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DEPARTMENT OF COMMERCE
BUREAU OF STANDARDS
WASHINGTON

Letter
Circular
LC 78

(August 23, 1922)

DESIGN OF A PORTABLE SHORT-WAVE RADIO WAVEMETER

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A wavemeter is a device for measuring the frequency or the length of radio waves. Radio waves always travel with the same velocity, and if the frequency is known, the wave length is also known.

Resonance is a most fundamental phenomenon of radio. When the inductance and capacity of a circuit on which an alternating electromotive force is impressed are adjusted so that the impedance of the circuit is a minimum and the current flowing in the circuit is a maximum, the circuit is said to be in resonance. For information regarding resonance and the measurement of wave length, reference may be made to "The Principles Underlying Radio Communication," Signal Corps Radio Communication Pamphlet No.40, and to Bureau of Standards Circular No.74. These publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D.C. The price of the former is $1.00, and the price of the latter is 60 cents.

Amateur radio stations in the United States are at present required by law when transmitting to use wave lengths not exceeding 200 meters, and it is therefore important that amateur operators should have a wavemeter available so that they may adjust their transmitting sets to comply with the law, and it is necessary that this wavemeter should be adapted to measure short wave lengths such as 200 meters. Other comparatively short wave lengths, such as 360 and 485 meters, are now used for radio telephone broadcasting, and it is important to have a wavemeter which can measure these wave lengths. The Radio Telephony Conference which met in Washington in February, 1922, recommended narrow bands of waves for particular services, some bands being only 10 meters wide. Stations which must work within such narrow bands must be provided with well-designed wavemeters if they are to comply with the requirements of the law. The design of a portable short-wave wavemeter is therefore a matter of importance. It is the purpose of this Circular to point out the most important considerations in the design of such a wavemeter, and to describe the construction of a wavemeter suitable for the measurement of frequencies from about 3000 kilocycles per second to 530 kilocycles per second (wave lengths from 100 to 570 meters).

The parts of a wavemeter are usually: a variable condenser, a fixed inductance coil, and a device to indicate current flow. The condenser will first be considered.

It will be well at the start to eliminate certain large classes of condensers whose construction makes them unfit for use in wavemeter circuits. Variable condensers employing other dielectrics than air, and condensers whose capacities are varied by a screw to change the distance between plates, however serviceable they may be for furnishing a variable capacity, will not in general retain their calibration and are therefore untrustworthy for use in a wavemeter. This elimination leaves only air condensers whose capacity is varied by changing the overlapping area of parallel plates,- the usual type of variable condenser. All condensers of this type can by no means be used in wavemeters. A condenser to be used in a wavemeter should have fairly heavy plates rigidly held together with ample tie rods and nuts, spacing washers of large diameter and sufficient thickness, adequate conical bearings, and, preferably, unimpeded rotation through 360 degrees of arc. Particulars in which variable condensers commonly fail to meet these and other requirements are: too thin plates, spring-supported bearings, extremely close spacing of plates, vertical or lateral play of the shaft in its bearings, contacts made by brushes wiping on movable parts, stops which in arresting the rotating plates shift them out of line, shifting scales or indices, and faulty workmanship which allows short-circuiting of the condenser at some settings. In general, anything that allows a capacity change without a change in scale reading or a change in reading without a capacity change destroys the usefulness of a condenser for wavemeter purposes. Some method of shielding is desirable to eliminate any change of condenser capacity owing to movements of surrounding bodies. The shield usually is a grounded metal case placed around the condenser.

The inductance coils will next be discussed. The requirements of a wavemeter coil are: (1) that its inductance be such that with the condenser used the desired range of wave frequency can be covered: (2) that its effective resistance and effective capacity be low; (3) that its inductance, resistance, and capacity all be constant.

The first requirement, which has to do with the range of wave frequencies, will first be considered. It is well to restrict the part of the condenser scale used for frequency measurements to the sector between 15° and 170° on a scale graduated in degrees, or between the eighth division and ninety-fifth division on a scale graduated in hundredths. Since the capacity at 170° or 95 hundredths will almost always be more than six times the capacity at 15° or 8 hundredths, the frequency obtained with any one coil at the lower end of this region will be not less than about two and one-half times the frequency obtained with the same coil at the upper end. This will make it possible with one coil to cover the range from 3000 to 1200 kilocycles per second (100 to 250 meters) and with a second coil to cover the range from 1330 to 530 kilocycles per second (from 225 to 570 meters).

