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EXPERIMENTAL RADIO

FOURTH EDITION

By

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Preface to the First Edition

These experiments have been collected from various sources during the past five years and have been given to my students in radio in condensed mimeograph form. Several of these experiments have been devised by the author. A larger number have been taken from the various texts on radio telegraphy and telephony. Reference to the various sources from which theory or experiments have been taken is made in the experiments. It has been my endeavor to make the course in radio at Indiana University on a par with any second year course in physics.

Some experiments, methods of test and practical directions for the construction of apparatus have been inserted for those who have not had college physics or who do not have access to regular physical apparatus. I have found that these practical directions have been of use to my students. This is not a textbook. A very small amount of theory has been included except in a few places where the texts are deficient.

R. R. Ramsey

Indiana University
Bloomington, Indiana
December, 1922.

Preface to the Second Edition

In this second edition EXPERIMENTAL RADIO has been revised and enlarged. Besides a number of new experiments, suggestions for the construction of simple radio laboratory apparatus have been added.

EXPERIMENTAL RADIO is not in its final form. In order that it may be improved I shall be glad to receive corrections, suggestions, or criticisms.

July, 1923

R. R. R.

Preface to the Third Edition

In 1923 the first mimeographed edition was published primarily for my own students. Its reception by the radio public, college, commercial and amateur, was such that it was necessary to get out a second edition in a few months. This second edition has been revised with slight changes and additions several times.

The third edition has been enlarged and revised in order to keep up with the rapid changes of Radio. No attempt has been made to

give the more complicated tests and methods of measurement. Simple tests are given which will bring out the fundamental principles. References are given which will describe the more elaborate methods.

I hope that this edition, printed in more permanent form, will continue to meet the approval of the radio public.

I am indebted to many friends for helpful criticisms and suggestions.

November, 1927

R. R. R.

Preface to the Fourth Edition

Since the publication of the third edition of *EXPERIMENTAL RADIO* the A and B battery has been discarded and rectified alternating current is used in most radio sets. In this edition the experiments and figures have been changed so that power supplies can be used in most of the experiments. Although radio apparatus has been greatly improved and is relatively easy to obtain many directions for making simple parts have been retained. A student who makes, measures, and uses a condenser or coil has a more concrete idea of capacity or inductance.

The average American radio engineer seems to have a correct idea of side bands and methods of obtaining combinational frequencies. He may call combinational frequencied beat frequencies but due to the fact that he has been guided by experiments using C.W. apparatus he has the correct conception. A large per cent of physicists still cling to the theory published and apparently justified in the days of spark stations. They believe with Helmholtz that combinational frequencies and beat tones are the same thing. That the addition of two sine waves give waves whose frequency is the sum and difference of the parent frequencies. That two closely coupled circuits will produce two frequencies.

The thought has been when designing experiments on coupling to show the fallacy of the above theory.

Experiments on attenuators and characteristic impedance have been introduced to illustrate simple line theory.

Again I wish to thank those who have offered criticism and made suggestions. I wish to thank Mr. William Strain, architect, for the cover design.

August, 1937

R. R. R.

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TESTING DRY CELLS

1—LARGE CELLS

In this class all cells used for induction coils or for A batteries to heat the filament of tubes are included.

The ammeter test. This test is useful to locate cells which have become exhausted or dried out. Connect the cell to a dead beat ammeter whose internal resistance is about .01 ohm. The maximum deflection is taken as the reading. New cells should give 20 to 30 amperes. Used cells will give lower values. When they show as low as 1 to 2 amperes they should be discarded. One ampere means that the internal resistance of the cell is about 1.5 ohms. Whether this resistance is detrimental depends upon the resistance of the circuit to which it is connected. When the internal resistance of the battery is equal to the external resistance of the circuit, one-half of the energy of the battery is used in the battery. If the battery is not working well, replace the cells which show the lowest current—i.e., the highest resistance. These discarded cells can be used with good results as cells for potential as in B batteries.

2—SMALL CELLS. B BATTERIES

The internal resistance of a B battery cell can be measured as in the case of large cells. This is usually not necessary. The essentials of a B battery are that its E.M.F. be high and that the cell is not noisy.

Use of voltmeter to test the E.M.F. of the B battery.—If a $22\frac{1}{2}$ volt battery reads from 15 to 22 volts it may be considered to be in fair condition. Connect a high resistance telephone head-set across the battery, care being taken to have good connection. There should be no sound in the telephone except the click made when the connection is made and broken. The loudness of this click on making contact can be taken as an indication of voltage of the battery. If a new battery is at hand, a comparison of the click made by the new battery with that of the old will give an indication of the E.M.F. of the old battery.

If there is a rattle or popping in the telephone when the telephone connections are good the battery is noisy and the poor cell or cells must be removed. This popping sound is caused by a poor

connection which makes the current intermittent. It may be a poor soldered joint or it may be inside the cell, probably due to the material of the cell becoming dry and making the conduction uncertain. Measure each individual cell or flash light battery. The cell whose E.M.F., as measured with the voltmeter, is less than 75% of the normal voltage is usually the one which causes the noise in the battery. Remove or short circuit this cell or flash light battery. "Fundamentals of Radio," p. 35.

Experiment 1. Testing Large Dry Cells.

Measure the short circuit current of each cell in a large battery by means of a low resistance ammeter. Measure the E.M.F. of each cell by means of a voltmeter. Compute the internal resistance of each cell, deducting the resistance of the ammeter. Calculate the internal resistance of the battery. [Batteries in series, in multiple and multiple series.] Compare the resistance of the battery with that of the apparatus to which the battery is connected—i.e., induction coil, or lamp, etc.

NOTE. Do not let the current flow longer than necessary. The life of the cell is shortened by letting the current flow for a long time.

Experiment 2. Testing Small Cells.

Repeat the experiment with small cells, such as flash light or B battery cells.

Estimate the E.M.F. of cells by means of the telephone click method. (The resistance of the phone should be at least 1000 ohms.)

Check with the voltmeter.

Compare new and old 22½ volt batteries. New and old flash light batteries. New and old individual cells.

Take a new and old cell and measure the E.M.F. with a 3 volt voltmeter, 15 volt voltmeter and a 150 volt voltmeter. Why do the readings of the new cell check? Why do the readings of the old cell not check? (A Weston 3, 15, 150 volt model 280 voltmeter is ideal for this experiment.)

NOTE. Short circuiting a cell always tends to ruin the cell. Make the time of connection of the ammeter to the cell short.

MEASUREMENT OF RESISTANCE

There are several methods of measuring resistance which are given in any good physics laboratory manual. Two methods will be described here as being the most important for use in radio measurements.

Ammeter-voltmeter method.—This consists of measuring the current through the resistance with an ammeter and the Pd around the resistance with a voltmeter, and solving for the resistance by means of Ohm's Law, $R = Pd/I$. This method is useful in measuring resistance which will carry relatively large currents and have resistances from about 0.1 ohm to 1000 ohms. The resistance of lamps, large rheostats, armatures and fields of motors and generators can usually be conveniently measured by this method. Small coils such as coils in ordinary resistance boxes should not be measured by this method, as there is danger of sending too much current through the coils and burning them out.

The assumptions made in these measurements are that the ammeter has zero resistance and that the current through the voltmeter is zero. These assumptions are only approximately true. In measuring a small resistance such as the resistance of an armature the connection should be made as in Figure 1. The source of current is a d-c 110 volt switch or a storage battery capable of delivering several amperes of current. R_h is a regulating rheostat or bank of lamps by means of which the value of the current is regulated, a, b are the points of contact of the voltmeter around the armature, R . In this case the current through the ammeter is the current through the armature which is several amperes, plus the current through the voltmeter which is only a few milliamperes. The voltmeter current in this case can be disregarded. In this case, $R = Pd/I$ is the resistance of the armature. If the connection was made as in Figure 2, then $R = Pd/I =$ resistance of armature plus the resistance of the ammeter and in certain cases the resistance

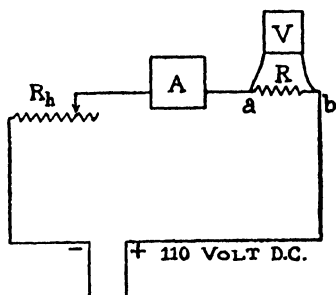


Fig. 1

of the ammeter and in certain cases the resistance of the ammeter will be equal to or greater than the resistance R . If the resistance is great, connect as in Figure 2. In this case the resistance R is great and an addition or error of a few hundredths ohms can be neglected.

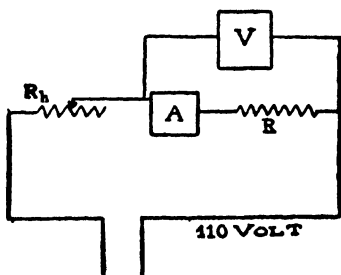


Fig 2

If connected as in Figure 1 the current through the voltmeter may be much greater than the current through the resistance R . Milliammeters and millivoltmeters can be used instead of ammeters, but the errors due to the resistance of milliammeter and the current through the millivoltmeter are liable to be great.

Caution: Be sure the current is not greater than the maximum range of the ammeter and that the Pd is not greater than the maximum range of the voltmeter.

Experiment 3. Measure the Resistance of Lamps, Tin Frame Rheostats, etc.

Measure the resistance of two lamps and place them in series and measure, place them in multiple and measure. Note that the resistance in series is not exactly the sum of the separate resistances. This is due to the fact that the temperature of the lamps is less when in series than when measured separately. The resistance of metallic filament lamps increases with temperature, while the resistance of carbon filament lamps decreases with temperature. Resistance of most conductors changes appreciably with temperature.

Experiment 4. To Measure Resistance with a Voltmeter.

If one has an ordinary voltmeter whose resistance is known it can be used to measure resistance. A battery whose E.M.F. is near the maximum voltage of the voltmeter should be used. The battery or source of E.M.F. should be constant not changing from time to time. The current through the voltmeter is proportional to the deflection. We can write, $I_1 = kd_1 = E/R_v$. R_v being the voltmeter resistance.

Placing the resistance to be measured in series with the voltmeter we have, $I_2 = kd_2 = E/(R_v + R)$.

From the first equation we have $E = kd_1R_v$, from the second we have $E = kd_2(R_v + R)$ or $d_1R_v = d_2(R_v + R)$. From which we have $R = R_v(d_1 - d_2)/d_2$. Thus the resistance can be calculated.

With a good voltmeter resistances whose value lies between one tenth to ten times the voltmeter resistance can be measured quickly with fair accuracy. Resistances outside of these limits can be estimated.

Experiment 5. To Make an Ohmmeter.

If one has a 1.5 volt voltmeter, and a good dry cell, or a 15 volt battery and a 15 volt voltmeter, or a 150 volt voltmeter and a potential of near 150 volts, 110 volts d-c will do, one can calculate (using the formula in Experiment 4) the resistance when the second deflection, d_2 is $1/10, 1/5, 1/4 \dots .8, .9, 9.5$ of the first deflection and a curve can be drawn using d_2 along the x -axis and resistance along the y -axis. Or the calculated values can be marked on the dial of the voltmeter. Then one has an ohm meter.

Care must be used that the voltage of the battery or source is the value assumed when the calculations were made.

Wheatstone bridge: The wheatstone bridge consists of four resistances. The value of one of these resistances is known. The ratio of the resistances of two others is known. The fourth is unknown, or is the resistance to be measured. These four resistances are connected together to form a closed circuit. Diagrammatically the resistances are connected to form a diamond or parallelogram as in Figure 3. R is the adjustable known. R_1 and R_2 are the ratio arms. The ratio of R_1 to R_2 is known. X is the unknown. A galvanometer is connected across one diagonal of the diamond and a battery across the other diagonal. The resistance R is changed until there is no current through the galvanometer, then the potential of b is equal to the potential of d . Then $Pd_{ab} = Pd_{ad}$ and $Pd_{bc} = Pd_{cd}$ and $I_1 = I_R$ and $I_2 = I_X$. Since $Pd_{ab} = I_2R_2$, $Pd_{ad} = I_1R_1$ and $Pd_{bc} = I_XR_X$ and $Pd_{dc} = I_RR$.

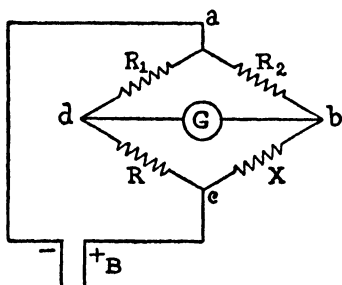


Fig. 3

Then

$$X = \frac{R_2 R}{R_1}$$

Experiment 6. Slide-Wire Bridge.

The bridge has two common forms—the slide-wire bridge and the box bridge. The slide-wire bridge consists of a No. 20 manganin or German silver wire usually 1 meter long, stretched on a board and soldered to two heavy bars of copper or brass. This heavy bar is extended along the back of the board and usually has four openings with binding posts so as to connect resistances. Two of these

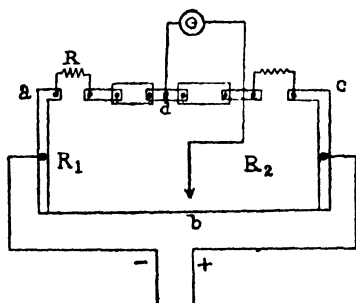


Fig. 4

openings for simple measurements are closed with heavy conductors. The resistance of these heavy bars and straps is considered to be zero. It will be seen that the resistances R_1 and R_2 are that of sections of the wire. Since the resistance of the wire is uniform, then l_1 and l_2 , lengths, can be substituted for R_1 and R_2 . In this bridge the known resistance R can be fixed and the ratio of R_1 to R_2 can be changed until the bridge is balanced. For exact measurements it is best to adjust the known resistance R so that the sliding point b is near the center of the wire. Slide-wire bridges can be constructed very cheaply and still give fair results.

BOX BRIDGES

The box bridge consists of three resistances and the unknown. These three resistances are usually placed in the same box and marked terminals and keys placed conveniently. In all bridge work two break keys k_1 and k_2 should be used, one in the battery and one in the galvanometer circuit. Figure 5 is a diagram of one form of box bridge, the letters on the diagram

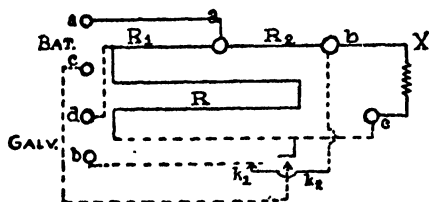


Fig. 5

correspond to those on diagram Figure 3. In any bridge work the bridge should be studied by diagraming it and determining the points which correspond to the diamond, Figure 3. Pieces of paper with letters can be fastened to the box until you are able to see the particular bridge in the "diamond form."

All box bridges are alike in principle but their outward forms may be very different.

Experiment 7. Use of Box Bridge.

In using a box bridge connect the unknown in and select some value for the ratio $R_1 = R_2 = 100$ ohms. Let $R = 0$. Press the battery key and then the galvanometer key and note the direction of deflection. This is the direction of deflection when R is too small. Select some large value of R . The direction of deflection will be in the opposite direction if R is greater than X . Then X lies between zero and the large value of R . Make R about $\frac{1}{2}$ of the large value, then from the direction of deflection it is easy to determine whether the value of X is greater or less than the last value. Make R some other value near the intermediate value, noting deflection. By approximating closer and closer, in a short time approximate value of X can be determined.

After the approximate value has been determined, the ratio of R_1/R_2 may be changed so as to obtain more exact measurement.

If the resistance to be measured is a coil containing much inductance care must be taken to close or open the battery key while the galvanometer key is open, otherwise there will be a momentary deflection or kick of the galvanometer even if the bridge is balanced.

Measure the resistance of coils separately and in series and in multiple and check by the formula for series $R = r_1 + r_2 + r_3 + \dots$ and the formula for multiple $1/R = 1/r_1 + 1/r_2 + 1/r_3 + \dots$.

If a good bridge is not available a cheap slide-wire bridge can be made. If a resistance box cannot be had, an ordinary telephone head set may be used for an approximate standard. In a number of commercial phones the variation of resistance from that marked on the phone was not greater than 2%. A telephone head set may be substituted for the galvanometer. Upon opening and closing the key in the galvanometer circuit, telephone circuit in this case, a click will be heard in the phone. Adjust until the click is a minimum.

Then the bridge is balanced. If a telephone is used as a resistance standard a galvanometer must be used with steady battery current. A simple galvanometer can be made by winding a flat coil of 50 or 100 turns over a flat board. Remove the board and insert an ordinary pocket compass. Place the coil so the plane of the coil points North.

GROUND RESISTANCE

If a good conducting sphere such as a copper sphere, is placed at the center of a hollow copper sphere and is surrounded with a poor conductor such as earth, the spheres, together with an insulated copper connecting wire, may be considered as perfect conductors and then all the resistance is due to the

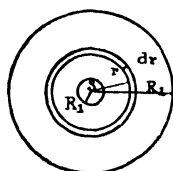


Fig. 6

earth. Let S be a conducting sphere of radius R_1 . About the center of S , draw two spheres of radius r and $r + dr$. The resistance of the spherical shell will be

$$dR = \rho \frac{\text{length}}{\text{areas of cross section}} = \frac{\rho dr}{4\pi r^2}.$$

Then,

$$R = \frac{\rho}{4\pi} \int_{R_1}^{R_2} \frac{dr}{r^2} = \frac{\rho}{4\pi} \left[-\frac{1}{r} \right]_{R_1}^{R_2} = \frac{\rho}{4\pi} \left(\frac{1}{R_1} - \frac{1}{R_2} \right).$$

If R_2 the radius of the hollow sphere $= \infty$ then

$$R = \frac{\rho}{4\pi} \frac{1}{R_1}.$$

All the resistance is near the small sphere and if the small sphere's radius is doubled the resistance of the "ground" is reduced one-half.

The same ratio will hold if the copper sphere is half buried on the surface of the earth, and it will be seen that in making good "grounds" a large amount of metallic surface must be exposed to the soil.

In making temporary "grounds" metallic stakes are driven into the ground.

Experiment 8. Measurement of Ground Resistance.

Drive two stakes into the ground 10 inches deep and 150 ft. apart. Connect the two with a good conducting wire whose resistance is known and measure the resistance with a Wheatstone bridge or testing set, which is a box bridge with battery and galvanometer contained in the box, or measure using ammeter-voltmeter method. About 10 inches

from the first stake, drive a second stake at each end, connect to the first stake and measure. Repeat with 3 stakes at each end; four stakes and five stakes. Drive the stakes 20 inches into the ground

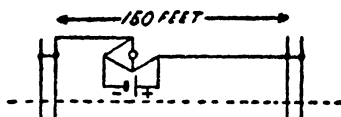


Fig. 7

and measure again. Remove the stakes and pour water into the holes and replace the stakes and measure. Or, set up the experiment again in damp soil. How does the resistance vary with number of stakes? With depth of stakes? Repeat with the groups about 10 feet apart. It will be seen that the resistance does not change with distance between groups but that as is shown by theory the resistance can be considered as being located near the stake. Drive several stakes at each end equally spaced on the circumference of a circle 10 inches in diameter to a depth of 10 inches and measure. Drive twice as many stakes on a circle 20 inches in diameter to a depth of 20 inches and measure. In this last case the two sets of rings will approximate to hemispheres of radii one and two respectively.

In some locations earth currents may flow giving a deflection of the galvanometer when the battery is disconnected. If a slide-wire bridge or a non-inductive box bridge is used alternating current can be used instead of the battery and a head set instead of the galvanometer. Use the 2.5 volt coil of a power transformer.

Experiment 9. To Measure the Resistance of a Particular Ground such as a Connection to a Water Pipe, or Aerial Ground Connection.

In the open soil some distance from gas or water pipe, drive two groups of stakes 25 or more feet apart. Measure the resistance of the groups. Connect the particular "ground" to one set of stakes

and measure. Then connect to the second group and measure again. From the above readings the resistance of the "ground" can be determined.

Let A and B be the two groups of stakes, C the particular "ground" to be measured. Since all the resistance is located near the "grounds" we can speak of the resistance A , the resistance B and the resistance C .

Let R_1 = resistance $A + B$, $R_2 = A + C$, and $R_3 = B + C$. Then $R_2 + R_3 = A + B + 2C$ and $R_2 + R_3 - R_1 = 2C$.

In certain soils and at certain times there will be disturbing electromotive forces at the stakes which will be so great as to make measurements with bridges impossible. The ammeter-voltmeter method using a rather high E.M.F. will give better results. Better still use an alternating E.M.F. with a-c ammeters and voltmeters.

ALTERNATING CURRENT

Since radio is a special phase of alternating current the student should be familiar with the effect of resistance, inductance, and capacity in alternating circuits. If there is not time to perform all these experiments the instructor should demonstrate some of the following in the lecture room especially those which show resonance.

For these experiments with 60 cycle a-c various coils, such as large air core coils, transformer coils and high potential condensers of one or more microfarad capacity can be used. For the resonance experiments a condenser of 10 microfarads variable in steps of one microfarad, and a coil of about 4000 turns of No. 18 wire wound on a tube $1\frac{1}{2}$ inch diameter and about 10 inches long with a movable laminated core is needed. Telephone condensers may be used but they are liable to puncture—place a fuse in series.

If we have a circuit with resistance and inductance in series our equation for current is, $I = E / \sqrt{R^2 + L^2\omega^2}$.

Squaring and solving we have, $E^2 = I^2 R^2 + I^2 L^2 \omega^2$.

The square of one term which equals the sum of the squares of two other terms suggests a right angle triangle.

All these quantities are electromotive forces and can be added by the vector method. (Parallelogram of vector method such as is often used with forces.)

In Figure 9 the base of the triangle is laid off equal to the IR drop in potential, the height proportional to the reactance drop of potential and the hypotenuse is equal to the E.M.F. applied to the coil.

Experiment 10. To Measure the Inductance, L , of a Coil, Impedance Method.

Measure the resistance R of the coil. Use the ammeter-voltmeter method using direct current.

Connect the coil to a source of a-c of known frequency. Since the frequency, n is known, ω is known, $\omega = 2\pi n$. The connections are the same as in the ammeter-voltmeter method of measuring resistance or as in Figure 8. R is a regulating resistance; L is the coil whose inductance is to be measured. Take the ammeter and voltmeter readings. Then the voltmeter reading is E . I times the known resistance R is the IR drop and we have the hypotenuse and base of a right tri-

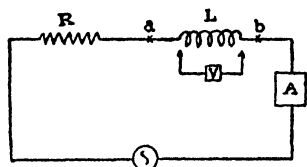


Fig. 8

angle to construct the triangle. On a horizontal, lay off to some convenient scale, ab proportional to IR . At b erect a perpendicular to ab . With a divider construct a circle with a as center and a radius equal to E using same scale as that of IR . Then $ac = E$ and $bc = IL\omega$, from the length bc the voltage $IL\omega$ is scaled out and, $L = IL\omega / I\omega$. The phase angle, $\theta = \tan^{-1} L / \omega R$.

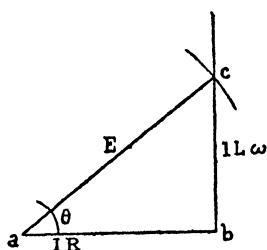


Fig. 9

Measure L of air core coils, transformer coils, lamp resistances, tin frame resistances, etc.

Repeat the experiment with an a-c current of different frequency.

Note, the phase angles depend upon frequency, while L of an air core coil is independent of frequency. In transformer coils or iron core coils L is not constant but depends upon the permeability of the iron which depends upon current. Any eddy current loss in the core or other parts will make R greater than the value measured with d-c current.

It will be noted that lamps and tin frame resistances are practically non-inductive for low frequency, 60 cycle.

In solving problems in alternating currents use the graphical method. Lay out the length of lines to exact scale. This method soon gives one an insight to just what is taking place in the circuit and in a great number of cases, calculation by any other method is very tedious.

Experiment 11. To Measure the Inductance, L , of a Coil by the Three Voltmeter Method.

In a coil, as we have just seen, there are three Pd 's, potential differences, which form a right triangle, such as $bb'c$, Figure 11, where bb' is the IR drop of the coil, $b'c$ is the $IL\omega$ of the coil and bc is the voltmeter reading around the coil. If a non-inductive resistance R , is inserted in series with the coil, Figure 10, then since the inductance, L is in the coil along the three E.M.F.'s of the circuit

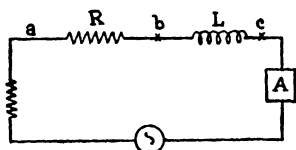


FIG. 10

will form the triangle abc , ab being the IR drop of the resistance R , ac the total E.M.F. and bc is the Pd around the coil.

Measure the Pd_{ac} , Pd_{ab} and Pd_{bc} . Construct a triangle Figure 11, using ab proportional to Pd_{ab} as the base. Set the dividers to equal the length ac proportional to Pd_{ac} and with a , as center draw an arc of a circle. With b , as center, draw an arc of a circle with bc as radius which is proportional to Pd_{bc} . The intersections of the arcs give the point c . Then draw the lines ac and ab . From c , drop a perpendicular on to ab , produced to b' . Then cb' is $IL\omega$ and bb' is IR_1 , where R_1 is the resistance of the coil. The angle cbb' is the phase angle of the coil. The angle, cab , is the phase angle of the complete circuit. It will be seen that adding resistances in series with the coil reduces the phase angle of the circuit, or the current is more nearly in phase with the E.M.F. A large resistance will make the phase angle practically zero. a-c voltmeters have large non-inductive resistances in series with the galvanometer coils. This

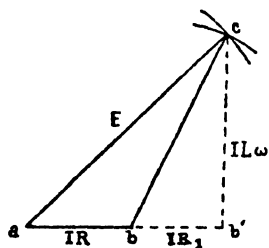


Fig. 11

resistance not only serves to make the galvanometer direct reading as in d-c voltmeters, but makes the current through the voltmeter in phase with the E.M.F.

Experiment 12. Resistances and Inductances in Series.

Connect two coils and three non-inductive resistances in series to an a-c source, Figure 12. Measure the Pd , ab , $ac \dots bc \dots$ making all possible $n(n-1)/2$ connections, 15 readings in this case. Lay off the triangle abc , Figure 13, as



Fig. 12

in the previous experiment. Then with a , b and c as centers lay off arcs cd , ad and bd , and thus locate the point d . In similar manner locate e , and then f . From c , d , e and f , drop perpendiculars on the line ab produced. The total length af' is the total IR drop or the

sum of the five separate IR drops. The line ff' is the total $IL\omega$, or the sum of the separate $(IL\omega)$'s. Dividing by I and $I\omega$, we have that the total resistance of a circuit in series is equal to the sum of the separate resistances and the total L of the circuit is the sum of the separate L 's.

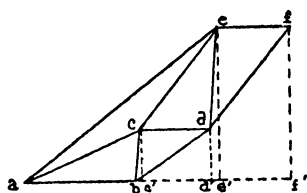


Fig. 13

This is true if the coils are so placed so as not to affect each other or if there is no mutual induction between the coils.

Place coil No. I on top of Coil No. II and repeat. The effect of mutual induction will be seen.

Experiment 13. Resistances and Coils in Parallel.

In this case the total current is equal to the vector sum of the separate currents.

Connect a non-inductive resistance and a coil in multiple, Figure 14. Place an ammeter in each circuit and a third ammeter to measure the total current. Measure the E.M.F. around the points ab . With ab proportional to Pd_{ab} as a diameter, construct a semicircle, Figure 15. Then I_1 is in phase with the E.M.F. ab since I_1 flows through resistance only. With some convenient scale draw aF_1 to represent the current through the resistance. Then with

aF_1 construct the triangle aF_1F_2 where F_1F_2 is the current in the coil and aF_{12} is the resultant current. Complete the parallelogram aF_1FF_2 . Then the angle F_1aF_2 is the phase angle of the current through the coil and the angle F_1aF_{12} is the phase angle of the resultant current. Then since the IR drop of the coil is in phase with

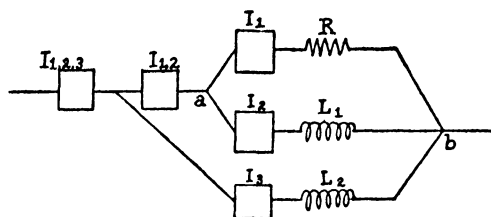


Fig. 14

with the current in the coil and since the E.M.F. vector right triangle of the coil must be inscribed in the semicircle of which ab is the total E.M.F., then the triangle aC_2b is the voltage triangle

and aC_2 is the IR drop and bC_2 is the $IL_1\omega$ of coil L_1 . In similar manner $aC_{12}b$ is the E.M.F. triangle of the resultant, and aC_{12} is the resultant IR drop and bC_{12} is the resultant $IL\omega$.

If a second coil is placed in parallel and its current and resultant of the three is measured, the resultant vector diagram of the three is found as before. The voltage vector triangles are found and we see that in the first two a resistance and an inductance in parallel can be replaced by a resistance and an inductance in series. Any number of resistances and inductances can be replaced by a single resistance and inductance in series. The law of calculating this resultant circuit is not simple and the above method of drawing to scale and calculating is for most purposes the easiest method to handle the case.

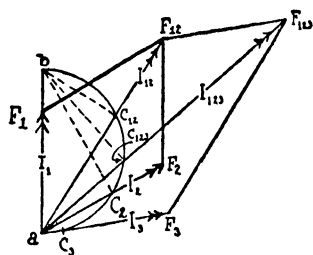


Fig. 15

CIRCUITS CONTAINING CAPACITY

If we have a circuit with a resistance and an inductance and a capacity in series, then our equations become

$$I = \frac{E}{\sqrt{R^2 + (L\omega - 1/C\omega)^2}}$$

If L is zero, then

$$I = \frac{E}{\sqrt{R^2 + (1/C\omega)^2}}.$$

Our reactance in this case is $-1/C\omega$ and our phase angle is negative and the current is said to lead the E.M.F. It will be remembered that it lagged in the case of resistance and inductance.

As in the case of resistance and inductance we can write the equation as

$$I = \frac{E}{\sqrt{R^2 + (x)^2}}$$

where x is the reactance, $-1/C\omega$, I being virtual current, E , virtual E.M.F.

$$\text{If } L = 0 \text{ and } R = 0, \text{ we have } I = \frac{E}{\sqrt{(1/c\omega)^2}} = CE\omega.$$

This equation will apply to a good condenser placed in an alternating circuit. The resistance of a good condenser being small.

Experiment 14. To Measure the Capacity of a Condenser.

Take a large condenser, about 10 microfarads, place it in an alternating circuit and measure E around the condenser and the current through the condenser. Calculate the capacity.

$$C = I/E\omega.$$

Care must be taken in this experiment to correct for the current through the voltmeter. The a-c generator must be one in which the E.M.F. varies as the sine of the angle. Any harmonic will be emphasized by the condenser and the results will not check with theory.

Experiment 15. To Measure the Capacity of a Condenser—Three Voltmeter Method.

Place a condenser and non-inductive resistance in series, Figure 16, and measure the current and potentials, ab , ac , and bc and from the vector triangle as in the case of resistance and inductance

in series calculate the capacity. The phase angle bac is negative in this case, Figure 17. The angle abc should be nearly 90° , since

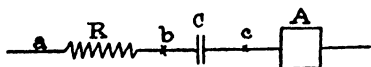


Fig. 16

the resistance of the condenser is nearly zero. ab is the IR drop across R and cb or cb' is $I/C\omega$. Measure cb' and calculate C . Condensers in large Ruhmkorff induction coils make good capacities for this experiment.

Experiment 16. Resistance, Inductance and Capacity in Series.

Connect a resistance such as a lamp in series with an inductance coil and a large condenser to an a-c E.M.F. as in Figure 18.

Measure the Pd , ab , ac , etc. with an a-c voltmeter making all possible measurements.

Construct the vector diagram. The phase angle due to inductance is positive. Plot the triangle abc as in Figure 19. The diagram may come out with d above the line as in Figure 19, or it may be below the line, as in Figure 20. The resultant phase angle bad is positive in Figure 19. In Figure 20 the resultant phase angle bad is negative.

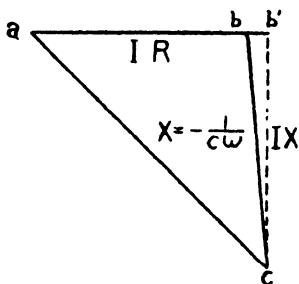


Fig. 17

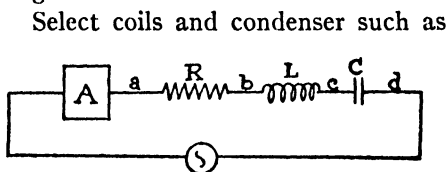


Fig. 18

will give diagrams of both types. The point d should be vertically below the point c , however, as a general thing the voltmeter being in parallel with the condenser gives the effect

of a resistance in series with the condenser.

Experiment 17. Series Resonance.

If in the equation

$$I = \frac{E}{\sqrt{R^2 + (L\omega - 1/C\omega)^2}}$$

L and C are such as to make $L\omega - 1/C\omega = 0$. Then we have $I = E/R$

This is the maximum value of the current. When this condition exists we have resonance. The capacity and inductance exactly

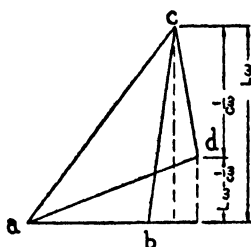


Fig 19

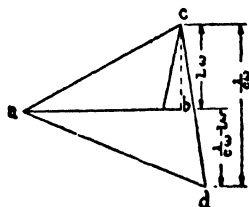


Fig 20

annul each other. In the equation

$$L\omega - 1/C\omega = 0 \quad C = 1/L\omega^2 \text{ or } L = 1/C\omega^2 \text{ or } \omega = \frac{1}{\sqrt{CL}}.$$

Thus it is possible to make the equation zero by changing C , or by changing L , or by changing ω . Since $\omega = 2\pi n$, the frequency being n we have,

$$n = \frac{1}{2\pi\sqrt{LC}}.$$

This is the fundamental equation in radio.

If a variable condenser or variable inductance coil with movable iron core is available, get the condition of resonance. This can be determined by watching the ammeter as the capacity or inductance is varied continuously in the circuit of Experiment 16. The point of maximum current is the point of resonance.

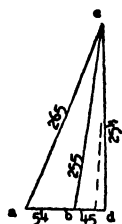


Fig. 21

Measure the voltages ab , ac , etc. and plot the diagram. d should lie on the line ab extended. Figure 21.

The condition is so critical that connecting the voltmeter tends to throw the circuit out of resonance thus making it hard to obtain good vector diagrams.

Experiment 18. Inductance and Capacity in Parallel.

If a coil of large inductance and small resistance and a condenser are placed in parallel in the circuit, Figure 22, then the current I_1 lags and is nearly at right angles to the E.M.F., ab . The current

through the condenser, I_2 is also 90° with the E.M.F. but the angle is negative. The sum of these currents or resultant is small,

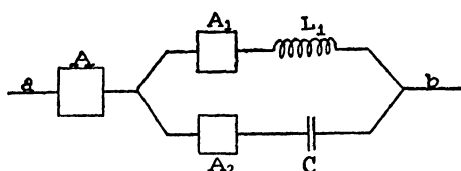


Fig. 22

or is the vector difference. If the values are varied until the resultant current is a minimum, then we have parallel resonance. If neither condenser or coil has resistance, then the two phase angles are exactly 90° , Figure 24, and the two currents are exactly opposite and the resultant current is zero when they are exactly equal, and the impedance in the circuit between a and b is infinite. This is called parallel resonance. Connect a variable condenser and variable inductance in parallel, with ammeters to measure each current and note the resultant current. This is the "fly-wheel" circuit of radio. Wave traps are made of a condenser and coil placed in parallel in the circuit and tuned to the frequency which is undesirable.

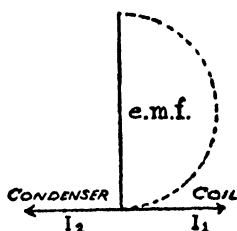


Fig. 24

In inductive circuits the current is said to lag behind the E.M.F. If the current lags the E.M.F. is ahead. In series circuits we primarily deal with voltages and these are ahead of the current when the circuit is inductive. When the circuit is capacitive the current lags by a negative angle or leads the E.M.F. In series circuits the phase angles are negative if capacitive. In parallel circuits the E.M.F. is fixed and we measure the current in reference to this E.M.F. The reactance $L\omega$ is positive and the reactance $1/C\omega$ is negative.

Experiment 19. To Measure the Capacity of a Radio Condenser.

The theory of the bridge connection is the same as in the case

or is the vector difference. If the values are varied until the resultant current is a minimum, then we have parallel resonance.

If neither condenser or coil has resistance,

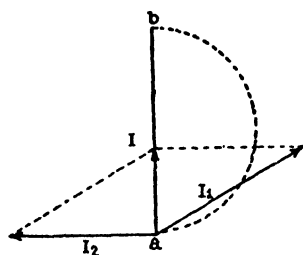


Fig. 23

where a ballistic galvanometer is used. When a ballistic galvanometer is used the capacities must be comparatively large (microfarads). With the buzzer method small capacities can be compared fairly accurately. B is a buzzer; D is a dry cell; M is a small transformer or telephone coil; T is a telephone receiver; and L is an inductance placed in series with the telephone. The inductance L is not essential but at times it helps to give a sharper minimum sound. C_3 and C_4 are the capacities to be compared, R_1 and R_2 are resistance boxes. These resistances must be non-inductive.

The standard condenser may be a standard mica condenser whose capacity is .05 microfarads or less. Commercial fixed radio condensers whose capacity is about .001 microfarads may be mounted and measured by the instructor and used as a standard. The measured value being the correct value. The marked value is a very rough approximation to the true value. The standard condenser may be a condenser made of two large sheets of metal and mounted parallel to each other as described later.

If there is difficulty in getting a balance, interchange the telephone and buzzer connections on the bridge. In changing the resistances, loosen the plug and wiggle it, making and breaking the connection around the resistance coil rapidly. Absolute silence in the room is necessary for accurate balance. The equation for balance is.

$$C_3/C_4 = R_2/R_1$$

The derivation of this equation is as follows:

In Figure 25 when the bridge is balanced and there is no current through the telephone, the potential across the resistance, R_1 is the same as the potential across the condenser C_3 or $Pd_1 = Pd_3$. In like manner, $Pd_2 = Pd_4$. The current through the resistance, R_1 is the same as the current through the resistance, R_2 . And the quantity of electricity in C_3 is the same as the quantity in C_4 .

From the above we have, $I_1 = I_2$ and $Q_3 = Q_4$.

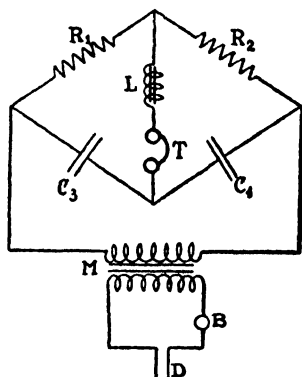


Fig. 25

Since, $Pd_1 = I_1 R_1$ and $Pd_2 = I_2 R_2$ also $Pd_3 = Q_3/C_3$ and $Pd_4 = Q_4/C_4$ we have $I_1 R_1 = Q_3/C_3$ and $I_2 R_2 = Q_4/C_4$. Dividing the last two equations one by the other term by term, we have

$$R_1/R_2 = (1/C_3)/(1/C_4) = C_4/C_3.$$

Note how the ratio is stated. In stating the ratio the terms are read off in a circle around the diamond of Figure 25. This is different from the ordinary resistance bridge used to measure resistances.

In this bridge we have, large capacity times small resistance equals small capacity times large resistance.

Instead of a buzzer a hummer can be used as in Figure 26. This hummer as described later, Figure 157, has a potentiometer which can be used as a Wagner Ground. In Figure 26 the head phone is

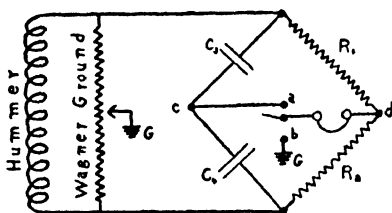


Fig. 26

connected to the point, *a*, and the bridge is balanced for a minimum sound. Then the phone is connected to the point, *b*. This point, *b*, is connected to the ground which is connected to the slider on the Wagner ground. The slider is adjusted until the sound is a minimum. Then the phone is connected to the point, *a*, and the bridge is adjusted to a better minimum. The point *b* is connected and adjusted again. When both connections are adjusted the minimum sound is zero and the bridge is perfectly adjusted and the points *c* and *d* are at ground potential and the phones are at ground potential and if the manipulator is connected to the ground there is no sound produced by the capacity between ground and manipulator.

When both capacities are small, best results are obtained when the resistances are large.

If a variable capacity is given, measure it at ten positions of the dial.

After the first position is obtained for balance, the resistance in one arm of the bridge can be changed by a small amount and the point of balance can be found by changing the variable

capacity and noting the reading of the condenser scale. In this way 10 readings can be taken in a short time.

Plot a curve using capacities as ordinates and scale readings as abscissas.

If the condenser is an old fashioned semicircular plate condenser, this curve should be a straight line except near the extreme ends, as in Figure 27.

Measure the capacity of a Leyden jar and of a fixed radio condenser. Make a glass plate condenser and measure, using the variable as a standard. Measure two capacities separately. Place in multiple and measure. Place in series and measure. Check with the computed values.

Check the value of the glass plate condenser by the formula $C = KS/4\pi d$. Divide by 900,000 to reduce to microfarads.

A bridge made of ordinary resistance boxes makes a good bridge for ordinary work. The ratio arms should be one to ten thousand ohms. For more exact work the bridge should be shielded. *Brown, Measurement, p. 25.*

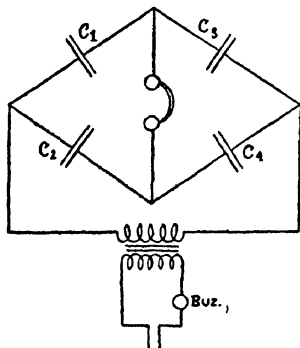


Fig. 28

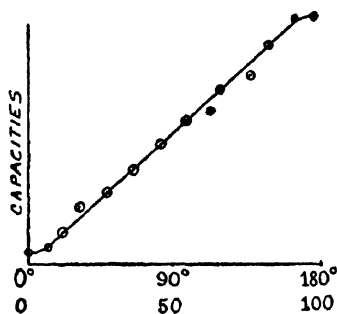


Fig. 27

CAPACITY BRIDGE

A bridge for the measurement of capacity can be made of four condensers. The connections are made as in Figure 28.

Condensers, C_1 and C_3 may be two variable condensers which have been calibrated.

If they are good semicircular plate condensers which give a straight line curve, when capacity is plotted against dial settings, and the straight line passes through the zero point of the curve and both condensers are approximately alike, the ratio of the dial readings can be used as the ratio of the capacities.

Starling, p. 325; Watson, p. 530; *Fundamentals of Radio*, Chapter VI.

C_2 , can be the standard condenser and C_4 the unknown condenser.

If the standard is a "straight line capacity" condenser, semi-circular plates, the capacity is proportional to the dial readings and facilitates calculation.

It might be remarked here that for most experimental purposes the "straight line capacity" condenser is much better than the modern shaped plate condenser.

In the case of the condenser bridge the ratio is $C_1/C_2 = C_3/C_4$. The derivation of this is left to the student.

Experiment 20. Measure the Dielectric Constant of Oil.

Measure the capacity of an air condenser in air and again when immersed in oil. The ratio of the capacity with oil to that with air will give k , the dielectric constant. For student work use kerosene.

Experiment 21. To Make a Condenser of Tinfoil and Photographic Glass Plates.

Connect the alternate sheets together. The capacity will depend upon the size and number of plates, and upon the thickness of plates. The thinner the glass the greater the capacity.

Glass plate condensers can be used for grid condensers and for by-pass condensers. They can be used in parallel with the tuning condenser to increase the wave length range of a receiver. One or more glass plate condensers about .001 m.f. capacity can be arranged to be placed in parallel with a variable condenser .001 capacity. A switch can be made so as to use the variable alone, variable and No. 1, then 1 and 2, etc., Figure 29.

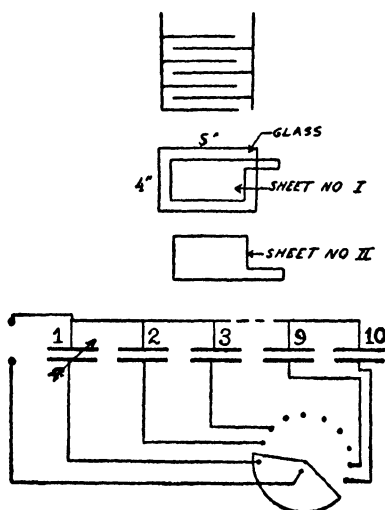


Fig. 29

Grid condenser and by-pass condenser can be made of tinfoil and paraffined paper such as bread wrappers. Four or five square inches of surface is required for a grid condenser.

If the grid condenser is mounted on a thin sheet of hard rubber with the terminals about $\frac{1}{4}$ inch apart lead pencil marks can be made between the terminals for the grid leak. More lead makes less resistance.

Experiment 22. To Make a Standard Condenser.

A standard condenser can be made of two heavy plane brass or aluminum sheets separated by small pieces of sheet glass. Use as little glass as possible to keep the sheets parallel to each other. The sheets should have 10 or more square feet of surface. Calculate the capacity using the formula

$$C = \frac{S}{4\pi d} \text{ Centimeters.}$$

Divide by 900,000 to reduce to microfarads. Unless the surface is large and the distance d small, edge effects may make the actual value greater than the computed value.

Experiment 23. Resistance and Phase Angle of a Condenser.

