNMENT 30

Study *Handbook* chapter on power supply. Perform Exp. 39

Questions

1) Define voltage regulation.

2) Why is it necessary to use direct current for the plate supply for vacuum tubes?

3) Compare high-vacuum rectifiers and mercury-vapor rectifiers as to voltage drop.

4) Define (a) inverse peak voltage; (b) peak plate current.

5) Name three types of tube rectifier circuits in common use.

6) Draw a circuit diagram of a full-wave center-tap rectifier and explain its operation. For the same output current and voltage, how does this circuit compare with the half-wave rectifier in the following respects: (a) inverse peak voltage on rectifier tubes; (b) tube current; (c) transformer secondary voltage required; (d) output wave-shape; (e) power taken from transformer.

7) Draw the circuit of a bridge rectifier and describe its operation. Compare with the center-tap rectifier on each of the points listed in Question 6.

8) Why is it necessary to use a filter with a rectified a.c. power supply?

9) What is ripple voltage? Define per cent ripple.

10) What order of per cent ripple is considered satisfactory for communication by c.w. and phone?

11) What is the difference between a "choke-input" filter and a "capacitor-input" filter?

12) Why is it necessary to use an air gap in the core of a filter inductance which is to carry direct current?

13) What is the ripple frequency of a full-wave rectifier operating from 60-cycle supply? From 25-cycle supply?

14) How does the d.c. output voltage of a capacitor-input filter compare, at light loads, to the a.c. voltage applied to the rectifier?

15) Draw a circuit diagram of (a) a single-section capacitor-input filter; (b) a two-section capacitor-input filter. What values of inductance and capacitance would be typical for the load resistances ordinarily encountered in practice, if the supply is designed to deliver direct current to the plate circuit of a vacuum tube or tubes?

16) Draw circuit diagrams of one- and two-section choke-input filters. What requirements must be met by the input choke to assure proper operation of the filter?

17) What is meant by "critical inductance" and "optimum inductance"? What are the advantages of a "swinging" choke?

18) Compare capacitor- and choke-input filters in the following respects: (a) d.c. output voltage, for a given rectified a.c. voltage; (b) output voltage regulation; (c) rectifier-tube peak current.

19) Why is it necessary to avoid resonance effects in the circuit formed by the input choke and the first filter capacitor?

20) A two-section choke-input filter is to be designed to have 0.1 per cent ripple with an output of 1000 volts at 200 milliamperes. The supply frequency is 60 cycles, with full-wave rectification. If the bleeder resistance is permitted to dissipate 10 per cent of the output power, what resistance is required, and between what inductance limits (minimum) should the swinging input choke vary from the bleeder load only to full load? If a smoothing choke having an inductance of 10 henrys is available, what capacitance is required in each capacitor, assuming that both have the same value, to give the required smoothing at full load?

21) What approximate output voltage will be obtained from a power supply having a transformer delivering 1100 volts each side of the center-tap (at full load), using mercury-vapor rectifiers, through a two-section choke-input filter when the filter inductances have resistances of 150 and 200 ohms, respectively, if the load current is 250 milliamperes?

22) If the rectifier and filter of Question 20 are to be used in a power supply delivering 250 ma. at 1000 volts, what is the transformer voltage required? What is the output volt-ampere capacity required? Allowing 1000 circular mils per ampere, what size wire would be suitable for the transformer secondary?

23) Name two methods which may be used to stabilize the output voltage of a power supply when it is necessary to have the best possible voltage regulation for low-voltage circuits.

24) Why is it possible to use a tube containing gas at low pressure for the purpose of voltage regulation? Describe the operation of a regulator circuit using such a tube.

25) Explain the operating principles of the electronic voltage regulator.

26) What is meant by the term "protective bias"?

27) What are the requirements for a bias supply intended to furnish operating bias?

28) A voltage divider is to be used with a power supply to furnish the following voltages and currents to a receiver: 100 volts at 20 milliamperes, 250 volts at 35 milliamperes, and 325 volts at 75 milliamperes. If the output voltage of the supply is 325 volts when the current is 140 milliamperes, what resistance is required in the voltage divider and how should it be distributed between the taps? What power will be dissipated in the resistor?

29) What is the principle of a voltage-doubling circuit?

30) Draw a circuit diagram of a vibrator power supply using a tube rectifier. Explain its operation.

31) What is the function of the buffer capacitor in a vibrator power supply?

32) What is the difference between synchronous and nonsynchronous vibrators?

33) What precautions must be taken when mercury-vapor rectifiers are to be operated in parallel?

EXPERIMENT 35
Detector Operation

Apparatus: The power supply, oscillator, v.t. voltmeter, test instrument, tube chassis and circuit board are required for this experiment, together with an assortment of fixed capacitors and resistors. The wiring diagrams for the three types of detectors tested are shown in Fig. 1. The oscillator may be operated either crystal- or self-controlled, with the plate voltage set to a low value so that the r.f. output will be small. Use the lowest tap on the power supply and adjust the output voltage by means of the variable resistor in the supply.

The coils L_1 and L_2 are the movable and fixed coils, respectively, on the circuit board. Use 25 or 30 turns, as required for tuning to the frequency selected. A frequency of about 3 megacycles will be satisfactory if the oscillator is operated self-controlled. C_1 is the 250-pf. capacitor associated with the fixed coil on the circuit board.

Procedure: The object of this experiment is to compare the sensitivity and linearity of the diode, grid-leak and plate detectors. Connections for determining the diode characteristic are shown in Fig. 1-A. The tube may be any type having a diode section (such as the 6H6, 6R7, 6Q7, etc.) or a small triode such as the 6J5 with grid and plate connected together. The latter is indicated in the circuit diagram. The v.t. voltmeter is used to measure both the applied r.f. voltage and the rectified output voltage. For the former purpose the "hot" lead is connected to point X and for the latter to point Y. While the output voltage could be measured by means of a d.c. microammeter inserted in series with the 500,000-ohm load resistor, the current is too small for accurate measurement with the ordinary test kit.

The value of the bypass capacitor across the load resistor is not critical, since the measurements are not being made at audio frequency. Although a 500-pf. capacitor is indicated in the diagram, a larger capacitor may be used if more readily available.

Set the oscillator plate voltage at 15 or 20 volts, couple L_1 and L_2 loosely together, and, with the v.t.v.m. connected to Y, adjust C_1 to resonance. Resonance will be indicated by maximum v.t.v.m. reading. Use the low range of the v.t.v.m. and adjust the coupling between L_1 and L_2 (and, if necessary, the oscillator plate voltage) to give a reading corresponding to about 10 volts, as shown by the v.t.v.m. calibration curve. Shift the v.t.v.m. lead to X and note the reading. When the shift is made it will be necessary to retune C_1 to resonance, since the input capacitance of the v.t.v.m. is now added across the tuned circuit. The r.f. voltage as read by the v.t.v.m. may be smaller than the d.c. output voltage; this may result from the fact that the v.t.v.m. loads the circuit slightly and consequently decreases the r.f. voltage, and also because the readings do not represent peak values. For the purposes of the experiment the absolute values of r.f. voltage are not especially important so long as the relative values are correct. Consequently the d.c. calibration of the v.t.v.m. can be used for reading r.f. voltage.

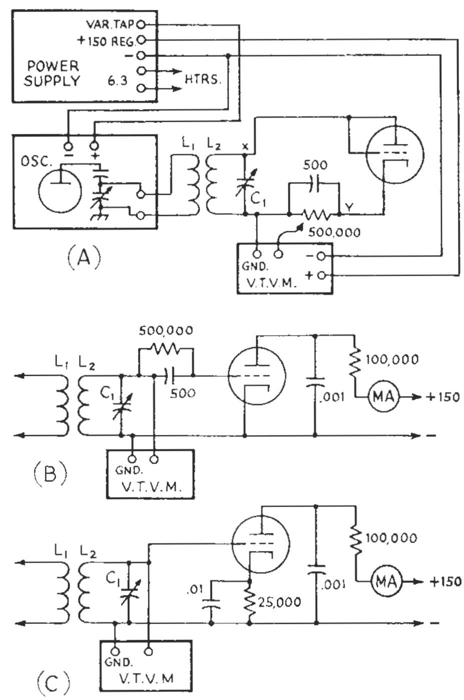


Fig. 1

After setting the r.f. voltage to give an initial d.c. output of about 10 volts, reduce the voltage in small steps, taking readings of both r.f. and d.c. voltage, until the r.f. voltage is reduced to zero. It will be satisfactory to take readings at intervals of about 1 volt. Plot the rectified voltage as a function of r.f. voltage, as shown in Fig. 2. The resulting curve should be practically a straight line, except when the r.f. voltage is quite low. This curvature is exaggerated by the conditions of the experiment, since the v.t.v.m. loading on the tuned circuit makes the r.f.-voltage readings low compared with the corresponding d.c. output reading; that is, the r.f. voltage actually operating when the v.t.v.m. is connected to Y is higher than the value existing when it is connected to X. This can be overcome by using two v.t. voltmeters, or by leaving the v.t.v.m. connected permanently to X and measuring the current in the load resistor by means of a microammeter. The error is not serious for the purposes of this experiment, but it should be realized that it exists. Because of it, the sensitivity of the diode (ratio of d.c. output voltage to r.f. input voltage) is measured to be higher than is actually the case.

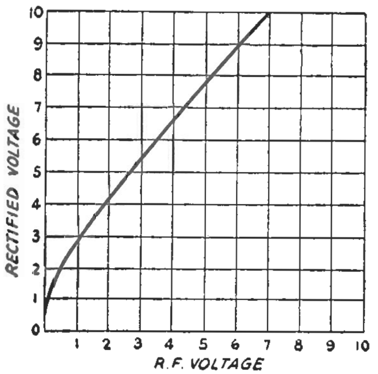


Fig. 2

Note that the d.c. output voltage does not drop to zero when the r.f. voltage is zero. This is the result of the fact that some electrons emitted from the cathode with relatively high velocity reach the diode plate even though the latter is not given a positive charge with respect to the cathode (see Exp. 21). In a receiving circuit the diode normally would be coupled to the following audio amplifier through a capacitor, so that this steady voltage would not affect the operation of the following tube.

Connections for the grid-leak detector are shown in Fig. 1-B. In this case, the v.t.v.m. is always connected across the tuned circuit. The grid leak and grid capacitor are in the grid lead to the tube, the cathode being grounded. The plate circuit is bypassed for r.f. by the 0.001-μf. capacitor (larger values may be used), and the plate voltage is taken from the 150-volt regulated tap on the power supply. The load resistor is selected to limit the plate current to the region of 1 milliampere with no signal, giving a plate voltage of well under 50 volts. The milliammeter is connected in the plate circuit as shown; the test kit may be used for measuring both plate current and v.t.v.m. current. In this case plate-current readings are taken for various values of r.f. voltage from zero up to 9 or 10 volts. If the same milliammeter is used for the plate circuit as for the v.t.v.m., the plate circuit of the detector should be closed when the instrument is connected to the v.t.v.m.

On plotting the data the curve showing plate current against r.f. voltage should have about the shape indicated in Fig. 3. As the r.f. or signal voltage increases the plate current decreases. This is because the bias on the tube is nearly zero with no signal, but rectification in the grid circuit develops a negative voltage between grid and cathode through flow of rectified grid current in the grid-leak resistor. The greater the r.f. voltage the larger the bias developed, hence the plate current decreases with increased signal input.

The output voltage of such a detector is the change in voltage drop in the load resistor, just as in the case of an audio amplifier (see Exp. 23). It is, therefore, equal to the *change* in plate current multiplied by the load resistance. For example, in Fig. 3 the plate current is 1.11 ma. with 4 volts r.f.; this value subtracted from the plate current at zero r.f. voltage, 1.3 ma., is the change ($1.3 - 1.11 = 0.19$ ma.) in plate current caused by a 4-volt signal. The output voltage is therefore $0.00019 \times 100{,}000$, or 19 volts. Other points on the output-voltage curve are found similarly. Notice that the curve has no really straight portion, and at high signal levels it flattens off, so that with more than a 6-volt signal there is no further increase in output.

The set-up for measuring the plate detector is shown in Fig. 1-C. It is similar to that for the grid-leak detector, but the tube is biased by means

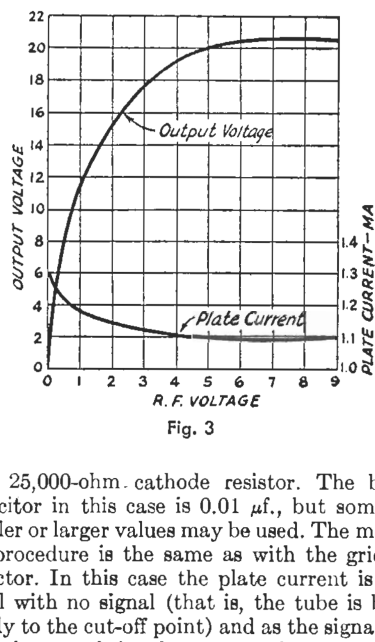


Fig. 3

of a 25,000-ohm cathode resistor. The bypass capacitor in this case is 0.01 μf., but somewhat smaller or larger values may be used. The measuring procedure is the same as with the grid-leak detector. In this case the plate current is quite small with no signal (that is, the tube is biased nearly to the cut-off point) and as the signal voltage is increased the plate current increases. If the same instrument is used both for measuring detector plate current and v.t.v.m. plate current, it is important that the plate circuit of the detector be closed when the meter is connected to the v.t.v.m. If this is not done there will be no plate current and consequently no bias, hence current will flow in the grid circuit of the tube and the r.f.-voltage measurements will be incorrect because of the load on the circuit.