The following table gives the number of turns required for two single-layer inductance coils which will cover approximately the stated ranges with each of the maximum capacities indicated in the table. It will be noted that the size of the wire and the spacing between turns are not specified. The inductance is nearly independent of the size of wire used, and the spacing is controlled by the number of turns and the length of the inductance coil, both of which are given. The length of the coil, as indicated, is the length of the actual winding, not the length of the supporting core.

Single-Layer Inductance Coils for Short-Wave Portable Wavemeter

Coil 1, Range 3000-1200 kilocycles per second (100-250 meters)
Diameter, 10 cm (4 inches); length of winding, 2.5 cm (1 inch)

Maximum capacity of condenser	Number of turns
0.0005 microfarad	16
0.0007 microfarad	13
0.0010 microfarad	11

Coil 2, Range 1330-530 kilocycles per second (225-570 meters)
Diameter, 10 cm (4 inches); length of winding, 5 cm (2 inches)

Maximum capacity of condenser	Number of turns
0.0005 microfarad	42
0.0007 microfarad	35
0.0010 microfarad	30

The second requirement stated for the coil was that the effective resistance and the effective capacity be low. Low resistance is desirable in order to secure sharper indication of resonance. There are several reasons for keeping the effective capacity low. This capacity serves to increase the total capacity of the circuit. This increase will be only a small part of the total capacity at the high-capacity end of the condenser scale and hence will not appreciably help in extending the frequency range downward, but it may be a considerable part of the capacity at the low-capacity end of the condenser scale and may seriously limit the upward extension of the frequency range. Another and more serious objection to a large effective capacity is that this capacity is always to a greater or less extent subject to variation as a result of change in the surroundings of the coil. Since this capacity can not be controlled, it should be, as far as possible, reduced. The practice of surrounding an inductance coil with quantities of miscellaneous insulating material is undesirable in any radio circuit and is especially to be avoided in the case of wavemeter coils. Imperfect insulating materials so used increase not only the effective capacity but also the effective resistance of the coil. This does not mean that all types of manufactured insulating materials are unsuitable for use in frames for wavemeter coils. Probably, however, the best form on which to wind the coil of a wavemeter like that here described is a hollow

spool of thoroughly dry wood lightly varnished with an extra grade of insulating varnish. The use of shellac is not considered advisable under any circumstances. The use of wood having even a comparatively small moisture content may seriously affect the accuracy of the wavemeter. Properly selected wood is chosen in preference to manufactured insulating materials, glass, or pasteboard. Many available manufactured insulating materials largely increase both the resistance and the capacity of the coil. While the electrical properties of glass make it well suited for a form, it presents too great mechanical difficulties. Pasteboard is not rigid enough and should not be used under any circumstances.

The wire used may be solid copper double cotton covered, No.24 B & S or larger. The wire should be lightly varnished with a single coat of an extra grade of insulating varnish. Further insulation merely increases the effective resistance and capacity of the coil without compensating advantages. The resistance can often be considerably reduced by the use of braided high-frequency cable. Care must be taken, however, in using the high-frequency conductor to see that all the strands are continuous and well insulated from each other and that every strand is joined at the terminals of the coil. If imperfect insulation exists between adjacent strands, these high-resistance contacts may cause a considerable increase in the power losses. Broken strands seriously increase both the effective capacity and the resistance of the coil. The strands may be tested for continuity by dipping one end of the cable in mercury and joining the separate strands at the other end successively to a buzzer or voltmeter joined to a battery, the circuit being closed through the mercury contact. The enamel may be removed from the ends of the separate strands by carefully heating the end of the wire cable to a red heat and dipping it in alcohol. This procedure makes the strands more fragile and consequently particular care must be exercised to avoid breaking them.

A single-layer coil has generally a lower effective capacity than a multilayer coil of the same inductance and radius. This, together with the greater precision with which specifications can be furnished for winding single-layer coils, was the reason for choosing this type of coil in the table already given. Since appreciable effective capacities exist when there are parts of the circuit near each other which have comparatively large areas and which are at different potentials, it follows that the leads from the coil to the condenser should not be long or close together. An additional reason for having the leads short is found in the third requirement previously stated for a wavemeter coil, namely, that the inductance, capacity, and resistance of the coil, including its leads, be kept constant. Long leads are apt to be flexible; and flexible leads, long or short, introduce possibilities of change in inductance, capacity and resistance which can not be compensated for by any slight advantage they may give in convenience of handling. The best leads are rigid metal terminals soldered to the ends of the wire and screwed to the wooden core. The position of the coil should be such that the

plane of the turns of the coil is perpendicular to the condenser plates if the condenser is unshielded. This is to prevent the induced current in the coil from itself inducing eddy currents in the condenser plates. Since it is almost always desired for convenience in coupling to have the plane of the coil vertical and the condenser plates horizontal, this matter will usually take care of itself. A very important precaution in giving the coil permanent characteristics is to draw all the turns tight and so fasten them that with ordinary care in handling they will not shift.