In a good air or mica condenser the resistance is very near zero and the current in the condenser is 90 degrees ahead of the electromotive force. The phase angle of the condenser is 90 degrees and the phase difference is said to be zero.

In a poor condenser there may be an appreciable resistance in the connections. The condenser may leak, and there may be a dielectric loss in the condenser. The residual charge of a Leyden jar is due to this dielectric loss. If the jar is charged and discharged very rapidly the glass will get hot showing that there is a dissipation of energy which appears as heat.

Some of these heat losses may be in series with the condenser and others may be a high resistance path in parallel with the condenser. A resistance in parallel can always be represented or the effect duplicated by a resistance in series with the condenser. See theory of alternating current.

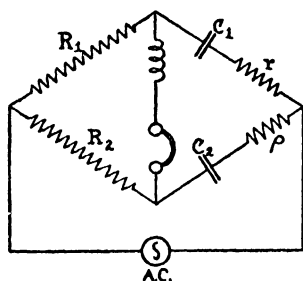


Fig. 30

If a good standard condenser is compared with a paraffine paper condenser by the bridge method the minimum sound in the condenser will not be good. The two currents in the two condensers are not a maximum at the same time. The phase angle of the good condenser is 90 degrees and the other is less than 90 degrees. If a resistance box is inserted in series with the good condenser the phase angle of that branch of the bridge can be made to equal that of the poor condenser.

Connect the condensers to the bridge as in Experiment 19. Adjust to the best minimum by changing R_1 or R_2 . Insert resistance r in the arm with the standard until the minimum is the best.

Adjust R_1 and R_2 again and then adjust r again. When the best condition is obtained then $R_1/R_2 = C_2/C_1 = r/\rho$, where ρ is the resistance in the condenser. The phase angle of the condenser is the angle whose tangent is $1/\rho C\omega$. Or the phase difference is the reciprocal or the angle whose tangent is $\rho C\omega$. Where ω is $2\pi n$, n being the frequency of the alternating source. For best results a good alternating source of pure wave form should be used instead of the buzzer.

The connections can be made as in Figure 26 using a Wagner ground. A good Wagner ground will be found to be a great advantage in this experiment. Measurements can be made by placing a high resistance in parallel with the standard condenser. This practically assumes that the phase difference of the condenser is due to a leak or resistance across the condenser. A good condenser has zero resistance in series or an infinite resistance in parallel.

If the phase angle of the condenser is near 90° the two values of the capacity as measured by the two methods will be equal. If the phase angle is 45° the value of the capacity obtained in the series method will be twice that obtained in the parallel method. This seems to have been overlooked by many experimenters when measuring dielectric constants of organic compounds.

Note on resistance in series and in parallel with condensers. As stated above when the loss in a condenser is large the value of the capacity measured depends on whether it is assumed to be in series or in parallel.

This can be shown theoretically as follows.

When we have resistance and capacity in series the vector

Brown, Measurements, p. 25.

diagram is that shown in Figure 17. The resistance is measured along the horizontal and the reactance, $X=1/C\omega$ is measured along the vertical, downward in this case since X is negative and the phase angle is negative. If Z is the impedance we can write, $Z=R-jX$, the letter j meaning that the vector X makes a right angle with the resistance, R . j also has the algebraic value of $\sqrt{-1}$. We can write $I=E/Z$ or $I=EY$, where Y , the admittance, is the reciprocal of Z .

Then $Y=1/Z=1/(R-jX)=(R+jX)/(R-jX)(R+jX)=(R+jX)/(R^2+X^2)$.

We can write $Y=G+jB$, where G is the conductance and B is the susceptance. Note that B is at right angles with G . Also note that when X is negative or capacitive that the susceptance, B , is positive.

Since the current, $I=EY=EG+jEB$ then if $E=1$ volt, G can be considered to be the current in phase with the E.M.F. and B is the current which is out of phase with E .

From above we have $G=R/(R^2+X^2)$, and $B=X/(R^2+X^2)$.

As a particular case assume that R is numerically equal to X and the phase angle is 45° .

Then since $X=1/C\omega$ we have $G=R/(R^2+X^2)$, and $B=X/(R^2+X^2)$.

Thus if we have a 2μ .f. condenser in series with 100 ohms and use a frequency of 796 ($\omega=5000$), we have $R=100$ ohms and $X=-100$ ohms. Suppose that this condenser and resistance is in a closed box and it is not known that the connection is series. Suppose we guess that the connection is parallel and measure it by placing a resistance in parallel with the standard condenser. Then we get the measured value of 1μ .f. capacity and 200 ohms in parallel. If the same condenser is placed in parallel with 100 ohms then we have $G=C\omega=.01$ mho and $G=1/100=.01$ mho and the phase angle is 45° again. If measured as parallel we get 100 ohms resistance in parallel with 2μ .f. capacity. If the standard condenser and resistance is placed in series we get 50 ohms resistance and 4μ .f. capacity in series. This can be worked out as above by letting $Z=1/Y=1/(G+jB)$ carrying through the above values will be obtained.

In measuring the dielectric constant of organic compounds where there is a large phase difference the values will depend on the assumption made or the bridge used. If the phase angle is less

than 45° the difference will be much greater than with 45° . If the phase angle is 84° the difference is about 1%.

Experiment 24. To Measure the Inductance of a Coil—Anderson's Method.

The method outlined here is one in which the effect of the inductance is balanced by a condenser.

We shall assume the inductance is a single layer radio coil whose inductance is near $1000\mu\text{h}$.

Measure the resistance of the coil by means of a Wheatstone bridge and galvanometer. (Experiment 5.) Connect the coil as in

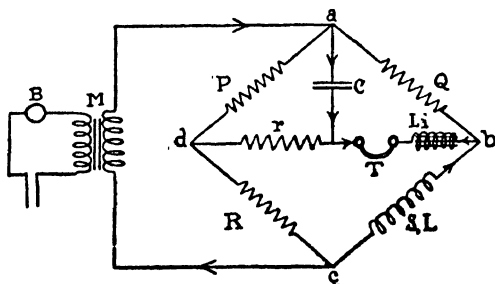


Fig. 31

the diagram, Figure 31. Balance the bridge to the nearest ohm. If the resistance, S , of the coil is known, this can be done without a galvanometer. C is a variable radio condenser whose capacity has been measured

in Experiment 19; r is a resistance box; T is a telephone; L_1 is an inductance the insertion of which helps in obtaining a distinct balance; M is a telephone coil and B is a buzzer.

The balance is made by adjusting the resistance r and the condenser C until a minimum sound is heard in the telephone. The same precautions must be taken as to noise in the room as in the buzzer-telephone method of measuring capacity.

The formula is $L = C(r(Q+S) + RQ)$. For derivation of formula see Starling. It will be noted that if the current is increasing as indicated by the arrows in the figure there will be a current through the telephone due to the charge of the condenser. At the same time, there will be a back E.M.F. in S towards which will cause a current to flow through the telephone in the opposite direction.

The value of the first current will depend upon the resistance r . When r is adjusted until the two currents are equal, there will be a minimum or no sound in the telephone.

Figure 30 is the diagrammatic connection.

Figure 32 shows the connection when a Leeds Northrup box bridge is used for the resistances. r is an extra resistance box and C may be a variable condenser. Figure 32 shows a hummer as described later (Figure 157), a filter, and a Wagner ground. The make and break keys on the box bridge are not used. For general directions in using the Wagner ground see Experiment 19.

When this bridge is used to measure the inductance of an iron core coil measuring the resistance of the coil with d-c current is practically useless as the a-c resistance is usually much greater than the value obtained. Usually one can make a rough guess at the resistance of the coil and then adjust until the true value is obtained. In general proceed as follows. Make the ratios P and Q equal to 1000 ohms each. Guess at the resistance and insert in the

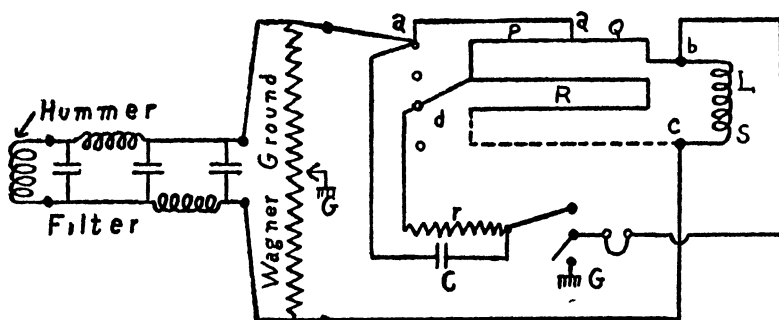


Fig. 32

R , arm. Set the capacity at some medium value. Insert resistance in the box, r . Note if the sound is diminished. Vary r and the capacity C until a fair minimum is obtained. Adjust the Wagner ground. Vary the resistance R , making the noise heard in the phone less. Balance the inductance by varying either r or C or both. Balance the bridge for resistance of the coil by varying R . Compensate for stray capacity effects by manipulating the Wagner ground. Finally when the noise is adjusted to zero the bridge is balanced for inductance and resistance at the same time. After a student has measured several coils he seems to know instinctively what to do next. There is no general royal way.

Measure the inductance of a single layer coil and check by the formula $L = 4\pi^2 n^2 r^2 l$ centimeter. n = turns per centimeter length.

r =radius of coil. l =length of coil in centimeters. The formula assumes that there is no flux leakage at the ends, or that the coil is long compared to the diameter. The value calculated without the end correction factor will be greater than that obtained with the bridge. The bridge value should be the correct one.

The more correct formula is $L=4\pi^2n^2r^2lK$ where K is H. Nagaoka's correction factor given in the table. Other slight

H. Nagaoka's factor, K for closely wound single layer solenoid coils. In the formula for the inductance of a single layer coil, $L=4\pi^2r^2n^2lK$, cm. K is given in terms of $2r/l$.

<i>Diameter</i> <i>length</i>	<i>K</i>	<i>Diameter</i> <i>length</i>	<i>K</i>
.00.....	1.000	.95.....	.700
.05.....	.979	1.00.....	.688
.10.....	.959	1.10.....	.667
.15.....	.939	1.20.....	.648
.20.....	.920	1.40.....	.611
.25.....	.902	1.60.....	.580
.30.....	.884	1.80.....	.551
.35.....	.867	2.00.....	.526
.40.....	.850	2.50.....	.472
.45.....	.834	3.00.....	.429
.50.....	.818	3.50.....	.394
.55.....	.803	4.00.....	.365
.60.....	.789	4.50.....	.341
.65.....	.775	5.00.....	.320
.70.....	.761	6.00.....	.285
.75.....	.748	7.00.....	.258
.80.....	.735	8.00.....	.237
.85.....	.723	9.00.....	.219
.90.....	.711	10.00.....	.203

corrections should be made for size of wire, etc., if exact results are to be obtained.

Watson, p. 543; Stanley, Vol. 1, p. 418; Starling, p. 329; Terry, p. 172; Bulletin of Bureau of Standards, 8, p. 224, 1912; Circular of the Bureau of Standards, 74, p. 252; *Fundamentals of Radio*, Chapter VII.

Experiment 25. Measurement of Inductance—Maxwell's Method.

This method consists of comparing the inductance of a coil with the capacity of a variable condenser.

Place the coil in a Wheatstone bridge and balance the bridge for steady current. With the bridge balanced connect an alternating current in the battery position. And a variable capacity around the resistance arm which is opposite the inductance. Figure 33.

Vary the capacity until the sound in the telephone, which is in the usual galvanometer position of the bridge is a minimum.

$$\text{Then, } L = CR_2R_3 = CR_1R_4.$$

Since the capacity of the usual variable condenser varies from .0001 to .0005 or .001 microfarads, the resistances must be so chosen that the products CR_2R_3 will be comparable to the inductance, L . With $R_2=100$ ohms and $R_3=100$ ohms the smallest value that can be measured is $.0001 \times 100 \times 100 = 1$ microhenry. This experiment works best with small coils. The hummer and Wagner ground can be used. A variable condenser placed across one arm of the ground will be necessary to get a perfect ground. Starling, p. 326.

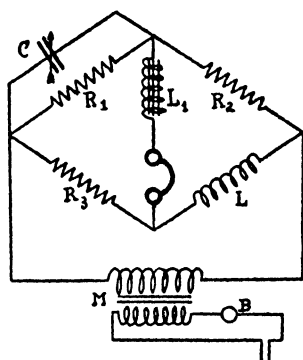


Fig. 33

Experiment 26. Measurement of Mutual Inductance.

If two coils are connected in series and so placed that they do not effect one another then the total inductance is the sum of the separate inductances,

$$L = L_1 + L_2.$$

If they are close enough together to effect each other, then,

$$L = L_1 + L_2 + M_{12} + M_{21},$$

where M_{12} is the mutual inductance or the E.M.F. induced in coil No. 1 by the current change of one ampere per second in coil No. 2, and M_{21} is the E.M.F. in coil No. 2 by the current change of one ampere per second in coil No. 1. Since

$$M_{12} = M_{21} \text{ then } L = (L_1 + L_2) \pm 2M.$$

Measure the coils as in diagram Figure 32 or Figure 33 and place them so that M is in the same direction as L . That is, in order that the current may circulate in the same direction in both coils. Then,

$$L' = L_1 + L_2 + 2M.$$

Reverse the current in one coil. Then

$$L'' = L_1 + L_2 - 2M.$$

Subtracting we have,

$$L' - L'' = 4M.$$

Take two coils such as a loose coupler tuning coil, couple as closely as possible and measure L' and L'' , and compute M .

Couple the coils as loosely as possible and repeat the measurements. From the values compute the coefficient of coupling in each case. The coefficient of coupling,

$$k = M/\sqrt{L_1 L_2}.$$

The value of k , will vary from unity, close coupling, to near zero, loose coupling. When the value is over .5 it is usual to call it close coupling. When the value of k , is less than .5 it is called loose coupling. L can be measured using either a bridge method or a wave meter method. k depends on M and $M\omega = \sqrt{R_1 R_2}$ at critical coupling. See Experiment 84.

Experiment 27. To Obtain the Characteristic Curve of a Crystal.

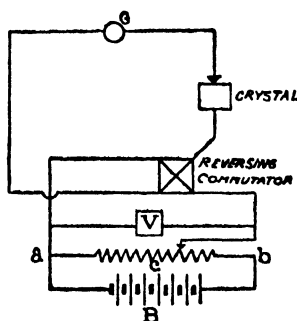


Fig 34

Connect a battery of four or six volts to a high resistance potentiometer, abc , Figure 34. Connect a , and the slider c , to a reverse key and then to the crystal through a galvanometer, G . Between a and c place a voltmeter. Measure the current through the crystal by means of the galvanometer as the potential between a and c is increased. Reverse the commutator and repeat. Call the smaller set of readings negative and plot a curve using potential along X axis and current

or galvanometer readings along the Y axis.

Set the wire contact on the crystal, C , to a new position and repeat. With the potential positive hunt a spot on the crystal that gives large deflections of the galvanometer and repeat.

The resistance of a crystal can be measured with a box bridge. Measure with current direct and with current reversed through the crystal. Note the difference.

Various kinds of crystals can be tested in this manner.

THE WAVE METER

The wave meter is the measuring instrument which is peculiar to radio.

The wave meter consists of an inductance and a capacity connected in series with some sort of current indicator. Either the inductance or the capacity is variable.

In alternating current when we have a circuit containing resistance, inductance and capacity we have,

$$I = E / \sqrt{R^2 + \left(L\omega - \frac{1}{C\omega} \right)^2},$$

where E is the E.M.F.; R , the resistance; C , the capacity; L , inductance; $\omega = 2\pi n$; where, n , is frequency. If $L\omega = 1/C\omega$, or $n = 1/2\pi\sqrt{LC}$, the current is a maximum, i.e., $I = E/R$ and the circuit is in resonance with the E.M.F. of the exciting source.

Also we have seen that if the circuit is discharged it will oscillate with a frequency $n = 1/2\pi\sqrt{LC}$.

In radio as in light we often speak of the wave length instead of the frequency of the oscillation. Since in any medium the velocity of the waves is independent of the source, the wave length depends only on the frequency of the vibrating source, and since electric waves are disturbances in the ether of space, the velocity of electric waves is the same as that of light. $v = 3 \times 10^{10}$ centimeters per second or 3×10^8 meters per second. The more exact value is 2.998×10^8 meters per second. Since in any medium $v = n\lambda$ where, λ is the wave length, we have,

$$\lambda = v/n$$

$$\lambda = 3 \times 10^8 / (1/2\pi\sqrt{LC}) = 3 \times 10^8 2\pi\sqrt{LC} \text{ meters.}$$

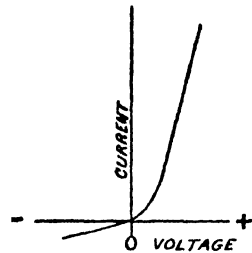


Fig. 35

In the above L is measured in henries and C in farads. When the inductance is expressed in microhenries and the capacity is expressed in microfarads the value of λ is,

$$\lambda = 3 \times 10^8 2\pi \sqrt{L 10^{-6} C 10^{-6}} = 1884 \sqrt{LC} \text{ meters.}$$

If we use centimeters and microfarads we have,

$$\lambda = 59.6 \sqrt{LC} \text{ meters.}$$

To get the frequency in any case divide the velocity of light by the wave length. Since, when the inductance is constant, the square of the wave length is proportional to capacity it is usually more convenient to calculate wave length than frequency.

Experiment 28. To Calibrate a Wave Meter—Calculation.

We shall assume that we have a coil whose inductance has been measured as in Experiment No. 24 or 25 and a variable condenser whose capacity curve has been drawn as in Experiment No. 19.

Express the inductance in microhenries and the capacity in microfarads.

Make up a table as illustrated. In column two place the capacity of the variable condenser as taken from the smooth curve made in Experiment 19. In the next place the value of the wave length expressed in meters as calculated from the formula, $\lambda = 1884 \sqrt{L \sqrt{C}}$.

If a slide rule is used this calculation can be made in 10 minutes. In the fourth column place the square of the wave length. This data will be useful in Experiment 31. In the last column place the frequency expressed in kilocycles. Divide 3×10^8 by the wave length.

Dial	Capacity	λ	λ^2	n
0				
1				
2				
5				
10				
				
				
				
95				
97				
98				
99				
100				

From the results plot a curve with condenser scale along the X axis, abscissas, and wave length along the Y axis, ordinates. Calculate the frequency for each 10 degrees and plot a curve, x =condenser reading and y =frequency.

We now have a curve from which the wave length of any circuit which is in unison with our circuit can be read. As a check on the accuracy of this method the wave meter can be compared with a standard. See Experiments 29 and 30.

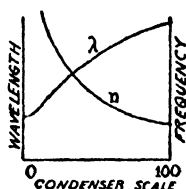


Fig. 36

Experiment 29. To Calibrate a Wave Meter by Means of a Standard Wave Meter.

With a standard wave meter the two meters can be brought close together, one can be used as a source or sending station and the other as a detector or receiving station. One is connected as in Figure 37a with a buzzer and the other as in Figure 37b or Figure 37c with a crystal and telephone. See diagrams of method of connecting. A buzzer must be used in Figure 37a. A hummer will not work.

Adjust the meters to approximate resonance. Adjust the crystal receiver to its most sensitive condition and move the meters apart, or loosen the coupling (make the mutual inductance as near zero as possible). Adjust the meters to resonance and read the scale of the condenser of your wave meter and the wave length of the standard. Repeat for several points distributed on the scale and plot a curve as in the previous experiment. This curve will be a little above that of the previous experiment due to the capacity of the coil.

DIAGRAMS OF METHODS OF CONNECTING THE DETECTOR TO THE WAVE METER AND OF USING THE WAVE METER AS A SOURCE OF HIGH FREQUENCY OSCILLATIONS

The most simple method of using a wave meter is to connect the coil, L , and the variable condenser, C , in series with a radio frequency milliammeter or galvanometer. These instruments can be obtained such that 100 milliamperes will give the full scale

deflection. The coil is brought near the radio frequency source, such as a transmitting station, and the condenser changed until the reading of the current as shown by the meter is the greatest. Then the reading of the condenser is taken and from the calibration curve the corresponding wave length is found. Instead of the milliammeter a small incandescent lamp such as a flash lamp bulb may be substituted. The readings on the condenser are taken when the lamp is the brightest.

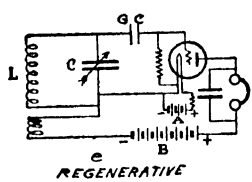
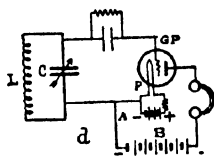
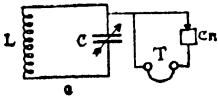
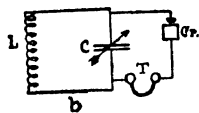
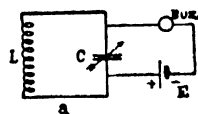
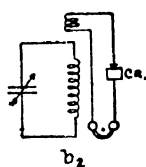
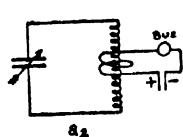
Figure 37i shows the connection. L is the coil, C is the variable condenser and A is the milliammeter or lamp bulb.

A Geissler vacuum tube, can be placed in multiple with the condenser. The current in the wave meter is the greatest when the tube glows the brightest. Figure 37j shows the diagrammatic connection.

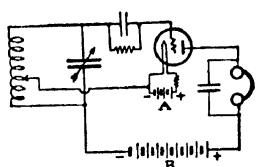
When the current in the oscillating circuit is not very great there will not be enough current in the wave meter to give a deflection of the milliammeter or to cause the lamp or bulb to glow. A telephone and crystal can be used as an indicator of current. One will recognize this connection as being essentially the secondary of a two coil loose coupler crystal receiver. This will work for damped waves, but not for continuous waves, Figure 37b.

The wave meter can be used as a generator of damped waves by placing a battery and buzzer around the condenser as in Figure 37a. This is essentially the connection of the primary of the oscillating transformer of a damped wave or spark transmitting station. The dry cell and the buzzer take the place of the transformer and spark gap.

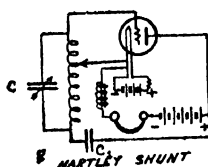
Figure 37a is a sending circuit. L is the coil; C , the capacity; Buz., a buzzer, and E , a battery. The frequency is $n = 1/2\pi\sqrt{LC}$. The group frequency is that of the buzzer. Figure 37b is a receiving circuit; Cr is a crystal detector and T , a telephone. Figure 37c is the same as Figure 37b except that the telephone and crystal do not change the wave length of the circuit as much as they do in Figure 37b. The signals will be more intense with Figure 37b. Figure 37d is a vacuum tube detector circuit. Figure 37e is a "regenerative feed-back" or oscillating circuit. This can be used for the reception of either damped or undamped waves, and as a generator of undamped waves. Figure 37f is an auto feed back circuit, in which the feed back coil is a portion of the main coil.



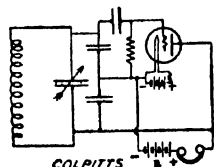
REGENERATIVE



HARTLEY SERIES



HARTLEY SHUNT



COLPITTS

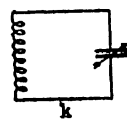
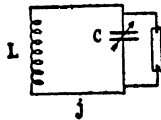
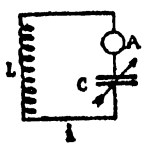


Fig. 37

This circuit is known as the Hartley Series Circuit. In this both the d-c and a-c components of the plate current pass through the lower part of the coil, L . Figure 37g is known as the Hartley shunt circuit. In this circuit the a-c component of the plate circuit passes through the condenser C_1 . Figure 37h is a capacity feed-back circuit. The wave length depends upon the combined capacity of the condenser, C , and the two condensers which are in series. Figure 37i shows the wave meter with a lamp bulb or milliammeter in the circuit. This can be used when the circuit to be measured contains a large current. Figure 37j, contains a Geissler tube for an indicator. Figure 37k is the coil and condenser connected alone. This circuit is used when the resonance click method is used with an oscillating receiver. In the regenerative or oscillating circuits the telephone should be by-passed with a condenser, capacity .0005 to .001 microfarads. This by-pass is for the radio frequency component of the plate current. In the Hartley shunt circuit the telephone should not be by-passed. This circuit requires a choke coil in series with the battery.

When the resistance of the coils is large the resistance may be so great the buzzer will not operate. The buzzer may be connected to two or three turns of wire wound about the coil and connected as in Figure 37a₂.

The telephone and crystal may be connected to a coil of few turns and placed near the tuned coil as in Figure 37b₂.

For rough work the wave length can be taken to be the same for a given coil and condenser in any of the above methods.

See Bureau of Standards Circular 74, p. 104; or Signal Corps Radio, p. 393; *Fundamentals of Radio*, p. 47.

Experiment 30. Resonance Click Method of Using a Wave Meter.

The wave meter is connected as in Figure 37k. An oscillating tube receiver is tuned on a distant sending station and the wave meter is brought near the receiver. When near enough the wave meter will absorb enough energy to cause the receiver to cease oscillating. This will cause a click in the phone. Loosen the coupling until the click occurs when the wave meter is exactly tuned, the click occurring at the same point on the condenser when decreasing as when increasing the capacity.

At certain times the Bureau of Standards transmits standard wave lengths and by using this method the wave meter can be tested or calibrated. For schedule consult Radio Journals. At present the schedule is 5 megacycles at 11-12:30 C.S.T., 10 megacycles at 1-2:30 C.S.T., 20 megacycles at 3-4:30 C.S.T. on Tuesday, Wednesday, and Friday.

If two or more standard wave lengths are received, one near the lower range and another near the upper range of the wave meter, and the square of the wave length, λ^2 , is plotted against condenser readings, a straight line will be obtained. From this line the wave length at various points is taken and a calibration curve is plotted. This assumes that the condenser is a straight line capacity condenser, semicircular plates.

This involves the principles of Experiment 31. This method can be used in Experiment 36.

Experiment 31. To Measure the Capacity of a Coil, the Natural Wave Length of the Coil, and to Correct a Wave Meter.

All coils and even straight wires have a certain amount of capacity. This is usually considered to be so small that it is neglected. In coils used with condensers of small capacity this becomes a source of error. It is assumed that one does not have an accurate standard wave meter.

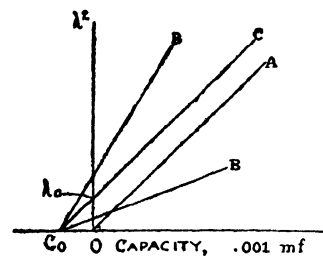


Fig. 38

We shall assume that the inductance of the coil is known and that the condenser is calibrated properly. In the equation $\lambda = 1884\sqrt{LC}$ we see that λ^2 varies with C or $\lambda^2 = (1884^2 L)C$. Thus $1884^2 L$ is the

slope of the straight line obtained by plotting, λ^2 along the Y axis and C along the X axis. Capacity in microfarads is to be plotted instead of condenser scale readings.

Calling C_0 the capacity of the coil we see that the true equation is $\lambda^2 = (C + C_0)1884^2 L$. Our data when plotted gives us a straight line through zero while the true line should cut the X axis to the left of zero by an amount equal to C_0 .

The values of λ^2 have been calculated in Experiment 28.

It will be seen that the error due to C_0 is greatest for small values of the condenser readings. When the capacity of the condenser is 100 times C_0 the error of capacity is 1% while when the capacity in the condenser is equal to C_0 the error is 50%.

A second wave meter whose maximum wave length is equal to the wave length near the lower end of the curve of your wave meter can be used to correct for C_0 . The second wave meter need not be accurately calibrated. The error of inductance will cause the slope of the straight line to be wrong. The error due to capacity of the coil will be small as long as large values of capacity in the condenser are used.

We shall assume that the maximum range of the second wave meter corresponds to 10 or 20 on the dial of the condenser of the meter being corrected. Take several readings of the wave length as given by the smaller wave meter at points ranging from 2 to 10 on the larger wave meter. Plot these readings on the same sheet as the λ^2, C curve, these will give a straight line which will cut the X axis at C_0 .

This line will not be parallel to the first line unless the second wave meter is accurately calibrated. But the line will cut through C_0 since we have assumed that we have used large values of capacity in the smaller wave meter. Since we have assumed that the inductance of the first wave meter is correct the slope of the first line is correct. Draw a straight line through C_0 parallel to the first line and this is the correct $\lambda^2 C$ line since the slope is correct and it passes through C_0 . The intercept on the Y axis gives λ_0^2 , or the natural wave length of the coil, i.e., the wave length of the circuit when there is no condenser in the circuit.

From this corrected line the values of λ^2 , and C can be taken off and from this data a corrected curve for the wave meter can be plotted. This curve can be placed as a correction on the same sheet as used in Experiment 28. Note that the convenient curve to use is the λ , condenser reading curve while we have been plotting λ^2 , capacity. If all data is correct the corrected curve should be a little above the curve made in Experiment 28. The capacity C_0 was neglected in Experiment 28.

USE OF THE WAVE METER

The wave meter can be used to measure the wave length of a sending set, to measure the wave length of stations that are

received, to measure the inductance of coils, to measure the capacity of a condenser, and, when provided with hot wire ammeter or galvanometer, it can be used to measure the decrement of a sending set, the resistance of a circuit, and the phase angle of a condenser.

Experiment 32. Measurement of Capacity. Capacity and Inductance of the Wave Meter Being Known.

The following four experiments, 32, 33, 34 and 35 are very much alike in theory and one experiment overlaps the other. The four experiments meet the four possible conditions met in practice and on this account the four experiments are listed.

This experiment assumes that we have two unknown condensers, one being variable, and an unknown inductance as well as the wave meter. Use the coil and condenser used in Experiment 28. Let, C , be the unknown fixed condenser, C_1 the known wave meter condenser, C_2 the variable condenser, L_1 the wave meter inductance, L_2 the second inductance. The value of C must be less than the maximum value of C_1 . .6 or .8 of C_1 .

Connect as sender and receiver as in first and second diagrams for wave meter connection, Figures 37a and b. Replace C_1 with C , the second wave meter being C_2L_2 .

Adjust to resonance, by varying C_2 then $CL_1 = C_2L_2$.

Replace the fixed condenser with C_1 and tune by changing C_1 , keeping C_2 unchanged, then $C_1L_1 = C_2L_2$ and $C = C_1$ the value of which is read from the calibration curve of C_1 .

Replace C_2 with C and tune to resonance by adjusting C_1 , then, $L_2 = C_1L_1/C$. (Experiment 33.)

Since L_2 is now known C can be replaced by other unknown condensers and their capacity determined.

A large capacity can be had by placing several known condensers in parallel. Scatter the condensers. Do not put one on the other.

Experiment 33. To Measure the Inductance of a Coil, the Capacity and Inductance of the Wave Meter Being Known.

This involves the measurement of capacity as well as inductance and is explained in the experiment Measurement of Capacity of a Condenser, the Capacity and Inductance of the Wave Meter Being Known (Experiment 32).

In these experiments it is assumed that the range of the wave meter will include the range of the unknown capacity and inductance combination.

By using condensers in parallel and coils in series a long wave meter can be made. Care must be used in placing coils in series to avoid mutual inductance (Experiment 26). Likewise there may be mutual capacity if one condenser is laid on the other.

The accuracy of these methods is not great since the capacity of the coil is neglected.

Experiment 34. To Measure the Capacity of a Condenser, Wave Meter Calibration Given.

A wave meter with the calibration curve being used. This involves having a known inductance. Use a standard wave meter.

Make the known inductance and unknown capacity into a wave meter and use one wave meter as a sender and the second as a receiver. See Methods of Connection of Wave Meter for diagrams of connections, Figures 37a and 37b.

Adjust the crystal for its most sensitive position and loosen the coupling until the telephone responds for sharp resonance.

$$\begin{aligned}\text{Since } \lambda &= 1884\sqrt{LC} \\ C &= \lambda^2/(1884)^2 L\end{aligned}$$

C will be expressed in microfarads if L is expressed in microhenries. This experiment is very closely allied to the corresponding experiment of measurement of inductance, Experiment 35.

Experiment 35. To Measure the Inductance of a Coil.

First having the wave length calibration curve given. This method requires the use of a known condenser. Place the known condenser in series with the inductance and thus make another wave meter. Use one of the meters as a sender and the second as a receiver, and adjust to unison with very loose coupling. See Figure 37 for connections. Adjust the crystal to its most sensitive condition and loosen the coupling until the telephone responds only at sharp resonance.

$$\begin{aligned}\text{Since } \lambda &= 1884\sqrt{LC} \\ L &= \lambda^2/(1884)^2 C\end{aligned}$$

L will be expressed in microhenries if C is in microfarads.

Experiment 36. To Calibrate a Wave Meter Using Overtones.

*If a standard wave meter or other standard wave length is available it is possible to calibrate any other wave meter using overtones. The two wave meters are connected to tubes so as to oscillate, using the Hartley or other oscillating circuitl Figure 37f. A telephone in either circuit, preferable in the circuit of higher wave length, will respond to the "beat" tone when the lower wave length circuit is in resonance with the fundamental, first second, etc., overtone of the higher wave length of the circuit; or to wave length of λ , 2λ , 3λ , etc. Where λ , is the wave length of the lower wave meter.

Thus if given a wave meter whose range is 200 to 600 meters it is possible to calibrate a wave meter whose range is 600 to 1800 meters using the second overtone. The range can be higher if the response to the higher overtones is good. Having the 600 to 1800 meter calibrated a third meter can be calibrated whose range is 1800 to 5400 meters by using the second as the standard.

If the standard is known to be accurate at one particular point or wave length, only, a wave meter can be calibrated by having the meter respond to λ , 2λ , 3λ . A sending station

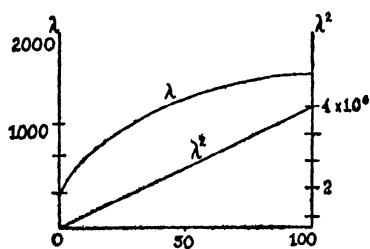


Fig. 39

which always uses a definite known frequency can be the standard. Then if the condenser capacity is proportional to the condenser readings, that is if the capacity is measured at a number of points and these points give a straight line when capacity and scale readings are plotted, the square of the wave length, λ^2 , is proportional to the condenser readings and the three or four points will lie on a straight line when the square of the wave length is plotted against the condenser scale readings. From this straight line the value of λ^2 can be taken and the value of λ at 20 or more points can be obtained.

It is well to plot λ^2 capacity curves when using the overtone method as it is easy to detect any error. If an approximate cali-

* An oscillator as described later Figure 161 is often convenient in this experiment.

bration is first obtained the danger of mistaking the overtone is much less.

In this experiment the value of the old fashioned semicircular plate condenser will be noted. Since the capacity is proportional to the dial readings the square of the wave length is proportional to the dial readings and when plotted a straight line is obtained. The intercept on the X-axis is proportional to the capacity of the coil. This will be true for each and every coil used with the condenser.

With the shaped plate straight line frequency or straight line wave length condenser assuming the plates are shaped right the curve will be a straight line, only when the coil has a certain capacity. If the condenser is so shaped as to give a straight line with one coil it will not give a straight line with a second coil of different self capacity.

Experiment 37. To Calibrate a Wave Meter Using Standard Frequencies from the Bureau of Standards.

We shall assume that the wave meter consists of a variable condenser and an inductance coil, and that the condenser has been tested as in Experiment 19 and that it has been found that the capacity of the condenser is proportional to the scale readings.

Use a regenerative receiver which can be made to oscillate at will. A loud speaker connected to the receiver will be found to be advantageous. The wave meter may be excited by means of a buzzer or it may be connected as a low power tube generator using an ordinary amplifying tube with about 60 volts on the plate. The connection may be the Hartley circuit. See specifications for coils and generator in Notes and Suggestions for Laboratory Apparatus. A modern small superheterodyne receiver can be used. Tune the receiver to the standard station. An oscillator such as described later (Figure 161) is convenient. As the dial of the oscillator is moved there will be a loud note from the receiver. Set the oscillator so the beat note is some convenient frequency, 1000 say. If the oscillator is beating with the standard station the frequency will remain at 1000 as the receiver dial is changed. The intensity will change but the frequency will be constant. If the frequency of the beat note changes the oscillator is beating with

some unknown frequency manufactured in the receiver. Broadcast stations make good standard frequency stations.

It will be a great help if the wave meter or receiver has been approximately calibrated before the test. This will enable one to find WWV, the Bureau of Standards station.

When WWV has been found listen to the preliminary announcements and then set the tube oscillating and tune until the beat tone is zero frequency or disappears. Then adjust the wavemeter to the same wave length and record the readings of the condenser. Experiments 29 and 38. It is well to record the readings on the receiver noting the amount of coupling and the readings of the aerial circuit as well as those of the primary circuit.

The Resonance Click Method can be used, Experiment 30. However, this is not as accurate as some other methods.

If the generator does not cover the same band of waves as those sent out the method of Experiment 36 can be used.

After the readings have been taken it is well to plot λ^2 and condenser readings. This should give a straight line. If any point fall off this line any considerable amount it is evident that an error in reading or recording has been made. If the readings of receiver as well as wave meter have been recorded the receiver and wave meter can set up as per the record and as a usual thing the error of reading, or record will be apparent.

After the straight line has been plotted the exact calibration curve or data can be taken from the straight line. Experiments 31 and 36.

It will be evident that the calibration will be exact for the particular connections which were used in the calibration.

Use the same tube with the same *B* battery and the exact relative position of the various parts, condenser coils and connections.

For schedule from WWV see schedule in magazines such as QST and Proc. I.R.E.

It will be well to practice this method by tuning to the carrier wave of the various broadcasting stations. The wave length may be taken from the lists of stations as found in the radio magazines.

At present WWV transmits on Tuesday, Wednesday and Friday. 5 megacycles 11 A.M. to 12:30, 10 megacycles 1 to 2:30, and 15 megacycles from 3 to 4:30 Central time. Modulated on Wednesday at 1000 cycles.

Experiment 38. To Measure the Wave Length of distant Sending Station.

Adjust the receiver until the station is heard clearly. Gradually loosen up the coupling, keeping the station as clear as possible. Make the coupling as loose as possible without losing the station. Connect a buzzer to the wave meter and bring it near the receiver; adjust the wave meter to resonance without changing the receiver. Make the coupling of the wave meter to the receiver as loose as possible. Read the wave length from the wave meter calibration. If the coupling is not loose there may be two points of resonance. Read the wave length for both points. To find which is the correct value, cut a few turns out of the primary of the receiver, decrease the inductance and if the stations can not be heard in the receiver the longest wave length is the correct value.

If the wave length of the stations is known, this method can be used to calibrate a wave meter. If the wave meter consists of a coil of a few turns and an ordinary 43 plate condenser the square of the wave length and condenser readings when plotted will give a straight line through zero. From this line the wave length at any reading of the condenser can be found. A modern receiver can be used instead of the regenerative receiver.

Experiment 39. To Measure the Natural Wave Length of an Aerial.

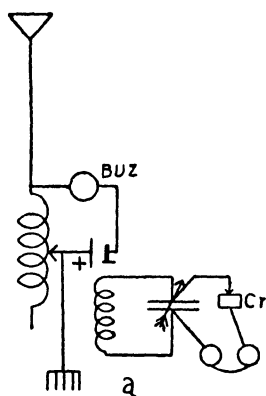
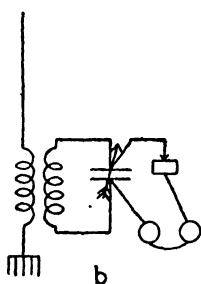


Fig. 40



Connect an inductance of a few turns in series with the aerial and a buzzer or shunted buzzer around the coil, Figure 40. Bring a wave meter near the aerial and measure the wave length. Move the grounded top so as to cut out one turn of wire and measure again. Repeat until a

very few turns are left, one if possible. Plot turns of wire along X and wave length along the Y axis. This will be almost a straight line. Extend the line back to zero turns, the intersection on the Y axis will give the value of λ_0 .

A short wire stretched at some little distance from the aerial and a calibrated receiver can be used, Figure 40.

2nd Method. A spark gap can be placed in series with the aerial and a strong buzzer or small induction coil is connected around the spark gap, Figure 41. The wave meter is brought near the aerial and readings taken. In this case there will probably be a noise in the wave meter phone due to the field of the induction coil. One must distinguish between that and the noise due to high frequency. The intensity of the coil induction will remain constant while that due to the wave will vary and be a maximum when tuned on the wave.



Fig. 41

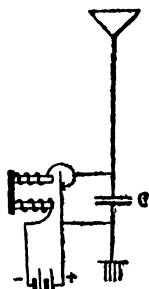


Fig. 42

It may be necessary to use a short wire and calibrated double coil receiver. Both primary and secondary circuits of the receiver must be tuned and the coupling made loose.

3rd Method. Place a large condenser in series and connect the spark gap of a buzzer around the capacity and measure with a wave meter, Figure 42. If the condenser is large it will have no effect on the wave length.

Experiment 40. To Measure the Capacity of an Aerial.

The capacity can be measured the same as the capacity of any condenser, using the bridge buzzer method, Experiment 19. Connect the aerial and ground connection in the place of unknown.

The capacity can be measured by means of a wave meter. Measure λ_0 , Experiment 38, then place a capacity in series and measure again.

$$\text{Since } \lambda_0 = K\sqrt{L_0C_0} \text{ and } \lambda_1 = K\sqrt{(C_0C_1)/(C_0 + C_1)L_0}$$

$$C_0 = C(\lambda_0^2 - \lambda_1^2)/\lambda_1^2.$$

Experiment 41. To Measure the Inductance of an Aerial with a Wave Meter.

Measure λ_0 , Experiment 39, and place a known inductance in series and measure again.

Since $\lambda_0 = K\sqrt{L_0C_0}$ and $\lambda_1 = K\sqrt{(L_1 + L_0)C_0}$

$$L_0 = \left(\frac{\lambda_0^2}{\lambda_1^2 - \lambda_0^2} \right) L_1.$$

The capacity and inductance of an aerial is distributed in the aerial. The measurements at high frequency will not be exactly the same as that measured at low frequency.

VACUUM TUBE CHARACTERISTICS

There are four characteristic curves which show the operating properties or characteristics of the three electrode tube. They are the Filament, the Mutual, the Plate, and the Grid characteristic curves.

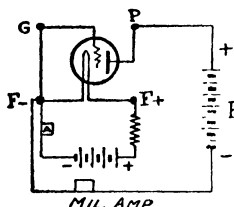


Fig. 43

Experiment 42. Filament Characteristic, Filament Current, Plate Current.

Connect the tube as in the diagram, Figure 43. Instead of batteries a power supply can be used (see Experiment 43 and page 196). Use a $22\frac{1}{2}$ volt dry battery on the plate. (Do not measure the E.M.F. of the battery with a voltmeter more than is necessary.) Connect a 6 volt storage battery to the filament, using an ammeter and variable resistance in series. Instead of a filament ammeter a voltmeter may be placed across the filament from $F-$ to $F+$, Figure 43. If power supply is used the filament meter must be an a-c meter. The filament potential can be changed from the maximum rated filament potential down to lower values. If a low filament potential tube is used place a 1.5 volt dry cell or a 2 volt storage cell in the filament circuit.

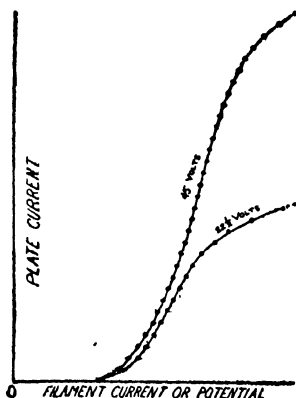


Fig. 44

A Weston voltmeter can be used in place of the milliammeter.* Resistance in the plate circuit does not change the current much. (Weston Model 280 voltmeter takes 15 milliamperes for full scale deflection.) Vary the filament current from maximum down to near zero and measure the plate current. Plot curve X = filament current, or filament potential, Y = plate current.

Reverse the $22\frac{1}{2}$ volt battery and try again. Repeat with a 45 volt battery on the plate. A power supply as used in Figure 46 can be used.

Experiment 43. Mutual Characteristic, Plate Current, Grid Potential Characteristic.

Connect the tube as in the diagram Figure 45. For the variable potential on the grid use a high resistance potentiometer around a $22\frac{1}{2}$ volt B battery or a potentiometer across the terminals of a 110 volt d-c lighting circuit. See that the potentiometer in the 110 volt circuit does not get hot.

Keep the potential of the plate and the current or potential in the filament circuit constant. Change the potential of the grid

from zero to positive by steps of a few volts and read the current in the plate circuit until the plate current ceases to change rapidly. If the tube is a soft or gas tube the current in the plate circuit suddenly may become very large. Do not continue.

The grid potential is measured by the voltmeter between the slider and the end of the potentiometer.

Change the potential of the grid to negative values by reversing the commutator. Take readings until the plate current is zero.

Repeat with a different current in the filament circuit. Never use more filament current than the rated value given by the makers of the tube.

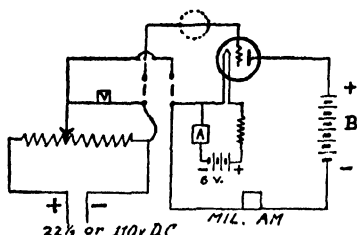


Fig. 45

* Any voltmeter can be used in which the voltmeter resistance is small compared to the tube resistance. The deflection can be multiplied by the proper constant to give the current in milliamperes. If the resistance, R_v , of the voltmeter is known, the constant is $1/R_v$. (The current when the meter reads one volt on the scale is $1/R_v$ amperes.)