The data secured should be plotted as shown in Fig. 4. The output voltage is found by calculating the change in voltage drop across the load resistor by the same method used in Fig. 3. The output-voltage curve should be fairly straight except near the upper end. The flattening off at the upper end is the result of several effects. Increasing plate current increases the voltage drop in the cathode resistor, and hence increases the negative bias on the grid; also, as the plate current becomes larger the voltage between plate and cathode becomes smaller because the drop in the 100,000-ohm load resistor increases. In addition, if the r.f. voltage becomes large enough the grid will be positive with respect to the cathode at some part of the cycle, causing grid current to flow. Such grid current causes an increase in the voltage drop across the cathode resistor, further increasing the negative bias. All these effects cause the plate-current curve to flatten off when the signal voltage becomes too high.

In all of the detectors the actual audio-frequency voltage would be given by the variation in output voltage, as shown by the curves, about a mean voltage representing the carrier output. For example, in Fig. 4 assume that the incoming unmodulated carrier has an amplitude of 3 volts. This would cause a change of 8 volts across the load resistor, but since this change is constant so long as the carrier is present there would be no audio-frequency output — simply a shift in d.c. plate voltage at the tube. However, with 100 per cent modulation the carrier voltage would vary from zero to twice its unmodulated value, or from zero to 6 volts. The output voltage as shown by the curve would vary correspondingly from zero to 18 volts. Since the carrier is represented by an output of 8 volts, the "negative" swing of the audio-frequency output voltage would be from 8 volts to zero, giving a negative peak of 8 volts, and the "positive" swing would be from 8 to 18 volts, giving a positive peak of 10 volts. The fact that the positive and negative peaks are not equal indicates that distortion is introduced by the detector. If the modulation is reduced to 50 per cent, with the same 3-volt carrier, the r.f. voltage varies between 1½ volts and 4½ volts. The corresponding output voltages are 3.2 and 13 volts, giving negative and positive audio-voltage peaks of $8 - 3.2 = 4.8$ volts and $13 - 8 = 5$ volts, respectively. The two peaks are more nearly alike in this case, indicating much smaller distortion. It is generally true of a detector that the distortion becomes larger as the modulation percentage is increased. So long as the carrier is not of such amplitude that the upper modulation peak falls in the flattened region at the top of the characteristic, the distortion is principally caused by the curvature near zero signal. The higher the percentage of modulation the more nearly does the instantaneous r.f. voltage approach zero on the down-peak, regardless of the carrier strength. The diode and plate detectors have longer linear sections to their characteristics than the grid-leak detector does; the latter is not really straight at any part, and becomes badly curved with signals of more than a fraction of a volt.

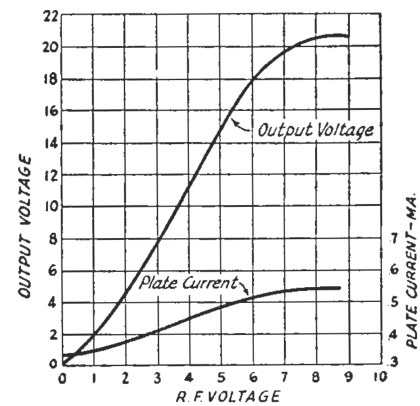


Fig. 4

The sensitivity of the detector is given by the slope of the characteristic (volts output divided by r.f. volts input) at the value of carrier voltage considered (see introduction to Part 4 for discussion on the slope of a curve). In Fig. 3 the slope is quite high at small signals, indicating that the sensitivity of the grid-leak detector is high. Comparing the three curves shows that the diode detector is the least and the grid-leak detector the most sensitive, with the plate detector intermediate.

Curves taken by the method given in this experiment do not hold exactly for the case of a modulated carrier, since the behavior with an a.c. output voltage will depend upon the effect of the bypass and stray capacitances while these capacitances do not affect d.c. measurements. For example, the grid bias in the case of the plate detector will not ordinarily follow the variations in the modulated carrier because the cathode bypass capacitor shunts the variations in plate current around the cathode resistor; only the steady carrier voltage is effective in determining the grid bias under operating conditions. The d.c. method is satisfactory for indicating the type of operation to be expected, however, and is adaptable to simple measuring equipment.

EXPERIMENT 36

Characteristics of Bandspread Methods

Apparatus: The equipment required for this experiment includes the plate power supply, oscillator, coils and capacitors from the circuit board, and a calibrated receiver. The oscillator is operated self-controlled, using the grid coil instead of the crystal. The regular plate coil is taken out of its socket and one of the tapped coils from the circuit board substituted, as shown at L in Fig. 5. The oscillator tank capacitor should be connected across 25 turns of the coil.

Oscillator plate voltage may be taken from the regulated tap, using a 0C3 regulator tube. However, voltage regulation is not essential, so that the plate voltage can be taken from one of the divider taps on the power supply, keeping the voltage at about 100 volts or less.

Procedure: Connect one of the variable capacitors on the circuit board across the 25 turns in use at L, as shown in Fig. 5-A, where the capacitor is designated as C_1. Set C_1 to minimum capacitance, adjust the receiver to 4 megacycles, and adjust the tank capacitor in the oscillator unit until the signal is heard. It will be advisable to keep the receiver gain low because the signal probably will be quite strong. If the receiver is a superhet, care must be used in setting the oscillator frequency actually to 4 megacycles rather than to an image frequency or other spurious-response point. The proper frequency will be the strongest signal heard as the oscillator tank capacitor is turned. (As another check, the oscillator frequency may be measured with an absorption wavemeter, if one is available.)

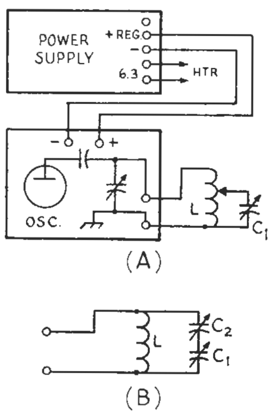


Fig. 5

When the proper setting of the oscillator tank capacitor has been found, increase the capacitance of C_1 by a small amount and measure the new oscillator frequency by means of the calibrated receiver. Continue increasing the capacitance of C_1 by small steps, taking a frequency reading each time, until maximum capacitance is reached. If the capacitor has a 100-division dial it will be satisfactory to take readings at every 10th division. After the series of readings is completed, connect C_1 across 20 turns of the coil, set it at minimum capacitance, and readjust the oscillator capacitor to bring the frequency to 4 megacycles. Increase the capacitance of C_1 in small steps as before, taking frequency readings. Continue this procedure with C_1 across 15, 10 and 5 turns, successively.

After a complete set of data has been obtained, plot a series of curves showing frequency against dial settings of C_1, one curve for each tap condition. A representative set of curves is shown in Fig. 6. The capacitor used had a maximum capacity of 250 pf., with "straight-line wavelength" plates. Plates of other shapes (semicircular or "straight-line capacitance," for example) would give curves of different shapes, although the end points would be the same for capacitors having the same maximum and minimum capacitance. Curves A, B, C, etc., represent C_1 connected across 25 turns, 20 turns, 15 turns, and so on. The effect of C_1 on the frequency range becomes smaller (bandspread increases) as the number of turns across which it is connected decreases. Practically any degree of bandspread can be obtained by proper choice of the number of turns across which the capacitor is connected, even though its capacity may be quite large.

In this system of bandspread the inductance acts like an autotransformer. If there were no magnetic leakage in the coil — that is, if all the flux set up by each turn cut every other turn of the coil — the capacitive reactance appearing across the whole coil due to the presence of C_1 across part of the coil would be equal to the reactance of C_1 multiplied by the square of the turns ratio. For example, with C_1 tapped across 10 turns of the 25-turn coil, the reactance would be multiplied by $\left(\frac{25}{10}\right)^2$ or 6.25 The higher reactance is equivalent to a correspondingly smaller capacitance than is actually in use at C_1. This transformation gives a new value of capacitance which can be considered to be simply in parallel with that already across the coil. If the capacitance in use at C_1 at a given dial setting is 50 pf., in the above example, the equivalnet capacitance in shunt across the whole coil would be 50/6.25, or 8 pf.

In practice, this simple relationship does not hold because there is considerable magnetic leakage, so that the effective capacitance of C_1 cannot readily be calculated from the turns ratio. In a general way, however, it indicates how the effect of the capacitor can be expected to vary as the number of turns across which it is tapped is changed.

For the second part of the experiment, connect the two 250-pf. capacitors on the circuit board in series across the 25-turn coil, as indicated at B in Fig. 5. Set the second capacitor, C_2, at maximum, adjust the oscillator tank capacitor to bring the frequency to 4 megacycles, and take frequency readings for various settings of C_1 in the same way as above. Then set C_2 to half scale, reset the tank capacitor to make the oscillator frequency 4 megacycles and repeat. Follow the same procedure for a third time with the series capacitor, C_2, set at ¼ scale. (The last two settings of C_2 will not be ½ and ¼ maximum capacitance, if the plates are not semicircular, but this will not matter for the purposes of the experiment.) Plot the data in the same way as in the first part of the experiment. Fig. 7 shows the results of such measurements, using capacitors having "straight-line-wavelength" plates.

The shape of the tuning curves in the series-capacitor method of bandspreading differs considerably from the shape obtained with the tapped-coil method. In the former case the tuning curve tended to straighten out as the bandspread became greater (tuning range reduced) and the effective shunt capacitance became smaller in comparison with the actual capacitance in parallel with the whole coil. This is generally true with either this bandspread method or the simple system using a small parallel capacitor (to which the tapped-coil method is essentially equivalent) unless the bandspread capacitor has plates of unusual shape. The frequency of any tuned circuit is inversely proportional to the square root of the capacitance, but if the *percentage* change in capacitance is small, the tuning is very nearly linear with respect to capacitance change. This can be seen by plotting a curve showing the variation of resonant frequency with tuning capacitance. Any small segment not too near the low-capacitance end is nearly a straight line even though the whole curve is far from straight.

With the series-capacitor method the curves show a relatively rapid rise at low values of C_1, flattening off toward maximum capacitance. The flattening of the curves becomes more marked as the series capacitance at C_2 is made smaller. The reason for this is as follows: When C_1 is near minimum, its capacitance is small compared with the

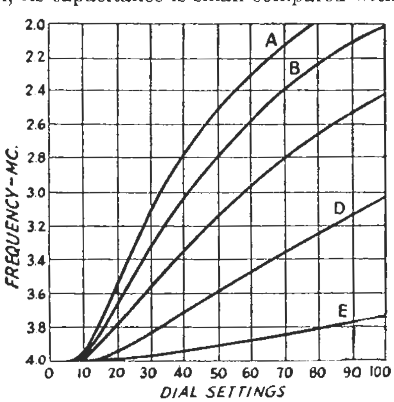


Fig. 6

capacitance of C_2, consequently a small change in C_1 makes a relatively large change in the resultant capacitance of the two in series, and hence in the frequency of oscillation. However, when C_1 is near maximum capacitance, particularly if C_2

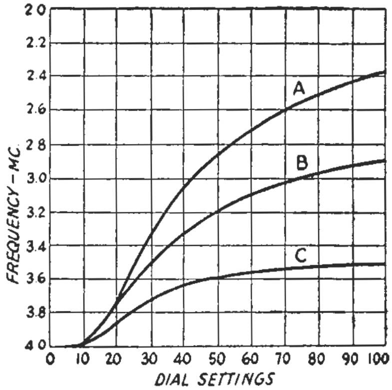


Fig. 7

is smaller than C_1, the change in resultant capacitance is considerably smaller for a given change in C_1, consequently the frequency change is small. This characteristic of series bandspread circuits makes it necessary to use some care in choosing capacitances for C_1 and C_2 if the bandspread tuning is to be reasonably uniform. If C_2 is smaller than C_1 the tuning will be relatively rapid at the high-frequency end of the band and quite slow at the low-frequency end. A better characteristic will be secured when C_2 is equal to or larger than the maximum capacitance of C_1.

The capacitors used in securing the curves of Figs. 6 and 7 showed practically no capacitance variation in the first ten dial divisions starting from minimum capacitance. This accounts for the fact that the curves begin at about 10 rather than at zero.

EXPERIMENT 37

Circuit Tracking

Apparatus: The circuit for this experiment is shown in Fig. 8. The plate power supply, tube chassis and circuit board are used. A small triode is connected as a Hartley oscillator, using a coil L from the circuit board. A 6J5 or similar small triode will be suitable. The grid leak is 50,000 ohms and the grid capacitor 100 pf. The oscillator is shunt-fed through the 2.5-mh. r.f. choke, RFC, with blocking and bypass capacitors of 0.002 μf. each. The oscillator plate voltage can be obtained from the regulated tap on the power supply, using a 0C3 regulator tube. However, voltage regulation is not essential, and it will suffice to set the output voltage from this or another supply at about 100 volts, using the ordinary voltage divider.

The various capacitors in the tuned circuit are: C_1, 25 to 50 pf. (small capacitor on the circuit board); C_2 and C_3, 250 pf. each (capacitors of higher or lower value may be used so long as the two are identical); C_4, 500-pf. fixed mica, subject to change according to circuit conditions.

A calibrated receiver is needed for measuring the oscillator frequency.

Procedure: The purpose of this experiment is to set up circuits which will track with a constant frequency difference, simulating the mixer (signal) and oscillator circuits in a superhet receiver. The oscillator is used as a convenience in checking the resonant frequency, which is measured by means of the calibrated receiver. The general coverage calibration of the average receiver will be sufficiently accurate.

To simulate the mixer or signal-frequency circuit the oscillator is first connected as shown at A in Fig. 8. C_2 is the tuning capacitor and C_1 is a parallel padding capacitor. Connect the two capacitors and the tube across 30 turns of the coil, as shown in the diagram. Set the cathode tap 10 turns from the grid end of the coil.

Adjust the receiver to 4 megacycles, set C_2 at minimum capacitance, and adjust C_1 to bring the oscillator frequency to zero beat with the receiver (the b.f.o. in the receiver should be on). Keep the receiver gain to the minimum necessary to give a good response. Move the tuning dial on C_2 ten divisions at a time, taking frequency readings by readjusting the receiver tuning to zero beat in each case, until maximum capacitance is reached.