The coils may be attached to binding posts on the wavemeter, so that they may be conveniently connected or removed. Various other methods of attaching may also be used.

The third part of the wavemeter is the device which shows current flow and thus indicates resonance. If a crystal detector and telephone receivers are used, only the one-point (unilateral) connection should be employed; that is, the detector and telephone receivers are joined in a closed circuit, and one point of this circuit is joined to one terminal of the coil. This arrangement is sufficiently sensitive and makes the calibration of the wavemeter fairly independent of the position of the telephone leads, at least so long as they are not closely drawn across some part of the wavemeter or wrapped around it. A more precise indicating device is a thermogalvanometer or a radio-frequency milliammeter. Available types of thermocouple instruments are usually found more satisfactory than the ordinary expansion type of hot-wire instrument, because they respond more quickly to changes of current. The instrument should give full scale deflection with a current of about 0.1 ampere. It should be able to stand a considerable overload. It is generally inserted directly in the wavemeter circuit, sometimes with a shunt to keep low the resistance of the circuit. It is important to note that the presence of the instrument will probably modify the capacity, inductance and resistance of the circuit, so that the wavemeter should be calibrated with the same instrument in the circuit as will be used in measuring frequencies. An inexpensive indicating device and one which is satisfactory when the power output of the generating circuit is large enough, is a miniature lamp, such as a flashlight lamp, inserted directly in the wavemeter circuit. To avoid any possibility of changing the calibration of the wavemeter, the lamp should not be changed if it can be avoided. If it must be changed it should be replaced by one of identically the same kind. The sensitiveness of this device can be greatly increased by having a dry cell and a rheostat in parallel with the lamp in the wavemeter circuit. By adjusting the rheostat until the temperature of the lamp filament is raised almost to the point of illumination, it is possible to have the lamp lighted by induced currents much smaller than would otherwise be required. However, changes in the battery and rheostat will be likely to change the characteristics of the circuit and hence the calibration of the wavemeter. This device should therefore be used with caution.

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The wavemeter may be excited by impact, that is by a source of highly damped waves having only a very few waves in a train. (See "The Principles Underlying Radio Communication," Signal Corps Radio Communication Pamphlet No.40, p.278, and Bureau of Standards Circular No.74.) The wavemeter can then be used as a source of damped waves to determine the frequency to which a receiving set is tuned. The buzzer, in series with the battery, is connected across the condenser terminals, completing its circuit, when the contact is closed, through the inductance coil of the wavemeter. Not more than four volts should be used to operate the buzzer. The buzzer will add to the capacity of the circuit, thereby decreasing its frequency. This decrease will be especially noticeable at the lower part of the condenser scale, where it may amount to several percent of the frequency. It can be reduced by having short, widely spaced leads to battery and buzzer. If the wavemeter is equipped with both a buzzer and an ammeter or current-square meter, the ammeter must be so connected in the circuit that the current from the buzzer battery can not pass through the ammeter. If this is not done, the ammeter or current-square meter may be burned out by the current caused to pass through it by the buzzer battery.

The assembling of the parts of the wavemeter must be such that each part is rigidly joined to the rest of the circuit. Mounting in a box is as good a means to this end as any from the standpoint of rigidity and is superior to any in portability and in the protection afforded to the parts. A convenient box mounting is shown in Fig. 1.

The overall dimensions are left to the constructor since the size of the component parts will vary. The box should be substantially constructed so that it will stand considerable handling. The component parts are all mounted on a panel of rigid electrical insulating material which will not absorb moisture. This panel is, in turn, secured to the supporting box. It is possible to use a panel of thoroughly dried and seasoned hard wood thoroughly varnished with an extra grade of insulating varnish. Fig. 1 shows one possible distribution of the component parts. Attention should be given to the convenience of operation and advantageous wiring of the circuit to keep distributed capacities at a low value. The most advantageous arrangement of the instruments on the panel will depend in part on the particular instruments used, and the constructor should work out the best arrangement in each case. Fig. 2 gives a circuit diagram showing the connections as they should appear underneath the panel. These connections should be made of No.12 solid copper wire soldered into lugs. Where bending is necessary, sharp right angle bends are used. If it is desired to make a short-wave portable receiving set, terminals for antenna and ground connections can be supplied without decreasing the value as a wavemeter in any way, provided suitable care is used in handling the instrument. A wavemeter should be handled much more carefully than an ordinary receiving set. If it is desired to shield the wave-

