A STUDY OF SHORT WAVE RADIO TRANSMISSION

by

Ferris Wood Sullinger

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I. INTRODUCTION

In the following thesis the writer has attempted to take up, in as logical a manner as possible, a study of short wave radio transmission in general, and short wave radio apparatus in particular, covering the frequencies (wave lengths) assigned amateurs from 3500 kilocycles per second (85.7 meters) to 401000 kilocycles per second (0.7477 meters). Since a license must be secured from the Government before any transmitting can be done, a temporary amateur license was secured by the writer, and all testing was done using the assigned call letters 4 T J.

The frequencies in kilocycles per second with the corresponding wave length in meters that are assigned for amateur use at the present time are given below:

Frequency Range Kilocycles per second	Wavelength Range (meters)
1500-2000	200-150
3500-4000	85.7-75
7000-8000	42.8-37.5
14000-16000	21.4-18.7
56000-64000	5.35-4.69
400000-401000	0.7496-0.7477

It might be well to mention here that the curves included in this thesis are all plotted with frequency of oscillation in kilocycles per second as ordinates rather than wave length in meters. If the latter is desired, it is merely necessary to divide 3×10^5 by the frequency. The scope of this thesis includes the designing, construction, and operation of a wavemeter, receiver, and oscillator and the calibration of the wavemeter for use in the range of frequencies previously mentioned, and the writer has endeavored to discuss all difficulties of importance encountered in constructing and operating the above mentioned apparatus, and, wherever possible, to analyze these difficulties and then give the methods used for overcoming them.

It is hoped that the information presented here, together with the simple apparatus constructed by the writer, may enable some future investigator to proceed much further with a study of the high frequencies (short waves) and to delve much deeper into the possibilities of consistent day and night transmission and reception over long distances using the higher frequencies (shorter wavelengths).

Due to limited time, it was impossible to do any field work with receiver or transmitter studying the travel of the short waves, as was originally planned, and as a result, this thesis is concerned chiefly with the design, construction, operation, and calibration of the short wave apparatus and the laboratory experiments performed, using this apparatus.

II. GENERAL SURVEY

In the early days of radio transmission, when crystal detectors were in common use and the first thermionic vacuum tubes had just been devised, the common practice with commercial companies was to operate on the higher wavelengths of 5000-25000 meters, because they had found that these higher wavelengths seemed to give them more consistent and stable transmission over long distances than did the shorter wavelengths. To-day there are still a number of long wave commercial stations operating on these higher wavelengths, but a great amount of work is being done toward using lower wavelengths and reduced amounts of power for transmitting; and already there are a number of commercial stations operating on wavelengths as low as 15 meters. There are several reasons for this: in the first place, the remarkable development of the thermionic vacuum tube has given us, first, a much more consistent and efficient generator of radio frequency oscillations, and, second, exceedingly more sensitive receivers with which to detect the radio signals; in the second place, studies of electromagnetic wave propagation by outstanding radio engineers have shown us that the radiation from a transmitting antenna, as far as reception is concerned, consists of two essentially different parts. The first is the part which follows the surface of the earth, and the second is the part which is propagated upward and is then reflected back to earth at distinct points. The former is the much more reliable of the two, but it suffers serious losses during its travel, in that its energy is continually being absorbed by objects on the surface of the earth and by the earth itself, and in order to transmit a given distance with the "ground wave", other factors being equal, a much larger amount of power must be used than to transmit the same distance with the "reflected wave". The reason for the selection of the longer waves in the earlier days was that they depended mainly on the "ground wave" to convey their messages and it is an experimental fact that the shorter waves travelling over the surface of the earth experience much more serious losses by absorption than do the longer waves. In fact, so pronounced is this absorption in the regions of 5-15 meters that, with ordinary power, there is encountered the "skip distance" effect wherein the "ground wave" is quickly absorbed and the only useful part of the wave for communciation is the "reflected wave" which comes back to earth at some distant point or points. If someone could formulate a law whereby the distance away from the transmitter at which the reflected wave would strike could be expressed as a function of the frequency (or wave length) of the transmitter, or as a function of any number of controllable factors, then these waves would be much more useful than they are at present. However, there are other variable factors which effect the reflection of these waves, such as the degree of ionization of the atmosphere, clouds, and perhaps the earth's magnetic field and other things. The principle idea is, of course, to be able to transmit to any desired locality at any time and under any weather conditions, since if these conditions are fulfilled, then reliable and consistent communication will result, and this is always the aim of the radio engineer.

Another point in favor of the higher frequencies (shorter waves) is that an antenna system operating on high frequencies (short waves) is inherently more efficient than one operating on low frequencies (long waves), so that, with a given amount of power available, more power will be radiated on the higher frequencies than on the lower frequencies. Another way of stating this is that at the higher frequencies the radiation resistance of an antenna system is a larger percentage of the total resistance than it is when lower frequencies are used.

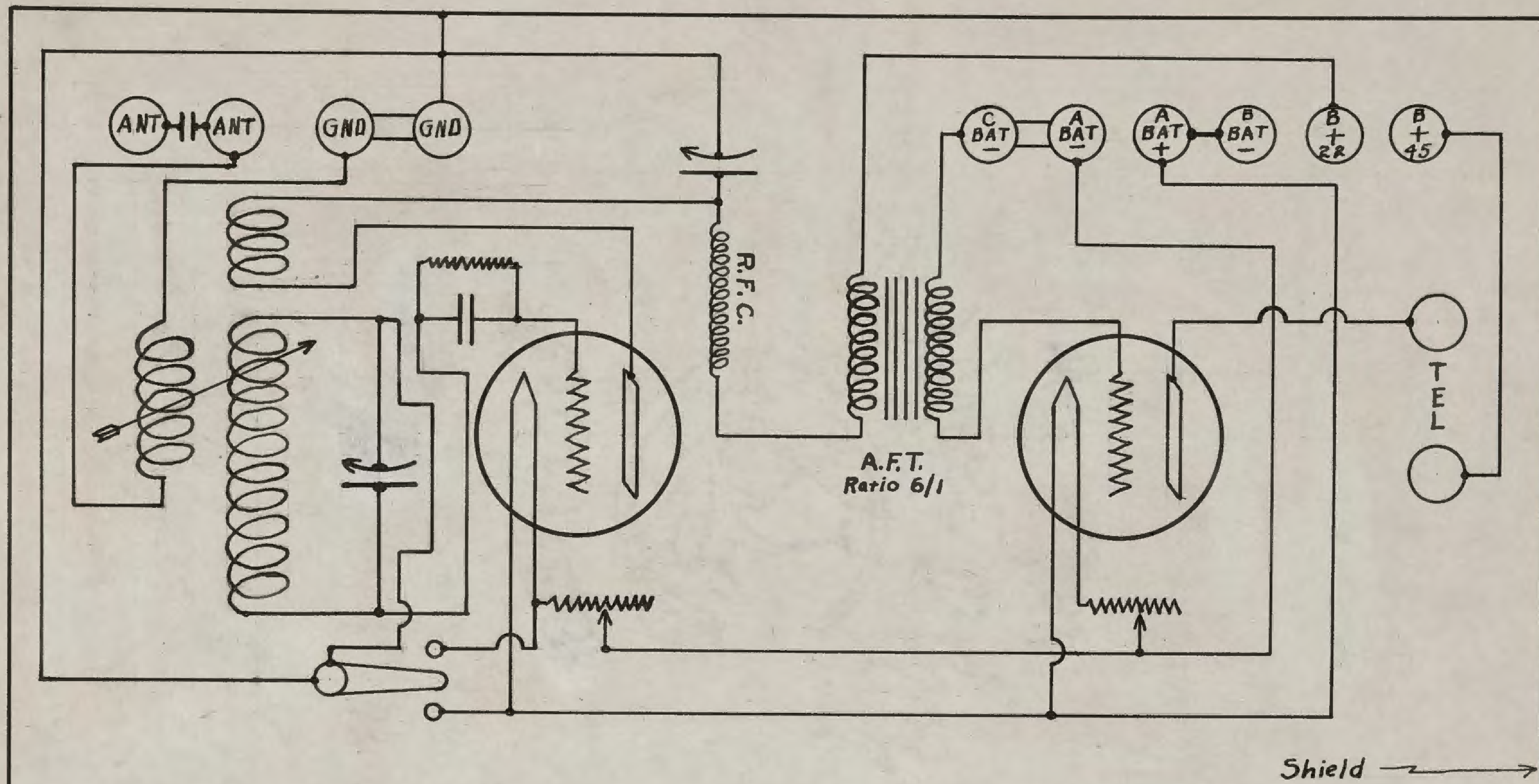
III. THE RECEIVER

1. Design

In designing the receiver the first step was to decide what circuit would be used, and, from past experience, the choice was a two-circuit regenerative receiver with fixed tickler and variable capacity feed back to control regeneration. Figure 1. is a schematic diagram of the receiver, and by referring to this diagram, it will be seen that one step of audio frequency amplification is employed. This is the maximum amount of audio frequency amplification that it is desirable to employ when headphones are used, since more than this gives too much noise, for comfort, in the phones.

It might be mentioned here that radio frequency amplification, or amplification ahead of the detector tube, is quite impractical in a receiver designed to operate on frequencies as high (wave lengths as low) as is this receiver; since, in any of the tubes obtainable, the grid to filament capacitive reactance, at these high frequencies, tends to short circuit the input coil, while the grid to plate capacitive reactance tends to by-pass the signal energy without amplifying it, so that a loss of signal strength would, very likely, be experienced instead of a gain if the radio frequency amplification were attempted. Then too, it would be quite difficult to control, efficiently, regeneration in the radio frequency tube.