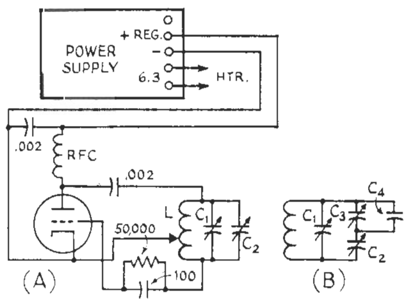


Fig. 8

Next, reduce the number of turns on the plate side of the coil by 5, so that the total number is 25. The connections from the stator plates of the two capacitors, as well as the plate-circuit lead from the tube, should all be moved down to the next tap. It will not be necessary to change the cathode tap. Set C_2 at minimum capacitance, set the receiver to 4.5 megacycles, and adjust C_1 until the signal is heard at zero beat in the receiver. The difference between 4.5 and 4 megacycles, or 500 kilocycles, represents the intermediate frequency in this experiment. Now connect C_3 in series with C_2 as shown at B in Fig. 8 and connect the 500-pf. fixed capacitor, C_4, across C_3.

Note the lowest frequency obtained on the first set of measurements, and add 500 kc. to it to find the low-frequency limit of the tuning range required in the circuit when it represents the superhet oscillator. For example, if the lowest frequency was 1500 kc., the lowest frequency to which the oscillator should tune will be 1500 + 500, or 2000 kc. The complete oscillator range therefore should be from 4.5 to 2 megacycles. Set the receiver to the required lowest frequency in the oscillator range (2 Mc. in the example), set C_2 at maximum capacitance, and vary C_3 to bring the oscillator signal to zero beat with the receiver. If the signal is not heard, retune the receiver to find it. If the frequency is too high with both C_3 and C_2 at maximum, more capacitance is needed at C_4, while if the frequency is too low with C_3 at minimum and C_2 at maximum, the capacitance of C_4 should be reduced. The proper capacitance to bring the oscillator frequency to the right value at some setting of C_3 can be found by using small mica capacitors in various combinations, if necessary. After the proper setting for C_3 has been found, set C_2 at minimum capacity, set the receiver to 4.5 Mc., and readjust C_1 to bring the signal to zero beat; then go back and check the low frequency again. Working back and forth in this way a few times will bring both ends of the tuning range to the proper frequencies. When this has been done, take frequency readings for every ten dial divisions of C_2, leaving the other capacitors untouched.

When all the readings have been taken, plot the data as shown in Fig. 9, showing frequency as a function of dial settings. The capacitors used in securing these curves were 250-pf. units having "straight-line-wavelength" plates. If the tracking is perfect, there will be a constant frequency difference of 500 kc. between the "signal" and "oscillator" curves. This ideal oscillator curve is shown by the dashed line in Fig. 9. Although the measured curve does not track perfectly, it follows the ideal curve fairly closely. Perfect tracking is not possible when identical capacitors are used in the signal and oscillator circuits, but in practice quite good results can be obtained. In the case shown in the curves, the maximum deviation from the ideal curve is about 75 kilocycles. The tracking is exact at the ends of the curve, since these points were set by measurement, and also is exact at a setting of about 27 on the dial, the oscillator frequency being slightly too high below this dial setting and too low above it. Such "crossing over" is characteristic of this tracking method.

Plot an ideal oscillator curve on the same sheet and compare the measured curve. Then take a new set of data by setting the oscillator frequency to give exact tracking at 20 and at 80 on the dial. This can be done by methods similar to those described above for aligning at the ends of the dial scale. In the curves of Fig. 9 the required oscillator frequencies would be 3575 + 500 kc. = 4075 kc. at 20, and 1725 + 500 = 2225 kc. at 80. Once the alignment has been secured, take frequency readings at every 10th division and compare them with the ideal curve. It will be found that the tracking is much more accurate over the majority of the tuning range than it was in the first case. In other words, the

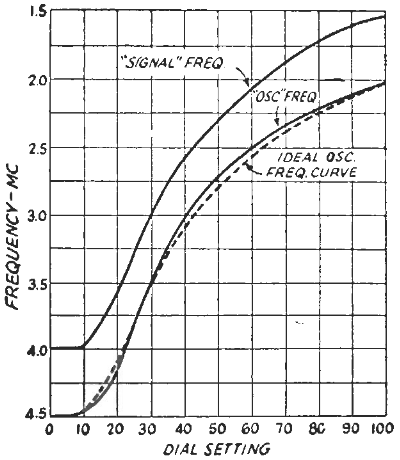


Fig. 9

tracking adjustments should be made at frequencies somewhat removed from the extreme ends of the range in order to secure a better compromise over the whole range. Although there is not room to plot such a curve on Fig. 9, this procedure, applied to the set-up which gave the curves shown, resulted in reducing the maximum tracking error to less than 50 kc., while the average error over the whole range was considerably less.

The importance of proper tracking on the sensitivity of the receiver can be appreciated by referring to the selectivity curves taken in connection with Exp. 15 (Fig. 9, page 32, Part 3). Although this curve happens to be for a frequency (3700 kc.) at which the tracking is good in Fig. 9 above, it can be seen that if the tracking error of 75 kc. had occurred at this frequency the signal strength would be reduced in the ratio of 3 to 1, using the curve for no loading, and in the ratio of 2 to 1 for a load of 100,000 ohms. In other words, the higher the Q of the signal circuit the more serious is the effect of poor tracking.

EXPERIMENT 38

Discriminator Operation

Apparatus: This experiment requires the use of the power supply, oscillator, vacuum-tube voltmeter, test kit, tube chassis and circuit board. The circuit arrangement is shown in Fig. 10. The coil L_1 is the movable coil from the circuit board, and replaces the plug-in plate coil normally used in the oscillator. The latter coil should be removed from its socket. The oscillator is operated self-controlled, using the grid coil instead of the crystal. About 30 turns should be used in coil L_1.

L_2 is the fixed coil on the circuit board, with 30 turns in use. The tap to which C_2 and the r.f. choke are connected is at the 15th turn. C_2 is the small capacitor on the circuit board, maximum capacitance 25 to 50 pf. C_1 is the tuning capacitor associated with the fixed coil on the board; a maximum capacitance of 100 pf. or more will be satisfactory. The rectifier tube is a 6H6 with 100,000-ohm load resistors bypassed by 100-pf. mica capacitors. Larger bypass capacitances may be used if more convenient. The two r.f. chokes indicated in the diagram are 2.5-millihenry units. The loading resistor R is 50,000 ohms, 1 watt. Do not use a wire-wound resistor.

The v.t. voltmeter obtains its plate supply from the regulated tap on the power supply, using a 0D3 regulator tube. The oscillator plate supply is from the variable tap, which should be adjusted to give 15 or 20 volts under load.

A calibrated receiver is needed for measurement of oscillator frequency. The calibration of an ordinary communications receiver will be sufficiently accurate.

Procedure: To obtain reasonably good results in this experiment it is necessary to use some care in setting up the circuit. The discriminator circuit must be perfectly symmetrical if the effects of stray currents are to be avoided. C_1 preferably should be a split-stator capacitor on this account, but the ordinary type of capacitor can be used if a balancing capacitor, C_3, is installed. This capacitor compensates for the somewhat smaller capacitance to ground from the stator plates than from the rotor plates, if the capacitor is of the usual type having a metal frame to which the rotor plates are connected. C_3 may be a small mica-insulated trimmer having a capacitance range of 3 to 30 pf. Also, the tap on L_2 should be at the exact center of the coil. When using the coil on the circuit board the five unused turns at one end will have some effect on the symmetry; it would be better to wind a new coil having 30 turns only, but with care it will be possible to perform the experiment satisfactorily with the original coil. Another possible source of error is in capacitive coupling between the adjacent ends of L_1 and L_2; this can be minimized by arranging the

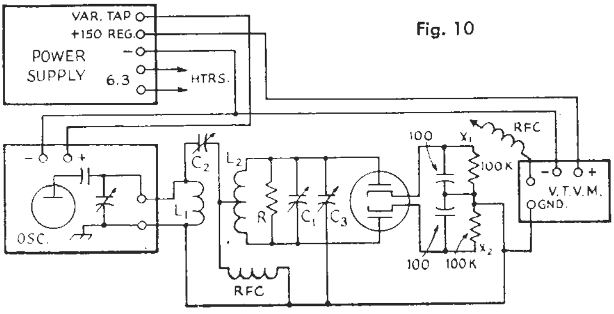


Fig. 10

circuit so that the grounded end of L_1 faces L_2 when the coils are coupled.

The v.t. voltmeter is set on the low range. It is used only for measuring the rectified voltage developed across the load resistors. The rectified voltage could be determined by measuring the d.c. current through the 100,000-ohm resistors, but the current is too small to be read with sufficient accuracy by a 0–1 milliammeter. The r.f. choke in the "hot" lead of the v.t.v.m. is used to prevent r.f. current from flowing through the voltmeter circuit. It should be clipped to the end of the flexible lead from the voltmeter so it is as close as possible to the point of measurement. The rectified output of each diode section is measured between the common (ground) connection between the two resistors and the points X_1 and X_2. The polarity of the measured voltage is always positive in this circuit arrangement.

As a preliminary check of the circuit symmetry, disconnect C_2 from L_2, couple L_1 and L_2 together, and set the oscillator frequency (by means of the variable capacitor in the oscillator unit) to about 3 megacycles, as indicated by the receiver. Connect the v.t.v.m. to either X_1 or X_2, and tune C_1 for maximum v.t.v.m. reading. Adjust the coupling between the two coils to bring the v.t.v.m. reading to about half scale. C_3 should be set at about minimum capacity. Set C_1 as carefully as possible to resonance, indicated by maximum reading. Since the rotor of C_1 is not at ground potential, some hand-capacitance effect will be observed; this can be compensated for by setting C_1 to a slightly higher capacity than exact resonance, so that the v.t.v.m. reading becomes maximum when the hand is removed. Note the v.t.v.m. reading and shift the "hot" lead to the other diode resistor. If the circuit is symmetrical the two readings will be the same. A difference of 10 per cent is permissible, but if the discrepancy is larger the probability is that the coil is not accurately center-tapped. In such case it is advisable to try a new coil, wound with greater accuracy.

When the two voltages are found to check satisfactorily, remove L_1 from the vicinity of L_2 so that the coupling between the two coils is negligible. Connect C_2 to L_2 and adjust its capacitance so that a deflection of about half scale is obtained on the v.t.v.m., the v.t.v.m. being connected to either X_1 or X_2. Swing C_1 through resonance, observing the voltmeter indication; at resonance there will probably be a rapid change in in the reading. Adjust the capacitance of C_3 to make this change as small as possible. The proper setting is likely to be near minimum capacitance, and when the circuit is properly balanced the pointer of the indicating instrument should give only a small flicker, or none at all, as C_1 is tuned through resonance. Under these conditions the rectified voltages measured at X_1 and X_2 should be within a few per cent of being equal. However, such voltage measurements may not be valid if there is appreciable inductive coupling between the two coils. This point can be checked by observing, with C_2 disconnected, whether the v.t.v.m. shows any indication when C_1 is tuned through resonance.

The following explanation of discriminator action, more detailed than that given in the *Handbook*, should be of assistance in interpreting the results of the subsequent measurements:

When L_2 is coupled inductively to L_1 a current flows in the circuit formed by L_2C_1; it may have the instantaneous direction indicated by the arrows in Fig. 11-A. The voltage E_1 developed by the current in flowing through the reactance of the part OA of the coil is applied to one diode and that from the current flow through OB, E_2, is applied to the other diode. The instantaneous current is flowing toward the center-tap in OB and away from it in OA; that is, viewed from the center-tap the currents are 180 degrees out of phase. Consequently the two voltages E_1 and E_2 also are out of phase with respect to the center-tap. These two voltages are equal, if the circuit is balanced, and result in equal rectified voltages from the two diodes. Because of the way in which the load resistors are connected, the points X_1 and X_2 are positive with respect to the common connection between the two resistors, so that the total voltage measured between X_1 and X_2 will be the *difference* between the two voltages. This difference will be zero, since the two voltages are equal.

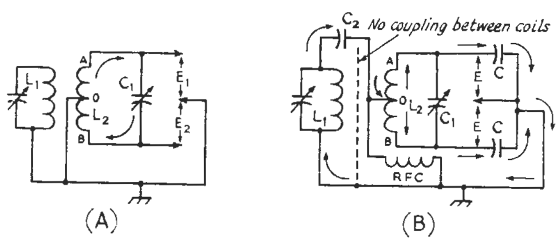


Fig. 11

When L_2 is not coupled inductively to L_1 but has its center-tap connected to the upper end of L_1 by means of C_2, the r.f. voltage across L_1 causes a current to flow as indicated by the arrows in Fig. 11-B. The circuit is completed through the capacitances of the diode rectifiers and the bypass capacitors across the diode load resistors, the effective capacitances being lumped together and represented by the capacitors labeled C in Fig. 11-B. At the center tap of L_2 the current divides and flows through the two branches of the coil. Viewed from the center tap these two components of the current are in phase. Since the diode capacitance is only of the order of a few picofarads, the reactance in this part of the circuit is quite high compared with the reactance encountered in either branch of L_2, with the result that nearly all of the voltage across L_1 appears between the diode plates and the return circuit (ground), without appreciable shift of phase. The r.f. choke provides a d.c. return circuit for the diodes but prevents short-circuiting the r.f. voltage in the return lead. The voltages between A and B are in phase with respect to the center tap, hence there is no difference of potential between A and B. This is the reason why varying the capacitance of C_1 should have no effect on the output voltage with the capacitor coupling only; no current flows through the capacitor because no voltage appears across its terminals. Since the same voltage is applied to both diodes, the rectified output voltages are the same from each, and again the total voltage between points X_1 and X_2, Fig. 10, is zero.

