# DESIGN AND CONSTRUCTION OF A RADIO STATION

BY

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ARMOUR INSTITUTE OF TECHNOLOGY

1920

# The Design and Construction of a Radio Station for the Armour Institute of Technology

A THESIS

PRESENTED BY

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TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE

IN

ELECTRICAL ENGINEERING

MAY 27, 1920

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## Object

The object of this thesis is to design and construct a radio station at Armour Institute of Technology, Chicago, Illinois.

INDEX OF PHOTOGRAPHS

# I. INTRODUCTION.

Since its founding in the Fall of 1914, the Armour Radio Association has felt the lack of an actual station with real apparatus. This thesis describes the station which has been built to fill this need.

The present radio apparatus of the Physics Department has been used as far as possible and other needed apparatus has been purchased or constructed. The station is located in a room of the Physics laboratory on the second floor of Chapin Hall. The antennae are supported by the towers on the Armour Flats and the Mission Building and by a wooden mast on the roof of Chapin Hall. Calibration curves, diagrams of connections, photographs, constants of circuits, etc. have been made for the systems set up and tested so that the results may be duplicated if parts of the station should be disconnected for experimental work.

A special government license has been taken out which will allow the members to operate on wave lengths of 200 and 375 meters. The chief operator will supervise this operation.

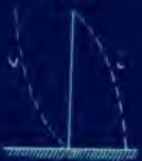
## 2. ANTENNA.

THEORY_ The simplest form of antenna is a single vertical wire, the lower end of which is connected to ground. This forms an oscillatory circuit, the inductance is due to the wire, and the capacity is that between the wire and ground. Thus in Fig I the capacity and inductance and the flow of current at any instant of time are shown diagrammatically. Some of the current from this wire is continually flowing off by the capacity paths to ground, so that the maximum current is flowing at the base of the antenna, while at the extreme top there is no current flowing in the wire. The distribution of current and voltage is approximately sinusoidal and is shown in Fig 2. This represents the fundamental oscillation of a simple antenna. The length of the wire is equal to the distance from node to loop or is one-fourth of the wave length. It is possible for the simple antenna to oscillate with other distributions of current and voltage as in Fig 3 where is

FIG 1

DISTRIBUTED CAPACITY AND INDUCTANCE IN A SIMPLE ANTENNA.

FIG 2

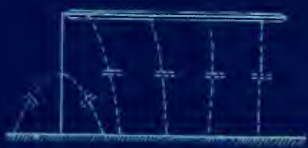



DISTRIBUTION OF CURRENT AND VOLTAGE AT FUNDAMENTAL FREQUENCY.

FIG 3

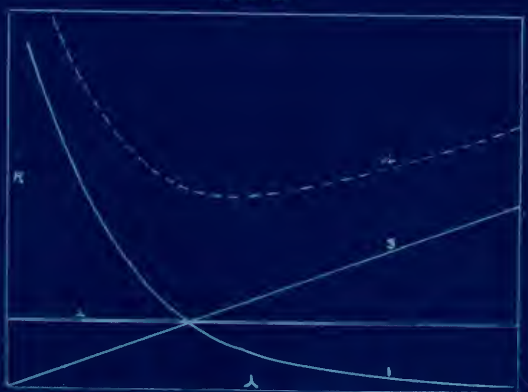

DISTRIBUTION OF V AND i IN SIMPLE ANTENNA AT 1ST HARMONIC

FIG 4



FORM OF ANTENNA OF LARGE CAPACITY.

FIG 6




VARIATION OF ANTENNA RESISTANCE WITH λ.

shown the next possible oscillation. Here the length of the wire is three-fourths of a wave length. Hence the wave length is one-third of the fundamental or the frequency is three times as great. Other possible oscillations have frequencies of five, seven, nine, etc times the fundamental.

ANTENNA WITH LARGE END CAPACITY. Suppose that a number of long horizontal wires are attached to the top of the vertical wire of the simple antenna, thus forming an inverted "L" antenna as in Fig 4. In this case only a small proportion of the current in the vertical portion flows off to ground through capacity paths, the main capacity flow taking place from the horizontal portion. Thus the current throughout the vertical portion will be very nearly constant. The total capacity will be much larger than that of the simple antenna and the inductance likewise somewhat larger, hence the wave length will be considerably increased.

There are a number of other forms of antennas which also have large capacity areas at the top of the vertical lead such as the "T", "umbrella" etc.

ANTENNA RESISTANCE_ The power supplied to maintain oscillations in an antenna is dissipated in three ways: (I) Radiation; (2) Heat;due to conductor resistance; (3) Heat due to dielectric absorption. ( At high voltages there is a further power loss due to brush discharge). The first of these represents the only useful dissipation of power since it is the power which travels out from the antenna in the form of the electro-magnetic waves which transmit the radio signals. The amount of power radiated depends upon the form of the antenna, is proportional to the square of the current flowing at the current antinode of the antenna, and is inversely proportional to the square of the wave length of the oscillation. Since the dissipation of power is proportional to the square of the current, it may be considered to be caused by an equivalent

or effective resistance which is called the radiation resistance of an antenna. Thus the radiation resistance of an antenna is that resistance which if inserted in the antinode of current in the antenna would dissipate the same power as that radiated by the antenna. The radiation resistance varies with the wave length in the same way as the radiated power i.e., inversely as the square of the wave length. Curve I of Fig 5 represents the variation of this component of the resistance of an antenna.

The second source of dissipation of power that due to ohmic resistance includes the losses in the resistance of the wires, ground etc., of the antenna. Due to eddy currents and skin effect in both the wires and ground, this resistance will vary somewhat with the wavelength, being greater at short wave lengths, but in an actual antenna these changes are so small compared to other variations that we may regard this component of the total antenna resistance to be almost constant, as it is

represented by the straight line 2 of Fig 5.

The third source of power dissipation i.e., that due to dielectric absorption is a result of the fact that the antenna capacity is an imperfect condenser. The magnitude of this power loss will depend upon the nature and position of imperfect dielectrics in the field of the antenna. Thus it has been found that a tree under an antenna may increase the resistance of the antenna enormously; buildings, wooden masts, and the antenna insulators also effect the absorption of the antenna capacity. The effective resistance of an absorbing condenser is proportional to the wave length. In the antenna therefore, the loss of power due to dielectric absorption may be represented as taking place in a resistance which increases in proportion to the wave length. This component of the antenna resistance is represented in Fig 5 by the straight line 3. The curve of the total antenna resistance is obtained by combining these three

resistance components as in curve 4 of the same figure. This is a typical resistance curve of an antenna.

STATIC AND MAGNETIC FIELDS_ If a long wire is placed vertically and positive and negative charges are alternately applied at the bottom and flow along the wire, there will be near the wire alternately static fields due to the charges; and at the same time alternately opposite magnetic fields, due to the alternating currents. Fig 6 shows in perspective the wire with a positive charge surrounded by its vertical static field s and its horizontal field m and Fig 7 the wire with a negative charge and both its fields reversed in direction.

RADIATION OF MAGNETIC WAVES_ These two fields of force changing their direction and intensity with great rapidity and traveling outward from the wire in the medium called the ether with the velocity of light, three hundred million meters per second, are the electromagnetic waves of radio telegraphy. They

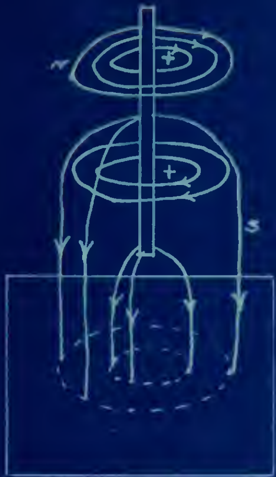



FIG 6


FIG 7

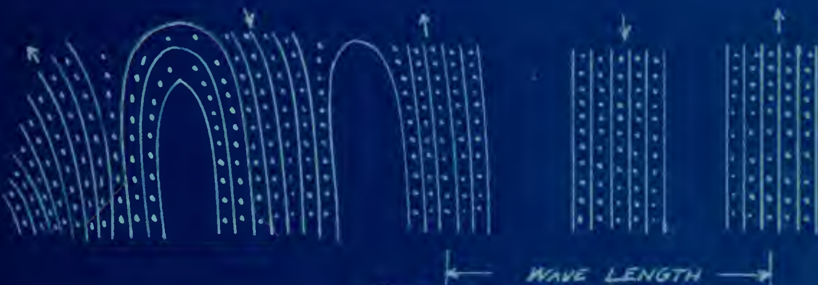



FIG 8

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spread simultaneously radially outward and upward from the vertical wire or antenna.The energy of the varying electric charges and currents is thus imparted to the medium or is radiated. The two fields constituting the wave and their outward motion in radiation are shown in a general way in Fig 8 where the field is indicated as lines and the magnetic field as dots, this latter being necessary because the magnetic field is perpendicular to the plane of the paper. At great distances from the transmitting antenna the static lines become straight and perpendicular to the surface of the earth and the magnetic lines straight and parallel to the surface.

These static and magnetic lines of force moving with the velocity of light, sweep across the antenna of the receiving station. The vertical static lines in the wave are directed alternately upward and downward and produce in the antenna moving charges of alternately opposite signs, that is alternating current. At the same time the horizontal magnetic lines

are directed alternately to the right and left and when cutting across the antenna produce an alternating current in it . The resultant current generated by these two fields gives an alternating current in the receiving antenna quite similar to that in the transmitting antenna although of course much weaker. It is these alternating currents which produce the signals in the receiving apparatus.

DESCRIPTION OF THE ANTENNAE._ Two antenna have been strung up, a short one for transmitting and receiving on short wave lengths, and a long one for receiving on long wave lengths. The short one of "T" type has in the horizontal portion four sixty foot #12 single copper wires with four foot spacing and four wires to form the rat-tail and lead-in to the set. A thirty foot wooden mast on Chapin Hall supports one end and the top of the Mission Building the other end giving a total height of seventy feet. The lead-in passes down fifty-

two feet to the second floor of Chapin Hall and into the radio room located there, and thence I8 feet to a pipe driven into the ground. A ground connection is also made on the steam piping system of the building. Eight-inch electrose insulators afford the necessary antenna insulation. The galvanized iron guy-wires which brace the mast are separated at the top in fastening to the 2 by 4 inch pole and also broken once in the middle of each by a strain insulator to decrease absorption and re-radiation of energy by them. Pulleys and ropes allow the antenna to be raised and lowered.

The long antenna consists of a single #I2 copper wire "T" type seventy feet in height supported by the towers on the Armour Flats and the Mission Building. One arm three hundred and eleven feet extends in a north and south direction, the other two hundred and twenty-four feet in a southwest-northeast direction. The single wire lead passes down to the window sill of the radio room. Each lead-in is connected to the blade of its own

SPDT IOO ampere lighting switch one jaw of which is grounded through a #4 copper wire to a grounded pipe driven six feet into the ground, the other jaw of which is passed through an insulator to the station apparatus. Hence either or both of the antennae may be grounded or led into the station. The photograph shows the mast and antennae with their lead-in wires.