Repeat with 45 volts in the B Battery. Repeat with 67½ volts and 90 volts. Insert a resistance in the plate circuit and repeat. Disconnect the grid, "grid free" and note the current. What grid

potential will give the same current. Note that a free grid or a grid condenser in the grid has the effect of a negative grid potential.

The data for measuring the amplification constant of the tube can be taken with this experiment. See Experiment 47. The reverse key may be a simple one made of four pools of mercury in a block of

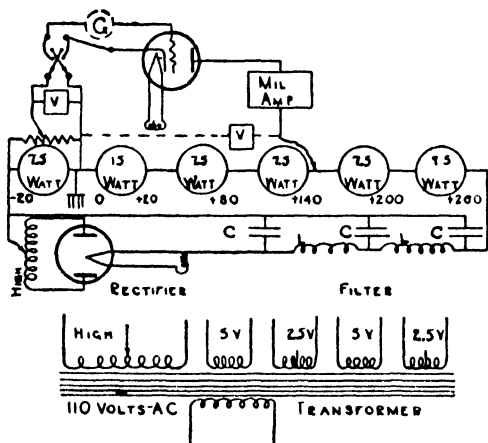


Fig. 46

wood as diagrammed in Figure 45. The connections are made between the pools by means of two parallel wires in the vertical position as shown in the diagram. To reverse the connections the wires are lifted and placed across the pools in the horizontal position.

A reverse key may be made of a double pole double throw electric switch by connecting as in Figure 67. The above assumes that one is to use batteries. In Figure 46 the three electrode

tube such as a 27 is connected to a power supply as described in "Apparatus" at end of book. In this there will be some little variation of the plate

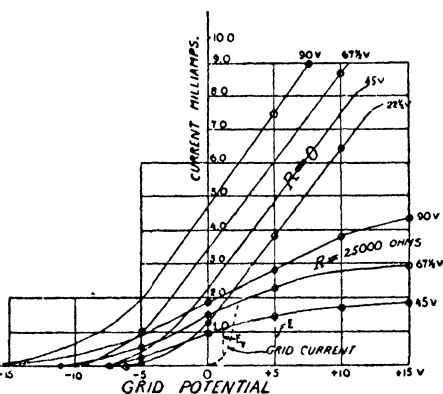


Fig. 47a

potential as the plate current increases. A voltmeter continuously connected to the B potential tends to increase this change due to the fact that a voltmeter causes a larger current drain. It is found better to measure the potential across the various lamps at the beginning of the experiment and assume that this potential is constant. In Figure 46 the potential across the first is 20 volts and across the others the potential is 60 volts each. The actual potential will vary somewhat with the individual lamps. All lamps are not quite alike.

Make the plate potential 20 volts, potential across the 15 watt lamp, and vary the grid potential and run the 20 volt curve. Interchange the 15 watt and a $7\frac{1}{2}$ watt lamp and run the 60 volt curve. Then the 80 volt curve. Follow the general method as outlined with batteries. With the reversing switch the grid potential can be made negative and positive. In most published mutual characteristics the negative part is given without the positive.

Take as many curves as possible, 20, 60, 80, 120, 140, 180, 200, 240, 260 volts. However do not exceed the rated plate voltage of the tube.

These curves will not be equally spaced as when batteries are used. If one had lamps so that the potentials were 25 and 50 volts instead of 20 and 60 volts the curves would be equally spaced.

Be sure that the filament or heater potential is not greater than the rated voltage. Consult a standard tube chart. One can not expect to remember the data for all tubes. Look up the data for every tube used.

If a filament tube such as the 201A tube is used with 5 volts a-c, on filament either the transformer 5 volt coil must have a mid-tap or a mid-tapped 100 ohm resistor must be used. Make connection to mid-tap instead of negative filament. Before tearing down the apparatus run the grid characteristic. Experiment 44.

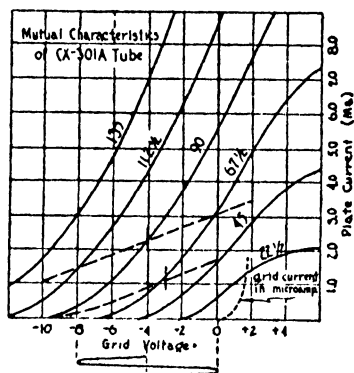


Fig. 47b

Brown, p. 223; Morecroft, p. 162; Terman, Measurements, p. 157; *Fundamentals of Radio*, Chapter X.

Experiment 44. Grid Characteristic. Grid Current, Grid Potential.

Connect as in Figure 45 or 46 except that a microammeter or sensitive galvanometer is placed in the grid circuit. With a small potential on the plate adjust the potentiometer until the plate current is near zero. Slowly increase the plate current watching the microammeter. As the grid potential approaches zero the microammeter will begin to deflect. Record the reading

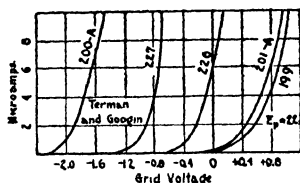


Fig. 48

of the grid current from zero to maximum value. The change of grid potential will be in the neighborhood of two volts. Carefully observe the potential at which the grid current starts and the point of greatest curvature of the curve. Repeat with a larger potential on the plate.

It will be found that the two curves nearly coincide.

Plot curves grid potential, abscissas, grid current ordinates.

In class A amplifiers grid current is avoided. Grid condenser-grid leak detectors operate on the point of greatest curvature.

The absolute value of the grid current is not essential.

Experiment 45. Plate Characteristic.

Plate current, plate potential. The connections for the plate characteristic is practically the same as that for the mutual characteristic, Figure 45 or 46.

In this the grid potential is kept constant and the plate potential, B battery, is varied and the corresponding plate current is read. When a number of these are taken we have a set of curves as in Figure 49.

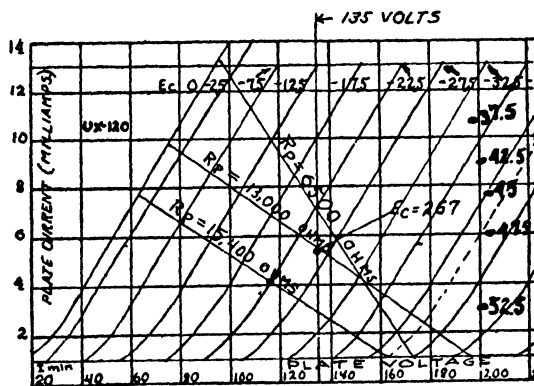


Fig. 49

The data for the plate characteristic curves can be taken from the mutual characteristic curves. If the grid is held at zero potential and the plate potential is made 20, 60, 80 volts in succession the plate current will be the same as that recorded on the mutual characteristic where the 20, 60, 80 volt curves cross the zero axis. In like manner the currents for -5 volts grid can be read at the points where the -5 volt line crosses these mutual curves.

From the mutual curves record the plate currents when the grid is $+5, 0, -5, -10, -15$ volts and plot as in Figure 49.

In like manner if a set of plate current curves are at hand, the data for the mutual characteristics can be taken by reading the current where the various plate lines cross some vertical line of constant plate potential. This data can be read for plate potentials 25, 50, 75, 100 volts, etc., and plotted. These lines will be equally distributed in contrast to the 20, 60 volts, etc. Take data from your plate characteristic and make a symmetrical mutual set of curves.

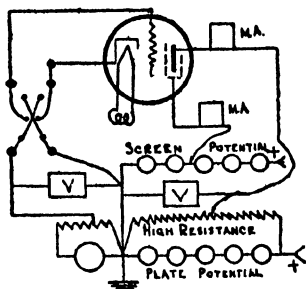


Fig. 50

Experiment No. 46. Characteristics of Multielectrode Tube.

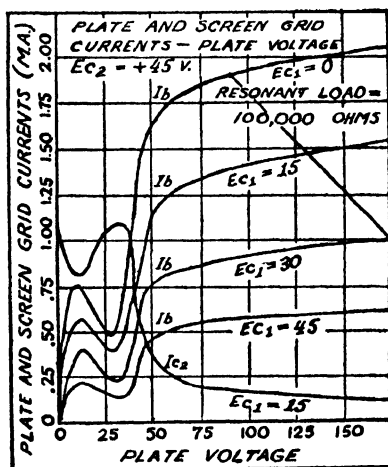


Fig. 51

Characteristics of a multi-electrode tube can be run in the same general manner as those of the three electrode tube. It is usual to run the plate characteristics. Figure 51 shows the connections for a screen grid tube, (four electrode) using power supplies instead of batteries. If large B batteries are used one set is enough. The screen grid is connected to a constant potential of about 100 volts.

The screen current varies and the screen potential may

vary if one power supply is used. It is better to use two supplies as shown in the figure. A high resistance potentiometer is placed around the plate potential and by this means the plate potential can be varied continuously from zero up to the highest value.

Figure 52 shows four plate curves and one screen grid current curve of a screen grid tube. The mutual characteristic curve data be taken from these plate curves. Or the mutual characteristics can be taken by varying the control grid potential.

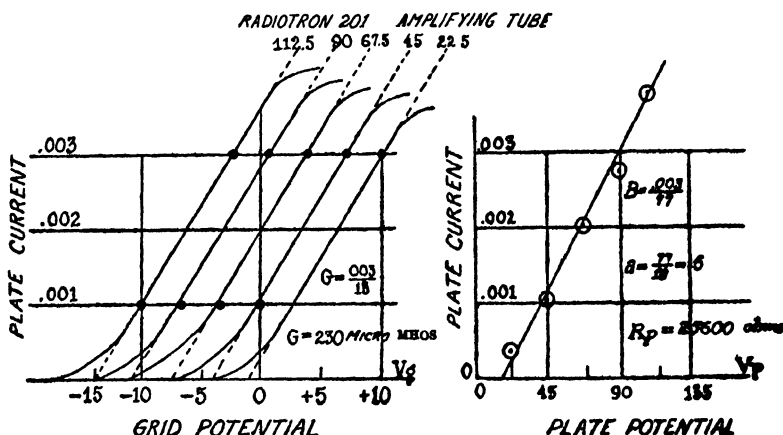


Fig. 52

These curves will be smooth curves if the plate potential is greater than the screen potential.

The plate curves of a pentode can be made by putting the proper potentials of the various electrodes and varying the plate potential.

Experiment 47. Calculation of Constants of a Tube.

Fundamentals of Radio, Chapter XII.

Select a tube and run the grid potential plate grid current characteristic curves at several voltages from the lowest up to the highest rated plate potential. Experiments 43. The tube used and the curve obtained in Experiment 43 and 45 may be used. The curves may be considered to be a series of parallel straight lines if the upper and lower ends are neglected.

Plate current 1. Milliampere. $\mu=7$.

V_p	22.5	45	67.5	90	112.5	
V_g	+3.5	0	-3	-6.3	-10.	
$V_p + \mu V_g$	45	45	46.5	45.9	42.5	

The straight part of the curve can be represented by the equation $I_p = A + B(V_p + \mu V_g)$ where I_p is plate current, V_p is the plate voltage, V_g is grid potential, a is the voltage amplification constant, and A and B are constants to be determined.

$dI_p/dV_g = \mu B = G_m$ the grid potential plate current conductivity or the mutual conductance.

$dI_p/dV_p = B = G$ the plate potential plate current conductivity.

$$\mu = \mu B / B = G_m / G.$$

From the slope of the grid potential, plate current curves, G_m can be calculated. If the various values of the plate current where the curves are cut by some vertical line, such as the line grid potential equal zero, are taken and a plate current plate potential curve is plotted, a straight line is obtained from the slope of which G can be obtained.

From these values of G_m , and G , μ , the amplification constant, can be had. After μ is determined, the quantity $V_p + \mu V_g$ for any constant value of I_p should equal a constant. Fill in the table from the values taken from the curve, where $I_p = \text{Constant value}$. Determine G_m the mutual conductances.

Determine G and $1/G = R_p$, the resistance of the tube.

Note: The characteristic curves of the "treated" filament tubes do not approximate to a straight line as nearly as do the tungsten filament tubes. Figure 52 are curves taken with a tungsten filament tube. Figure 47 is taken with a 01A tube. Take the slopes at the normal working conditions.

Experiment 48. Measurement of the Amplification Constant of a Tube.

The tube is connected, Figure 53, to a resistance or potentiometer by means of which the ratio of the potential applied to the plate

to that applied to the grid can be changed. If the grid is raised 1. volt and the plate potential is lowered μ volts the plate current will be constant. When there is minimum noise in the telephone in the plate circuit we have, $\mu = R_2/R_1$.

By referring to the $I_p V_o$ curve of the tube the proper value of the potential of the B battery and of the C battery, (the battery in the grid circuit), can be obtained. It is often convenient to make the B battery such that the C battery can be zero. In the curves given in Experiment 47, B should be 60 volts with zero

grid potential. A condenser of large capacity can be placed in series with the hummer. A variometer connected as in Figure 76 corrects for phase change. The condenser and variometer can be omitted.

Figure 53 shows connections using power pack, Figure 46. The C supply of the pack can not be used. Separate C batteries must be used. Usually

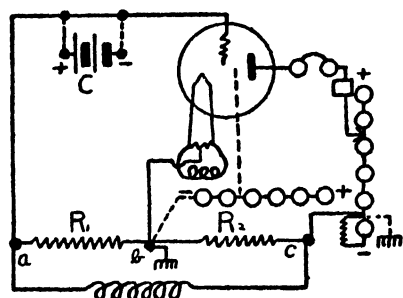


Fig. 53

zero C potential is sufficient. Figure 53 shows a second power pack, which can be used for screen potential if the tube is a screen grid tube. Connect the point b to the ground.

Use two resistance boxes for the potentiometer. R_1 should be 10 ohms or less.

A d-c milliammeter or galvanometer can be substituted for the telephone if a battery of 10 volts and key is inserted in place of the telephone coil. See Figure 76. Adjustment is made until there is no change of deflection when the key is closed or opened. The filament current should be the normal rated current. Change the filament current to a lower value and measure again. Measure several tubes using rated current and potentials.

Lauer & Brown, p. 160; Van der Bijl, p. 194; Morecroft, p. 494.

Experiment 49. Determination of the Resistance of a Tube.

1st method. The a-c resistance of the tube can be determined from the curves since the resistance is the reciprocal of the conductivity. Or $R_p = 1/G$. Experiment 47.

2nd method. The d-c resistance can be measured by inserting a known high resistance in series with the milliammeter in the plate circuit.

Since $E = I_1 R_p$ when the inserted resistance is zero and $E = I_2 (R_p + R)$ when R is inserted.

$$R_p = RI_2 / (I_1 - I_2).$$

Experiment 50. Measurement of the Resistance of a Tube, Bridge Method.

Connect as in the Figure 54. This will be seen to be a simple bridge circuit for measuring resistance. Since a-c is used with a telephone the batteries in the arms can be disregarded. R_1 and R_2 are the ratio arms and R is the rheostat arm of the bridge.

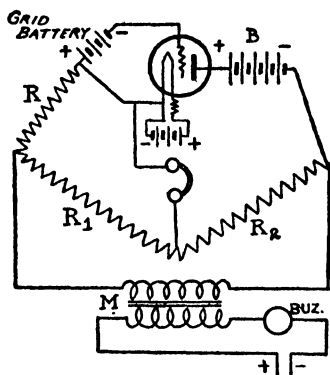


Fig. 54

$$R_p = \frac{R_2 R}{R_1}.$$

A power supply can be used for A and B batteries. The C must be batteries.

Van der Bijl, p. 203.

Experiment 51. To Measure the Plate Capacity and the Grid Capacity of Tubes.

The capacity between the various elements of a vacuum tube has a distinct value and becomes of great importance in short wave work.

The capacity can be measured the same as that of the capacity of a small condenser. The measurements should be made when the tube is mounted as it is when used as a detector or as amplifier.

For the plate capacity treat the tube as a condenser whose terminals are filament and plate. For the grid capacity, use terminals filament and grid. The heating battery should not be connected. It is of interest to take measurements with the filament cold and then hot. If the tube is in a socket part of the capacity

Since $dI_p = dE_p/R_p = \mu dE_g/R_p$, $dI_p/dE_g = \mu/R_p = G_m$, $G_m = dI_p/dE_g = dI_p/I_1 R_1$. Then if $dI_p = I_1$, $G_m = I_1/I_1 R_1 = 1/R_1$.

Connect the battery, C , (a single dry cell) so that the current through it will flow backward through the milliammeter when the key is closed. The plate current flows forward through the milliammeter. Then if the resistance, R_1 is adjusted so that there is no change of deflection when the key is closed we have the change of the plate current equal to the current from the battery, C . Then $I_1 = dI_p$ and $G_m = 1/R_1$. Reverse the battery C and adjust again.

The battery should be adjusted so that the current I_1 through the milliammeter is of the order of one or more milliamperes. It is assumed that the tube is operated on the straight part of the characteristic.

The mutual conductance of the tube should be large in a good tube. This will be seen to mean that the amplification constant of the tube is large and the resistance of the tube is small. The mutual conductance is usually expressed in micromhos. The mutual conductance of 27 tubes is about 1000 micromhos. The value will depend on plate potential and filament current. Determine G_m of several types of tubes and compare with the values calculated by other methods. The mutual conductance of a screen grid tube can be measured by placing a separate screen grid potential as in Figure 53.

Van der Bijl, p. 202.

Experiment 53. The Vacuum Tube as an Oscillator.

When the grid of a tube is made positive the plate current is increased. If the plate current is passed through a coil of wire such as F , in Figure 57 and this coil is coupled to the coil, L , so that the mutual inductance is such as to increase the grid potential while the current is increasing the change of the grid potential will be much greater.

When the grid potential is reversed the effects will be reversed. Energy is fed into the oscillating circuit, LC , from the plate circuit

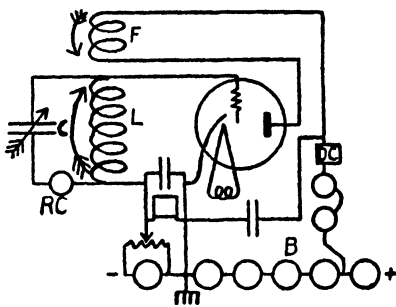


Fig. 57

If there is more energy given to the circuit than is used up in the circuit, radiated as heat say, then the circuit, LC , will oscillate and the current in LC , will increase until the energy used up in the circuit is equal to that fed into it. Two coils as shown on page 185, a variable condenser, a by-pass condenser .001 μ f., a 100 milliamperere radio meter, and a voltmeter for d-c meter are needed if a small tube is used.

There are several different connections which will serve as oscillator circuits. All radio telephone and C.W. circuits come under this class.

The following general directions should be followed in order to obtain the maximum current in any particular case.

(1) Uncouple the two coils, *i.e.*, change the connections so that the circuit will not oscillate.

(2) Adjust the grid potential by means of a battery or potentiometer so that the plate current is normal rated plate current. See tube data sheet or grid potential plate current curve. Some circuits require a grid condenser in the grid circuit. The value of the grid condenser and the resistance of the grid leak must be adjusted so that the average potential of the grid has this value. This must be done while the circuit is oscillating. See Experiment 64 for grid resistance.

(3) Gradually couple up the coils until oscillation begins, and then a little more as a margin of safety. When the tube begins to oscillate there will be a peculiar click in the phone. If a milliammeter or voltmeter used as a milliammeter is in series with the phone there will be a sudden kick of the pointer. A by-pass condenser must be around the phone and milliammeter.

Adjust the C bias and the coupling until the radio frequency ammeter in the tuned circuit gives the largest reading. Stop the oscillation and perhaps the d-c plate current is found to be zero. The bias potential must be reduced before the oscillation will start again. This is a class C oscillator. Touch the grid of the tube and note the sound in the phone and the action of the d-c meter in the plate circuit. Loosen the coupling and touch again. Note action.

Place a grid condenser and grid leak in the grid circuit and adjust.

These directions must be followed in principle as the exact order of proceedings will differ with the particular circuit. The above directions will apply to the circuit of Figure 57.

Connect up two such circuits. (It will be noted that this is the wave meter circuit shown in Figure 37e, Diagrams of Methods of Connection of Wave Meters.)

When the two circuits are almost in unison there will be a shrill tone heard in the telephone. This note will get lower in pitch and disappear when the circuits are exactly in resonance. An oscillator as described, Figure 161, is convenient here.

Compare wave meter calibration with this method. Two students working together can compare results of previous work. Experiments 32, 33, 34, 35, 29 and 36.

Connect up a Hartley oscillator and adjust. "Fundamentals of Radio," Chapter XV.

Experiment 54. Adjustment of an Oscillating Circuit.

Take an ordinary receiving tube and run the characteristic curves, connect the tube up to an oscillating circuit as in the diagram, Figure 58. Place a d-c milliammeter in the plate circuit and a hot wire ammeter in series with the condenser. The d-c instrument will measure the plate current plus the rectified component of the r-c current. The hot wire instrument will measure the r-c current in the oscillating circuit. Regulate the grid potential

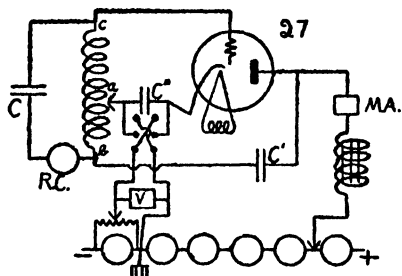


Fig. 58

by means of the potentiometer in the grid circuit. Make the grid potential such as to make the plate current small, some place on the lower half of the characteristic curve. Connect the filament connection at the bottom of the coil, at the plate connection, and read both meters. Move the filament connection up a turn or two and read. Take readings with the filament connection at regular intervals along the coil. As the filament connection is moved the relative number of turns in the plate coil and grid coil is changed. Thus the values of M , the mutual inductance, is changed. Plot a curve X = number of turns of wire between the filament connection, a , and the plate connection on the coil, b , and Y = the d-c current. Also a second curve where Y = the r-c in the hot wire ammeter.

Make the grid potential near the middle of the characteristic curve and repeat. Then repeat with the grid potential near the top of the curve. Plot curves for each case.

Place a grid condenser .00025 m.f. and a grid leak 25,000 to 100,000 ohm and repeat.

The intensity of the oscillation will depend upon the value of inductances. There is a certain ratio which will give the best result. This is shown by the hot wire instrument. The current in this circuit may be much greater than in the plate current. The value in this circuit depends upon the resistance, *i.e.*, $I = E/R$. If a wave meter with a low resistance meter in the circuit is brought near the oscillating circuit the current in the wave meter may be greater than that in the main circuit. What are the adjustments for maximum output? What for maximum efficiency?

Experiment 55. Characteristic of an Oscillating Tube.

When a tube is set into oscillation there will be, in general, a change in the d-c current of the plate circuit. This is due to the rectified component of the r-c current. When the tube is oscillating near the lower end of the plate current, grid voltage curve there is positive rectification, and when near the top of the curve there is negative rectification.

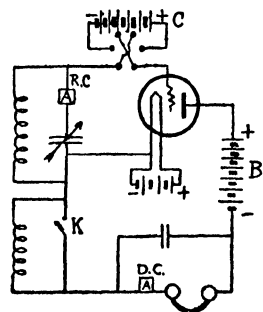


Fig. 59

Connect as in the Figure 59 placing a regenerative coil in the circuit. A loose coupler with a feed-back coil will answer the purpose. The circuit of Figure 57 can be used, placing a key, *K*, across the feed back coil, *F*.

Place a by-pass condenser around the milliammeter and telephone in the plate circuit. Tune with the variable condenser in oscillating circuit. The *C*, battery, the battery in the grid circuit, is composed of a few low resistance dry cells. If old dry cells, high resistance, are used there will be an effect such as that obtained with a grid condenser in the circuit.

Couple the coils so the tube oscillates and "kill" the oscillation by closing the key, *K*. If one changes the grid potential and reads the meters the data will give the mutual characteristic, Experiment 43.

Adjust the grid potential until the plate current is zero. Read the plate current with the key, K , closed and then again with the key open. Take reading at regular intervals until the grid potential is zero. Reverse the C , potential and read until the tube fails to oscillate.

Plot the readings as in Figure 60. The dotted line is the regular mutual characteristic. The full line is the oscillating characteristic.

With modern tubes the upper loop may be much smaller than the lower loop. With tungsten filament tubes the loops have nearly equal areas.

The d-c plate current, I can be considered to be $I_{\max}$ of the a-c plate current or $I = I_{\max}/\sqrt{2}$. Oftentimes the plate a-c current can be estimated in this way. Experiment 111.

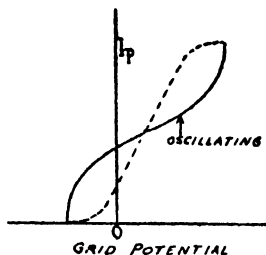


Fig. 60

Fundamentals of Radio, p. 160.

Experiment 56. The Oscillating Tube and Parallel Resonance.

The oscillating tube can be considered to be a particular case of parallel resonance, Experiment 18.

Connect the tube with the tuning coil and condenser in the plate circuit. In the grid circuit connect tickler coil, Figure 61.

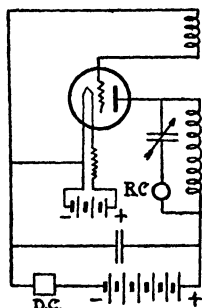


Fig. 61

The grid circuit can be considered to be a device which varies the plate current and which takes little or no energy. The plate current can be considered to have two components, a constant d-c current and an alternating radio current the frequency of which is governed by L and C in the tuned circuit. The r-c current in the plate circuit then is the resultant of the two currents, one the condenser current and the other the current through the coil. These two currents are practically the same in numerical value and almost in opposite phase.

Let the vertical dotted line represent the direction of the E.M.F. Figure 62. If the resistance is considered to be all in the

coil the condenser current is represented by oc which has a positive phase angle of 90° in advance of the E.M.F. The current through the coil lags behind the E.M.F. by an angle represented by the angle pol . The current through the coil is represented by ol whose magnitude is approximately equal to oc , and nearly opposite to oc . Both are equal to the current as measured by the radio ammeter

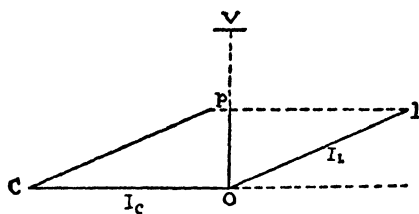


Fig. 62

in series with the condenser. The vector difference is op and is equal to the radio frequency current flowing into the plate.

The a-c plate current can be read with a sensitive thermo junction or it can be estimated by the reading

of the d-c ammeter. See Experiment 111. The d-c meter reads the average current in the plate, which is approximately the maximum r-c current.

The virtual current is the $\text{max.}/1.41$. Lay out the vector diagram, having oc and ol equal to the radio milliammeter reading, and op equal to $1/1.41$ of the d-c ammeter reading.

The tangent of $pol = L\omega/R$ and the tangent of $plo = R/L\omega = op/ol = \text{plate current divided by the resonant current}$. This assumes that $\tan plo = \sin plo$.

Measure the resistance of the circuit by the resistance variation method, Experiment No. 89. Measure the wave length with a wave meter and the inductance of the coil L . (If the condenser C has been calibrated the value of $L\omega$ can be calculated since $L\omega = 1/C\omega$. Then $R/L\omega$ should equal the ratio of the currents.

Notice, use precaution in measuring the resistance in Experiment No. 89.

This check will be rather rough but a thorough understanding of the principles gives one an insight into the theory of oscillation.

This experiment can be extended by placing the tuned circuit in the grid circuit and proceeding as above. By this time a student should be able to adapt a power pack to the circuit.

Experiment 57. The Tube Oscillating at Low Frequencies.

If an audio frequency transformer is used as the inductance the tube can be made to oscillate at low frequency and the tube becomes a low frequency alternator. The frequency depends upon the inductance of the coil and upon the capacity of the condenser used. With some audio amplifying coils using a 43 plate variable condenser the frequency is low enough to be counted. Connect the condenser to the terminals of the secondary coil. Figure 63. Connect the same two points to the filament and to the grid of the tube. Connect the primary of the coil in the plate circuit with a *B* battery and a telephone. If the tube does not oscillate reverse the connections of the primary coil.

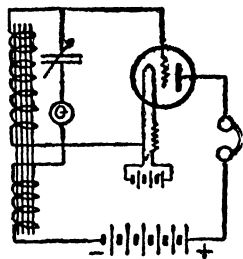


Fig. 63

The tone in the telephone will be a very low note, perhaps low enough so that the individual oscillations can be counted. Change the capacity of the condenser and note the change of the frequency. A galvanometer can be placed in the oscillating circuit and the alternations be made visible to a class.

Experiment 58. To Measure the Relative Detecting Efficiency of Vacuum Tube.

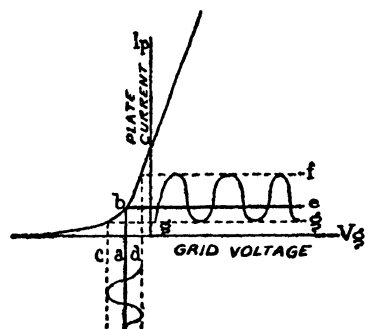


Fig. 64

The plate current grid potential characteristic curve of the tube, is seen, to consist of a curved line at the ends and a straight part in between. The curved part at the foot of the curve will be noted. The Figure 64 represents the foot of the curve. If by means of a battery or potentiometer the potential of the grid is brought to the point *a*, which corresponds to the point *b*, of greatest curvature of the

curve. Then if an alternating potential is placed upon the grid so as to cause the grid potential to vary between *c* and *d*, the plate

current which was constant at e , will vary between g and f . But since the curve is not straight the upper loops of the plate current will be greater than the lower loops and the average current through the telephone will be increased. If this effect is due to a damped train of waves each train will cause a click in the telephone. A series of trains will cause a musical note. The rectified component of the current through the telephone or the signal current is equal to

$$\frac{v^2}{4} \cdot \frac{d^2 i_p}{dV_o^2}.$$

Fundamentals of Radio, Chapter XII.

The detection action of a vacuum tube is a rectifying action. In this experiment the tube is used to rectify low frequency a-c instead of radio frequency current.

Connect the tube as in Figure 65 using a buzzer connected to a telephone coil as in previous experiments. This circuit requires a C battery of four or five good dry cells. Each cell can be counted as 1.5 volts. The buzzer should be connected to a good 2 volt

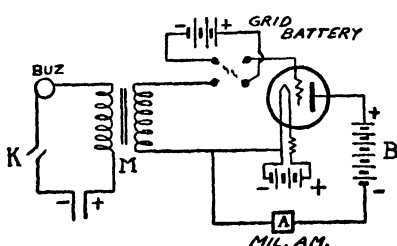


Fig. 65

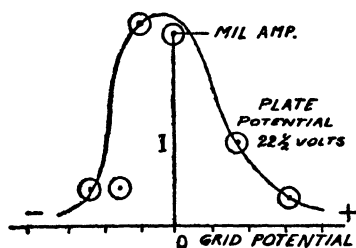


Fig. 66

storage battery. A and B batteries are shown. A power supply can be used instead of the batteries. Instead of the C batteries the potentiometer of the power supply can be used. Consult Figure 57 for method of using the C potentiometer. Instead of the buzzer and coil the hummer, Figure 157, can be used. The potentiometer used as the Wagner ground can be used as means of changing the potential on the tube. Connect to one end and the mid-tap. A d-c voltmeter can be used as the milliammeter in the plate circuit.

In general there will be a change of the plate current when the

a-c signal is impressed on the grid. Read the plate current with and without the signal impressed. The difference is the detected current. Vary the potential of the grid by means of the C battery or C supply and read both currents at each value of the grid bias.

Plot a curve Grid potential along the X axis and the difference of the readings along the Y axis.

Figure 66.

Change the intensity of the signal and repeat. Place a grid condenser and grid leak in the grid circuit of the tube and repeat. The current now should diminish when the signal is impressed.

Which method is best for strong signals? Which for very weak signals. Figure 67 shows a special C bias which may be handy if the power supply is not used. Compare with the mutual characteristic of the tube. A number of tubes can be used, 201A, 27, 56, 2A3, etc.

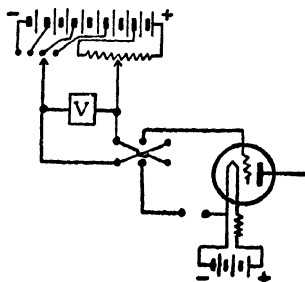


Fig. 67

Experiment 59. To Compare the Relative Efficiency of Various Methods of Detection.

Connect a buzzer to a wave meter so that it may be used as a generator of damped waves. Use a 2 volt storage battery instead

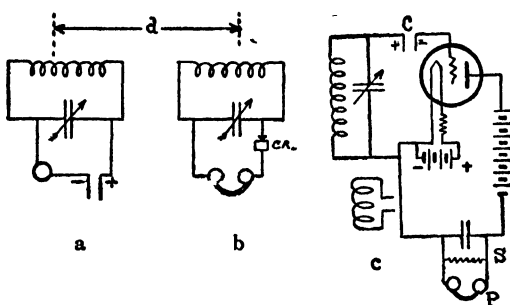


Fig. 68

circuit as in Figure 68b adjust the crystal to the most sensitive condition. Loosen the coupling by increasing the distance, d , or

of a dry cell in the buzzer circuit. The buzzer must be capable of running a long time without any variation of the high frequency current in the wave meter. Connect a crystal and a telephone to a second

by rotating the coil until the sound is just audible. Keep both tuned to the same wave length. It will be better if it is possible to place the receiver in a sound proof room with the transmitter in another room.

Replace the crystal detector with a vacuum tube detector keeping the coil in the same position. The connections are diagrammed in Figure 68c. The circuit of Figure 57 can be adapted for Figure 68c if a power pack is used. Remove the coil, *F*. When a regenerative receiver is wanted replace coil, *F*. By means of a resistance, *S*, in shunt with the telephone decrease the sound until it is just audible. Then since $I_p = I(S/(S+P))$, and $I/I_p = (S+P)/S =$ the detecting efficiency of the tube compared with the crystal detector. *I* = total current, *I_p* = current through the phone, the least audible current; *S* = the resistance in the shunt; and *P* = the resistance of the phone. See Experiment 96. The *C* battery or potentiometer, should be adjusted until the response is the loudest.

Remove the *C* battery. Make grid potential zero and in its place put a grid condenser with a grid leak resistance. Adjust the condenser and leak resistance until the response is the best and measure as before.

Place a regenerative coil in the plate circuit and repeat again. Couple the regenerative coil for the best response.

Couple the regenerative coil until the tube oscillates and repeat again.

The value of the plate battery should be changed until the best value is found. In some soft tube the value of the plate potential is very critical. The grid potential can be changed conveniently if a potentiometer is placed across the terminals of the filament.

Give the values of I/I_p for the various methods of detection.

An audibility meter is convenient to use instead of the shunt around the telephone.

The experiment can be extended by using a different type of tube. It will be found that the best adjustments of plate and grid voltage for one tube may not suit a second tube.

Van der Bijl, p. 349.

Experiment 60. Practical Methods of Using a Detector Tube.

The tube should be one which is recommended as a detector by the makers and the various potentials as recommended should be

used. The mutual characteristic curve and the grid characteristic curve for these potentials should be at hand. Either take data and make them or get them from a data book.

The tube can be used as a substitute for a crystal if connected as in Figure 69, or as in Figure 37d in which a grid condenser is used. If Figure 69 is used there must be some way to adjust the C bias to the curved portion of the curve.

If a power pack is used the bias can be as in Figure 70.

If the circuit is coupled inductively to a coil connected to an aerial we have the circuit of Figure 70 with the tickler coil omitted.

Connect without the tickler coil and tune to some station. In order to be sure of finding a station the coils should be such as to tune in the broadcast band. Use a wave meter with a buzzer and determine the wave length range of the receiver. If not in the broadcast band and no station is found get other coils such as to cover part of the broadcast band.

Adjust the grid bias for the loudest signal and compare with the mutual characteristic. Connect the tickler coil as in Figure 70 and adjust bias and regeneration. Estimate the relative intensity of signal compared with that with no regeneration.

Add a grid condenser and grid leak and repeat. The value of the grid condenser is about $.00025 \mu\text{f}$. A grid condenser always places a negative grid bias on the tube.

Since the greatest curvature

of the grid curve is near zero potential it may be necessary to place a positive bias on the tube by means of C batteries or the C supply and then adjust the leak until the grid condenser makes the right negative value to bring the working point on the grid curve. The resultant grid bias can be determined by

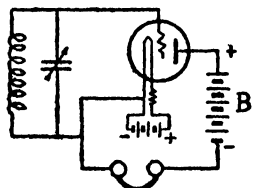


Fig. 69

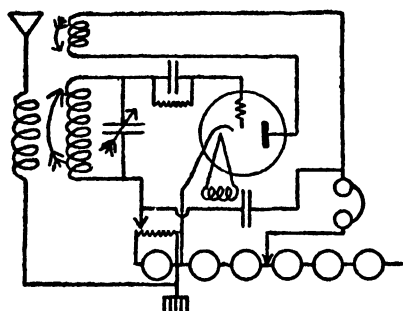


Fig. 70

means of a d-c milliammeter in the plate circuit and comparing with the curves.

The grid leaks can be commercial grid leaks. In this case various leak resistances must be inserted and tried. High resistance leaks give large negative bias. Why? The leak may be lead pencil marks on a hard rubber strip connected across the condenser. More lead pencil marks the less the resistance. Use an eraser to increase the resistance.

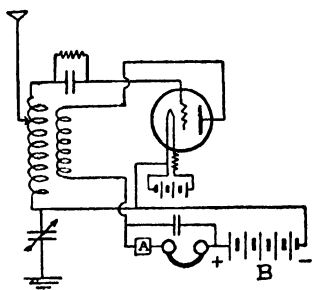


Fig. 71

Measure the leak resistance using a 150 volt voltmeter and 110 volts d-c. Experiment 4.

Place the tickler coil as in Figure 70 and repeat and note the added intensity of the signal. Care should be exercised in using this circuit in the broadcast band. Do not let the tube oscillate. This causes a disturbance which may interfere with other local receivers.

Use coils which will tune in the amateur bands or in the long wave bands. 1000 meters or more. Hunt for C.W. stations with the tube oscillating.

Regenerative circuits can be made with two coils as in Figure 71 or as in Figure 72. A very simple and efficient circuit is made as

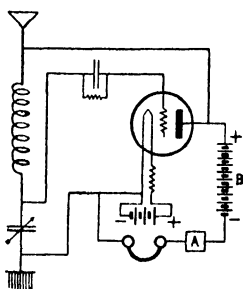


Fig. 73

in Figure 73. Use a wave meter to determine the wave length of this receiver. Figure 73 requires a rather long aerial.

If a power supply is used which is not well filtered there will be noise due to the 60 cycle.

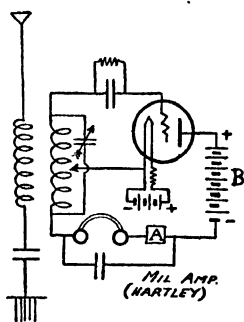


Fig. 72

Connect extra chokes in the plate circuit between the supply and head phone and ground the choke terminal through large condensers. If in Figure 70 an audio choke coil is placed between

the phone and the supply the disturbance will be less. A large condenser, $2\mu\text{f}$ are larger, placed between the ground and the point of connection to the power supply will diminish the disturbing noise. A second large condenser placed from ground to the junction of phones and choke coil will perhaps render the noise inaudible. This in general will apply to any circuit using power supply. Two or more chokes can be used with condensers connected to junctions. The choke can be the primary of an interstage coupling transformer.

Experiment 61. Measurement of a Detector.

In Experiments 58 and 59 methods of getting the relative detection of a tube has been outlined. In this experiment it is proposed

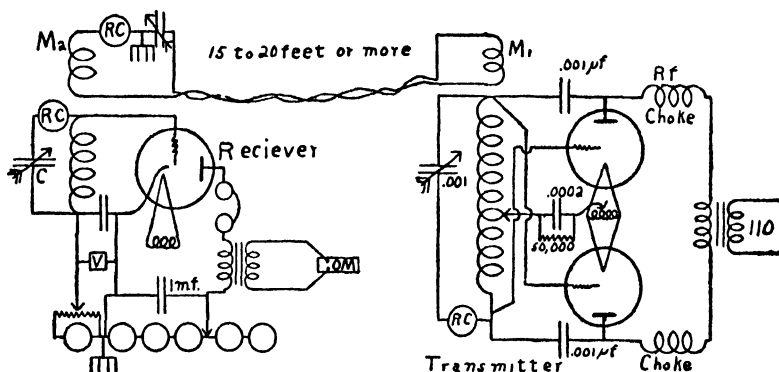


Fig. 74

to measure the detection efficiency when the potential impressed on the grid is known. In measuring the performance of a detector it is standard practice to use an oscillator which is 30% modulated. Such an oscillator can be used. A push pull oscillator as diagrammed in Figure 74 or as diagrammed in Figure 3, Chapter XXV, "Fundamentals of Radio," can be used. These oscillators use unrectified a-c on the plates and can be considered to be 100% modulated.

The purpose of the experiment is to measure the radio frequency potential across the tuning condenser of the receiver and then measure the rectified current or potential of the audio component. With the push pull oscillator the frequency of the audio potential

is 120 cycles per second. The potential on the grid of the detector tube is that across the tuning condenser of the receiver. Since this potential is $I/C2\pi n$ where the current is I , the potential can be calculated. The radio frequency milliammeter will measure current from 100 to 20 milliamperes and a fair estimate down to 10 milliamperes can be made. Let us assume a condenser capacity about .0003 μ f. and a frequency one million (300 meters). Then the Pd is $I/.0003 \times 10^{-6} \times 2\pi \times 10^6 = I/.002 = Pd = 500$ volts if I is one ampere or .5 volt if I is one milliampere. It will be necessary to measure the current to a fraction of a milliampere.

The current in the receiver coil can be measured by placing the receiver fairly close to the transmitter in such a manner as to get a readable current in the receiver and then by increasing the distance and calculating the current assuming that the current diminishes inversely as the distance cubed. This is very rough. Inasmuch as the distance, d , is hard to determine and then when the distance is increased to such an extent that the proper current is obtained stray radiations and reflections usually produce effects of about the same intensity. This also can be done by using a tuned connection link made of two coils connected with a twisted line, telephone wire or lamp cord, and a variable condenser. The receiver is thus removed some distance from the transmitter. The distance should be great enough so that no signals can be heard in the head set of the receiver when the line is not used.

The condenser in the line should be a .001 variable condenser and should tune on the middle or somewhat above the middle of the dial. The tuning should not be too sharp. It should require at least four divisions on the dial to detune the current to one half value. If too sharp resistance can be inserted in the line.

The radio frequency ammeter in the line can be a one ampere meter. Tune the line for maximum current with the coupling M_1 at the transmitter fairly loose. Increase the coupling until the meter reads the maximum. Care must be taken that the coupling is not "close," two humps, see Experiment 84, "Fundamentals of Radio," Chapter XVII. Couple the receiver to the line, M_2 . Tune to maximum and then increase the coupling until the meter in the receiver reads 100 milliamperes. Detune the line by means of the condenser in the line and read the currents in line and receiver. It will be noted that the two currents decrease at the same rate. This is true

since in any transformer, $I_2 = M\omega I_1$. If the maximum current in the receiver is reduced and is known then currents too small to be read on the receiver meter can be calculated from the readings of the current in the line. Decrease the coupling M_2 until the current in the receiver is 20 milliamperes when the current in the line is one ampere. Then the current in the receiver is $2/100$ of that in the line, and if the current in the line is reduced to 10 milliamperes then that in the receiver is 0.2 milliamperes. Decrease the coupling M_1 and replace the meter in the line with a milliammeter. Taking care not to change the coupling M_2 . Couple M_1 until the maximum current in the line is 100 milliamperes. The current in the receiver is now 2 milliamperes. By detuning the line current to 20 milliamperes the receiver current is .4 milliampere. The potential on the grid of the tube is now .2 volt. If the coupling M_2 had been decreased until the current was 10 milliamperes (deflection $\frac{1}{4}$ of that at 20) and the current in the line is made 10 milliamperes, the potential on the grid is .05 volts. It will be noted that smaller potentials can be obtained if in the equation $Pd = I/C\omega$, C and ω are increased. By judicious selecting the receiver constants the potential can be measured down to .01 volt.

The receiver as shown in Figure 74 is a simple receiver. The plate circuit should contain a d-c milliampere, a head set and an audio coil to which a Weston output meter is connected to the secondary. Headset helps in tuning the set. The d-c milliampere helps to locate the conditions on the mutual characteristic. Especially is this true if a grid condenser is used. The audio frequency coil is an ordinary interstage audio coil. However it is found that larger readings are obtained when the coil is reversed. Use the secondary as primary, etc.

The figure shows the receiver connected to a power pack as described Figure 46 and in "Apparatus" at end of book. This has a potentiometer which serves as a C potential. Adjust this C potential for maximum output on the meter. The voltmeter will give the potential of this C supply in any case. Since this C voltage must be large enough to reduce the plate current to zero the B potential may have to be reduced. Use the potential recommended for the detector tube used if possible. Run the mutual curve for the tube as used with phone meter and coil in the plate circuit. Also run the grid curve. See Experiments 43 and 44.

The tube may be used in three manners as a detector. Grid condenser grid leak method, grid bias method, and as a linear detector. Linear detectors are used with large potentials on the grid. One to five volts, (27 tube). Grid bias with .5 volts and less. Grid condenser with small potentials.

Linear detector. Use potentials of a volt or more on the grid. Bias the tube for maximum output. Vary the potential from low values up until the output does not increase with potential. The output should vary with potential. It will be found that this does not hold for small potentials and for potentials where the tube is overloaded. Plot a curve X_1 potential on the grid and Y , output.

