MSS:AN
I-6

DEPARTMENT OF COMMERCE
BUREAU OF STANDARDS
WASHINGTON

Letter Circular - LC 171

(July 10, 1925)

REQUIREMENTS, CONSTRUCTION AND OPERATION OF APPARATUS FOR MEASUREMENT OF THE FREQUENCIES OF DISTANT RADIO TRANSMITTING STATIONS.*

Contents Page

I. General

The increasing use of radio for broadcasting and other purposes and the necessarily small separation in frequency of transmitting stations have created a demand for information about the methods of measurement of the frequencies of radio transmitting stations. Measurements of this character are necessary to take advantage of the standard frequency signals transmitted by the Bureau of Standards and also of the standard frequency transmitting stations listed in the Radio Service Bulletin each month, (The Radio Service Bulletin is a monthly publication of the Department of Commerce and is obtainable from the Superintendent of Documents, Government Printing Office, Washington, D.C., at 25 cents per year.) Detailed description of an assemblage of apparatus for this purpose is given herein.

The apparatus for measuring radio station frequencies consists of a frequency meter (wavemeter), a radio-frequency generator and a radio receiving set. Such equipment permits measurements

* Prepared by M.S.Strock, Assistant Physicist.

of the frequencies of radio transmitting stations, either distant stations or at the point where the apparatus is located. This letter Circular gives a detailed discussion of the requirements, construction and operation of such apparatus (with the exception of the receiving set) for the measurement of frequencies above 550 kilocycles (wave lengths below 545 meters).

The requirements in view are: accuracy, low cost, and the adapting of improvements to apparatus that an experimenter is likely already to have. A possible fourth requirement is that the apparatus be compact and portable.

Accuracy in the measurement of radio frequencies is of fundamental importance if the results are to be of value. To obtain it requires a properly constructed frequency meter with a reliable calibration, and care and knowledge on the part of the observer. A careful compliance with the instructions in this circular will usually permit the obtaining of an accuracy of 0.5 per cent or better in the measurement of radio frequencies. This estimated accuracy includes all deviations in frequency which may occur between the primary source from which the frequency meter is originally calibrated and the final reading of the frequency from the calibration curves after the frequency meter has been adjusted to another source of radio frequency which is being measured. If the primary source of frequency deviates by 0.2 per cent from the absolute or true value of frequency, then in order to be certain of an accuracy of 0.5 per cent, the subsequent errors in calibration and observation must not be greater than 0.3 per cent. This follows because these errors might be either all positive or all negative; if they were of opposite sign the accuracy of the particular measurement would be better than 0.5 per cent, but the uncertainty of the measurement would in general be 0.5 per cent.

Accuracy must not be confused with precision. Precision refers to accidental deviations, errors in observation without reference to the true values. It is possible to have precise measurements and very poor accuracy. The attaining of accuracy with the usual type of frequency meter generally requires that the instrument be used with a generator employing a storage battery to supply filament current to the electron tube. This is due to the fact that the resonance indicator is rather insensitive. The use of a storage battery renders the equipment unportable.

In the discussion in this circular devoted to the frequency meter, a sensitive type of resonance indicator is described (as described in Bureau of Standards Scientific Paper No.502, "An Improved Type of Wavemeter Resonance Indicator," obtainable from the Superintendent of Documents, Government Printing Office, Washington, D.C., at 5 cents a copy). This device has sufficient sensitivity to permit the frequency meter being used with an inexpensive portable generator equipped with an electron tube which

may be operated from dry batteries. This resonance indicator costs no more than the type commonly employed and it may be added to most portable frequency meters. By its use, the requirements of accuracy, low cost, adaptability and portability of the measuring equipment are fulfilled.

II. The Frequency Meter.

A. General Construction.-- Generally speaking, there are two types of frequency meters, transmitting and receiving. Transmitting frequency meters may in turn be divided into two general classes, those which have buzzer excitation and those which have electron tube excitation. This latter type of frequency meter is usually called a heterodyne frequency meter.

The receiving type of frequency meter only is considered in this circular. The transmitting type which uses buzzer excitation does not permit of reliable measurements. The heterodyne frequency meter is useful for approximate measurements and has certain advantages in the way of precision, but the variations introduced by variations in the tube currents or constants make it unsuitable for use as an accurate standard unless recourse is had to very special design.

A receiving type of frequency meter consists essentially of a coil of wire, a variable condenser and a resonance indicating device to show when the instrument has been properly adjusted to the source of radio-frequency power which is being measured. By the substitution of various coils, the frequency range is extended. It is also possible to obtain measurements outside the range of the frequency meter by utilizing harmonics from a generator.

A reliable frequency meter is not marked directly in frequencies. Instead, an arbitrary reading is taken from an engraved dial attached to the shaft of the condenser and the value of the frequency is determined from a curve showing the frequency corresponding to each setting of the condenser. This curve is plotted from values obtained from a calibration of the frequency meter (Part IV, B).

B. Mechanical and Electrical Requirements.-- The fundamental requirement of a frequency meter, that it be capable of making accurate measurements, largely determines its mechanical and electrical construction. It should be of such construction that it will, with proper care and freedom from rough handling, maintain its calibration over a considerable period of time. This requires a minimum of variation in the inductance of the coils and in the capacity of the condenser for any particular setting. In general, the construction must be such that the parts and wiring will not become displaced.

If the frequency meter coils are to maintain a constant value of inductance, the wire must be held firmly in place and

it must be protected from mechanical injury. The requirement for the variable condenser, that its capacity remain constant for any particular dial setting, demands detailed attention to its construction. Condensers other than the rotating plate type should not be considered. Variable condensers which employ an insulating material as a dielectric are almost certain to undergo a change in capacity for any given adjustment of the condenser dial. The plates should be of sufficiently heavy material so that they will not become bent, and they must be rigidly supported. A condenser giving close spacing between the fixed and moving plates is undesirable because a slight shifting in the position of the rotating shaft will produce an appreciable change in capacity. The bearings must have large wearing surfaces and they must be so designed that there is no end play in the shaft. The dial must be secured to the shaft in such a manner that there is no possibility of loosening. The condenser should have unimpeded rotation through 360 degrees as the use of stops is very likely to shift the position of the rotating plates.

In addition to the points discussed above, the requirement for accuracy in frequency meter construction demands consideration of three other features which relate to precision in its adjustment. These are (1) a condenser dial which will indicate small changes in adjustment; (2) means of eliminating the effect of body capacity and of obtaining a slow movement of the rotating plates; (3) a circuit of low radio-frequency resistance.

The condenser dial should be of metal engraved over one-half of its circumference with evenly spaced divisions which divide the dial into 100 equal parts or into 180 degrees. The lines should be sharply defined and of minimum width. In order to secure sufficient precision in setting the frequency meter condenser, it is necessary that the dial settings be read to a tenth of a division. This requires the use of a vernier scale.

The second requirement of precision in adjusting the frequency meter necessitates proper shielding and the use of a slow-motion device for the rotating plates. Shielding usually consists in mounting a metal sheet on the under side of the panel and connecting it to the rotating plates of the condenser. Shielding may also include lining the inside of the cabinet with metal. The slow-motion device may consist of a small knob geared to the shaft of the rotating plates. A simpler method of obtaining a fine adjustment of the condenser is to attach a light strip of wood about one foot in length to the condenser knob. This also eliminates body capacity, and shielding will probably not be necessary.