The antenna circuit is of the fixed tuned type and



Schematic Diagram Of Receiver

Figure 1

is inductively coupled to the input or grid coil of the receiver. This coupling is variable and is secured by having the antenna coil movable.

In order to efficiently cover the previously mentioned frequency bands, it was decided to use a "plug in" coil arrangement in connection with a 100 picofarad (micro-micro farad) straight line frequency variable condenser. A maximum circuit capacity of 112 picofarads and a minimum circuit capacity of 17 picofarads were assumed and the desired inductance of each coil were calculated from the formula:

$$L = 10^{12}/4\pi^2 f^2 c$$

When L = Inductance in microhenries

f = Frequency of oscillation in kilocycles per second

c = Capacity of condenser in picofarads

It was decided to space wind the inductances on bakelite tubing 2-7/8" in diameter, using #19 bare copper wire wound in threads cut 14 to the inch. In order to reduce dielectric hysteresis as much as possible without sacrificing mechanical strength, it was decided to "blank out" the forms, leaving eight strips on which to wind the wire, thus reducing the surface of the bakelite, actually touched by the wire, more than one half. Having determined the desired inductance of the coils, the number of turns was found by using the approximate formula given in the U.S. Army Signal Corps Handbook:

$$L = \frac{0.0395\, a^2 n^2 k}{b}$$

Where L = Inductance of a single layer solenoid in microhenries

a = Radius of coil to center of wire, in centimeters

n = Total number of turns in the coil

b = Total length of winding in centimeters

k = Nagaoka's constant

After the receiver was constructed, it was found necessary to make slight changes in the number of turns on some of the coils, and these were varied until the desired frequency range was secured. It was decided to incorporate in the receiver an arrangement to change the grid return of the detector tube from the positive filament line to the negative filament line, in order to provide for different plate voltages and different tubes, and to accomplish this the three point switch shown was placed in the filament return lead of the grid coil at a point as near the tube as possible, in order that it might not introduce any losses. Due to occasional interference on the higher amateur wavelengths by nearby broadcasting stations, it was decided to completely shield the receiver proper, leaving only the phones and batteries outside the cabinet. Sheet copper was selected for this purpose, since it was readily obtainable and also because it was possible to solder all joints.

2. Construction.

The two variable condensers and the detector tube rheostat are mounted on the 7 x 19" bakelite panel, while the remainder of the apparatus is secured to the wooden sub-base.

The panel and sub-base are fastened securely together and are readily removed from and replaced in the cabinet, thus allowing the set to be operated either inside or outside of the cabinet. Figure 2 is a front view of the receiver in the cabinet.

The left hand dial is the tuning control, while the right hand dial is the feedback or oscillation control. As would be expected, however, these two controls do not operate entirely independently of each other, but are interlocked to a slight degree. The dials used are equipped with vernier movements which reduce the motion of the condenser shaft 63/1 and are indispensable for tuning on the high frequencies. Figure 3 is a rear view of the receiver removed from the cabinet and shows the arrangement of the various units.

In constructing the coils, the tubing was first put on a lathe and threaded, and then taken off and "blanked out". In winding the wire, one end was secured, and current from a storage battery was sent through the wire of sufficient intensity to make it quite hot; it was then wound in the threads and, after the finish end was secured, the storage battery was removed and when the wire cooled it contracted and made quite a tight job. Each coil is mounted on a bakelite strip equipped with four plugs, which fit into four jacks mounted on a bakelite strip secured to the sub-base. The plug carrying the grid lead is spaced farther away from the others than they are apart in order to reduce losses and also to prevent the coil being put in backwards. The plug connections, beginning at the end nearest the tube, are as follows: grid, plate, positive "B", and filament. The tickler coils were wound with #24 double silk

Figure 2

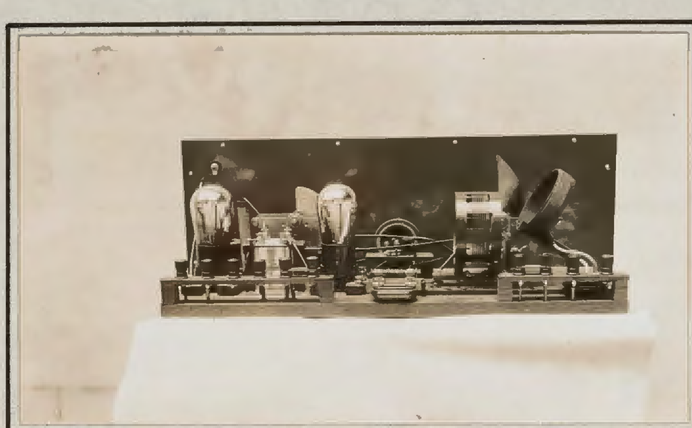


Figure 3

Figure 4

covered wire, doped with a solution of celluloid in acetone to make them self-supporting, and then glued in the filament end of the secondary coils. The number of tickler turns was determined experimentally.

Figure 4 is a photograph of the receiver coils, and it will be noticed that the two smallest coils are self-supporting, and are wound with heavy copper strip. The ticklers for these coils are also wound with #24 D.S.C wire and glued inside the filament end of them.

3. Operation

To operate the receiver, two type UX201A tubes are placed in the sockets; a six volt storage battery is connected to the A+ and A- binding posts; the negative side of the "B" battery is connected to the B- post, and the 45 volt post of the "B" battery is connected to the B+ 45 post. Either 22½ or 45 volts may be connected to the B+ 22 post. If 22½ volts are used the grid return is made positive, while if 45 volts are used the grid return is made negative. When receiving phone signals smoother control of the regeneration is obtained if 22½ volts are used on the plate of the detector tube with a positive grid return; while on continuous wave telegraphy louder signals will result with 45 volts on the plate of the detector tube and a negative grid return. The ground lead is connected to the binding post marked "GND" nearest the antenna binding posts, and, in most cases, the strap provided is allowed to remain across the two "GND" binding posts, thus grounding the shielding of the receiver. If a long antenna is used, it is connected to the outside antenna binding post, thus placing the fixed condenser, provided, in series with it; while if a short antenna is used, it is fastened to the inside antenna binding post which connects it directly to the antenna coil. It might be mentioned here that when a good ground is available, and the set is operated removed from the cabinet, it seems to pick up signals about as well without an antenna as with one, although this might not be true for every location.

In operating the receiver, immediately after construction, considerable difficulty was experienced, on some frequencies, in controlling regeneration. The feedback condenser seemed to work backward at these frequencies, causing the tube to go into violent oscillations when the capacity (of the feedback condenser) was reduced. This was later found to be due to the radio frequency choke in the plate lead which, apparently, in series with the tickler coil, feedback condenser, and tube capacity, formed a tuned circuit which caused the trouble. This difficulty was overcome by replacing the first choke with one wound with finer wire. The choke eventually used consisted of $2\frac{5}{8}$ inches (of winding) of #33 E.S.S.C. wire wound on a 5/8 inch fiber tube. Another difficulty experienced was that at certain points when the oscillation frequency happened to fall on the natural oscillation frequency of the R.F. choke, it would absorb sufficient power to stop the receiver from oscillating, giving rise to "dead spots" in the oscillating band of the receiver. It was decided to construct a radio frequency choke, using small insulated resistance wire, since this coil, due to its resistance, would not have a sharp resonant frequency, but it was found that the new choke wound with the #33 wire seemed to have sufficient resistance, since no "dead spots" were found after this choke was installed.

The grid condenser and leak are placed on the same mounting, and both are so arranged that they may readily be removed in order that they may be replaced with different size units. A 100 picofarad grid condenser and a 3 megohm grid leak were found to give very satisfactory results, although a 50 picofarad condenser with a 7-10 megohm leak would probably give better results on the highest frequencies. It might be stated here that the smaller the grid condenser is, the higher must be the resistance of the leak and vice versa for satisfactory operation. Also too high a resistance leak will cause the receiver to go into oscillations with a long-drawn howl. This, of course, can be remedied by using a lower resistance leak. With a given size of grid condenser, the tube tends to go into oscillations more smoothly as the resistance of the grid leak is increased, but, as was mentioned above, if the leak resistance is made too high, the tube will go into oscillation with a long-drawn howl, so that the best value for the leak is just below the value that causes this howl.

When using any of the three coils wound on bakelite tubing, the receiver will oscillate nicely with 22-45 volts on the plate of the detector tube, but with the largest self-supporting coil a minimum of 45 volts is necessary for satisfactory operation, while 65-70 volts are required for the smallest coil. When using either of the smallest two coils, and especially the smallest, a number of "dead spots" will probably be found in the oscillating band of the receiver, due to resonance with the antenna and ground leads, and in some cases it is necessary to detach both the antenna and the ground leads before the receiver will oscillate at these points. Of course these points can be shifted by employing the series condenser in the antenna lead, and, perhaps, another in the ground lead which will shift their natural oscillating frequency.

