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WAVEMETERS AND DECREMETERS

Radio Communication Pamphlet No. 28

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The following publication, entitled "Wavemeters and Decremeters," Radio Communication Pamphlet No. 28, is published for the information and guidance of all concerned.

[062.1, A. G. O.]

BY ORDER OF THE SECRETARY OF WAR:

JOHN J. PERSHING,
General of the Armies,
Chief of Staff.

OFFICIAL:
P. C. HARRIS,
The Adjutant General.

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WAVEMETERS AND DECREMETERS.

RADIO COMMUNICATION PAMPHLET NO. 28.

SECTION I.

USES OF WAVEMETERS AND DECREMETERS.

1. Definitions and uses.—A *wavemeter* is a radio frequency instrument used (1) to measure the length of electro-magnetic waves generated by some other circuit; (2) to emit, as a low-power transmitter, waves of a known length; (3) with the help of other apparatus to measure the inductance of a coil, the capacity of a condenser, etc.; and (4) in certain special cases, to measure the logarithmic decrement of the waves. A *decremeter* is a special type of wavemeter which can function in all respects like a wavemeter and in addition has a direct reading scale which can be used to measure the logarithmic decrement of a transmitter. Both are thus calibration instruments which are useful in the field and the laboratory.

A wavemeter or decremeter can be used either at a transmitting or a receiving station, where (1) an unknown wave length can be measured; (2) the circuits can be set at any predetermined wave length; (3) the circuits can be calibrated over their scales of wave lengths; and (4) the logarithmic decrement of a transmitter can be measured in the case of certain wavemeters.

SECTION II.

FUNDAMENTAL PRINCIPLE OF WAVEMETERS; FORMULAE.

2. Fundamental principle.—The fundamental principle upon which all wavemeters operate is the same. The meter almost invariably contains three essential elements: (1) A coil as an inductance; (2) a condenser, as a capacity; and (3) auxiliary apparatus that varies with the use to which the meter is to be put. A circuit of inductance and capacity has a certain natural frequency of oscillation, or natural wave length, which depends upon the values of the inductance and capacity. In a meter these are known and the wave length can be accurately computed from their values. By varying the capacity or the inductance, the wave length of the meter can be changed so as to bring it into resonance with another circuit. As the wave length of two circuits at resonance is the same, the wave length of the circuit under measurement thus becomes known. The general circuit diagram of a wavemeter is shown in figure 1.

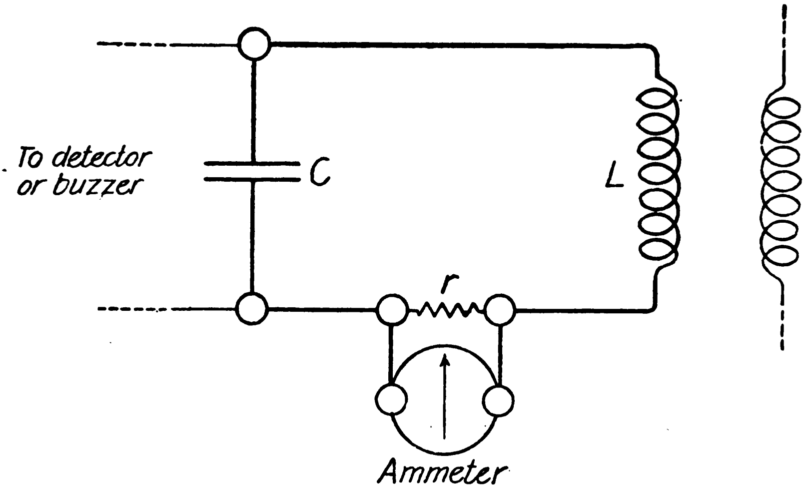

FIG. 1

3. Fundamental formulae.—The fundamental formula for the computation of the wave lengths of a meter with its known inductance and capacity is as follows:

$$\lambda = \frac{2\pi V}{\sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}}$$

where λ (read "lambda") is the wave length,

π (read "pi") 3.14,

V Velocity of light, 3×10^8 meters per second,

L Inductance of the coil,

C Capacity of the condenser,

R High frequency resistance of the circuit,

all to be expressed in a consistent system of units. In all practical cases the quantity $\frac{R^2}{4L^2}$ is so small as compared with $\frac{1}{LC}$ that it can be neglected in comparsion with it, so that the formula simplifies to

$$\lambda = 2\pi V\sqrt{LC}$$

This formula can be expressed in many different systems of units, of which only the one in most common use will be given here:

If λ is in meters, L in milli-henrys, and C in microfarads, then

$$\lambda = 59{,}600 \times \sqrt{LC} \text{ meters.}$$

A numerical example in the use of the formula is as follows:

Let L be 0.040 milli-henrys.

And C 0.004 micro-farads.

Then L×C is 0.00016.

And $\sqrt{LC}$ is 0.01265.

And hence λ is 59,600×0.01265, or 754 meters.

Section III.

COMPONENT PARTS OF WAVEMETERS.

4. General design features.—A wavemeter may be set at any one of its wave lengths by varying either (1) the capacity of its condenser, or (2) the inductance of its coil. If the capacity is variable, then generally the inductance is constant, and similarly if the inductance is variable, the capacity is constant. The design of the inductance and capacity should be such that their high-frequency resistances are as low as possible, so that the losses in the wavemeter circuit are small. In general, the smaller these losses the more sensitive is the wavemeter, the sharper its tuning to resonance, and the lower its decrement, as will be explained in later paragraphs.

4a. Capacity.—If a variable capacity is used, it is almost always an air condenser, with a continuous change from a certain minimum, which is not zero, to a maximum value. The design and construction should be such that the internal losses at high frequency are as small as possible; thus a good contact must be made between all the fixed plates and also between all the moving plates; there should be no material between the fixed and moving plates or elsewhere in circuit, where the electric field of the charged plates may cause the flow of wasteful high-frequency currents, etc. The handle of the variable condenser carries a pointer for reading either on a scale of wave lengths or a scale of degrees or numbers. Some wavemeters have both these scales. As the maximum value of the capacity may

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be perhaps 20 or more times greater than the minimum, and as the wave length increases as the square root of the capacity (see paragraph 3), the longest wave length on a scale may be $\sqrt{20}$, or about 4.5 times the shortest wave length. In some types of condensers there are two sets of fixed and moving plates in the space usually occupied by a single set of each. This design permits the moving plates to be mechanically balanced; and also gives a larger change in capacity from minimum to maximum than in the usual condenser, and hence a longer scale of wave lengths for any given coil. The condensers are often contained in a compartment with a metal lining, on which the fixed or moving plates may be grounded, which shields the condenser from the influence of outside circuits and keeps the capacity more nearly constant as the meter is being handled by the operator.