The third requirement for precision of the frequency meter, that it have a low resistance is necessary in order to obtain rapidly changing deflections of the resonance indicator with small changes in the condenser adjustment. The frequency meter will have a low resistance if its construction agrees with the

points previously discussed, if the proper type of resonance indicator is used, and if the coils are wound with sufficiently large wire properly spaced. The resonance indicator and the coils are discussed in paragraphs C and D.

C. Resonance Indicator.-- If the experimenter has a frequency meter which he desires to use with equipment described in this circular, an examination of its construction should be made to see if it conforms to the requirements of accuracy discussed above. This examination may show the need for some alteration which may be made without the necessity of constructing a new frequency meter. When the instrument is examined, some derangement of the circuit may occur which will affect its calibration. It is probable, however, that a new calibration will be required. (Part IV, B).

In addition to an examination of the frequency meter, a test should be made to determine if it has sufficient precision for accurate measurements. To make this test, the instrument is coupled to a source of radio frequency power so that good deflections of the resonance indicator are obtained. The frequency meter is now carefully tuned to resonance and the setting of the dial is recorded. This frequency meter is then detuned and again tuned to the same source of power, which has been kept at constant frequency, and another dial setting is recorded. This process is repeated until a number of readings are obtained. The frequencies corresponding with these various adjustments are then determined from the calibration curves, and the percentage difference between them is computed. If they agree within about 0.1 per cent it is an indication that the frequency meter is capable of making precise measurements.

The tests just described to determine the precision of a frequency meter equipped with the usual type of resonance indicator may show that it is suitable for measurements of frequencies from a high-power generating set such as a radio transmitting set. However, for general use in conjunction with a low-power radio-frequency generator, as described in this circular, the more sensitive type of resonance indicator above mentioned (described in Bureau of Standards Scientific Paper No.502) is desirable. The schematic wiring of this resonance indicating circuit is shown in Fig.1 and these parts are lettered to correspond to Fig.6 in Scientific Paper No.502. The essential parts of the resonance indicator are a crystal detector D and a sensitive direct-current milliammeter MA giving a full-scale deflection with not more than 1 or 2 milliamperes. Undoubtedly, the use of a crystal detector will seem objectionable to many persons. It has been found, however, that if a detector of substantial mechanical design which is equipped with a good galena crystal is used, no difficulty is experienced in maintaining a sensitive adjustment.

The first step in the application of the resonance indicator is to short-circuit the old resonance indicating device by a heavy

conductor (Z, Fig.1) firmly clamped or soldered in place. Reference should now be made to Scientific Paper No. 502 for details of wiring. The sensitivity of this resonance indicator is largely determined by the size and number of turns of the coil L', Fig.1, (Fig.6, Scientific Paper No.502). This coil is used in a frequency meter for measurements with a radio-frequency generator employing an electron tube of about five watts power. If the frequency meter is to be used with a low-power generator as described in this circular, L' will consist of more turns, determined experimentally in the tests described below. Due to different types of frequency meter construction, some variations in the connections of this resonance indicating circuit may be required for best results. For this reason, connections may be temporarily made, and the test described below will indicate if the circuit is in proper working condition. The connections should then be rigidly and permanently made.

The most satisfactory test of the resonance indicator is made by means of a low-power generator such as described in Part III. In place of this, a radio transmitting circuit may be used. However, this will not be as satisfactory because there will be no way of determining if the resonance indicator is sufficiently sensitive for use with a low-power generator. The frequency meter is coupled to the generator which is adjusted to a frequency corresponding to the lowest setting of the frequency meter condenser when using the smallest coil. With a low-power generator the respective coils of the generator and frequency meter should be separated by about six or eight inches. Closer coupling will probably produce a reactive effect which will prevent precise measurements. It may happen that the generator is of such low power that a change in coupling will affect the setting of the frequency meter. This condition may usually be overcome by employing a higher plate voltage for the tube used in the generator. If a source of high power is used, very loose coupling must be employed.

The crystal detector is adjusted to a sensitive condition and the frequency meter is tuned to resonance with the generator by noting the maximum deflection of the milliammeter. With the coupling specified above for a low-power generator, the resonance deflection of the milliammeter should not be greater than about one-third the total range of the scale. This deflection may be secured by varying the number of turns of L'. The generator is now adjusted to a frequency corresponding to approximately the highest setting of the frequency meter, and the latter is again tuned to resonance so that a maximum deflection of the milliammeter is obtained. These two deflections should be made as nearly as possible the same. This may be done by shifting the one-point connection from X to E or F, Fig.1. Greater deflections may of course be obtained by using increased coupling, but if the coupling is too close the reactive effect will spoil the precision of the measurement. With the proper amount of coupling to the generator, greater resonance deflections

may also be obtained by the use of more turns of wire on the coil L' Fig.1. If the number of turns of this coil is too great, it will absorb so much power from the frequency meter circuit that a readjustment of the crystal detector will spoil the calibration. Tests should be made to determine if this effect is in evidence.

This effect is most pronounced at the high-frequency adjustments. Therefore, the frequency meter condenser should be adjusted near minimum capacity with the coil of the smallest inductance. The generator is tuned approximately to resonance, the frequency meter is tuned very carefully to the exact resonance point, and the setting of the condenser dial is recorded. The crystal detector is then readjusted so that the resonance deflection is reduced about one-third. The frequency meter is again tuned, and a second reading of the condenser dial is taken. If several repetitions of these tests indicate that the adjustment of the crystal detector produces an appreciable change in the setting of the frequency meter dial (corresponding to frequency differences of more than about 0.1 per cent), then it is an indication that too many turns are used on coil L' in the resonance indicating circuit, Fig.1. Reducing the number of turns of this coil may reduce the resonance deflections of the milliammeter at the low-frequency adjustments to such an extent that a precise setting of the frequency meter condenser can not be obtained from a low-power generator. In this case a metal plate B, Fig.1, connected in the resonance indicating circuit may be used to secure somewhat larger deflections which do not give changed settings in the condenser upon readjusting the crystal. This plate is mounted inside the frequency meter case near the plates of the condenser which are not connected to the shield and should have an area of about six or eight square inches.

If the milliammeter is not provided with internal damping, a damping resistance should be connected across its terminals. The most satisfactory value of this resistance would, as far as securing stability of the needle is concerned, be the critical damping resistance of this instrument. However, in order to insure a satisfactory sensitivity this resistance should be sufficiently high so as not to reduce the normal deflection of the milliammeter by more than about one-third.

D. Construction.-- In the specifications for the construction of a frequency meter given below, it is assumed that there is an agreement with all the requirements of accuracy previously discussed. The description given below is principally devoted to details of construction applicable to this particular frequency meter, which will cover a frequency range from about 500 to 3000 kc (545 to 100 meters). Accurate measurements of considerably higher frequencies may be obtained by the use of harmonics.

The essential parts of the frequency meter are: two coils, a variable condenser, a resonance indicator, a panel of insulat-

ing material and a cabinet. The general appearance of the completed instrument is shown in Fig. 2. The coils are made by winding wire on wooden forms 4 inches in diameter and having a winding space of 7/8 inch. Two brass strips are attached to each coil form to permit the substitution of either coil in the circuit by inserting their slotted ends under binding posts mounted on the panel. The terminals of the coil are connected to the brass strips. The wood for the coil forms must be well seasoned and should be protected from moisture by a good grade of varnish. Instead of using the round coil forms, each form may be built up of a block of wood 7/8 inch thick and 4 inches square which is placed between two thin squares of wood/of somewhat larger dimensions so as to form a shallow groove or winding space. The corners of the blocks should be rounded.