Grid bias detector. Use potentials under 1 volt on the grid. Adjust the C potential for maximum output and vary the potential on the grid and plot. The output should vary as the square of the potential. When overloaded the curve ceases to follow the square law.

Grid condenser grid leak. Place a .00025 condenser and a leak of 1 megohm or more in the grid circuit. Interchange the C supply terminals to make the grid positive. The grid bias and grid leak will make the grid negative and a positive C may be necessary to place the working point on the grid curve. Adjust as before using small radio frequency potentials on the grid. The milliammeter in the plate circuit must be used in determining the point on the curves which is used.

Compare the best working conditions with the curves. The linear detector should be biased to near zero. To the point where the straight line part of the mutual curve if drawn backward cuts the grid potential axis. The grid bias detector should be biased to the point of greatest curvature of the mutual curve. The grid condenser-grid leak should be biased to the point of greatest curvature of the grid curve. In this last the milliammeter in the plate circuit will show the condition.

For a 27 tube the plate current should be that for about 1 volt negative. The output will vary with the grid condenser and grid leak. Use various grid leaks and determine the best values for the tube used. In Experiment 87 a method of using a condenser as an attenuator is suggested.

Experiment 62. Measurement of the Amplification Constant. Use of an Electrostatic Voltmeter or Electroscope.

It will be noted that when the grid voltage is changed the plate current is changed. The potential between the terminals of the plate and filament is that of the B battery or is constant unless there is an appreciable resistance inserted in series with the battery. With a resistance in series the dV_p , is equal to the change of the Pd , potential difference, at the terminals of the resistance.

Since $Pd = Ir$, $-dV_p = dI_p R$, where R is the inserted resistance.

Since $I_p = A + B(V_p + \mu V_g)$, $dI_p = BdV_p + \mu BdV_g$

$$= GdV_p + G_mdV_g$$

$$-dV_p = R(GdV_p + G_mdV_g)$$

$$-dV_p = dV_g RG / (1 + RG) = dV_g (G_m / G) R / (R + 1/G),$$

$$-dV_p = dV_g \mu R / (R + R_p)$$

Since $G/P = \mu$, and $\frac{1}{G} = R_p$.

If R is made large in comparison to R_p , then the quantity $R/(R + R_p)$ approaches unity, and then dV_p/dV_g is equal to μ , the amplification constant. The actual potential between the plate and filament must be several volts or the current must be one or two milliamperes so there are practical difficulties in making R great. If $R = R_p$ the actual measured amplification will be one-half of μ , the theoretical value.

If $R = 4R_p$ the value is .8 of μ , and the actual potential across the plate will be $\frac{1}{5}$ of the B battery.

Connect a high resistance in series with a B battery of one or two hundred volts and connect an electrostatic voltmeter or an electroscope across the plate terminal to the filament, Figure 75. Change the potential of the grid a volt or two and measure the change in the plate potential, from the known value of $R + R_p$ and the readings calculate μ .

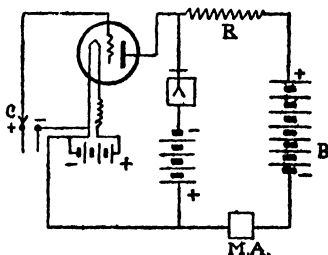


Fig. 75

Note that this is the principle of the resistance amplifier.

If the potential between the plate and filament is too small to use the electroscope, a *B* battery can be used to increase the potential between the case and the leaf system of the electroscope. Connect the positive terminal to the filament and the negative to the case of the electroscope. See Experiment 64 for method of making resistances. However it is better to use a good grade of commercial resistances, those that are constructed for resistance amplifiers.

For construction of an electrostatic voltmeter see Notes on Laboratory Apparatus.

A screen grid tube can be used if a large load resistance is used with a potential of 400 volts or more. The screen being held at 90 or 100 volts.

The potentials *A*, *B*, and *C* can be taken from a power pack. A two or more stage resistance amplifier of the Loftin-White type can be measured by this method.

Fundamentals of Radio, p. 146.

Experiment 63. A Method of Measuring the Amplification of Two or More Stage Audio Amplifiers.

This is an adaptation of the potentiometer method of measuring the amplification constant of an electron tube, Experiment 48.

The negative terminal of the filament is connected to the middle point, *b*, of a potentiometer made of two ordinary resistance boxes, Figure 76. The mutual inductance can be omitted as in Figure 53. This negative terminal may

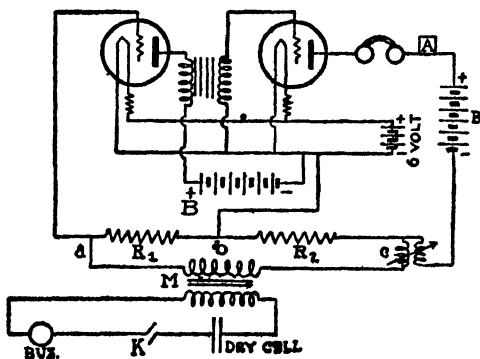


Fig. 76. Two Stage Audio Amplifier.

be connected to the earth also. An alternating E.M.F. generated by a buzzer working through a telephone induction coil is connected to the terminals, *a*, *c*, of the potentiometer. The point, *a*, is

connected to the grid of the first tube and the point, c , is connected through a suitable B battery and telephone to the plate of the last tube. A hummer can be used instead of the buzzer and two power packs can be used for the batteries.

The tubes are connected together with audio frequency coils. Care must be used in connecting the coil. The coil must be connected so that when the potential of the grid of tube No. 1 is made positive the potentials of the second and of all other tubes are positive. When the grid potential of the first tube is made positive the plate current of all tubes must increase. A second B battery must be used for the plate potential of all tubes except the last.

When the potential of the point, a , is positive the current runs from a to c through b . The potential of c will be negative. The potential of b being zero.

If the potential of the grid of tube No. 1 is raised, the current in the plate circuit of the last tube is increased unless the plate potential is decreased. When the plate potential is diminished enough to keep the plate current constant there will be no sound in the telephone, or a minimum of sound.

If the resistance R_1 is set at some convenient value, one or two ohms,* say, and then R_2 adjusted to minimum sound, then the ratio of R_2 to R_1 is the amplification constant of the amplifier.

$A = R_2/R_1 =$ Change of plate potential divided by the change of grid potential. If the amplification constant of the tubes have been determined then the amplification constant of the audio coil can be determined. $A = a_1 C_1 a_2 C_2 a_3 \cdots a_n$.

Where $a_1, a_2, \cdots, a_n$ is the amplification constant of the various tubes, and $C_1, C_2, \cdots$, is the amplification constant of first, second, etc., coils a mutual inductance can be inserted as in the diagram and correction made for change of phase angle. This can be left out.

Best results are obtained with two tubes and one coil. The plate potential must be such as to let the tubes operate on a point near middle of the plate current, grid potential curve. C batteries of suitable values may be inserted in the grid circuits of the tubes if necessary.

R. R. Ramsey, Ind. Acad. Sci. Proc., p. 195, 1923; Inst. Radio Eng., Vol. 15, p. 767, 1927.

* The resistance R_1 must not be too large or the input signal will be too large and the last stages will be overloaded.

to 2 megohms. The condensers, C , can be from .1 μ f. to 1. μ f. A buzzer connected as in Experiment 63 works better than the dry cell.

The resistances r and the grid leaks r_1 can be made of card board soaked with India ink. These strips can be mounted on glass tubes. The resistance should be measured by bridge or other suitable method. The exact length and width of the cardboard is a matter of trial. Try 1 inch by $\frac{1}{2}$ inch at first.

In expressing the gain or amplification of an amplifier it is becoming customary to give the amplification in terms of decibels (db). The (db), N in any given case is ten times the logarithm (base 10) of the ratio of the output to the input expressed in watts.

$N = 10 \log_{10} P_2/P_1$, where P_1 is the input and P_2 is the output. Thus an amplification ratio of 100 is 20 db. If input and output are expressed in current, $N = 20 \log_{10} I_2/I_1$.

Experiment 65. Practical Method of Measuring the Amplification of the Various Stages of an Audio Amplifier.

If one has an amplifier with jacks in the plate circuit of each tube the amplification from stage to stage can be measured using the shunted telephone method. Experiment No. 96.

The amplifier and receiver can be tuned to some given station, one which will remain constant for some time, either local buzzer or distant station, and the telephone placed in the detector tube circuit and shunted until the sound is just audible. The resistance of the shunt is recorded. The same procedure is carried out with each tube in succession. In order to measure the amplification of the second stage it will be necessary to reduce the amplification of stage No. 1. The receiver and amplifier must be in the best adjustment before this first tube is turned down.

Then from the theory of the shunted telephone the current, I , in each case is determined in terms of the least audible current, I_p , which is assumed to be constant in each case. We have $I = I_p(S - P)/S$, then the amplification of the first stage is $a = I_1/I_d$, where I_1 and I_d are the currents in the plate circuits of the first amplifying tube and the current in the plate circuits of the detector tube respectively.

The ratio of the other tubes can be determined in the same way.

If one tube is found which gives a low amplification it will be well to test it by running the plate current grid voltage curves. The grid voltage or plate voltage may not suit that particular tube.

Experiment 66. Calculation of Voltage Gain and Power Output of Class A Audio Amplifiers.

A class A amplifier is one in which there is no or little distortion. The amplifier is made up of one or more tubes in series. These tubes are connected together with resistances or transformers or other combinations. A tube together with the coupling device is called a stage. Thus an amplifier consists of one or more stages.

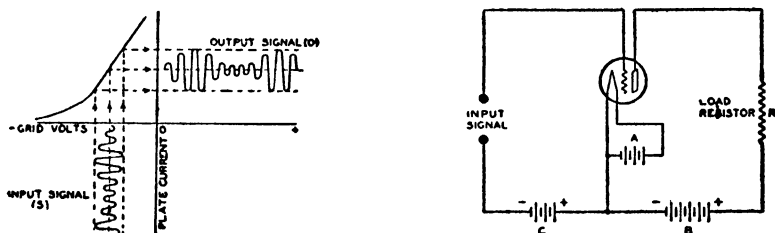


Fig. 78

A transformer whose secondary is loaded with resistance is equivalent to a resistance load in the secondary. Experiment 73. A tuned parallel circuit is also equivalent to a resistance, Experiment 102, so the load is considered to be a resistance load. Figure 78 shows a tube connected to a resistance R . The tube had an a-c resistance R_p and an input E.M.F. of μE_g or E_p .

Consider a battery of E.M.F., E , and internal resistance R_p connected to a load resistance R . The current is,

$$I = E / (R_p + R).$$

The potential across the resistance, R , is,

$$Pd = IR = (E / (R_p + R))R = E(R / (R_p + R))$$

The power in the load resistor, R , is

$$W = EI = (E(R / (R_p + R)))(E / (R_p + R)) = E^2 R / (R_p + R)^2$$

In the case of the tube if the input potential is μE_g we have the output voltage, $Pd_R = E_g(\mu R / (R_p + R))$ and $W_R = E^2(\mu^2 R / (R_p + R)^2)$.

The potential output increases as the load resistance increases. But it can be shown that the power output per volt squared input is a maximum when $R = R_p$. The first stages of an audio amplifier are voltage stages while the last stage is a power output tube. However the first stages must develop enough power to swing the grid of the next tube. There are certain factors such as excessive potentials and distortion effects which limit the load to one, two or three times that of the tube in the case of triodes. In the case of pentodes these factors limit the load to a rather small fraction of the plate resistance.

Figure 79 is the plate and mutual characteristics of a 2A3 tube. The plate resistance R_p is given as 800 ohms and the amplification constant, μ , is given as 4.2.

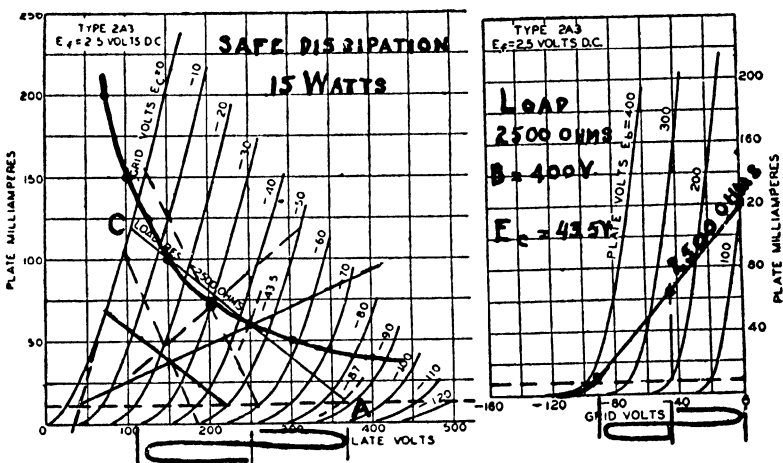


Fig. 79

Verify these values; Experiment 47.

In using the mutual characteristic the curve must be run with the load resistance in series with the plate. The line marked 2500 ohms is such a curve. The voltage amplification can be calculated by means of the formula given above. It can also be taken from the ratio of the voltage swings in the two curves. The plate swing is from about 120 up to 360, or a swing of 240 volts. Considering this to be an alternating potential the virtual E.M.F. is $120/\sqrt{2} = 85$ volts. Calculate the virtual E.M.F. on the grid from the grid swing.

In the mutual characteristic the current swings along the 2500 ohm line if the load is 2500 ohms. The lower limit of current is arbitrarily limited so as not to use the curved portion of the line so that distortion is avoided. Ten milliamperes in this case. The upper limit is where the curve crosses the zero line or where there is distortion due to grid current. From the limits calculate the virtual current. The current limits are the same in both curves so the virtual current is the same in both.

We have power, $W_R = EI \cos \theta$. Since this is resistance load $\cos \theta = 1$

or
$$W_R = (E_{\max} - E_{\min})(I_{\max} - I_{\min})/8.$$

Verify this formula from the above.

In the plate characteristic we have the Pd on the plate $Pd = (E - IR)$, $Pd = (400 - I \ 2500)$. For several values of the current calculate the Pd . These points will all fall on the line CA .

When the current is zero the potential on the plate is that of the B supply, 400 volts in this case. The slope of this line is the negative tangent of the angle CAO . Tangent of this line is current divided by potential. $\text{Tangent} = -I/(400 - Pd) = 1/2500$. The line CA is the load line. The load line is a line drawn such as the slope of the line is the negative reciprocal of the load resistance. Any line drawn parallel to CA is also a load line. The short heavy line in the figure is also a load line. This cuts the X axis at 250 volts. To avoid distortion the voltage swing must be lower. Calculate the power using this line. The result is about 1 watt.

Calculate the power output using the dotted load lines.

These load lines are 800 ohm lines. If the load is equal to the resistance of the tube the load lines and the plate characteristics make isosceles triangles. This is assuming the characteristic curves are straight parallel lines.

It will be noted that the higher the load line on the curve the higher the B potential, the higher the negative grid bias and the higher the maximum grid swing and that the power output is proportional to the square of the grid swing. Why not place the 2500 ohm line so that we use 500 or 1000 volts on the plate and a corresponding grid bias? This might be done if the tube will stand the high potentials. The insulation may break down or the tube plate may melt. If the tube is not in use all the energy must be

dissipated as heat. In the case of the 2A3 this is set at 15 watts. The product of the d-c E and I when there is no signal must not be more than 15 watts. The load line and the average plate potential must not intersect above the equilateral hyperbola drawn on the curve.

If the load is a good transformer the d-c resistance is small and the a-c resistance is 2500 ohms. Then the B potential can be about 250 volts instead of 400 assuming a resistor.

Make calculations using Figure 49; also for the 2A5 using Figure 80.

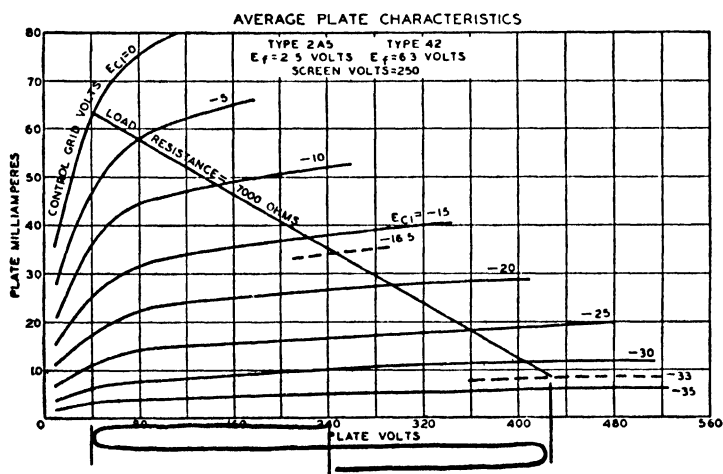


Fig. 80

Calculate the volts output per grid volts input, for each load. The maximum volts output for no distortion. The watts output per grid volt input. The maximum undistorted watt output.

Fundamentals of Radio, Chapters XIV and XXVIII.

Experiment 67. Calculation of the Distortion of a Class A Amplifying Tube.

In most amplification calculations it is assumed that all characteristic curves are a family of parallel straight lines. Most curves are not exactly straight and they are not exactly parallel. This produces distortion in the amplifier. Any curved line by Taylor's theorem can be represented by a linear term, plus a square term,

etc. In alternating current this means a fundamental frequency plus a double frequency term, etc. In detectors we use the square

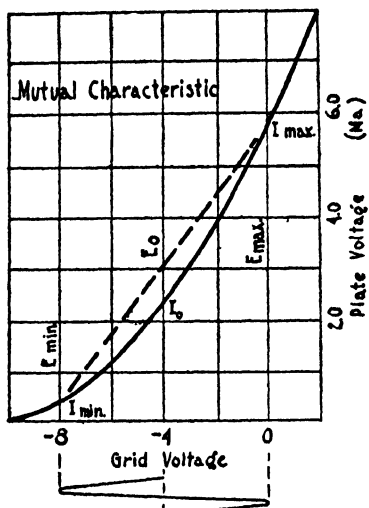


Fig. 81

term. Or in other words a detector is a distorter. Two frequencies added through a detector manufacture two new frequencies. If the characteristic lines are not straight new frequencies appear which are not in the input frequency.

The per cent of distortion is calculated as follows. In Figure 81 we have a mutual characteristic which is purposely made far from straight. The grid swing is from zero to -8 volts.

The average current in this case will be 3 milliamperes. The point where the straight dotted line crosses the average grid potential is -4 volts. The actual

current at -4 volts is about 2.25 milliamperes or I_0 . The per cent of distortion is given as

$$\% \text{ distortion} = \frac{((I_{\max} + I_{\min})/2) - I_0}{(I_{\max} - I_{\min})}.$$

These values of the current can be taken from the load line on a plate characteristic as well as off the mutual characteristic. I_0 is the plate current which flows when there is no signal on the grid of the tube. 5% distortion is allowable.

Calculate the per cent of distortion in Figures 79, 80 and 49, and other tubes, the curves for which are available.

In the average tube how can the distortion be decreased by limiting the current $I_{\min}$? In the pentode draw parallel load lines one centimeter above and below the published line and calculate the distortion. In triodes first stages where signal voltage is small how adjust the B and C potentials for low distortion? For efficiency in B battery drain how adjust B and C supply? If the

plate current is very small, neglecting distortion, what is the amplification?

If making a three stage amplifier using the same type of triode tube in each stage how adjust the *B* and *C* potentials of the first? Of the second? Of the third? Taking distortion, amplification, and *B* battery efficiency into account.

Draw such an amplifier showing the *B* and *C* potentials used. Assume batteries are to be used.

Compare with published circuits: the R.C.A. Cunningham Tube Manual will be useful, RCA Radiotron Co., Harrison, N. J. Price, 25 cents.

Experiment 68. Push-pull Amplifier; Class A; Class B.

Push-pull stages of amplifiers may operate as class *A* tubes or the tube may be biased to almost cut off in which case it is called class *B*.

If in an amplifier two tubes are placed in parallel, class *A*, the maximum output will be twice that of a single tube. The current is doubled but the load must be halved for maximum output. In push-pull, class *A*, the two tubes are placed in series but so arranged that while the plate current in one tube is increasing, that in the second tube is decreasing. The power with two tubes should be the same as when in parallel, therefore the load on each tube is the normal load making the load resistance of the two twice that of one tube.

The potential on each grid must be the same as that which was placed on the grid of the tube when in parallel therefore the driving potential must be twice that of one tube.

The chief advantage of class *A* push-pull is that distortion produced by curvature of characteristic in one tube is counteracted by that produced in the other. Usually the output is fed into a special transformer and the plate current of one tube counteracts the magnetization of the core which is produced by the second tube. Distortion due to the transformer is made less.

Usually large tubes are used in push-pull and special transformers are used as input transformers and as output transformers.

Figure 82 gives the usual connection for push-pull. However, this diagram shows class *B* push-pull.

The voltage input and the output circuits must be suited to the tube used. On this account the exact details will depend on the

square root of the resistance ratio, or from 30 to 50. Assume the load to be small compared to 4000 ohms then the output meter can be used to measure the output voltage around the 15 ohm resistance. It will be of advantage if the available transformers have had their characteristic impedance measured. In order to reduce the maximum output work the tube at 100 to 150 plate potential. Use the plate curves of the tube and place the load line for the voltage and load selected and determine the negative grid bias needed for class *A*. Figure 83 shows connections for 27 tubes.

Take readings of the output meter as the grid potential is increased. A radio frequency ammeter can be placed in series with the load and the current read instead of the potential. Power is now I^2R . Plot *X* grid volts and *Y* output volts of secondary. This should be a straight line. The watt output is E^2/R_p . This is for push-pull class *A*. Increase the grid voltage until the plate current is near zero. About one milliamperere for two tubes. Repeat the readings and plot.

See *Fundamentals of Radio*, Chapters XXVII and XXIX.

Experiment 69. To Test a 60 Cycle High Potential Transformer.

We shall assume that the transformer is rated as 1 K W. 60 cycle, 110 volts primary and 10,000 to 25,000 volts secondary. It is practically impossible to test a high potential transformer unless you have access to an electrostatic voltmeter. An ordinary voltmeter takes several milliamperes of current. This current load through the voltmeter is a large per cent of full load current. Since 10,000 volts $\times$ 0.1 ampere is 1000 watts 100 milliamperes is full load value of the secondary current. However, tests can be made for shorts and grounds.

Test for ground to core.—Connect one terminal of the coil to a d-c 110 volt circuit with a lamp or d-c voltmeter in series. Connect the other terminal of the 110 volt circuit to the frame. There should be no indications of a flow of current.

Tests for shorts in secondary coil.—Connect the primary to a 110 volt a-c circuit with an ammeter in series. Close the switch and note the current. Let the current flow for a short time and open the switch. Note the temperature of the secondary coil. If there is any rise of temperature the coil is short circuited. This assumes that there is no sparking over at the terminals of the

secondary coil. If there is sparking, the potential of the primary circuit should be reduced by means of a rheostat or choke coil until there is no sparking over. It is well to note the current in the primary coil, the secondary being open, when the transformer is new. At later times the primary current can be compared with this reading. Any considerable increase of current under the same conditions indicates a short circuit.

Experiment 70. To Test and Mark a Power Transformer.

A power transformer such as is used in power packs to furnish a-c current for the *A* circuit, filament or heater, and rectified d-c potentials for *B* and *C* circuits consists of a 110 volt coil and usually several secondaries. Where the maximum *B* potential is not over several hundred volts there may be several secondaries. For large outfits such as transmitters two transformers are usually used. One to furnish the high potential to be rectified and a second to furnish filament current. This is done in order to get better insulation.

Small transformers such as used in radio sets consist of a high potential secondary a 110 volt primary and usually two or more low potential secondaries. When purchased new these terminals are marked or a chart or color scheme to designate the terminals is furnished. Often these markings are lost and one must test to find the terminals.

Resistance test. The resistance can be measured roughly with a d-c voltmeter or an ohm meter. Experiments 4 and 5. Connect a terminal to the voltmeter and test by connecting to each of the other terminals in turn. The deflection of the voltmeter will be zero except when connection is made to the terminal of this coil. One such terminal will be found if it is a simple coil. Two if the coil has a mid-tap. In some cases where the coil is a special coil more may be found. From the relative deflections the resistance of the coil can be estimated. The coil of highest resistance is the high potential coil the next the 110 volt coil and the others filament coils. The resistance of the filament coils probably will be so low that the resistance can not be measured.

A-c test. Connect 110 volt a-c to the 110 volt coil and measure the voltage of the filament coils. The voltage will in all probability be 6.3, 5, 2.5. In a rather large transformer there may be higher

potentials for filaments of transmitting tubes. The potential of the high coil probably is 600 volts or higher. This coil is alive and must be respected while measuring the low coils. This high coil usually has a mid-tap. The potential from mid-tap to end is one half of the total.

While testing the coils tests should be made to the core. There should be no connection.

Experiment 71. Measurement of Impedance of Iron Core Coils.

Impedance is made up of resistance and reactance and an inductance bridge such as Andersons bridge. Experiment 24 can be used. A variable one microfarad condenser is convenient to use. The bridge must be balanced for resistance as well as for inductance. The reactance, $L\omega$, can be calculated if the frequency of the generator is known.

Then the impedance $Z = \sqrt{R^2 + L^2\omega^2}$ or $R + jL\omega = Z \angle \theta$.

Various other bridges can be used to measure R and L from which the impedance can be calculated.

If one has a standard variable inductance an impedance bridge like Figure 84 can be used. The bridge consists of two resistance ratio arms, P and Q , two gaps for known and unknown, and a third resistance which can be thrown in series with the known or unknown at will. The diagram shows the bridge connected to a hummer with a Wagner ground. A head set is used to indicate balance.

The standard inductance is placed in the arm R , say and the unknown in the arm, S . The standard is a coil of known resistance and inductance at any setting. When a good balance is obtained we have,

$$P/Q = R/S = L_R/L_s.$$

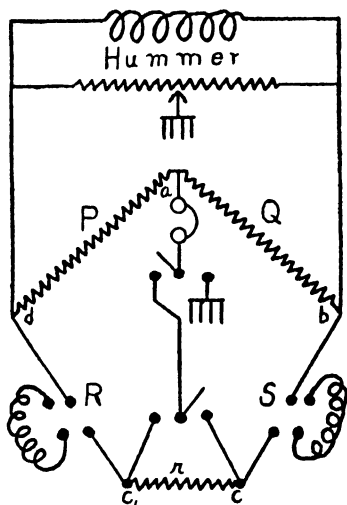


Fig. 84

If the unknown has high resistance the third resistance of the bridge must be placed in series with the standard. Then R in the equation is the total resistance in the R arm. If the unknown resistance is small it may be necessary to place the extra resistance, r , in series with the unknown. Then the unknown resistance is the calculated resistance S minus the added resistance.

This bridge can be used in Experiment 19 and 23 if condensers are placed in the arms R and S .

In the above the reactance X is $L\omega$ and the impedance $Z = R + jX = Z \angle \theta$. The numerical value of $Z = \sqrt{R^2 + X^2}$.

The letter, j , means that X is at right angles with R . Z is the hypotenuse. Resistance, R , and impedance, X , are added vectorially as in Experiment 10.

If condensers are used $Z = R - jX$. Where $X = 1/C\omega$.

Measure the resistance and inductance of transformers and choke coils and calculate the reactance and the impedance using an 800 cycle or 1000 cycle hummer.

In this experiment as well as the Anderson method one gains skill and efficiency with practice.

Experiment 72. Measurement of the Inductance of Filter Coils.

Filter coils in B battery filters carry both d-c and a-c currents. Since these coils usually have iron cores the inductance of these coils depends upon the permeability of the iron and in turn the permeability of the iron depends on the field, H , and this is directly proportional to the current. In air core coils the permeability is unity for all values of current and consequently the inductance is independent of the current.

A simple way to measure the inductance when there is a d-c component in the current is to place two coils which are exactly alike in series with a battery, a d-c meter and regulating resistance. These coils are then placed in parallel in the arm of an inductance bridge. The connections being made, one at the junction of the two coils and the other at the mid point of the battery. These two points must be at the same potential.

The diagram, Figure 85, shows the connections made in an Anderson bridge. (Experiment 24.)

A milliammeter is placed in series with the coils and a regulating

rheostat. The value of the d-c current can be regulated with the rheostat.

When the two points are the same potential there will be no current flowing through the other arms of the bridge. If current does flow through there will be either an increase or decrease of current through the milliammeter. The connecting point on the rheostat can be varied until there is no change of the meter reading on making connection.

After the coils are adjusted so the points connected to the bridge are at equal potential the measurements are made in the usual manner. Measurements can be made with various values of d-c current through the coils.

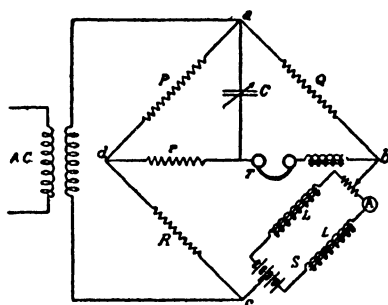


Fig. 85

The values obtained are for two coils in multiple and the value of the inductance of one coil will be twice this value.

Experiment 73. To Measure the Voltage Ratio of a Coupling Transformer.

At times it is desirable to connect a source to a sink, a power tube to a loud speaker, say, where the two impedances are not matched, i.e., not equal. This can be done by means of a transformer. The theory is very simple if we can assume a perfect

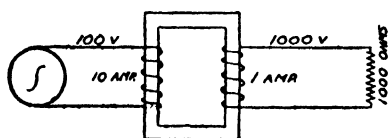


Fig. 86

transformer, one in which there are no losses, i.e., one in which the coils have no resistance and in which the core has no hysteresis and no eddy current losses.

Consider a simple power transformer, Figure 86. Suppose the primary is connected to a 100 volt generator which delivers 10 amperes to the transformer. The voltage ratio of the transformer is 10 and the secondary of the transformer has a potential of 1000 volts and delivers one ampere

to a 1000 ohm resistance. The generator could deliver the same current, i.e., 10 amperes to a resistance of 10 ohms. Then the transformer seems to have 10 ohms in the primary when the secondary is 1000 ohms. Then $R_1 = R_2(E_1/E_2)^2$. The resistances are to each other as the square of the voltage ratio. The voltage ratio is directly proportional to the ratio of the number of turns of wire in the coils.

Then $Z_1/Z_2 = (n_1/n_2)^2$.

If the transformer has appreciable losses these must be taken into account. However the above formula will give a good approximation to the correct result in most cases.

Measurement of the Amplification Ratio of a Transformer. An audio frequency transformer or any other kind of a transformer is connected as in the diagram, Figure 87. C_1 and C_2 are condensers,

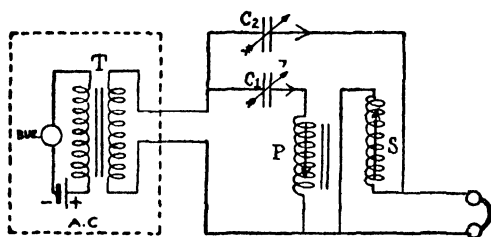


Fig. 87

one of which should be variable. The ordinary 43 plate variable condensers will do if the ratio is not more than four. P and S are the primary and secondary of the coil to be measured. The secondary must be connected

“reversed” as in the diagram, Figure 87. T is a telephone coil connected to a buzzer so as to give an alternating E.M.F. The hummer p. 184 works well. A telephone is connected around the secondary S .

The capacities of C_1 and C_2 are adjusted until the sound in the telephone is a minimum. Since the capacity of the condensers is small the impedance in the two coil circuits is all due to the condensers, and I_1 is proportional to C_1 and I_2 is proportional to C_2 . This can be seen from the equation,

$$I = \frac{E}{\sqrt{R^2 + \left(L\omega - \frac{1}{C\omega}\right)^2}} = CE\omega.$$

Since there is no current through the telephone,

$$MdI_1/dt = LdI_2/dt \quad \text{or} \quad MI_1 = LI_2$$

Since M is proportional to n_1n_2 and L is proportional to n_2^2 , $n_1I_1 = n_2I_2$.

Then $n_2/n_1 = I_1/I_2 = C_1/C_2 = A$, the amplification ratio of the two coils.

If C_1 and C_2 are variable condensers, semicircular plates, which are exactly alike (same make) then the readings of the dials can be substituted for the value of the capacities.

Experiment 74. Test of an Audio Frequency Transformer.

National Electrical Manufacturers Association Method, "NEMA Method."

The following diagram and method is taken from the NEMA Handbook of Radio Standards, Third Edition.

The primary of the transformer is connected to an audio oscillator by means of the resistance, B , which is in series with a potentiometer, AC , whose resistance is 10 times the resistance, B , Figure 88. These resistances may be non-inductive resistance boxes or a calibrated potentiometer.

The secondary of the transformer is connected to a tube voltmeter.

The galvanometer or milliammeter, G , serves as an indicator for the tube voltmeter. The switch is then turned to

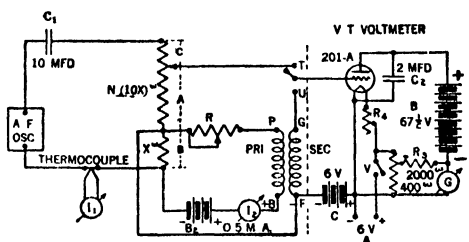


Fig. 88

the position, T , and the slider on the potentiometer is adjusted until the tube voltmeter indicates the same potential. Then the amplification of the transformer is given by the ratio of the resistances, $a = A/B$.

The audio oscillator should be free from harmonics and have a frequency range of 30 to 7000 cycles per second and be capable of delivering from 10 to 25 milliamperes through the resistances in the potentiometer circuit. The thermocouple in this circuit has a range of from 5 to 25 milliamperes.

In series with the primary is a battery d-c milliammeter, and

regulating resistance. This battery is to furnish a d-c current through the primary equivalent to the usual plate d-c current. It is recommended that readings be taken at 30, 45, 60, 100, 200, 500, 1000, 2000, 3500, 5000, and 7000 cycles. The results should be plotted on semi-logarithmic paper. The results can be expressed in decibels.

Experiment 75. To Construct an Attenuator.

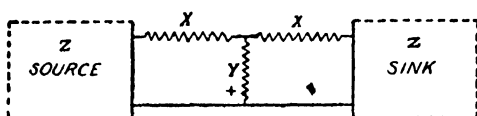


Fig. 89

If we have a shunt or attenuator, Figure 89, made up of the two resistances X and the shunt resistance Y , connecting the source to the sink and since we assume that the sink has been designed to match the source both source and sink must have the same impedance, Z , and the impedance of the attenuator looking from the source must have the impedance, Z , and the output impedance of the attenuator looking backward from the sink must match the impedance, Z , of the sink.

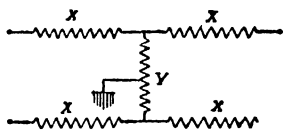


Fig. 90

It can be shown that X and Y have the following values

$$(1) \quad X = Z(k - 1)/(k + 1).$$

$$(2) \quad Y = 2Zk/(k^2 - 1).$$

When k_1 is the ratio of input to output current.

It is usual to make the attenuator in the form of Figure 90 in which the resistance X in Figure 89 is divided into two equal parts; then the value of X in Figure 90 is

$$(3) \quad X = \frac{Z}{2} \cdot \frac{(k - 1)}{(k + 1)}.$$

Sometimes it is convenient to ground the middle point of the attenuator and the middle point of the resistance is connected to the ground. Attenuators are constructed so as to give several different values of attenuation simply by moving sliding switch contacts. These attenuators of course are designed for a particular

value of input and output impedance and must be used with apparatus which has this same impedance.

It is usual to give the attenuation in decibels where $k=10^{N/20}$. The following table gives the value of k and the corresponding number of decibels, N . k is the ratio of the currents.

N	k	N	k
1	1.122	8	2.51
2	1.259	9	2.82
3	1.413	10	3.16
4	1.585	20	10.
5	1.778	40	100.
6	1.995	60	1000.
7	2.24	80	10000.

Take a galvanometer whose resistance is $R=Z$, 100 ohms say and connect to a battery whose resistance is also R ohms and adjust the E.M.F. of the battery for full deflection. Calculate an attenuator making $k=2$. Make up the attenuator out of three resistance boxes. Insert in the circuit. The deflection is now halved. Calculate when k is 3, 4, 5, 7, 10. Make up and test.

If the galvanometer is very sensitive the E.M.F. may be the potential between the side plugs of a resistance box which are connected around 1 to 10 ohms of a resistance box connected in the circuit. Experiment 87 suggests a method of attenuating radio frequency current.

Fundamentals of Radio, Chapter XXIX.

Experiment 76. Characteristic Impedance.

If we have a telephone line or a lamp cord or cable the characteristic impedance of this line is the impedance of an infinite length of this line. Another definition of characteristic impedance is that impedance which if connected across the far end of a line of any length makes the impedance measured at the near end of the line equal to the characteristic impedance of the line. This impedance may involve resistance, inductance, or capacity. The best condition is when this impedance is a pure resistance. The line is assumed to be made up of equal sections or lengths. The line is always one or more of these sections in series. An attenuator can be considered to be one section of a line.

Calculate and make up a section of an attenuator where k is 2 and $Z_0 = R_0 = 150$ ohms, or $k = 3$, $R = 100$, or any other values. It is an advantage in calculation if X and Y come out simple whole numbers.

Make up the attenuator, place the characteristic resistance across the far end and measure the resistance with a bridge. If the values X and Y are not complicated calculations can be made of this resistance.

Calculate or measure the resistance when the far end is open. Make the same calculations when the far end is shorted or connected together with a zero resistance. The square root of the product of these results is the characteristic impedance. Make up a second section like the first and place it in front of the first section. Make the same calculations or measurements as when there was one section. Repeat with three, four, five, . . . sections. The square root of the product of the open times the closed is equal to the characteristic impedance of the line. Note the values of the various open values. They are larger than the characteristic impedance but approach that value as the number of sections increase. The closed values are smaller than the characteristic impedance but approach that value as the number increase. If one had an infinite number of sections the measured impedance would be equal to the characteristic impedance, independent of the connection at the far end. Three or four sections of the attenuator seem to be almost an infinite number.

You have verified the two definitions of characteristic impedance and have shown that the square root of the product of the open and closed values gives the characteristic impedance.

Fundamentals of Radio, Chapter XXIX.

Experiment 77. Measurement of Characteristic Impedance.

Characteristic impedance can be measured by measuring the open and the closed impedance as illustrated with an attenuator in Experiment 76. With attenuators we have resistance and all measurements are resistances. In a telephone line or lamp cord there is resistance and inductance in series and leakage and capacity between the lines.

With the line shorted at the far end we get the resistance and the reactance due to the inductance. The resistance and inductance can be measured with an impedance bridge or the Anderson bridge.

See previous experiments. With the line open we have capacity with some resistance. Measure as with a leaky condenser, Experiment 23. Instead of placing the resistance in series with the standard condenser the resistance can be placed in parallel. Then the admittance, $1/Z = Y = 1/(r + jC\omega)$ or $G + jB$. J means the two quantities are at right angles, Y is the hypotenuse of the triangle.

$$Z_0 = \sqrt{Z_{\text{open}} \times Z_{\text{closed}}} = \sqrt{Z_{\text{open}}/Y_{\text{closed}}} = \sqrt{(R + jL\omega)/G + jC\omega}$$

If $R/G = L/C$ then Z is a pure resistance and the line does not have frequency characteristics. Lines are loaded with inductance coils to make the ratio L/C equal to R/G .

The Z_0 of the lamp cord perhaps will be 500 ohms. The lamp cord is a 500 ohm line. A student who has had experience with inductance and capacity bridges can get fair results with 100 ft. of lamp cord.

Transformers, Experiment 73, are used to match lines of different characteristic impedances. The characteristic impedance of the primary should be that of the line to which it is connected and the secondary should be that of the line to which it is connected.

Measure the characteristic impedance of the primary by measuring with secondary open, then closed. Measure the secondary characteristic impedance as the primary was measured. Measure the voltage ratio, Experiment 73. The ratio of the two characteristic impedances should be about the square of the voltage ratio.

Connect a resistance equal to the characteristic impedance of the secondary across the secondary and measure the impedance of the primary. This should be the characteristic impedance of the primary.

It is convenient in a laboratory to have all transformers marked with the characteristic impedance of primary and secondary. This serves when one is looking for a transformer to connect a loud speaker to a particular tube. A 15 ohm connected to a 2A3 tube should be connected with a transformer whose impedances are 15 and 800 ohms.

Experiment 78. To Construct a Filter.

We shall deal with two simple types of filters, low pass filters and high pass filters. We can not give the theory here. The references must be consulted.

In a filter we assume that the source and sink have matched impedances, i.e., equal impedances. If they are not equal they must be coupled by means of a suitable transformer so as to match the impedances.

The low pass filter of one section, T type, consists of two coils, whose inductance is $L/2$, in series and a condenser of capacity, C ,

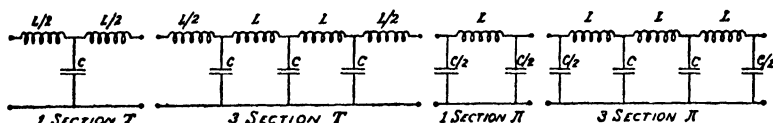


Fig. 91a. Low Pass Filter

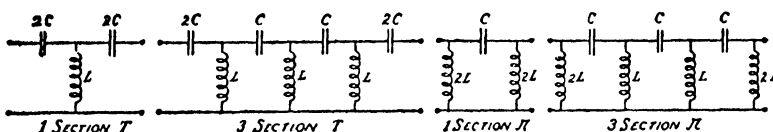


Fig. 91b. High Pass Filter

connected between the two coils and across the two lines as in Figure 91a. Figure 91a also shows a low pass T filter of three sections and filters of π type. Any number of sections can be used but it is usual to use one, two and sometimes three sections. It is seldom that more than three sections are used.

A low pass filter will pass all frequencies with little or no attenuation up to a certain frequency known as the cut off frequency. If the coils and condensers have no resistance the cut off is fairly abrupt. If the coils have resistance the cut off is gradual in the neighborhood of the cut off frequency.

The formulas given apply to coils of zero resistance and apply fairly well if the resistance is kept rather low. It is usual to use the commercial honeycomb coils in making filters for such circuits as loud speaker circuits. In B battery eliminators we use low pass filters where the cut off frequency is well below 60 cycles.

The two equations used to calculate a low pass filter are

$$\omega_0 = 2/\sqrt{LC} \quad \text{and} \quad R = \sqrt{L/C}$$

where $\omega_0 = 2\pi n_0$, n_0 being the cut off frequency, and $R = Z$ the impedance of source or of the sink.

From the above we have

$$L = 2R/\omega_0 = .3183R/n_0 \text{ Henries.}$$

and

$$C = 2/\omega_0 R = .3183/(n_0 R) \text{ Farads.}$$

These equations apply to Figure 91a.

A high pass filter is one in which the filter passes all frequencies above a certain frequency. Figure 91b is a diagram of a high pass T type filter. Also three sections of such a filter and a π type high pass filter are shown.

The equations for a high pass filter are

$$\omega_0 = 1/(2\sqrt{L/C}) \quad \text{and} \quad R = \sqrt{L/C}$$

from which we get,

$$L = R/2\omega_0 = .0796/n_0 \text{ Henries.}$$

and

$$C = 1/(2\omega_0 R) = .0796/(n_0 R) \text{ Farads.}$$

These equations apply to Figure 91b.

The filters can be tested if one has a beat tone oscillator, and an amplifier connected to a thermo junction so as to measure the output. The output must be constructed so that the ammeter measures the a-c component of the current alone. See Figure 124 or Figure 125. An output transformer matching the tube will do.

Place the filter in the output circuit of the oscillator and measure the current output of the oscillator. Measure and plot curves with filter and without filter. The oscillator should have no "built in" filter. The circuits must all be matched or there will be distortion due to reflections.

Connect a good microphone to the amplifier and a good loud speaker to the oscillator and measure the current output as the frequency is changed from low to high values. Then connect the filter either in the output of the oscillator or in the output of the amplifier and note the difference in the two curves. Plot frequency against current or current against log of frequency.

Note that Pierce uses the terms T and π in a different sense than that used here.

Pierce's *Electrical Oscillations and Electric Waves*, Chapter 16, Johnson's *Transmission Circuits*, Chapter 16 and 17; Everett, Chapter VII. *Fundamentals of Radio* p. 376.

Experiment 79. Measurement of Impedance; Ammeter-Voltmeter Method.

The impedance of coils and transformers can be measured the same as resistance is measured in Experiment 3. However this measures the numerical value only and does not give the phase angle or the relative values of resistance and reactance.

As a usual thing the current in the coils is rather small and the errors due to resistance of instruments and due to the current taken by the voltmeter will be large unless special precautions are taken.

Usually one will have to use a milliammeter of the thermal type such as radio frequency milliammeter. Rectifier types of milliammeter can be used but the resistance is high, 5000 ohms perhaps. A Weston outmeter, resistance 4000 ohms, can be used. A good vacuum tube voltmeter can be used.

Voltmeter effects. To test for the change of current of the volt meter one can place the coil and a reasonable load resistance and a milliammeter in series and read the current. Place the voltmeter across the coil to measure the voltage. If the current is the same the voltmeter does not make an error. If the current changes a correction can be made which will give approximate values. The resistance of the milliammeter must be used in calculating the total resistance.

Half deflection method. The impedance of the secondary of a output transformer can be measured by measuring the voltage of the coil open circuit and then placing resistance in series with the coil until the deflection or voltage is one half of the first. Or a known resistance can be placed in and the second voltage measured.