4b. Inductance.—If a variable *inductance* is used, it is almost always in the form of a variometer with a continuous change from a certain minimum, which is not zero, to a maximum value. In general, a variometer consists of two coils connected in series, one of which is smaller than the other and is rotatable within it. When the two coils are in the same plane and the direction of the current is the same in both coils, the inductance is a maximum; and when the smaller one has been turned through 180 degrees and the current is in opposite directions in the two coils, the inductance is a minimum but is not zero. At intermediate positions the inductance has intermediate values. The wire used in the variometer should be of low resistance so that its high frequency loss is as small as possible. In some meters a special low resistance wire, know as "Litzendraht," consisting of a large number of separately insulated fine wires, is used. It has been found best not to use a large inductance for long waves and taps on it for short waves, but rather to use a set of coils each adapted to a different range of wave lengths. In explanation it may be stated that actual experience has shown that if there are "dead ends" of a coil in the magnetic field of the active coil, high frequency currents will be induced in them which will cause losses therein and change the inductance of the coil. When a set of coils is used, it is evidently necessary that the choice of coils be such that with the given condenser, the different ranges or scales overlap so as to include all wave lengths within the range of the wavemeter.

In some types of wavemeters, the coil is contained within the set box of the wavemeter. As it is necessary to know where the coil windings are in order to be able to make the proper coupling with the coil of the circuit under measurement, the plane of the windings or "Plane of coil" is generally marked by an arrow on the box. Sometimes the "Axis of coil," which is perpendicular to the plane of the windings, is marked instead of the "Plane of coil."

5. Auxiliary apparatus.—The auxiliary apparatus depends entirely upon the use to which the meter is to be put. At a transmitter the wavemeter is used as a receiver and the auxiliary apparatus is some device which indicates when the transmitter and the wavemeter are in resonance. At a receiver the wavemeter is used as a low power damped wave transmitter and the auxiliary apparatus is almost always a buzzer driven by a dry cell battery which furnishes the power to the meter. The circuits of the receiver and the wavemeter are tuned to resonance, which fact is indicated by the detector of the receiver.

5a. Resonance indicators.—When the wavemeter is used at a transmitter, the resonance indicator may be any one of the following devices, depending on the character of the transmitter, as will be explained in later paragraphs: (1) Hot-wire ammeter; hot-wire wattmeter; thermo-couple and galvanometer or thermo-galvanometer; miniature lamp, etc.; or (2) crystal detector and telephone; vacuum-tube detector and telephones, etc. If the device is of low resistance, as an ammeter, wattmeter, etc., as mentioned in (1), it is connected in series in the wavemeter circuit. Although the ammeter, etc., may be of only a few ohms resistance, yet in some cases even this may be too high a resistance to be included in series and it is therefore shunted by a resistance, so that the joint resistance is much reduced. (See Fig. 1.) It is evident that the shunt must be carefully chosen, for if it is of *very low* resistance, only a very small current will flow through the ammeter, etc., and the sensitivity of the wavemeter will be seriously reduced. Most meters are provided with an adjusting screw so that the needle can be set on the zero mark, but this is not absolutely necessary.

If the device is of high resistance, as a crystal detector and telephones, etc., in (2) of the previous paragraph, they are connected in shunt to the wavemeter circuit as in figure 1. In the shunt circuit (1) the detector and telephone may be in series; or (2) the telephones may be in shunt to the detector and the two in series with a small condenser. In the so-called "Unipolar" connection the telephones are in shunt to the detector and the two connected by a single wire to one terminal of the wavemeter. Although this connection is less sensitive than the usual type, it has the possible advantage of adding less outside capacity to that of the variable condenser than any other connection. In some cases the metal lining of the condenser compartment and the machine screws on the panel are used as a convenient means of connecting parts of the detector circuit and for this reason the meter will be inoperative unless it is assembled with all parts in place.

Although a wavemeter with a crystal detector, etc., is much more sensitive than one with an ammeter, galvanometer, etc., yet it is not generally as useful as the latter type for the following reasons: The ammeter, etc., is operated by every type of spark and continuous wave transmitter, whereas the detector and telephones are operated only by spark transmitters, and those types of continuous wave transmitters that are modulated at an *audio* frequency. Many meters of recent design, therefore, are provided with an ammeter, galvanometer, etc., but not with a detector. However, in a few cases binding posts at the terminals of the condenser have been added so that a detector, etc., can be connected into circuit if desired.

5b. Buzzer.—When the wavemeter is used at a receiver, a buzzer operates or excites the wavemeter so that it acts as a low-power, damped wave transmitter giving wave trains at an audio frequency. Its action may be explained as follows: A buzzer in series with a battery is connected to the terminals of the meter and at each break at the buzzer contacts, part of the energy of the buzzer circuit is released to charge the condenser of the meter; the condenser then discharges through the coil of the meter; and thus the circuit is set into oscillation at a known wave length corresponding to the known values of its inductance and capacity. Most meters are provided with a battery compartment and the insertion of a battery in place automatically makes the necessary connections. In some cases the metal lining of the condenser compartment and the machine screws on the panel are used as a convenient means of connecting parts of the buzzer circuit as well as the detector circuit, and for this reason the meter will be inoperative unless it is assembled with all parts in place.