The inductance of the coils must be such that the specified range of frequencies will be covered with a variable condenser having a maximum capacity of 0.001 microfarad. This inductance is determined principally by the size and shape of the coil form, the number of turns and the spacing between turns. A fairly reliable capacity rating of the condenser is specified by the manufacturer. Since the frequency meter is required to cover a given range, (550 - 3000 kc), allowances must be made for slight deviations in the inductance of the coils and the capacity of the condenser from the required values. The data given in Table I considers these deviations and if adhered to, the desired frequency range of the frequency meter will be secured, together with a sufficient "overlap" between the coils. Larger wire is used on coil 2 in order to reduce the resistance at the higher frequencies.

Table I.
Coils for Frequency Meter

Maximum capacity of variable condenser-microfarads.	Coil 1 - 7/8 inch winding space. Range 550 to 1500 kc.		Coil 2 - 7/8 inch winding space. Range 1400 to 3000 kc.	
	Round form (4 inches dia.)	Square form (3 3/4 inches square).	Round form (4 inches dia.)	Square form (3 3/4 inches square).
0.001	One closely wound layer No.28 AWG d.c.c. wire.		10 turns No.20 AWG d.c.c. wire evenly spaced.	

The coil terminals are brought out through small holes in the winding form and soldered to the brass connection strips. The turns must be protected from moisture by the proper application of varnish. Only varnishes of the best quality, especially made for electrical insulation purposes, should be employed. Even if

this precaution in the selection of the varnish is taken, it frequently happens that as the varnish ages, the inductance of the coil changes appreciably. To partially overcome this difficulty, the varnish should be applied sparingly. In no case should an attempt be made to impregnate the coil.

The turns of the coil must be protected from mechanical injury and displacement. In the case of the round coil forms this may be accomplished by wrapping strips of celluloid around the edges, or if square forms are used, thin strips of wood may be secured to the edges.

The panel upon which the parts are mounted must be made of a piece of insulating material of sufficient thickness to insure rigidity. It is fitted into a cabinet of suitable size, approximate dimensions being indicated in Fig.2. These dimensions will, of course, vary somewhat with the size of the parts. The illustration suggests dimensions of sufficient size to provide a separate compartment for storing the coils and the milliammeter. Provision should be made for the elimination of shock to these parts and the compartments should be provided with a separate cover which is readily removable.

After the panel is drilled in accordance with the requirements for mounting the parts and binding posts, the lower side of this panel should be shielded. For this purpose a sheet of thin brass or copper is satisfactory. The shield is connected to the rotating condenser plates. It must be carefully cut away so that no contact is made with the binding posts, wiring or other parts of the circuit except where these parts are themselves connected to the rotating condenser plates.

The schematic wiring of the frequency meter is shown in Fig. 1. The wiring must be made with great care so that permanently rigid connections will result. The condenser C and coil L form the resonance circuit, the wiring of which merely consists in running two rigid leads from the terminals of the variable condenser to the binding posts where the coils are to be connected. The parts of the resonance indicating circuit should be temporarily wired together, and tests made to determine a satisfactory operating condition, as previously described under Part II, C. The wiring is then permanently and rigidly made.

In case it is desired to use a variable air condenser which is shielded and already calibrated in terms of capacity, as the condenser in the frequency meter, it may be considered undesirable to open the condenser in order to attach the coil L' and plate B of Fig.1. One reason for not desiring to open a shielded calibrated condenser is that the capacity calibration is likely to be changed when the condenser is removed from the shield.

Assuming that such a condenser is used, the resonance indicating device indicated in Fig.1 may be modified somewhat and

satisfactory results obtained. Plate B may be omitted and coil L' consist of two or three turns of No.10 or 12 A.W.G. copper wire. The coil L' should have the same diameter as coil L and be firmly fastened in the position in which it is calibrated, which may be within 2 or 3 inches of coil L.

III. The Generator.

A. Requirements.-- A generator of radio-frequency currents consists essentially of a coil of wire, a variable condenser, and an electron tube. The inductance of the coil and the capacity to which the condenser is adjusted practically determine the generated frequency. The frequency range of the generator is extended by the substitution of coils of different inductance. A fundamental requirement of a generator when used in conjunction with a frequency meter and radio receiving set, as described later, is that it be of sufficient power to permit precise adjustments of the frequency meter. The latter device when equipped with the type of resonance indicator previously described permits the use of a low-power generator having an electron tube operated by dry batteries. Other requirements of the generator are that it be capable of gradual frequency variation, that it be simple in operation, and that it maintain a constant frequency for a particular adjustment during the time interval required for a measurement.

B. Construction.-- The cost of the generator is much less than that of a wavemeter. The schematic wiring, utilizing the well-known Hartley circuit, is shown in Fig.3, and the general appearance of the completed generator is shown in Fig.4. Variations in the inductance of the coils and in the capacity of the condenser for a particular setting over any except a short time interval are of no consequence. Hence the precautions necessary to secure constancy as prescribed for the wavemeter are not necessary. For the uses to be described the required frequency range of the generator should be approximately 300 to 3000 kc. This is obtained by two coils and a variable condenser of 0.001 microfarad capacity.

The generator cabinet accommodates the dry cell A and B batteries and provides storage space for the coils. The variable condenser, tube socket, and rheostat are mounted on the under side of a wooden panel. A panel of insulating material may be used but it is not necessary. The arrangement of the parts on the panel as suggested in Fig.4 permits short connecting wires and provides space inside the cabinet for batteries. The electron tube used should be of a type which may be operated on dry cell A batteries requiring a small amount of space. The B battery should consist of at least three 22 1/2-volt units and if the dimensions of the cabinet are as shown in Fig.4, the small size battery unit is required. Although these suggestions for the A and B batteries are given with the idea of using a

small amount of space in order that the apparatus may be most readily transported, it will, in general, be more satisfactory to employ a high plate voltage on the tube, and this will probably require the use of more B batteries which can not be mounted inside the generator cabinet having the dimensions shown in Fig.4. The use of higher plate voltages increases the power of the generator so that looser coupling may be employed between the generator and frequency meter. Thus the use of more plate batteries while rendering the equipment somewhat less portable, has the advantage of requiring fewer precautions in the measurements.

The generator coils are of the so-called spiderweb type, as shown in Fig.4. This type of coil is easily wound to an approximate required inductance since it does not require the selection of a cylindrical winding form of a given diameter. It also has the advantage of compactness. On the other hand, it is probable that single-layer coils wound on cylindrical forms will give slightly better results. The two terminals of each coil are anchored to the cardboard form and allowed to project about six inches. A third terminal is formed by soldering a wire to a point near the center of the coil. The three terminals are connected to binding posts on the generator panel.

The variable condenser used in the generator should have a maximum capacity of 0.001 microfarad. This determines the specifications for the coils as shown in Table II in order that the generator may cover the required range of frequencies (approximately 300 to 3000 kc) with sufficient overlap between coils. The coils are wound with No.20 or 22 AWG d.c.c. wire upon cardboard forms having an odd number of projections or spokes.

Table II.
Coils for Radio Frequency Generator.