When the two methods of coupling are combined, the operation of the circuit is determined by the phase relationships existing between the voltages E, E_1 and E_2, Fig. 11. Both coils are in the same magnetic field, consequently the voltages *induced* in both are in phase. In the case of the primary, L_1, this induced voltage is the voltage appearing across the coil, since it is caused by the current flowing in L_1. The voltage induced in the secondary, L_2, is small, but causes a large current to flow in the series circuit formed by L_2 and C_1, when the circuit is resonant. At series resonance the induced voltage and current are in phase, since the inductive and capacitive reactances cancel, therefore the secondary current and the primary voltage are in phase. In flowing through the reactance of L_2 the current builds up a large resonant voltage (in proportion to the Q of the circuit) which appears across the terminals A and B, Fig. 11-A. In the coil this reactive voltage leads the current by 90 degrees, as in any inductance. These relationships are shown in Fig. 12-A, where E_p represents the primary voltage, E_s the voltage induced in the secondary, I_s the secondary current in phase with both the primary voltage and induced secondary voltage, and E_x the resonant voltage appearing across L_2, 90 degrees ahead of I_s in phase. (See Exps. 12 and 13.)

Viewed from the center tap of L_2 the reactive voltage consists of two equal components 180 degrees out of phase, as explained above. This division of the voltage can be represented by two lines of equal length 180 degrees apart, as shown in Fig. 12-B, labeled E_1 and E_2 to correspond to the voltages indicated in Fig. 11-A. The primary voltage, indicated by E to correspond to Fig. 11-B, is now 90 degrees behind (in the counterclockwise direction) one part of the reactive voltage E_1 and 90 degrees ahead of the other part E_2. The resultant voltages appearing across each half of the coil, and consequently the voltages applied to each diode, are found by the triangular relationship. The resultant voltage can be found by drawing lines (shown dashed in the drawing) parallel to the voltage lines, beginning at the ends, to form a parallelogram. The diagonal of the parallelogram gives the amplitude of the combined voltage. At resonance, the two resultant voltages are equal, as shown by Fig. 12-B. The r.f. phase relationship between them is of no importance since it disappears in rectification. Since the amplitudes of the two voltages are the same, the rectified voltages are equal and the total output voltage (between X_1 and X_2, Fig. 10) is zero.

If the applied frequency is lowered, leaving the tuning of L_2C_1 unchanged, the voltage induced

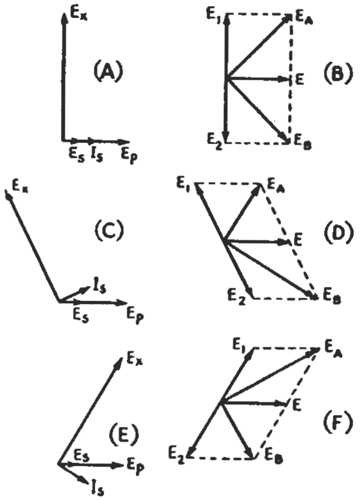


Fig. 12

in L_2 is still in phase with the voltage across L_1, since both voltages result from the current flowing in L_1. However, the series circuit formed by L_2C_1 is no longer resonant. Since the frequency has been lowered, the inductive reactance of L_2 is smaller than the capacitive reactance of C_1, hence the net reactance of the circuit is capacitive. As a result, the current flowing in the circuit leads the induced voltage. This is shown at Fig. 12-C, where the designations correspond to those of Fig. 12-A. The reactive voltage, E_x, is 90 degrees in advance of the current, as before, and is therefore drawn at right angles to it as shown. From the viewpoint of the center tap the conditions are as shown in Fig. 12-D, where the reactive voltage has again been split into two parts, E_1 and E_2, drawn at the same angle with respect to the primary voltage, E, as in Fig. 12-C. On completing the parallelograms to find the resultant voltages E_a and E_b, it is found that the amplitude of E_a has decreased and that of E_b increased, because of the shift in phase of the voltage developed in the resonant circuit. Consequently the voltage applied to one diode is greater than the voltage applied to the other. The rectified voltage appearing across the terminals X_1 and X_2 is the difference between the rectified output voltages of the two diodes. Since the diode on side A is assumed to have the smaller voltage (sum of E_1 and E, phase considered) it is less positive than the diode on side B. Hence A is negative with respect to B. If X_1 corresponds to A and X_2 to B, X_1 is negative with respect to X_2.

The conditions existing when the applied frequency is higher than the resonant frequency of L_2C_1 are shown in Fig. 12 at E and F. In this case the net reactance of the series circuit is inductive and the current lags behind the induced voltage. On dividing the reactive voltage into the two components it is found to combine with the primary voltage as shown in Fig. 12-F. In this case E_a is larger than E_b, so that the *other* diode now has the greater voltage applied. The rectified output voltages of the two diodes are in proportion, consequently a voltage appears between X_1 and X_2. However, the polarity of this voltage is opposite to that resulting from applying a frequency lower than the resonant frequency to the circuit, since the second diode is now at the higher potential.

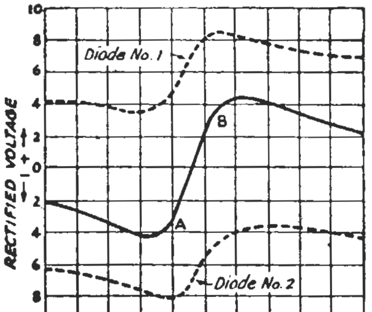


Fig. 13

The resultant voltage on either side, for a given frequency deviation, depends upon the amplitudes of the r.f. voltages acting in the circuit and on the circuit Q. The primary voltage, E, is independent of the Q of the secondary circuit since there is no resonant effect so far as it is concerned. In the case of an i.f. transformer, this voltage will depend upon the Q of the primary circuit in the same way that it does in any tuned circuit, so that the voltage will decrease on either side of the resonant frequency. (In the experimental set up this variation is eliminated since the oscillator output voltage is practically constant over the frequency range used.) However, the current which flows in the secondary circuit as a result of the induced voltage will depend both in amplitude and phase on the Q of the secondary circuit. If the Q of the circuit is low, the change in amplitude is relatively slow and the phase change is likewise slow. If the circuit Q is high, both amplitude and phase change rapidly with frequency. For these reasons the frequency deviation at which the maximum resultant voltage (combination of reactive voltage and primary voltage) occurs will be larger as the Q of the circuit is made smaller. Conversely, if the Q of the secondary circuit is high the maximum resultant voltage will come at a relatively small frequency deviation from resonance. These facts can be made clear by assuming the induced voltage and reactance to be fixed, and then calculating the reactive voltage and phase change for various assumed values of internal resistance in the circuit (see Exps. 12 and 13).

To obtain the characteristic of the experimental discriminator, after having made the checks for circuit balance previously described, first move L_1 away from L_2 so that the inductive coupling is minimized, and then adjust C_2 so that the v.t.v.m. indication is at or slightly below half scale. Then disconnect C_2 from L_2, and couple the two coils so that the v.t.v.m. gives about the same indication as when coupling through C_2 alone. The voltage measurement may be made on either diode. Then restore the connection between C_2 and L_2, set the receiver to 3 megacycles, adjust the oscillator frequency to zero beat, and carefully tune C_1 to as nearly exact resonance as possible. The resonant point can best be checked by the effect of C_1 on the oscillator frequency. The reaction of the secondary circuit on the oscillator will be greatest at resonance, hence the oscillator frequency change will be most marked at this point.

Once the resonant point is found, do not touch the secondary tuning controls or the coupling between L_1 and L_2. Set the oscillator frequency to 2.75 Mc., as checked by the receiver calibration, and measure the rectified output voltage of both diodes. Then increase the frequency in steps of about 25 kc., taking voltage readings each time, until a frequency of 3.25 Mc. is reached. When the complete set of readings has been secured, convert the readings to volts by means of the v.t.v.m. calibration curve. The data may be plotted as shown in Fig. 13. Since the output voltage of the discriminator is taken between the points X_1 and X_2, Fig. 10, and the relative polarity of the voltage with respect to one end such as X_2 (which is grounded in the normal discriminator circuit) depends upon which diode is delivering the largest output voltage, the output of one diode can be plotted as "positive" voltage and the output of the other as "negative" voltage. That is, if X_2 is grounded the mid-connection between the two load resistors will be negative with respect to ground, because of the direction of rectified current flow, while point X_1 will be positive with respect to the mid-connection because the rectified current flows in the opposite direction through the upper load resistor. If the output voltage of the upper diode is larger than that of the lower, the net output voltage will be positive, and vice versa. Hence the output of the lower diode may be plotted as a negative voltage and the output of the upper as a positive voltage. The dashed curves in Fig. 13 show the results of such measurements. Below resonance the output of the upper diode (No. 1) decreases very slightly to a minimum at about 2.9 Mc., when it rises rather rapidly to reach a maximum at about 3.025 Mc. As the frequency is further increased the output continues to decrease rather gradually. The curve for the second diode closely resembles the first except that the minimum occurs on the high-frequency side of resonance and the maximum on the low-frequency side. The region of rapid change is the region in which the phase shift is most rapid. With a lower circuit Q — obtained, for instance, by using a lower value of resistance at R — the change would be less abrupt, while with a larger loading resistance (or none at all) the rise in voltage in the vicinity of resonance would be more steep.

The discriminator output voltage is the difference between these two curves. To plot it, subtract the voltage from diode No. 2 from that of diode No. 1 at the same frequency, selecting as many points as are necessary to permit drawing a curve. If the output of No. 2 is larger than No. 1, the output voltage is negative, and vice versa. The solid curve shows the result of taking the difference between the two dashed curves in Fig. 13. The curve has a negative maximum at a little over 2.9 Mc. and a positive maximum at about 3.05 Mc. It crosses the zero line (equal voltage outputs from the two diodes) at 2.98 Mc., showing that this is the resonant frequency. The peaks are separated by about 150 kc. in this particular characteristic. The characteristic is straight between the points A and B, which would constitute suitable limits of frequency deviation for undistorted detection. Point A is at 2.95 Mc. and point B at 3.01 Mc., so that the maximum frequency swing which could be handled by this circuit would be 60 kilocycles. That is, the maximum permissible frequency deviation, corresponding to 100 per cent modulation of an amplitude-modulated transmitter, would be 30 kilocycles.

For further investigation the same data may be taken with no loading on the secondary circuit, and also with 25,000 ohms at R. As the peaks come closer together it will be found that the adjustments are more critical, and measurements must be taken at smaller frequency intervals to obtain significant results. In all cases it is advisable to maintain the oscillator r.f. output voltage as constant as possible. Normally it should not vary more than a few per cent over the range 2.75 to 3.25 Mc., but if the variation is larger it may be compensated by adjusting the d.c. plate voltage on the oscillator. The r.f. voltage may be measured by connecting the v.t.v.m. across the primary circuit, using the medium voltmeter range.

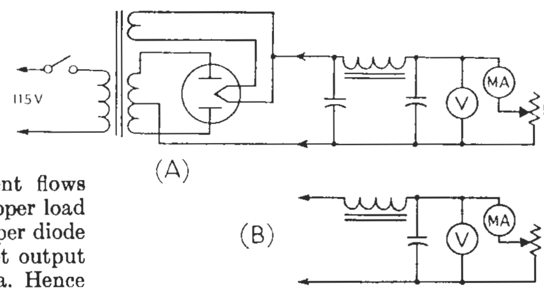


Fig. 14

EXPERIMENT 39

Voltage Regulation with Capacitor- and Choke-Input Filters

Apparatus: The plate power supply and test instrument are used for this experiment. An adjustable load resistor, R, Fig. 14-A, also is required. It is convenient to use two resistors in series for this purpose, one a 25,000-ohm 25-watt unit and the other 25,000 ohms with a 50-watt rating. Both should be adjustable by frequent taps or sliders. Disconnect the regular bleeder resistance in the power supply and substitute the load resistor as shown. The test instrument may be used to read both current and voltage if provision is made to complete the circuit to the resistor when voltage readings are being taken. A push-button can be used for this purpose.

For the choke-input filter test, the first filter capacitor in the power supply should be temporarily disconnected, giving the circuit shown in Fig. 14-B.

Procedure: The purpose of this experiment is to compare the effect of choke- and capacitor-input filters on output voltage as the load current is varied. Taking first the capacitor-input filter, measure the voltage with no load except the voltmeter on the power supply. Then connect the load resistor and increase the current in steps of approximately 10 milliamperes until a maximum current of 100 ma. is reached, noting the output voltage at each current. Use the heavier load resistor for the higher currents. Then disconnect the first filter capacitor so that the circuit becomes that of Fig. 14-B and repeat the procedure. Plot the data to show output voltage as a function of load current.

The curves of Fig. 15 show the results of such a procedure using the power supply described in Fig. 4, Part 3. The transformer in the supply is rated at 350 volts each side of the center tap. With no load on the supply the output voltage is approxmately the peak value of a 350-volt sine wave, or 350 × 1.41 = 490 volts. This is true with either the capacitor- or choke-input filter. As the load current increases, the output voltage drops off with the capacitor-input filter as shown by the upper curve in Fig. 15. With the choke-input filter the decrease is most rapid at low load currents, then levels off at a current of 30 to 40 milliamperes. In this region the output voltage is equal to the *average* value of the a.c. transformer output (peak × 0.636 or 310 volts) and further decreases in voltage result from *IR* drop in the filter choke and rectifier tube, as well as voltage drop in the transformer itself. This is the characteristic operation of the choke-input filter, and results from the tendency of the input choke to smooth out the variations in the output current of the rectifier, permitting only the direct current (which is the average of the rectified wave) to flow. With the capacitor-input filter, on the other hand, the input capacitor charges with each pulse of rectified current from the rectifier, and discharges only as much (when the rectifier output is in the low-voltage part of the cycle) as is permitted by the time constant of the circuit. Consequently the output voltage will be high when the load current is low, and will decrease when the load current is high, since a high load current represents a low load resistance and hence a smaller time constant, the capacitance in the circuit being fixed. Increasing the input capacitance will increase the time constant and thus increase the output voltage for a given load current, and a vice versa.