6. Wave-length scales.—As the range of wave length in meters with any *one* coil, or with any *one* condenser is limited, many meters are provided with a set of coils or condensers so that their range is greatly increased thereby. Generally the various coils have marked on them the range of wave lengths to which they apply and they may be connected into circuit as needed. The insertion of any coil in circuit may operate a device which sets a pointer on the scale to be used with the given coil. The various condensers are generally thrown into circuit by a switch and their capacities are so chosen that the corresponding wave lengths are a whole number of times smaller or greater than the scale reading. Thus, if the wave lengths on the scale for one condenser are from 150 to 450 meters and the other two condensers are respectively nine times smaller and larger than the one for 150 to 450 meters, it is evident that the wave lengths will be respectively three times ($\sqrt{9}$) smaller and three times ($\sqrt{9}$) larger than the scale value. In this case the condenser switch may have the values of the multipliers, as 1/3, 1, 3, marked on the contact corresponding to the capacity in use.

If on account of the overlapping of two scales, a wave length can be measured on both, it is generally best to use the end of the first scale rather than the beginning of the second, as the accuracy is greater in the former case.

7. Calibration curves.—In some cases where special accuracy is desired, the meter is calibrated by reference to a standard meter, in which the wave lengths are measured for certain points on its scale, as at every 20 degrees, and a curve is plotted with the degrees along the horizontal line, called abscissas, and the wave lengths in

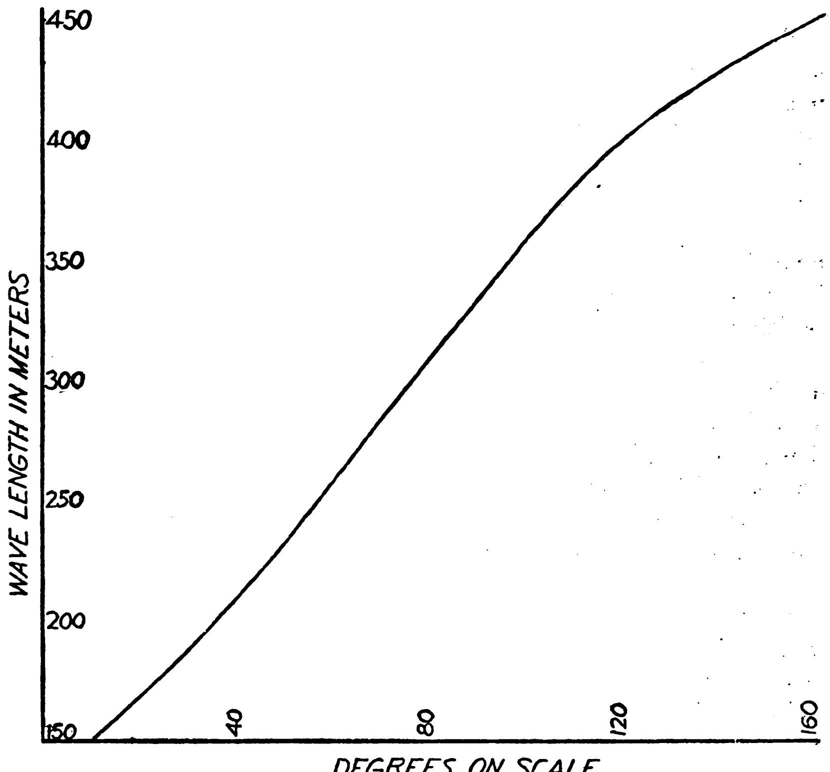

FIG. 2.

meters along the vertical line, called ordinates. The various points are connected by a smooth curve called a calibration curve, so that the wave lengths can be read off for any degree or fraction. Such a curve is shown in figure 2. In special cases meters are calibrated by reference to standard meters by the Bureau of Standards, Washington, D. C. In some meters it is found that there is a slight difference in the calibration curves, depending on whether the meter is used (1) with a buzzer, (2) detector and telephones, or (3) wattmeter. This is due to the small differences in capacity that may be added when the buzzer, etc., are connected into circuit. In such a case separate calibration curves will be given, each correct for its special use.

Section IV.

CARE OF WAVEMETERS AND DECREMETERS.

8. General care.—There are certain general instructions on the care of wavemeters and decremeters that must be observed. The most important are as follows: A wavemeter and its component parts must be carefully handled; all the component parts must be properly secured in place when not in use or during transportation; and it must be kept in a dry place.

9. Care in handling.—A wavemeter is a delicate instrument which must be handled with great care. Rough handling may break the internal mechanism of the hot-wire ammeter or thermo-galvanometer which is an essential part of a decremeter and of many types of wavemeters; and may injure the windings of the coils and the plates of the condensers. In this respect a wavemeter is more delicate than a receiving set for the following reasons: If either the coil or condenser of a set is slightly changed in any way, the set in general can be retuned to resonance without loss of any of its functions, whereas if the same changes occur in a wavemeter, the values of wave lengths may be seriously changed from those marked on the wave length scales. In meters with a variable air condenser it is the usual practice to provide a device for clamping the moving plates and the *plates should always be so clamped* except when the meter is in actual use. Care must be taken not to drop the telephone receivers or to injure the diaphragm. In the former case the caps may be broken so that the diaphragm can not be held in place. In the latter case the diaphragm may be bent or dented and so touch the pole pieces of the permanent magnets where, if the attraction is strong enough, it may be "frozen" and the telephone made inoperative although otherwise in perfect condition. The telephones should never be taken apart, as it is certain that the adjustments will be disturbed. In explanation it may be stated that in order to get the correct clearance between the diaphragm and the pole pieces, it has been found necessary to grind the latter after the assembly of the telephone, as the standard parts can not be assembled with the necessary accuracy.

10. Care of component parts.—It is absolutely essential that *all* the component parts of a wavemeter, as given in its parts list, be kept with it, as otherwise the meter may be made useless; thus the loss of a coil would make it impossible to measure the wave lengths within its range; the loss of the thermo-galvanometer might make it impossible to obtain measurements at a continuous wave transmitter, etc. For this reason all parts not in actual use should be kept in their proper places in the set box. All types of wavemeters which use a buzzer exciter should have a battery in place in the battery compartment, but the battery *should not be kept there* if the wavemeter is to be stored away, as its deterioration may cause corrosion at the battery contacts and elsewhere. When the wavemeter is to be shipped special care should be taken that (1) the moving plates are clamped; (2) the telephones are stored away according to the following standard practice: Put the two receivers with the faces of the caps together so that all access to the diaphragm is closed; and then bind them together in this position by winding the telephone cord around the outside of the head bands beginning close to the caps; (3) all parts are securely fastened in place; and (4) all parts on the parts list are included.