Coil No.	1 (Range 300 to 1400 kc)	2 (Range 800 to 3000 kc)
Approximate outside diameter of flat coil form.	6 1/4 inches	6 inches
Inside diameter of flat coil form.	3 inches	3 inches
Number of turns	50 - No.22 AWG d.c.c.wire.	20 - No.20 d.c.c.wire

The condenser should be provided with a dial and a type of knob which will permit attaching a light wooden strip about 14 inches in length. This will allow adjusting the condenser without any

appreciable capacity effect from the body of the observer, a necessary condition for precise adjustments. This method of adjusting the condenser eliminates the necessity of shielding.

The schematic wiring of the generator is shown in Fig.3. Insulated wires are brought out from the batteries and connected to the proper binding posts on the panel which is then secured in position. The batteries are held in place inside the cabinet by wooden strips. The head phones are connected to the proper binding posts, the rheostat turned on, and the coil terminal which leads to the grid of the tube is tapped lightly with a moistened finger, while the condenser is rotated. A succession of clicks show that the circuit is in a generating condition.

Part IV. Measurements.

A. Accuracy.-- That requirement for accuracy in the measurement of radio frequencies which relates to a properly constructed wavemeter can be realized by careful attention to the preceding discussions in this circular, while the other requirements for accuracy (a reliable frequency meter calibration and care and knowledge on the part of the observer) will be met by a following out of the suggestions given in parts B and C.

B. Frequency Meter Calibration.-- In calibrating the frequency meter, auxiliary apparatus, consisting of the generator previously described and a radio receiving set (preferably one which is capable of being adjusted to a generating condition) will be required. After the frequency meter calibration is obtained, one or both of these auxiliary pieces of equipment will be used for the general purpose of the measurement of frequencies of distant transmitting stations. Therefore, in making a calibration, some knowledge of such measurements will be gained.

The method of calibration utilizes the emitted ("primary") frequencies of transmitting stations having frequencies which are known to be accurate. There are two distinct groups of transmitting stations which supply these primary frequencies. They are (1) "Standard Frequency Stations" and (2) Stations WWV, Bureau of Standards, Washington, D.C., and 6XBM, Stanford University, California.

"Standard Frequency Stations" are those listed monthly in the Radio Service Bulletin and include a number of broadcasting stations of suitable frequencies for this work. Stations WWV and 6XBM transmit semimonthly schedules of standard frequencies on unmodulated continuous waves. Schedules giving the hours of transmission and the transmitted frequencies are announced every two months in the Radio Service Bulletin and in radio magazines and newspapers.

In arranging the apparatus preparatory to obtaining primary

frequencies for the frequency meter calibration, the generator should be placed between the frequency meter and the receiving set so that coupling will be obtained between them. This also gives coupling between the generator and the frequency meter. Very loose coupling is required between the receiving set and the generator.

The method of obtaining a frequency meter calibration from the primary frequencies of distant stations consists in obtaining points on the frequency meter corresponding to those frequencies and obtaining additional points by utilizing harmonics from the local generator. This method gives a sufficient number of points to permit the plotting of reliable calibration curves. As many primary frequencies as possible should be obtained. If this is done, time will be saved by a reduction in the number of harmonics which will be required, and errors in calibration which might be caused by the deviation of a primary frequency will be largely eliminated. On the other hand, it is possible by the use of harmonics to obtain a complete frequency meter calibration from a single primary frequency. If it is desired to check a calibration previously obtained rather than to obtain a new calibration, the primary frequency signals will often be sufficient without the necessity of employing harmonics from the local generator.

The method of obtaining primary frequencies for the calibration employs the principle of zero beat and permits of a high degree of precision. If an unmodulated primary frequency signal is being received (WWV or 6XBM) it will be most convenient to first adjust the receiving set to the point of self-generation. If a non-generating receiving set is used, it is necessary to tune it approximately to the transmitting station and then adjust the generator until an audible beat note is produced in the phones of the receiving set. Retuning the receiving set slightly will produce a beat note of maximum intensity. If a broadcasting station is being received, the set is tuned to maximum signal, but is not adjusted to a generating condition. The generator is then tuned until it produces an audible beat note with the incoming carrier frequency.

When the desired transmitting station has been tuned in on the receiving set, the local generator must be adjusted to a condition of zero beat while the receiving set is in a non-generating condition. This adjustment transfers the frequency of the distant station to the local generator. It must be made with great care so that the error in setting will be small. The observer should place himself in such a position that the body capacity will not affect the adjustments of the frequency meter and generator. An extremely precise adjustment of the generator may be obtained by tapping the pointer attached to the knob of the condenser. The frequency meter is now carefully tuned until the resonance indicator shows a maximum deflection. As it is tuned near the point of resonance, the reactive effect may cause a slight variation in the frequency of the generator, with the

result that the beat note will again be heard. This change may be measurable on the frequency meter and therefore adjustments should be made to again attain the condition of zero beat. This may require decreased coupling between the frequency meter and the generator in addition to a slight readjustment of the generator. To reduce the errors in observation as much as possible a number of successive readings of the frequency meter should be taken, the generator being of course always kept at the adjustment corresponding to zero beat. In general, the mean value of these readings will be most reliable. In case one of these readings shows a comparatively great deviation from the mean value, that reading is disregarded and a mean value of the others is obtained.

C. Use of Harmonics.-- Having determined as many primary frequency points as possible, the method of harmonics is used to obtain additional points over the range of the frequency meter. This method as described below is not intended to be inclusive, that is, it does not give in detail the obtaining of all the points necessary for plotting calibration curves. By following through the method as described, the experimenter will gain a sufficient idea of the process to enable him to vary it slightly according to the apparatus which is at hand. For this work, two generators, which may be of the type previously described, are required. A receiving set which can be adjusted to a generating condition, or the circuit of a continuous wave transmitter in the room where the apparatus is located, may serve as one of the generators. To obtain stronger harmonics it is sometimes desirable to increase the plate voltage above the normal value and to somewhat reduce the filament current. Headphones are inserted in the plate circuit of one of the generators. In using the method of harmonics, it is important to be able to readily determine the harmonic which is employed to obtain zero beat. To this end, it is very desirable to have an approximate calibration of the generator so that an idea of the frequency to which it is adjusted may be obtained by noting the condenser setting and the particular coil which is used. If the generator is constructed as previously described, the approximate frequency to which it is adjusted may be estimated.

The calibration by harmonics should preferably be started at the same time a primary frequency signal is being received. This will permit setting the generator to zero beat with the incoming signal. If the primary frequency has been previously transferred to the frequency meter, the generator may be adjusted to this frequency by tuning to resonance with the frequency meter. The primary frequency signal is thus reproduced in the generator instead of the generator being directly adjusted to the incoming signal, and therefore the observational error is increased. After adjusting the generator to the primary frequency, precautions should be taken to see that the frequency of the generator remains constant. This may be determined by noting the constancy of the pitch of the beat note obtained by reaction with a second generator. Fig. 5 shows graphically the method of obtaining

harmonics between generators. Assume that a primary frequency of 600 kilocycles is being received. Having set generator A to 600 kilocycles, generator B is tuned to the same frequency by zero beat. In order to determine that this beat is produced by the fundamental frequencies of the two generators, the settings of the condensers may be noted and (assuming that the generators are of similar construction) will be found to be approximately the same, or the frequency meter may be used to indicate that the beat note produced between the two generators comes from their fundamental frequencies. The condenser of generator B is now reduced to about 1/4 its scale setting until a second beat note is heard. This beat is caused by the second harmonic of generator A (1200 kc) reacting with the new fundamental frequency of generator B. The frequency meter is now carefully tuned to resonance with generator B, and a number of readings are taken to reduce the errors in observation. The 1200-kc point frequency thus obtained is recorded.