Then $Z = (V_1 - V_2)(R/V_2)$. This is true if the impedance of the coil is a pure resistance. Instead of algebraic sum or differences vector sum or differences should be used. However this will give a value of the same order as the true value. Instead of using an output meter a milliammeter can be used. Get the short circuit

current and then introduce resistance and take a second reading. If this coil is connected to the amplifier say or to the device as it is to be used and the E.M.F. is that which is normally produced by the amplifier the value of Z is the characteristic impedance of the coil. The frequency should be a normal frequency. An audio frequency of 800 cycles or 1000 cycles is much better than 60 cycles. These methods work fairly well if Z is low, 10 or 15 ohms. Using the milliammeter whose resistance may be 5 ohms the resistance of the meter must be considered to be part of the Z computed. Subtract for true impedance. If the voltage ratio is known, Experiment 73, the Z of the primary is the Z of the secondary multiplied by the square of the voltage ratio. This should be near the plate resistance of the tube to which the transformer is connected.

The impedance of a load such as a loud speaker can be measured by placing an ammeter in series and measuring the voltage. If the impedance is high the milliammeter perhaps is a rectifier type having perhaps 5000 ohms resistance. A voltmeter, output meter has perhaps less resistance than the milliammeter. Resistance can be inserted and the second current read. From this the resistance can be calculated as above. This now is the total resistance of the circuit. If the output impedance of the source is known and the resistance of the milliammeter is known that of the load can be calculated. This assumes that the E.M.F. is constant and that all impedances are pure resistances.

There are numerous assumptions or corrections in the above so the results are at best approximations.

Experiment 80. Measurement of the Impedance of Coils. Direct Current in the Coil.

The primary of audio frequency coils and many types of loud speakers carry d-c as well as a-c at the same time. The inductance of iron core transformers depends on the current through the coil and consequently the impedance of the coil is not the value obtained by the usual methods.

The method consists of measuring the a-c current and the a-c potential around the coil and calculating the impedance in the usual manner.

The a-c potential can be measured by a tube voltmeter of such type that there is a condenser in the grid circuit. It is evident that

the d-c potential will not affect the reading of the voltmeter. The a-c current is measured by means of a d-c milliammeter and an a-c milliammeter in series. The a-c meter should be a hot wire instrument or a thermo junction instrument which will read the same with d-c current direct and reversed.

The d-c instrument will measure the direct current independent of the alternating current. The thermal instrument will measure the root mean square of the two currents. The measured current, $I = \sqrt{I_d^2 + I_a^2}$, where I_d is the direct current measured by the d-c instrument and I_a is the alternating current. Then $I_a = \sqrt{I^2 - I_d^2}$.

The impedance, Z , can then be calculated. $Z = E/I_a$.

Figure 92 shows the connections for a test made with 60 cycle a-c. The transformer is a low potential, toy, transformer. The a-c

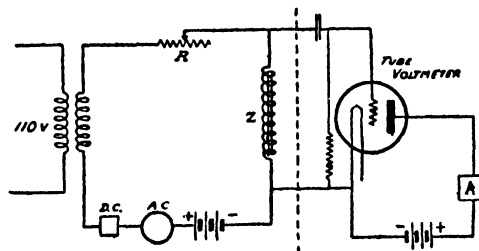


Fig. 92

current can be regulated by means of the transformer and the d-c current can be regulated by means of the number of cells in the battery and the resistance, R . The value of the a-c current should be equal

to or greater than that of the d-c current in order to get accurate values of the a-c current.

The method can be tested if one measures the impedance of an air core coil. It can be shown that the values obtained when there is direct current through the coil are the same as those obtained with alternating current alone. If the current is of the order of one or two amperes ordinary a-c instruments can be used for ammeters and voltmeters. It will be necessary to take the battery resistance into account in order to have the values check.

This method measures the numerical value of the impedance but does not give the phase angle.

Experiment 81. To Tune a Spark Sending Station.

The sending station, Diagram Figure 93, consists of a primary circuit consisting of an oil condenser or a number of Leyden jars the primary coil of an oscillation transformer and a spark gap.

The secondary circuit consists of the secondary of the oscillation transformer, O.T. in series with the aerial and if necessary a loading inductance, and a condenser in series. The modern radio regulations have practically outlawed all spark stations. It will be necessary to use a dummy aerial consisting of a condenser and coil giving the same constants as the regular aerial. The condenser is connected to the secondary of a high potential transformer. The primary of this transformer is connected to an ordinary source of alternating current, usually 110 volts 60 cycles. The spark gap may be an open gap, a rotary gap, or a quenched gap. The quenched gap tends to keep the primary circuit from reabsorbing the energy

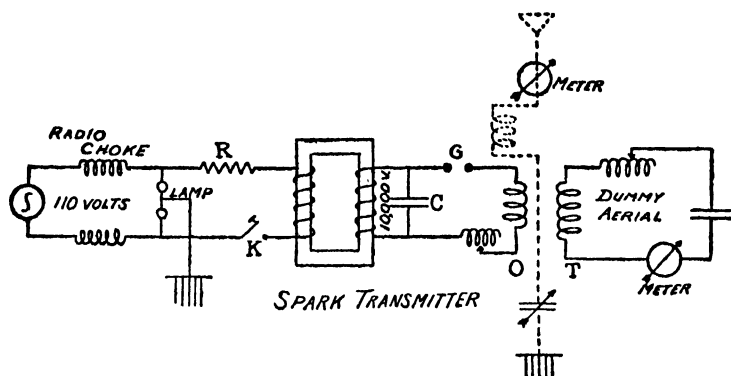


Fig. 93

from the secondary circuit. The rotary gap also tends to do the same thing as well as to regulate the number of discharges of the condenser.

Use reduced power by placing resistance in the 110 volt a-c circuit. There is no use in "tearing up the ether" and thus making the station a nuisance to those who are receiving.

The natural wave length can be measured by tuning the aerial with a number of secondary turns of the O.T. in series and then cutting out one and measuring the wave length turn by turn until nearly all the turns are cut out. Plot a curve wave length and turns in the O.T. and extend the curve to zero. This curve will be a straight line. Loosen the coupling of the O.T. Connect variable inductances in the primary and secondary circuits. Couple a wave meter as loosely as possible to the aerial and measure the wave

length or wave lengths at which the aerial is oscillating. Vary the capacity and inductance in the primary of the O.T. until a sharp wave is secured. Then gradually change the inductance in the aerial circuit so as to change the wave length towards the required wave, 175 meters to 200 meters, at the same time follow up with the primary circuit keeping both circuits approximately tuned to the same wave length. When the required wave is reached use as large capacity as possible in the primary circuit and small inductance. (There is some question as to whether this is the best condition. It would seem that this is the best condition for the so called "shock" transmitter.)

While tuning the circuit it will be of interest to measure the decrement of the various conditions.

Data for the resonance curve can be taken at this time.

Adjust the gap and coupling to make the wave sharp. Insert the rotary gap and note the sharpness and decrement. Use the quenched gap and repeat. It will be found that the coupling can be much closer with the rotary and the quenched gap.

Finally, after the adjustments have been made, place the normal voltage on the transformer and note the current in the aerial.

For these adjustments, if the aerial current is too small to be read accurately with the aerial ammeter, an improvised wave meter consisting of a few turns of wire and a variable condenser and a hot wire galvanometer can be used. The coil may be placed near the aerial and the condenser and galvanometer may be placed near the observer, connection being made with lamp cord. This wave meter can be calibrated by comparison within a standard wave meter. Due to the capacity and leakage of the lamp cord this meter will not be as accurate as a standard. If the coil is stationary the current in the aerial will be proportional to the current in the wave meter.

Note in taking curves do not hold the key down continuously as the condensers will heat. Also watch the motor and generator bearings.

Turner, p. 36; Stanley, p. 222.

Experiment 82. To Plot the Resonance Curve of a Damped Wave Transmitter.

Use a wave meter with a hot wire or thermo junction milliammeter or a high frequency galvanometer. Couple the wave meter

so that the current when in resonance will give a good deflection on the instrument. Diminish the capacity of the variable condenser until the current is a small value. Read and record the current for various settings of the condenser as the capacity is increased through maximum current down to a low value. Plot condenser readings or capacity along the X axis and current squared along the Y axis, the form of the curve will show whether the circuit is tuned right or not. A sharp curve is desirable, Figure 94. With an open gap it is interesting to plot several curves with various degrees of coupling. See Experiment 81, Tuning Aerials. In case the circuit gives a sharp curve introduce resistance in the circuit and take the curve again. Explain.

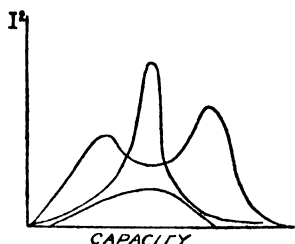


Fig. 94

Couple the wave meter to the transmitter with a tuned link as in Figure 98. Use loose coupling between transmitter and link and also loose coupling between link and wave meter. Tune all to the same frequency and take a curve as before. Detune the link a few kilocycles and repeat. Note the position of the peak of the curve. Compare these results with those of Experiment 83. It seems that the ordinates of the resonance curve measures the value of the current at the particular frequency represented by the X axis.

Stanley, Vol. 1, p. 426; Lauer & Brown, p. 68; Turner, p. 21, 28.

Experiment 83. To Plot the Resonance Curves of a Continuous Wave Transmitter.

Use a tube oscillator with considerable power output. At least one ampere in the tank circuit. Use d-c or rectified a-c on the plate of the tube. Do not use "raw" a-c. Couple a wave meter or wave meter circuit loosely to the oscillator and tune to resonance. Increase the coupling or mutual inductance by bringing the wave meter closer to the oscillator. Keep the wave meter tuned to resonance. The current in the wave meter increases as in Figure 95 until a certain point and then as the coupling is made closer it becomes uncertain. With close coupling if one tries to obtain data for a resonance curve as in Experiment 82 one will get curves something like

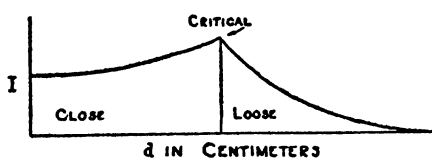


Fig. 95

Figure 96. A smooth double humped curve can not be obtained.

Instead of changing the capacity of the wave meter vary the frequency of the oscillator by changing

the variable condenser in the oscillator a curve somewhat like Figure 96 is again obtained. With loose coupling the smooth single "hump" curve is obtained by varying either condenser. Measure the frequency or wave length with a wave meter keeping this wave meter as loosely as possible and it is found that with close

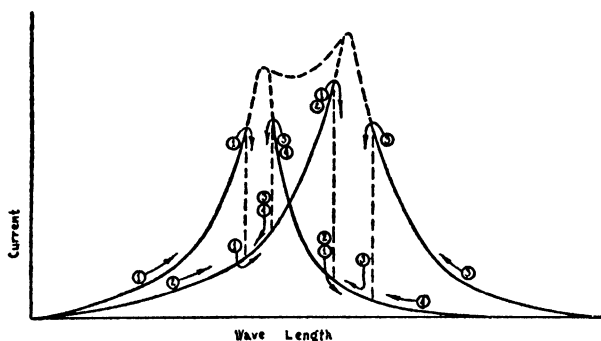


Fig. 96

coupling there is change of frequency. The oscillator abruptly jumps from one frequency to another frequency with close coupling.

Make curves both with change of frequency and by changing the impedance of the wave meter circuit by means of the condenser.

Compare these curves with those obtained with a spark transmitter.

Fundamentals of Radio, Chapter XVII.

Experiment 84. Study of Coupled Circuits. Loose and Close Coupling.

Circuits or links of a circuit can be coupled in several different ways. In Figure 97 the links from left to right are mutual inductance coupled, resistance coupled, capacitive coupled, and self

inductive coupled. We also speak of electron coupling. However electron coupling transmits in one direction while the other methods will transmit a signal from left to right and also from right to left of Figure 97. For experimental purposes mutual inductive coupling is the easiest to use since the mutual inductance between

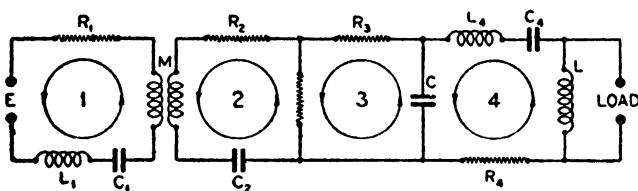


Fig 97

two circuits can be changed easily by changing the distance between the two coils. All other constants of the circuit will remain the same as the distance is changed. On page 52 "Fundamentals of Radio," is found the equation for the primary current for a circuit which is mutual inductively coupled. In this equation is found the expression $M^2\omega^2/Z_2^2$ in two places. If the coupling is self inductive the expression $(M\omega)^2$ is changed to $(L\omega)^2$. If capacitive, $(M\omega)^2$ is $(1/C\omega)^2$. If resistance coupled R is written for $(M\omega)^2$.

Resonance curves are single "humped" and double "humped" curves. Dromedary and camel types. In Experiment 83 we had trouble in getting the two "humped camel." Instead of coupling directly to the oscillator one must use a tuned link which is loosely coupled to the oscillator. In this case the frequency of the oscillator is independent of the change of coupling between link and wave meter. Figure 98.

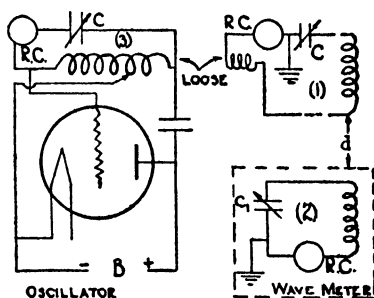


Fig. 98

Plot frequency curves for the oscillator, for the link and for the wave meter circuit. Compare with a standard frequency meter. It is much better to use frequency than wave length. With these curves the various circuits can be set at any frequency at will.

Tune the three circuits to the same frequency with loose coupling between the circuits. It will be advantageous to change the coupling between the oscillator and link so that the maximum current in the wave meter circuit is the maximum current which the meter will register, 100 milliamperes, say. Vary the distance, coupling, between circuits 1 and 2 Figure 98, and plot a curve, X = distance and Y = current in circuit, 2. A curve like Figure 95 is obtained. The maximum current is obtained at critical coupling, $M\omega = \sqrt{R_1 R_2}$. With loose coupling vary the condenser in circuit 2

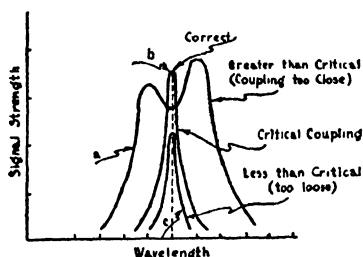


Fig. 99

and plot a curve. Note the frequency at which the maximum current is obtained. Detune circuit 1, a few kilocycles and repeat. A second curve like the first is obtained. Note the frequency at which the maximum is obtained.

The frequency of the E.M.F. has not changed. The maximum current is less because the imped-

ance of circuit 1, has been increased.

The curves plotted are admittance curves. The current is proportional to the admittance of the wave meter or inversely to the impedance. Changing the condenser of circuit 2 changed the impedance. $Z = \sqrt{R^2 + (L\omega - 1/C\omega)^2}$. The reactance is zero for maximum current and is $(1/C_r\omega - 1/C\omega)$ when detuned. C_r being capacity at resonance. This reactance can be written $1/\omega(C - C_r)/CC_r$, or $k\Delta C$. Assuming that C is near enough to C_r so that $CC_r = C_r^2$. The current diminishes as the change of the capacity, ΔC , is made larger. Tune all three circuits to the same frequency and take readings again changing the frequency of the oscillator. Plot a second curve X = frequency and Y = current. This curve looks like the the first and is easily confused with the first.

Tune all circuits to the same frequency as at first. Change the coupling between 1 and 2 to close coupling. Take a resonance curve by changing frequency of the oscillator and a double humped curve is obtained. If the tuning of circuit 1 and 2 are exact the humps are the same height. Figure 99. Increase the coupling and the humps are farther apart. Figure 100. Change the tuning of circuit 2 slightly

and repeat. One of the humps is higher than the other. How de-tune 2 to make the left hand hump high? How make the right hand high?

Start over again, loose coupling, tuning all circuits again to the original frequency, close couple 1 to 2 and repeat by varying the impedance of 2 with the condenser. Plot the curves. Double humped curves are not obtained. Admittance curves are not the same as frequency or resonance curves. Compare this experiment with Experiment 82. The conclusion is that there are more than one frequency or a band of frequencies in a spark station but one frequency at any one time in a tube oscillator. With close coupling it seems that a tube oscillator may have two possible frequencies but only one at any one time. With close coupling the frequency may change abruptly from one frequency to the other without any apparent reason or cause.

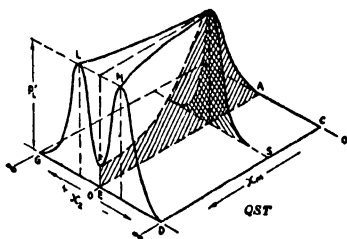


Fig. 100

Resonance theory of coupled circuits based on spark station results will not fit the modern single frequency stations.

With capacitive or self inductive coupling theory is the same. However in tuned circuits the total L and C must remain constant. The coupling L or C is part of this total and any change of coupling involves a second change to keep the total constant.

Experiment 85. To Plot the Resonance Curve of a Superheterodyne Intermediate Frequency Transformer.

The intermediate frequency transformer is placed in a shielding tube or can and adjusted so as to give a double humped curve. The frequency between humps is a few kilocycles so adjusted to give a curve which will approximate to a rectangular curve with a flat top 10 kilocycles wide.

Figure 101 gives a suggested circuit. Figure 101 shows pentode tubes. Triodes can be used. An oscillator circuit is coupled loosely to the intermediate coil with a small condenser. The coil is connected to a radio frequency amplifying tube which has a tuned circuit in the plate. This coil has a radio frequency meter in the

and grid leak as in Figure 102 is more satisfactory than other forms of grid bias. The grid leak should be 25,000 ohms, a 20 watt resistor.

Connect a coil, variable condenser, milliammeter or radio galvanometer and a radio resistance box in series, making a wave meter circuit. Couple the circuit to a high frequency generator. The coupling should be loose enough so that changing the current in the wave meter will not change the current in the generator.

With the resistance in the box zero, read the current in the milliammeter. Insert a resistance R_1 in the box and read again. Care must be taken to see that the circuit is in resonance in each

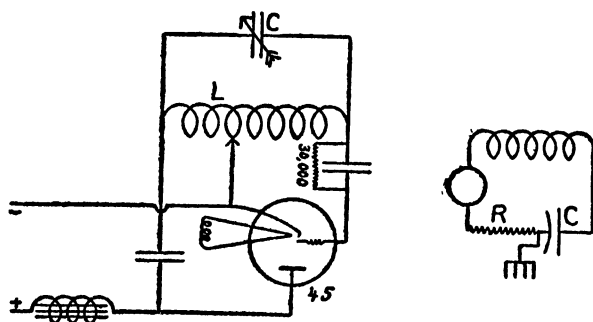


Fig. 102

case. In the first case $I_1 = E/R$. In the second, $I_2 = E/(R + R_2)$. Then $R = R_1 + I_2/(I_1 - I_2)$. When I_2 is made one half of I_1 the resistance in the box is equal to R the resistance of the wave meter. This is known as the half deflection method.

Note. The current must be read. If a galvanometer or a so-called "wattmeter" is used the square root of the deflections must be used in the place of the currents.

If the coupling is close the resistance measured will be the resistance of the wave meter plus the effective resistance of the generator.

From the resistance, R , and the current I_2 , calculate the electromotive force in the circuit. Calculate the potential across the condenser.

The resistance as measured this way is the resistance of the coil condenser and the milliammeter. If a good low loss condenser is used its resistance will be small and as a usual thing can be neg-

lected or said to be zero. The milliammeter can be measured by placing a second milliammeter in series with the first and measuring again. This resistance less the first is the resistance of the second milliammeter. The first meter can be removed and the circuit measured again. The second reading minus the third is the resistance of the first meter. The resistance of any other meter coil or resistor can be measured by placing in the circuit and following the same general plan. The insertion of a meter or other piece may change the inductance. The circuit must be tuned each time. The wave meter circuit should be grounded between the rotor of the condenser and the meter.

A good shielded condenser is quite an advantage.

Measure at 600 meters and at 300 meters. The resistance is greater the higher the frequency. A good milliammeter should have the same resistance unless the frequency is very high.

A tube with small filament like the old 199 tube can be used as a standard resistance. Place a potential of about 45 volts on the plate and measure the plate current as when running the filament characteristic. The plate current is an indication of the temperature of the filament. Measure the resistance of the tube by the ammeter volt meter method when the current is 60, 55, 50, 45, 40, 35, and 30 milliamperes in the filament. Correct for the resistance of the meter. Plot a curve giving resistance against filament current. Also a curve giving resistance against plate current.

Place in the radio frequency circuit and when a certain plate current is obtained one knows both the current and the resistance of the tube.

This will serve as a standard of resistance and also as a means of calibrating the milliammeter at high frequency. The diameter of the filament is so small that the resistance is the same as the d-c resistance up to more than 10 megacycles.

Herbert Hazel, *Proc. I.R.E.*, Vol. 16, p. 70.

Experiment 87. To Measure Resistance of a Circuit with the Impedance Variation Method.

The circuit is coupled to a generator as in Experiment 86. The current is read when the circuit is in resonance. Then the capacity of the wave meter is changed until the square of the current is one half of the first current squared. The current is reduced to .707 of

the first value. If a galvanometer or "watt meter" is used the deflection is halved.

In the first case $I^2 = E^2 / (R^2 + (L\omega - 1/C\omega))^2 = E^2 / R^2$. Since $L\omega = 1/C_r\omega$, $1/2I^2 = E^2 / (R^2 + (1/C\omega - 1/C_r\omega)^2)$.

Then $R = (1/\omega)(C_1 - C_r)/CC_r = \Delta C/\omega LC_r C = k\Delta C$.

If the square of the current is not exactly halved then

$$R = [(1/\omega)(C - C_r)/CC_r] \sqrt{I_1^2 / (I_1^2 - I_2^2)}.$$

Where I_1 is the current at resonance and I_2 is the current when the capacity is C .

When the resistance of the circuit is very small it may be impossible to get an accurate value of ΔC , the capacity which will reduce the current to .707 of the initial value. Since $I_1 = E/R$ $1/2I_1^2 = E^2/2R^2 = E^2/(R^2 + k\Delta C^2)$. R being equal in value to $k\Delta C$. Then since R is constant, $I = E/Z = E/(R + j(nk\Delta C))$. J meaning that delta C is at right angles to R . Z is the hypotenuse, R is the base and $n\Delta C$ is the height of a right angled triangle. If we have a straight line capacity condenser and assuming the value of $CC_r = C_r^2 = \text{a constant}$ we can speak of $n\Delta C$ meaning n times the capacity which reduced the current to $I_1/\sqrt{2}$. This capacity can be read in terms of change of dial readings.

When $n=1$, I is $I_1/\sqrt{2}$, when $n=2$, I_1 is divided by the square root of 2 squared plus one or $I = I_1/\sqrt{n^2+1} = I_1/\sqrt{5}$. If $I = I_1/\sqrt{5}$. Then the change of capacity is $\sqrt{5^2-1} = \sqrt{24} = 4.9$. So if the current is reduced from 100 milliamperes to 20 milliamperes the change of capacity is $4.9\Delta C$. From this ΔC the capacity to reduce the square of the current to one half can be calculated. This $4.9\Delta C$ should be measured with increasing capacity and also with decreasing capacity and the average used. We assume that $CC_r = C_r^2$. If $C_r = .0005\text{m.f.}$ and $n\Delta C = .0001\text{m.f.}$ Then we assume that $\sqrt{5 \times 6} = 5$ when the capacity is increased and that $\sqrt{4 \times 5} = 5$ when the capacity is decreased. Or that $5.48 = 5$ in the first place and that $4.47 = 5$ in the second place. If CC_r is assumed to be constant then ten ΔC will reduce the current to about one tenth of the initial value. If the resistance of the circuit is small so that ΔC is small then the current is reduced to $1/100$ of the initial value by introducing $100\Delta C$ $100^2 = \sqrt{100^2-1}$. In general the current is reduced to the order of the $1/100$ of the initial value.

This method can be used as an attenuator for radio frequency currents. Experiment 61.

Measure the resistance by reducing the current to one fifth and calculate ΔC and assume the half deflection method and calculate R . Supply in the general formula and calculate with the same data. Compare this method with Experiment 86.

Experiment 88. To Measure the Resistance of an Aerial.

The resistance of an aerial can be measured by the half deflection method. If a radio frequency ammeter is placed in the aerial and the current is measured when the circuit is in resonance, i.e., when $I = E/R$. Then if R , is increased until the current is $\frac{1}{2}$, the resistance in the first case is equal to the amount added to R , in the second case.

This assumes the frequency is the natural frequency of the aerial and that the added resistance is such that the high frequency resistance is the same as the low frequency resistance, and that there is no inductance or capacity in the resistance box. These assumptions are seldom true unless a good radio frequency resistance box is at hand, but the result may be looked upon as a good estimate.

Hot wire ammeters are not very sensitive, so the current must be large which is true only in a sending aerial or when one has an oscillator of some considerable

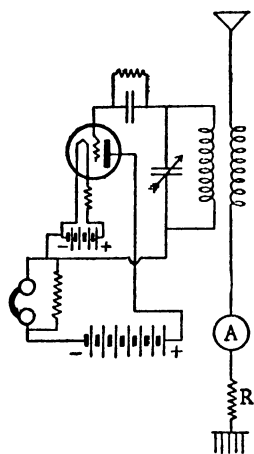


Fig. 103

power coupled to the aerial. An approximate measurement of a receiving aerial can be made by using phones and a vacuum tube circuit. Adjust the primary and secondary until signals from some convenient high power station come in the loudest using loose coupling. In this case both primary and secondary are in resonance with the sending station and the aerial $I = E/R$. Shunt the phone until the signals are just audible. $I_p = IS/S + P$. Then calculate the resistance of S , so that the current through the phone is two times I_p or $S_2 = (2S_1P)/(P - S)$, Experiment 97.

Insert this value in the shunt and insert resistance in the aerial at R until the signals are just audible, then the resistance of the aerial is equal to the inserted resistance. This assumes that the amplifying ratio of the tube is constant.

Do not use an oscillating or a regenerative circuit. These circuits introduce an E.M.F. in the circuit. The E.M.F. should be the received signal. The resistance of an aerial can be separated into its component parts by measuring the resistance at a number of wave lengths and plotting a curve.

Experiment 89. To Measure the Resistance of an Oscillating Circuit or Tube Generator.

An r-c meter and an r-c resistance box is inserted in series with the oscillator's tuning condenser in the tank circuit. (Caution: do not overload the resistance box. It may be necessary to reduce the power of the oscillator.) The resistance in the box can be increased until the current as read by the meter is reduced to one half, then the resistance of the circuit is equal to the resistance in the box, the initial resistance in the box being zero. This is true if the E.M.F. of the circuit is constant. Care must be used in using this assumption. If the E.M.F. is constant any amount of resistance can be inserted into the box and the resistance of the circuit can be calculated. However experience shows that as the resistance in the box is increased there is a value at which the circuit ceases to oscillate. It is quite evident that the radio frequency E.M.F. has changed.

A suggested procedure is to use the half deflection method. Assume the resistance to be equal to the resistance R , in the box. Make a second measurement in which the resistance in the box is changed from zero to $2R$ and calculate the value of the resistance of the circuit. If both results are substantially the same the resistance, R , is the true resistance.

If the two values differ substantially the true result can not be determined. The circuit must be made to oscillate more vigorously and measured again if the resistance box will carry the current.

Experiment 90. To Compare the d-c and the a-c Resistance of a Sample of Wire.

Take two samples of the wire of equal length and place them in the two legs of a differential air thermometer formed as an H, the cross connection being in the form of a U.

This H is blown from glass as in Figure 104, each leg being exactly alike in every particular. The wires are passed through

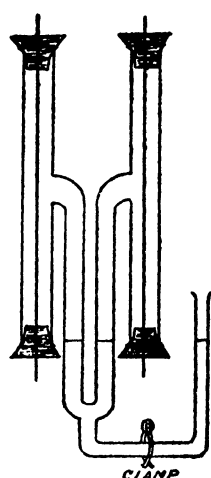


Fig. 104

corks and made air tight with wax except for one small pin hole in each leg. The connecting U-tube is made with inside diameter about two millimeters and a small amount of water is drawn into the tube.

When finished the tube is placed with the U-vertical and when in temperature equilibrium the pin holes are closed. One wire is connected into a high frequency circuit, r-c, with a hot wire ammeter. The other wire is connected to a d-c circuit with ammeter. If the heating effects of the two wires are unequal the liquid will be of unequal height. Adjust the currents so the pressure is the same on each side.

Then $I_1^2 R_1 = K i_2^2 R_2$ where R_1 and R_2 are the d-c resistance of conductors 1 and 2 respectively, K is the ratio of the a-c resistance to the d-c resistance and I the d-c current in conductor one and i_2 is the a-c current in conductor two. Interchange the connections and adjust again to

The following table gives the frequency expressed in wave lengths and the diameter of the wires, such that the a-c resistance differs from the d-c resistance by 1% Fifty-six hundredths (.56) of this diameter reduces the error to 0.1%

Material	Resistivity in c g s units	λ 600	(Maximum diameter in millimeters)				λ 12	λ 6	λ 1.2
			1200	600	120	60			
Manganin									
Iron	44×10^{-8}	2.4	1.1	.75	.34	.24	.11	.075	.034
$\mu = 1000$	10×10^{-8}	.033	.015	.010	.0046	.0033	.0015	.0010	.00046
$\mu = 100$	10×10^{-8}	.099	.044	.031	.014	.0099	.0044	.0031	.0014
Copper	10×10^{-8}	.49	.22	.15	.069	.049	.022	.015	.0069
Constantin	1.75×10^{-8}	2.6	1.2	.83	.37	.26	.12	.063	.037
Platinum	49×10^{-8}	1.2	.57	.37	.17	.12	.057	.037	.017
Carbon, arc.	10.10^{-8}	23.6	10.6	7.5	3.4	2.36	1.06	.75	.34
Concentrated CuSO ₄	3500×10^{-8}	175.	78.	55.	25.	17.5	7.8	5.5	2.5
Tungsten Lamp Filament		.83	.37	.26	.118	.083	.037	.026	.0118

equality of pressure. Then $I_2^2 R_2 = K i_1^2 R_1$ where I_2 is the d-c current in 1 and i_1 is the a-c current in 2 and i_1 is the a-c current in 1. From the above

$$K R_2 / R_1 = I_1^2 / i_2^2 \quad \text{and} \quad K R_1 / R_2 = I_2^2 / i_1^2 \quad \text{hence} \quad K = I_1 I_2 / i_2 i_1.$$

By taking the two sets of readings the inequalities of the two sides of the apparatus are eliminated. No. 20 iron wire works well in this apparatus. Figure 105 shows apparatus for the comparison of d-c, and r-c, resistance of coils.

Compare small wires and large wires of copper, of iron, German silver and other alloys.

Starling, p. 367; Fleming, Proc. Phys. Soc. Lond. 23, p. 103, 1911.

Experiment 91. To Measure the Resistance of a Radio Condenser.

The resistance of a large condenser can be measured at low frequency by the method given in Experiment 23. This method is not accurate enough to measure the resistance of a radio condenser.

Substitution Method. The usual method used is to measure the resistance of a radio circuit by the Resistance Variation Method, Experiment 86, or by the Impedance Variation Method, Experiment 87, and then insert a standard condenser whose resistance is known, or usually its resistance is assumed to be zero, and measure the resistance of the circuit again and the difference of the two results is assumed to be the resistance of the condenser. If the standard is a good "low loss" air condenser the resistance is of the order of a tenth ohm and as a usual thing can be neglected.

The resistance of a condenser may be a resistance in series such as resistance in the terminals or connections or it may be dielectric loss which can be assumed to be in parallel with the condenser. The resistance may be due to eddy currents or other effects. All these can be represented by a resistance in series with the condenser.

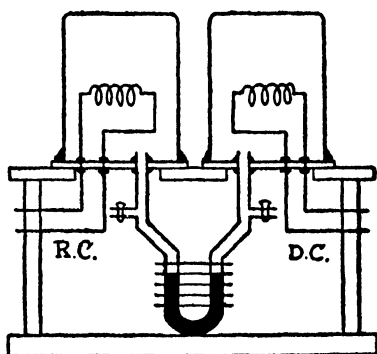


Fig. 105. Drawing showing the differential thermometer. The heat developed in the coil in the left hand beaker by the radio frequency current is balanced by the heat developed in the coil in the right hand beaker by the direct current. The equality of the height of the water in the U-tube indicates when equilibrium is established.

The resistances are represented in Figure 106.

In measuring with this method care must be taken to have the circuit in tune with the oscillator and the coupling should be very loose. There should be no reaction on the oscillator when the circuit is tuned to the oscillator.

Thermometer Method. The resistance of a radio condenser can be determined by the thermometer method. This is very much like Experiment 90.

The condenser is placed in a thermometer bulb made of a pyrex beaker sealed to a sheet of glass with bees wax. A second bulb is



Fig. 106. At left, diagram showing a perfect condenser in series with a resistance; at right, showing how the actual resistance of a condenser may be in series or in parallel with a condenser.

made exactly like the first. These two are connected to U-tube which passes through holes drilled in the glass plate and sealed with wax. In the U-tube a small amount of water serves as a pressure indicator. Rubber tubing with

pinch cocks, or glass stop cocks are fastened to T-tubes on each side of the U-tube. These cocks serve to equalize the pressure in the bulbs. Electrical connections are sealed in holes drilled in the glass plate.

The apparatus is practically the same as shown in Figure 105.

The resistance of the condenser is compared with a short piece of resistance wire, two or three ohms, which is placed in one bulb. The condenser under test is placed in the other bulb. To make the thermal capacity of the bulbs equal a second condenser exactly like the first is placed in the bulb with the resistance wire.

The procedure is as follows. The condenser is made a part of a high frequency circuit coupled to an oscillator. The resistance wire is connected to a d-c source. A suitable r-c ammeter is placed in the r-c circuit and a d-c ammeter is placed in the d-c circuit.

A preliminary run is made to get an approximate value of the currents and to test for leaks in the sealed joints. The stop cocks are opened and the apparatus is allowed to come to thermal equilibrium which is attained in an hour or two. Then the stop cocks are closed and the radio frequency current is started. The d-c current is adjusted so as to keep the pressure in both bulbs equal. This adjusting of the d-c current is continued until the

pressure remains in equilibrium for several minutes with both currents constant. Then since the heat produced in the two bulbs is the same, $i^2r = I^2R$, small letters referring to the r-c circuit and the capitals to the d-c circuit. Then the condenser resistance, $r = RI^2/i^2$. Several determinations should be made and the mean value used.

The condensers and coil should be interchanged in the bulbs and another determination made to correct for any inequality of the bulbs or surroundings.

Measure the resistance of the condenser at several dial settings and with different frequencies.

Proc. I.R.E., 18, p. 1226, 1930.

Experiment 92. To Test for Dielectric Absorption.

In making radio apparatus it is important that the material used for forms should not absorb any of the energy of the high frequency current. These tests may be made in a very simple manner. The only apparatus needed is a loose coupler receiver, one in which the space between the coils can be made rather large. Hinged coil couplers are good.

Tune the receiver to some sending station and couple the coils very loosely. Have the coils far apart. Insert the material to be tested between the primary and secondary coil of the receiver and note the intensity of the signals or music. If there is any absorption of the material the intensity will diminish.

Test wooden boards, sheets of mica, formica, paper tubes, and various material in sheet or tube form.

Test coils. It will be found that with good coils such as honey comb coils with relatively few turns of wire there will be no absorption, while a coil with a large number of turns will completely absorb the incoming energy. A short circuited coil will absorb or choke out the energy.

A few tests will show why a large coil with many taps is not efficient on the shorter wave ranges. The efficiency of radio frequency choke coils can be treated in this manner.

Materials should be tested in the summer when they are moist. A paper tube may test all right in the winter and be poor in the summer.

Experiment 93. To Measure the Decrement of a Sending Station.

The measurement of the decrement of the sending station is one of the important measurements in radio.

In the equation of a damped wave,

$$I = I_0 e^{-\alpha t} \sin \omega t.$$

Where $\alpha = R/2L$, we have $I_1 = I_0 e^{-\alpha T}$ and $I_2 = I_0 e^{-\alpha 2T}$ for the first and second maximum values of current and $\alpha T = \log I_1/I_2 = d$.

Then $d = RT/2L$, where T is the period of the oscillation.

The term decrement is now applied to C.W. stations, and circuits. Since $d = RT/2L$ and $T = 2\pi\sqrt{LC}$, $d = \pi R\sqrt{L/C}$.

Thus decrement, or logarithmic decrement can be considered to be a constant of a simple radio circuit, being π times the product of resistance by the square root of the ratio of the capacity to the inductance of the circuit.

Make up a decremeter of a coil of wire so wound that the distributed capacity will be small, a hot wire meter, and a variable condenser. Make the connecting wires as short as possible. Do not use lamp cord or twisted wire. This introduces capacity and leakage.

A coil of six or seven turns of No. 18 wire on a frame 50 centimeters square, the wire placed about 1 centimeter apart makes a good decremeter. Choose the number of turns so as to have the capacity readings above the middle of the condenser scale. Small capacity makes the potential on the condenser great and there is danger of a brush discharge. This leakage is a waste of energy and acts the same as if resistance were inserted in the decremeter.

Bring the decremeter near enough to get a good deflection when in resonance and read the capacity. Change the capacity until the current squared is $\frac{1}{2}$ the initial current squared, i.e., $I = .707$ of maximum; read the capacity. Calculate the decrement from the formula.

$$d = \pi(C_r - C_2)/C_r = \pi(C_1 - C_r)/C_r.$$

There are two values of C one less than C_r and another greater than C_r . Use the mean difference. Or $d = \pi(C_1 - C_2)/2C_r$. Correction for the decrement of the decremeter must be made. See Experiments 94 and 95. Compute the number of oscillations per spark.

Experiment 97. To Compare the Sensitiveness of Phones.

Measure the resistance of the phones. Place the phones in series in a high frequency circuit (100 to 1000 cycles), Figure 108a, the resistance of which is very high; i.e., the current is constant. The plate circuit of a vacuum tube will answer. With a resistance box shunt around the phone until the sound is just audible. Then the current through the phone is

$$I_p = IS/(S + P),$$

where I_p is phone current
 I is the current of the circuit
 S is the resistance of the shunt.
 P is the resistance of the phone. Repeat with the second phone. Then the sensitiveness is proportional to the reciprocal of I_p .

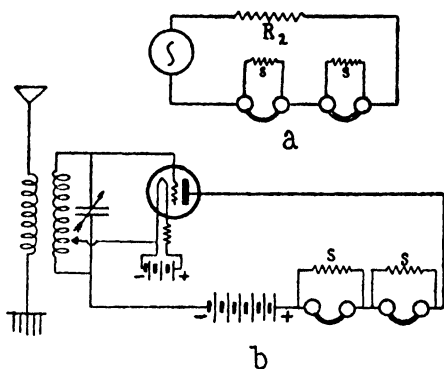


Fig. 108

This assumes that I is constant at all times or that the total resistance of the circuit is not changed appreciably by shunting the phone.

If both phones are shunted at the same time and both shunts adjusted until the sound is just audible in both phones at the same time, the current I need not be constant. Note that an adjustment of shunt No. 2 will change the current in phone No. 1, unless the resistance, R_2 , of the circuit is very great. The true adjustment is obtained only after a series of approximations.

A good source of alternating current for the comparison of phones is to tune to one of the Atlantic coast stations, such as New Brunswick, N.J., a self heterodyne circuit being used, Figure 108b. The sensitivity of a phone varies to some extent with the frequency. The frequency of the a-c in this case can be varied at will. Phones can be compared at low and high pitches. A tuning fork can be used to get the approximate frequency.

A good source of alternating current for the comparison of phones is to tune to one of the Atlantic coast stations, such as New Brunswick, N.J., a self heterodyne circuit being used, Figure 108b. The sensitivity of a phone varies to some extent with the frequency. The frequency of the a-c in this case can be varied at will. Phones can be compared at low and high pitches. A tuning fork can be used to get the approximate frequency.

To measure the audibility of signals. The telephone is shunted until the signals are just audible. Then, $I = I_p(S + P)/S$. I_p is the least

current which is audible and is assumed to be known and constant. The relative audibility of signals can be determined by taking the ratio of the currents.

Sig Corp. Radio, p 448

Experiment 98. Neutralization of Circuits.

When one makes an amplifier there is a tendency for the amplifier to become an oscillator. The tube oscillates due to the capacity feed back through the tube. "Fundamentals of Radio," p. 164.

In the early days radio frequency amplification when using "short waves" was not (or usually was a howling) success. The broadcast band was then considered to be short waves. Radio frequency amplifiers were usually untuned circuits which were so inefficient that the set did not oscillate. The neutrodyne neutralization was the first successful method. Various other methods are used, one of which is known as Rice neutralization. This last is usually used in transmitting amplifiers while the neutrodyne is

used in receivers. Experiment 73 shows the principle of the neutrodyne. See Figure 87. When we have this applied to a tube we have Figure 109.

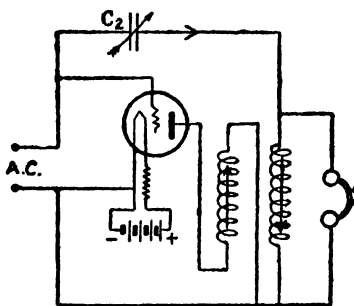


Fig. 109

Professor Hazeltine in 1923 made public a method of neutralizing the capacity of the tubes by means of a small condenser placed between the grids of the tubes. This condenser is marked C_H in the diagram for radio amplifier, Figure 110. It is made of a small metal tube one inch long

which is slipped over the ends of No. 12 or 14 insulated wires which are about $\frac{1}{4}$ inch apart. These two wires are connected to the grids of the two tubes. The coils consist of a primary, 13 turns of No. 24 D.S.C. wire wound on a tube $2\frac{3}{4}$ inches diameter and 4 inches long. The secondary coil consists of 55 turns of No. 24 D.S.C. wire wound on a tube 4 inches long and 3 inches diameter. The primary is placed inside of the secondary. The coupling is so close that both coils can be tuned with a variable condenser placed in the secondary

coil. The receiving coil may be one of these coils. The coils are placed $6\frac{1}{2}$ inches apart at an angle of 60° with the horizontal. It is better to set the coils with the centers all in a straight line and the axes of the coils mutually perpendicular one to another. The coils of the neutrodyne transformer must be connected "reversed." See Experiment 73.

To adjust the condensers the amplifier is tuned to a loud signal and the filament of the first tube is turned out. The signal will still be heard through the capacity of the cold tube. The first condenser, C_H , is adjusted until the signal is not heard. C_H then neutralizes the capacity of the first tube. The first filament is

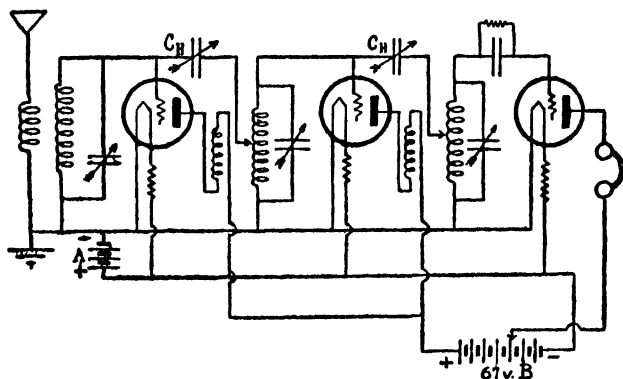


Fig. 110

heated and the second tube is turned down and the second neutrodyne condenser is adjusted. The neutrodyne condensers were originally connected from grid to grid of the tubes. The neutralizing condensers then had to be smaller than the capacity of the tube. Connected as in the diagram the capacities are about equal. Some circuits use a third coil in place of the lower part of the secondary coil.

Rice neutralization is illustrated in Figure 114 in the transmitter circuit. The neutralization condensers are marked C_n . To adjust Rice neutralization follow the same general instructions as given above for the neutrodyne.

For details see *Wireless Age*, April, 1923, p. 7; *QST*, April, 1923, p. 54; *Radio News*, May, 1923, p. 1949.

Coils 1 and 4 in the diagram, Figure 111, are the usual neutrodyne coils. See Experiment 98. These are tuned with 23 plate variable condensers. Coils 2 and 3 are untuned radio frequency coils. These may be purchased or may be made by winding two flat coils each containing about 40 feet of No. 36 to No. 40 copper wire wound in two circular channels cut in a hard rubber rod $1\frac{1}{2}$ inches diameter. These channels are separated by about 1 millimeter of hard rubber and are from 1 to $1\frac{1}{2}$ millimeters wide. The inside diameter is about $\frac{1}{2}$ inch. The outside diameter is at least 1 inch. Coils 5 and 6 are audio frequency coils.

Neutrodyne condensers, C_n , see Experiment 98, are placed between the secondaries of coils 2, 3, and 4 and the grids. In coil 4 a tap may be made on the thirteenth turn from the filament end of the secondary.

The primary of coil 5 is placed in the plate circuit of tube 4. The secondary of this coil is placed in series with the secondary of coil 2. Coil 6 is placed in series with coil 3. The telephone or loud speaker is placed in series with the primary of coil 4.

Jacks, J , may be placed in series with the primary of coils 5 and 6 as well as in the plate circuit of tube 3. With the jacks in place a telephone may be inserted in the plate circuit of tubes 4, 2, and 3, at will. 0.002 mf. condensers must be placed around the primaries of coils 5 and 6 as well as around the telephone to by-pass the radio frequency current. Coil 1 may be replaced with a coil aerial if so desired.