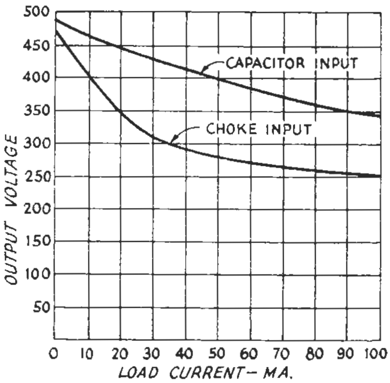


Fig. 15

The point at which the output voltage of a choke-input rectifier reaches the average value of the rectified a.c. is determined by the relationship between load resistance and choke inductance, as explained in the *Handbook*. With a given load resistance, the initial drop in voltage comes at a smaller load current as the input inductance is increased. In Fig. 15 the "critical" point is with a load current of about 30 ma. The load resistance at this point is equal to E/I, or 310/0.030, which is approximately 10,000 ohms. Using the formula for critical inductance, $L = R/1000$, indicates that the effective inductance is about 10 henrys at this current. The voltage regulation beyond this point is not particularly good in Fig. 15 because of the voltage drops in the choke and rectifier. With mercury-vapor rectifiers and low-resistance chokes the regulation can be held within 10 per cent in a reasonably well-designed power supply

Part Eight

WAVE PROPAGATION, ANTENNAS AND TRANSMISSION LINES

THE practical difficulties of measurement make it impossible to devise satisfactory simple experiments on antenna systems. Also, the limitations of simple test equipment preclude the possibility of comprehensive measurements on transmission lines. In this section of the course there is, as a result, only one experiment.

ASSIGNMENT 31

Study *Handbook* sections on wave propagation.

Questions

1) What is meant by the polarization of a radio wave?
2) Name the two general groups into which radio waves are classified as to the way in which they travel.
3) How may the direction of travel of a radio wave be changed?
4) What is the ionosphere?
5) Name the important ionosphere layers. What are their approximate heights?
6) What is meant by the term "critical frequency"? What is its relationship to maximum usable frequency?
7) What is the "wave angle" or "angle of radiation"?
8) What is the skip zone? What factors determine the skip distance?
9) Why do radio signals fade?
10) Name three means by which u.h.f. signals may be transmitted beyond the horizon. What are the general characteristics of each?

ASSIGNMENT 32

Study *Handbook* sections on antenna principles and the half-wave antenna.

Questions

1) What factors determine the optimum angle of radiation of a given antenna system?
2) What is meant by the impedance of an antenna? Where is it usually measured?
3) How is the polarization of an antenna system specified?
4) How are the standing waves of current and voltage distributed along a half-wave antenna?
5) What is the proper length, in feet, of a half-wave antenna which is to be operated on 7150 kc.? On 5000 kc.? On 12,500 kc.?
6) What is the resonant frequency of an antenna 32 feet 6 inches long?
7) What is a "radiation pattern"? Describe the pattern for a half-wave antenna.
8) What is the approximate value of the impedance of a half-wave antenna? How does the impedance vary at different points along the antenna wire?
9) When a horizontal antenna is used, at what height, in feet, should the antenna be erected if maximum radiation is desired on 14,200 kc. at a wave angle of 20 degrees, assuming ground having high conductivity?
10) In general, how does the optimum radiation angle vary with the height above ground of an antenna?
11) What factors determine the shape of the effective radiation pattern of an antenna, considering such a pattern to give relative field strength in various compass directions?
12) What is the effect of the ground on the impedance of an antenna system?
13) If the optimum wave angle of a half-wave horizontal antenna is in the vicinity of 45 degrees, would you expect the antenna to show any observable directive effects (in the horizontal plane) at distances for which such a wave angle would be useful?
14) What is meant by the terms "current feed" and "voltage feed"?
15) What is the disadvantage, in ordinary cir-

cumstances, of feeding power directly into an antenna without using a transmission line?

16) Draw a circuit showing current feed to a half-wave antenna. Explain the uses of the various circuit components.

17) A half-wave antenna has a resonant frequency of 3650 kilocycles. It is to be current-fed, using a coupling coil having 16 turns 2 inches in diameter, spaced 8 turns to the inch. If two tuning capacitors are used, one on each side of the coil, what capacitance is required in each, assuming that they are adjusted to equal capacitances?

ASSIGNMENT 33

Study *Handbook* section on transmission lines. Perform Exp. 40.

Questions

1) Name four common types of transmission lines used for carrying radio-frequency power.

2) What are the principal requirements for a good transmission line?

3) Why is it necessary to use relatively small spacing between the wires of a transmission line? What determines whether the spacing is "large" or "small"?

4) What is the "characteristic impedance" of a transmission line? What line constants determine its value?

5) The outer conductor of a certain concentric transmission line has an inside diameter of ½ inch. If the inner conductor is No. 10 copper wire, what is the characteristic impedance of the line?

6) What is the characteristic impedance of a two-wire line using No. 18 wire if the spacing, center to center, is 1½ inches? What is the characteristic impedance if a line of the same spacing is constructed of No 12 wire? If the line is made from half-inch tubing?

7) Define standing-wave ratio. What determines the standing-wave ratio on a line terminated in a resistance?

8) A 500-ohm line is terminated in a resonant antenna having a resistance of 25 ohms. If the current flowing into the antenna terminals is 2 amperes, what is the current at a current node? What are the maximum and minimum values of the voltages along the line?

9) A 600-ohm line is terminated in a resistance of 70 ohms. If the line is a quarter wavelength long what is the impedance looking into the input terminals? What is the nature of the impedance? What is the impedance if the line is one-half wavelength long?

10) A quarter-wave line section is to be used as an impedance transformer to match a 100-ohm load to a 550-ohm transmission line. What value of characteristic impedance is required in the matching section? How could such a line be constructed?

11) Under what conditions does a transmission line show reactance at its input terminals? When does it show resistance only?

12) What is the difference between a resonant and a nonresonant line?

13) What is the purpose of tuning equipment at the input end of a transmission line? Describe a method by which the loading on the transmitter may be adjusted.

14) A 600-ohm nonresonant line is to be coupled to a transmitter by means of a parallel-tuned circuit with the line connected to the ends. If the frequency is 14 Mc., what would be suitable values for the inductance and capacity? If the power is 500 watts, what current flows into the line, and what is the voltage across the line terminals?

15) Compare the various systems of coupling with respect to harmonic transfer.

16) A half-wave antenna is fed at the end by a transmission line ¾ wavelength long. Which should be used, series or parallel tuning? Which should be used if the same line is connected to the center of the antenna?

17) What, in principle, must be done to terminate a transmission line in its characteristic impedance when it is connected to an antenna?

18) What are the respective advantages and disadvantages of resonant and nonresonant operation of transmission lines?

19) A 600-ohm line is to be matched to a half-wave antenna using a delta matching transformer. If the operating frequency is to be 7100 kc., find the dimensions of the system.

20) A 500-ohm line is connected to the center of a half-wave antenna having a resistance of 70 ohms. What is the standing-wave ratio on the line? If it is desired to bring about an impedance match between the antenna and line, using a quarter-wave linear transformer with conductors of half-inch tubing, what center-to-center spacing is required between the conductors? Find the length of the antenna and the length of the matching section if the frequency is 8.15 megacycles.

21) Describe the method of matching a transmission line to an antenna when the line is tapped on an open-wire quarter-wave matching section, the matching section being connected to the center of the antenna.

ASSIGNMENT 34

Study *Handbook* sections on long-wave antennas and multiband antennas.

Questions

1) What is a "long-wire" antenna?

2) What is the general effect of increasing the

length of an antenna, in terms of half-wavelengths, on the directive pattern of the antenna? What is the effect on the radiation resistance?

3) What is the "power gain" of an antenna? How is it possible for an antenna system to give a gain in field strength, in its optimum direction, as compared to the field strength from a half-wave antenna driven with the same power input?

4) An antenna is to be 3 wavelengths long at an operating frequency of 7.2 megacycles. What is its length in feet?

5) An antenna 130 feet long is to be operated on its fundamental, 2nd, 3rd, 4th, and 5th harmonics. What is the resonant frequency in each case? Compare the harmonic resonant frequencies with the actual harmonics of the fundamental frequency.

6) Why cannot a harmonic antenna be fed at a current node (except when fed at the end) if it is to operate as a long wire?

7) Describe an antenna system capable of operating on several harmonically related bands.

8) Why is it difficult to use nonresonant feeders with a multiband antenna?

ASSIGNMENT 35

Study *Handbook* sections on directive arrays.

Questions

1) What is the physical arrangement of the elements of an antenna array when the elements are collinear?

2) What is the difference between broadside and end-fire arrays? What is the physical arrangement of the elements in such arrays?

3) What is the basic principle upon which antenna elements are formed into arrays to secure power gain and directivity?

4) What does the term "stacking" mean in connection with the elements of a directive array?

5) Sketch the arrangement of a simple four-element array using two parallel pairs of collinear elements, connected for broadside directivity with half-wave spacing. Connect the feedline to the junction of one pair of collinear elements and show proper phasing of the transmission line connecting to the other pair of collinear elements.

6) Using two parallel driven elements spaced a half-wavelength apart, indicate proper connections of the transmission lines to give (a) broadside operation and (b) end-fire operation, when (1) the power is introduced into the system at the end of one element, (2) when the feed point is at the middle of the line connecting the two elements, and (3) when the feed point is at the center of one element. Show relative direction of current flow in the various wires.

7) What is a parasitic element? How is radio-frequency power fed to such an element?

8) What is the difference between a reflector and a director?

9) What is the meaning of the term "front-to-back ratio"? What relation does this ratio bear to the power gain of the antenna?

10) What is the effect on the radiation resistance of a driven element when the spacing between such an element and a director or reflector is decreased?

11) Describe a suitable method for feeding the driven element of an antenna system consisting of such an element with one or more parasitic elements.

12) What is a "folded dipole"? What advantage does this type of antenna have over a simple half-wave antenna?

EXPERIMENT 40

Reactance Characteristics of Transmission Lines

Apparatus: This experiment requires the power supply, oscillator, a receiver capable of tuning to 30 megacycles (approximately), a small coil and variable capacitor which also can be tuned to 30 megacycles, and an open-wire transmission line about 20 feet long. The line should preferably be made of bare wire (No. 18 is convenient for indoor use) and should be stretched tightly between such supports as may be available. A spacing of about two inches between wires will be satisfactory. Both ends of the line should be insulated. Spacers to maintain uniform distance between the wires may be made of wo-inch strips of wood.

The circuit arrangement is shown n Fig. 1. Capacitor *C* may be the small capacitor from the circuit board; it should have a maximum capacitance of 35 to 50 pf. and should be of the type having semicircular plates. (Other plate shapes may be used if a calibration curve is available for the capacitor.) The coil *L* should have sufficient inductance so that the circuit formed by *L* and *C* can be tuned to 30 megacycles with *C* at approximately half capacitance. Self-supporting construction can be used, with No. 12 wire wound to a diameter of about an inch. Allowing 7 or 8 turns per inch, the number of turns required will be of the order of 10. The variable capacitor, *C*, should be provided with an insulating extension shaft five or six inches long so that hand capacitance will not interfere with tuning. It should be equipped with a 100-division dial, of the "vernier" or slow-motion type if possible, to facilitate accurate setting. The coil *L* should be mounted close to the capacitor so that the shortest possible leads can be used to connect the two.

To use the oscillator at 30 megacycles it will be necessary to provide new coils for the plate and grid circuits. The plate coil can consist of three turns of wire of any convenient size, the turns being spaced so that the total length of the coil is 1½ inches. The grid coil should consist of about five turns, wound with about ⅛ inch spacing between turns. A 5000-ohm 1-watt non-

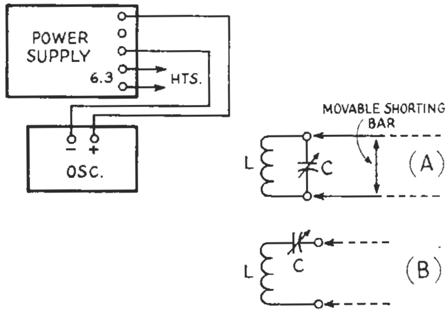


Fig. 1

inductive resistor should be connected in parallel with the grid-leak resistor already in the oscillator unit. The plate voltage on the oscillator should be set, by means of the taps and variable resistor on the power supply, to 50 volts or so.

Procedure: The purpose of this experiment is to measure, by means of its effect on a tuned circuit, the reactance at the input terminals of a two-wire transmission line, as the line length is varied. The line length is changed by means of a "shorting bar" which actually may consist of a pair of small copper-plated battery clips fastened back-to-back to extend between the wires of the transmission line. The clips will make better electrical connection to the line than a plain metal bar or knife edge, and will hold themselves in position when measurements are being made.

Set the oscillator frequency to 30 Mc., as indicated by the signal in the calibrated receiver. The actual frequency is not especially important so long as it is near 30 megacycles, but the frequency selected should be maintained throughout the experiment. Therefore the receiver should be thoroughly "warmed up" before any measurements are made. Connect L and C in parallel, but do not connect the transmission line. Put the tuned circuit formed by L and C in the position it will occupy (at the end of the line) during the experiment, and bring the oscillator near enough so that when C is tuned through resonance there will be a slight change in the oscillator frequency. The beat-frequency oscillator in the receiver should be on, to make this resonance indication readily apparent. Use the loosest coupling between the oscillator and the tuned circuit which will give a good resonance indication.

In making measurements the shorting bar is moved along the line a foot at a time, so it will be convenient to mark one of the line wires at one-foot intervals, starting from the end which will be connected to the tuned circuit. This measurement must start right at the tuned circuit itself, since any connecting wires unavoidably become part of the line.