To facilitate the selection of the proper coil for a desired frequency range, approximate calibration curves are supplied for the receiver coils. In figures 5 to 7 inclusive are the approximate calibration curves for the three largest coils which are wound on bakelite tubing, while figures 8 and 9 give the approximate calibration curves for the two smallest, self-supporting coils. In both cases setting of the left hand dial is plotted against frequency of the received signal in kilocycles per second. These curves are necessarily approximate, because they are effected by the type of detector tube used and by the setting of the antenna coupling coil and feed-back condenser. They are also effected by the size of grid condenser used and are slightly effected by the resistance of the grid leak. For frequencies higher than those reached with the smallest coil in the receiver, a temporary arrangement similar to the oscillator was resorted to. Figure 21

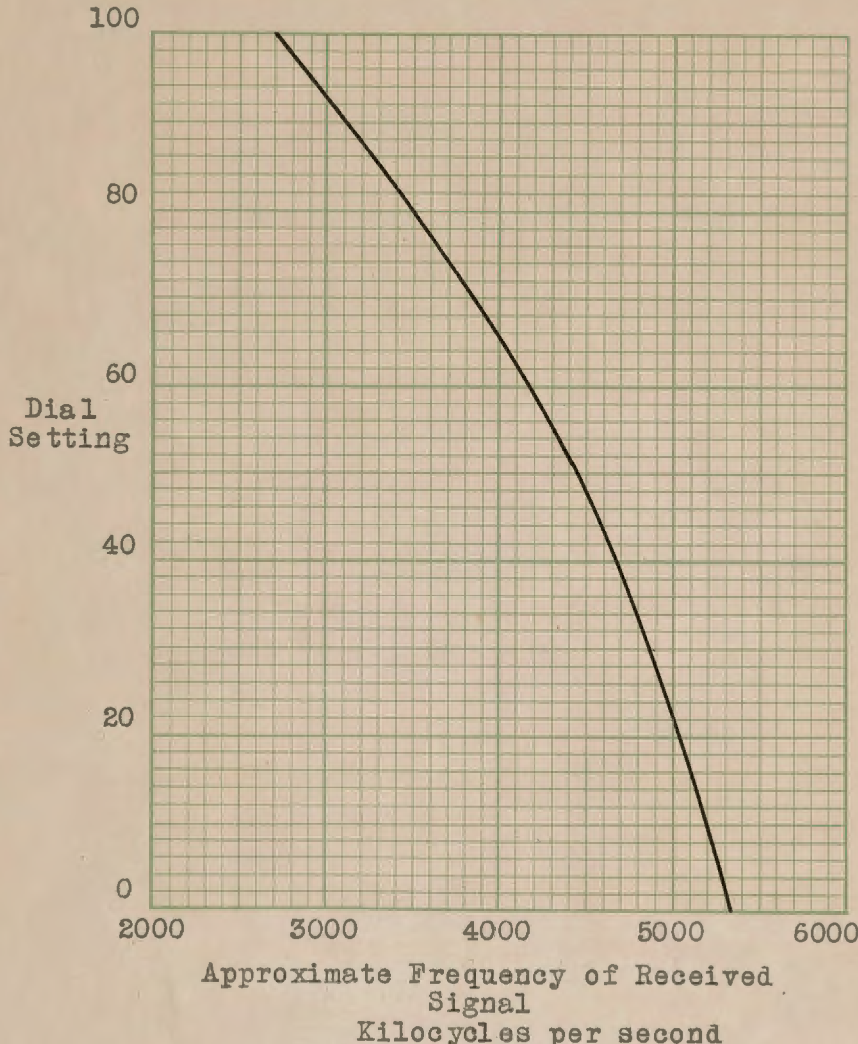


FIG. No. 5

TITLE:- Approximate Calibration Curve for Receiver

18 Turn Coil

INTERPRETATION OF CURVES

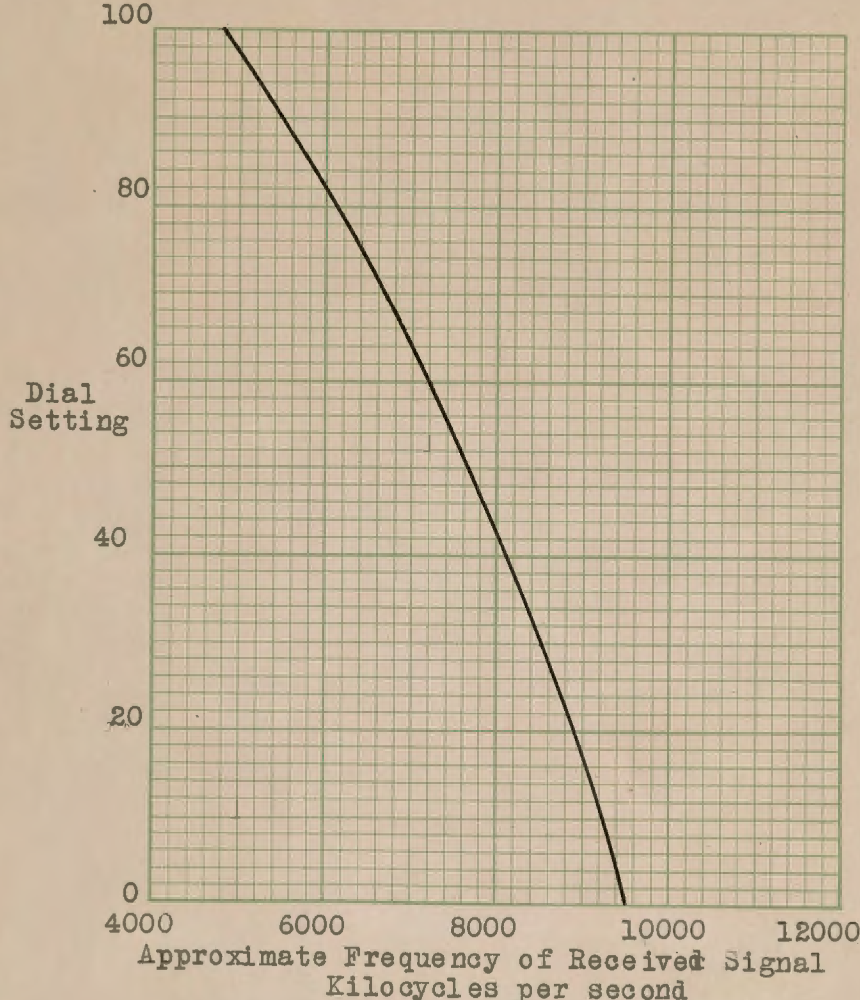


FIG. NO. 6

TITLE:- Approximate Calibration Curve for Receiver

9 Turn Coil

INTERPRETATION OF CURVES

LABORATORY

DATE

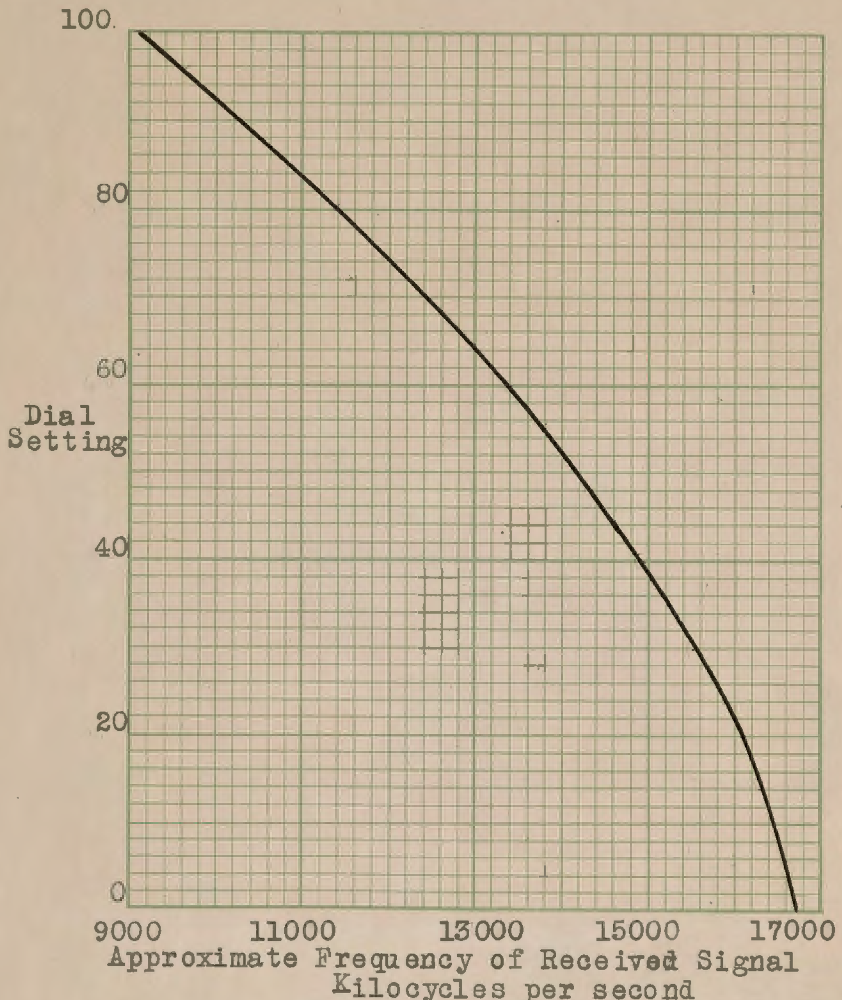


FIG. NO. 7

TITLE:- Approximate Calibration Curve for Receiver
4 Turn Coil

INTERPRETATION OF CURVES

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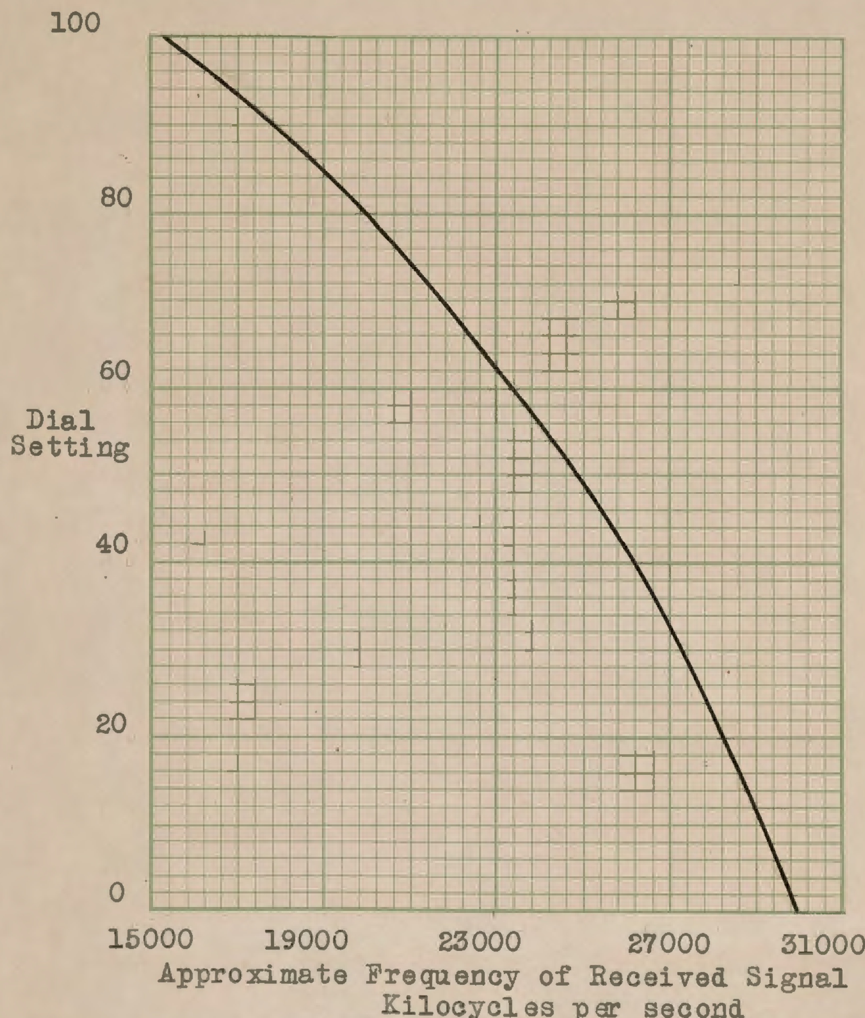

FIG. No. 8

TITLE:- Approximate Calibration Curve for Receiver
4 Turn Self-Supporting Coil

INTERPRETATION OF CURVES

LABORATORY

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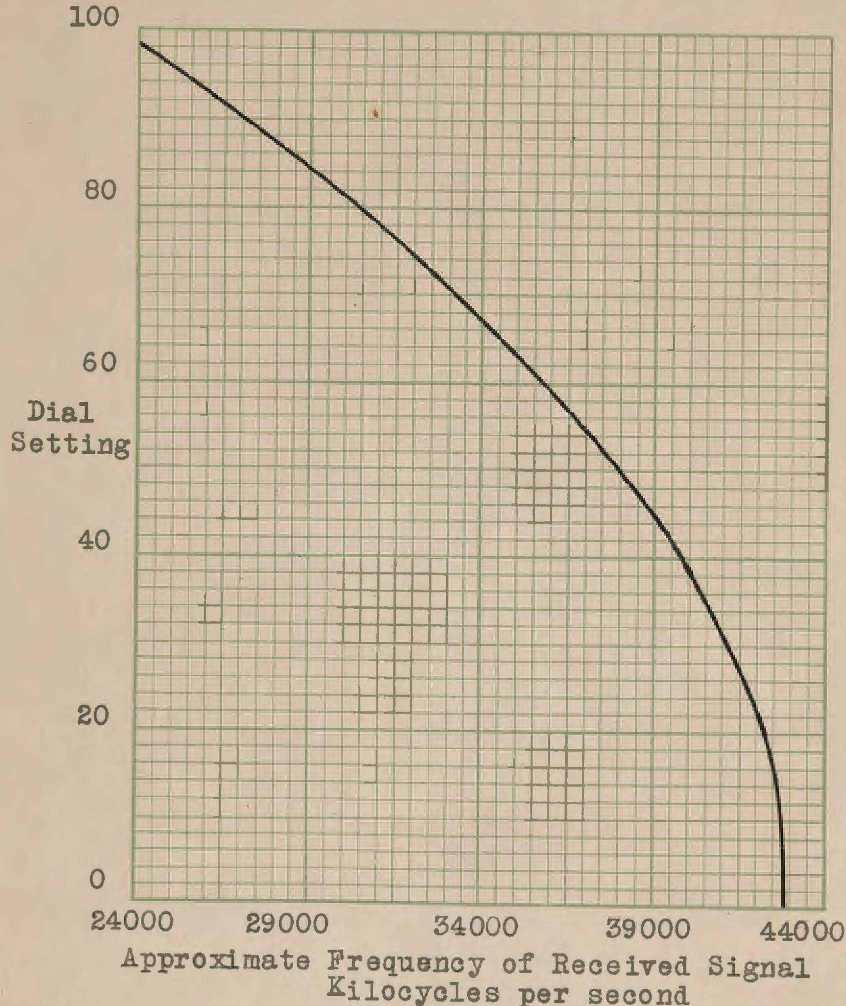

FIG. No. 9

TITLE:- Approximate Calibration Curve for Receiver

2 Turn Self-Supporting Coil

INTERPRETATION OF CURVES

which is a schematic diagram of the oscillator, shows the point at which a headset may be inserted in order to use the circuit for a receiver. Of course no control of regeneration and oscillation is possible except that of varying the plate voltage, but since this arrangement was used only for continuous wave signals, this control, although desirable, was not necessary.

IV. THE WAVEMETER

1. Design