When properly constructed this set has the desirable features of the neutrodyne set and is easier to tune. The amplification is enough to work a loud speaker and the quality is free from the distortion caused by excessive iron core amplification.

The neutrodyne coils may be made as directed in Experiment 98 or they may be wound on one tube. The primary is placed on the tube and a layer of paraffined card board is placed over this and the secondary is wound over this. If the wire is well insulated spider web coils can be made by winding two wires in parallel until the required number of turns for the primary is placed on the coil and then continuing with one wire until the secondary is finished. The coils may be made in the form of the "low loss" coils or the figure eight coils which are described in many radio text books.

When adjusting the neutralizing condensers it will be necessary to remove the audio frequency coils. Build the set as per the diagram, test all the circuits and then remove the audio frequency coils and connect the taps made in the circuits and adjust the condensers with the telephone connected in the detector tube plate circuit. This method of adjusting the neutralizing condenser applies to all reflexed neutrodyne receivers. Short circuiting the primary and secondary of the coils will not do. The coils must be removed.

Experiment 100. Superheterodyne Amplification.

Superheterodyne amplification dates from before the days of broadcasting. It was a means by which radio frequency amplification was applied to "short waves" before it was known how to neutralize the capacity feed back of the tube. The early superheterodyne sets often were oscillators and due to this they were a nuisance in the neighborhood of other sets. In modern sets this has been guarded against by placing a stage of radio frequency amplification ahead of the heterodyne tube. This first tube is often called a buffer tube. The modern set combines selectivity with fidelity by using band pass intermediate frequency coils. See Experiment 85. The general principle of the super probably can be best understood by the study of an old circuit.

In the superheterodyne amplifier the signals are received and detected with a tube connected to a receiving coil which is very much if not identical to one of the ordinary receivers. Coupled to this is a second tube which is connected to a regenerative circuit so as to oscillate at a lower or higher frequency than that of the signal being received. The plate circuit of the first tube is connected to a radio frequency transformer which is tuned to the beat note produced by the difference of the frequency of the two circuits. Then follows several stages of amplification at the low frequency or long wave length of the beat note. This is detected by a detector tube and usually there is one or two stages of audio frequency amplification.

While tuning, the frequency of the oscillator is changed as the frequency of the receiver is changed so as to keep the difference of frequency constant. If the signal is 300 meters wave length or 1000 kilocycles frequency and the oscillator is set to 333 meters

or 900 kc. the beat note is 100 kc. or 3000 meters. The amplification transformers are tuned to 3000 meters. If the signal is 500 meters or 600 kc. the oscillator is tuned to 600 meters or 500 kc. and the beat note is the same as in the first case.

The diagram, Figure 112, shows an eight tube superheterodyne receiver. The lower tube, by itself, is the oscillator. The first tube,

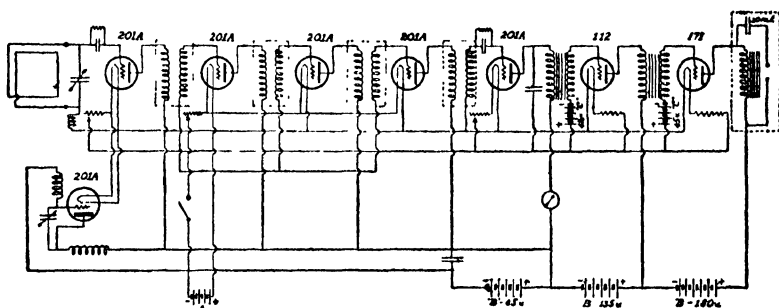


Fig. 112

to the left, is the first detector which picks up the signals from the loop. The following four stages are intermediate frequency stages which are tuned to the beat note. The fifth tube is the intermediate frequency detector. The second, third, and fourth tubes are amplifying tubes. The last two stages are audio frequency amplifiers.

Some sets use five intermediate stages instead of four. In some sets the loop is made regenerative by connecting the middle of the loop to the filament and one side of the tuning condenser to the plate of the detector tube by means of a small variable condenser.

This will be recognized as the Hartley shunt circuit.

This regenerative circuit may oscillate and create a disturbance the same as a single tube regenerative circuit. A superheterodyne connected to an aerial is often a nuisance to the neighborhood if allowed to oscillate.

The coils can be made and tuned with a fixed condenser or they may be untuned coils with the peak adjusted to the intermediate frequency. The coil connected to the last detector is tuned. This coil is sometimes called a filter.

The intermediate frequency coil can be made by turning a cylinder of wood two and a half inches in diameter. In the cylinder turn two channels one fourth inch wide and one inch deep. Leav-

ing in the center a cylinder one half inch in diameter. The two channels are one fourth inch apart.

In one of these channels wind 850 turns of No. 36 insulated wire for the primary and in the other channel wind 1000 turns of No. 36 wire for secondary coil.

The filter coil can be wound on the same wooden form with 500 turns for primary and 600 turns for secondary. The secondary is tuned to the natural wave length of the other coils with a condenser. Capacity about .00025 μ f.

Figure 113 is a modern superheterodyne receiver. The first tube is the tuned radio frequency buffer stage. The second tube, 2A7

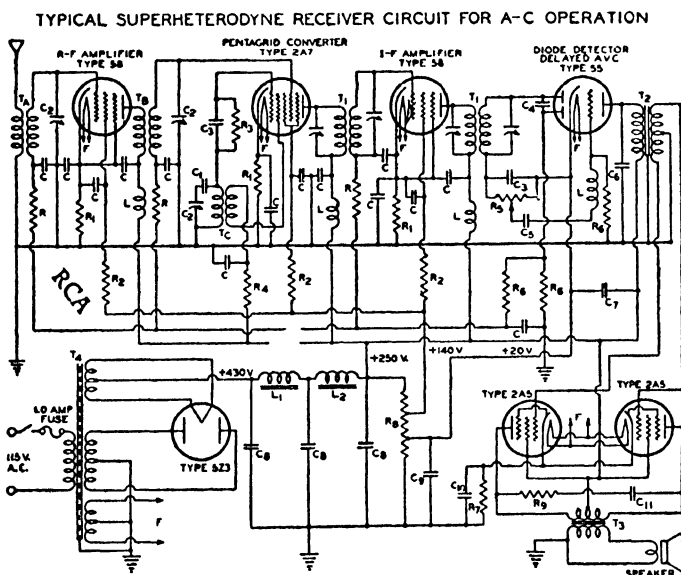


Fig. 113

serves as the oscillator and first detector and is called a converter tube. The coils marked T_c are the oscillator coils. The circuit is a tuned grid circuit using the cathode, the first grid, and the second grid as a three electrode tube. The signal is fed into the tube on the third grid which is surrounded by the screen grid.

There are three condensers marked C_2 . The third of these gang condensers is connected to the oscillator. These are straight line frequency condensers. A second condenser C_1 is in series with C_2

in the oscillating circuit. This is the padding condenser and has a large capacity compared to C_2 . The inductance of this oscillator coil has an inductance whose value is about .8 of that of the tuned radio frequency coil. This oscillator is tuned to a frequency 175 kc. above the frequency of the radio frequency circuit. Thus the intermediate frequency is kept at 175 kc. This must be true for each setting of the receiver.

The oscillator is made to "track" as follows. Assuming the intermediate coils are tuned and the radio frequency coils are tuned. Set the dial to a high frequency 1450 kc. say. A strong station can be used or a local modulated oscillator can be used. Tune the oscillator for best results using a small trimming condenser attached to and connected to C_2 . (Not shown in diagram.) Now tune to a low frequency 600 kc., say. Tune this station in by varying the padding condenser C_1 . This condenser being large .001 to .002 μ f and being in series with C_2 does not change the value of C_2 much when it is set at small values. However it may be necessary to set on 1450 kc. again and retune with the trimmer. Set on 600 again and tune with the padding condenser. In a short time both will be tuned so that the oscillator and radio coils track for these stations. It can be shown theoretically or demonstrated experimentally that when set to 1500 kc. for perfect tracking the frequency must be raised and when set on 640 kc. the frequency must be lowered for perfect adjustment. This proves that the tracking curve is an S curve and crosses the zero line at some frequency between 600 and 1450 kc. So there are three points on the curve which track perfectly.

The intermediate frequency coils T_1 can be tested as in Experiment 85 by removing the 2A7 tube and by attaching a wire very loosely to the grid of the 58 tube, this wire being connected to a standard oscillator oscillating at 175 kc. The 2A7 tube is then replaced and the first 58 tube is removed and the signal is fed to the grid of the 2A7 & the second coil is adjusted.

Any oscillator so tuned that the fourth harmonic gives zero beat with WLW 700 kc is set at 175 kc.

Experiment 101. Adjustment of an Oscillating Circuit for Linear Modulation.

The usual and perhaps the best method of modulation is the Heising Plate Modulation. In this the potential of the plate of the

oscillating tube is varied and the radio frequency output of the tube is varied in unison with the potential.

The amplitude of a two ampere alternating or oscillating current is twice that of one ampere of current. Then if an oscillator or radio frequency amplifier tube is adjusted so the current in the tank circuit is proportional to the potential on the plate the amplitude of the current will be proportional to the plate potential.

The experiment consists of adjusting the bias of a class C radio frequency amplifier or class C oscillator to such a value that the radio frequency current in the tank circuit of the modulated tube is directly proportional to the plate potential on that tube.

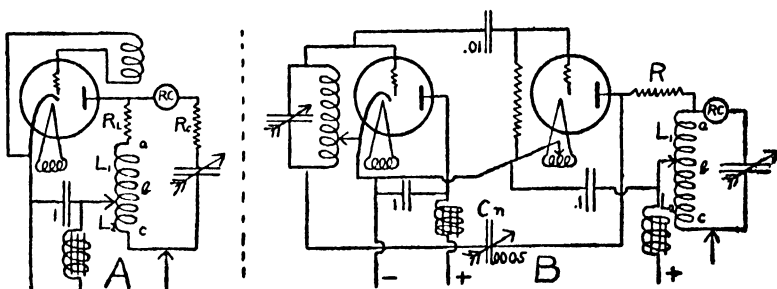


Fig. 114

In the case of a Hartley oscillator this can be done by adjusting the fixed negative bias with batteries or as in Figure 58. Or this may be done by means of grid condenser and grid leak as in the oscillator of Figure 74.

In the case of a radio frequency amplifier this can be done perhaps with fixed bias or perhaps better by means of grid bias grid leak as in the output stage of Figure 114. Specific directions can not be given as method will depend on circuit and tube used. The plate potential should be changed from low values up to a value about twice the normal plate potential. Assume a 45 tube, the potential on the plate should be 50, 100, 150, 350, 400 volts. Plot the plate potential along the X axis and the radio frequency current in the tank along the Y axis.

The potential of the grid should be varied until this curve is a straight line passing through the zero point. For a 45 tube Hartley oscillator a grid condenser $.0002\mu f$ and a grid leak of 30,000 ohms is suggested as a start. Vary the condenser and the leak until the

curve is a good straight line through zero. Then the output is directly proportional to the plate potential. Or the amplitude of the output varies directly with the plate potential. An a-c voice potential of $200/\sqrt{2}$ volts will give 100% modulation.

Experiment 102. Adjustment of a Radio Frequency Oscillating Circuit for Maximum Output.

The output of a tube is a maximum when the plate or load resistance is equal to the tube resistance. This load resistance is not necessarily d-c resistance in the plate circuit. In Experiment 18 we have shown that a parallel resonant circuit is a high impedance in phase with the applied E.M.F. Thus this impedance is a pure resistance since it is in phase with the E.M.F.

In Figure 114A we have first an oscillator with a tuned plate circuit and in B a radio frequency amplifier with a tuned plate circuit output. In Figure 114A the tuned plate circuit consists of a coil whose inductance is $L_1 + L_2$, a condenser C , and two resistance R_L and R_C . These resistances may be supposed to be equal and their sum is the measured radio frequency resistance of the LC circuit, measured as in Experiment 86 or 89. Since the circuit is tuned we have $(L_1 + L_2)\omega = 1/C\omega$. The sum of the susceptances of the two parallel circuits is zero. The sum of the conductances is $(R_L + R_C)/((R_L + R_C)^2 + (L_1 + L_2)^2\omega^2) = R/(R^2 + L^2\omega^2)$.

The reciprocal of the conductance is the resistance which is $(L_1 + L_2)^2\omega^2/(R_1 + R_2)$. The resistance term is very small compared to the reactance. This is the resistance in the plate circuit if the potential is applied at the point c , the lower end of the coil. If the potential is applied at b then $L_1\omega = (1/C\omega - L_2) = \text{zero}$.

The conductance becomes $(R_1 + R_2)/L_1^2\omega^2$ approximately and the resistance is $L_1^2\omega^2/R$, R being the total resistance of the circuit.

It will be noted that if the coil and condenser have little resistance the resistance of the parallel circuit is large. With a good coil and condenser this is usually large compared to the resistance of the tube.

The r-c meter measures the current output. If the plate potential connection is moved turn by turn from c towards b the meter will read larger values until the maximum is obtained. Then $(L_1\omega)^2/R$ is equal to the tube resistance.

Select a tube whose resistance is rather low, a 45 tube, say. The coil should be one made of heavy wire with a sliding contact

making contact with one wire at a time. If the condenser C is calibrated the inductance can be calculated since $L\omega = 1/C\omega$. Use a wave meter to measure the frequency. This gives the total inductance, $L_1 + L_2$. Calculate the total inductance of the parallel circuit from c to a . The calculation of the inductance from b to a at best will be an approximation. $L = L_1 + L_2 + 2M$ when two coils are connected in series. In this case the value of M is uncertain. We can assume that the inductance is proportional to the square of the number of turns. Then $L_1 = L(n_1^2/n^2)$. Or we can assume the inductance is proportional to the turns. The exact law will depend on the size and shape of the coil. The check using L_1 will not be very exact but the experiment shows that a maximum output can be obtained.

Place a resistance R in series with the plate making the apparent tube resistance twice the normal value. Adjust again for maximum output. The number of turns in L_1 will be greater than that in the first case. This shows that the plate load resistance is not the d-c resistance.

Everett, Communication Engineering, page 73.

Experiment 103. Construction of a Portable Demonstration Radio Phone Transmitter.

A small illustrative radio phone transmitter can be constructed using small amplifying tubes. The exact construction and voltages used will depend upon the tubes which are used. The usual method is to use the Heising plate modulation using at least two tubes.

Instead of an antenna a square coil consisting of from four to seven turns of wire mounted on a cross made of two laths four feet long is used. All the turns can be connected as one coil and the connection may be made as a Hartley coil or as diagrammed in Figure 115. Or the turns can be divided and the connection can then be made in a tuned plate circuit as in Figure 116. The first tube is the oscillating tube and the second is the modulating tube. The microphone T , is connected to a microphone transformer, M . This transformer can be made from an old interstage audio transformer. Usually the primary coil of an audio transformer is the defective coil. If this coil can be removed and replaced by a new coil the old secondary will serve.

Replace the secondary with a coil wound of No. 30 wire. Often the old primary can not be removed but a new coil can be placed on the core. A battery of about 6 volts is inserted in the microphone circuit as in Figure 116. In Figure 115 the A battery serves as this battery. The choke coil X_1 is an iron core choke coil, 30 henry

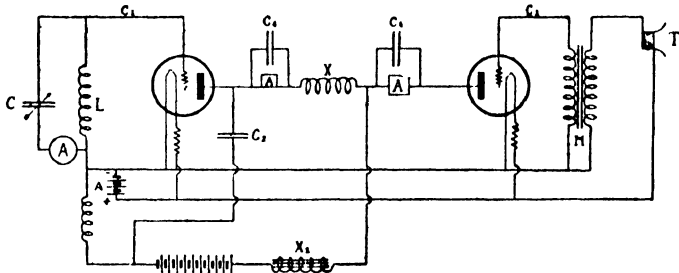


Fig. 115

inductance. An old audio transformer will serve if the tubes are small tubes. The radio frequency choke coil, X , is an air core coil of about $2000\mu\text{h}$, inductance. 260 turns of No. 30 wire on a $2\frac{1}{4}$ inch tube will serve.

It is convenient to have millimeters in the plate circuits of each tube. Voltmeters can be used as a milliammeter. The volt-

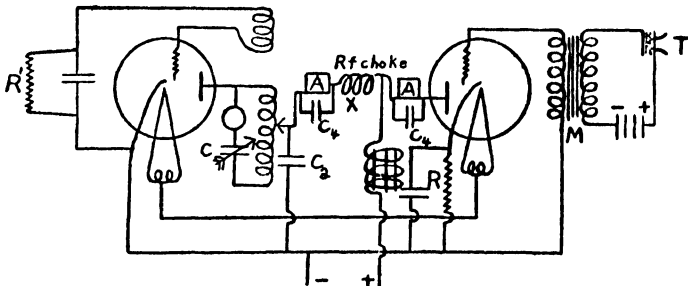


Fig. 116

meter should be by-passed with a condenser capacity $.001\mu\text{f}$. These condensers may be glass plate condensers.

If batteries are used this may be set up on a small table which can be moved from point to point.

The frequency should be in the amateur band and the set should

be operated under an amateur license. The set can be picked up with an ordinary receiver operating on the wave length of the transmitter. The receiver can be tuned to the transmitter or the transmitter can be tuned to the receiver.

The oscillating coil and tube should be adjusted so the output is proportional to plate voltage. See Experiment 101. This is done by changing the grid condenser and grid leak. Figure 116. If the tuned circuit is a tuned plate circuit as in Figure 116 the oscillator can be adjusted for maximum output, Experiment 102. If the coil is connected as a Hartley oscillator this will be harder to do. In Figure 115 it is supposed that the grid bias will be provided with *C* batteries at *C* in the figure.

The modulator tube should be adjusted as a class *A* amplifier. This is done in Figure 116 by inserting a resistance, *R*, in series with the cathode. This resistance will depend on the tube used. Consult the characteristic curve of the tubes used. The grid bias, $Pd = IR$,

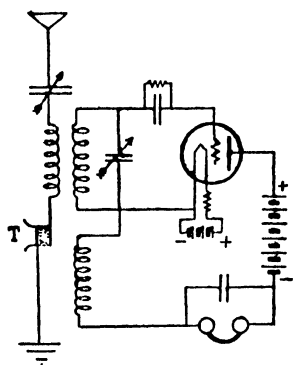


Fig. 117

where *I* is the plate current and *R* is the required resistance. With a given plate potential, *I* is the plate current at the mid point of the straight line part of the curve and *Pd*, is the required grid bias to hold the current at this value. See Class *A* amplifiers, Experiment 66. The grid swing produced by the microphone should not swing to the lower curved portion of the curve nor should it swing beyond zero and draw grid current.

The set can be made as a grid modulated set, Figure 118, or as absorption modulation as in Figure 117. Absorption modulation will work better perhaps with an antenna.

Adjust the set as outlined above and as in Experiment 105.

Fundamentals of Radio, Chapter 26.

Experiment 104. Absorption Modulation and Grid Modulation.

A simple absorption method of modulation consists of placing an ordinary telephone transmitter in the aerial of an oscillating circuit. Any receiving circuit that will oscillate will answer, Figure 117.

This method using an oscillating receiving tube can be made to work a distance of a few blocks. The diagram shows the ordinary three coil regenerative receiver with the telephone transmitter or microphone in the aerial circuit. Couple the circuit so that the tube oscillates vigorously.

Grid modulation consists of a circuit in which the voice changes the potential of the grid of an oscillating tube in unison with the voice frequency.

The diagram, Figure 118, given is that of a "Resistance" Telephone circuit in which the modulated current is connected to the oscillator by means of resistances instead of coils. The circuit is the Colpitts circuit. R_1 is a resistance coil approximately equal to the resistance of the microphone. R_2 is a grid leak resistance of 50 to 100 thousand ohms made of India ink on card board. Or of lamp black in a glass tube of about five millimeters diameter and ten to fifteen centimeters long. Brass plugs or screws are inserted into the ends for connections.

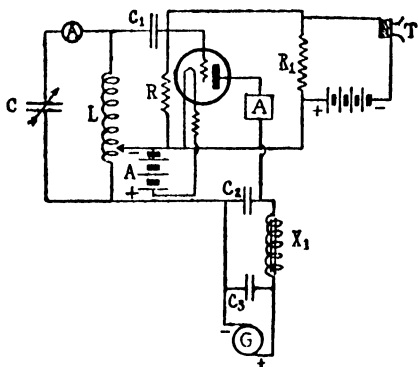


Fig. 118

Experiment 105. Adjustment of a Radio Telephone Transmitter.

Any radio phone transmitter will serve. Small power tubes will serve as well as the large tubes to illustrate the function of the various parts. If power tubes are not at hand small amplifying tubes can be used as described in Experiment No. 103, and illustrated in Figure 116. If these small tubes are used the radio current in the tank circuit may be small, 50 milliammeters can be obtained with 01A tube. D-c milliammeters can be placed in the plate circuits of the modulating and oscillating tubes. With the small tubes X_1 may be the primary or the secondary coil of an ordinary audio frequency transformer. The capacity, C , is an ordinary variable condenser. If power tubes are used a transmitting condenser should be used.

The d-c milliammeters can be voltmeters, Weston 280 or others. If placed between C_2 and the plate of the tube a by-pass condenser C_4 should be placed around the meter to by-pass the radio frequency current.

The tubes should be normal tubes of their class. In order to determine this the plate current grid voltage characteristic curve of all tubes should be taken with normal filament current and plate potential. A tube may be a freak and cause the conclusions to be erroneous. With amplifier tube 01A the plate potential should be 90 to 135 volts. The condensers may be made of glass plates. C_3 , Figure 118 should be a good condenser of large capacity, microfarads. The 2 microfarad telephone condensers can be used but there is danger of short circuiting. Place a fuse in series. For inductances and choke coils the high side of ordinary transformers may be used.

Arrange an ordinary receiving circuit and tune it to the transmitter in the same manner as when receiving a distant transmitter. Either the transmitter or receiver should be portable. If a high potential generator is used place the receiver on a portable table using a coil aerial.

Start the oscillator and tune the receiver and note the presence or absence of the generator hum. Move the portable piece far enough away so that the voice of the operator at the transmitter can not be heard except through the telephone. Place the stationary set in a closed room if possible. Note the plate potential, the grid potential, and the readings of the ammeters and the quality of the voice as heard over the phone. Change the potential of the grid of the oscillator by inserting a C battery at C_1 , and record the readings of the various instruments and the quality of the voice.

Change the potential of the grid of the modulating tube by inserting a C battery at C_1' and record the readings. The change made on one tube may change the adjustment of the other tube. Compare the readings of the plate current with the plate current grid potential curve of the tube. Note the position of the optimum readings on the curve. Use various telephone transformers at M . Try various microphones or transmitters at T . The quality of the best radio phone transmitting station is no better than the microphone T . Change C_3 and X_1 and note generator hum. Use small and large condensers for the by-pass condenser C_2 and note results.

Compare the loudness and tone of the carrier wave squeal when the receiver tube is oscillating to the intensity of the speech when the receiver is not oscillating as X_1 is changed. Remove the by-pass condensers from the milliammeters and note the results. Increase the distance between the receiver and transmitter as much as possible. The same thing may be done by rotating a coil aerial about a vertical axis. A certain position should be found such that the transmitter can not be heard. Endeavor to get the modulation such that the position where the voice dies out is near the position where the carrier wave squeal dies out.

The efficiency of the oscillating tube should be as great as possible. Adjusted as in Experiment 102, the intensity of the voice should be loud with no distortion at all audible frequencies. Place an amplifying tube in the microphone circuit so that the voice frequency is amplified before being impressed on the modulator. Use resistance coupling and then an audio transformer coupling.

Record the readings of all the meters both when speaking and when not speaking and note the values of the capacities and inductances if known. If not known record the number or marks of the various pieces. When the best adjustment is obtained measure the capacities and inductances.

Instead of batteries in the grid circuits at C_1 and C_1' grid condensers and grid resistances may be used. Negative bias can be obtained with resistors placed in the cathode connection, as in Figure 116. These will be more tedious to adjust and more uncertain in value. After the final adjustment compare the characteristic curve taken with the given plate voltage. Use a cathode ray oscillograph if available to examine the wave form and modulation.

These adjustments can be made with grid modulation using one tube. See Figure 118. R_1 is an ordinary cheap resistance box. R is a grid leak made of card board and India ink. These must be adjusted by trial. See Experiments 64 for grid leaks.

110 volt d-c may be used on the plate if that current is available. See Experiment No. 107.

Theory suggests that the plate current of the modulator tube should be equal to the plate current of the oscillating tube.

Note diagrams of modern radio telephone sets.

Fundamentals of Radio, Figures 18 and 19, Chapter 26.

Experiment 106. Constant Frequency Circuits.

Most modern radio telephone circuits are controlled by a quartz crystal so that the frequency is constant. The circuits are radio frequency amplifiers much like Figure 114b. Early constant frequency circuits were controlled by a small tube connected to an oscillating circuit with several stages of amplifier before the last or power stage.

At the present time all transmitters are controlled by crystals so that the frequency is almost constant, especially if the crystal is held at constant temperature. The quartz plate or crystal is made to oscillate either at its fundamental frequency or at an overtone of the fundamental. For details on cutting the quartz and mountings see *Inst. Radio Engineers*, p. 448, August, 1926; *QST*, p. 15, July, 1926 and p. 26, Sept. 1926.

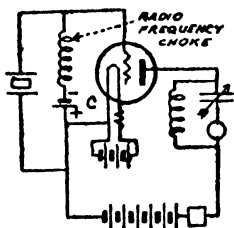


Fig. 119

The crystal can be connected to a tube as in Figure 119.

As the tuning condenser in the plate circuit is varied the meters will indicate oscillation when the circuit is in unison with the fundamental and perhaps with various overtones of the crystal. An oscillating wave meter or receiver will indicate that the frequency of oscillation is constant and is independent of any slight variation of the tuned circuit. If the circuit is detuned too much the tube ceases to oscillate.

If the oscillating set is "beat" with the carrier wave of a good broadcast station as in Experiment 36 the beat note will remain constant as the dial of the set is changed. The intensity of the note will diminish due to detuning but the frequency will remain the same.

Experiment 107. Use of 110 Volt d-c Lighting Circuits for Filament and Plate Supply.

The 110 volt lighting circuit can be used as filament and plate supply where such tubes as 01A and 30 is used. The tube should operate well on 100 volts plate potential and preferably should not take much filament current. Incandescent lamps can be used as resistors in the main circuit. The connections are made as in

Figure 157 which shows a small tube oscillator which is very convenient for demonstration and laboratory purposes. A 25 or 30 watt lamp is used to limit the filament current for a 01A tube. The circuit is connected Hartley shunt.

A grid condenser and grid leak is used in the grid circuit and a .001 μ f by-pass condenser is used. If a small switch is placed in series with the grid leak the circuit will be modulated when the switch is opened. The tube ceases to oscillate and starts several times per second. Such a modulated circuit is convenient at times.

Such an oscillator can be calibrated and used as a wave meter for rough laboratory work. If more power is wanted a tube like the 48 can be used as a triode.

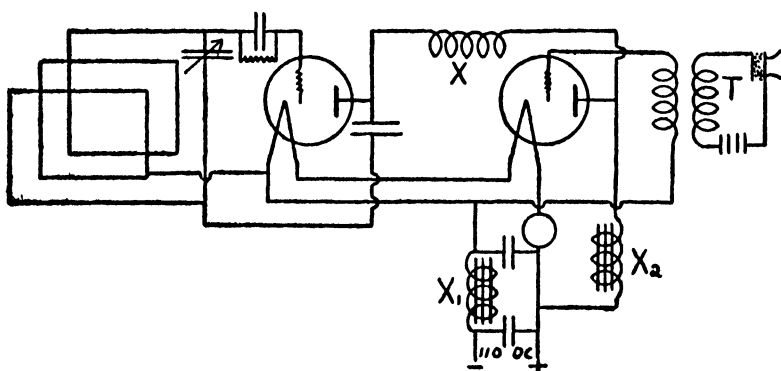


Fig. 120

Figure 120 shows a Heising plate modulated phone circuit with 110 volt supply. The two filaments are in series. The grid bias of the oscillator is supplied by the grid condenser and grid leak. The bias of the modulator is the drop through the oscillator tube. If this is not great enough a resistance can be placed in the negative lead from the oscillator tube.

In adjusting the filament circuit an ammeter should be used and the tubes should be removed and connection made so the current will flow without the filament. Adjust the resistance or lamps until the rated filament current is obtained and then place the tube in the socket.

Experiment 108. To Measure the Input and the Output and the Efficiency of a Tube Generator or of a Transmitting Station.

In a tube oscillator circuit the energy used in the filament or heater is neglected. The input is the product of plate potential and plate current. The output is that of the tank coil or aerial circuit and is measured as I^2R . Where the current is the r-c current and the resistance is the radio resistance of the tank or aerial circuit.

Set up a tube generator using the Hartley circuit, or any other circuit. Place an ammeter in the filament circuit, a milliammeter in the plate circuit, and a radio ammeter in the radio circuit. Be sure the plate current does not flow through the radio ammeter. Measure the voltage of the B battery or generator.

Adjust the connections until the radio ammeter reads a maximum. Measure the resistance of the radio circuit, Experiment 86.

From the various readings calculate the plate input, $V_p I_p$, the output, I^2R , and the efficiency.

The measurements may be taken with a regular transmitting station. Measure the efficiency of a regular tube oscillator. Couple a wave meter circuit for maximum current and measure the power in the wave meter. Calculate the efficiency of the transfer from oscillator to wave meter.

Measure the output, input, and efficiency in both cases.

Fundamentals of Radio, page 160.

Experiment 109. Measurement of the Per Cent of Modulation.

The per cent of modulation is defined as the ratio of the change of amplitudes of the wave due to modulation to the amplitude of the wave when not modulated, expressed in per cent.

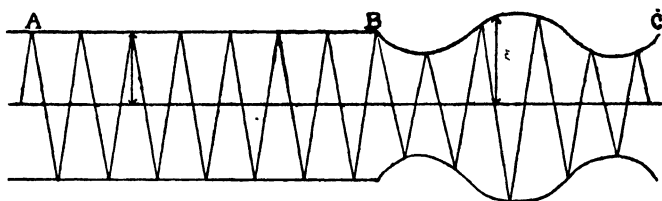


Fig. 121

Figure 121 represents from A , to B , the carrier wave, the amplitude of which is c . From B to C the diagram represents a wave

modulated with a sine wave potential. The maximum amplitude of the modulated wave is m . The per cent of modulation is $100(m-c)/c$.

If $m=2c$ then there is 100% or complete modulation.

The modulation can be determined by measuring the amplitude of the carrier wave and again measuring the maximum amplitude when the wave is modulated. A peak voltmeter can be used, Experiment 132.

The transmitting station can be received on a single tube or a radio frequency amplifier of two or three tubes. When the transmitter is quiet, not running, the grid potential of the detector tube may be brought to the required potential to make the plate current zero. Care must be taken to see that the potential is not more negative than this point. The point of zero plate current on the mutual, grid characteristic, Experiment 43 is to be found. A convenient potentiometer is shown in Figure 67. The C battery potential is read on the volt meter. When the carrier wave with no modulation is picked up the C battery is adjusted again for no plate current. This C battery potential minus the first potential gives the amplitude corresponding to c . The transmitter is now modulated, preferably by a constant harmonic E.M.F. and the C battery again adjusted for zero current. This reading minus the first gives m . For good results the transmitter must be modulated with a constant a-c potential.

The per cent modulation of a broadcasting station can be measured. In this case the modulation is not constant and readings will give maximum modulation.

Measure the modulation of a small local transmitter. Measure several commercial C.W. stations and broadcasting stations.

Jolliffe, Jour. O. S. A., Dec. 1924; Proc. Rad. Eng., 17, p. 666, 1929.

Experiment 110. Measurement of Side Bands.

Theory shows that if we have amplitude modulation we can explain the effect by two other frequencies called side bands. "Fundamentals of Radio," p. 315. If one modulates a long wave oscillator with a frequency of 2000 cycles or more the side bands can be found with a wave meter.

Construct an oscillator for 60 kilocycles. The coil should have little resistance so as to give a sharp resonance curve. Modulate

this oscillator with a modulating tube using Heising plate modulation at a frequency of 2000 cycles or more. When modulated with 1000 cycles the modulation seems to be masked in the "skirts" of the resonance curve. Use a wave meter as when getting

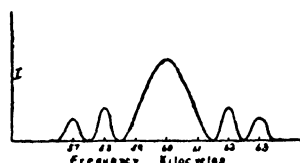


Fig. 122

the resonance curve and two peaks, one on either side of the carrier will be found at 58 kilocycles and at 62 kilocycles. Figure 122. If the modulation frequency is 3000 cycles the side bands will be at 57 and 63 kilocycles.

Compare the amplitude of the carrier and side bands. Measure the per cent of modulation and compare with theory. For 100% modulation theory says the amplitude of the carrier is one half of the carrier.

In the apparatus the tank is tuned for the carrier and much detuned for the side-band frequencies. A good broadcasting station is supposed to be band tuned, or the resonance curve is flat, not sharp.

Use frequency modulation and search for side bands.

A tuned link circuit as used in Experiment 84 will help to bring out the side bands if they are masked.

Experiment 111. Method of Estimating the a-c Current in the Plate Circuit of a Power Tube.

Assume the curve in Figure 123 is the characteristic curve of the tube. Assume the grid potential is V_g , three volts negative, say, and that the plate current is I_p , two milliamperes, perhaps. Assume the a-c potential, Max. Pot., is e_1 . Then the alternating

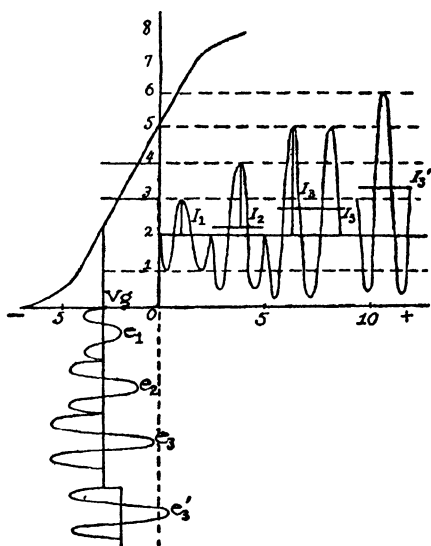


Fig. 123

current in the plate circuit is represented by the sine curve, the amplitude of which is I_1 . This will be a sine curve and the average value of the current is still I_1 , and the d-c ammeter reading is still two milliamperes.

Let the grid potential be doubled to e_2 . The a-c current is represented by I_2 , which is nearly a sine curve, the bottom tips being slightly deformed by the fact that the foot of the characteristic curve is bent. The average current is almost the same as before. The d-c meter will indicate a little more than two milliamperes.

Suppose the grid a-c potential is made e_3 , which is three times e_1 . Then the a-c current is represented by I_3 . The upper part of the deformed sine curve extends from 2 mil-amperes to 5 mil-amperes and the lower extends down from 2 to near zero. The average value of this curve which extends from zero up to 5 will be near $2\frac{1}{2}$ milliamperes. The upper amplitude of this curve is 3 milliamperes. The lower half should be 3 milliamperes. Then if the steady d-c current is increased to 3 milliamperes by decreasing the negative potential of the *C* battery to 2 volts, the change of the d-c meter will be slight when the E.M.F., e_3 , is applied to the grid.

The amplitude of the sine curve is 3 milliamperes and the virtual a-c current is $3/\sqrt{2}$. If the steady current is increased to $3\frac{1}{2}$ milliamperes the d-c ammeter will not change but the excursions in either direction is three. If the *C* battery is made zero the plate current will be five and the ammeter will not change due to the fact that there is an a-c current of $3/\sqrt{2}$ milliamperes in the plate circuit, unless the characteristic curve bends near 7 or 8 milliamperes.

To determine the a-c current the milliammeter is read. Then the a-c potential, e , is applied at intervals, and the reading of the d-c meter noted. By means of a *C* battery potentiometer the plate current is decreased until there is a change of reading when the potential, e , is applied. The reading of the d-c instrument at the point where this change is just large enough to be detected may be taken as the amplitude of the a-c current. The a-c current is the d-c meter reading divided by the radical 2.

The power is proportional to the square of this value, or $I^2/2$.

To measure power arrange a convenient *C* battery potentiometer. Arrange to apply a known small a-c potential.

Measure power with change of e and with change of *B* battery.

Practical Application.—In amplifiers we wish power but do not wish to waste *B* battery. A *C* battery may be used to reduce the plate current. This should not be reduced beyond the point where a d-c milliammeter reading is not constant when the amplifier is in use.

Any fluctuation of the milliammeter indicates that the a-c curve is being deformed. This of course means that we have distortion and poor reproduction of musical tones.

To estimate the a-c current in a plate circuit from the action of a d-c milliammeter.—Suppose the steady reading of the milliammeter is 2 milliamperes. Suppose that at times when loud tones come in the milliammeter increases to 4 milliamperes.

The average value of this deformed curve is 4. The upper excursion is at least up to 8 milliamperes. This is six above the steady value. Therefore the steady value should be near 6 milliamperes so that the excursions can extend up from 6 to 12 and down from 6 to zero.

The characteristic curve of this tube should be a straight line up to 12 or there will be distortion due to the bend. If the load causes the current to move to the point where the curve is not straight the tube is overloaded and a larger tube should be used.

If there is distortion due to the upper bend the milliammeter will fluctuate to lower values than the steady value of the current when loud signals are being amplified. This will be true unless the steady value happens to be in the middle point of the curve. Then we have distortion on both halves of the sine curve.

Grid Current Distortion.—In a transformer coupled amplifier the resistance of the secondary coil of the transformer is very high. The d-c grid current may be made almost zero if the potential of the grid is negative. The grid current is zero and the only current is the small capacity current, $CE\omega$, where the capacity, *C*, is the tube capacity. If the potential extends much past the zero then we have grid current and then an *IR* drop in potential.

Since this current is zero during part of the cycle and is not proportional to the E.M.F. of the a-c current, there will be distortion due to this erratic *IR* drop. In our curve, Figure 123, there will be a slight grid current when the plate current reaches 6 milliamperes.

If the a-c current is much more than $3/\sqrt{2}$ it will be well to increase the B battery and thus move the characteristic curve to the left and use correspondingly more negative C battery.

Experiment 112. Measurement of Power in Power Amplifiers.

Connect a power tube to a resistance load as in Figure 124. A loud speaker can be in series with R and still be an approximate resistance load.

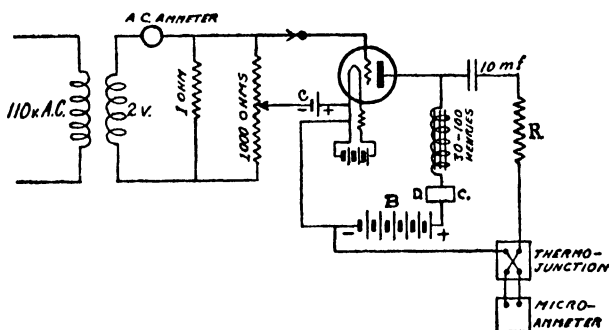


Fig. 124 Measurement of Power in Power Circuit.

Connect the grid terminals to a 60 cycle a-c so that the potential can be varied from .01 volt or less to one or two volts.

The d-c plate current will flow through the choke coil and the d-c milliammeter will give the d-c current. If the choke is large enough a hot wire meter in series with the d-c meter will read the same as the d-c meter. A condenser and hot wire meter is placed in series with the load which may be a resistance or loud speaker. (We have assumed a resistance load. R should equal the resistance of the tube for maximum output.) The output will be I^2R . The square of the hot wire meter readings will be proportional to the power. A "current squared" meter reading will be proportional to the output. This should be proportional to e .

Connect up and check the d-c ammeter to see that the a-c current is all going through the condenser.

Increase e and V_p , the plate potential, until readable results are obtained.

Increase e and read the power, keeping V_p constant.

Repeat, using larger and larger B battery.

Note the d-c ammeter at the same time. If the d-c ammeter is not constant there is distortion.

Change the *C* battery until there is no distortion. The d-c ammeter should read as low as possible but not low enough to create distortion.

Compare the results with the plate current grid potential curve.

The *C* battery should be adjusted so that the grid current is zero.

Distortion is due to two things—to rectification and to the *IR* drop of grid current.

Plot I^2 against e , V_p being constant.

Plot I^2 against V_p , e being constant.

If a sensitive thermo junction is not available a current transformer can be used as in Figure 125. An improvised transformer

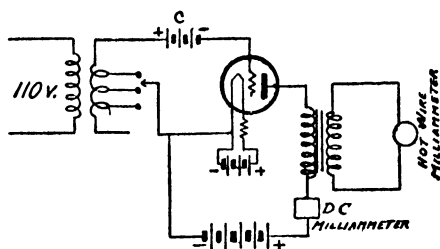


Fig. 125

can be made from a burned out audio transformer. Usually the primary coil opens and the secondary is still good. Remove the primary coil and wind a second of No. 30 wire.

The ratio of the transformer can be measured

by measuring the current through the "secondary" with a delicate junction and at the same time the current in primary with a milliammeter. Or by Experiment 73 the load in the secondary should be such as to make the "reflected" load in the primary equal to R_p .

Experiment 113. To Calibrate a Wave Meter by Means of Lecher Wires.

Some years ago it was shown by Lecher and others that it was possible to produce stationary electric waves on wires and that the velocity of these waves was very approximately the same as electro-magnetic waves in free space. In the early days the oscillatory discharge of a condenser through an inductance was used to produce the waves. During the last few years the three electrode tube has been used to produce the disturbance.

The oscillator, Figure 126, consists of a single turn of No. 12 copper wire four inches in diameter connected to the grid and plate terminal of an ordinary porcelain vacuum tube socket. The middle of this loop or turn of wire is cut and a .002 mica fixed condenser inserted. Across the grid and plate terminals a special variable condenser is fastened. This condenser is made from a Cardwell condenser by removing the stator plates and substituting two plates of sheet copper. Terminals are soldered to these sheets making two variable condensers in series, the rotor being the middle of the two. The rotor is connected to the negative filament, making a Colpitts circuit. The plate current is fed to the plate through a choke coil made of 150 turns of fine wire wound in one layer on a glass tube one-fourth inch in diameter. A grid leak resistance is connected from the grid to the filament. Such an oscillator will oscillate at frequencies corresponding 3.5 meters to 5.5 meters. By reducing the capacity and the diameter of the loop the wave length can be reduced to less than 1.5 meters. A small power

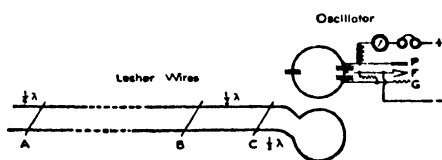


Fig. 126. Diagram of Lecher wires, and oscillator.

tube such as the 10 or 45 tube may be used, or an ordinary 01A amplifying tube can be used with about 100 volts *B* battery.

The Lecher wires consist of two parallel wires fifty to one hundred feet long, strung on insulators in a hall or between two posts or trees in the open. These wires should be from ten to twenty centimeters apart and about seven feet high. At one end the wires should extend about three feet beyond the insulators. These two ends are fastened together to form a loop which can be placed near the oscillator. When using a 01A tube in the oscillator a milliammeter or voltmeter used as a milliammeter is inserted in the plate circuit to indicate when the wires are in resonance with the oscillator. A head set may be substituted, using the resonance click method. When the wires and oscillator are in resonance there will be a sudden kick of the meter as the frequency of the oscillator is changed by rotating the variable condenser. If the wires are long there will be five or six such points of resonance on the dial. If the loop of the wires is too close the wires may absorb so much energy

that the oscillator ceases to oscillate. Loosen the coupling so that the kick occurs at the same point on the dial when the capacity is decreasing as when the capacity is increasing.

Set the oscillator in resonance with the Lecher wires using the longest wave possible. Have an assistant connect the two Lecher wires with a short sliding wire at the far end. This will throw the Lecher wires out of resonance. Manipulate the slider until a point of resonance, A , is found. This point will be approximately one-fourth wave from the end. Then place the slider across the Lecher wires near the oscillator and find the point, C , which is one-half wave from the loop end. Then find the point, B , which is one-half wave from C . The distance $A - C$ is a whole number of half waves. $(A - C)/(B - C)$ should be near a whole number, n , say. Then $(A - C)/n$ gives a better value for the length of a half wave. It will be seen that the entire length of the wires will be $n + \frac{3}{2}$ half waves. Then $(n + \frac{3}{2})\frac{1}{2}\lambda = a$ constant, L , which is the length of the Lecher wires.

Find the next point of resonance and find A , B , C and L . Proceeding as above for all points of resonance, the various values of L give a check on the accuracy of the method.

Since the frequency of the oscillator is found to vary with the filament current it is better to calibrate the wave meter while taking these readings.

Wave Meter

A very simple and efficient wave meter for short waves can be made by bending a piece of No. 12 bare copper wire into a circle about four inches in diameter and fastening to a wooden board. The ends of this circular wire should be about one inch apart. By means of a short screw at the center of the circle fasten a wire so as to slide over the circular wire. Between the screw and one end of the circular wire insert a small fixed glass plate condenser. The capacity of this condenser should be about .00003 microfarads. Using photographic plate glass, the area of the two plates of sheet metal is about one square inch. The exact area must be found by trial. A dial or scale should be provided to measure the angular position of the slider.