After having set the tuned circuit to resonance, connect the transmission line as at A in Fig. 1, connect the shorting bar across the line at the three-foot mark, and readjust C to obtain the new resonance indication. The resonance point should be found near the maximum-capacitance end of the scale. If there is no indication, set C at maximum and slide the shorting bar back and forth until the resonance point is found, as indicated by a shift in the oscillator frequency. Measure the length of the line at this point, then move out to the next one-foot interval of length and adjust C for the new resonance point. Note the capacitor dial reading. Continue at one-foot intervals until the resonance point moves to the minimum end of the capacitor scale. Should the resonance indication be weak (effect on oscillator frequency just perceptible) in any case, the oscillator can be moved nearer the tuned circuit, the oscillator frequency being readjusted whenever such a change is made so that it always corresponds to the frequency to which the receiver is set. Too-pronounced indications also are to be avoided, and in case the frequency change at resonance, with the line connected, becomes greater than is necessary for easy identification, the oscillator should be moved away from the tuned circuit.

At a line length of about 13 feet the capacitance required at C for retuning to resonance probably will become too small for the capacitor range, so that further measurements cannot be made until the line becomes about 19 feet long when the capacitor again will resonate near maximum capacitance.

The parallel-tuned circuit should be used over as much of the line as possible, but in the regions where it cannot be used the series connections shown at B can be substituted. Using series tuning, start with the line one foot long, tune C to resonance, and note the dial reading. Move the shorting bar to the two-foot point, again note the dial reading at resonance, and continue at one-foot intervals until no further measurements are possible (C at minimum capacitance). Then move the shorting bar out along the line until a resonance indication is observed again, this time with C near maximum capacitance. This will probably occur at about the 15-foot point. Continue taking readings until the end of the line is reached.

To interpret the dial readings it is necessary to have a calibration for the capacitor in the tuned circuit. In only a few cases is an actual calibration likely to be available, but if the capacitor has semicircular plates an approximate calibration can be constructed without much

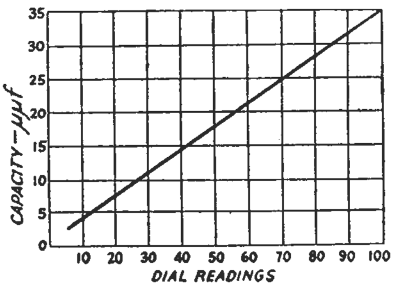


Fig. 2

difficulty. It is necessary to know the maximum and minimum values of the capacitor used; this information is usually to be found in the manufacturer's catalog. In the case of semicircular plates the capacitance is, within reasonable limits, directly proportional to the angular movement of the rotary plates over most of the capacitor range. The most important exception is at the minimum-capacitance end of the scale, where there is usually a small range of movement of the rotary plates before they actually begin to mesh with the stationary plates. This normally amounts to about five divisions on a 100-division dial. By assuming that minimum capacitance occurs at "5" on the dial scale and maximum capacitance at "100," and then drawing a straight line between these two points, the calibration will be somewhat nearer the truth than if the line is simply drawn from 0 to 100. Fig. 2 shows a calibration curve of this type. The capacitor had a rated maximum of 35 pf. and a minimum of 2.5 pf.

The capacitor calibration curve gives a means of determining the change in capacitance necessary to retune the circuit to resonance when the line length is varied. In turn these capacitance changes can be converted into reactance variations, giving the amount of reactance which must be added to or subtracted from the circuit to compensate for the reactance introduced by the line. The way in which the compensation is brought about depends upon the way in which the tuned circuit is connected; that is, whether the tuning is series or parallel.

As an example, assume that the circuit is resonated by itself and that the coil and capacitor each have a reactance of 500 ohms, as in Fig. 3-A. Suppose that the particular length of line used causes the line to have a reactance at its input terminals (at the resonant frequency) of 1000 ohms, inductive. Connecting the line to the tuned circuit is then equivalent to shunting an inductive reactance of 1000 ohms across the circuit, as in Fig. 3-B. The two inductive reactances in parallel will combine to give an equivalent reactance of $\frac{500 \times 1000}{500 + 1000}$ or 333 ohms. To make the circuit resonant, the capacitive reactance must also be changed to 333 ohms. Since reactance is inversely proportional to capacitance, the setting of the capacitor must be increased to a value which corresponds to a reactance of 333 ohms. The increase in capacitance could be brought about by leaving the original capacitor setting unchanged and adding a second capacitor in parallel, as in Fig. 3-B. The additional capacitance required would be such that its reactance would be 1000 ohms, when the two capacitive reactances in parallel would combine to give an equivalent reactance of 333 ohms. In other words, the difference between the capacitance required for tuning to resonance with the line connected, and the tuning capacitance at resonance with the line disconnected, is equivalent to a shunt capacitance having the same absolute value of reactance as the reactance exhibited by the line. The sign of the reactance is opposite to that of the line, however.

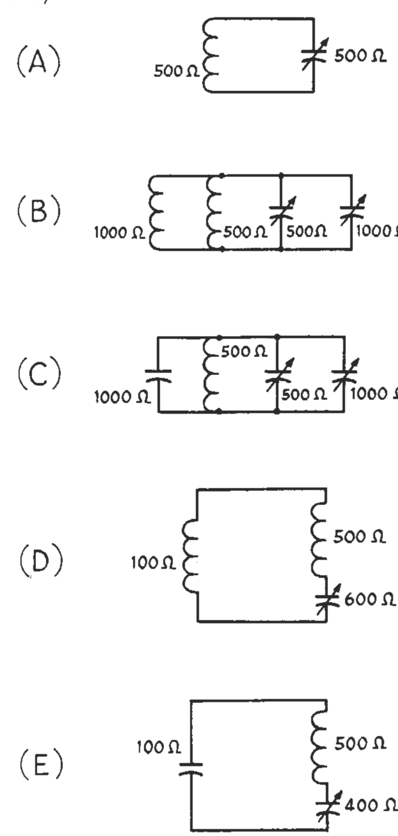


Fig. 3

When the reactance of the line is capacitive, the capacitance of the line and the capacitance of the capacitor are in parallel and hence add directly. This gives a new value of capacitive reactance to the complete circuit; if the line reactance is 1000 ohms and that of the capacitor 500 ohms, the two combine in parallel to give an equivalent reactance of 333 ohms. To bring the whole circuit back to resonance it is necessary to increase the capacitive reactance; that is, the capacitance must be decreased. This is indicated in Fig. 3-C, where the "negative" capacitance of the second capacitor is in parallel with the original capacitor. This means simply, that the setting of the tuning capacitor must be decreased until the resultant capacitive reactance in the circuit is restored to the original value of 500 ohms; this is necessary because the inductive reactance has not changed. The setting of the capacitor is simply decreased by an amount equal to the shunt capacitance added by the line. When the circuit is thus reresonated the difference between the two capacitor settings is equal to the line capacitance, hence the reactance of this difference in capacitance is equal in absolute value to the line reactance. In summary, if it is necessary to *increase* the capacitor to retune to resonance when the line is connected, the line is inductive; if it is necessary to *decrease* the capacitance the line is capacitive.

It is convenient to calibrate the capacitor in terms of these reactances so that the line reactance can be read directly from the capacitor settings. In the experimental work which led to the results described later, the capacitor whose synthetic calibration curve is shown in Fig. 2 was used. This capacitor resonated at 30 megacycles (with an 11-turn coil constructed as previously described) when set at 40 on the dial scale. Using this dial setting as a reference point, the difference in capacitance between various other settings and the reference setting was found from Fig. 2 and the corresponding reactance calculated to obtain the curves marked "parallel" in Fig. 4. For example at 40 the capacitance is 14.4 pf. while at 60 it is 21.3 pf.; the difference, 6.9 pf., represents a reactance of 770 ohms. Since the setting at 60 represents higher capacitance than the setting at 40, the line reactance is inductive and the calibration curve is accordingly plotted above the reference line in Fig. 4. Settings lower than 40 are plotted below the line to indicate capacitive reactance, which is usually considered negative. When the difference in capacitance is very small the reactance is very high, and would be infinite at 40 on the scale; that is, when connecting the line makes no difference in the tuning of the circuit. The curves of Fig. 4 have not been carried beyond 2000 ohms.

In the region where series tuning is used (when the input reactance of the line becomes too low to permit compensation by the parallel-tuned circuit), the line is connected in series with the tuned circuit and hence may be represented as a reactance in series. This is shown in Fig. 3-D, where the line has an inductive reactance of 100 ohms. The equivalent inductive reactance therefore is 600 ohms, and to resonate the circuit the capacitive reactance also must be changed to 600 ohms. That is, the capacitance must be decreased, since its original reactance was 500 ohms. The difference between the reactance at the new setting and that at the old setting must be 100 ohms (note that this is *not* the reactance of the difference in capacity.) If the line has a capacitive reactance of 100 ohms, as at E in Fig. 3, the reactance of the capacitor must be changed to 400 ohms so that the total will equal 500, the value required for resonance. This requires an

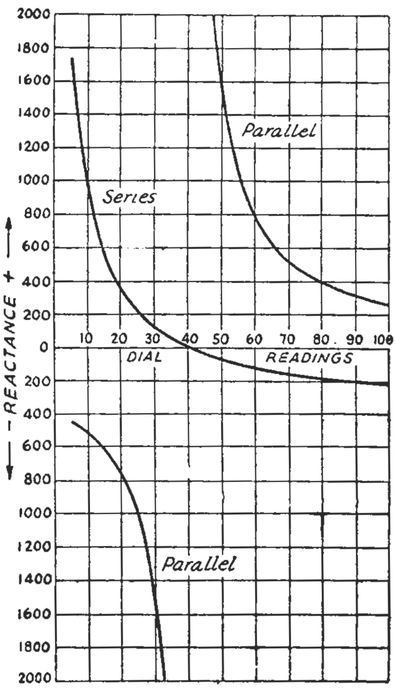


Fig. 4

increase in capacitance, with the difference in the reactance at the old and new settings equaling 100 ohms. Thus with series tuning the capacitance must be increased when the line is capacitive and decreased when the line is inductive, the opposite of the case when parallel tuning is used.

A reactance calibration for series tuning also is included in Fig. 4. It was constructed by calculating the reactances represented by various capacitor settings and then taking the difference between the reactance at a particular setting and the reactance at the reference setting at 40.

Settings below 40 represent an inductive line reactance and settings above 40 a capacitive line reactance.

Measurements with series tuning are less reliable than with parallel tuning for the reason that the actual capacitances effective in the circuit are not known accurately. Stray capacitance and distributed capacitance of the coil both have an effect on the resonant frequency, and cannot readily be calculated or estimated. On the other hand, when parallel tuning is used the measurements are based only on the *difference* in capacitance between two capacitor settings, and such a difference can be measured with considerably more accuracy even though the calibration curve is an assumed one.

When the measurements and calibration curves have been completed, the line reactance can be plotted from the data and curves in terms of length of line, measured from the tuned circuit to the shorting bar. The resulting curves should resemble those of Fig. 5, taken by this method. The parallel and series curves do not quite coincide, for the reasons just mentioned. The solid portions of the parallel curves represent regions in which measurements were possible, while the dashed parts are interpolated. Assuming that the parallel curves are more nearly correct than the series curves, the latter are useful for indicating the *shape* of the parallel curve in the regions where measurements were not possible with parallel tuning. The series curves could be made to coincide with the parallel curves by assuming a small additional capacitance acting in parallel with the tuning capacitor, an assumption which is justified by the fact that stray and distributed capacitances do exist. This additional capacitance would have to be of the order of only 1 or 2 micromicrofarads to bring the curves of Fig. 5 together.

As shown by the curves, the reactance of a short-circuited line is inductive and very low when the line length is small (in terms of wavelength). As the line length is increased the reactance increases until the length is a quarter wavelength (indicated at *B* in Fig. 5) when it is infinite. At this point the line may be connected directly across a parallel-tuned circuit without affecting its resonant frequency. Series tuning cannot be used in the quarter-wavelength region because it is impossible, with practicable components, to compensate for the large reactance introduced in series with the tuned circuit. As the line length increases beyond a quarter wavelength the reactance becomes capacitive — i.e., the line acts like a capacitor — starting at a very high value of reactance and decreasing to zero when the line length reaches a half wavelength. At this point (*A* in Fig. 5) the line acts like a short-circuit, viewed from the input terminals, hence parallel tuning cannot be used. With series tuning, however, the resonant frequency

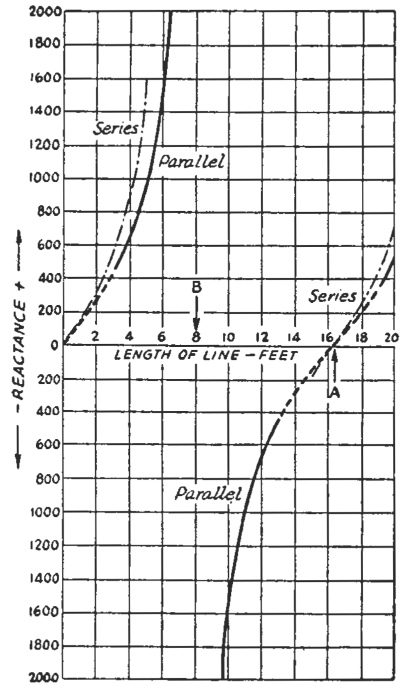


Fig. 5

of the tuned circuit itself will not be affected by connecting the line in series Beyond a half wavelength the line becomes inductive again, and if the measurements could be continued it would be found that the behavior on succeeding quarter wavelengths is the same as on the first two quarter wavelengths.

Since a quarter-wave short-circuited line has infinite reactance at its input terminals, such a line can be connected across any circuit without affecting its tuning. By considering the line represented in Fig. 5 as a short-circuited quarter-wave line in series with an open-circuited line, the same curves also indicate the behavior of an open-circuited line. Then any length of line greater than ¼ wavelength is equivalent to an open-circuited line ¼ wavelength shorter than the actual length. For example, if the short-circuited line is 10 feet long, it is equivalent to an open-circuited line having a length equal to 10 feet minus ¼ wavelength, so far as input reactance is concerned. Consequently the reactance characteristics of an open-circuited line will be the same as though the origin of the line-length axis in Fig. 5 were shifted to the right a quarter wavelength — that is, to point *B*. An open-circuited line shows capacitive reactance when less than ¼ wavelength long, zero reactance when exactly a quarter wavelength long, and inductive reactance when more than ¼ but less than ½ wavelength long.