11. Protection against moisture.—A wavemeter must be kept dry under all conditions. This precaution is particularly necessary in meters having coil forms of wood, whose shape may be greatly changed by exposure to moisture and whose wave lengths would also be changed thereby. If for any reason a wavemeter gets wet, it should be carefully dried out but not by direct exposure to heat.

SECTION V.

COUPLING AS APPLIED TO WAVEMETERS AND DECREMETERS.

12. Definition of coupling.—In all cases where a wavemeter or a decremeter is used, one of the things that must be done is to bring the wavemeter or decremeter circuit in resonance with another circuit or conversely bring another circuit in resonance with a wavemeter or decremeter circuit. In order to obtain resonance between two circuits, it is necessary to have a transfer of energy between the two. This transfer of energy in all types of wavemeters and decremeters now in use is brought about by inductive coupling. Inductive coupling is obtained by having the magnetic lines of force from one circuit pass through another circuit. In other words, there is a mutual interlinkage of lines of force. It is these mutual magnetic lines of force which transfer energy between the two circuits. If a large proportion of the lines of force from one circuit interlink with another circuit, the coupling is said to be close. If only a small proportion of the lines of force interlink, the coupling is said to be loose.

13. Effect of coupling on natural wave length of a circuit.—As has been shown, the natural wave length of a circuit depends upon the value of inductance and capacity in that circuit. The value of an inductance in a circuit for any given current depends upon the number of magnetic lines of force passing through the parts of the circuit. The inductance, and hence the natural wave length of a circuit, is changed by a change in the number of lines of force passing through it, such as is brought about by adding the magnetic lines of force from an outside circuit. Thus if an external circuit is coupled to a wavemeter circuit, the latter circuit will have its natural wave length changed. Therefore, in order to make the least possible change in the natural wave length of a wavemeter circuit, the outside circuit should be coupled to it as loosely as possible and yet permit a transfer of energy.

14. How to vary coupling.—Coupling between two circuits may be accurately expressed by the following formula: $\frac{M}{\sqrt{L_1 L_2}}$, where M is the mutual inductance, and L_1 and L_2 are the inductances that are coupled together. It is seen from this formula, therefore, that a variation of M or a variation of the inductances in either or both circuits will change the coupling. The mutual inductance, M, may be varied by a lateral or an angular movement between the two coils which comprise the inductances in question. If the coils are moved closer together, the coupling is made closer or tightened. If the coils are moved apart, the coupling is loosened. Also the coils may be rotated with respect to each other. If the two coils are parallel, the coupling is the tightest. If the two coils are at right angles, the coupling is loosest. In some cases inductance coils have taps on them so that a varying number of turns in the coils may be employed. Changing the number of turns in use changes the inductance and, as has been noted, this changes the coupling between that coil and the circuit with which it may be linked. Of course it is possible to use any combination of these methods in varying the coupling.

It is seen that in order to vary the coupling by moving one coil with respect to another, the position of the coils must be known. In some wavemeters these coils can not be seen, as they are mounted inside the set box. However, in this case, the outside of the set box usually shows by appropriate marking the position of the coil.

15. Tests for correct coupling.—The correct coupling to use is a *loose* coupling. A good method of testing for this proper coupling is as follows: Bring the two circuits in resonance, using what is judged to be a loose coupling. Loosen the coupling by moving one circuit farther away or by any other method, and note whether or not the two circuits remain in resonance. If the two circuits do remain in resonance, the coupling is sufficiently loose. If the two circuits do *not* remain in resonance, continue to loosen the coupling until they do remain in resonance, and then the coupling is sufficiently loose.

SECTION VI.

GENERAL DIRECTIONS FOR USING A WAVEMETER AT A TRANSMITTER.

16. Various uses.—The following instructions apply generally to the uses of a wavemeter at a transmitter of either damped or continuous waves. In later sections explicit instructions will be given for the use of each type of Signal Corps wavemeter. At a transmitter the wavemeter is used as a receiving set to receive the signals at resonance and to measure them from the known electrical constants of its own circuit. It may be used (1) to measure an unknown wave length; (2) to set the transmitter at a predetermined wave length; (3) to calibrate a transmitter in wave lengths; and (4) in some cases to measure the logarithmic decrement of the radiated waves. (See Section XIV.) A careful record should be kept of the adjustments at all measured wave lengths. It must be remembered, however, that in general the antenna circuit adjustments will differ with different antennas, unless it should so happen that they have the same electrical constants.

17. Type of resonance indicator to be used.—Some wavemeters have more than one indicating device, and the one to be used depends in general on the type of the transmitter. If it is a spark set (damped wave), any of the devices mentioned in paragraph 5a may be used—thus, the ear can hear the note of the signals in the telephones of any of the detectors, and the eye can see the movement of the needle of the ammeter, galvanometer, etc. If, however, it is a tube or other continuous wave set, there will be no sound in the telephones unless it is modulated at an audio frequency, and for this reason the ammeter, galvanometer, etc., is used at a tube transmitter.

If a wattmeter or galvanometer is used, care must be taken to use loose coupling not only so as not to change the wave lengths, but also so as not to obtain more than a full scale deflection, otherwise the meter may be burnt out by the excessive current. It is not necessary that the needle of the ammeter or galvanometer be adjusted to zero, as the meter is used to indicate relative and not absolute values. Similarly, if a lamp is used, care must be taken not to burn it at more than normal candlepower.

18. Measuring an unknown wave length.—During these measurements the following general directions are to be observed: (1) The transmitter circuits must be kept *unchanged* at the unknown wave length; (2) the wavemeter coil must be loosely coupled only with the *antenna coil* of the transmitter; and (3) the wavemeter must be tuned to resonance with the transmitter.