By the substitution of a different coil the frequency of generator B is again increased until another beat note is obtained. This is caused by the third harmonic (1800 kc) of generator A leading with the fundamental of B. It is transferred to the frequency meter in the same manner as before. Leaving generator B adjusted to 1800 kc, the frequency of generator A is increased until another zero beat note is obtained. This is the second harmonic of generator A (fundamental now 900 kc) beating with the fundamental frequency (1800 kc) of generator B. This is transferred to the frequency meter. Generator A is now left at the 900-kc adjustment, and the frequency of generator B is increased to 2700 kc producing zero beat with the third harmonic of A. The frequency of 2700 kc is then transferred to the frequency meter. Harmonics from other primary frequencies are obtained in the same manner.

Of equal importance to obtaining accurate frequency points is the plotting of these points on cross-section paper so that a smooth curve may be drawn between them permitting the accurate determination of frequencies corresponding to any setting of the frequency meter dial. Curves obtained for the frequency meter described in this circular are shown in Figs. 6a and 6b.

Assuming that the observations are accurate, the more points obtained for the plotting of curves, the better. If in attempting to draw a smooth curve through the points, some of them appear to lie to one side, then these points usually indicate observational errors, and it is best to repeat the observations. However, it sometimes happens that in drawing a curve only a few of the points will lie slightly outside of its path. In this case a "mean" curve should be drawn, that is, a smooth curve so located that these points will lie equally on each side. Accuracy in the use of calibration curves depends to a considerable extent upon the scales chosen for locating the points. The scales for these curves should be chosen sufficiently large so that any

errors in plotting the points or in reading the frequency from the curve after the points have been plotted will be less than the observational errors in making measurements. To illustrate, reference may be made to the frequency meter dial. The vernier scale suggested for this dial permits reading to 0.1 of a division and estimating to about 0.05 of a division. Therefore, the points for the frequency meter scale (located on the horizontal axis) should be plotted to such a scale on the cross-section paper that they may be readily located to within 0.02 or 0.03 of a division of the frequency meter dial. As a second illustration, reference may be made to the frequency points as located on the vertical axis. It has been previously assumed that by following the specifications for frequency meter construction and operation, an accuracy of better than 0.5 per cent may be obtained. Therefore the scale of frequencies is to be so chosen that the points may be laid off to an accuracy considerably greater than 0.5 per cent, say one or two tenths per cent.

This discussion relative to the scales used in plotting curves must be given with a word of caution. While it is true that in order to eliminate or reduce the errors in reading frequencies from the curves, the scales should be chosen so that these errors are less than any errors which may be made in the observations, it is also true that one can not expect to obtain a more accurate value of frequency from these curves than is possible to obtain by the actual calibration of the frequency meter. For instance, suppose that a certain dial setting on the frequency meter shows from the completed curve that the corresponding frequency is 500.5 kc. The value of 0.5 kc represents a discrimination of 0.5 part in 500 which is equivalent to 0.1 per cent. Since, however, the accuracy of the frequency meter calibration may not be better than 0.5 per cent, the frequency as chosen from the curve will be recorded as either 500 or 501 kc.

D. <u>Methods of Measurement</u>.-- In the preceding discussion giving methods of calibrating the frequency meter, its use as a measuring instrument is described to a considerable extent. This is particularly true in regard to precautions to be taken in the measurements so that the observational errors will be a minimum. However, the discussion below will add something to the knowledge of frequency measurements previously obtained by describing some particular kinds of measurements.

Consideration will first be given to the measurement of a frequency of a transmitting station where the measuring equipment is located. This measurement subdivides into two parts, first when the frequency of the transmitting station lies within the range of the frequency meter, and second when the transmitted frequency is higher than a frequency which can be directly measured.

The first kind of measurement merely requires coupling the

frequency meter to the transmitting circuit and adjusting the dial until a maximum deflection is obtained on the resonance indicator. In making this measurement precautions must be taken to see that the coupling is not too close, that the effect of body capacity of the observer is not appreciable, and that observational errors are reduced to a minimum. This latter is accomplished as previously mentioned by taking a number of separate readings on the frequency meter, preferably using different degrees of coupling. The frequencies corresponding to these different settings are then determined from the calibration curves, and if they do not differ by more than approximately 0.1 or 0.2 per cent, the mean is assumed to be accurate.

In case the frequency of the local transmitter which is to be measured is above the range of the frequency meter, then the measurement may be made by the use of harmonics. This requires a radio-frequency generator with headphones connected in the plate circuit. The generator is tuned until one of its harmonics beats with the fundamental of the transmitter and the generator is then carefully adjusted to zero beat. The frequency of the generator is then measured and its value obtained by reference to the calibration curves. It is necessary to determine whether this frequency is 1/2, 1/3 or possibly 1/4 of the frequency of the transmitting station. To this end, the approximate frequency of the transmitting set must be known. For instance, assume that the transmitter frequency is approximately 4000 kc, and suppose that the frequency as measured by zero beat from the generator is 1026 kc. Dividing 4000 by 1026 gives 3.9, which shows that the 4th harmonic of the generator was used to obtain zero beat. The true frequency of the transmitter is therefore 1026 x 4 = 4104 kc.

The second kind of measurements which are far greater in scope, are made upon distant transmitting stations. Methods of calibration previously described, as well as methods of measurement just given almost cover this subject. In the following further discussion, it is assumed that there is a careful observance of the precautions previously mentioned.

First, there is the measurement of a distant transmitting station of a frequency within the range of the frequency meter. This operation is essentially the same as locating a point from a transmitting station when the frequency meter was calibrated. After the generator is tuned to zero beat with the incoming signal, the frequency meter is tuned to the generator, the setting of the frequency meter is read, and the frequency is determined from the calibration curves.

A second kind of measurement of a distant transmitting station is sometimes desired when the frequency of this station is higher than that which may be directly measured. In this case the generator is tuned to zero beat with the incoming frequency, the zero beat being produced by a harmonic of the

generator combining with the received frequency. The generator frequency is then measured as previously described, and it is merely necessary to determine the harmonic of the generator which was used in setting to zero beat.

V. Care of Frequency Meter.

In following the instructions for the construction and use of radio-frequency measuring equipment given in this circular, it must be understood that the calibration of the frequency meter is not permanent. Proper care of the instrument, such as avoiding mechanical shock and exposing it to sunlight, or more especially, to dampness, will be of assistance in maintaining the calibration. However, after a period of a few months, particularly when the frequency meter is new, it is necessary to obtain a check of its calibration, and in case this shows a change of more than about 0.2 per cent, a new calibration should be made.

As a suggestion for checking the calibration it will usually be sufficient to obtain three or four points for each curve, provided these points are so located that two of them lie near the ends of the curve and that the other points are approximately uniformly spaced. In obtaining a check in this manner the source of the primary frequencies must be known to be accurate, otherwise it may appear that the calibration of the frequency meter is inaccurate, when, as a matter of fact, the inaccuracy is due to the points used for checking. If these points lie at appreciably different distances from the curve, then it is probable that the frequency meter calibration has changed and a complete new calibration should be obtained. It may happen that these points all lie upon one side of the curve at the same distance from it. In this case, assuming that the points have been carefully taken from an accurate frequency source, it is permissible to draw a new curve through them and parallel to the old curve. This amounts to a recalibration of the frequency meter without the necessity of obtaining many new frequency points.