ANTENNA CONSTANTS_ A small spark-gap was placed in the unloaded circuit of the small antenna and energized from the transmitting transformer of the spark set. A wave meter placed near the lead-in wire then may be made to read the fundamental wave length at which the circuit oscillates. This value was one hundred and seventy meters for the short and five hundred and sixty-five meters for the long antenna.

A loading coil was then placed in series with the antenna and the wave length again read. The short antenna loaded gave three

hundred and twelve meters, and the long, six hundred and thirty-five meters. The inductance of the load coil was calculated as follows:

$$Ls = \frac{.03948 \times 8.25^2 \times 13^2 \times .6256}{12.5} = 22.26$$

micro-henry

from the equation

$$Ls = \frac{.03948 \times a^2 \times n^2 \times K}{b} = \text{microhenries}$$

where $n$ = number of turns

$a$ = radius of coil

$b$ = length of coil

$K$ = a factor depending upon $\frac{2a}{b}$ found from a table in the Bul. Stds. No. 74.

Using a correction equation

$$Lo = Ls - .01257 \times n \times a(A + B) \text{ microhenry}$$

where $Lo$ = low frequency inductance

$D$ = pitch of winding

$B$ = length of the equivalent current sheet = $nD$

$A$ = diameter of bare wire

and substituting the proper values

$$Lo = 22.62 - .01257 \times 13 \times 8.25(-.830 + .278)$$

$$= 23.522 \text{ microhenries}$$

The antenna inductance equals

$$L = \frac{\lambda_1^2 \ell}{\lambda_2^2 - \lambda_1^2} = \frac{160^2 X .023522}{312^2 - 160^2} = .00872 \text{ millihenry}$$

Similarly for the large antenna

$$L = \frac{565^2 X .023522}{635^2 - 565^2} = .089 \text{ millihenry}$$

The capacity of the small antenna was obtained from the formula

$$C = \frac{.00028I \lambda_2^2 - \lambda_1^2}{I,000,000 X 1} = \frac{.00028I X 7I800}{I,000,000 X .023522} =$$

.000858 MF

Similarly for the large antenna

$$C = \frac{.00028I X 84300}{I,000,000 X .023522} = .00I \text{ MF}$$

3. Spark Transmitter

Theory_ In Fig 9 is shown a typical circuit for the generation of high frequency oscillations by means of a spark discharge. The alternator supplies the low voltage winding P of a step-up transformer. The high voltage side S leads to the terminals of the condenser C across which is an inductance L and spark-gap G in series. The coil L is loosely coupled to the antenna circuit Lm in transmitting. During an alternation, as the voltage across S increases the condenser C becomes charged and discharges through the inductance L and the gap G. The discharge consists of a train of oscillations of a frequency approximately corresponding to the inductance and capacity of the circuit. It is possible to adjust the voltage of the transformer and the length of the gap so that the discharge takes place when the voltage is at a maximum either positive or negative. In this case one spark and one train of oscillations is obtained per alternation of the supply, thus with a sixty cycle generator the

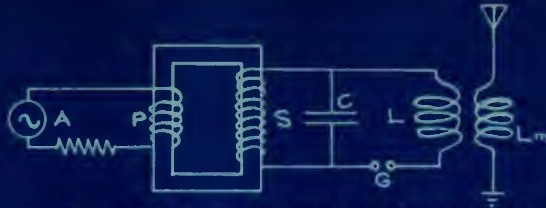



FIG 9 SPARK CIRCUIT FOR H.F. OSCILLATIONS


FIG 10 TWO SPARK DISCHARGES PER CYCLE.

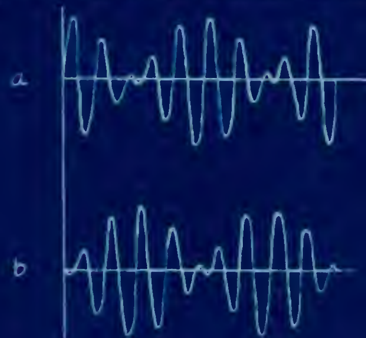



FIG 11 CURRENT (a) PRIMARY AND (b) SECONDARY FOR ORDINARY GAP.

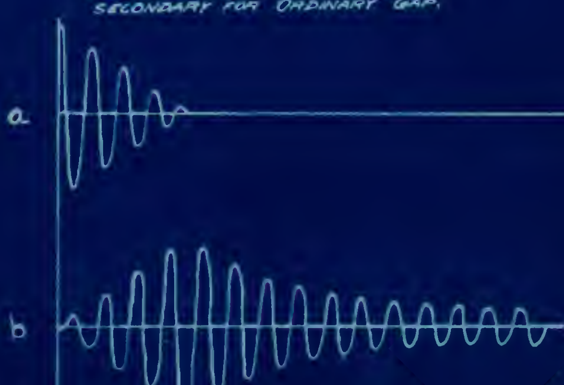



FIG 12 QUENCHED GAP

spark frequency will be one hundred and twenty. By shortening the gap or raising the voltage several discharges per alternation may be obtained. These are called partial discharges and occur somewhat irregularly. The first case is illustrated in Fig IO. In (a) is shown the transformer secondary voltage as it would be if the spark gap were absent. In (b) is shown the current oscillation in the condenser discharge. The spark-gap has an effect upon the damping of the oscillations of the high- frequency train. In a circuit with constant resistance the amplitude would decrease exponentially but in the case of a circuit with a spark-gap the decrease of amplitude tends to become linear. This is due to the increase of the spark as the amplitude of the current decreases, the effect depending upon the material in the electrodes etc.

A serious difficulty in the operation of the spark circuit is caused by the short-circuiting of the transformer secondary by

the spark. As a result there is a heavy flow of current through the gap causing the formation of an arc which reduces the amplitude of the oscillations and distroys the electrodes. In order to eliminate this difficulty the resonance transformer is used. The alternator, transformer, and secondary condenser are adjusted to make a system which is in resonance for the alternator frequency. When the condenser is short-circuited by the spark the condition of resonance is destroyed, and in effect this is equivalent to the sudden insertion of a reactance in the transformer primary. As a result, there is no heavy flow of current through the gap.

In order to obtain constant high-frequency current with a simple spark gap it is desirable to use a low spark frequency in order to prevent heating of the gap which would lead to arcing. Magnesium electrodes have been found to give the best results and to furnish oscillations most closely logarithmic in damping.

If the resonance transformer is not used the arcing across the gap may be reduced by inserting resistance or inductance coils in the primary of the transformer and by employing an air blast to blow out the arc. Or in place of a simple gap a rotary gap may be utilized. Its characteristics are intermediate between those of a simple and a quenched spark gap.

It has been found that if a series of short spark gaps be substituted for a single long gap and a discharge passed through them the discharge path returns much more quickly after the discharge to its initial condition of high resistance . This is a result of the more rapid deionization of the gap and is called the quenching action. The quenching action is increased if the surfaces of the gaps are of silver or of copper and the gap is kept cool and air-tight. The metal discs are separated by rings of insulating paper mica, or rubber and are about two-tenths of

millimeter thick. A number of such gaps are stacked in series and clamped together and either the leads to the gaps are provided with clips so that the number of gaps used may be varied or means are provided for short-circuiting as many of the gaps as desired.

While close coupling with the secondary circuit in the case of ordinary spark gaps is to be avoided, since it causes the generation of two frequencies of which only one can be utilized, good working of the quenched gap on the other hand requires a close coupling between the primary and secondary circuits. This secures high efficiency and still permits a single wave to be obtained. The explanation is as follows: Assume first that the primary circuit contains an ordinary spark gap, the secondary ( which may be an antenna) is fairly closely coupled to the primary and that the two circuits when separated have the same natural frequency.

Due to the coupling oscillations of two frequencies one lower and one higher than that common to the uncoupled circuits will result in both circuits after the discharge takes place in the primary. The combination of the two frequencies will result in beats in both circuits, the amplitude of the resultant oscillation will rise to a maximum and fall to a minimum in each circuit, being a maximum in the primary when a minimum in the secondary and vica-versa. As a result the total energy of the oscillations (excepting that dissipated) is transferred back and forth between the two circuits. Although the current in the primary circuit may pass through a zero value the rapidity of deionization of the ordinary spark gap is not sufficient to render it nonconducting in the short interval of time available and the spark reignites. The phenomina are shown in Fig II where (a) represents the voltage oscillations in the primary and (b) the oscil-

lations in the secondary.

If on the other hand a quenched gap is used and the coupling between the primary and secondary is favorable it will become deionized when the primary oscillations are a minimum and thus prevent reignition. At this time all of the energy has been transferred to the secondary and since the primary has become inoperative, this energy will be dissipated in a train of oscillations of which the frequency and damping are determined entirely by the constants of the secondary circuit. The oscillations of the primary and secondary are shown in (a) and (b) of Fig I2. In ideal operation the time during which the primary circuit is operative will be extremely short there will be only the one frequency, and since the major loss of power takes place in the high resistance primary circuit the efficiency will be high. With proper operation the primary circuit may remain in operation until the second

or third minimum.

The connections for the quenched gap are similar to those of a plain spark gap using a resonance transformer. Best operation is generally obtained when the inductance in the primary circuit is somewhat greater than that required for resonance. On account of the rapid quenching of the gap, the supply alternator may have a frequency of five hundred cycles and adjustments made so as to obtain one spark per alternation.

Efficiency of Transmitter_ The antenna resistance, the radiation resistance and the antenna all change as the frequency or wave length changes. If at any one frequency or wavelength the square of the antenna current in amperes is multiplied by the antenna resistance in ohms the product $I^2R$ is in watts and represents the power delivered by the closed oscillating circuit to the antenna. That is, it is the antenna input, as it is sometimes called, or the watts in the anten-

na. If the number of watts delivered by the alternator is known the efficiency from alternator to antenna can be found by dividing the watts in the antenna by the watts in the alternator. In the earlier types of spark sets this value was as low as ten or twenty per cent, whereas in modern quenched spark sets it may be as high as fifty per cent. If a motor-generator set is used and the number of watts delivered to the motor is known, the over-all efficiency can be found similarly by dividing the antenna watts by the motor watts. The percentage thus found will be of course lower than before as it allows for losses in the motor-generator which were not considered in the previous case.

The rating of the earlier radio sets was given as the output of the alternator but in modern sets it is often given as the number of watts delivered to the antenna. In the latter case the antenna inductance, capacity and resistence together with the current and watts at a given wave length must then be

specified.