Wave Meter



Fig. 127

The meter can be calibrated by setting the oscillator to a definite wave as measured on the Lecher wires and then removing the coupling loop and placing the wavemeter in its place and by sliding the radial wire until resonance is indicated by the voltmeter in the plate circuit. With the Lecher wires of reasonable length, some five or six points can be thus obtained. When the angle or position of the radial wire is plotted against wave length it is found that a line is obtained which is nearly straight.

To compare a long wave meter with a short wave meter

A tube oscillator which is made to oscillate vigorously, and thus be rich in overtones is brought near the short wave oscillator. Numerous overtones will be heard in a telephone which is in the long wave oscillator. Set the two oscillators to exact resonance when the short wave meter is set for its longest wave. Then $W = nw$, where W , is the long wave as read by the long wave meter, w , is the short wave as read by the short wave meter, and n , is a whole number to be determined. Change the short wave oscillator to a shorter wave very slowly and count the overtones passed. Then $W = (n + m)w_2$ where w_2 , is the second wave read with the short wave meter.

From the above, $W = mw_1w_2/(w_1 - w_2)$ and $n = mw_2/(w_1 - w_2)$. n must be a whole number and the value obtained should be very close to a whole number.

Use n as the nearest whole number and check the value of W .

Application to Transmission Lines.—Transmission lines are Lecher wires which are terminated with the proper characteristic impedances. See Experiment 76. The purpose of transmission lines is to carry energy from the transmitter to the aerial. If all the energy is delivered to the aerial there can be no reflection and without reflections there can be no standing waves. This can be done and at the same time the line can be made into the proper impedance transformer to match the transmitter to the aerial. See Everett, *Communication Engineering*, 2nd Ed., p. 273.

This can be explained by using the theory of Experiment 102.

In Figure 114 the impedance of the load is made equal to the tube resistance by moving the tap on the inductance. The resistance of the load being L^2w^2/R , where L is the inductance included between the two points of connection or between the taps.

In Figure 128 we have an incoming line feeding energy to a terminating line, Lecher wires in this case. Assuming the wires have been tuned. The length from the sliding contact to the ends will be an odd number of quarter wave, three quarters in the figure. The length, x , of the closed line if to itself will have an impedance which is inductive. The length $(1-x)$ will have an impedance which is capacitive.

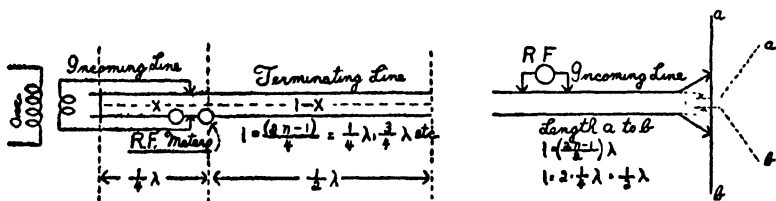


Fig. 128

The length, x , will correspond to the coil in Figure 114 while the length $(1-x)$ will correspond to the condenser. If the incoming line is connected to a point $\frac{1}{4}\lambda$ from the closed end we have a point of maximum potential across the lines and the impedance offered to the incoming line will be a maximum. As the taps are moved toward the shorting bar the impedance will become smaller, the same as that in Figure 114, when the tap is changed from ac to ab . As the points are moved the value of L_1 diminishes and there is some place where $L_1^2 \omega^2 / R$ is equal to the characteristic impedance of the incoming line. When this is true all the energy is delivered to the load and there is no reflection and consequently there will be no standing waves on the incoming line.

If our Lecher wires are made $\frac{1}{4}\lambda$ long the length of wire is $\frac{1}{2}\lambda$. When straightened out we have a rod $\frac{1}{2}$ wave long. At the right of Figure 128 we have a feeder wire feeding energy into this $\frac{1}{4}$ wave Lecher wires or to this $\frac{1}{2}$ wave rod. If the position of the taps is moved to the proper point the impedance of the rod is made equal to the characteristic impedance of the feeding wires and there will be no stationary waves on our feeders, or Lecher wires. If there are no standing waves a r-f meter swung from the wire will show the same reading at all points. There are no nodes and antinodes. If the coupling of the line to the oscillator is

changed by changing the mutual inductance of the transformer, or other coupling device, until we have maximum transfer of energy then we have the impedances matched at the oscillator and the aerial.

The half wave aerial can be adjusted to the exact length by having the rod made into two adjustable halves with a r-f meter at the middle point and by adjusting the length until the meter shows a maximum or by having an adjustable rod made of solid rod which fits snugly into a thin brass pipe and a second double slide halves with a r-f milliammeter or flash lamp placed at the middle. See Experiment 114. This second rod is set at some distance from the aerial and parallel to it. The current in this second aerial is proportional to the current in the main aerial. The length of the aerial is adjusted until the current in the exploring aerial is a maximum.

The length of the exploring aerial can be changed until it is a half wave when the current will be a maximum. By making adjustments in one and then in the other in turn in a short time both will be one half wave long. The taps of the feeder wires are then changed until there are no standing waves in the feeder wires. As this is done the reading of the exploring aerial will increase to a maximum. All the energy from the feeders is absorbed by the aerial and none reflected. The exploring aerial will again increase as the coupling at the oscillator is adjusted.

When all adjustments are made we have the energy of the oscillator all transferred to the aerial with little or no attenuation.

This adjustment is for a particular frequency. If one wishes to transmit on another frequency this or a second aerial must be adjusted for that frequency.

A radio frequency meter can be connected to terminal wires a foot or two long and hung on one wire and slid along the wire. The reading of the meter should be independent of position if there are no standing waves.

The meter can be connected to a coil of one or two turns and swung between the wires.

Proc. I.R.E., April, 1935; QST, April, 1937, page 21; Fleming, p. 265; J.O.S.A., Vol. 11, p. 641, Dec., 1925; QST, p. 19, April, 1925; Phil. Mag., Vol. 42, p. 265, Aug., 1921.

Experiment 114. Standing Waves in Space.

If waves, on water or on a rope are reflected so that there are two sets of waves moving in opposite directions there will be stationary waves set up. Nodes being the place where there is no disturbance and antinodes being at the place of greatest disturbance.

If an electric wave is reflected from a reflector there will be nodes and antinodes formed in space. These antinodes can be detected by a convenient detecting device, lamp or milliammeter if the power is sufficient. In a rope which has one end tied the frequency or length of the rope must be changed until the length of the rope is an odd number of quarter wave lengths. In the same manner the distance from transmitter and reflector must be adjusted.

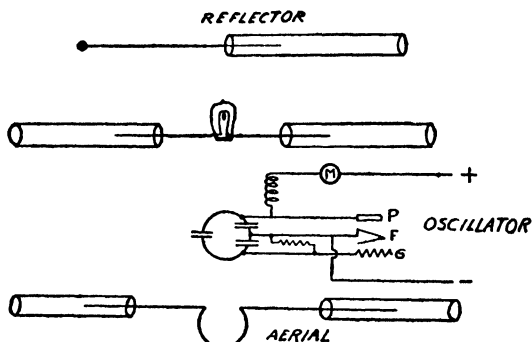


Fig. 129

The oscillator can be a short wave tube oscillator as described in Experiment 113 on Lecher wires. This is coupled to a vertical aerial with counterpoise, or if there is not a vertical aerial and counterpoise can be placed

horizontal. Figure 129. This can be made of two brass rods slipped into equal lengths of close fitting brass tubing. The length of these rods and tubes will depend upon the wave length. If the pieces are from one half to three fourths of a meter long the aerial can be adjusted to be in the neighborhood of two meters from end to end. These are placed end to end and joined together at the middle with a loop of wire about four inches in diameter. Make the two ends of equal length and couple the loop loosely with the oscillator. With a milliammeter in the plate circuit the adjustment for resonance can be made.

Adjust to resonance and couple to the oscillator until a large amount of energy is absorbed by the aerial system.

The reflector can be a second rod and tube whose total length

is about the same as the first or a little longer. This can be adjusted by bringing it a foot or so from the first and changing length until the plate meter shows resonance. Place this parallel to the oscillator aerial at a distance of 8 or 10 meters measured on a line perpendicular to the aerial. The exact distance depends upon the wave length.

A third aerial system constructed much like the first can be connected with a small lamp or other indicating device at the middle point. The positions of the reflector and the detector are moved until the detector shows a maximum current. This will be a fourth wave from the reflector when best results are obtained.

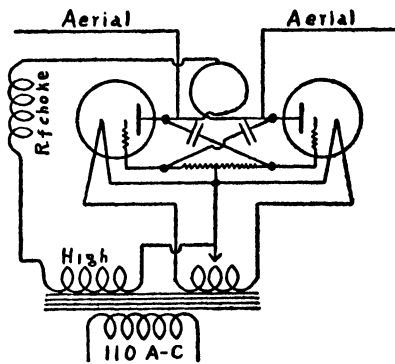


Fig. 130

from the reflector when best results are obtained.

When properly adjusted the antinodes will be found a half wave apart.

The field in the direction of the reflector can be increased by placing a quarter wave rod $\frac{1}{4}$ wave behind the oscillator. If two such rods are placed $\frac{1}{2}$ wave on either side the intensity will be increased. If a number of rods are placed along

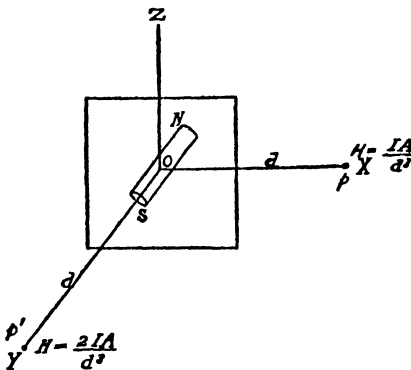


Fig. 131

a parabola drawn through the position of three rods, the oscillator being at the focus, we have a parabolic reflector which reflects most of the energy along the axis of the parabola.

Experiment 115. To Measure the Induction Close to a Coil.

The field due to a current in a coil can be calculated from the curl Idl/r . See Fundamentals of Radio, pages 14 and 204.

In the case of induction the field can also be calculated as if the coil had a magnetic moment IA . The field can be measured when the current is d-c current with a magnetometer, the same as if the coil were a short magnet.

If the current is a-c current the induction field is the virtual field and is numerically the same as that from a d-c current.

If the plane of the coil is in the YZ plane the axis of the coil is along the X axis. The field at the point P distance x from the axis is

$$H_x = d/dy(Il/r) - d/dz(Ih/r)$$

$$\text{or } H_x = d/dy(Il/\sqrt{x^2 + y^2}) - d/dz(Ih/\sqrt{x^2 + z^2}).$$

Applying this to the coil where we have $+Ih$, $-Ih$, $+Il$, $-Il$, corresponding to $z = +\frac{1}{2}l$, $z = -\frac{1}{2}l$, $y = -\frac{1}{2}h$, and $y = +\frac{1}{2}h$ we get $H_x = 2IA/x^3$. The same as a magnet end on, $H = 2M/x^3$.

Applying the curl equation to the case of the point in the plane of the coil we get $H = IA/r^3$.

The field close to an oscillator is mostly all induction and at a distance $\lambda/2\pi$, the induction and radiation are numerically equal and since they are in quadrature the measured result will be 1.41 times the value of either. Since from a coil the radiation varies inversely as the first power of the distance and the induction varies inversely as the cube of the distance, at distances of $\lambda/20$ or less all the field is practically due to induction.

Since the induction field of a coil is the same as that from a short magnet or magnetic shell, Figure 131, the intensity of the field in the plane of the coil is $H = IA/d^3$ and perpendicular to this direction the intensity is $H = 2IA/d^3$; where I is the current in the oscillator and A is the area of the coil, i.e., $A = n$ times the areas of one turn when there are n turns.

The E.M.F. induced in a coil at any position is ωHa , where $\omega = 2\pi n$, n being the frequency, H the field perpendicular to the plane of the coil, and a is the area of the pick up coil.

Then E.M.F. $e = 2\pi n I A a / d^3$ at a distance d from the oscillator and in the plane of the oscillator. The current $i = e/R$ where R is the radio resistance of the receiving coil. Current and resistance must be expressed in absolute units and all lengths in centimeters.

The oscillator can consist of a coil of 5 to 7 turns wound on a frame 4 feet in diameter. Connect to a power tube using the

Hartley circuit, Figure 132. The wave length will be 300 to 500 meters.

The receiver will consist of a similar coil with a variable condenser and a radio milliammeter in series.

If the resistance of the receiver is kept low, readable current can be obtained when the distance is 2 to 7 meters or more. Take readings at various distances in the plane of the oscillating coil and perpendicular to the plane of the coil. It will be found that maximum readings are obtained when the two coils are parallel.

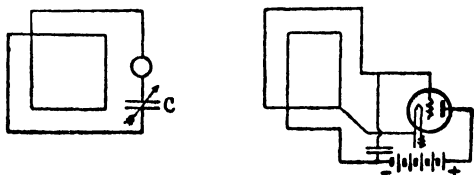


Fig. 132

Measure the resistance of the receiving coil, using the resistance variation method and a radio frequency resistance box.

Compute the value of received current and compare with the experimental results.

Starling, p. 3 and p. 225; Dellinger, Bureau of Standard Scientific Papers, No. 354, p. 452; *Fundamentals of Radio*, pages 14 and 203.

Experiment 116. To Measure the Radiation from a Coil.

The field due to alternating current consists of two parts, induction and radiation. For 60 cycle a-c it is necessary to make the distance hundreds of miles before the radiation field is comparable to the induction. Close to the circuit the induction is so enormous compared to the radiation that radiation is never noticed.

Since the intensity of induction and radiation are numerically equal at a distance of $\lambda/2\pi$, the field from radio antennas is usually all radiation at the position of the receiver.

The theory of radiation is too long to give here but it can be shown that from an aerial the induction varies inversely as the square of the distance while radiation varies inversely as the distance. From a coil the induction varies inversely as the cube of the distance and the radiation varies inversely as the distance.

From a coil aerial the radiation is, $H = 4\pi^2 I N A / (10\lambda^2 d)$. A short wave generator will be advantageous since the distance, d , can be small and since the value of H varies inversely as the square of

wave length, and also because the received current is proportional to n , the frequency. The oscillator can be a one turn coil connected to a high potential condenser using a Colpitts circuit and a power tube. With such a circuit and a coil whose diameter is 2 or 3 feet, a wave length of less than 20 meters can be obtained. The receiver is a single turn of wire with a small variable condenser and sensitive low resistance thermo junction for ammeter.

Figure 133 gives the diagram of connections for oscillator and receiver.

Since the E.M.F. induced in a coil by a field, H , is $E = H a \omega$ where a , is the coil area and $\omega = 2\pi n$, And since the current $i = E/R$, Dellinger's formula for i can be derived. This formula is,

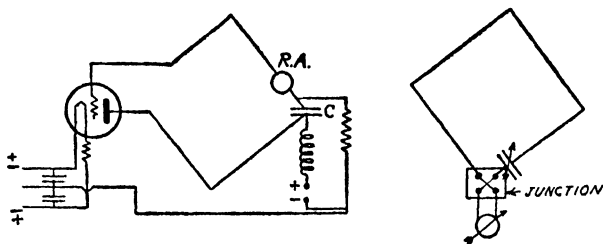


Fig. 133

$i = 7450 h_s l_s h_r l_r N_s N_r / (R \lambda^3 d)$ where h , l , and N are height, length and number of turns respectively and the subscripts, s , and r , refer to sending and receiving coils.

The E.M.F. e , induced in a vertical wire by a magnetic field moving with a velocity, v , is $e = h H v$ where h is the height of the wire. If the same wire is in an electrostatic field, E , the E.M.F. is $e = E h$.

In electromagnetic waves we have two components, the electric, E , and the magnetic, H , which are at right angles to each other.

From the above we get that $e = h H v = E h$ or $E = H v$, where $v = 3 \times 10^{10}$. In the electromagnetic system of units we find that this is also the relation between E and H . The energy is both electrostatic and electromagnetic and are equal and are always associated together. So that E and H are really two aspects of the same thing and if we know H , we know E . Radiation is usually given in terms of E .

$E = 3 \times 10^{10} H$ absolute units per centimeter. If we divide by 10^8 we have volts per centimeter. If we multiply by 100 we have volts per meter. If we multiply by 10^6 we have microvolts per meter. Or $E = 3 \times 10^{10} H$ microvolts per meter. Thus field strength expressed in absolute units is numerically, the same as when expressed in microvolts per meter. Radiation fields are usually expressed in microvolts per meter, written $\mu V/m$.

In order to neglect the induction measurements must be made at a distance greater than one half a wave length.

Measure the radiation at distances greater than $\lambda/2$ and check with theory. The resistance of the receiver must be measured with a resistance box which is accurate at high frequency. In a direction perpendicular to the coil the radiation is zero. Verify experimentally.

Note the effect of trees and buildings. It is interesting to set the oscillator so a tree is in the plane of the coil. Measure the intensity at various points about the tree. Plot a curve showing the intensity about the tree.

Dellinger, Bureau of Standards Scientific Papers 394, p. 463; Moullin, p. 217; *Proc. I.R.E.*, Vol. 21, page 1586, 1933.

Experiment 117. To Measure the Radiation from a Distant Sending Station.

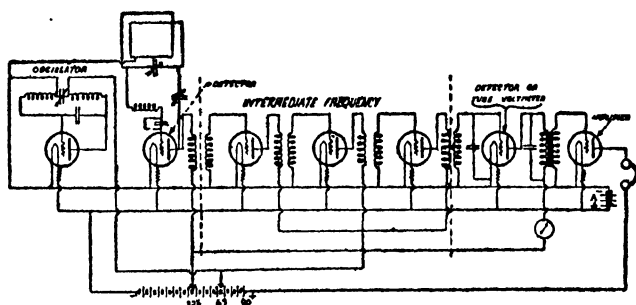


Fig. 134

In measuring the radiation of a distant station a receiver is used which is very much like a superheterodyne receiver. The diagram Figure 134 shows the connections. For exact work the set

should be screened so as to eliminate inter tube action. See references. A tube voltmeter is used to measure the potential on the intermediate frequency detector. This is not very hard to do but to calibrate the voltmeter in terms of microvolts per meter is a more difficult matter. Since the calibration depends upon all the tubes, coils, etc. remaining exactly constant it is impossible to calibrate it once for all.

The usual method is to apply a variable but known small potential to the receiving coil until the tube voltmeter reading has the same value as it did when receiving the station. This is seen to be a substitution method. From this potential which is the same as that across the receiving condenser the value of E or H is calculated.

This potential must be a radio frequency potential with the same frequency as the receiving station. This requires an attenuator or potentiometer made of radio frequency resistances, which is difficult to construct.

A more simple method is to create an equal field at the same frequency and thus duplicate the readings. The field can be produced by a coil connected to a tube in an oscillating circuit.

From the current in the coil, dimensions of the coil, and the distance, d , from the receiver the field can be calculated. However there are many disturbing factors which render this method very uncertain. Reflections from objects such as walls and furniture make this method give nothing but a general idea of the magnitude.

With a small coil coupled to a screened oscillator the distance need not be so great and reflections do not play so great a part.

An attempt to make the measurements will be instructive if the only result is the discovery of the difficulties. Calculations should be made before hand to get an approximate size of coil to produce a given field when the current is a readable amount. The field intensity for good reception of broadcast programs, free from all interference such as violent static and tube noises must be about $10,000 \mu V/m$. Fair reception is often had when the field intensity is very much less than this.

From the average broadcast station the field is less than $1000 \mu V/m$ at 100 miles. The average night intensity, 800 miles from a

5000 watt station during the winter months has been found to be $5. \mu V/m$ varying from $16 \mu V/m$ to $0.1 \mu V/m$.

Proc. I.R.E., Vol. 14, p. 333, June, 1926; Proc. I.R.E., Vol. 14, p. 508, Aug., 1926; Proc. I.R.E., Vol. 15, p. 768, Sept., 1927; Fundamentals of Radio, Chapter 19.

Experiment 118. To Reactivate a Tube.

If a modern thoriated filament tube has had too much plate potential on the plate or the filament has been too hot while in use or if old age has overtaken the tube it can usually be rejuvenated.

The tube without plate or grid potential, grid and plate open or free, is first "flashed" for a short time and then "aged" for a longer time.

The following general instructions will apply to all such tubes. The tube is flashed for thirty seconds to one minute with a potential on the filament three times the rated filament potential. For a 01A tube this is three times five volts.

Then the tube is aged for two to ten minutes by having the filament connected to a potential 50% higher than the rated potential. For a 01A tube this is $7\frac{1}{2}$ volts.

A storage battery can be used or any other convenient potential. A toy transformer such as are used to run toy trains is convenient. This has a switch on the secondary giving voltage steps of $2\frac{1}{2}$ volts up to about 25 volts.

Figure 135 shows a mutual characteristic curve of a 01A tube taken before and after reactivation.

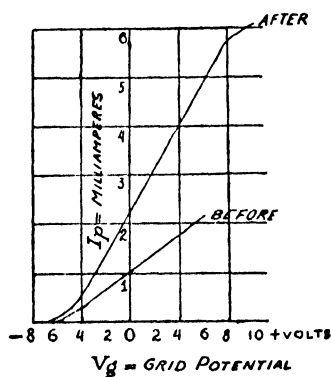


Fig. 135

Experiment 119. Measurement of Electrodynamic Speakers.

Most modern electrodynamic speakers are matched to the tube with transformers. The primary of the transformer impedance should be measured and tested for "match" to the tube as outlined in Experiments 73 and 74.

Assuming the transformer is matched to the tube the impedance of the speaker can be measured using the ordinary 100 milliampere thermal millimeters, there being no direct current flowing through the coil.

If one has a delicate vacuum junction and microammeter a voltmeter can be made by inserting non-inductive resistance in series with the heater of the junction. The voltage is the current times the total resistance in the heater circuit. The junction can be calibrated in terms of current. Experiment 130.

Using the junction as a voltmeter and the milliammeter the impedance can be calculated. The match of transformer to speaker can be tested by measuring the open circuit voltage of the trans-

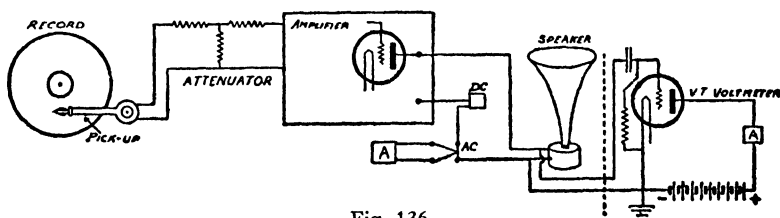


Fig. 136

former when the connection to the speaker is broken. This open circuit potential should be twice that with the speaker connected if the impedances are matched.

Since the resistance of the milliammeter will be from two to five ohms and the impedance of the speaker from ten to twenty ohms corrections must be made for the resistance of the milliammeter.

It will be interesting to measure with and without the d-c field current; with and without horn; with and without the speaker connected to its baffle board. Compare modern and old dynamic speakers. It will soon be apparent that the impedance curve and the current curve are nearly reciprocal and one can usually get a general idea of the performance of the speaker simply by watching the milliammeter as the frequency is changed.

Figure 136 is a diagram for the measurement of the impedance of a loud speaker as it is used in commercial apparatus. The E.M.F. of variable frequency is taken from standard frequency records. If the amplifier should generate a radio frequency current a filter must be placed between the amplifier and the instruments.

By taking the impedance curves and by making tests of the sound output of the speaker as in Experiment 120 for a few typical speakers one can soon judge to considerable degree of accuracy the sound quality of the speaker by watching the ammeter alone.

Figure 137 gives the current input curve for an old dynamic speaker.

Experiment 120. To Test a Loud Speaker.

In order to test the quality of a loud speaker one needs an oscillator covering the audio range of frequencies and an amplifier which does not have any peaks of selective amplification within the same range of frequencies.

In order to insure this several tests must be made. These tests will be outlined very briefly. (Experiment 119 gives approximate tests.)

The Oscillator. After constructing the oscillator, see Laboratory Apparatus, it must be tested for output. It should preferably have constant output at all frequencies. In order to get an output large enough to measure, one must have one or two steps of resistance coupled amplification after the detector tube. The output should be arranged with a matching transformer as in Figure 125 or with a choke and large condenser as in Figure 124 in order to measure the a-c output alone. A thermo junction or hot wire meter should be connected in series with a resistance so that the total resistance

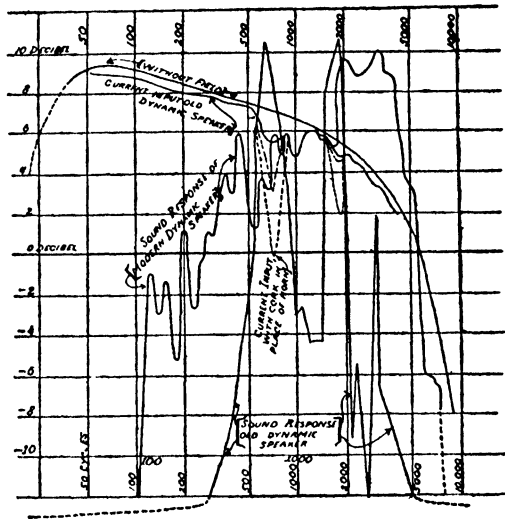


Fig. 137. Curves showing current input for an old dynamic speaker and sound response for both old and modern dynamic speakers.

With field remove the current input is a smooth curve. With the field on there is a decided diminution of current when the sound response is great. This is unusually large without horn and when the horn is replaced with a cork.

The response curves seem to be rather irregular due to the magnification of the ordinates.

of the meter circuit is equal to the tube or transformer impedance. The output and input must be matched. Then vary the frequency and read the current as given by the meter. If the current varies considerably insert a low pass filter whose cut off is 10,000 and repeat. If there are still many peaks insert a 5000 cycle low pass filter and repeat. Unless the oscillator has been made with considerable care perhaps the 5000 low pass filter will have to be used and one must be content with measurements below 5000 cycles. Even if the output has some humps later results can be compared with this curve.

Amplifier. The amplifier should be a resistance coupled amplifier or it must be made with the best audio coils. To test the amplifier connect the amplifier direct to the oscillator with an attenuator in which the attenuation loss is such that the output current of the amplifier can be measured with a meter. The meter must be connected so as to measure the a-c current and its impedance must be "matched."

Take readings and draw a curve as has been done for the oscillator; compare the two curves. Both curves should be flat or at least both should be alike at all frequencies if the amplifier is a faithful amplifier. Now we know that the amplifier is faithful or at least we know the ratio of amplification at all frequencies in the range.

Connect the loud speaker to the oscillator so that its impedance matches that of the oscillator. If the impedance is less than that of the oscillator resistance can be placed in series until the total impedance is that of the oscillator. This resistance must be non-inductive and be such that it can carry the current and not get hot. Place the meter in series and read current as the frequency is changed, and plot the curve. This curve should be the same as that of the first curve taken with the oscillator. Any humps or peaks are due to selectivity or resonance in the speaker. This may be due to resonance in the electric circuits or it may be due to selective motional impedance. A good speaker should be free from these resonance points. In a dynamic speaker the motional impedance can be largely eliminated by making the d-c field current zero, or by clamping the moving parts so they can not move. It might be well to take readings with and without the horn. The difference shows the selective effect of the horn.

With the oscillator connected to the loud speaker and with a good microphone connected to the input of the amplifier, take readings of the current as measured by the ammeter in the output of the amplifier as the frequency is changed from low to high values. The ideal condition will be when the output current is constant for all value of frequency provided that the oscillator gives constant output at all frequencies. If the oscillator and amplifier have defects, i.e., have humps in the curves, the ratio of output to input currents can be calculated at various frequencies and this ratio can be plotted against frequency.

In taking this data caution must be taken to eliminate room patterns or standing waves produced by reflections from the walls of the room.

The ideal place to perform this experiment is in an open field far removed from disturbing noises. There should be little or no wind.

If the data is taken indoors the room should not be too small. It should be at least 25 feet square with rather high ceiling. The walls should be well padded. To eliminate the ever present room patterns the microphone can be made to revolve about a circle of five to eight feet diameter. The period of rotation should be about one per second. The period must be short compared to the period of the meter. The meter should give a deflection proportional to the average current during the swing. The microphone can be suspended on the end of a pendulum and vibrated so as to vary the positions of the sound patterns in the room.

In plotting the curves the rates of output to input can be plotted as decibels, db. A one to one ratio is zero db. When the ratio is greater than one the db. is positive; when the ratio is less than one the db. is negative.

When plotting in terms of decibels arrange the data in a column; take the ordinary logarithm of the data and place in a column alongside the data. Select some value near the average value of the logarithm for the zero db. Subtract this value from all other then multiply this difference by 10 if the data is given in power units or by 20 if the data is given in terms of current. Figure 137 gives the sound response curves for an old, and for a modern dynamic speaker. In comparing response curves of speakers one should note the scale to which the curves are plotted. If in Figure

137 the ordinates had been ten decibels per division instead of two decibels per division the curve would seem to be nearly flat.

For method of measuring total output of a speaker see Darrell Green's Thesis.

Experiment 121. Construction and Test of a Rectifier.

The most simple rectifier perhaps is the aluminum cell rectifier. This consists of two electrodes one of lead and the other of aluminum in a dilute solution of ordinary baking soda. There are many other solutions which will work but baking soda is very convenient. The connections are made as in Figure 138.

The potential on each cell should not be more than 50 volts. Several cells can be put in series for high voltage. The surface of the aluminum should be one square inch for each 40 milliamperes.

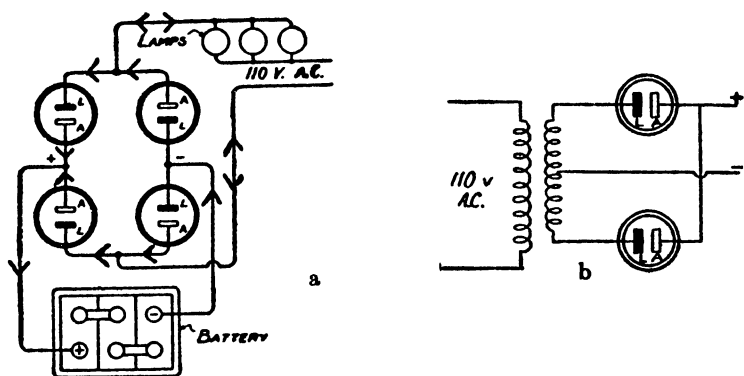


Fig. 138

Figure 138a is a "full wave" rectifier connected to the ordinary lighting circuit. Figure 137b is a rectifier connected to a special transformer with a middle tap.

In Figure 138b the aluminum cells might be replaced with two electrode vacuum tubes. If the two tubes replace the cells and have their plates connected, one each to the two terminals of the transformer, the current will come out of the filament terminals. (A battery must be used to heat the filaments.) The filament terminal will be positive and the mid tap will be negative.

A gas rectifying tube can be used as in Figure 139. In this figure a filter is shown which smooths the pulsating d-c to a con-

In wired wireless a number of transmitters can use the same transmission line. The listener can select the station he wishes to listen to by tuning his receiver.

The transmitter can be any radio telephone transmitter using an antenna aerial placed parallel to the transmission line. The transmission line absorbs the energy of the transmitter and carries it to the various receivers which may be connected to aerials which parallel some wire of the same transmission system.

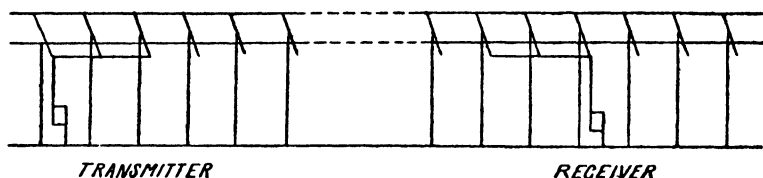


Fig. 140. Diagrammatic Connections Used in Wired Wireless.

Connect a small radio telephone transmitter such as that described in Experiment 103 using a coil aerial. Make a coil of a few turns of wire and connect one end of the coil to a large condenser, microfarad, and connect the coil and condenser to a plug screw into a lamp socket of the lighting circuit. Place this coil near the coil aerial. In an adjoining room or building connect a receiver to a short aerial which is placed near the lighting circuit or connect by means of the ordinary apparatus which is used when the lamp socket is used as an aerial. This apparatus is simply a condenser whose capacity is about .001 μ f.

Tune to the transmitter in the ordinary manner.

There will be objectionable noises due to the 60 cycle hum or other causes. Filter circuits can be arranged to remove these noises.

Experiment 123. Television.

Television is in the experimental stage and a beginner can not expect to get very good results without an elaborate outlay.

The principles can be demonstrated with a rather cheap outfit.

It is well to pick out some station which transmits "television" at certain stated times and prepare to receive from this station. The data needed is first the frequency, or wave length of the transmitting station, the speed of and number of holes in the scanning disk. A receiver which will receive the station with good volume

and quality when the station is transmitting music is also needed. The last tube in the receiver must be a power tube.

Having decided on the station, the speed of the scanning disk frames per second and the type of scanning disk lines per frame must be exactly like that of the transmitting station.

Having the receiver, the disk and motor, the other theoretical requisites are a neon tube and lots of patience. The neon tube can be the small one which sells for less than a dollar or the larger one.

Since the distant transmitting stations transmit occasionally only, it perhaps is well to construct a small transmitting station working at about the same frequency as that of the distant transmitter. This can be done if one has a photoelectric cell, a good amplifier, and a small transmitter as described in Experiment 103.

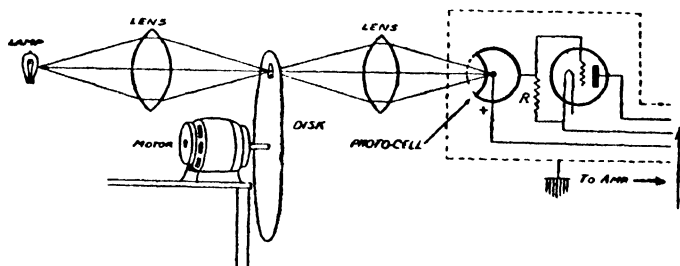


Fig 141

With this outfit one can transmit the image of such objects as the filament of an incandescent lamp.

The photoelectric cell and the first tube of the amplifier must be well screened from induction noises from the motor or other disturbances. If the rest of the amplifier is screened so much the better.

If the frequency is in the broadcast range the receiver can be a regular superheterodyne receiver with a power tube in the last stage. Figure 141 gives an outlay of the optical system and the first stage of amplification at the transmitter. The first lens forms a real image of the lamp filament on the scanning disk which is so placed and of proper size that the holes in the disk will take light in turn from all the image. The second lens brings this light to almost a point in the photoelectric cell. This causes a small current to flow through the 20 megohm resistance, R . A B battery of about

180 volts is connected in this circuit. (The potential of the battery must not cause a blue glow in the cell.) This is amplified by the tube shown in the diagram and from this the signal is carried to a three stage amplifier. All the wires to the photocell and the first tube are carried through an earthed metal tube. The amplifier output is connected to the modulating tube of the radio transmitter.

The neon glow lamp is connected in the plate circuit of the last tube of the receiving set, Figure 142. The potential of the battery must be enough to cause the neon lamp to glow. A stabilizing resistance, R , of two to five thousand ohms is connected in series. By means of a jack the loud speaker is cut in while the set is being

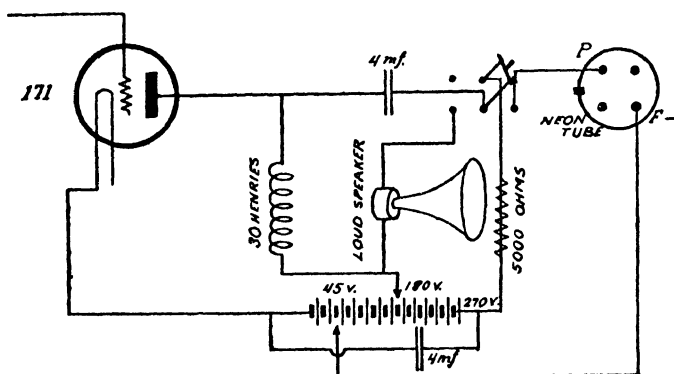


Fig. 142

tuned. The neon lamp is placed behind the scanning disk and is viewed direct. The motor of the sender should run approximately at the speed of the motor of the distant sending station. The motor at the receiver must be one in which the speed can be controlled.

The sending and receiving motors must run absolutely at synchronous speeds. If both receiver and transmitter motors are synchronous motors running at speeds of 1800 rpm. or 1200 rpm. using 60 cycle a-c, then it will be necessary to get the disk on the receiving motor turned until it is in the right position, i.e., so the first hole in the disk is at the top at the same time that the first hole in the transmitting disk is at the top and then the two disks will remain in synchronism. However, since in all probability the distant sending motor is on a different power system the receiving

motor will not run at the right speed; 60 cycles may mean anything from 58 to 62 cycles. The induction motors on the market usually run at about 1750 rpm. and are supposed to be slowed down to 1200 rpm. The motor is rather unstable at 1200 and is hard to hold to the exact speed. They are supposed to be regulated by means of resistance. A friction brake helps.

A little practice will enable one to get occasional "flashes" of the lamp filament in the picture. Perhaps the filament will come out dark instead of white. The connections in Figure 142 are those which gave a positive image. It will take some practice and a great deal of patience to get everything right. Probably the hardest thing is to get the receiving motor synchronized.

See *Fundamentals of Radio* for cathode ray tube television apparatus.

Experiment 124. Photoelectric Cells.

There are three types of photoelectric cells, the selenium cell, the photronic cell and those which are usually called photoelectric cells. Of the latter there are two types, the high vacuum cells and the gaseous cells.

The photoelectric cell and the Weston photronic cells are the ones in most common use. The photronic cell is an oxide cell and produces a small electromotive force which is proportional to the light intensity. The photoelectric cell requires a potential of one hundred or more volts on the "plate." The potential derived from the photronic cell is about equal to that from the photoelectric cell and one stage of amplification. For experimental purposes the photronic cell is the most convenient while for fidelity the photoelectric cell is the best. These cells are used for many purposes and a few typical cases only are given here.

Measurement of light intensity. A photronic cell is convenient in this case. With a microammeter of the proper resistance the current is almost proportional to the intensity. Connect the cell to a microammeter or sensitive galvanometer with a resistance box in series. Place the cell in the place of the "grease spot" of a Bunsen photometer and measure the current as the intensity of the light as varied by changing the distance from a standard incandescent lamp.

This lamp can be standardized by means of a standard candle. The ordinary paraffin 12s candle is near one candle and can be used

as a standard. The potential across the terminals of the incandescent lamp should be held at some constant potential. Plot current against candle power. The resistance in series can be changed and calibrated again. For some particular resistance the curve will be near a straight line. This experiment can be varied by using a photoelectric cell, by using color screens or colored lamps or by making a spectroscopic study of the response of the cell.

Sound transmission on a beam of light. The set-up of the apparatus is shown in the diagram, Figure 143. In this diagram the microphone, *M*, is connected to a two-stage microphone amplifier. The amplifier is connected to the transformer, *T*, which is an ordinary low impedance output transformer such as is used in connecting a tube to a dynamic speaker. The transformer, *T*, is connected across the terminals of the arc lamp through a four microfarad condenser,

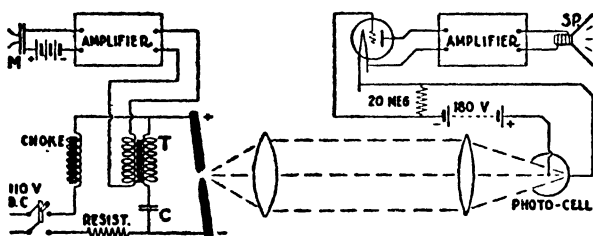


Fig. 143

C. A large choke coil is placed in the d-c supply line. This choke coil prevents the voice frequency being absorbed by the power line.

The diagram shows the receiving photoelectric cell connected to a resistance coupled amplifier. There should be two stages of resistance amplification and then two or three stages of transformer coupled amplification. The amplifier is then connected to a loud speaker.

It will be apparent that the exact connections will depend upon the amplifiers and speaker available.

The arc used was an old-fashioned arc projection lantern. This was focused so as to give a parallel beam of light. The parallel beam of light was focused on the light cell by means of a large reading glass.

Instead of the photoelectric cell a Weston photronic cell can be used. The photronic cell gives practically the same results with a

stage or two less amplification in the amplifier. In the figure the photronic cell should be connected directly to the amplifier.

In the place of the microphone and the microphone battery a pick-up unit can be substituted and music from an ordinary record can be transmitted.

The connections of the arc lamp are the connections for a speaking arc. If the arc is working well one should hear the arc "talk" in a quiet room.

It is found that hard carbons give better results than the usual soft-cored carbons.

This set-up makes a striking experiment in a large darkened room where the length of the parallel beam is long, especially if there is enough dust in the air to make the path of the beam visible. Any object interposed in the beam causes the music to cease.

Use of incandescent lamp. An ordinary small incandescent lamp can be substituted for the arc lamp. It is surprising how distinct the voice is. One would suppose that the temperature of the filament would be almost constant and the light emission constant.

Instead of the above set-up, a radio frequency Heising modulation radio telephone can be used. The power of the circuit must be large enough to light a flash lamp with the radio frequency current.

The lamp can be placed in the oscillating circuit or it can be placed in a tuned "wave meter circuit" and tuned to the radio phone.

This last method perhaps is the most convenient as the temperature can be regulated by varying the coupling.

The uses of the photoelectric cell are numerous. When used in connection with Thyatron tubes or mechanical relays the energy of large plants can be controlled.

Science, 78, 105, 1933.

Experiment 125. Cathode Ray Oscillograph.

The cathode ray oscillograph is a useful device to make visible that which takes place in a circuit. For description see *Fundamentals of Radio*, p. 396. With a linear sweep circuit one can see the wave form and determine if it is a sine wave or otherwise. Without a linear sweep one can compare one circuit with another circuit and get Lissajou figures. These figures are the combination

of two sets of sine waves at right angles, a straight line varying to an ellipse or circle perhaps when the two waves have the same frequency. Certain figure eight figures when the ratio is two to one. If one is well acquainted with these figures the various ratios can be determined.

Modulation Figures. Take a modulated radio circuit and modulate it with a pure sine wave. The modulation potential can be placed on the horizontal axis and the radio frequency on the vertical axis. If there is no phase shift due to the connections one will get an equilateral triangle with the vertex at zero on the horizontal axis if the modulation is 100%. If the modulation is less than 100% the vertex will be cut off. If the modulation is more than 100% the figure will start as a straight line and then form the delta. If the modulation is not distorted the sloping lines will be straight lines. It is not expected to see the pattern of the radio frequency sine wave. The outline only will appear. The inside of the delta will be a smear of the radio frequency vibration. If the modulation has harmonics or if the modulation introduces distortion the sloping lines will be curved in various forms.

Picking out side bands. If a low frequency Heising modulated circuit is used 60 kc., say, or less, one can with a linear sweep circuit resolve the radio frequency wave and when modulated with rather high frequency get the form of the modulated radio frequency. 60 kc. modulate with 8000 cycles say. Connect the vertical plates to the tank coil with rather large condensers.

If a wave meter circuit of small decrement, or high selectivity is tuned to the modulated oscillator circuit one can tune to the carrier wave and to the two side bands at will. The selectivity is made such that both side bands are "cut" off when one has the carrier. Usually one can tune between the carrier at such a point that the wave meter will accept some of the carrier and some of the side band and we have the addition of two sine waves. Note the difference between this and that from the modulated oscillator. The modulated is $(A + A_0 \sin pt) \sin \omega t$. The curve from the wave meter is $a_1 \sin \omega t + a_2 \sin (\omega - p)t$. To modulate these frequencies it is necessary to use a non-linear detector. Add the two frequencies through a non-linear medium or apparatus. If the modulation is 1000 or 2000 perhaps the selectivity will not

be great enough to resolve the various frequencies and a sum of two or all three will be received. Compare this with Experiment 110.

Figure 144 shows the connection for showing the characteristic of a screen grid tube. "Fundamentals of Radio," p. 399. Many other circuits can be devised to show interesting forms. Damped waves and damped waves received with a very selective circuit, grid modulation, input and output of amplifiers, are, some suggestions.

The 913 tube is a relatively cheap cathode ray tube which can be used for experimental purposes. See *QST*, Jan., 1937.

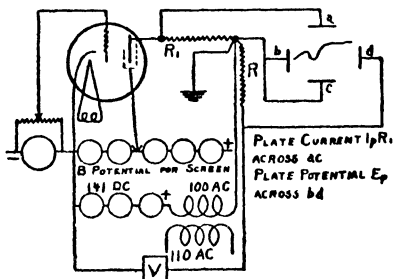


Fig. 144

ILLUSTRATIVE EXPERIMENTS

Experiment 126. Oscillatory Discharge of a Leyden Jar.

One of the earliest experiments upon which radio depends is the discovery of the fact that when a condenser, Leyden jar, discharges through an inductance the discharge is oscillatory. The usual method of showing this is by means of the rotating mirror. This method is objectionable because the mirror is usually not in the right position at the time the discharge takes place.

A method which I have described in *The Physical Review*, Vol. 35, 405, 1912, is as follows. Connect a Leyden jar in series with a rather large inductance, the secondary coil of an induction coil, Figure 145. Make a spark gap of two metal rods mounted in

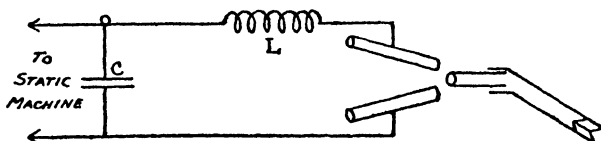


Fig. 145

wooden supports, one above the other but not quite parallel. Make the distance between the closest ends about one centimeter. By means of a small tube direct a stream of air against the small end of the gap. The discharge will take place at the closest point

and the air stream will drive the ionized air along the gap so that the successive oscillations will follow the air blast and thus be spread out along the gap.