If the unknown wave length is approximately known, the wavemeter coil or condenser should be selected which includes this wave length within its range; but if it is entirely unknown, the correct coil, etc., can be found only by trial of the various units. Having chosen the proper indicating device, the wavemeter should then be assembled, taking care that only the necessary connections are made to it—thus, if a wattmeter is to be used, the buzzer and detector circuits must be opened, etc. Next the wavemeter coil should be loosely coupled with the *antenna coil* of the transmitter, and thereafter the coupling between the wavemeter and the transmitter must *remain unchanged.* The wavemeter is then tuned to the transmitter by varying its condenser or variometer slowly over the scale until resonance is obtained, as shown by the maximum response of its indicator. When the two circuits are thus in resonance, the unknown wave length can be read from the wavemeter scale or from the calibration curve.

19. Setting on a predetermined wave length.—During these measurements the following general directions are to be observed: (1) The wavemeter must be set on the predetermined wave length which must *not be changed* thereafter; (2) the wavemeter coil must be loosely coupled with the *antenna coil* of the transmitter; and (3) the transmitter must be tuned to the wavemeter.

The wavemeter coil or condenser should be selected which includes the predetermined wave length within its range and the wavemeter set at this length. Having chosen the proper indicating device, the wavemeter should be assembled, taking care that only the necessary connections are made to it. Next the wavemeter coil should be loosely coupled with the *antenna coil* and the transmitter adjustments varied until resonance with the wavemeter is obtained, as shown by the maximum response of its indicator. When the two circuits are thus in resonance, the transmitter is set at the predetermined wave length.

20. Calibrating a transmitter.—The procedure is the same as outlined in the previous paragraph except that the transmitter is set in succession at a series of predetermined wave lengths, say 100 meters apart, over its range of wave lengths. The various adjustment points are tabulated, or plotted as a calibration curve similar to that in paragraph 7. From this curve a transmitter can be correctly set at any wave length within its range.

21. Wavemeter without a resonance indicator.—At a tube transmitter under certain special circumstances a wavemeter can be used to measure a wave length *without* the use of a resonance indicating device. The method can be applied if there is a sensitive ammeter, (1) in the circuit supplying power to the plate circuits of the vacuum tubes; or (2) in the antenna circuit. In both cases the essential principle is the same, and is as follows: When the wavemeter is loosely coupled to the antenna coil of the transmitter and it is being tuned to the transmitter, or vice versa, there will be a small amount of energy withdrawn from the transmitter by the wavemeter. When the two circuits are *in resonance*, there will be a small but sudden increase in the amount of energy withdrawn. This will be indicated by a corresponding *change* in the reading of either or both ammeters. This method of indicating when the two circuits are in resonance can be used in setting a transmitter at a predetermined wave length and in calibrating a transmitter in addition to the other methods described in this section.

22. Precautions in using a wavemeter at a transmitter.—Referring to paragraph 18 on the precaution of opening the buzzer and detector circuits when the wattmeter is in use, it will be seen from figure 1 that they are connected in shunt to the wavemeter coil and condenser. If either of these circuits is permanently closed, it is evident that both the coil and condenser are short-circuited, and that the meter will probably be made inoperative for this reason.

In coupling the wavemeter coil with the antenna coil, care must be taken that it is coupled *only with this coil*, as it is evident that it is the antenna coil which carries the current of the same wave length as that supplied to the antenna for radiation. This precaution is particularly necessary at a *spark* transmitter where the primary circuit coil may carry a current of a wave length different from that in the antenna.

In applying the method outlined in paragraph 19 to the setting of a *spark* transmitter at a predetermined wave length, it is often difficult to keep the primary and secondary circuits *in resonance* as the transmitter is tuned to the wavemeter. For this reason it may be more convenient to tune the two transmitter circuits to resonance and then to tune the wavemeter to the transmitter. If the measured wave length is not correct, the transmitter circuits should be retuned to resonance at a slightly longer or shorter wave length, according to the results of the previous measurement, and the wavemeter again tuned to the transmitter. This should be repeated until the wavemeter, when tuned to the transmitter, shows resonance at the predetermined wave length. In the calibration of a *spark* transmitter, it is more convenient to use the method of this paragraph than that of paragraph 20. Although in general the calibration points will not be at a uniform distance apart, yet the calibration curve itself will be the same as in the other method.

Section VII.

GENERAL DIRECTIONS FOR USING A WAVEMETER AT A RECEIVER.

23. Various uses.—The following instructions apply generally to the uses of a wavemeter at a receiver. In later sections explicit instructions will be given for the use of each type of Signal Corps wavemeter. At a receiver the wavemeter is used to generate damped waves of a wave length in meters which is known from the electrical constants of its own circuit. It may be used (1) to measure an unknown wave length; (2) to set a receiver at a predetermined wave length; and (3) to calibrate the receiver circuit in wave lengths.

24. General instructions.—The adjustments of the primary or antenna circuit will differ with different antennas, unless it should so happen that they have the same electrical constants, but the adjustments of the secondary circuit will be practically independent of the antenna.

The adjustments of the following circuits of the receiving set will be known or desired: (1) Antenna and secondary; (2) only the antenna; or (3) only the secondary. In the first two cases the ground and antenna connections should be made and the wavemeter coil loosely coupled with the *antenna circuit coil;* and in the third case the ground and antenna should be disconnected; the antenna circuit coupled as loosely as possible with the secondary so as to avoid any reaction between them; and the wavemeter coil loosely coupled with the *secondary coil.* A careful record should be kept of the adjustments of all measured wave lengths.

25. Measuring an unknown wave length.—During these measurements the following directions are to be observed: (1) The circuits should be set according to the instructions of the previous paragraph at the same adjustments as when receiving the unknown wave length, and they must be kept *unchanged;* (2) the wavemeter coil must be loosely coupled with the proper coil in the receiving circuit; (3) the wavemeter caused to generate oscillations; and (4) the wavemeter tuned to resonance with the receiving set, as shown by the telephones of the latter circuit.

If the unknown wave length is approximately known, the wavemeter coil or condenser should be selected which includes this wave length within its range; but if it is entirely unknown, the correct coil, etc., can be found only by trial of the various units. The wavemeter should be assembled and the buzzer connected into circuit. Care must be taken that only the necessary connections are made to the wavemeter—thus, the detector circuit must be opened, etc. Next the buzzer should be started and the wavemeter tuned to the receiver by slowly varying its condenser or variometer over the scale until the loudest signals are heard in the telephones of the receiving set. The wavemeter is then in resonance with the receiver at the unknown wave length, which can be read from the wavemeter scale or calibration curve.