A wavemeter is, essentially, a tuned circuit used for absorbing power, inductively, from an oscillating circuit whose frequency of oscillation is desired. Conveniently it takes the form of a variable capacity with different sizes of fixed inductances, which may be shunted across this capacity. Due to the inherent inductance and minimum capacity of a convenient sized wavemeter to cover the lower frequencies studied in this thesis, it was found necessary to construct a special small wavemeter, using a three plate variable condenser and a special terminal arrangement to cover the highest frequencies studied. The circuit arrangement for both wavemeters is identical and takes the simplest form, eg., a variable condenser shunted by an inductance. It was decided not to incorporate an indicating device in either wavemeter, since the resistance of this device would make the tuning of the wavemeter "broad" instead of "sharp", as it should be. The large wavemeter box is completely shielded with copper sheet to prevent "body capacity" effects, while the small one is provided with a glass extension handle to reduce this feature, since shielding would tend to raise its minimum capacity, which it is desired to keep as low as possible.

A straight line frequency condenser, having a maximum capacity of 100 picofarads, was chosen for the large wavemeter, and the desired inductance and number of turns for each coil was calculated, using the formulae given under the design of the receiver. The three plate variable condenser used in the small wavemeter was devised, arbitrarily, and the size of the coils for it were determined experimentally.

2. Construction

The large wavemeter consists of a 100 picofarad (maximum capacity) straight line frequency condenser, mounted on a 7" x 9" bakelite panel and equipped with a vernier dial, having a reduction of 63/1. Two binding posts with non-removable tops spaced 1⅛" apart are provided at one end of the panel to which the inductances are fastened. The box carrying this panel is lined with sheet copper and a sheet of copper covers the back of the panel; one terminal of the wavemeter is connected to this shielding.

Figures 10 and 11 show, respectively, an inside and an outside view of the large wavemeter, while figures 12 and 13 show, respectively, the same views of the small wavemeter. The coils for the large wavemeter, excepting the smallest, were wound on bakelite tubing, having an outside diameter of 2-7/8". Gauge 16 bare copper wire was used, and was wound <u>hot</u> in threads cut 10 to the inch. The ends of the wire were soldered to terminals which were spaced so as to slip over the binding posts on the wavemeter panel.