FREQUENCY IN RADIO MEASUREMENTS_ It will be noted that it has been necessary to speak of the frequency of circuits from two or three different points of view which will be summarized as follows: (I) The frequency of the alternator which depends upon the speed and design of the alternator as from sixty to five hundred cycles per second. This frequency is independent of the radio circuits. (2) The spark frequency or wave-train frequency which depends on the alternator frequency, the capacity of the closed circuit condenser, the voltage at the spark gap, etc as I20 to 500 or I000 sparks per second. (3) The frequency of the oscillations in the radio circuits which depends only on the capacity and inductance in the circuit in question, as I,000,000 oscillations per second for a wave length of 300 meters, or I00,000 oscillations for a wave length of 3,000 meters.

COUPLING_ Since the natural period of a circuit depends upon the self-induction if the effective current is varied. Therefore coupled circuits having the same or nearly the same natural periods are found to have two periods of oscillation one faster and the other slower than the natural period of each. The open radiating circuit generally sends electric waves of two lengths one longer and the other shorter than the natural wave length of the circuit. The closer the coupling the greater the difference of these two waves. This difference divided by the natural wave lengths of the circuits is called the per cent of coupling. For instance if an open circuit having a natural wave length of four hundred meters sends when coupled to a closed circuit of the same natural length two waves one of four hundred and forty-five, the other of three hundred and sixty-five meters the per cent of coupling equals twenty per cent.

If the circuits have loose coupling that is are moved farther apart the mutual induction is less and the difference in wave lengths radiated is less. This distance can be increased until the two waves practically coincide with the natural wave lengths of the circuit. This is very loose coupling but since without mutual induction no energy can be transferred the two can never be the same. Most of the energy is in the long wave and until recently that in the short wave was practically wasted.

LOGARITHMIC DECREMENT OF THE OSCILLATIONS— When electrical oscillations are created in an antenna or other circuit by means of condenser discharges, each electric spark discharge creates a train of oscillations which die away. The oscillations are assumed to decay away according to the law that the ratio of any oscillation to the one preceding is constant. This constant ratio is called the damping of the oscillation and the Naperian logarithm of the ratio of one oscil-

lation to the preceding one is called the logarithmic decrement. Thus let the maximum amplitudes of successive alternations be represented by A1, A2, A3, A4, etc. and $\frac{A1}{A3} = \frac{A3}{A5}$

In terms of logarithms we may write $\frac{A1}{A3} = \varepsilon^{\delta}$ where $\varepsilon$ is the base of the Naperian system of logarithms and $\delta$ a constant termed the logarithmic decrement. By transposition

$$\delta = \log_{\varepsilon} \frac{A1}{A3}$$

The oscillations in a spark discharge can be computed as follows:

$$m = \frac{\log \frac{A1}{Ax} + \delta}{\delta}$$

If we denote the last oscillation by Ax then

$$\frac{A1}{Ax} = 100 \text{ and}$$

since the log of 100 equals 4.605 then

$$m = \frac{4.605 + \delta}{\delta}$$

hence when $\delta$ equals one tenth there will be forty-seven complete oscillations.

The tuning qualities of a train of electric waves from any given transmitter depend greatly upon the decrement of the oscillations

and therefore the determination of the quantity is an important measurement. It is found by experiment that a transmitter having less than twenty-four complete oscillations in the antenna circuit per single spark discharge possesses undesirable tuning qualities and will interfere with the operation of other radio stations not tuned to the same wave length. A group of twenty-four complete oscillations corresponds to a decrement of two-tenths for a complete oscillation which is the arbitrary figure enforced by the United States statutes.

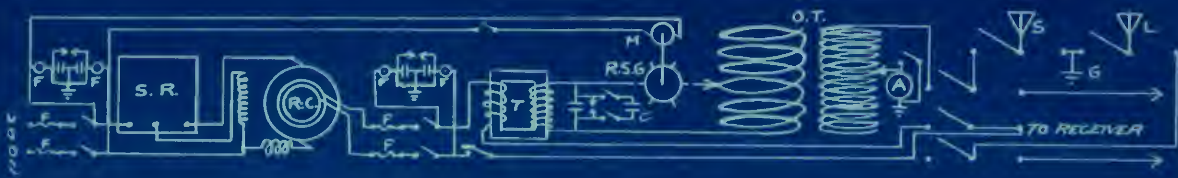
DESCRIPTION OF SET_ The transmitter is a spark type of one-half KW capacity and consists of the following instruments: rotary convertor of one-half KW capacity operated from the IIO volt direct current lighting circuit; Thordason one KW variable magnetic leakage type radio transformer rated secondary voltage 20,000; heavy contact transmitting key; four one microfarad paper condensers with gaps and fuses which protect the convertor from high frequency surges in both the direct current and alternating current low voltage power circuits; three Murdock moulded condensers capacity of each .0017 MF; a six point aluminum spark gap with two sets of copper stationary points; aluminum tube helical type oscillation transformer; and a hot-wire ammeter.

The apparatus is mounted on a panel two by four feet with the starting box, switches, fuses, etc. The key and transfer switch which control the current in the

primary of the transformer will be located on the operating table which carries the receiving panel. The panels are made of clear pine wood well shellaced. A platform two feet by twenty-two inches placed at the bottom of the transmitting panel carries the convertor and supports the panel in an upright position. Successive shelves placed on the rear side of the panel support the transformer, spark gap, condensers, oscillation transformer, . The hot-wire ammeter, starting box, fuses, switches, gaps, etc are placed on the front face of the panel. The panel is placed at right angles to the receiving panel and close to it so that the operator can manipulate the switches without leaving his seat. A protective gap placed across the transmitting condensers protects them from excessive strain in the event that the rotary gap does not operate. The gap motor control switch is placed in a convenient place to the operator's position. A short-circuit switch is placed

in shunt with the hot-wire ammeter to put it out of circuit for ordinary transmission work when the meter is not needed. A pan-cake loading inductance is mounted on the back of the panel and is used in series with secondary of the oscillation transformer when transmitting on three hundred and seventy-five meters. A switch is provided for throwing one section of transmitting condenser into circuit for the two hundred meter wave and all three in for the longer wave. The connections of the instruments are shown in Fig I3. and the general arrangement can be seen in the photograph.

TRANSMITTING PANEL CONNECTIONS
FOR
ONE-HALF KILOWATT, NON-SYNCHRONOUS SPARK,
TWO HUNDRED + THREE HUNDRED AND SEVENTY-FIVE
METER SET.




F = FUSE
S.R. = STARTING RHEOSTAT
R.C. = ROTARY CONVERTER
T = VOLTAGE TRANSFORMER
C = TRANSMITTING CONDENSER
R.S.G. = ROTARY SPARK GAP

M = MOTOR
O.T. = OSCILLATION TRANSFORMER
A = HOT WIRE AMMETER
S = SMALL ANTENNA
L = LARGE ANTENNA
G = GROUND

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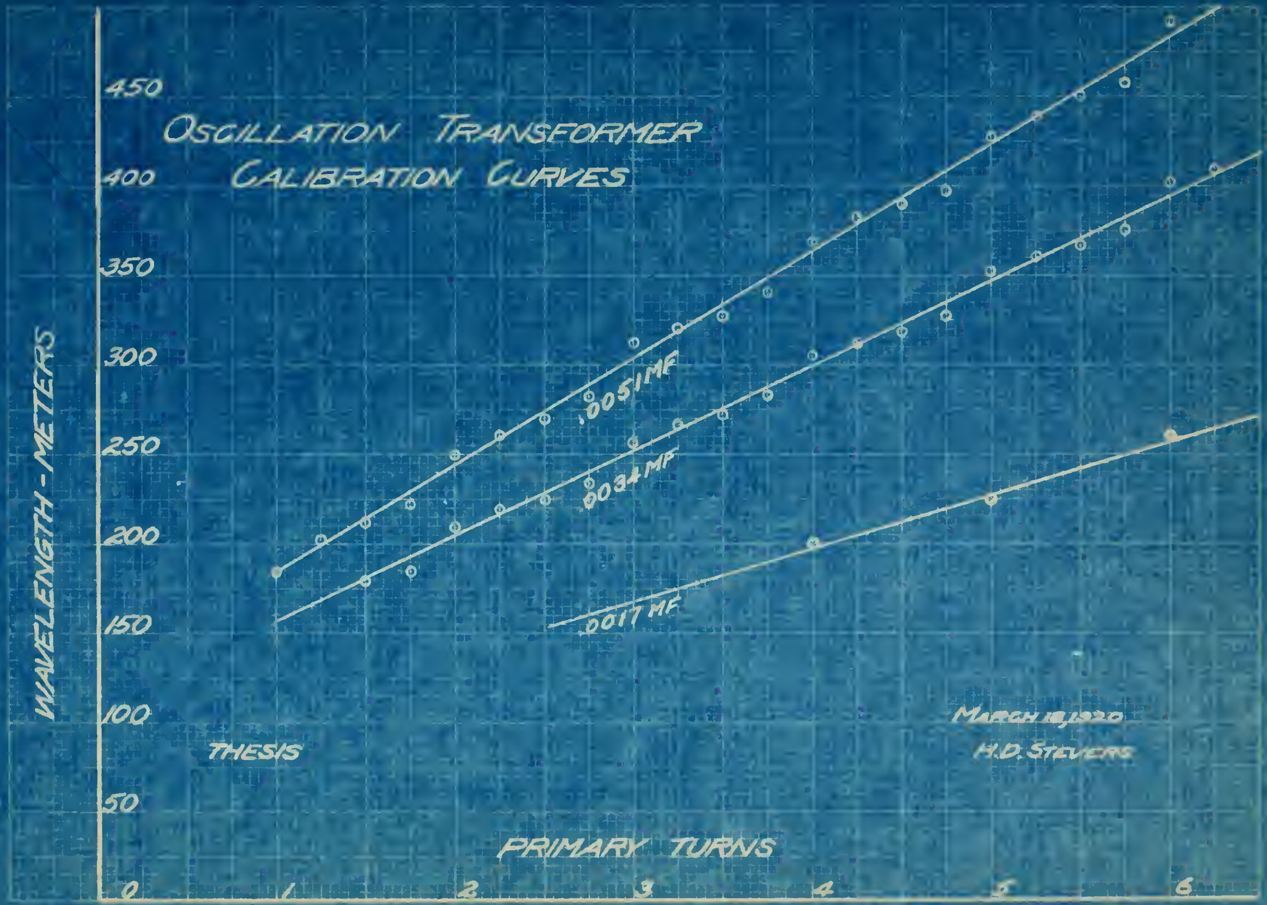
FIG 13