Attached:
6 Figures.

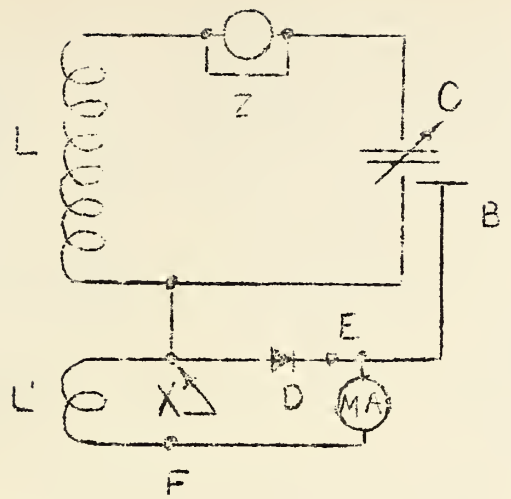


FIG. 1

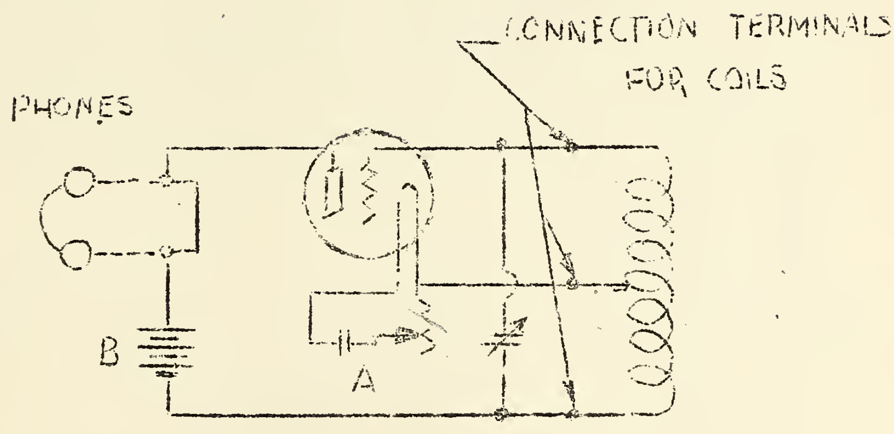


FIG. 3

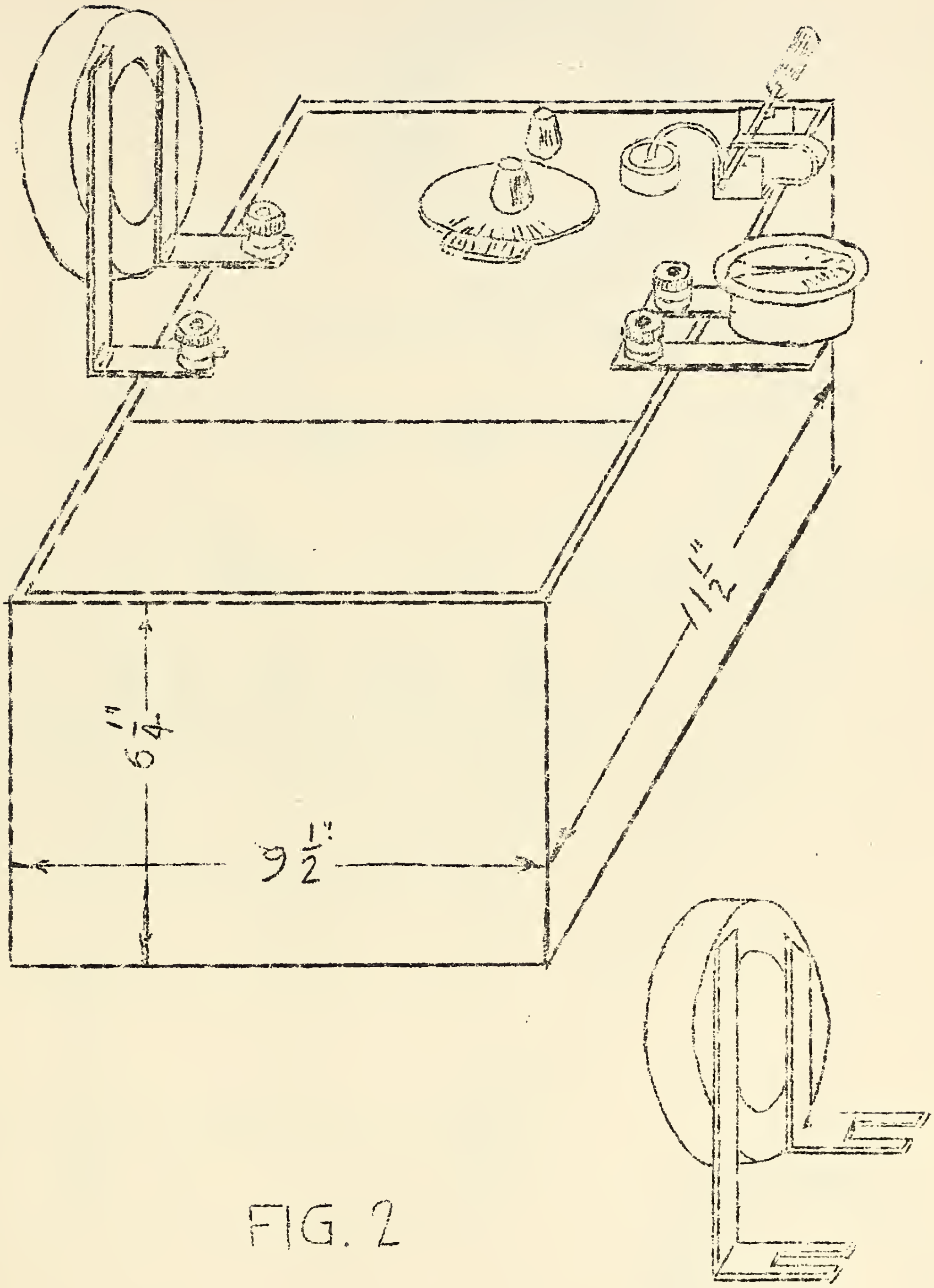


FIG. 2

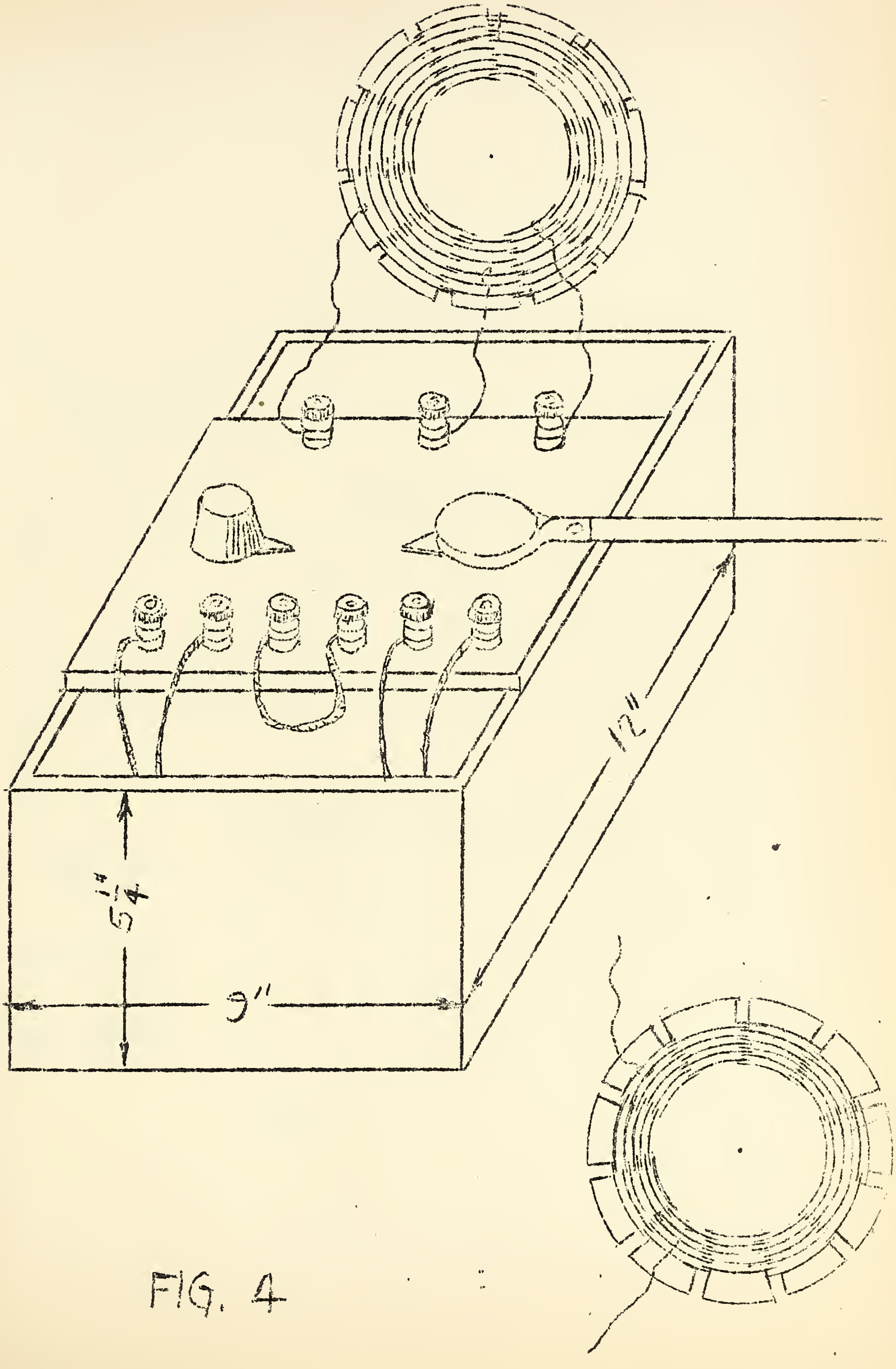