In order to distinguish between the two wavemeters, the larger was marked "wavemeter No. 1", and the smaller "wave-

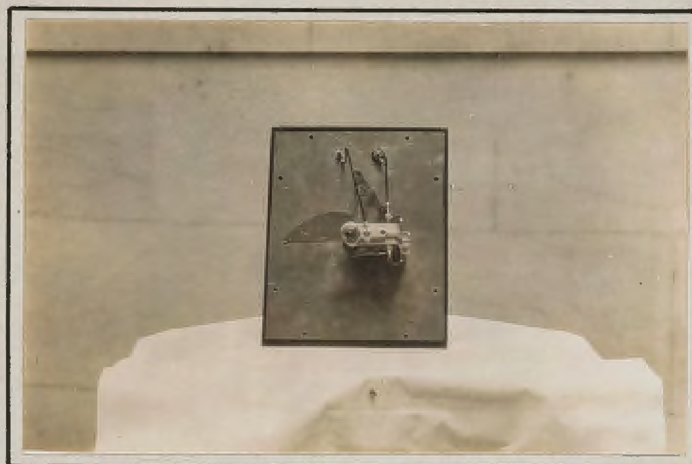

Figure 10

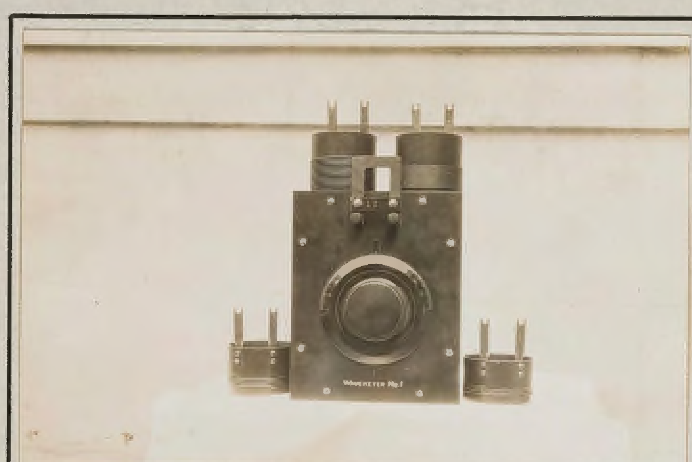

Figure 11

Figure 12

Figure 13

meter No. 2". The coils for the larger wavemeter are stamped and designated as 1 A, 1 B, etc., while those of the smaller wavemeter are marked and designated as 2 A, 2 B, etc., In figure 11 all of the coils for the large wavemeter are shown, while in figure 13 all of those for the small wavemeter are shown.

3. Calibration.

a. Of the Large Wavemeter

The only wavemeter in the labratory is a large general radio wavemeter, which goes down to only 150 meters. Therefore, the following method was used to calibrate the large wavemeter whose range extends well below this:

A large coil, temporarily constructed, was placed in the receiver and, by employing a large variable condenser temporarily shunted across the tuning condenser, it was possible to make the receiver oscillate as high as 500 meters. Next, another oscillator was set up, which could be tuned to the frequencies covered by the wavemeter; it was set to oscillating and, with the receiver headset on, the receiver tuning condenser, beginning at maximum capacity, was slowly reduced until a beat note was heard in the receiver. This meant that some harmonic, say the nth, of the oscillating receiver was the same as the fundemental frequency of the oscillator. The wave length of the oscillating receiver was then read, using the large general radio wavemeter, and the value recorded. Next, the receiver tuning condenser was again reduced slowly until another beat note was heard in the receiver; this meant that the $(n-1)^{th}$ harmonic of the receiver was the same as the fundemental of the short wave oscillator and also that the difference between these two receiver wave lengths was the wave length of the short wave oscillator. A number of readings were taken in this manner and the average of the differences between successive wave lengths of the oscillating receiver was divided into the first wave length of the receiver recorded; this should give a whole number indicating the harmonic of the receiver, but due to experimental inaccuracies, it did not. However, since it was known that it was some harmonic of the oscillating receiver, the nearest whole number was selected as this harmonic, and it was then divided into the first receiver wavelength recorded. This gave the approximate wavelength of the short wave oscillator. If we call this harmonic n, then (n-1) was divided into the second receiver wavelength recorded; (n-2) was divided into the third, and so on, giving a number of values for the wavelength of the short wave oscillator, which were averaged, and this average was taken as the correct value. By tuning the short wave wavemeter to resonance with the short wave oscillator and noting the dial reading, one point was thus obtained on the calibration curve for one of the coils. This procedure was repeated until sufficient points were obtained to draw smooth calibration curves for the wavemeter coils. Figures 14 to 18 inclusive give these curves, dial settings being plotted against frequency of oscillation in kilocycles per second. After the largest two coils were calibrated, they were, in turn, used to calibrate the smaller coils in a similar manner.

LABORATORY

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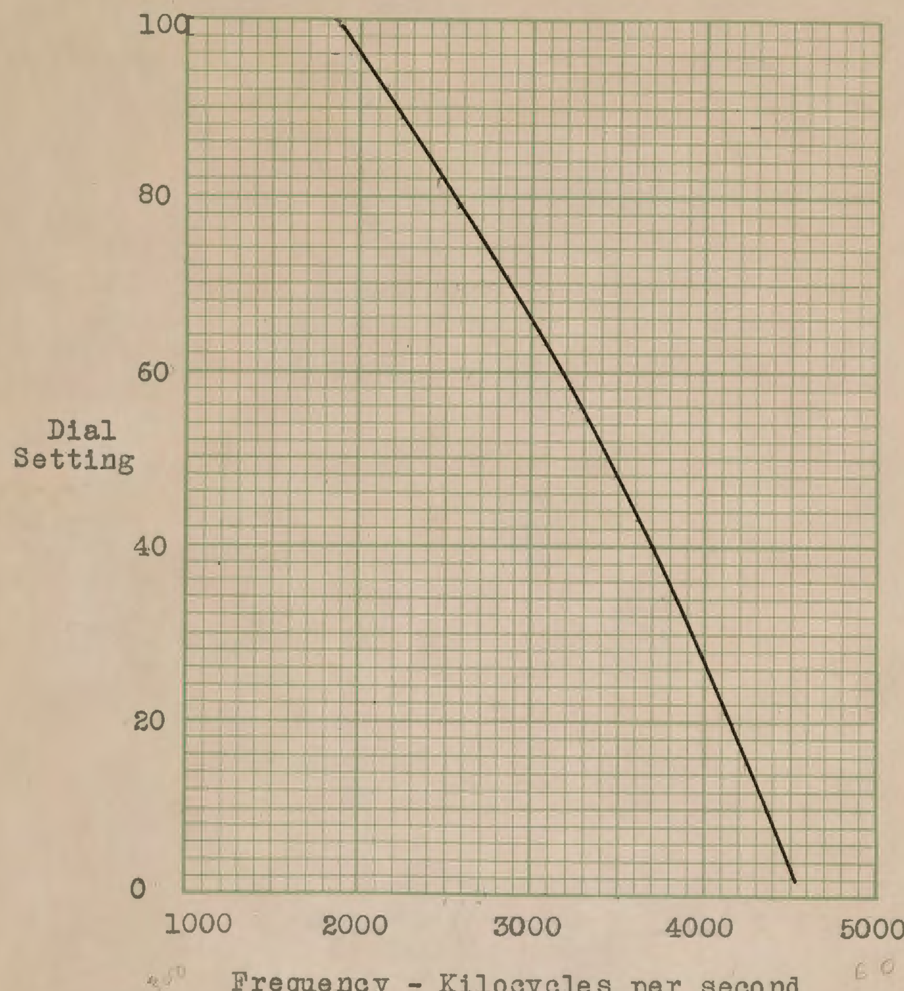

FIG. NO. 14

TITLE:- Calibration Curve for Wavemeter No. 1

Coil No. 1 A

INTERPRETATION OF CURVES

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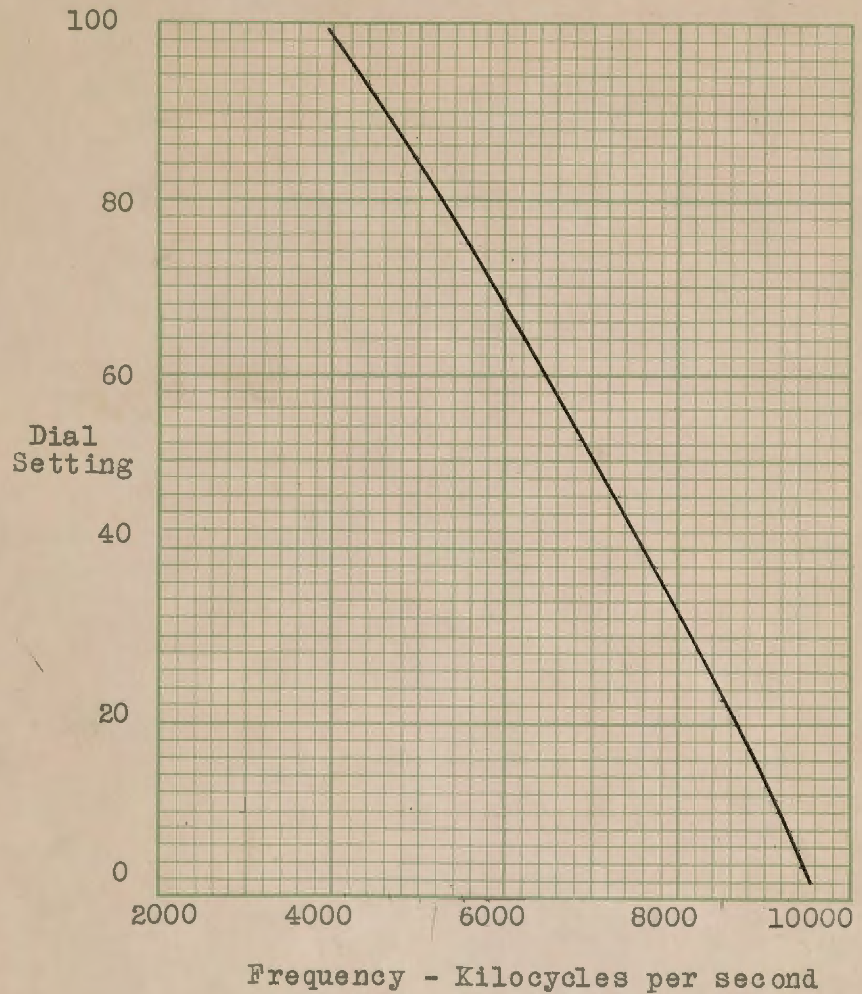