meter, a copper or brass sheet can be permanently fixed on the under side of the panel and spaces cut in it to allow for the terminals and supports of the various units. There should be at least one-eighth of an inch clearance for the terminals. Fig.3 gives the dimensions and construction of the inductance coils.

The forms are turned in a lathe from thoroughly seasoned wood. Several coats of extra grade insulating varnish applied to this form will be desirable in keeping low the absorption of moisture. The proper number of turns of the correct size of wire is wound in a single layer in the recess provided for this purpose. A light coat of extra grade insulating varnish is applied to the wire to keep it in place and to prevent moisture from changing the distributed capacity of the coil. The terminals of the inductance coil are brought out through the wood form and soldered to the supporting brass terminals. The wood screws holding the coil form to the brass supports should be of brass rather than a magnetic material.

It is desirable that the box be provided with a protecting cover and a carrying handle.

After the wavemeter has been constructed, it must be calibrated. This service has been done in the past by the Bureau of Standards. It has lately been necessary however, on account of the limited personnel available for this work, to limit the tests of radio materials made by this Bureau to tests of precision instruments which will in turn be used as standards for testing considerable numbers of other instruments, tests for Government institutions and state universities, and a few other tests for which there is a special reason why they should be undertaken by this Bureau. Standardization of instruments of the kind described in this Circular can be obtained from various commercial firms and some college and university laboratories.

Consideration has been given to the transmission of standard wave length signals from laboratories equipped with precision measuring apparatus. This would make it possible to determine accurately several points on the calibration curve of a wavemeter without sending it to a standardizing laboratory. The carrier waves of some radio telephone broadcasting stations may be adjusted to some particular wave, such as 360 meters, and one point on a wave length calibration can thus be determined. A wavemeter transported for standardization should be packed in a wooden box large enough to give room for three inches of excelsior on every side, otherwise the wavemeter may easily receive internal damage which will not appear except in its subsequent behavior. The package should be marked "Scientific Instrument. Handle with Care."

Two cautions are offered as to the use of the finished and standardized wavemeter. The first is, not to subject the instrument to any treatment apt to change its calibration. The second is not to couple it too closely to the source of the radio-frequency current which is being measured. The latter error can

be avoided by never having the wavemeter so close to this source that it can not be brought closer without changing the setting for resonance.

It is possible to make a decremeter out of a wavemeter by placing a suitable scale on the variable condenser. For a wavemeter having a condenser with semicircular plates or any condenser such that the graph of its capacity against its setting is a straight line, the capacity being very small at zero setting, it can be shown that the decrement scale to be used is one in which the graduations vary as the logarithm of the angle of rotation.[1] Such a scale, designed for a semicircular plate condenser, is shown in Fig. 2. This scale may be copied or cut from this Circular and trimmed to fit the dimensions of the condenser dial with which it is to be used. It may be made stationary with a moving pointer traveling over it, or it may be mounted on a dial rotating under a fixed pointer. At the setting corresponding to maximum capacity the scale reading should be zero. Since the scales of most condensers read counter-clockwise, this arrangement usually places the decrement scale in the unused space opposite the capacity scale. A measurement of decrement is made by first observing the current squared at resonance, then reading the decrement scale at the settings on either side of resonance where the current squared has one-half its value at resonance. The scale is so constructed that the difference between these two readings is equal to $\delta' + \delta$, that is, the decrement of the transmitting circuit plus the decrement of the wavemeter itself. It is then necessary to subtract the wavemeter decrement from the total just obtained. The decrement of the wavemeter is determined as follows: the wavemeter is coupled and tuned to a source of unmodulated continuous waves. The sum, $\delta' + \delta$ is measured as just described. Since the waves are continuous, δ, the decrement of the waves, is zero and the result obtained is δ', the decrement of the wavemeter alone. From determinations of the decrement of the wavemeter made at different points on the scale, the calibration curve of decrement plotted against condenser setting is obtained. The conditions necessary to permit the use of this scale in the manner described are as follows:

(1) The condenser must have semicircular plates. Condensers with plates of a different pattern will have different decrement scales just as they have different capacity calibrations.