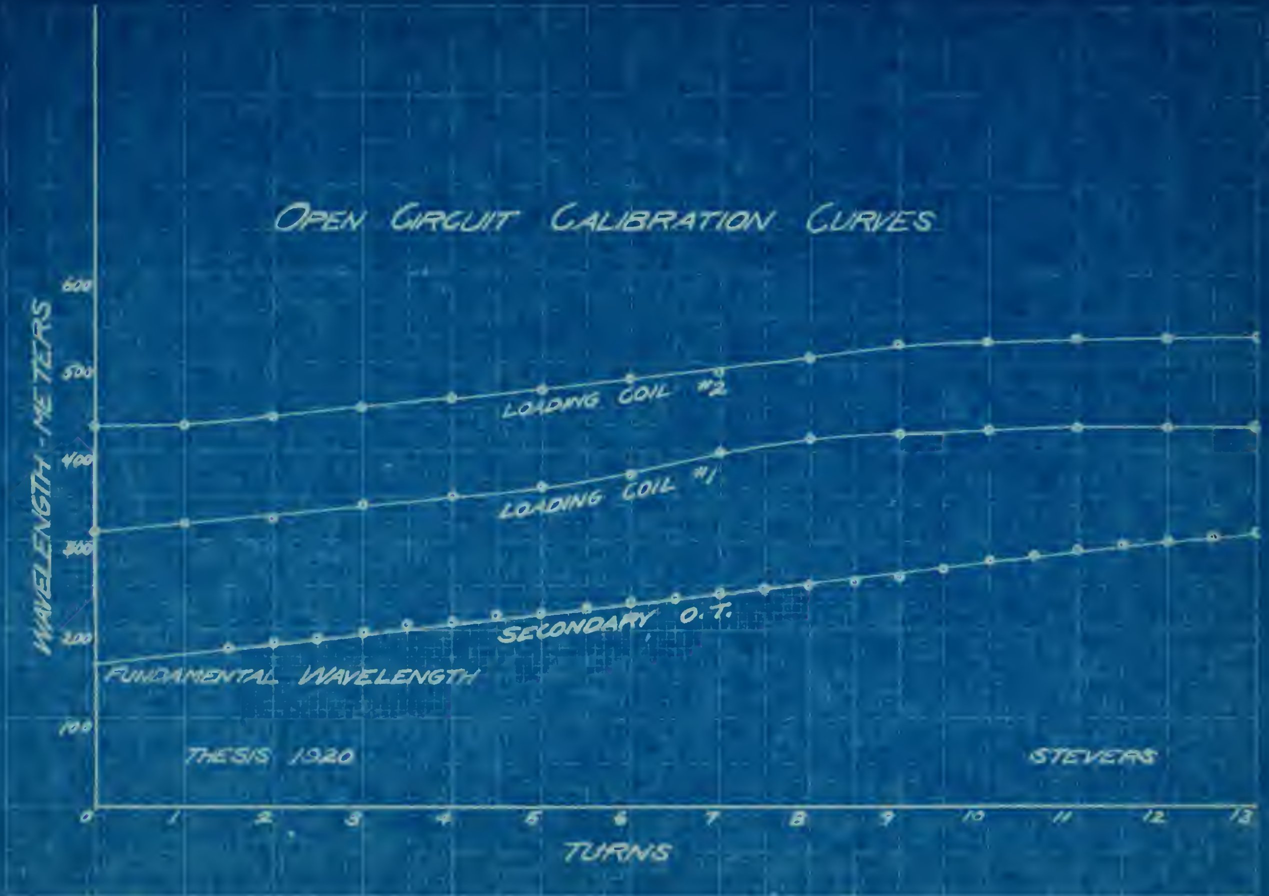
TRANSMITTER CONSTANTS_ Data for the oscillation transformer was taken with a wavemeter. First the secondary of the oscillation transformer was removed. A set of readings of wave length with one, two and three sections in turn were taken by varying the primary inductance in quarter turn steps. One lead from the condenser was fastened to the lowest point of the primary and the other from the rotary gap was equipped with a clip so that it could be clipped on at any desired point. Curves of wave length against turns of primary inductance show graphically the results as obtained. The reason for the points of the curve following the peculiar arrangement in groups of four comes from the effect of the inductance of the variable lead. Which on one side of the coil adds and the other side subtracts. But inasmuch as this lead is necessary in the actual operation of the set its error cannot be avoided. A switch provides a means of throwing in different



OSCILLATION TRANSFORMER
CALIBRATION CURVES
.0051 MF
.0034 MF
.0017 MF
WAVELENGTH - METERS
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
PRIMARY TURNS
THESIS
MARCH 18, 1920
H.D. STEVERS

amounts of condenser for the various wave lengths.

The primary inductance connections were then taken off and leads were run from the voltage transformer to a small gap in the antenna circuit in which was placed the secondary of the oscillation transformer. Readings of wave length against turns then were made. A loading coil was inserted in the circuit for lengths up to three hundred and seventy-five meters. These results are plotted as shown in curves. These curves serve to indicate the number of turns of inductance to take to obtain a given wave length. The clips however are then adjusted by trial to get the best radiation of energy from the antenna, correct wave length and proper coupling. For the three seventy-five meter wave three and one-half turns of primary , three condensers, thirteen turns of secondary, and twelve turns of loading coil are used. The proper places for the clips



OPEN CIRCUIT CALIBRATION CURVES
WAVELENGTH - METERS
600
500
400
300
200
100
LOADING COIL #2
LOADING COIL #1
SECONDARY O.T.
FUNDAMENTAL WAVELENGTH
THESIS 1920
STEVERS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
TURNS

are marked by tags. The two hundred meter wave is obtained by using 4.5 turns of primary inductance with one condenser and five turns of secondary.

On the shorter wave length an antenna current of 1.2 is obtained and for the longer one 2 amperes . The following set of data was taken with the set transmitting: direct current ammeter 4.8 amperes; direct current voltmeter 112 volts; alternating voltmeter 76 volts; alternating ammeter 6.2 amperes; antenna current two amperes; wave 375 meters.

WATTS RADIATED_ If the form factor of the antenna is denoted by F the formula for watts radiated is

$$W = 1578 \left(\frac{Fh}{\lambda}\right)^2 I^2$$

$$F = .637 \left(1 + \frac{L}{h}\right) \sin \left(\frac{h}{h+L}\right) 90^\circ = .788$$

when $L = 50$; $h = 70$; $\lambda = 375$; $I = 2$ then $W = 12.$[illegible]

RADIATION RESISTANCE_

$$R = 1578 \left(\frac{Fh}{\lambda}\right)^2$$

Substituting in the same values a result of 3.16 ohms is obtained.

DECREMENT PER OSCILLATION_ If the effective capacity C, the effective inductance L and the effective resistance R of an aerial are known the decrement per complete oscillation of the antenna circuit can be calculated by the formula

$$\delta = \pi R \sqrt{\frac{C}{L}}$$

Substituting for C = .00096 and for L = 8.7

$$\delta = .095$$

4. DAMPED WAVE RECEIVER.

THEORY_ Consider an evacuated vessel containing a filament F, which may be heated by current from a battery A as in Fig I4. Let P be a plate which by an external source B of emf of Eb volts may be maintained at a potential different from that of F. Let an ammeter b indicate the current Ib flowing in the circuit from P to F inside the tube, and through B and b outside the tube. An ammeter a in the filament circuit indicates the current heating the filament. Now for a fixed value of the current Ia let a series of readings be made of Ib for various values of Eb. If these are plotted as in Fig I5 the points will be on a curve of the form odf given by the full line.

The current flows as a result of the attraction of the plate P for the electrons emitted by the heated filament and of the repulsion exerted by the filament F upon the electrons, that is the electrons move from F to P as a result of the electrostatic field maintained between F and P by

TWO-ELEMENT VACUUM TUBE


FIG 14

$I_B$-$E_B$ CHARACTERISTIC

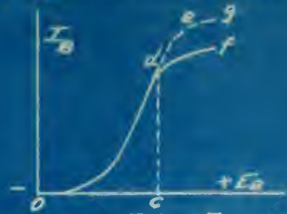



FIG 15

$I_B$-$I_A$ CHARACTERISTIC

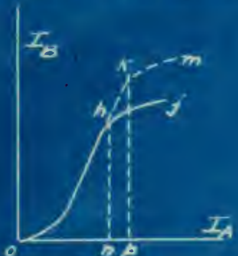



FIG 16

THREE-ELEMENT VACUUM TUBE


FIG 17

$I_B$-$E_C$ CHARACTERISTIC

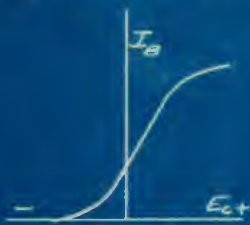



FIG 18

DEPENDENCE OF OUTPUT ON $E_c$

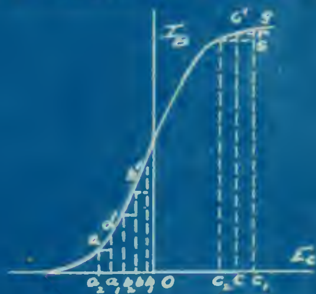



FIG 19

TYPICAL CIRCUIT


FIG 21

RESISTANCE IN PLATE CIRCUIT

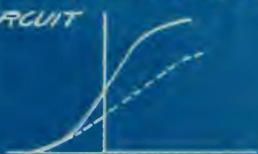


FIG 20

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the emf Eb. This field is conveniently measured in terms of the voltage Eb and when the resistance of the ammeter b and the battery B is small it may be taken equal to Eb. As long as Eb does not exeeed the value oc the number of electrons drawn from F to P per volt, that is, conventionally the current from P to F, is found by analysis of the curve od to be roughly to be proportional to the square of the field intensity.

However consider the effect when Ec is increased beyond oc. Remembering that the current is the number of electrons transferred per second through a cross-section of the conducting path, it appears that if the field oc due to Eb is sufficient to transfer all the electrons emitted by the filament, a further increase in Eb cannot increase the current.

Such an increase in current can come only be increasing the number of electrons emitted by the filament, and hence available for producing a current between F and

P or an increase in available carriers may arise from ionization of any residual gas in the tube if Eb is sufficiently increased. In a pure vacuum device the number of available electrons may be increased by heating of the filament. If the filament temperature is raised by increasing Ia to some new fixed value, it is found for further increases of Eb the current is given by the dotted portion deg of fig I5. If then it is desired to utilize fields up to a strength represented by some definite value of Eb, and to have the current follow the approximate square law it becomes necessary to heat the filament by some definate value of Ia.