FIG. NO. 15

TITLE:- Calibration Curve for Wavemeter No. 1
Coil No. 1 B

INTERPRETATION OF CURVES

LABORATORY

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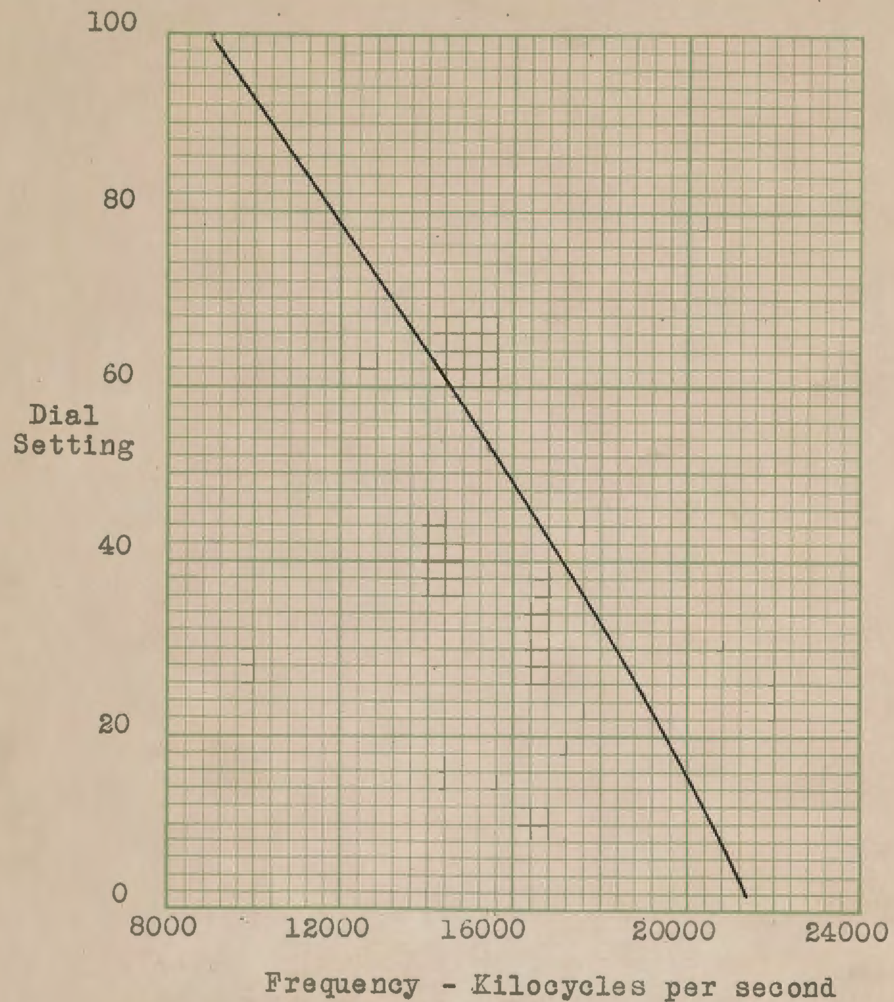

FIG. NO. 16

TITLE:- Calibration Curve for Wavemeter No. 1
Coil No. 1 C

INTERPRETATION OF CURVES

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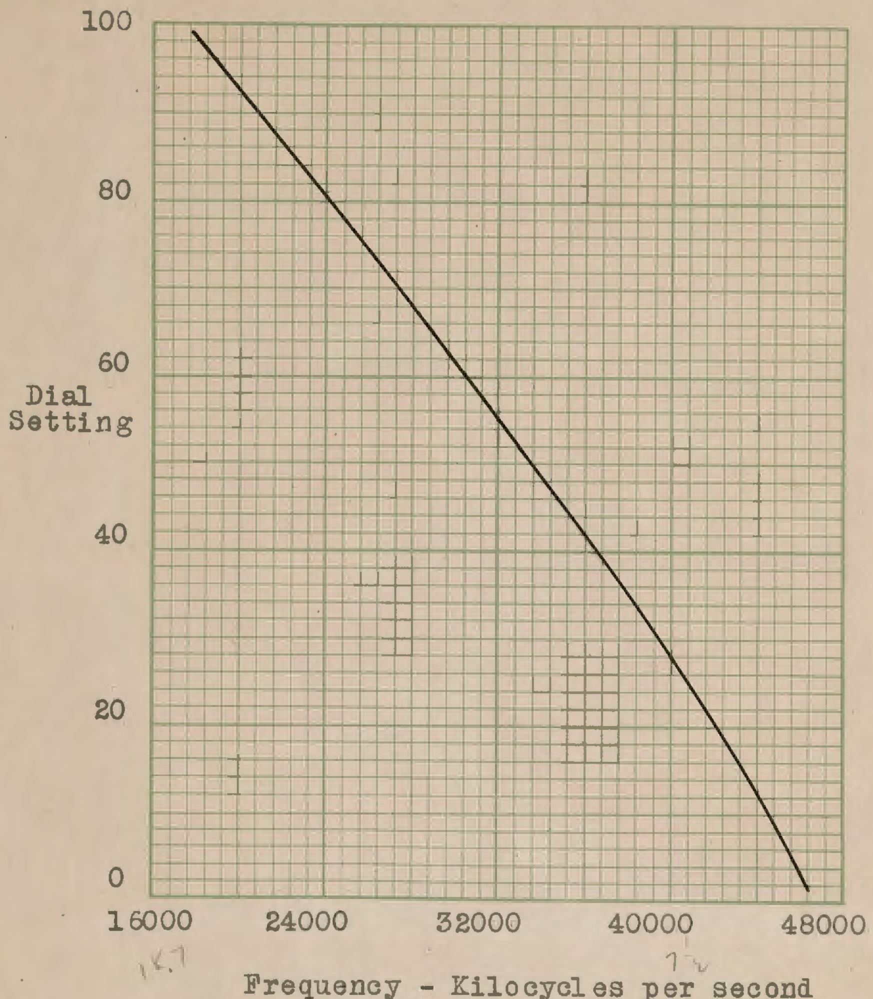

FIG. NO. 17

TITLE:- Calibration Curve for Wavemeter No.1
Coil No. 1 D

INTERPRETATION OF CURVES

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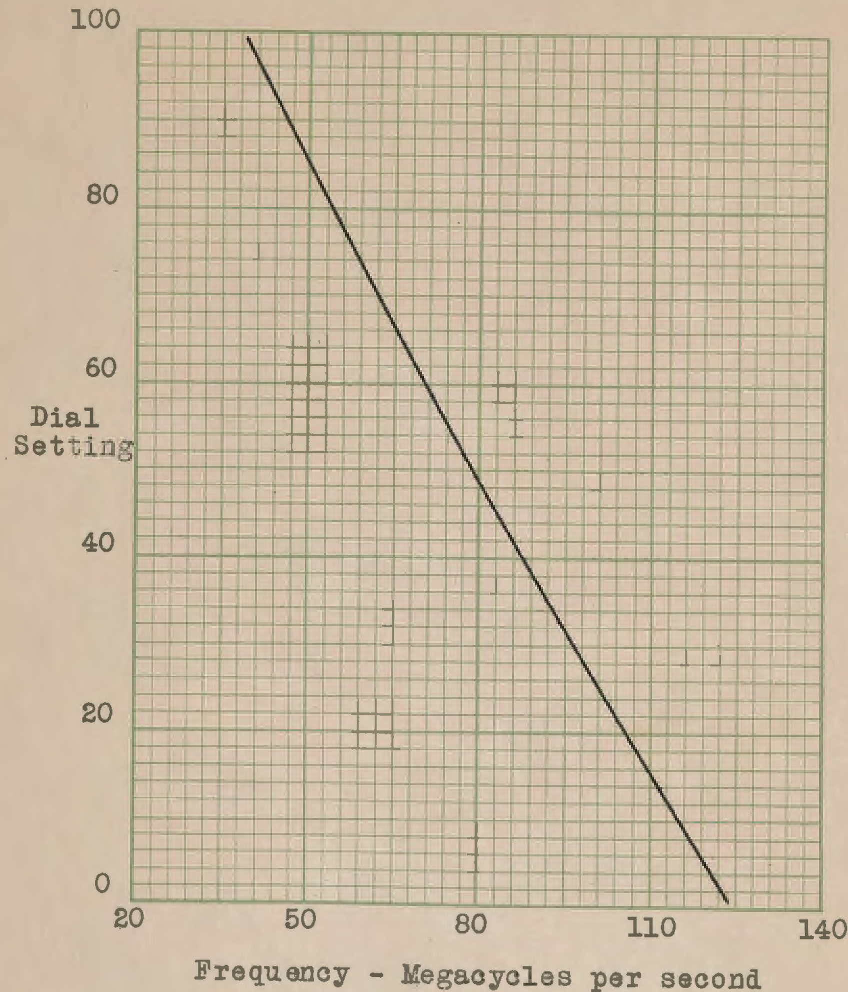

FIG. NO. 18

TITLE:- Calibration Curve for Wavemeter No. 1
Coil No. 1 E

INTERPRETATION OF CURVES

b. Of the small wavemeter.