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[1] J.H.Dellinger. Measurements of radio-frequency resistance, phase difference and decrement, Proc.I.R.E., vol. 7, pp.27-61, Feb., 1919. Circular 74 of the Bureau of Standards, Radio Instruments and Measurements, p.197.

(2) It must be remembered that only when resonance is indicated by a current-square meter is the deflection to be reduced to one-half its maximum value in detuning to either side of resonance. If a milliammeter is used, the reading must be reduced not to one-half its maximum value but to the maximum value divided by the square root of 2 or to 0.71 of the maximum value.

(3) The generator must have an output sufficiently large that the coupling employed may be loose enough to prevent any considerable reaction of the wavemeter on the generator.

(4) Neither the generator nor its coupling with the wavemeter must be changed during the measurement of decrement.

The following precaution is to be observed in measuring the decrement of a transmitting station. The decremeter must be coupled only to the antenna circuit to be measured, not to the primary circuit; consequently it should be kept not less than two meters away from the oscillation transformer, and coupling to the antenna circuit should be obtained by placing the decremeter near the antenna or ground lead, preferably the latter. If the antenna current is small, it will be necessary to make a single turn of small diameter in the lead to which the decremeter is coupled.

The following articles are of interest in connection with the construction of simple wavemeters:

Cox, R.T., and Kruse, S., Portable wavemeters for short-wave radio, QST, 5, 14, Sept., 1921.

Sleeper, M.B., A wavemeter for radio experimenters, Everyday Engineering, 7, pp.357-359, Sept., 1919.

Sleeper, M.B., A heterodyne wavemeter for 170 to 21 000 meters, Everyday Engineering, 9, 247-250, June, 1920.

Lacault, R.E., How to make and use a wavemeter for short wave lengths, Radio News, 3, 384-385, Nov., 1921.

Wavemeters. Wireless Age, 9, 36-41, Nov., 1921.

Goddard, R.W., Heterodyne wavemeters, Wireless Age, 7, 15-17, Feb., 1920.

Clemons, D.R., A practical 50-5000 meter wavemeter, Radio News, 3, 939, April-May, 1922.

Kent, A.D., The design and construction of a continuous-wave wavemeter, Wireless World, 8, 6-13, April, 1920.

Atkinson, Cyril T., The construction of a continuous-wave wavemeter, with special reference to heterodyne reception, Wireless World, 9, 444-447, Oct. 15, 1921.

Ballhatchet, A.V., A wavemeter, Model Engineer, 44, 89-91, Feb. 3, 1921; Radio Review, 2, 217, April, 1921.

Pacent, L.G., Wavemeter construction and operation, QST, 3, 8-10, December, 1919.

Washington, D.C.

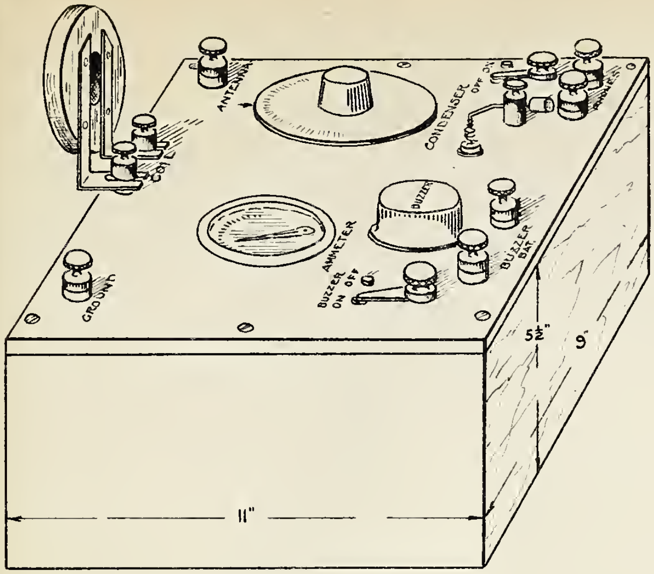


FIG. 1. ONE ARRANGEMENT OF WAVEMETER BOX AND ASSEMBLED UNITS.