To find the required value of Ia let Eb be given some definite value, and let a plot be made as in Fig I6. of Ib for various values of Ia. The relation will then be found to be that of the curve ohj of this Fig. After $I_a$ has reached a value of on there is no increase in the current Ib for further increases in

the temperature of the filament. For a definite value of the field Eb, the number of available electrons increases with the filament temperature as shown by the part of the curve oh of Fig Ib. When the temperature corresponding to Ia = on is reached, the accumulation of electrons in the space between F and P is sufficient to neutralize the impressed field at F and to prevent a further increase in the number of electrons in the tube. A condition of stability is therefore attained under which no increase is to be obtained even though the source of electrons is capable of supplying a larger source. Although there is no increase in the number of electrons and hence in the current, there is a constant current flow through the tube and the external circuit or conducting path. As fast as electrons are subtracted from the plate they are returned by the battery B to the filament and there emitted so as to maintain the condition of equilibrium.

When the source of electrons is capable

of supplying a large number of electrons as when Ia is greater than on, then a greater current may be obtained by increasing the field. The partially dotted curve ohkm of the figure shows the relation between Ib and Ia when the voltage Eb has been increased. If the filament has been heated by a current less than on, it is evident that the plate circuit Ib does not increase with increased Eb. In order then that the vacuum tube system should obey the square law namely Ib proportional to the square of the field intensity it is necessary that the current Ia should be made as large as op, where the curve ohkm is taken for the maximum value of Eb which it is expected to use with the tube.

THREE ELEMENT TUBE_ From the previous description of a simple vacuum tube system envolving two elements namely a filament source of electrons, and a plate, it appears that Ib is proportional to the square of

the field between the two electrodes. For the case just considered, the field is due entirely to the battery B and Ib equals $K(E_b)^2$ where K is a constant. The field may however receive contributions from another source of emf if a third electrode is inserted as at G in Fig I7. The relation between Ib and the field then becomes

$$I_b = k(E_b + kI\,vI)^2$$

where kIvI represents the contribution to the field of the third electrode G. This grid is maintained at a potential different from that of F by a third source of emf vI. The value of KI in the vacuum tube equation is determined by the design of the tube.

Consider first the case where vI is due to a battery of Ec volts. The relation is

$$I_b = k(E_b + kI\,E_c)^2$$

It is usually more convenient to draw the curve shown where the relation of Ib and Ec are given as in Fig I8. This relation is

$$I_b = a(gE_b - E_c)^2$$

when vi equals Ec. The constants a and g are used and obviously g equals $\frac{1}{ki}$ and a equals $ki^2k$. When Ec is zero then Ib is $ag^2Eb^2$. Also when Ec is $-gEb$ then Ib is zero. The constant g then represents the fraction of the voltage Eb which must be applied to the grid making it negative with reference to the filament in order that the current in the plate circuit shall be reduced to zero. The reciprocal of g, that is ki apparantly represents the relative importance in producing an effect upon a current Ib in a voltage applied at G and one applied at P. In some commercial forms of tubes ki will be found to have values lying between five and forty.

It is evident that a small voltage at G is equivalent to a larger voltage at P. Hence this tube system may be used as an amplifier or means whereby a small cause may produce a large effect. The energy supplied is of course furnished by the A and B batteries, and there is no violation of

the principle of the conservation of energy.

In general the voltage v impressed on the input terminals of the tube that is on F and G is made up of a constant voltage Ec and a variable voltage say v. The current in the output circuit that is from F to P is then expressible as

$$Ib = (gEb + Ec + v)^2$$

where $Eo = gEb - Ec$

If $v = E\sin\omega t$ then the output Ib will consist of four terms:

$$Ib = aEo^2 + \frac{aE^2}{2} + 2aEoE\sin\omega t + E^2\frac{(\cos 2\omega t)}{2}$$

of which one represents an amplified repetition of the input and another is a double-frequency term. The vacuum tube may therefore be made to indicate by a change in the value of the direct current flowing in the plate circuit, the fact that a sinusoidal voltage is impressed on the grid, or to give a repetition of the input or to produce a change in the frequency.

If Ec is of value Ga it is evident that

when v is zero the current Ib is of value aa', when v= Esin 90° = E then Ib has increased to ad. When v becomes Esin270° = _E then Ib becomes zero. From Fig I9 it appears that de is greater than ea, hence the output current is increased by the impressed sine wave of voltage more than it is decreased. The output is evidently a distorted sinusoidal current and its average value is greater than ea, which is the value of Ib before the voltage v is impressed. Conversely if Ec is equal to Oc the positive half of the input wave produces a change in the current rq which is smaller than the change rs produced by the negative half wave of v. The average current in the plate circuit is less than ce'. Some value of Ec as Ob may however be found such that if E is not too large, the two half waves of alternating current will be sinusoidal and symmetrical. For this condition there will be in the output circuit a repetition free from distortion

of the impressed wave form. The average value of the current Ib would be bb' that is the same as if v were not impressed.

VACUUM TUBE AMPLIFIER_ From the foregoing it appears that the three-element vacuum tube may be used as a distortionless repeater, provided that Ec is properly chosen. A criterion and test is the constancy of the direct current through the plate or output circuit, independent of the alternating voltage input.

The characteristics plotted so far are all upon the assumption that the external plate circuit is of negligible resistance and hence that the fields between P and F is independent of the plate current Ib. If however, there is in the plate circuit a resistance R the field is not proportional Eb but instead to Eb - IbR. If Eb is kept constant the equation for Ib becomes

$$Ib = a( g(Eb-IbR) + Ec + v)^2$$

$$\text{or} \quad Ib = a( Eo-gIbR + v)^2$$

qualitatively it therefore appears that the

curve of current given in Fig I8 and reproduced in the full line of Fig 20 would be more like the dotted curve if the resistance were made large. One method of reducing the effect of the double frequency term, that is, one method of obtaining a linear relation or direct proportionality between the output and input is then to insert a high resistance in the plate circuit.

For greatest output this resistance, should be made equal to the average internal resistance of the tube just as in the case of a direct current generator the greatest output occurs when the external and armature resistance are equal.

The internal impedance is essentially a pure or ohmic resistance. This resistance however depends upon the field between P and F. In fact it may be said that it is by virtue of this dependence of resistance upon the field that the devise has the characteristics shown in the figures.
The internal impedance of the output

circuit of the tube is to be found by taking the slope of the Eb-Ib characteristic. This of course varies from point to point. The input impedance that is the impedance between G and F is infinite as long as G is negative with respect to F. This is evident when it is remembered that electrons can be drawn to G from F only in case G is positive with respect to F. When however, G is made positive then a current can flow. As long as $E_c + v$ is negative however, the input circuit has an infinite resistance and absorbs no energy from the source of emf v.

In Fig 2I this tube operates as a detector or as an amplifier depending upon the adjustments. Transformers are shown for connecting the tube to the source from which v is to be derived, and to the apparatus where the amplified or detected current is to be utilized.

DETECTOR ACTION OF TUBE WITHOUT GRID CONDENSER_ Assume for example the potential

of the grid with respect to the filament is that corresponding to the point where the grid and filament have the same potential; then a negative charge applied to the grid a decrease in the plate current and a positive charge imparted to the grid produces an increase in the plate current.

Hence if an alternating emf such as a group of incoming radio frequency oscillations is impressed upon the filament and the grid the plate current will rise and fall at the frequency of the impressed emf, i.e. the incoming radio frequency current will be repeated in the plate circuit, but often, with increased amplitude owing to the radio frequency amplifying action of the valve.

This current however will not be heard in the receiving telephone because its frequency is above audition and the positive and negative halves are of equal amplitude. But as the curve of Fig 22 clearly indicates if the potential of the grid is adjusted by

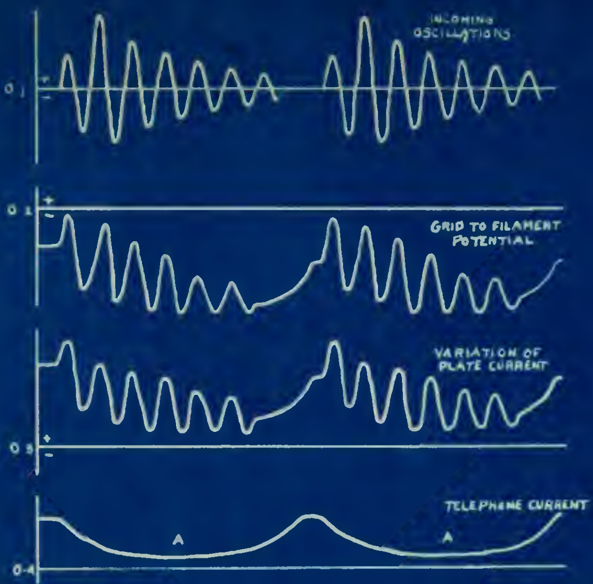


FIG 24 OSCILLATION DETECTOR WITH GRID CONDENSER

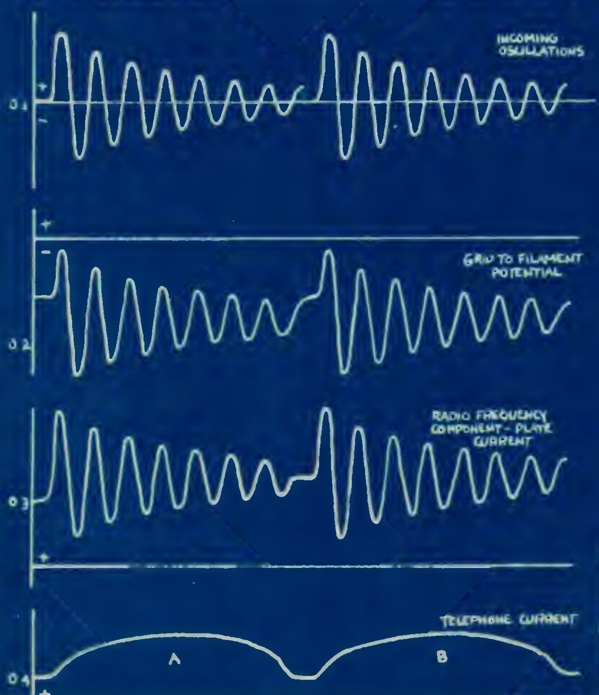


FIG 22 DETECTOR ACTION WITHOUT GRID CONDENSER.

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a potentiometer to a point where a small decrease in the grid potential ( that is a change toward zero ) causes a comparatively large increase of the plate current ; on the other hand an increase of the grid potential ( in a negative sense ) causes a relatively small decrease of the plate current. Hence if the grid and filament are connected to the secondary terminals of a receiving tuner, what amounts to a rectified current will flow in the plate or output circuit, that is the average increase in current occasioned by the positive halves of the incoming osciailtions exceeds the average decrease in current due to the negative halves of the incoming oscillations. This current charges the telephone condenser which discharges through the telephone probably in one direction.

Since each group of incoming oscillations causes a large increase of current through the head telephone, the diaphragm will produce one click for each spark discharge at

the transmitter.