26. Setting at a predetermined wave length.—During these measurements the following general directions are to be observed: (1) The wavemeter should be set at the predetermined wave length, which must *not be changed* thereafter; (2) the wavemeter coil must be loosely coupled with the proper coil in the receiving circuit; (3) the wavemeter caused to generate oscillations; and (4) the receiver tuned to resonance with the wavemeter, as shown by the telephones of the receiver circuit.

The wavemeter coil or condenser should be selected which includes the predetermined wave length within its range and the wavemeter set at this wave length. The wavemeter should be assembled and the buzzer connected into circuit. Care must be taken that only the necessary connections are made to the wavemeter—thus, the detector circuit must be opened, etc. Next the buzzer should be started and the receiving circuits tuned to the wavemeter, as though it were a distant station, until the loudest signals are heard in the telephones of the receiving set. The receiving circuits are then in resonance with the wavemeter at the predetermined wave length.

27. Calibrating a receiver.—The procedure is the same as that outlined in the previous paragraph except that the wavemeter is set in succession at a series of predetermined wave lengths over its range of wave lengths. The various adjustment points are tabulated or plotted as a calibration curve similar to that described in paragraph 7. From this curve a receiver can be correctly set at any wave length within its range.

Inasmuch as the secondary circuit wave lengths are independent of the antenna, it is the general practice to mark the wave lengths only on the scales of this circuit. If, however, the primary values are known, even for a temporary antenna, they should be tabulated as they will permit of a quicker use of the set on all its wave lengths.

28. Wavemeter without a resonance indicator.—At a receiver, under certain special conditions a wavemeter can be used to measure a wave length *without* the use of the buzzer or other auxiliary device. The method is similar in principle to that described in paragraph 21, and can be applied if the receiver is provided with an oscillating tube detector or "autodyne." When the wavemeter is loosely coupled with the proper receiving circuit coil and it is being tuned to the receiver, or vice versa, a small amount of energy is withdrawn from the receiving circuits by the wavemeter. When the two circuits are *in resonance* there will be a small but sudden increase in the amount of energy withdrawn and a corresponding *change* in the current in the telephones of the receiving set. This will be indicated by a "click" in the telephones. This method can be used in setting a receiver at a predetermined wave length and in calibrating a receiver in addition to the methods described in this section.

29. Precautions in using wavemeter at a receiver.—In almost all cases only a single dry cell is needed to operate the buzzer, and if, with the cell in circuit, the buzzer can not be operated, the cell should be replaced. No more batteries should be used than are needed for the operation of the buzzer, as additional batteries tend to cause an arc at the buzzer contacts, which may prevent the generation of any oscillations. This is similar to the case of a spark transmitter where an arc instead of a spark is produced at the gap when the voltage of the transformer is excessive.

SECTION VIII.

MEASUREMENT OF INDUCTANCE OR CAPACITY BY THE USE OF A WAVEMETER OR DECREMETER.

30. Measurement of inductance or capacity.—As stated previously, a wavemeter or a decremeter can be used with other apparatus to measure an inductance or a capacity. If a local resonant circuit containing either a known inductance and an unknown capacity, or an unknown inductance and a known capacity, is set into oscillation by any convenient means, such as a buzzer, small spark coil, tube oscillator, etc., then according to paragraph 3—

$$\lambda = 59{,}600 \times \sqrt{LC} \text{ meters.}$$

If now the wave length of the local circuit be measured by a wavemeter or a decremeter, then all but one of the quantities in the formula are known, and the unknown inductance or capacity can be found from either of the two following formulas which are derived by simple algebra from the formula above:

$$L = \frac{\lambda^2}{3.56 \times 10^9 \times C}$$

$$C = \frac{\lambda^2}{3.56 \times 10^9 \times L}$$

where as before L is the inductance in milli-henrys,
C is the capacity in microfarads,
λ is the wave length in meters.

Section IX.

WAVEMETER; TYPE SCR-60-C.

31. Use and range of wave lengths.—This wavemeter can be used at either a damped or a continuous wave transmitter, and at a receiver, for all purposes except the measurement of the logarithmic decrement of a transmitter. Its range of wave lengths is from 75 to 2,000 meters.

32. Description of meter.—The meter is of the type that uses a set of coils for the inductance; and a variable air condenser for the capacity. It is provided with a hot wire galvanometer; with a crystal detector but *no* telephones; and with battery and buzzer, etc. All parts are mounted on a panel, and are contained in a box with a removable cover. The top view is shown in figure 3, and the interior in figure 4. The over-all dimensions are approximately 9½ by 9 by 8 inches high, including the carrying handle. Its weight is about 7 pounds.

33. Component parts.—There are three *coils* permanently mounted on the underside of the panel and connected in series. A three-way rotary switch in the upper center of the panel makes the connections at numbered contacts, as follows: (1) Short-circuits two of the coils, leaving the third coil in circuit for the shortest wave lengths; (2) short-circuits one coil, leaving the two others in circuit in series for the medium wave lengths; and (3) removes the short circuits and leaves all three coils in series for the longest wave lengths. The three scales of wave lengths corresponding to the three positions of the switch are marked on the dial of the variable condenser and are as follows: (1) 75 to 200 meters; (2) 200 to 550 meters; and (3) 550 to 2,000 meters. The coils are in the right end of the set box or wavemeter and the plane of the windings is parallel to the front and rear of the box, although not indicated by an arrow as is usually the case.

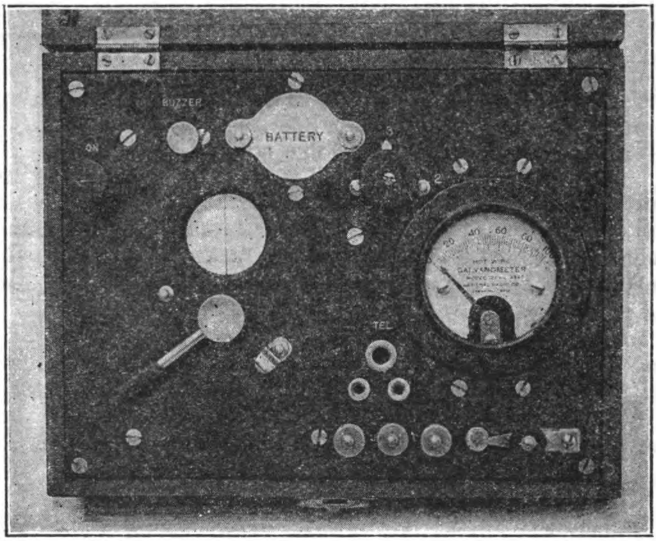

FIG. 8.