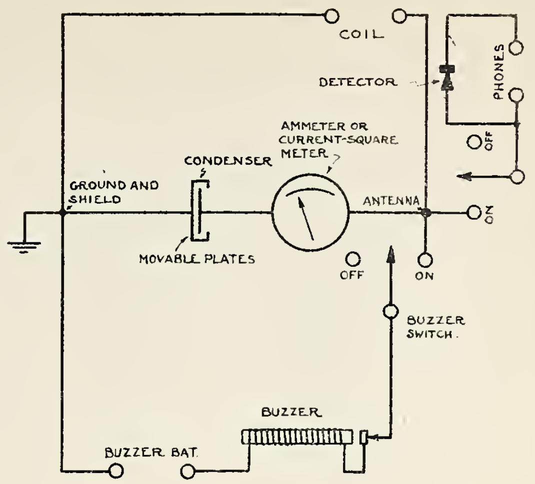


FIG. 2. WAVEMETER CIRCUIT.

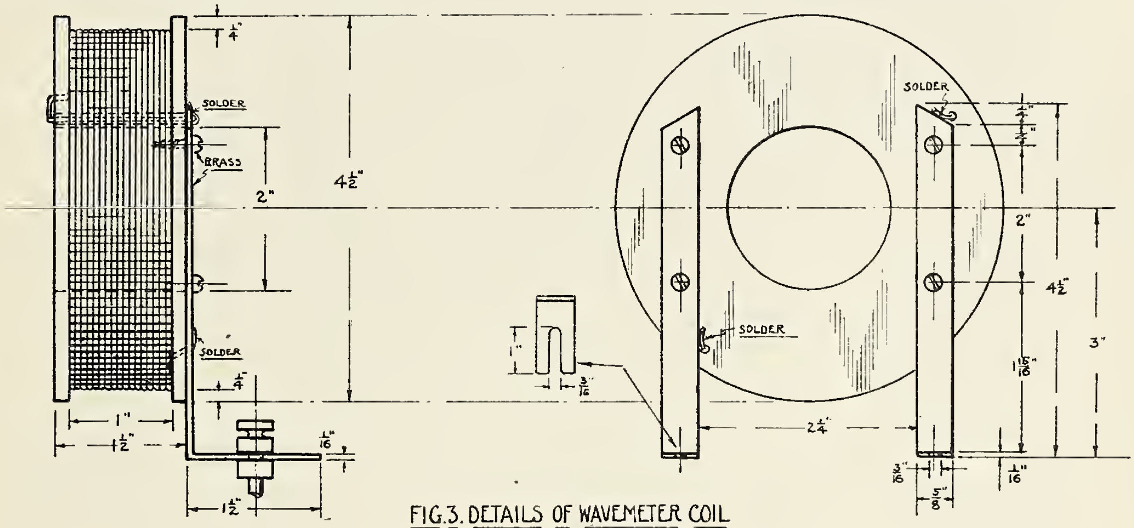
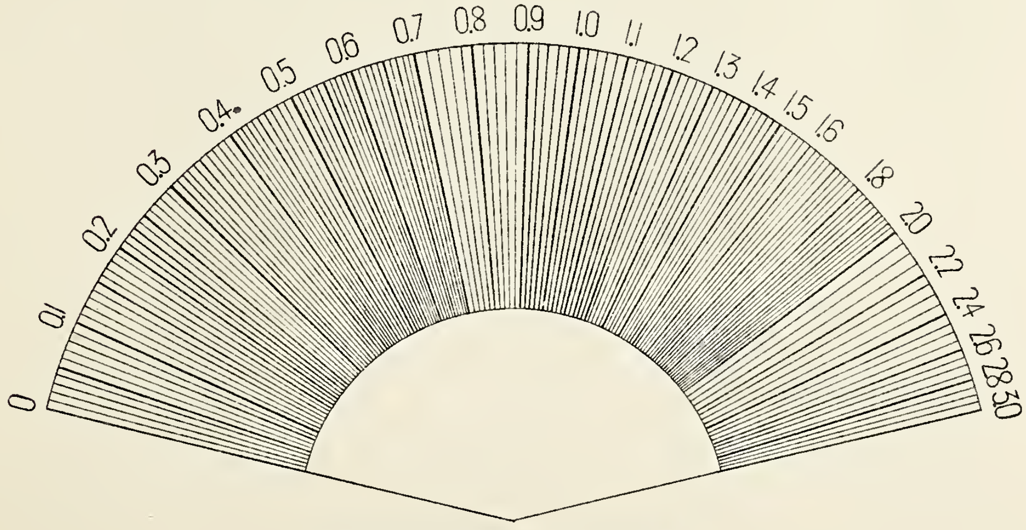


FIG. 3. DETAILS OF WAVEMETER COIL



DECREMETER SCALE.
FIG. 4.