It is apparent from the characteristic curve that the repeated plate current may have uniform increase or decrease, or it may assume the nature of a rectified current depending upon the point on the characteristic curve at which the valve is worked. Thus near the upper bend, and the lower bend a rectified current will flow in the plate circuit but along the straight portion of the curve equal increase and decrease of the plate current will be obtained. In the latter condition the valve is properly adjusted for amplification at radio frequencies.

The grid battery is connected in the grid circuit to take advantage of the non-uniform properties of the tube, but it should be understood that the tube will function in the same way without the grid battery; that is, if a good sample of a valve is used by careful adjustment of the filament temperature and the plate current, the operator can obtain the best operating characteristic

for a given condition of service. In other words he thus locates the point on the curve which will give the loudest response in the head telephone without employing a grid battery.

Relaying Action_ Owing to the relaying action of the valve a current of any wave form impressed upon the grid circuit may be repeated with amplification in the plate circuit.

DETECTOR ACTION WITH GRID CONDENSER

A grid condenser may be connected between the grid and the upper terminal of the secondary coil of the receiving tuner. The function of the grid condenser is to store up the currents which are rectified by the valve action between the grid and filament. The charge and discharge of this condenser during the reception of damped oscillations in radio telegraphy decreases and increases the plate current at an audio frequency.

When the incoming oscillations tend to charge the grid negatively no current flows

from the grid to filament but when the grid is charged positively current passes from the grid to the filament and the grid condenser therefore receives a uni-directional charge over the duration of a wave train. Therefore a charge of increasing strength piles up in the grid condenser C2 of Fig 23 which is negative on the grid side. This as is clear from the fundamental curve of Fig I8 obstructs more and more the passing of electrons from the filament to the plate causing a decrease in the plate current . At the termination of the incoming oscillations, the incoming charge in the grid condenser leaks off either through the valve itself or through a special leak resistance of several thousand ohms shunting the grid condenser. The grid then returns to normal potential and plate current. It is evident that each spark at the transmitter eventually reduces the telephone current at the receiver. In other words the telephone current varies as the frequency of the trans-

mitter.

During the time that the incoming oscillations undergo rectification the potential of the grid fluctuates at a radio frequency and the plate current rises and falls at a radio frequency but this current is not heard in the head telephone. Although this repeated radio frequency is not heard in the head telephone it is put to account in the regenerative and amplification circuits.

Thus it is seen that the two results are obtained simultaneously in the plate circuit. During the time that the rectified oscillations are building up a charge in the grid condenser, the current in the plate circuit decreases, but when the charge leaks out of the condenser, the plate current returns to normal value. This reduction follows the spark at the transmitter. Meanwhile the incoming oscillations are repeated in the telephone circuit.

ULTRAAUDION CIRCUIT_ In Fig 25 is shown the connections for the reception of undamped waves and called the "ultra-audion". The oscillatory circuit is connected between the grid and plate with a condenser in the grid lead. The variable condenser shunts across the plate battery and phones and is important in the production of oscillations; in general, its value cannot be increased beyond a certain point without stopping the oscillations. By this beat method high senitiveness and selectivity are obtained in receiving. Interference is minimized because even slight differences in the waves from other sources result in notes either of different pitch or completely inaudible.

DESCRIPTION OF SET_ The damped wave receiver will have a wavelength range from two hundred to twelve hundred meters . Included in this set are: receiving tuner, variable and fixed condensers, audiotron detector, Western Electric Company phones, This apparatus will be used for the reception of short wave length signals especially in connection with the actual handling of messages in conjunction with the spark transmitter. An amplifier consisting of VT I2 tubes with iron core step-up transformers may be connected to the detector to increase the strehgth of weak signals. The damped wave set is placed to the right of the transmitting key and near the change-over switch.

5. UNDAMPED WAVE RECEIVER

THEORY_ If two sources which separately furnish undamped oscillations of say 100,000 and 101,000 frequency as shown in (a) and (b) of Fig 30 act together upon the same circuit the resultant oscillations in the circuit obtained by adding the components will be of the form shown in (c). The amplitude of the combined oscillation will rise and fall becoming a maximum when the component oscillations are in phase and a minimum when they are out of phase. The beats or periodic rise and fall in amplitude occur at a rate equal to the difference in frequencies of the two oscillations. Thus the beat frequency in the case assumed above would be 1,000 per second. If rectified these beats will produce a note in the telephone of like frequency. In the reception of undamped signals by this method called the heterodyne method the incoming signals represent one component oscillation. The other oscil-

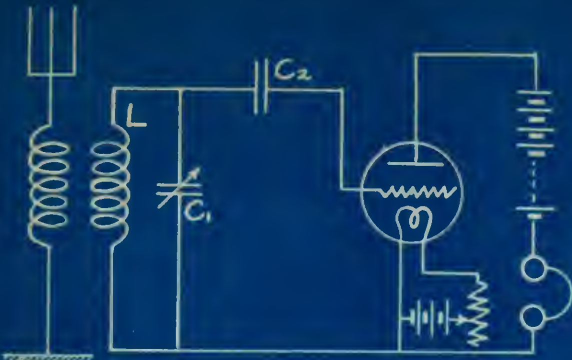

FIG 23 DETECTOR OF DAMPED OSCILLATIONS.

FIG 26 1. INCOMING OSCILLATIONS
2. VARIATIONS IN PLATE I.
3. EFFECTIVE PHONE I

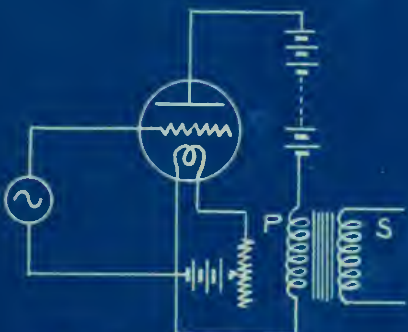

FIG 29 AMPLIFIER

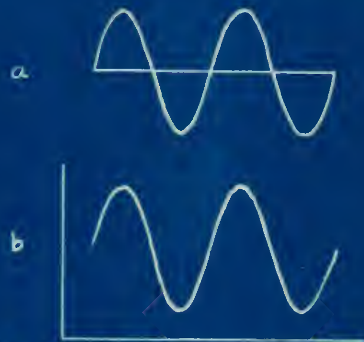

FIG 27 (a) GRID VOLTAGE
(b) PLATE CURRENT

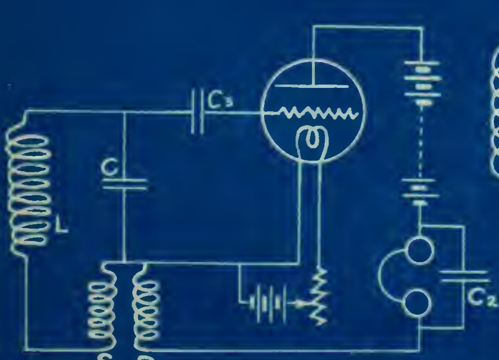

FIG 28 REGENERATIVE AMPLIFIER.

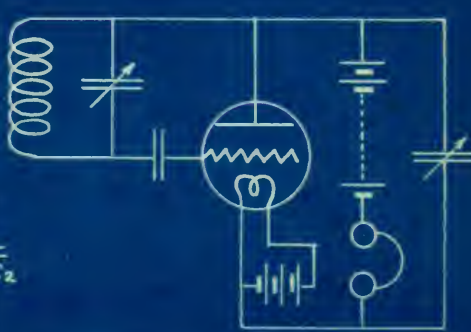
FIG 22 ULTRAUDION CIRCUIT FOR RECEIVING UNDAMPED OSCILLATIONS.

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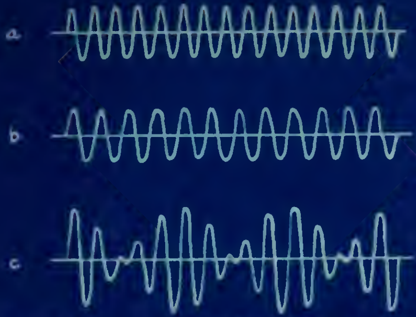



Fig 30 Heterodyne Reception Curves

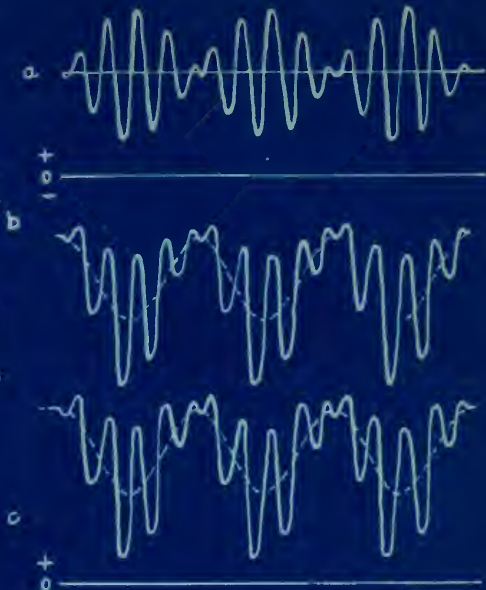



Fig 32 Variations of Grid Voltage and Mean Plate Current for Beat Oscillations.

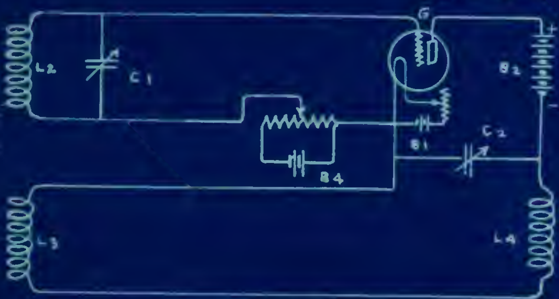



Fig 31 Radio Frequency Generator Circuit.

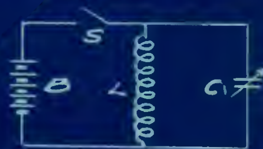



FIG 33

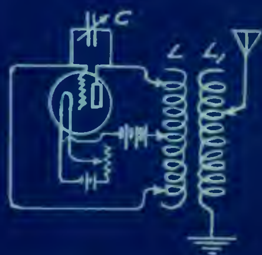



FIG 34

lation is generated in the receiving apparatus and both act in the same circuit. The rectified resultant furnishes a musical note in the phones, the pitch of which can readily be altered by varying the frequency of source of local oscillations. The electron tube may serve as a convenient source of local oscillations and at the same time as an amplifier and detector of the received signals. This is called the autodyne method. Numerous circuits may be utilized to produce these results of which that shown in Fig 28 may serve as an illustration. Incoming signals set up oscillations in the antenna. By means of the coupling between the antenna and the coil L oscillations of the same frequency are set up in the circuit LC and as explained above are amplified on acconnt of the feed-back between S and L. Further the coupling S and P is such that the tube

oscillates, the frequency of these oscillations depending largely upon the constants of the circuit LC. If this latter frequency is adjusted to be slightly different from that of the incoming oscillations beats will result and the potential of the grid will follow the beat oscillations. Just as explained before in the case of reception with a grid condenser, there will be an increased flow of negative electricity from the filament to the grid when this latter is positive and its mean potential will be lowered. Thus, as the oscillations in the beat are increasing the potential of the grid will follow the variations in potential of the grid, reproducing the beat oscillations and decreasing in mean value as the mean potential of the grid is lowered. The curve (a) of Fig 32 represents the oscillations in the circuit LC. In (b) is shown the oscil-

lations of the grid potential, the mean potential being indicated by the dotted line. In (c) is shown the plate current the mean value of which is also shown by a dotted line. The telephone current will likewise correspond to this mean value and hence the note will correspond to the beat frequency.