When the line is terminated in a resistance instead of being open- or short-circuited, the behavior of the line is determined to a considerable extent by the value of the terminating resistance. For values below the characteristic impedance of the line, the reactance varies somewhat in the fashion of the short-circuited line, while for values higher than the characteristic impedance the reactance variation goes through reversals similar to those which occur on an open-circuited line. If the termination is reactive as well as resistive the reactance variation also depends upon the amount and kind of reactance in the termination. In most radio applications the termination, which is usually an antenna, will be practically resistive only. If a line is used for tuning purposes (that is, for intentionally introducing reactance into a circuit) it will be short- or open-circuited.

Answers to Problems

The answers to general questions are to be found in the *Handbook* text in the section associated with the assignment under consideration. With one or two exceptions, therefore, the answers given below are confined to those questions for which a numerical answer is obtainable. With two exceptions, the solutions to problems can be found through straightforward manipulation of equations given in the *Handbook;* these two problems are worked out in detail at the end of the list of answers.

Assignment 3:

Q. 4 — The magnetizing effect in the second case is smaller because with this method of connection the currents are flowing in opposite directions in the two coils. Consequently the magnetic fields caused by the currents also oppose, resulting in less field strength than with either coil alone at the same current.

Assignment 4:

Q. 3 — 16,670 ohms.

Q. 4 — 25 henrys.

Q. 5 — 6 henrys.

Q. 10 — 3.155 ohms; 1.902 amp. 5-ohm resistor: 1.2 amp.; 7.2 watts. 14-ohm resistor: 0.429 amp.; 2.57 watts. 22-ohm resistor: 0.273 amp.; 1.64 watts.

Q. 11 — 114,300 ohms.

Q. 12 — 0.6 second.

Q. 13 — 4 μf.

Q. 14 — 1000-ohm resistor: 35.7 volts; 0.0357 amp. (35.7 ma.). 500-ohm resistor: 35.7 volts; 0.0714 amp. (71.4 ma.). 250-ohm resistor: 26.8 volts; 0.1071 amp. (107.1 ma.). 300-ohm resistor: 18.36 volts; 0.0612 amp. (61.2 ma.). 150-ohm resistor: 9.18 volts; 0.0612 amp. (61.2 ma.). 600-ohm resistor: 27.55 volts; 0.0459 amp. (45.9 ma.).

Q. 15 — From end to 75-volt tap: 7500 ohms. Between 75-volt tap and 125-volt tap: 5000 ohms. From 125-volt tap to 250-volt end: 12,500 ohms.

Q. 16 — At "75-volt" tap: 18.75 volts. At "125-volt" tap: 56.25 volts. (See discussion on page 101.)

Q. 17 — From end to 75-volt tap: 3000 ohms. Between 75-volt tap and 125-volt tap: 2000 ohms. From 125-volt tap to 250-volt end: 5000 ohms. With load, at "75-volt" tap: 52.5 volts. With load, at "125-volt" tap: 97.5 volts. No.

Q. 18 — With 25,000-ohm divider:

	Without Load	*With Load*
7500-ohm section	0.75 watt	0.0468 watt
5000-ohm section	0.5 "	0.282 "
12,500-ohm section	1.25 "	3.00 watts
Total	2.5 watts	3.328 "

With 10,000-ohm divider:

	Without Load	*With Load*
3000-ohm section	1.875 watts	0.919 watt
2000-ohm section	1.25 "	1.013 watts
5000-ohm section	3.125 "	4.65 "
Total	6.25 watts	6.58 watts

Q. 19 — Connect 10,000 and 40,000 ohms in parallel, and the combination in series with 12,000 ohms.

Q. 20 — 316 volts; 0.00632 amp. (6.32 ma.).

Q. 21 — From negative end, 1st tap: 20 volts; second tap: 120 volts; 3rd tap: 220 volts; 4th tap (top): 300 volts.

Assignment 5:

Q. 13 — 15,000,000 cycles.

Q. 14 — 1.96 megacycles; 1,960,000 cycles.

Assignment 6:

Q. 1 — 45.5 ohms; 167.2 ohms.

Q. 3 — 1327.6 ohms.

Q. 4 — 2910 ohms.

Q. 5 — Circuit of Question 3: 0.0868 amp.; 115 volts across capacitor; 3.47 volts across resistor; 3.02 per cent power factor. Circuit of Question 4:0.0395 amp.; 104.7 volts across capacitor; 47.5 volts across resistor; 41.3 per cent power factor.

Q. 6 — 11,300 ohms; 0.1173 μf.

Q. 7 — 44.7 ohms if π is taken as 3.14; 41.5 ohms if π is taken as 3.1416.

Q. 8 — (Using 41.5 ohms for total reactance) 204.2 ohms;

	I	E_C	E_L	E_R	P.F
Complete circuit	0.049	156	154	9.8	98%
Capacitance shorted	0.00318	0	10	0.636	6.36%
Inductance shorted	0.00314	10	0	0.628	6.28%
Resistance shorted	0.241	767	757	0	0

(I in amperes, E in volts)

Q. 13 — 11,300 ohms; 26,500; 10,600; 2650.

Q. 14 — 530,000 ohms (0.53 meg.); 10.6 volts; 15 volts.

Q. 15 — 47 per cent.

Assignment 7:

Q. 1 — 19 turns.

Q. 2 — No. 13 B&S on secondary; No. 25 B&S on primary (nearest size capable of carrying the current).

Q. 3 — 2130 turns.

Q. 5 — 7500 ohms.

Q. 8 — 0.815 to 1 (or 1 to 1.23).

Q. 9 — 117.7 watts; 1.022 amp.

Q. 10 — 19,450 ohms; 12,930; 38,900; 648; 32.4.

Q. 11 — 37.4 to 1 pri. to sec.; 3.16 volts; 0.632 amp. 118.3 volts.

Q. 13 — 30 per cent; volt-ampere rating.

Q. 14 — 15 turns; 5.33 amp.

Q. 15 — 174 turns.

Assignment 8:

Q. 1 — 10 volts; 500 volts; 500 volts.

Q. 5 — 125; 55,000 ohms.

Q. 6 — Neglecting internal resistance: 11.4; 38.7 ohms. Including internal resistance: 10.4; 42.2 ohms.

Q. 8 — 4.55 μh.; 114 pf.

Q. 9 — The curve should go through the following points:

50 pf. — 41.4 μh.
100 pf. — 20.7 μh.
150 pf. — 13.8 μh.
200 pf. — 10.4 μh.
250 pf. — 8.3 μh.

Q. 10 — The curves should go through the following points:

C *pf.*	*Q* *10,000 ohms*	*Q* *5000 ohms*
50	11	5.5
100	22	11
150	33	17
200	44	22
250	56	28

Q. 11 — 3760 kc.
Q. 12 — a) 7120 kc.
b) 224.
c) 100,000 ohms.
d) 224 volts.
e) 1.12 volts; 0.56 amp.; 0.0025 amp.; 224 = *Q.*
f) 7400 ohms; error = 8.1 per cent (could be neglected), 160 per cent.
g) Neglecting internal resistance: 0.56 amp.; 0.0312 amp.; 17.9. Including internal resistance: 0.557 amp.; 0.0338 amp.; 16.5.
Q. 13 — 2.99 μh.; 42 pf.
Q. 17 — Same in both cases.
Q. 18 — 10 ohms.
Q. 19 — 63.3 pf.; 157,000 ohms.

Assignment 9:

Q. 7 — 135 μh.; 3.7 pf.; no; 1.35 μh.; 370 pf.; tap load down on coil.
Q. 8 — (For a frequency of 7100 kc.):

R	*Circuit*	*C (pf.)*	*L (μh.)*
10	A	224	2.24
20	A	112	4.48
70	A	32	15.7
150	C	200	2.5
600	C	100	5.0
2000	B	112	4.48
5000	B	44.8	11.2

Capacitance values for circuit A are maximum, for circuit B minimum; fairly wide range of values can be used with circuit C.

Assignment 10:

Q. 1 — 450 kc., 4450 kc.; 3901.5 kc., 3898.5 kc.; 1000 cycles, 14,299 kc
Q. 6 — 19 pf. or higher.
Q. 7 — 32 μf. or higher.
Q. 8 — Yes (47,000 ohms); no (5650 ohms).

Assignment 12:

Q. 11 — 0.175 watt per peak volt or 0.24 watt per r.m.s. volt.
Q. 14 — 12.04 db.
Q. 16 — 31.6 to 1, input to output.
Q. 17 — 75 volts.
Q. 18 — 97 db.

Assignment 13:

Q. 13 — 12,500 ohms.
Q. 14 — 667 ohms.
Q. 15 — 408 ohms, 48.9 μf.
Q. 16 — 9000 ohms.

Assignment 14:

Q. 13 — 250 pf.

Assignment 15:

Q. 9 — The left-hand drawing below is with linear sweep, the right-hand drawing with sine-wave sweep.

Assignment 17:

Q. 16 — 250 pf. or larger.
Q. 17 — 60 pf. or larger.
Q. 18 — In plate circuit, 38 pf. and 13.7μh.; in grid circuit, 57 pf. and 9.1 μh.

Assignment 18:

Q. 5 — 160 pf. for B; 80 pf. per section for E.
Q. 6 — 24.4 μh.

Assignment 19:

Q. 10 — 72 per cent.
Q. 16 — 3898.4 kc., 3901.6 kc.
Q. 17 — 8400 cycles, or 8.4 kc.
Q. 18 — 28,645 and 28,655 kc
Q. 23 — 150 watts.
Q. 24 — 13,333 ohms.
Q. 26 — 260 watts.
Q. 31 — 70,000 ohms; 16,130 ohms; 194 watts.

Assignment 20:

Q. 4 — Grid modulation: 40 watts (efficiency 33⅓ per cent) to 53.4 watts (efficiency 40 per cent).
Plate modulation: (75 per cent efficiency) 240 watts, neglecting increased dissipation with modulation; 160 watts, continuous 100 per cent sine-wave modulation.
Q. 14 — Continuous sine-wave modulation: 176 watts; 4860 ohms. Neglecting increased dissipation with modulation: 196 watts; 3560 ohms. (See discussion on page 102.)

Assignment 21:

Q. 4 — 112.5 watts; 1.2 to 1, primary to secondary

Assignment 23:

Q. 7 — 28.64 Mc.; 8 kc.; 2.
Q. 10 — 7239 to 7241 kc.; 1000 cycles.

Assignment 26:

Q. 13 — 6.7 pf.; 45 pf. less minimum capacitance of bandspread capacitor.
Q. 14 — 7.53 to 9.2 Mc.; 6.02 to 6.8 Mc.; 4.6 to 4.91 Mc.
Q. 15 — 3.34 to 4.07 Mc.
Q. 17 — 44.2 pf.; 32.2 μh.

Assignment 27:

Q. 4 — 13,085 kc., 13,995 kc.; images, 12,620 kc., 14,450 kc. respectively.
Q. 12 — 4455 to 8455 kc.

Assignment 30:

Q. 13 — 120 cycles; 50 cycles.
Q. 20 — 50,000 ohms; 50–5 henrys (minimum), 50–10 henrys for optimum inductance at full load; 5.7 μf. with minimum inductance, 4 μf. with optimum inductance.
Q. 21 — 886 volts.
Q 22 — 1215 volts r.m.s. each side c.t.; 455 v.a.; No. 27.
Q. 28 — Between ground and 100-volt tap, 10,000 ohms; between 100-volt and 250-volt taps, 5000 ohms; between 250-volt tap and end, 1150 ohms. Power dissipation. 1, 4.5, and 4.9 watts in respective bleeder sections; 10.4 watts total.

Assignment 32:

Q. 5 — 65.5 ft.; 93.6 ft.; 37.4 ft.
Q. 6 — 14,400 kc.
Q. 9 — 52 feet.
Q. 17 — 447 pf.

Assignment 33:

Q. 5 — 95.5 ohms.
Q. 6 — 517 ohms; 433 ohms; 215 ohms.
Q. 8 — 0.1 amp.; 1000 volts; 50 volts.
Q. 9 — 5150 ohms; resistive; 70 ohms.
Q. 10 — 234 ohms; with ½-inch tubing, 1.76 inches center-to-center spacing; with ¼-inch tubing, 0.88 inches center-to-center spacing.

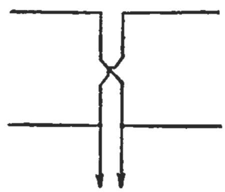
Q. 14 — 0.68 μh., 190 pf.; 0.91 amp.; 547 volts.
Q. 16 — Series; parallel.
Q. 19 — L, 66 ft.; C, 17.3 ft.; E, 20.8 ft.
Q. 20 — 7.15; 1.19 inches; 57.5 ft.; 28.7 ft.

Assignment 34:

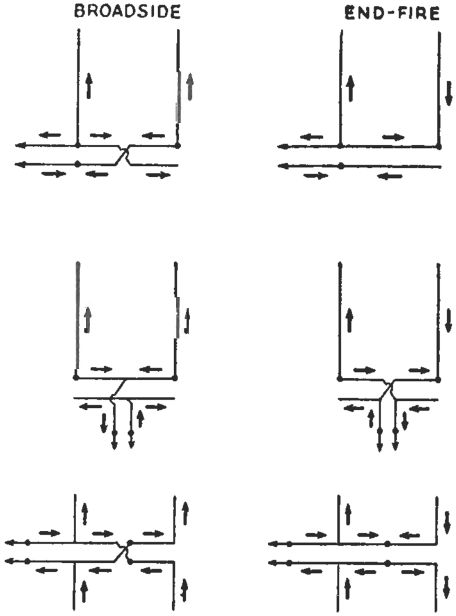
Q. 4 — 407 ft.
Q. 5 — Resonant frequencies: 3600 kc.; 7380 kc.; 11,170 kc.; 14,970 kc.; 18,750 kc. Harmonics of 3600 kc.; 7200, 10,800, 14,400, 18,000 kc.