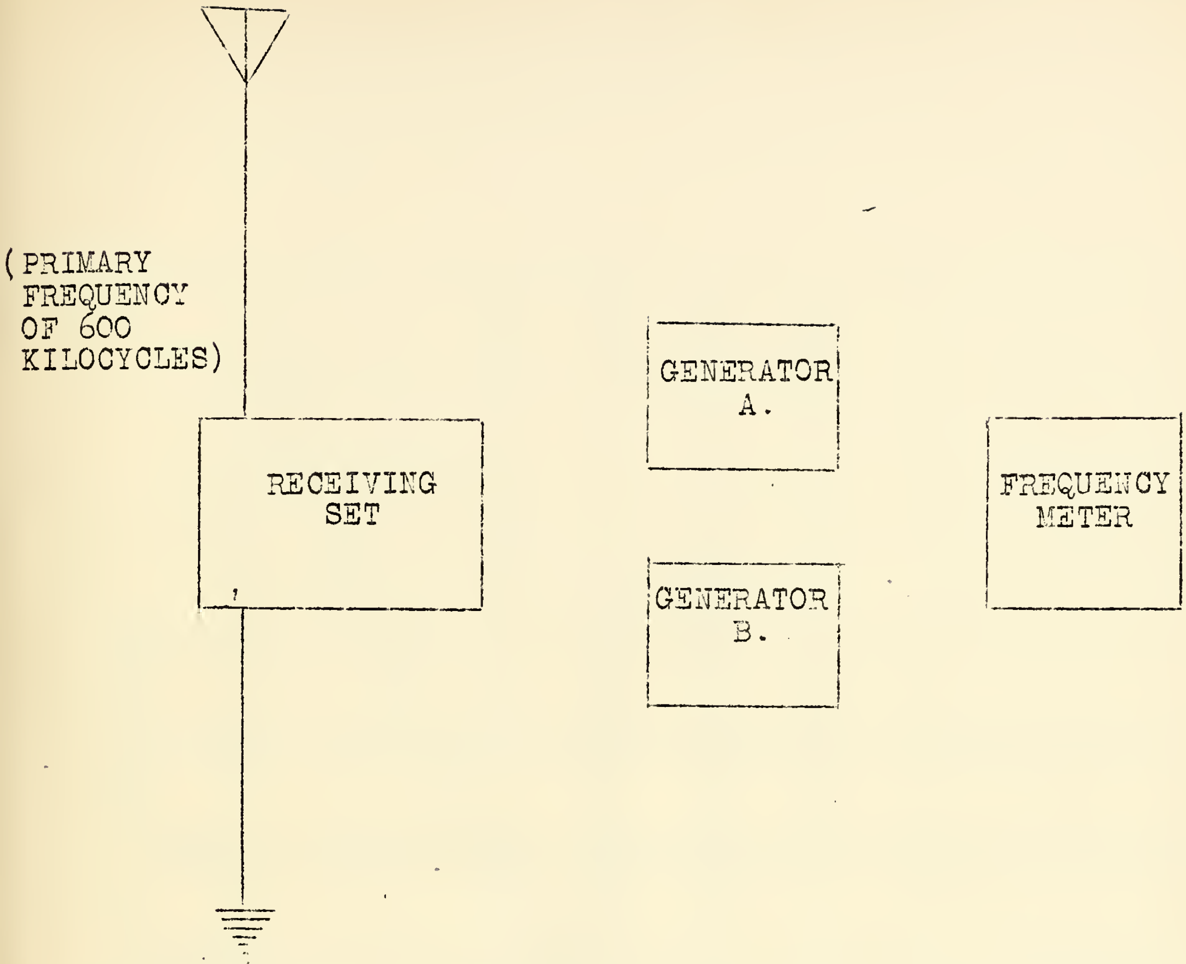


FIG. 4



ADJUST A TO 600 KC --	TRANSFER	TO	FREQUENCY	METER
" B 1200 KC	"	"	"	"
" B 1800 KC	"	"	"	"
LEAVE B AT 1800 KC				
ADJUST A TO 900 KC --	"	"	"	"
LEAVE A AT 900 KC				
ADJUST B TO 2700 KC --	"	"	"	"