CASCADE AUDIO FREQUENCY AMPLIFIER_ It has been pointed out how the successive groups of incoming ( damped ) oscillations may be rectified and stored up in a grid condenser, and how during the piling up of this charge the plate current decreases. At the termination of the incoming wave train the charge leaks out of the condenser and the plate current returns to normal value.This variation of the continuous current in the plate circuit is termed the audio frequency component of the plate current. The audio frequency component may be

amplified through the medium of a second valve. One method is where the plate circuit of the first valve and the grid circuit of the second valve are coupled inductively through an iron core transformer. The primary and secondary coils consist of several thousand turns of relatively fine wire wound over a common iron core, the inductance of each winding amounting to a henry or more.

The apparatus functions as follows: The successive groups of incoming oscillations are converted to audio frequency variations of the plate current through the charge and discharge of the grid condenser. Generally three valves are connected in cascade, being coupled together through simple iron core transformers between the output and input circuits of successive valves. The audio frequency component of the plate current is impressed upon the grid circuit of the second valve through the coupling

transformer. No attempt is made to tune these transformers to the desired frequency.

AUDIO FREQUENCY REGENERATIVE SYSTEM

The audio frequency component of the plate current can be reinforced to amplify the incoming signal by the regenerative transformer which couples the plate and grid circuits of the detector bulb. The circuit functions as follows: As the incoming signals are rectified and trapped in the grid condenser the plate current is gradually reduced ( due to the increasing negative potential of the grid ). The resultant reduction and subsequent increase of the continuous plate current in turn causes energy to be transferred to the grid through the iron core coupling transformer the windings of which have an inductance of a henry or more. For this reason the preferred types of receiving circuits are made up of fixed inductances (or thoses varied by plug or dial step)

mounted so that they can either be pulled apart or one coil revolved so that it changes its plane and hence the mutual induction with reference to the others. The variometer type mounted like variable condensers are now being manufactured. Their self induction can be varied quickly and conveniently and close adjustment of period (tuning) made with them or with the variable condensers, but the entire coil is always in the circuit.

Each section of an inductance not in circuit should be opened at both ends i.e. entirely disconnected, and if its natural period is large it should be mounted so that the inductive effect of active parts on it is a minimum. This applies especially to loading coils for long wave lengths. All inductances are wound on hard rubber, porcelain or glass and so as to have a minimum high frequency resistance. The

decrement of the entire circuit must not exceed three-tenths.

From the formula for damping it can readily be seen that a very pronounced natural period- a stiff circuit- can not be obtained unless the self-induction is large compared with the total resistance (including the radiation resistance).

CONDENSERS IN RECEIVING CIRCUITS_

A variable condenser usually consists of semi-circular metal plates separated by an air dielectric, alternate plates being fixed. The other plates are movable on an axis by turning which any desired amount of the movable plates can be included between the fixed plates. The axis carries a pointer which moves over a scale graduated in degrees or directly in microfarads. If used in connection with a fixed inductance, the scale, like a wavemeter, which in this case it becomes, may be graduated directly in wave

lengths. Fixed condensers in receiving circuits are often called stopping condensers. They may be of any compact type and the capacity may be quite small.

INDUCTANCES IN RECEIVING CIRCUITS_ Variable inductances include the step by step, roller and variometer types. The first is made up of plug or dial steps, giving a limited number of changes, one section of a coil being varied at a time, or it may be of a cylindrical coil of insulated wire wound on hard rubber, glass or porcelain, one point in each turn being bare and connections being made by a slider giving as many adjustments as there are turns of wire in the coil. These types of variable inductances can be readily mounted so as to vary the mutual induction between them by any definite amount. They are suitable for loading but not suitable for loose coupling.

REGENERATIVE AMPLIFIER_ In order that the maximum strength of signals may be obtained from a spark transmitter by means of the regenerative system it is essential that the coupling between the plate and grid circuits be very carefully adjusted because if the coupling is too close the oscillations for each spark at the transmitter will not decay to zero before the next group is impressed upon the valve circuits. Consequently the desired change of current through the head telephone will not be obtained. It must be kept in mind here that it is not alone the amount of current flowing through the head telephone which produces the greatest of signals, but it is the change or variation in the strength of current as well, which deflects the telephone diaphragm. The complete functioning of the regenerative circuit may be summed up in the following statements:

(I) The incoming oscillations are repeated in the plate circuit reinforced through coupling to the grid circuit causing still greater variation of the grid potenial; in the meanwhile through rectification a charge piles up in the grid condenser which is negative on the grid side of the condenser. This partially obstructs the flow of electrons to the plate, and thereby reduces the strength of the plate current. (2) At the termination of the wave train the charge in the grid condenser leaks off through the shunt resistance, the grid returns to normal potenial and the plate current returns to normal value. Amplications of fifty fold are thus secured.

A condenser by-passes the radio frequency component of the plate current around the head telephone. Its capacity is generally fixed. The apparatus will function without this condenser, the

required capacity being found in the parallel coils of the head telephone.

IIO VOLT PLATE CURRENT SUPPLY_The plate current of a vacuum tube may be fed with direct current from a dynamo. Ordinarily the fluctuations of current due to the commutator would cause an interfereing hum in the receiving telephones, but this is largely prevented by shunting to the direct current line a condenser of large capacity which has the effect of smoothing out the current that is to say, when the current generated by the dynamo decreases, the energy stored up in the condenser discharges through the circuit and maintains the line voltage at a nearly constant value. A potentiometer permits the plate voltage to be adjusted to the requisite value.

SELECTIVITY BY THE HETERODYNE_ In addition to the selectivity afforded by the usual radio frequency tuning of the

receiver circuits, an additional discrimination between the different stations operating near the same wave is secured by reason of the beat phenomenon. If the frequency of the incoming oscillations from the station desired is for example 37,500 cycles per second wave length 8,000 meters, and the frequency of the local oscillations 36,500 cycles, wave length 8,219 meters, the beat pitch will be 1,000 per second. Suppose however that another station sends at a wave length corresponding to a frequency of 37,000 cycles per second wave length 8,108 meters, then a beat note of 500 per second will be obtained, and due to the differences of tone, the operator can concentrate on the particular signal he desires to receive.

Then if several undamped wave transmitters operate simultaneously at such wave lengths as to produce a beat note

in the receiving apparatus when its locally generated current is adjusted to a certain frequency the operation in many cases can produce a change in the pitch of the beat note of the station it is desired to receive, to a pitch that one can concentrate on with the exclusion of others.

Also if the frequency of the local current is maintained at a definite value signals will be heard only from such stations as will produce a beat pitch between values of say I6 to I0,000 per second. It must be remembered, however, that the best response is generally obtained when the beat pitch is somewhere near the value of I,000 per second.

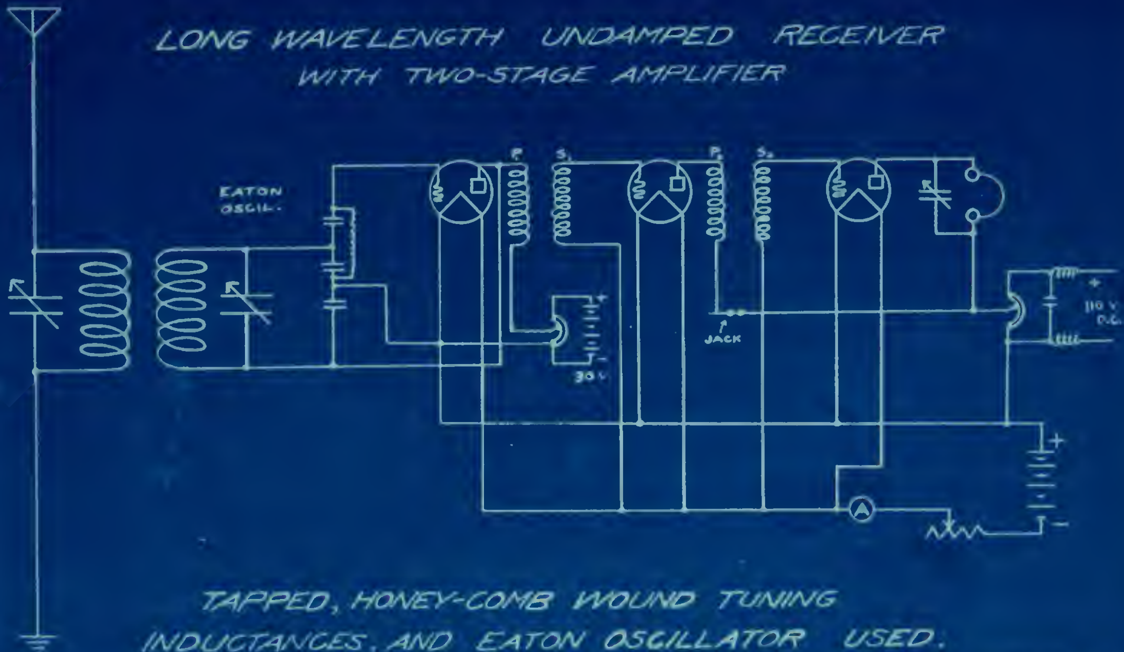
It is easily seen from the foregoing that if the frequency of an interfering signal is sufficient to cause a beat current of a frequency above or below the limits of audibility it will not be heard

in the telephone even if the receiving station is near enough to the transmitter to be energized by forced oscillations.

UNDAMPED WAVE RECEIVER.