Assignment 35:

Q. 6 — Diagram below.

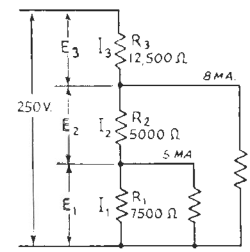


Q. 6 — Diagram below. Dots show points where current reverses.



Problem 16, Assignment 4

To work out this problem it is necessary to solve Problem 15 first, obtaining 7500, 5000 and 12,500 ohms for the three resistances. These are labeled, respectively, R_1, R_2 and R_3 in the accompanying figure. In essentials, the problem is to find the voltage drops, indicated as E_1, E_2 and E_3 on the diagram, across these three resistors. I_1 is the current through R_1, I_2 is the current through R_2, and I_3 is the current through R_3. The current through R_1 is not known, but I_2 is equal to the sum of I_1 and the 5-ma. load current taken from the tap between R_1 and R_2, while R_3 is the sum of I_2 and the 8-ma.



load current taken from the tap between R_2 and R_3. In equation form,

$$I_2 = I_1 + 0.005$$
$$I_3 = I_2 + 0.008 = (I_1 + 0.005) + 0.008 = I_1 + 0.013$$

and

$$E_1 = I_1 R_1$$
$$E_2 = I_2 R_2 = (I_1 + 0.005)R_2$$
$$E_3 = I_3 R_3 = (I_1 + 0.013)R_3$$

Also,

$$E_1 + E_2 + E_3 = 250 \text{ volts}$$

so that

$$I_1 R_1 + (I_1 + 0.005)R_2 + (I_1 + 0.013)R_3 = 250$$

Substituting the proper values for R_1, R_2, R_3, and expanding,

$$7500I_1 + 5000I_1 + 25 + 12{,}500I_1 + 162.5 = 250$$

Collecting gives

$$25{,}000I_1 = 250 - 187.5 = 62.5$$
$$I_1 = 0.0025$$

Then

$$E_1 = I_1 R_1 = 0.0025 \times 7500 = 18.75 \text{ volts}$$
$$E_2 = I_2 R_2 = 0.0075 \times 5000 = 37.5 \text{ volts}$$
$$E_3 = I_3 R_3 = 0.0155 \times 12{,}500 = 193.75 \text{ volts}$$

The last is needed only to check the work; the three voltages should add up to 250. The two voltages actually asked for in the problem are E_1 and $E_1 + E_2$. E_1 is given above and $E_1 + E_2$ is 56.25 volts.

Problem 14, Assignment 20

This is a practical problem and was therefore included in the form given, rather than being phrased in such a way that the answer could be read directly from the design chart in the *Handbook* section on cathode modulation. It can be solved by the trial-and-error method, but two answers are possible depending upon the initial assumptions concerning efficiency and dissipation.

The chart is based on continuous 100 per cent modulation with a sine-wave modulating signal. The "plate-modulation rating" referred to is consequently based on an average power input, which is the sum of the carrier input and the modulating power; the power input is therefore 1.5 times the carrier input. The two tubes have a combined plate dissipation of 120 watts and the assumed efficiency is 77.5 per cent, so that the maximum permissible power input is 120/0.225, or 533 watts. Since this is the input with 100 per cent modulation, the carrier input will be 533/1.5, or 355 watts, and the carrier output will be 355 × 0.775, or 275 watts. These last two figures constitute the plate-modulation ratings.

At this point it is necessary to assume different values for m, finding W_{in} for each value and then applying the corresponding factor for W_a to W_{in} to see whether the required audio power turns out to be 80 watts, the amount specified in the question. The proper value for m is 59, when $W_{in} = 355 \times 0.77 = 273$ watts; $W_a = 273 \times 0.29 = 80$ watts (near enough). The carrier output is therefore 273 × 0.65 = 176 watts. The modulating impedance readily can be found, since the power input, plate voltage, and percentage of plate modulation are known.

The second basis assumes that it is safe to operate the tubes at rated plate dissipation under carrier conditions only, neglecting the increased dissipation when the power input increases with modulation. This is frequently done in amateur practice, where the voice modulation is not sinusoidal and the average increase in power input under modulation is quite small. In this case it is necessary to find a value of m which will make the plate dissipation 120 watts and require an audio power of 80 watts. On trying different values of m it is found that when m is 50 per cent the plate efficiency, N_p, is about 62 per cent, so that the carrier power input is 120/0.38 = 316 watts. W_a at this point is 25 per cent of 316, or approximately 80 watts. The carrier output is therefore 316 × 0.62 = 196 watts.

Course Outline

The course outline on the following page has been prepared for the benefit of instructors and others desiring to organize this course in terms of classroom and laboratory periods. It requires a total of 40 weeks, allowing one classroom and one laboratory period of approximately two hours each per week. At appropriate intervals periods have been set aside for review or examination. When more than one experiment has been assigned to a single laboratory period it may not be possible to complete all of them in the time allotted, and it is suggested that such uncompleted experiments be left for the succeeding periods (marked with an asterisk).

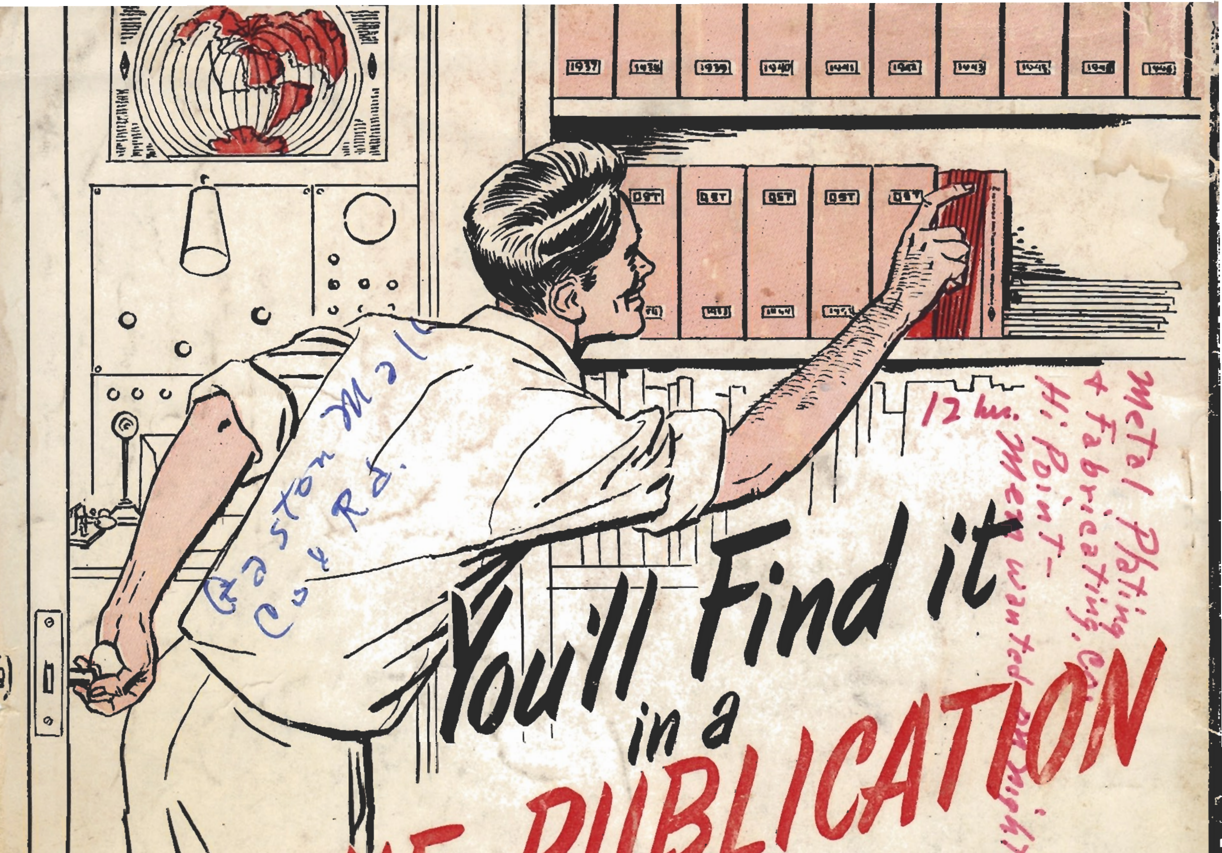
In the latter half of the course the amount of experimental work decreases, with the result that, particularly toward the end, laboratory periods might well be used for classroom work if there is no unfinished experimental work to be made up. Two of the laboratory periods in this half have been designated for review and examination purposes.

Classroom Period	*Lesson Assignment No.*	*Subject*	*Laboratory Period*	*Experiment No.*
1	1	Electrostatics	1	1
2	2	The electric current	2	2, 3
3	3	Electromagnetism	3	4, 5, 6
4	4	Ohm's Law	4	7, 8
5		Review	5	9, 10
6	5	Alternating current	6 *	11
7	6	Ohm's Law for a.c.	7	12
8	7	The transformer	8	13, 14
9	8	Resonant circuits	9	15
10	9	Coupled circuits	10	16, 17, 18
11	10	Linear circuits, etc.	11	19
12		Review	12 *	20
13	11	Vacuum tubes	13	21, 22
14	12	Amplification	14	23, 24
15	13	Multielement tubes, etc.	15	25
16	14	Oscillators	16	26
17	15	Cathode-ray tubes	17 *[1]	
18		Review	18 *	
19	16	Transmitters — oscillators	19	27
20	17	Transmitters — circuits	20	28
21	18	Power amplifiers	21	29
22	18	Continue on power amplifiers and frequency multipliers	22	30
23	19	Modulation	23	31, 32
24	20	Grid modulation, etc.	24	33
25	21	Modulators	25 *	
26	22	Modulation checking	26 *[2]	
27	23	Frequency modulation	27	34
28	24	Keying	28	Review
29	25	Receivers — detectors	29	35
30	26	Receivers — amplifiers, tuning methods	30	36
31	27	The superheterodyne	31	37
32	28	The superheterodyne, continued	32 *[3]	
33	29	F.m. reception	33	38
34	30	Power supply	34	39
35		Review	35 *	
36	31	Wave propagation	36 *	
37	32	Antenna properties	37 *	
38	33	Transmission lines	38	40
39	34	Long-wire antennas	39 *	
40	35	Directive antennas, etc.	40	Review

[1] If an oscilloscope is available, a simple experiment demonstrating the operation of oscilloscope controls can be used at this point.
[2] A demonstration of the use of the oscilloscope for checking modulation should be given in this period if possible.
[3] Practice in the alignment of a superheterodyne receiver can be given in this period if test equipment is available.

104

NOTES



You'll Find it in a LEAGUE PUBLICATION

The whole picture of amateur radio from basic fundamentals through the most complex phases of this appealing hobby is covered in ARRL publications. Whether novice or old-time amateur, student or engineer, League publications will help you to keep abreast of the times in the ever-expanding field of electronics.

THE RADIO AMATEUR'S HANDBOOK
Internationally recognized, universally consulted. The all-purpose volume of radio. Packed with information useful to the amateur and professional alike. Written in a clear, concise manner, contains hundreds of photos, diagrams, charts and tables.
$4.00

THE RADIO AMATEUR'S LICENSE MANUAL
Sturdy guide and reference book, points the way toward the coveted amateur license. Complete with typical questions and answers to all of the FCC amateur exams—Novice, Technician, Conditional, General, Advanced and Extra Class. Continually kept up to date.
$.50

THE ARRL ANTENNA BOOK
Theoretical explanation and complete instructions for building different types of antennas for amateur work. Simple doublets, multielement arrays, mobile types, rotaries, long wires, rhombics and others. Transmission lines are exaustively discussed. Profusely illustrated.
$2.50

THE RADIO AMATEUR'S OPERATING MANUAL
Written for the amateur who prides himself on good operating procedures. It is a ready reference source and guide to good operating practices. Ideal for the amateur who wishes to brush up on operating procedures, and who wishes information on all facets of amateur operating.
$1.50

HOW TO BECOME A RADIO AMATEUR
Tells what amateur radio is and how to get started in this fascinating hobby. Special emphasis is given the needs of the Novice licensee, with a complete amateur station featured.
$1.00

LEARNING THE RADIOTELEGRAPH CODE
For those who find it difficult to master the code. Designed to help the beginner. Contains practice material for home study and classroom use.
$.50

THE RADIO AMATEUR'S V.H.F. MANUAL
A thorough treatment of v.h.f. Covers receiving and transmitting principles, techniques and construction, antenna and feed system design, u.h.f. and microwaves, test equipment, interference causes and cures. Emphasis throughout is on tried and tested equipment and practice.
$2.50

UNDERSTANDING AMATEUR RADIO
For the beginner. Explains in simple language the elementary principles of electronic and radio circuits. Includes how-to-build-it information on low-cost receivers, transmitters and antennas. A "must" guide for the newcomer.
$2.50

THE MOBILE MANUAL FOR RADIO AMATEURS
Scores of selected articles on mobile receivers, transmitters, antennas and power supplies. Between its two covers is all the practical information on amateur needs for carefree and dependable mobile operation.
$2.50

SINGLE SIDEBAND FOR THE RADIO AMATEUR
A digest of the best s.s.b. articles from QST. Includes discussions of theory and practical "how-to-build-it" descriptions of equipment. Covers reception and transmission.
$2.50

HINTS AND KINKS
If you build and operate an amateur radio station, you'll find this a mighty valuable book in your shack and workshop. More than 300 practical ideas.
$1.00

The AMERICAN RADIO RELAY LEAGUE • NEWINGTON, CONN. 06111