The "lecher wire" method was used for calibrating the small wavemeter, only one wire being used. The method of procedure was as follows:

A piece of bare copper wire, about fifty feet long, was stretched between insulators in the laboratory, and a short wave oscillator was placed at one end of it, so that the coil of the oscillator was sufficiently near the end of the wire to feed power to it when resonance existed. Figure 19 shows a schematic layout of the apparatus used. The lead from the thermocouple was first hooked over the end of the wire nearest the oscillator and the tuning condenser of the oscillator was varied until the micro-ammeter, connected to the thermocouple, was deflected, indicating resonance between the oscillator and the wire. Next, the lead from the thermocouple was slid along the wire until a maximum reading of the micro-ammeter was obtained, indicating a voltage peak on the wire; this point was marked, and the lead from the thermocouple was then slid along the wire until another voltage peak was found. As many of these voltage peaks as existed on the wire were located and marked, and, since the distance between successive peaks was equal to 1/2 a wavelength, the average of the differences between successive peaks, when multiplied by two, was taken as the correct wavelength of the oscillator. By tuning the wavemeter to resonance with the oscillator, and noting the dial reading one point was thus obtained on the calibration curve for one of the coils. In a similar manner a number of points

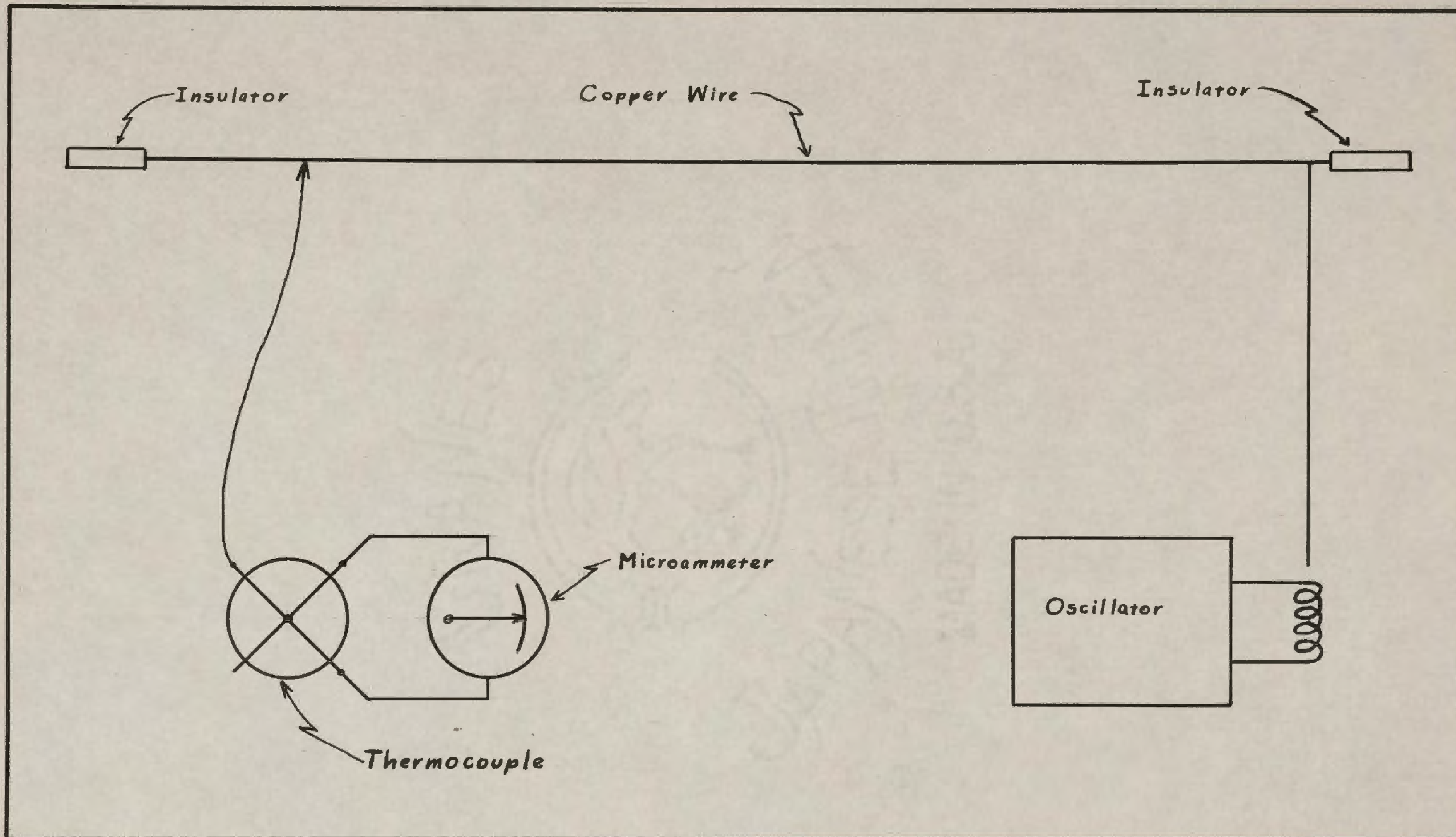

Figure 19
Schematic Layout Of Apparatus For Calibrating Wavemeter Number 2

LABORATORY

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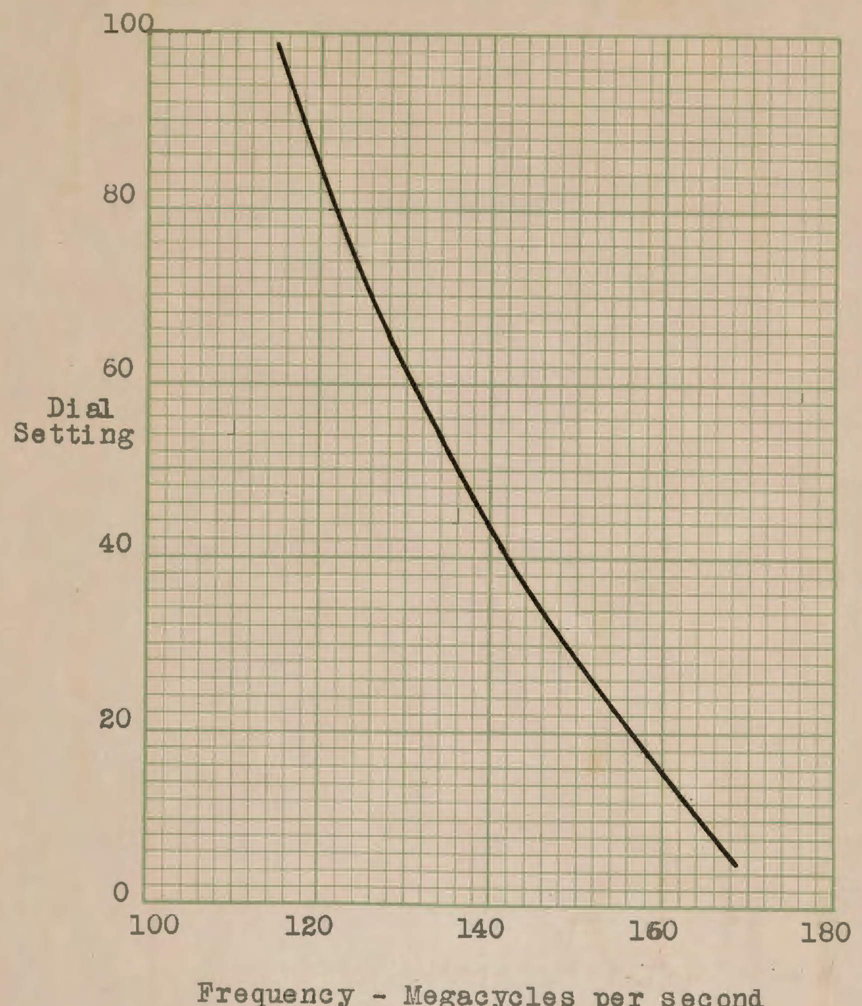

FIG. NO. 20

TITLE:- Calibration Curve for Wavemeter No. 2

Coil No. 2 A

INTERPRETATION OF CURVES

were located on the calibration curve of the wavemeter inductance and a smooth curve was drawn for the coil. Figure 20 gives this curve and, as will be noticed, dial setting is plotted against frequency of oscillation in kilocycles per second.

4. Use of Wavemeters

There is very little to be said about the use of the wavemeters. The principal thing to remember when using a wavemeter is that it is a tuned circuit which is capable of absorbing power inductively from an oscillating (A.C.) circuit when it is tuned to resonance with that circuit. Another thing to remember when using the large wavemeter is that it is provided with stops at both ends of the scale, and if force is used on the dial after these points are reached, the result will be either a springing of some of the parts of the variable condenser, or else a slipping of the dial on the shaft, either of which will spoil the calibration of the wavemeter. The vernier attachment on the dial is provided with a friction arrangement against the panel, so that if it is used it will be impossible to apply too much torque to the shaft of the condenser.