The jar should be charged by a static machine so that one discharge will take place in five or ten seconds. In this experiment every discharge can be seen to be spread out by all the observers. The inductance can be short-circuited to show the effect of the inductance.

Experiment 127. The Singing Arc.

The singing arc is an experiment which audibly shows the principle of the arc sending station.

Take an ordinary arc lamp on a 110 volt d-c circuit, Figure 146. Place hard carbons in the lamp. Cored carbons will not hiss. In

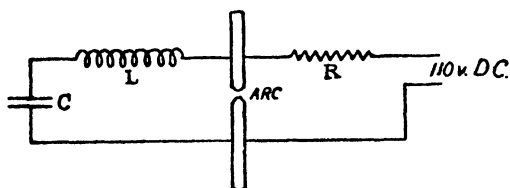


Fig. 146

multiple with the arc place a condenser and inductance in series. The condenser can be paper condensers in multiple so as to have from five to ten microfarads capacity.

The inductance is made of a cylinder of wood four or five inches in diameter wound with No. 6 or 9 bare copper wire. The turns being $\frac{1}{4}$ inch apart. The oscillations set up in the circuit will cause a shrill note to be given from the arc. The pitch of this can be varied by means of the inductance or capacity. When the note is very high if a "long wave meter" which is connected to a tube so as to oscillate is brought near the singing arc the wave length can be measured. It can be shown that the arc has a definite wave length but that the wave is not a pure sine wave. It is sine wave with a large number of irregular ripples superimposed upon it.

If the pitch of the arc is put in unison with a Dalton whistle or a high pitch tuning fork and the wave length is measured we have a method of checking the wave meter against a known audible frequency.

Experiment 128. Seibt's Experiment.

Seibt's experiment is a good visible illustration of the effect of tuning. Two coils wound on glass tubes about two feet long

and three inches in diameter are wound with one layer of insulated wire.

One is wound with No. 30 wire and the other with No. 26. These coils usually terminate with brass terminals with a ball at the top and a support at the lower end. These coils are connected to the circuit at the lower end. The circuit consists of a Leyden jar or two for the condenser and a variable inductance made of heavy bare wire wound on a wooden cylinder. If this coil is mounted so as to rotate about the axis of the cylinder and the sliding contact is a wheel on a brass rod the inductance can be varied by rotating the cylinder. A spark gap is inserted in series with the circuit. The coils are connected to one side of the gap and the other side is connected to the ground, Figure 147. The Leyden jars are connected to an induction coil or high potential transformer. As the inductance is varied the wave length is varied and when the wave length of the circuit is the natural wave length of one of the coils, if the oscillation is strong enough, the upper end of the coil rises to such a potential that sparks break out into the open air. As the wave length is varied the second will flare out when its natural wave length is struck.

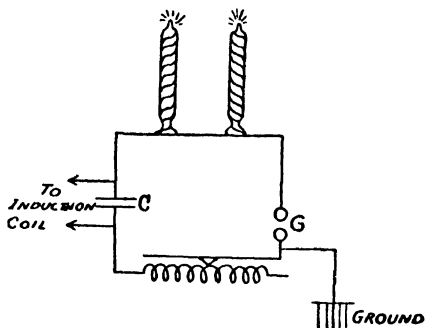


Fig. 147

The wave length can be measured by means of a wave meter with a lamp or milliammeter in series or by closing the gap and placing a buzzer around the condenser of the circuit and by means of a telephone and crystal in the wave meter.

A large tube generator might be used if a means of showing the high potential is fixed to the top of each coil. A brush of light paper or foil.

Experiment 129. The Tesla Coil.

The principle of the Tesla coil is that of the oscillating transformer used in all spark transmitters. The circuit consists of

condenser, Leyden jars, the primary of the Tesla coil, which consists of five to ten turns of heavy wire wound about 10 inches diameter, a spark gap and a variable inductance, Figure 148.

This is energized by an induction coil or high potential transformer. The secondary coil consists of a coil of fine wire on a glass tube, see Seibt's experiment, set in the middle of the primary coil. As the variable inductance is changed the secondary coil

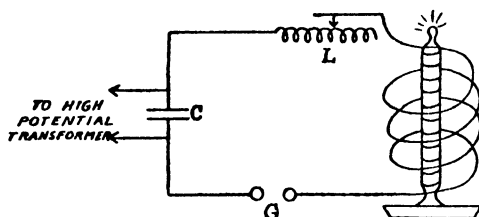


Fig. 148

"spits fire" when in tune with the circuit. In this experiment the small coil is inductively coupled to the circuit while in Seibt's experiment it is conductively coupled.

A tube generator might be used if a potential indicator is fastened to the top of the primary. The wave length can be measured as in Seibt's experiment.

Experiment 130. Calibration of Radio Frequency Meters.

Radio frequency meters are usually hot wire meters or thermocouple meters. Both depend on the effect of heat generated in the circuit.

Both types can be calibrated in the same manner. Since heat is proportional to I^2R , it is evident that the resistance of the element in the meter must be the same at all frequencies. Measure the resistance of the meter using a box bridge or other method. Measure the radio frequency resistance at several frequencies. 500 kc., 1000 kc., 5000 kc., etc. Experiment 86. The resistance should be the same as the d-c resistance at all frequencies. If the resistance is materially increased at 5000 kc. say, then the readings can be reduced by multiplying by the ratio of R/R_f . R_f being the larger resistance.

Test with d-c current. Connect to a d-c source and send a known current through the meter. Be sure to start with small values.

Radio frequency meters will not carry much over load. Adjust to a value on the middle of the scale. Reverse the current. The two deflections should be the same. If not, the meter cannot be used as a d-c meter nor can it be calibrated with d-c current. Hot wire

instruments can be so used and calibrated. Thermal instruments depend on the E.M.F.; e , develops in the junction. In some junctions the E.M.F. is, e , plus or minus Ir , where r is a small resistance in the junction. With 60 cycle a-c the Ir drop will cause an a-c current to flow in the d-c meter connected to the junction which will not produce a deflection and the deflection will be due to the E.M.F., e .

Perhaps milliammeters will be the meters calibrated most often and the following will apply to such a meter where 100 milliammeters will give full deflection.

These directions will also apply to a junction used with an outside galvanometer such as a Leeds Northrup type P galvanometer. If the deflections right and left are the same, use d-c current placing a good d-c milliammeter in series with the junction. Read the current and the deflection of the galvanometer. Plot a curve $X = \text{current}$, $Y = \text{deflection}$.

If deflection and the square of the current is plotted the curve should be near a straight line. If the meter is a milliammeter proceed as above and plot a curve $X = \text{current}$ and $Y = \text{readings}$. If correct the curve should be a straight line making 45° with the axes. (Both axes having the same scale.) If not at 45° the curve can be used to make corrections.

If the meter is a current squared meter the deflections and the square of the current should give a straight line. If this is a straight line at 45° then the meter obeys the law $I = k\sqrt{d}$ where k is a constant and d is the deflection as read on the meter. If $d = 100$ then $I = k10$ or $k = I/10$. If $d = 1$ then $I = k$, and k is the current which will give one division deflection. If maximum current is 115 milliamperes then 11.5 milliamperes will give a deflection of one division. Thus a 100 milliamperemeter is not very accurate below 20 milliamperes.

If a-c is used use a standard resistance as in Figure 124. Measure the current through the resistance and then calculate the Pd at the terminals of the standard. Thus if the standard is 0.1 ohm and the current is 10 amperes the Pd is one volt. Place the milliammeter in series with a good noninductive resistance box of 1000 ohms and connect to the terminals of the standard resistance. If the resistance of the meter and box is made 1000 ohms the current is one milliamperemeter; if 100 ohms we have 10 milliamperes; if 10 ohms

we have 100 milliamperes. In the case of the 10 ohms resistance the error is 1% since the resistance in parallel with the standard is 100 times that of the standard. The actual resistance between the terminals of the standard is 0.099 instead of 0.1 ohm. If the resistance is made 9.9 ohms instead of 10 ohms the current is 100 milliamperes. If one has a good a-c milliammeter one can proceed as above with d-c current. In using a-c meters one must be sure they are not influenced by stray fields. Keep transformers and d-c meter away from the a-c instruments. See Experiment 86.

Fundamentals of Radio, Chapter XXI.

Experiment 131. Calibration and Use of Audio Frequency Instruments.

Ordinary a-c instruments can be used where the frequency is not more than 100 cycles per second. Radio frequency instruments can be used as current measuring instruments. One must remember that these instruments have appreciable resistance and a resistance correction must be applied.

The resistance of the meter must be counted in as part of the total resistance. Using low impedance loud speakers such as dynamic speaker a 100 milliampere r-f instrument can be used to measure the current. An output meter (oxide rectifier type instrument) can be used as a voltmeter. It is perhaps best to place the voltmeter so as to measure the voltage across the output transformer. The power is $EI \cos \theta$. Usually $\cos \theta$ is assumed to be unity. In that case the power used is the total minus that used in the meter which is $I^2 r$. There r , is the resistance of the meter. The error of this is the assumption that the impedance of the speaker is a pure resistance. If the output meter is placed across the speaker terminals the current is that of the speaker plus that of the output meter. This is vector sum of a sine curve and a rectified sine curve.

Rectified type of meter. These meters are used as a-c meters in the audio range. They will give indications in radio frequency circuits but are not guaranteed for this work. They are usually high resistance instruments 5000 or 4000 ohms and are usually calibrated in volts.

They can be used as high resistance ammeters. The current is the reading on the voltage scale divided by the resistance of the

instrument. Since the current is rectified harmonics are introduced and it is questionable that the current read is that which is in the circuit when a noninductive resistance, of 5000 ohms say, is inserted in the circuit. They can be used but it should be stated that such an instrument has been used when recording results.

Since these instruments are usually calibrated in volts they can be checked by placing them in parallel with a good voltmeter and comparing readings. Use a good d-c voltmeter if d-c potentials are used and a-c voltmeters to calibrate a-c voltages. The reading with d-c and a-c will not check exactly.

Experiment 132. Measurement of Potential with a Tube.

Peak Voltmeter. In the peak, or slide back, voltmeter a tube is connected as in Figure 149. *C* is a *C* battery, connected to a potentiometer of a few hundred ohms, made of a noninductive resistance. Referring to Figure 150 which is the mutual characteristic curve, I_p , V_g , the action of the peak voltmeter can be explained. Under normal conditions when the grid

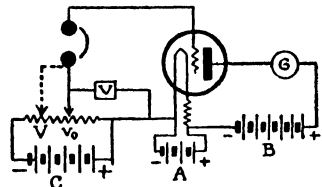


Fig. 149

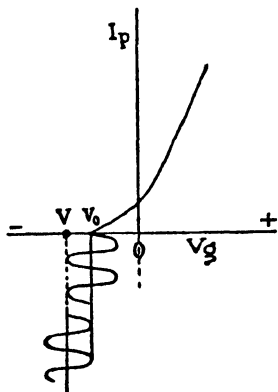


Fig. 150

is connected to the negative filament the plate current can be made zero by applying a negative potential of v_0 volts to the grid. This can be seen to be measured by the d-c voltmeter, V .

If an a-c potential of whose maximum, peak, voltage is v , is superimposed on the grid there will be a current which will be indicated by the ammeter in the plate circuit. If the potential of the grid is made equal to negative V , the current will again be zero. Then $v = V - v_0$.

The ammeter in the plate circuit should be very sensitive, either a microammeter or sensitive galvanometer works best. With a sensitive instrument there is some uncertainty of the exact point of setting, so much so that often it is thought best to set to some small

deflection, one division say, instead of zero. The potential measured is the peak voltage. The virtual voltage is this value divided by 1.41 provided the wave form is a sine curve.

Tube Voltmeter. The tube voltmeter is a three electrode tube connected so that there will be a rectified current in the plate circuit. The tube is connected to a known a-c potential, 60 cycle or more, with a good wave form. A curve is plotted and when the tube voltmeter is connected to another circuit the voltage is assumed to be that read off the curve.

Referring to the diagram of Figure 88, Experiment 74 "Test of an Audio Transformer," a tube voltmeter is shown with the various constants given. This diagram is taken from Nema Handbook. This circuit uses a 01A tube. Some recommend a tube of

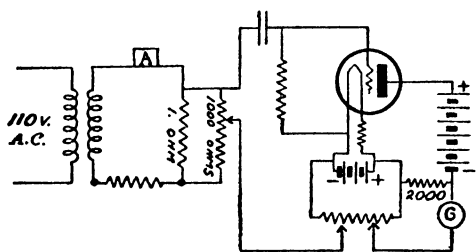


Fig. 151

low impedance such as a 71 tube with a large resistance in the plate circuit. The resistance being from 200,000 ohms to 2.5 megohms with a B battery from $22\frac{1}{2}$ volts to 250 volts.

Figure 151 shows a circuit for calibrating a tube voltmeter. A low potential transformer, toy transformer, is connected to a 110 a-c supply. The low side is connected to an accurate 1. ohm resistance with an ammeter and regulating reho-stat in series. Care should be taken that none of these resistances are over loaded. A potentiometer made of a good resistance box whose resistance is 1000 ohms or more is connected around the terminals of the 1. ohm coil. By means of a slider or traveling plugs the desired potential can be applied to the grid of the tube. If the current in the ammeter is one ampere and the potentiometer resistance is 1000 ohms the potential per ohm of the potentiometer is $1/1000$ of a volt.

A second potentiometer with two sliders is shown connected around the A battery. One slider regulates the initial potential of the grid and the other regulates the initial current in the galvanometer. The initial current can be made to be zero.

When a tube voltmeter contains a grid condenser it is sometimes called a "leaky grid voltmeter." As the voltage increases the plate current diminishes. Figure 152 is a diagram of a leaky grid instrument.

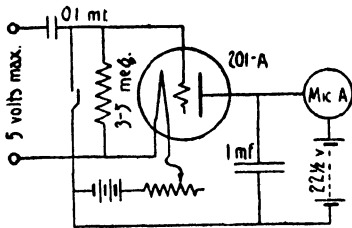


Fig. 152

Figure 153 is a calibration curve of such an instrument. A shorting key as shown in the diagram is used to test the plate current for the initial zero condition. This is regulated by a resistance in the heater circuit.

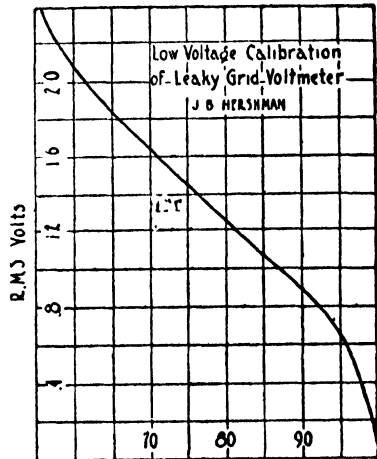


Fig. 153

Figure 154 shows a possible combination voltmeter for various potentials.

Each connection should be calibrated independently. There is no direct relation between the various calibrations for ordinary measurements. The following five rules or precautions are given. These must be applied in any case.

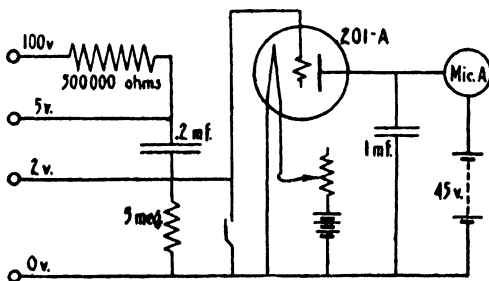


Fig. 154

(1) The impressed voltage must cause no appreciable grid current.

(2) The filament terminal of the voltmeter must be grounded.

(3) The effective capacity and resistance must be known. (Especially necessary in measurement of small capacities.)

(4) The effective capacity and resistance must be known. (Especially necessary in measurement of small capacities.)

(4) The grid must not be isolated through high resistance. (Does not apply to leaky grid voltmeter.)

(5) Inductive effects must be avoided by shielding and through the use of short leads.

The leaky grid voltmeter avoids excessive grid current through the use of a grid condenser and grid leak resistance, and consequently places almost a zero load on the circuit.

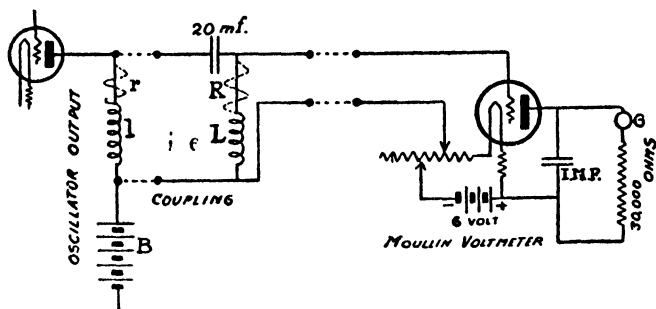
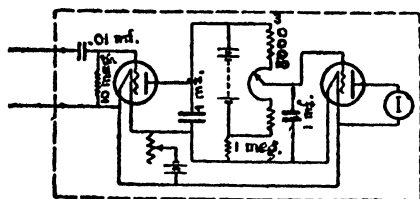


Fig. 155

Moullin's high frequency voltmeter has the plate circuit connected to the positive *A* battery terminal. As manufactured it measures potentials up to 1.5 volts.

Figure 155 is a diagram of the Moullin voltmeter circuit.

When using a tube voltmeter to measure the potential around such a device as a loud speaker through which there is a d-c current a coupling device of a large condenser and large choke coil or resistance should be used. If the potential is around an inductance the inductance, *L*, should be at least 10 times *l*. *L*, should be 50 or 100 henries. If the potential is measured around a resistance, *r*, instead of an inductance a large resistance, *R*, should be used. This resistance should be about 20 times the resistance, *r*.



V.T. Voltmeter

Fig. 156

Figure 156 shows the diagram of a tube voltmeter in which two tubes are used, one being an amplifier. With this apparatus millivolts can be measured.

The electron ray tube. The electron ray tubes, 6E5, and 6G5 or "magic eye" tubes can be used as indicators of potential. This potential on the grid must be d-c or rectified potential for the shadow to be definite. If high frequency potential is placed on the grid the shadow will change with the potential at the frequency of the potential. The plate current changes from near zero to 200 or 250 microamperes as the potential is changed from negative values to zero.

If a d-c microammeter is placed in series with the megohm resistor in the plate circuit one can get an indication of the potential on the grid. Bias the grid to near zero current (or 50 microamperes perhaps) with zero potential and the plate current will be "rectified" current and will be proportional to the potential assuming the potential is a sine curve. Calibration must be made with 60 cycle a-c.

Moullin, *Radio Frequency Measurements*, p. 35; Dickey, *Inst. Radio Eng.*, Vol. 15, p. 687, 1927; Medlam and Oschwald, *Experimental Wireless*, London, Oct. and Nov., 1926; Colby, *Journal of Scientific Instruments*, Vol. 3, p. 342, 1926; *Fundamentals of Radio*, Chapter XXI.

LABORATORY APPARATUS*

Condensers. For radio condensers use 43 and 23 semicircular plate variable straight line capacity condensers mounted in separate cases with binding posts. If the case is metal and connected to the rotor and grounded stray or lead capacity is diminished. For fixed condensers use those made of tin foil and photographic plates. Directions for making are given in Experiment 21. With ordinary photographic plates a condenser of four or five sheets of tin foil will have a capacity of about .001 microfarads. Two sheets of tinfoil and three glass plates make good grid condensers. After one or two have been constructed and measured one can judge the number of sheets to use to make a condenser of any particular capacity.

Where a glass plate condenser is used by students it is hard to keep the terminals connected to tin foil. Thin sheet copper with the terminal wires soldered to the sheets are more substantial. The glass plates can be bound together with electrician's adhesive tape.

* The General Radio Co., Cambridge, Mass. makes a specialty of high grade precision apparatus for laboratory use.

The commercial fixed condenser of 100 μf and larger can be used.

Buzzers. Any buzzer such as Century buzzer will serve. The buzzers listed in electrical catalogs as Lungen buzzers have been found to be very satisfactory. Their frequency is not very high but the noise from the buzzer seems to be rather easy to muffle.

The buzzer, dry cell and a break key should be mounted together. The buzzer should be placed in a wooden cubical box, inside dimensions 5 inches. The box is filled with hair deadening felt.

Induction coils. In capacity and inductance measurements use the small induction coil found in all old fashioned telephones.

Telephones. Use good telephones, resistance 2000 ohms or more.

Audio Oscillator. For bridge work when measuring capacity and inductance a 796 cycle ($\omega = 5000$) or 1000 cycle oscillator is con-

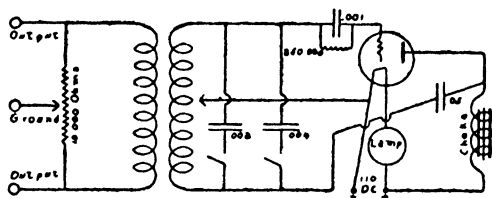


Fig. 157

venient to use instead of a buzzer. If the frequency does not enter into the calculations a buzzer whose frequency is near these values can be used. (When using a frequency bridge the exact value of the frequency is needed.) If one has 110 volts d-c on the mains one can construct a generator which is as portable as the ordinary resistance box.

The general construction is shown in Figure 157. A tube such as a 01A is connected in series with a 30 watt lamp. The lamp limits the filament current to the proper value. The plate of the tube is connected through an audio choke to the positive terminal making the plate potential about 100 volts. The coil used is an audio transformer replacement coil. The primary has a mid tap and is connected to the tube making a Hartley shunt circuit. The frequency is adjusted by trial to the frequency desired by placing fixed condensers across the primary coil.

The values given in the diagram are approximately the required values.

The output is taken from the secondary coil which is closely

coupled to the primary coil. This insulates the bridge from any conductive connection with the 110 volt line. A 10,000 ohm potentiometer connected across the output terminals serves as a Wagner ground.

The oscillator can be used with or without the grid condenser and grid leak. The grid condenser in the circuit reduced the harmonics and also reduces to some extent the output. The open

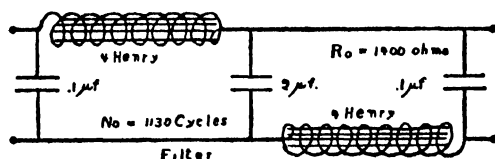


Fig 158

circuit voltage is near 12 volts. A simple filter made of telephone inductance coils giving a cut off of about 1200 reduces the harmonics when the fundamentals is near 800 cycles. Figure 158 gives the diagram and values for this filter.

Coils. Coils such as slide tuning coils can be used. However with the ordinary slide tuning coil there is danger of the slider touching two or more turns of wire at once. In this case the turn or turns are short circuited and choke out the oscillation. Again the exact position of the slide is doubtful and there is difficulty when reproducing the exact conditions at a later time.

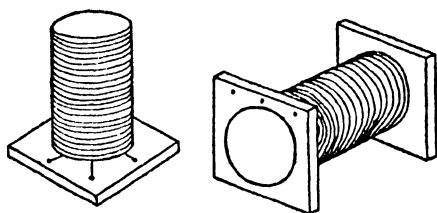


Fig. 159

Coils made in sets have proven very satisfactory. These coils are made on tubes of such diameter that one will slide into the other, both coils having the same number of turns of wire. All coils are wound single layer. Three terminals are brought to binding posts on each coil. The two ends and the middle point. In this way the coils can be used with a tube to make regenerative circuits such as Hartley circuit or the usual "feed back" circuit.

Figure 159 gives a general idea of the set. The tubes are paper tubes procured from a local carpet store. Linoleum, when shipped

is rolled on these tubes. Sets are made with 20, 40, 80, 160, etc. turns.

The following table will serve to give one a general idea of the wave length range of coils when used with an ordinary .001 μ f 43 plate variable condenser. This data is approximate only.

Diameter	No. turns	No. wire	Wave length	
3 $\frac{1}{4}$ inch	10	20	100 to	225 meters
3 $\frac{1}{2}$	20	20	150	360
3 $\frac{1}{2}$	40	20	175	500
3 $\frac{1}{2}$	40	20	200	650
3 $\frac{1}{2}$	80	20	300	1170
3 $\frac{1}{2}$	80	20	400	1400
4	25	20	200	600
5	20	20	175	550
5	35	20	300	850
3 $\frac{1}{2}$	260	30	1000	3500
6	100	18	600	2000
6	200	18	1000	3200
6	130	20	800	2500
6	260	20	1300	4200
5	190	22	1100	3700
5	380	22	1700	5500
6	350	22	2000	6000
Square coil				
50 $\times$ 50 centimeters	7	20	150	450
Square, 4 ft.				
diagonal	3 $\frac{1}{2}$	22	225	700
diagonal	7	22	300	1000
Square 2 $\times$ 2 meters	4		150	720
Square 2 $\times$ 2 meters	6		230	1000
Square 2 $\times$ 2 meters	10		350	1700
Rectangular				
18 $\times$ 40 feet	1		200	730
18 $\times$ 40 feet	2		300	1100
18 $\times$ 40 feet	3		400	1580

For the extreme long waves honey comb coils are convenient.

(If the student has a receiver or other apparatus it adds to the interest to allow him to measure and calibrate his own apparatus. Usually it is possible to make connections to condensers and coils by means of twisted wires. The circuit must be open however. Paper placed under the tap contact on the inductance usually will do this.)

MILLIAMMETERS

If a milliammeter is not at hand voltmeter can be used in many cases since the resistance of 200 ohms to 1700 ohms is small compared to the resistance of a tube. For student work it is much safer to use a voltmeter as a milliammeter than it is to use a regular milliammeter as the resistance of the voltmeter prevents excessive currents in case of short circuits. Weston Voltmeter Model 280 requires 15 milliamperes for full scale deflection. Model 1 Weston requires about 10 milliamperes for full scale deflection. When these voltmeters are placed in a circuit, where there is a radio frequency component in the current, by-pass condensers must be placed around the instrument to take care of the high frequency current.

RADIO FREQUENCY METERS

The smallest range of a radio frequency ammeter is about 100 milliamperes for full scale deflection. These should be used in wave meter circuits. Hot wire or thermo junction ammeters can be had from instrument makers in any range from 100 milliamperes to hundreds of amperes. Special thermo junctions can be had which when connected to a micro-ammeter will measure as low as one milliampere. Experiment 130.

WAVE METERS

Any of the above coils and a 43 plate condenser will make a good wave meter. Connect the coil and condenser with short heavy wire. Do not use twisted wire or lamp cord. The connections should be made so that the coil and the condenser will always occupy the same relative position. The capacity and the inductance can be measured and the wave lengths calculated. Experiments 19, 24 and 28.

It is easier to get good results using a coil whose maximum wave length is 4000 to 6000 meters than a short wave coil.

The measurements and calculations may be made with the large coil and a second short wave meter made and compared using overtones, Experiment 36, or it may be compared directly with the Bureau of Standards, or a broadcasting station, Experiments 36 and 37.

For accurate work a wave meter should be used in the same manner as it is calibrated. It should not be calibrated with a buzzer and then used with a crystal and head phone. Every piece has a certain capacity and inductance and changes the calibration to some extent. However it is very convenient at times to use the wave meter in various ways. This can be done if extreme accuracy is not necessary. Figure 160 is a diagram of a wave meter which

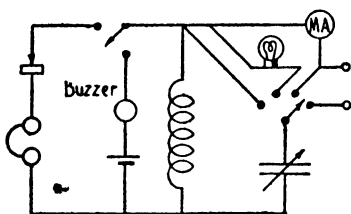


Fig. 160

can be used with buzzer, head set and crystal, flash lamp, and with a radio frequency meter. Several coils can be made and used one at a time and calibrated so that the one wave meter and coils will practically cover the entire radio spectrum.

Oscillating Wave Meter. Often it is necessary to have an oscillating circuit to use with certain experiments such as Experiment 53. An oscillator can be set up but it is convenient to have one that can be started at a moment's notice. The one described is much like the audio oscillator using 110 volts d-c. In fact the principle is exactly the same. The coil is an air core coil of the proper dimensions to cover the frequency or wave lengths wanted. 25 turns on an oatmeal box if the broadcast band is wanted. The condenser is an ordinary variable condenser. A straight line capacity, 43 plate, .001 μf is assumed. The diagram is given in Figure 161. This outfit when equipped with a lamp cord and plug is ready at a moments notice. A dry cell and a buzzer is connected so

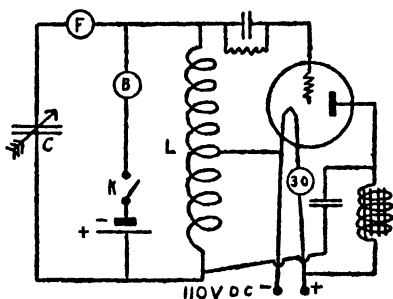


Fig. 161

as to use the outfit as a damped wave transmitter. There will be some discrepancy in the calibration as oscillator and as a damped wave transmitter.

The set may have a coil giving thousands of meters. This can be calibrated by placing the various overtones of the set in unison

with a broadcasting station. Some four or more points on the curve can be had in this manner.

If the condenser is a straight line capacity condenser, λ^2 and dial reading will give a straight line. Several of these oscillators can be made or several coils with one outfit covers the radio spectrum.

A Straight Line Frequency Audio Oscillator.

In a laboratory there is need of a source of alternating current of varying frequency. This need was formerly met by using alternating generators in which the speed of the rotor could be changed. Frequencies from a few cycles up to 3000 cycles were obtained in this manner. Since the three-electrode tube has come into general use, audio oscillators having iron cores have been used, Experiment 57. In order to get any considerable range of frequency it is necessary to substitute several coils and condensers from time to time. This is troublesome, and each coil or condenser calls for a new calibration.

If two oscillators which are oscillating at radio frequency are tuned so they are near the same frequency a continuous note is heard in a telephone which is connected to one of the oscillators. This note is due to the alternating currents producing beats, caused by the difference of the frequencies of the oscillators. The frequency of this current can be made anything from near zero to frequencies above the limits of hearing. The intensity of this current is small but this can be amplified to usable values by means of a resistance amplifier.

If one takes an ordinary .001 μ f semicircular plate variable condenser and a coil which will give a maximum wave length of about 12,000 meters and plots the frequency curve for the combination, one will get a curve which has great curvature for small capacity and becomes almost a straight line for the higher values of the capacity. One can choose two points on the curve such that the difference of the capacity is .00025 microfarads and the difference in the frequency is 5000 cycles. This curve between the two points is not far from a straight line. If one has two such oscillators and sets them so as to oscillate at the particular frequency corresponding to the first point, places a .00025 condenser set at zero in parallel with one of the condensers, and then changes the capacity of the small condenser, he can get any audio frequency he wishes between zero cycles and 5000 cycles per second. The small

condenser should be made of semicircular plates so that the capacity is proportional to the dial setting. With a 0 to 100 division dial each division on the dial corresponds to 50 cycles.

The curves in Figure 162 give the calibration of an oscillator which consisted of a 400 turn honey-comb coil and a .001 microfarad variable air condenser with a 0 to 100 dial. Since the capacity was found to be proportional to the dial readings the abscissas are plotted as dial readings instead of in terms of capacity. The straight line was obtained by plotting the square of the wave length λ^2 ,

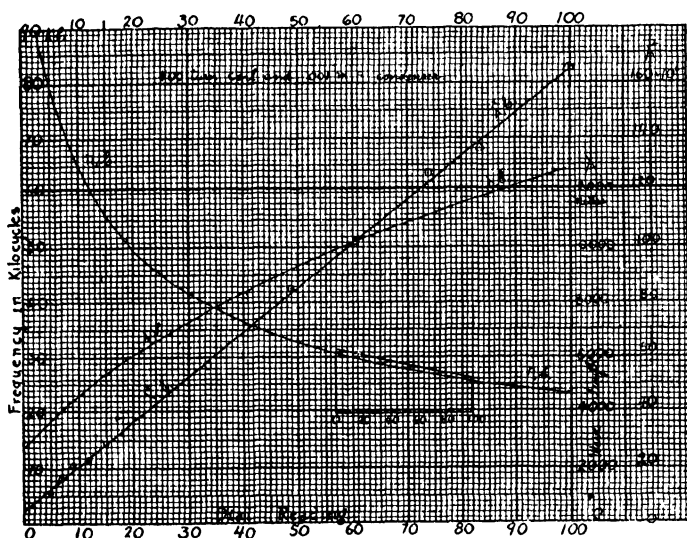


Fig. 162. Calibration curves of the audio oscillator. The curve showing the frequency is approximately a straight line through a change of frequency of 5000 vibrations.

against the dial readings. The data for this curve were obtained by comparing the oscillator to an oscillating wave meter whose maximum range was 5000 meters.

The fundamental, first and second overtones was used in getting this line. From this line wave length curve and frequency curves were gotten as in Experiment 36.

The lower end of the curve flattens out and a small portion of it is not far from a straight line. It will be noted that the frequency which corresponds to 57 on the dial differs from the frequency

which corresponds to 82 on the dial by exactly five kilocycles or 5000 vibrations. The capacity change between the two points corresponds to 25 divisions on the dial, or one-fourth of the total of the .001 condenser, or .00025 microfarads. In Figure 162 a straight line has been drawn just above the curve connecting these points, in order to show how near the curve approaches a straight line.

If the oscillator condenser is clamped so as to remain fixed at the value corresponding to 57, and a .00025 condenser is placed in parallel and set at zero capacity, and a second oscillator is set so that the beat frequency between the two oscillators is zero then

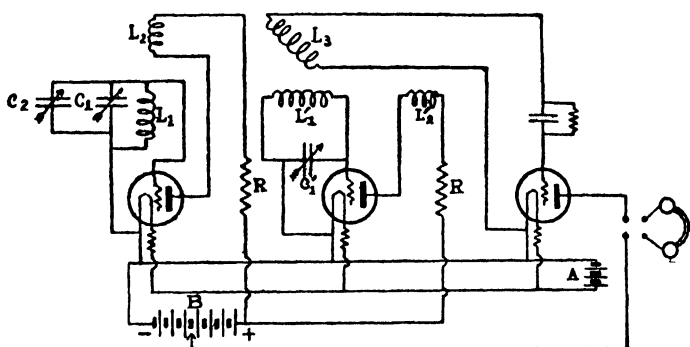


Fig. 163. Diagram of the connections of the audio oscillator.

as the small condenser is changed the beat frequency will change from zero to 5000 as the condenser dial readings change from zero to 100.

If more accuracy is needed, the frequency should be read off of the curve between the two points instead of off of the straight line. Using the straight line the average error is about five per cent.

The diagram of the connections is shown in Figure 163. The oscillators consist of a honey-comb coil of 400 turns, with a tickler coil of 150 turns, in the plate circuit, $L_1L_1^1$, $L_2L_2^1$ and a .001 μf variable air condenser, C_1 and C_1^1 . Resistances of 20,000 ohms are inserted one each in the plate circuit of the tubes which were 01A amplifier tubes. The B battery was 45 volts. The purpose of the resistances is to suppress harmonics in the oscillator.

The coils of the two oscillators are placed so that one set of coils is perpendicular to the other set of coils. The pick-up coil, L_3 , is a 1200 turn honey-comb coil connected to a detector tube. This coil

is placed so as to make angles of about 45° with each oscillator. C_2 is the .00025 microfarad condenser placed in parallel with C_1 . The intensity of the current as it comes from the detector is great enough for most work where a head set is used. One stage of amplification makes the intensity about right. Two stages make the intensity very loud. The intensity changes to some extent with the frequency.

In many cases the change with frequency is immaterial, since null methods are used.

The oscillator is very simple in construction and is one that can be made in most laboratories, either permanently or "scrambled"

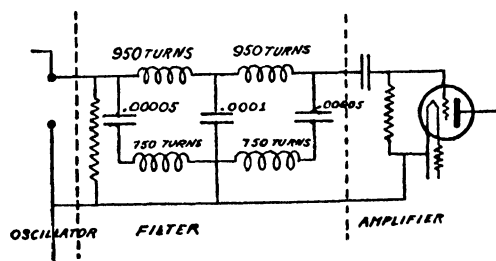


Fig. 164

together for the occasion. If the tubes are pentodes so that the plates are "electron coupled" and the oscillators are placed in separate screen compartments the set can be made to give very low frequencies. With tri-

odes the two oscillators tend to lock together when these two frequencies are near the same value.

To insure good tone quality a filter should be placed between the oscillator and the amplifier. Such a filter is shown in Figure 164.

CONSTRUCTION OF AN ELECTROSCOPE OR ELECTROSTATIC VOLTMETER

Instead of an electrostatic voltmeter an electroscope can be used in Experiment 62.

This electroscope is patterned after the electroscopes used in the measurement of radio-active substances such as radium. A radio-activity electroscope can be used if one is at hand. The case of the electroscope is a can $2\frac{3}{4} \times 3\frac{1}{4} \times 5$ inches with a lid made of sheet tin by a tinner. Openings or windows 1×2 inches are cut in the side of the can. The lower edge of these windows are $1\frac{1}{2}$ inches from the bottom. The edges are $\frac{1}{2}$ and $\frac{3}{4}$ inch from the sides. These are placed in the broad sides. On the outside of the can rectangular

tubes are soldered about the windows. These tubes are $1\frac{3}{4}$ inches long and of such dimensions as to leave $\frac{1}{4}$ inch spare between the edge of the window and the inside of the tube. The elevation and plan of the electroscope is shown in Figure 165. In one of the narrow sides a hole with a collar about $\frac{3}{4}$ inch in diameter is placed. The center of this opening is $1\frac{1}{2}$ inches from the top.

In the short cylinder a rod which has one end bent up at right angles to the rod is insulated by pouring melted sulphur into the cylinder while the rod is supported in proper position by a cork which extends a short distance into the cylinder. After a few hours the cork can be removed leaving the sulphur plug. In melting the sulphur, care must be used not to get the sulphur too hot or to burn it. The melted sulphur must be clear amber liquid. If the sulphur takes the waxy condition it should be discarded.

The leaf is attached to a narrow plate which is supported on the bent end of the rod by means of a short length of small tube which is soldered to the back side of the plate and which fits snugly over the bent end of the rod. The leaf which is a narrow strip of gold or aluminum foil should be attached to the plate with gum from a postage stamp so as to be straight and to swing freely, bending at a point near the plate.

Opposite to the insulated plate is a second plate of metal so placed that its position can be altered and thus change the sensitivity of the electroscope.

To read the deflection a scale, *S*, as shown in the plan is mounted on the back window. A strip of cross section paper, stuck to the glass with paraffin while hot, will answer. The paraffin serves two purposes; it sticks the paper to the glass and renders the scale translucent. Half way between the scale and the leaf system a mirror, *M*, is mounted. This mirror may be a narrow strip of an

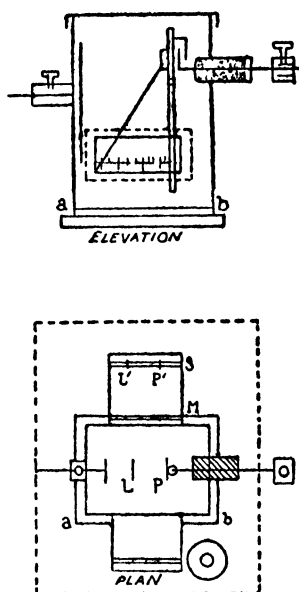


Fig. 165

ordinary mirror. Through the front window one sees in the mirror images of the plate, P , and the foil, L , at P' , and L' . These images are in the same plane as the scale, S , which can be viewed by looking over the mirror, M . The position of L' can be read on the scale, S , and after the position has changed, its position can be noted again. By comparing the two positions with the calibration curve of the electroscope the change of potential dV_p can be obtained.

Calibration of Leaf. The instrument can be calibrated by connecting to known potentials and noting the deflection of the leaf. A AB battery with taps is convenient, Figure 166. The power supply

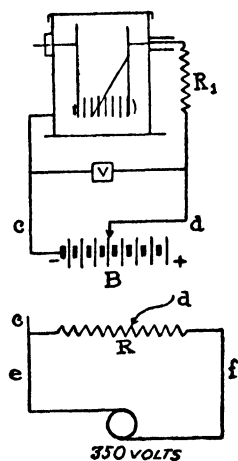


Fig. 166

described later is convenient. Readings should be taken every five volts from 0 up through the maximum deflection. A curve, Figure 167, can be plotted using $X = \text{deflections}$, $V = \text{volts}$. Since it may be necessary to change the sensibility of the electroscope by means of the movable plate in order to obtain convenient deflections it is well to calibrate the electroscope after using it in the experiment. Care must be taken to calibrate it with the movable plate and all other parts in the same relative position as they were in the experiment. A small camera level attached to the base of the instrument makes it convenient to set the electroscope in the same position every time.

There is danger when using the electroscope that the potential may be great enough to deflect the leaf until it touches the movable plate and short circuits the battery. This will fuse the leaf and a new one must be placed. A resistance such as a grid leak resistance may be placed in series with the leaf and thus protect the leaf from heavy current, if d-c is used for calibration. The narrower the leaf is cut the more sensitive the instrument will be. Aluminum leaf cut 1 millimeter wide will be extremely sensitive. Five volts per millimeter deflection is good. Cut the leaf between paper with a sharp safety razor blade. The paper and foil is held on a sheet of glass by means of a straight edged ruler.

Instead of a d-c generator a transformer can be used for calibration if one has an a-c voltmeter. For extremely high potentials, 10 to 30 kilovolts, a high potential transformer can be used. The potential of the transformer can be approximately determined by the voltage ratio of the transformer when the transformer is not loaded. This is done by placing a small a-c potential, 4 or 5 volts on the primary and measuring the potential of the secondary coil by means of a calibrated electrostatic voltmeter. The maximum range of this voltmeter being about 500 volts. From the known potentials the ratio can be determined. Having the voltage ratio the potential of the transformer can be computed when the primary voltage is varied from 30 to 110 volts. The voltage of the secondary in both cases is the open circuit voltage since the current taken by the electrostatic voltmeter is of the order of 10 microamperes or less. When using d-c a grid leak

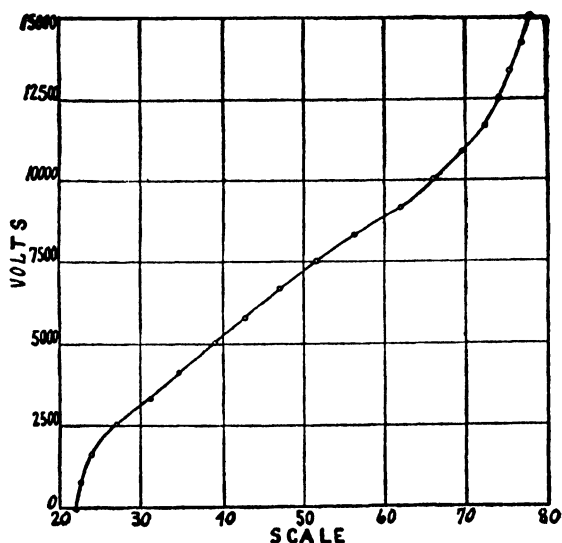


Fig. 167

resistance can be placed in series with the electrostatic voltmeter for safety. When using a-c the grid leak can not be used.

The following are the maximum potential ranges of the above instrument: with an aluminum foil leaf 1 millimeter wide, 75 to 300 volts; with a gold foil leaf 1 centimeter wide, 100 to 500 volts; with a leaf made of sheet aluminum .05 millimeter thick and 9 millimeters wide, 500 to 3000 volts. This last is the upper limit of a instrument of the above dimensions since the distances between parts are small and sparking began at about 3500 volts. For 30,000 volts the distance between parts should not be less than about 2

inches. For this potential the case should be about $6 \times 9 \times 15$ inches with other parts in proportion. The leaf should be made of heavier sheet metal and suspended so as to hinge over a small wire. The sheet will not bend as does the foil. The leaf of .05 millimeter foil is hinged by hanging over a small wire. The insulation in the larger instrument is a disc of hard rubber or "Bakelite" at least 4 inches in diameter fastened in a hole in the side of the case. All sharp corners and points should be rounded off.

Figure 167 is a calibration curve of an instrument made according to the above directions. The case of this instrument is a five gallon oil can. With a heavier "leaf" higher potential can be measured.

The power used in such an instrument is approximately zero, since it is essentially a condenser whose capacity is very small. The capacity of the smaller instrument is from 5 to 10 centimeters. The larger instrument should not be more.

J. A. Swindler, Phys. Rev., Vol. 18, p. 1140, 1926.

Power Supply. Figure 46 page 48 is a diagram of a laboratory power supply which has proven to be very convenient. A 60 cycle power transformer is used. This transformer has a high potential coil and a number of low potential coils. One of these low potential coils is used for the heater of the rectifier tube which may be an 80, 82 or other two electrode tube or a raytheon tube can be used in which case a heater coil is not used.

The rectifier tube is connected as in Figure 46 through the proper choke coils with by-pass condensers forming a filter. The "bleeder" resistance is composed of five small lamps, $7\frac{1}{2}$ watts, in series with one 15 watt tube. The potential around the $7\frac{1}{2}$ tube is about 60 volts and that around the 15 watt tube is about 20 volts. By changing the positions of tubes one has any potential within certain limits from 20 to 250 volts for plate supply.

The lamp on the negative end is in multiple with a potentiometer. This gives a variable C supply of up to about 20 volts. The extra coils have potentials of $1\frac{1}{2}$, 2.5, 5 and 6.3 volts for heater supply.

The diagram shows the supply connected for the mutual characteristic curves of a 27 tube or 56 tube.

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