FIG. 5

COIL 1 550-1500 KC

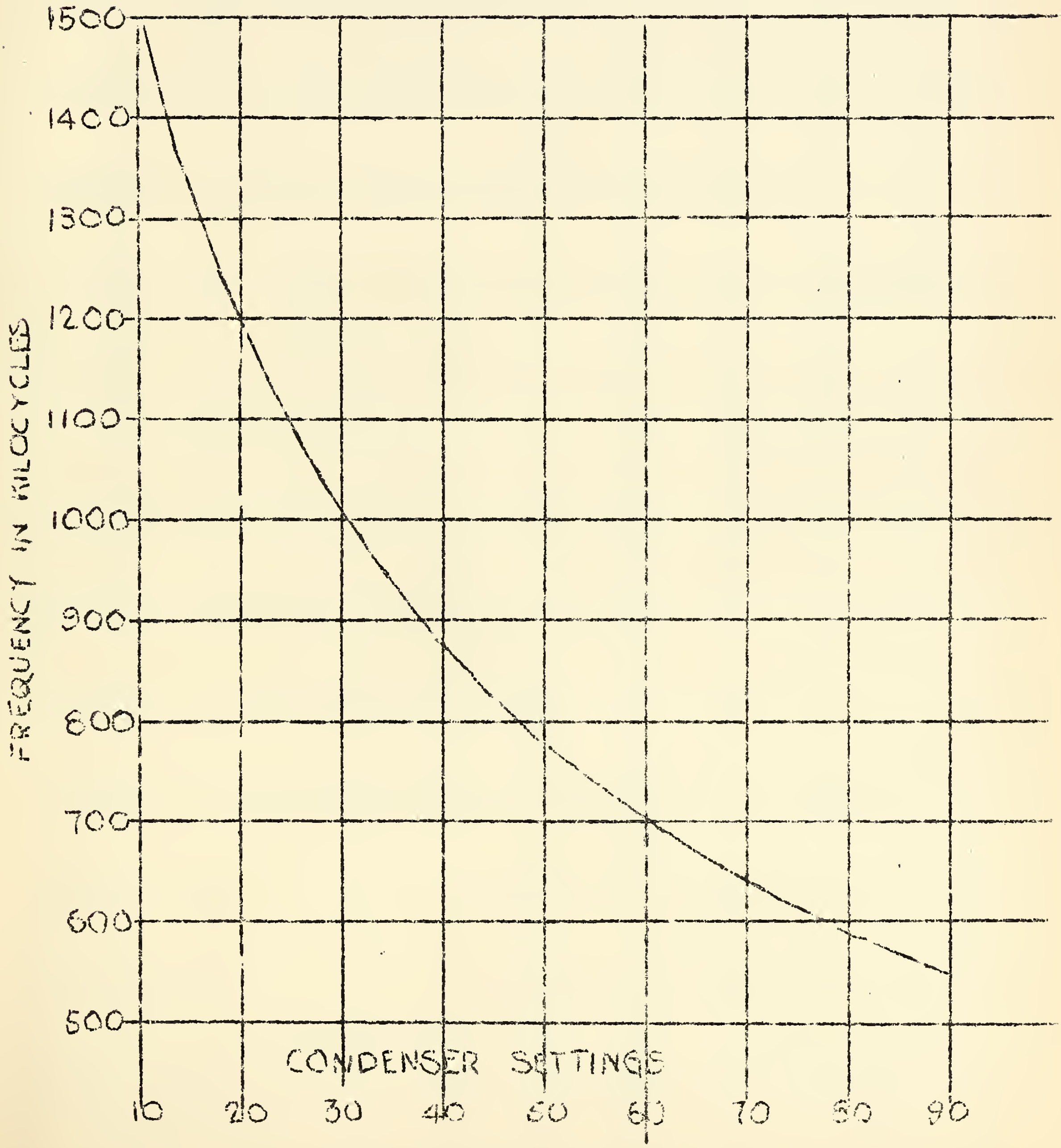


FIG. 6-a

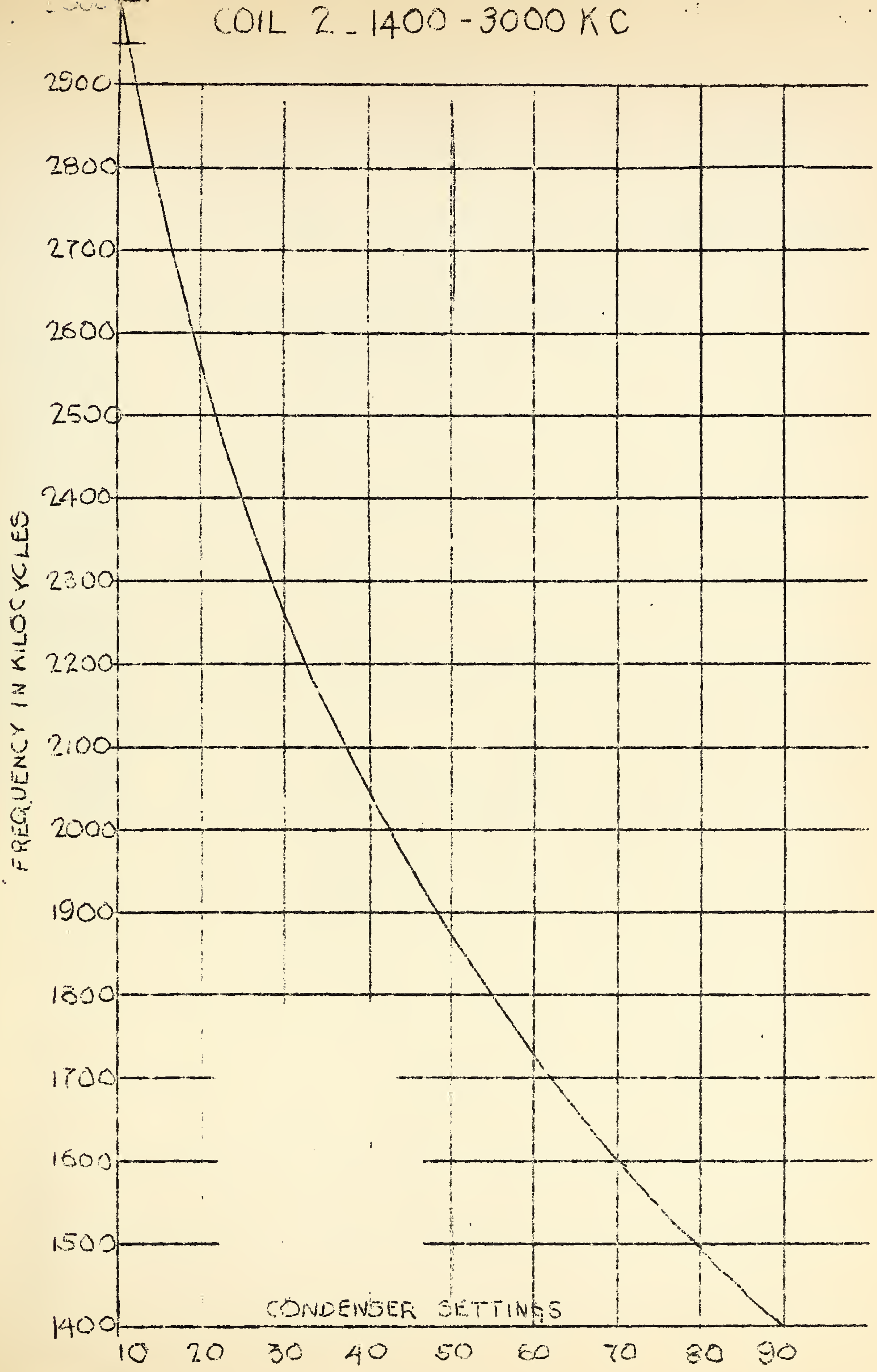

COIL 2 _ 1400 - 3000 KC
FREQUENCY IN KILOCYCLES
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
CONDENSER SETTINGS
10
20
30
40
50
60
70
80
90

FIG. 6 b