The *condenser* is a variable air condenser of the usual type. The handle at the left of the panel carries the wave length scales on a depressed dial that is read through a circular opening in the panel just above the condenser handle. The moving plates can be clamped by turning the handle to its extreme position, where it is locked in place by a spring catch.

The meter is provided with two means of indicating resonance: (1) A *hot wire galvanometer;* and (2) a *crystal detector.*

The galvanometer is connected in series in the circuit and is not shunted by a resistance. It is provided with a zero adjusting screw.

The *detector* is a galena crystal (lead sulphide) in light contact with a metal point on a flat spring which is adjustable as to pressure by means of a screw. It may be put into circuit in either of two types of connections, depending on the manner in which the telephones are connected: (1) In series with the telephones across the condenser; or (2) in the "unipolar" connection to one terminal of the condenser.

The *telephones*, which must be supplied from outside sources, should be of the high impedance type, and may be provided with (1) ordinary tip terminals; (2) standard plug, type PL–5, as in the standard head sets, type P–11; or (3) standard plug type PL–7, as in the standard head sets, type HS–2. In the first case two different connections can be made depending on which two of the three binding posts at the lower edge of the panel are used. If the telephones are

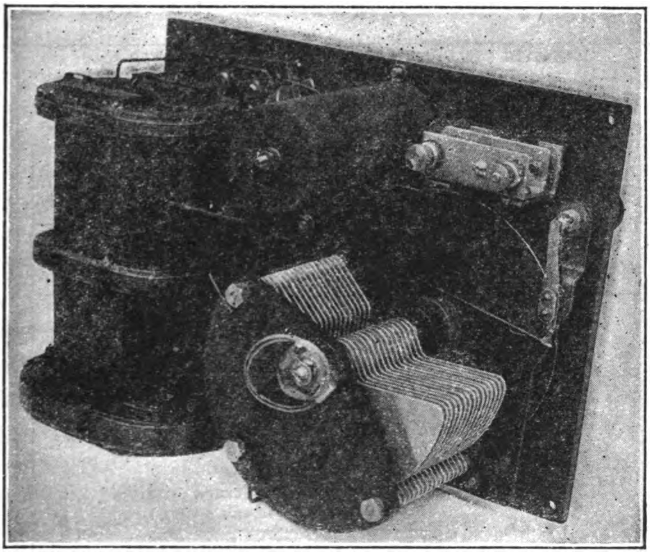

FIG. 4.

connected to the two posts between which the letter "D" is stamped, the detector and telephones are in series across the condenser terminals. If they are connected to the two posts between which the letter "U" is stamped, the detector and telephones are in the unipolar connection. If either of the standard plugs is used, the telephones are in series with the detector across the condenser.

The buzzer exciting circuit comprises the buzzer, battery, and switch, which is connected to the terminals of the condenser as shown in the schematic wiring diagram in figure 5, with the circuit completed through the three inductance coils. The *buzzer* is mounted on the underside of the panel with an adjustment screw for the vibrator projecting through the panel in the left corner and marked "Buzzer." It is driven by a single dry cell *battery*, that is contained in the compartment at the top of the panel marked "Battery." The *buzzer switch* is the button at the left edge of the panel and is closed when the arrow on the button is pointing to "On" and open when pointing away. The schematic wiring diagram of the wavemeter is shown in figure 5.

34. General instructions.—Before making any measures with the wavemeter, reference should be made to Sections IV, V, VI and VII for the various points which must be observed in the care of meters and in their use at a transmitter and at a receiver. When the meter is not in use, or is to be stored away, or made ready for transportation, the condenser plates should be clamped by the spring catch.

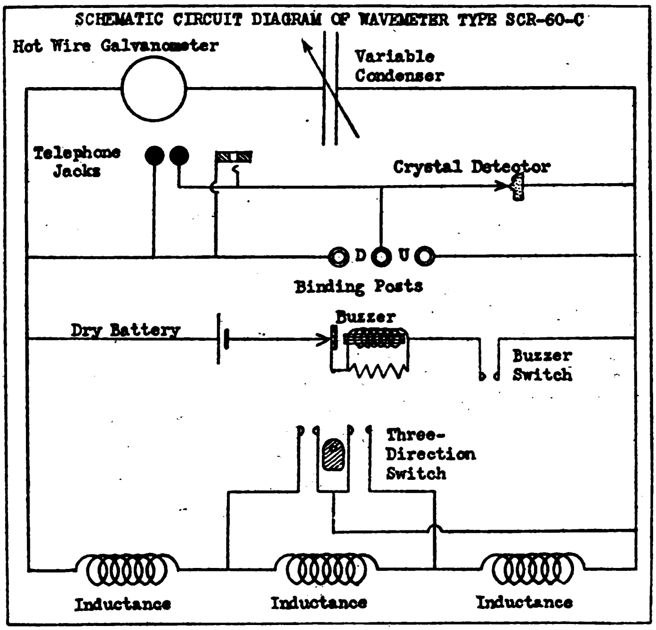

FIG. 5.

35. Measuring an unknown wave length at a transmitter.—Set the three-way switch on the scale that includes within its range the wave length to be measured; unclamp the condenser plates; disconnect the telephones; open-circuit the detector; and set the buzzer switch in the "Off" position. Make no other connections on the meter. Loosely couple the wavemeter coils with the *antenna coil* of the transmitter; and turn the condenser handle slowly over its scale until a maximum reading is obtained on the galvanometer, thus indicating that the wavemeter is in resonance with the transmitter. Read the wave length in meters on the scale corresponding to the position in which the three-way switch is set.