DESCRIPTION OF SET_ The long wave length receiver will have a range of from 2,500 to 20,000 meters. The inductances are wound in the well known honey-comb form which gives compactness and efficiency, A novel feature about the colis is the fact that each has several taps so that the inductance can be varied in steps as well as by coupling . Another innovation employed is the Eaton oscillator used as a capacity feed-back from the plate circuit of the detector bulb to its own grid. The detector is the tubular audiotron noted for its sensitiveness and the ease with which it oscillates. The two stage amplifier consists of the following equipment: iron core step-up transformers between the detector and first stage and between the first stage and the second stage audion bulbs which are of the VT-I2 type. The "A" battery supply of six volts with

LONG WAVELENGTH UNDAMPED RECEIVER
WITH TWO-STAGE AMPLIFIER



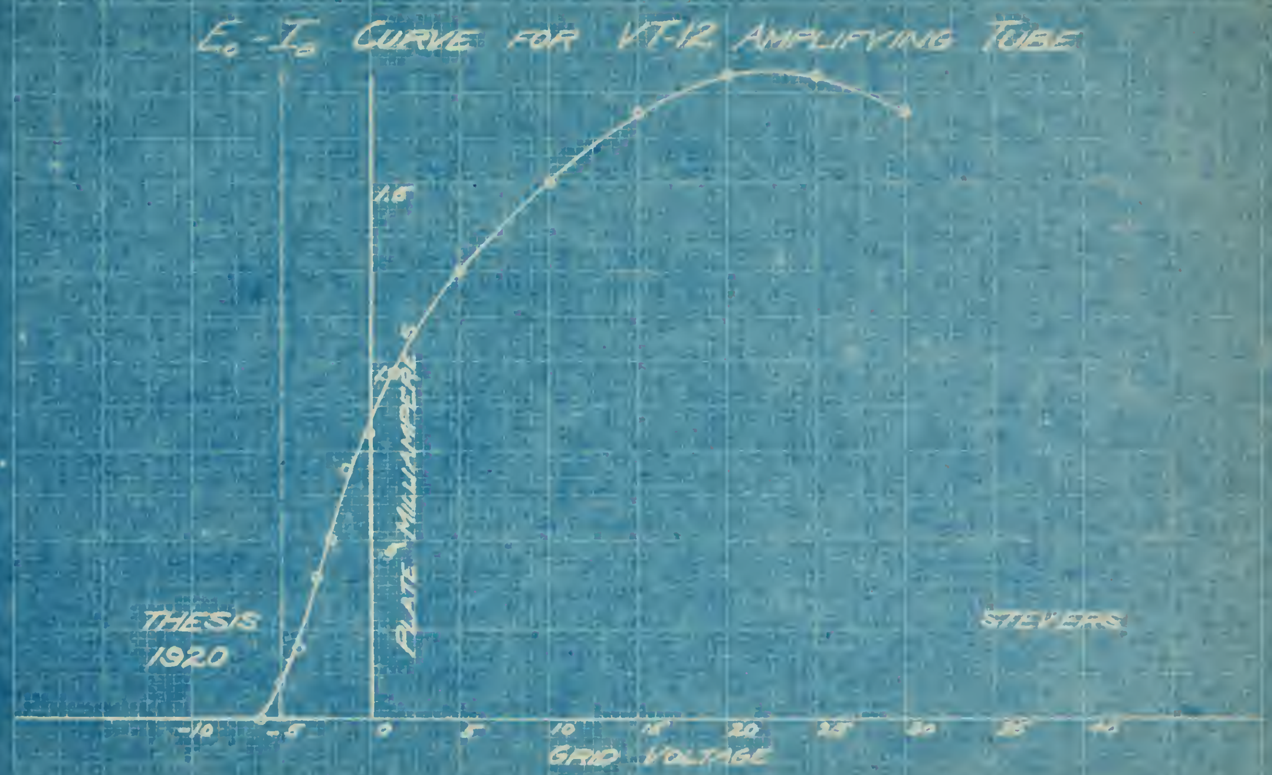

TAPPED, HONEY-COMB WOUND TUNING INDUCTANCES, AND EATON OSCILLATOR USED.

FIG 35

THESIS 1920

STEVERS

rheostat control furnishes current to all three bulbs in multiple. The detector has a separate "B" potential battery of 25 volts while the amplifier plates receive their potential from a filter circuit operated from the IIO volt lighting system. Variable condensers across the primary and secondary receiving coils aid in tuning while another across the telephones improves the pitch of the received signals.



$E_g$ - $I_p$ CURVE FOR VT-12 AMPLIFYING TUBE
1.5
PLATE MILLIAMPERES
THESIS
1920
STEVERS
-10
-5
0
5
10
15
20
25
30
35
40
GRID VOLTAGE

6. VACUUM TUBE TRANSMITTER.

THEORY_ A vacuum tube connected as in Fig 3I may be employed to generate the local radio frequency currents for beat reception. The grid and plate circuits are coupled through coils L2 and L3. The grid circuit is tuned to a given frequency of oscillation by the condenser C-I and the plate circuit by the condenser C-2. The conditions present in the plate circuit are substantially those of the circuit of Fig 33 where an oscillation circuit including coil L and condenser C is shunted by the battery B, the circuit being impulsed by the opening and closing of the switch S. When the switch S is closed the energy supplied by the battery is stored temporarily in coil L and condenser C but when switch S is opened this stored energy is released and the stored energy is made to oscillate in the circuit LC at a radio frequency determined by the product of the capacity and the inductance of the circuit.

Now switch S can be considered to be replaced in Fig 3I by the valve grid G which varies the current of B-2 by change of its potential.

It has been shown that if the grid is charged to a high negative potential the circuit of B-2 is completely opened (but this does not occur in practical operation) and consequently it is easily seen that if any variable emf applied to the grid circuit, will vary the strength of the plate current, which will set circuit L3, C2, L4 into oscillation at a radio frequency.

Though the coupling L2, L3 the grid circuit L2, CI will be set into oscillation and it will vary the plate current through change of grid potential. In this way the complete system oscillates at a radio frequency which may be varied over a wide range of frequencies by change of capacities CI and C2 or by variation of inductances

L2, L3 and L4. It is found in practise that the condenser C2 and the coil L4 can be eliminated sufficient energy being liberated in the plate circuit to keep the valve circuits in self oscillation through the coupling coils L2 and L3.

It should now be clear that in order to set the valves into self-oscillation through the coupling coils L2 and L3, it is necessary to change the potential of either the grid or plate circuits, and to provide static or magnetic coupling between the circuits in order that some of the energy released by the plate circuit may be fed back into the system. A switch may be connected in the circuit of the battery B4 to set the system into oscillation. It is frequently found that sudden variation of the capacity of condenser CI or C2 will vary the potential sufficiently for the purpose.

A simpler valve circuit for the

generation of sustained oscillations is shown in Fig 54 where the grid and plate circuits are magnetically coupled through the coil L; additional regenerative coupling is provided by the condenser C. By proper selection of the values L and C, the valve circuits will oscillate at any desired frequency. These oscillations produce currents in the coil LI and the antenna which radiate as radio energy in the form of electro-magnetic waves.

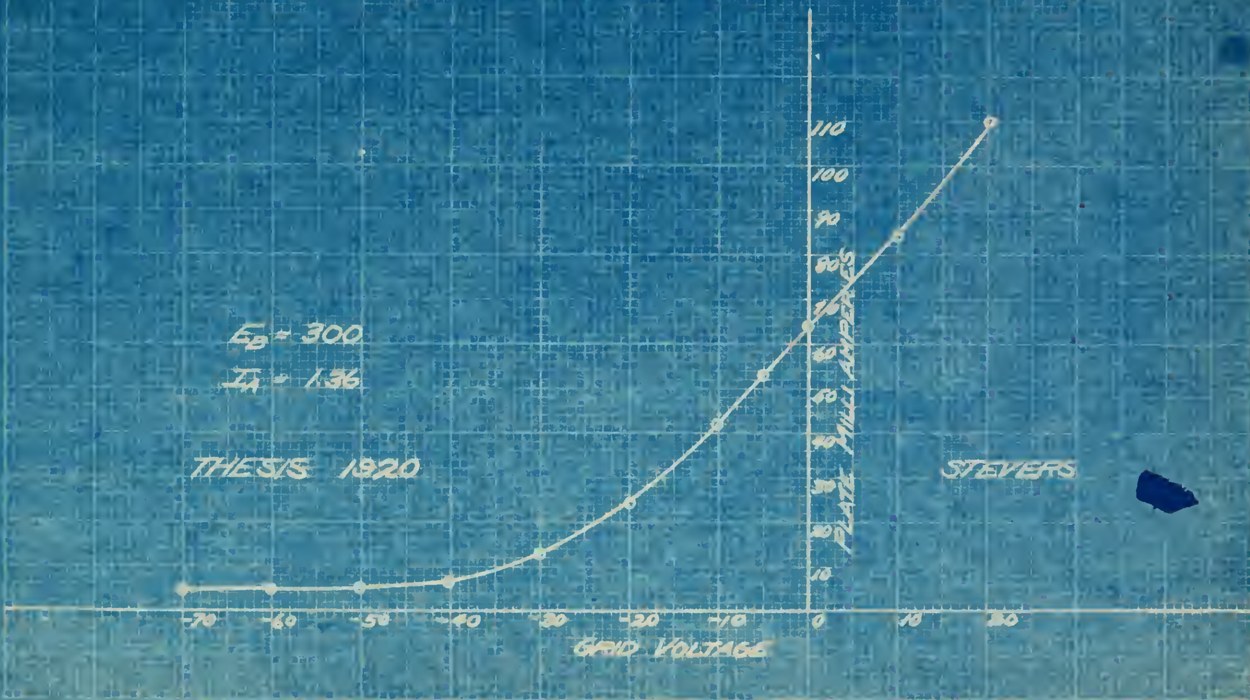
DESCRIPTION OF SET_ Two of the small size Western Electric transmitting tubes operated in parallel are mounted on the front of the transmitting panel. The coils forming the oscillation circuit are placed below the tubes. The motor generator which furnishes the plate potential of 300 volts is placed on the platform in back of the rotary converter. Swiches enable the set to be thrown onto the antenna and ground and the transmitting key to be placed in circuit.

The diagram of connections is shown in Fig 34. The key in series with the plate battery starts the system to oscillating when depressed. Wave lengths tuned for are the same as for the spark set that is, 200 and 375 meters.

A quarter kilowatt General Electric bulb is available for this purpose but no suitable I,000 volt source of plate potential is procurable.

Two VT-2 bulbs gave .I ampere in antenna.

## $E_c$-$I_p$ Curve for VT-2 Transmitting Tube



## CONCLUSION.

Work upon the construction of the station continued through the last week of school. It was expected that the Radio Club members would help with this phase of the work but outside of two faithful members very little aid was forthcoming. On this account little testing and actual operating with other stations was done.

We carried on damped signal communication with local stations. Commercial stations situated on the Great Lakes could be heard on the damped wave receiver. On the undamped set, messages were copied from all the U.S. Naval stations such as Annapolis, Maryland and San Diego, California and Pearl Harbor, Hawaiian Islands. Other stations heard were Mexico City, and Carnavan, Wales.

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