There are, in general, two methods of determing when a wavemeter is in resonance with an oscillating circuit: the first is to use an indicating device with the wavemeter, and the second is to use an indicating device in the oscillator circuit, which will show when power is being absorbed from it. In the first case, the indicating device may be incorporated in the wavemeter circuit (and generally takes the form of a thermo-milliammeter) or it may be an external indicator inductively coupled to the wavemeter coil. A very convenient form for this is a small flashlight bulb mounted in a socket with the ends of a loop of heavy copper wire about 3" in diameter fastened to its terminals. If this is placed just back of the wavemeter coil, (and sufficient power is available) the bulb will light when the wavemeter is tuned to resonance with the oscillating circuit. If a vacuum tube oscillator is used, the best indicator is a milliammeter in the plate circuit of the tube. When the wavemeter is brought into resonance with the oscillating circuit, the needle of the milliammeter will rise suddenly, and, by making the coupling between the wavemeter coil and the oscillator sufficiently "loose", a very sharp indication can be secured in this manner. The vernier attachment on the large wavemeter is very useful for locating the exact resonance point, since it prevents the "over-running" usually experienced when turning a dial. In order to secure accurate results, the loosest coupling which will give a sharply defined indication should be used.

After locating a point on the wavemeter, the next thing to do, of course, is to turn to the proper calibration curve and read off the frequency in kilocycles per second. If desired, this may be converted to wavelength in meters by dividing it into 3×10^5 .

V. THE OSCILLATOR

To generate the lower frequencies which were used for calibrating the wavemeter, a series feed hartley circuit with a variable by pass condenser was used. The variable by pass condenser was found useful for bringing the tube just into oscillations, since it was found that if the capacity were increased too much an audio frequency howl was produced and confusing harmonics were generated. This condition can be detected with the wavemeter, since the plate milliammeter needle drops instead of rising when the wavemeter is brought into resonance with the oscillator. The principal idea, in this case, was to produce a strong fundemental frequency with harmonics as few and as weak as possible, and this was effected by using as low a plate voltage as would cause the tube to operate steadily, and as small an amount of feedback capacity as would produce strong oscillations. The hartley circuit is quite common and no circuit diagram of it given in this thesis.

The oscillator used to generate the highest frequencies reached was of the colpitts type. Figure 21 is a schematic diagram of this oscillator. It will be seen that the circuit is particularly adapted to the generation of high frequencies because the external capacity is in series with the grid to plate capacity of the tube, thus reducing the effect of this latter capacity in the oscillator circuit, it being remembered

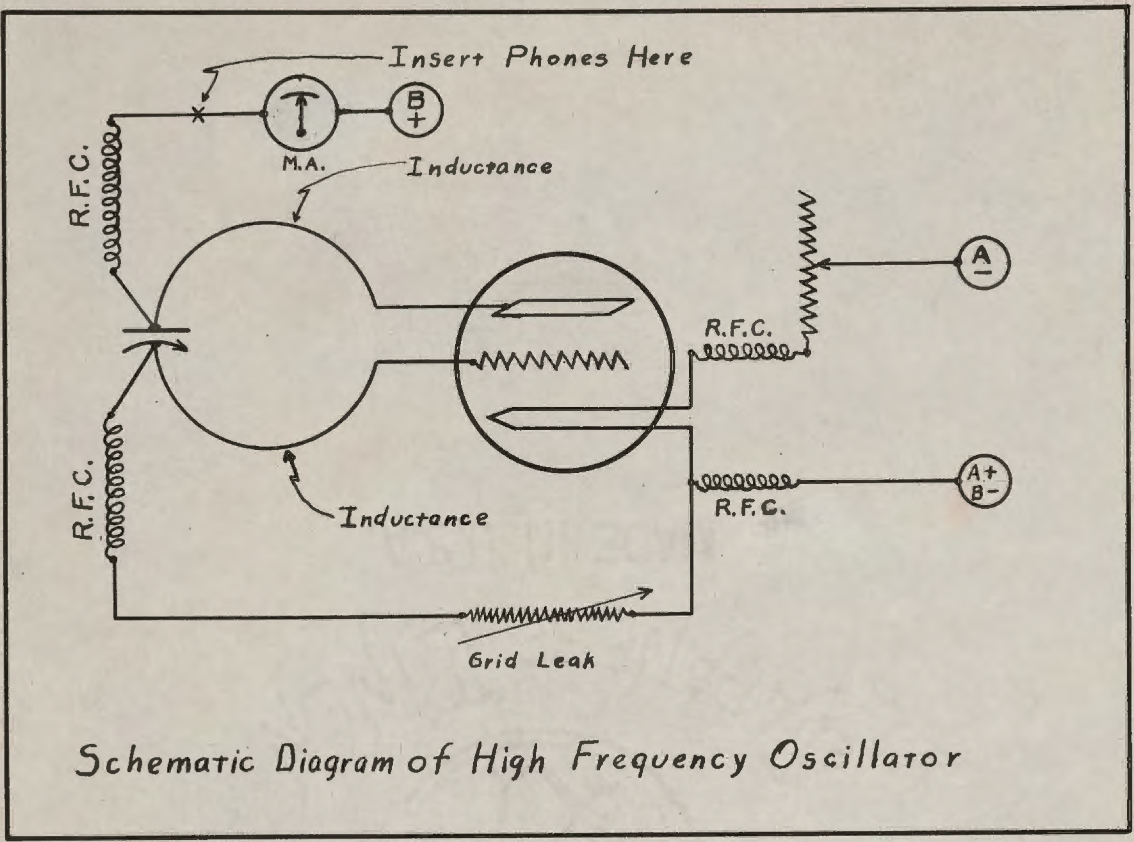

Figure 21

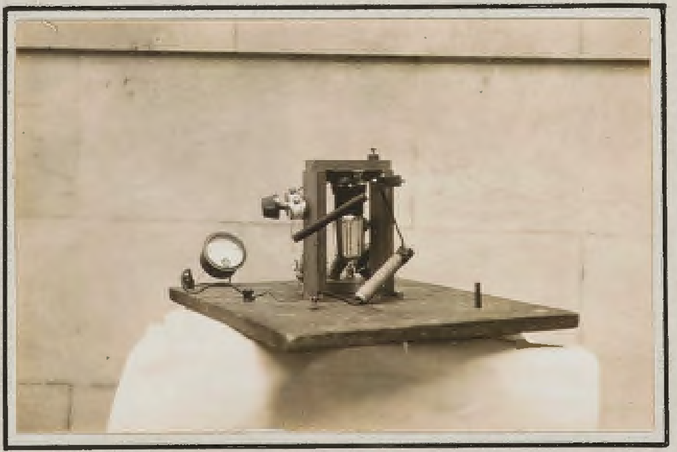

Figure 22

that the total capacity in the oscillating circuit is:

$$C_t = \frac{1}{\frac{1}{C_x} + \frac{1}{C_p}}$$

Where C_t = Total capacity

C_x = External Capacity

C_p = Grid to plate capacity

It will be noticed that radio frequency chokes are placed in all battery lines and in the grid leak circuit. These are essential for the operation of the oscillator and the most convenient form to construct is a single layer solenoid. Figure 22 is a photograph of the oscillator constructed by the author. A bakelite "Air Gap" socket was mounted in the inverted position shown in order to facilitate experimenting with variations in the circuit. The tube shown in the oscillator is a "magnavox" tube and was used to produce the highest frequencies generated, since its inter-electrode capacity is appreciably smaller than that of any of the tubes readily obtained. The highest frequency obtained, using 300 volts on the plate of the magnavox tube and the inductance and capacity shown in the photograph of the oscillator was approximately 160000 kilocycles per second. This will serve to give the reader an idea of the extremely small values of capacity and inductance necessary to generate oscillations of this frequency. This frequency corresponds to a wavelength of 1.88 meters and was the minimum wavelength reached by the author. In order to generate higher frequencies it would be necessary to secure a tube having lower inter-electrode capacities; and one with the grid and plate leads coming out opposite ends is practically a necessity, because when they come out the same end the glass insulation between them generally breaks down very soon if high plate voltages are used (that is at these very high frequencies). The R. F. chokes used by the author consisted of ordinary porcelain wiring tubes wound full of wire; #29 E.S.C.C. wire was used for the grid and plate chokes, while a larger wire, about #22, was necessary for the filament chokes in order to carry the filament current. The chokes are more effective with small wire than with large wire, since the former has less distributed capacity than the latter, and for best results the smallest wire that will carry the current passing through it should be used. In an oscillator, when R. F. chokes are employed, points will be found at which the circuit refuses to oscillate on account of resonance existing with one of the chokes. This trouble was experienced by the writer, and it was found that the quickest and surest way to locate the offending choke was to grasp each choke separately at the low (radio frequency) potential end and the proximity of the fingers changed the natural period of the choke sufficiently to cause the tube to start oscillating, which was indicated by a drop of the plate milliammeter needle. In case it is desired to have the tube oscillate at this particular frequency a few turns may be unwound from the choke, thus reducing its natural period.

It might be mentioned here that the only addition to a good oscillator necessary to make it a transmitter is a keying arrangement in case continuous wave telegraphy is used, and a modulation arrangement in case phone is used. Of course much greater range is obtained with the C.W. than with the phone. If any distance is desired an antenna is necessary and a means of feeding the energy of the oscillator to the antenna. "The Radio Amateur's Handbook", published by the "American Radio Relay League" at Hartford, Connecticutt, gives all of this information in workable form, and is an excellent volume for any one taking up a study of short waves from the experimental side. Much valuable matter is also to be found in the QST Magazine, which is published monthly by the "American Radio Relay League" at Hartford, Connecticutt and which is devoted entirely to "Amateur Radio" or to matter pertaining to bands from 0.7477 meters to 200 meters. In the Bibliography are given a number of references to articles in this magazine which, it was thought, might be useful to anyone carrying on additional studies of transmission, employing the higher frequencies.

F I N I S

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APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

Name Chas A Perkins

Title Professor
Electrical Engineering.