At a *damped wave* (spark) transmitter when the detector and telephones are to be used, the following directions are to be followed: Set the three-way switch on the scale that includes within its range the wave length to be measured; set the buzzer switch in the "Off" position; and plug the telephones in the jacks or connect them to the binding posts as the case may be—for present purposes there is no essential difference between the two types of connections. Make no other connections on the meter. Loosely couple the wavemeter coils with the *antenna coil;* and adjust the detector to a sensitive point. Turn the condenser handle slowly over its scale until the loudest signals are heard in the telephones, thus indicating that the wavemeter is in resonance with the transmitter, etc., as above.

36. Setting a transmitter at a predetermined wave length.—Set the three-way switch on the scale that includes the predetermined wave length, and the condenser at the wave length; set the buzzer switch at the "Off" position; connect in the galvanometer or the detector and telephones; and do not change the wavemeter adjustments thereafter. Loosely couple the wavemeter coils with the *antenna coil* and tune the transmitter to the wavemeter until the galvanometer or telephones show by the maximum response that the two circuits are in resonance at the predetermined wave length. At a *spark transmitter* it may be more convenient to tune the wavemeter to the transmitter, as described in paragraph 22.

37. Calibrating a transmitter.—The procedure is the same as in the previous paragraph, except that the transmitter is set in succession at a series of predetermined wave lengths, etc., as described in paragraphs 19 and 20.

38. Measuring an unknown wave length at a receiver.—Set the three-way switch on the scale that includes within its range the wave length to be measured; disconnect the telephones; and open-circuit the detector. Be sure that there is a battery in circuit in the battery compartment, and then turn on the buzzer switch, adjusting the vibrator by the screw at "Buzzer," if necessary, until the buzzer gives a clear, steady note. Loosely couple the wavemeter coil with the proper receiving circuit coil, as described in paragraph 24. Turn the condenser handle of the wavemeter slowly over its scale until the loudest signals are heard in the telephones of the receiving set, thus indicating that the receiver circuits are in resonance with the wavemeter at the unknown wave length. Read the wave length in meters on the scale in use.

39. Setting a receiver at a predetermined wave length.—Set the three-way switch on the scale that includes the predetermined wave length, and the condenser on the wave length; disconnect the telephones; open-circuit the detector; turn on the buzzer switch;

and do not change the wavemeter adjustments thereafter. Loosely couple the wavemeter with the proper receiving circuit coil, as described in paragraph 24, and tune the receiver circuits to the wavemeter, as though it were a distant station, until the telephones of the receiver indicate by the loudest signals that the circuits are in resonance with the wavemeter at the predetermined wave length.

40. Calibrating a receiver.—The procedure is the same as in the previous paragraph except that the wavemeter is set in succession at a series of predetermined wave lengths, etc., as described in paragraph 27.

Section X.

WAVEMETER; TYPE SCR-61.

41. Use and range of wave lengths.—This wavemeter can be used at a damped wave transmitter and at a receiver for all purposes, except the measurement of the logarithmic decrement of a transmitter. If provided with an external "current squared" meter or an ammeter, it can be used at a continuous wave transmitter. Its range of wave lengths is from 150 to 2,600 meters.

42. Description of meter.—The meter is of the type that uses a set of coils for the inductance and a variable air condenser for the capacity. It is provided with a crystal detector and telephones; and with a battery and buzzer, etc. There are also provided binding posts for connection to an external vacuum tube detector, and galvanometer or ammeter. Most of the parts are mounted on a panel and the rest carried in compartments. The meter is self-contained in a box with hinged cover and a carrying strap. It is shown assembled and ready for use in figure 6. The over-all dimensions are approximately 15½ by 9 by 11 inches high, including the carrying strap. Its weight is about 23 pounds.

43. Component parts.—Three *coils* are provided, wound on mahogany forms with the windings protected by insulating covers. Each coil is marked with a letter and its inductance in milli-henrys as follows: "A" 0.052 M. H.· "B" 0.319 M. H.; and "C" 1.715

M. H. Three scales of wave lengths, "A," "B," and "C," are marked on the dial at the variable condenser to correspond with the three coils and their ranges are as follows: "A," from 150 to 500 meters; "B," from 400 to 1,200 meters; and "C," from 800 to 2,600 meters. There is also provided a scale of degrees from 0 to 180 so that a calibration curve can be made for each coil if desired. A coil is connected into circuit by placing it in the left end of the cover of the box with the lettered side uppermost and toward the top of the cover. Two centering pins, a large one at the left and a small one at the right, fit into corresponding holes in the brass strip across the center of the coil, and automatically permit only the correct placing of the coil in circuit. It should be fastened in

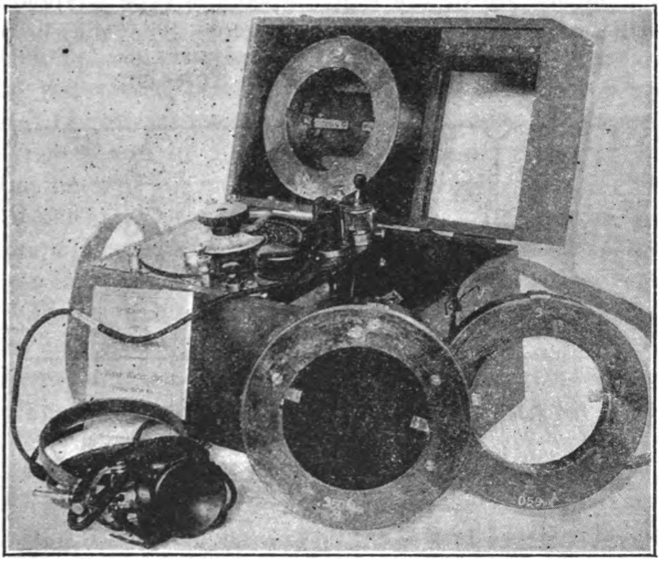

FIG. 6.

place by giving the winged thumb nut one-quarter of a turn. In this position the terminals of the coil at the two small brass plates on the underside of the wood form are connected to the two spring contacts in the cover and thence by flexible leads to the air condenser.

The *condenser* is a variable air condenser of the mechanically balanced type with two sets of fixed and moving plates. The moving plates can be clamped in place by the nut close to the condenser handle either to keep the meter at a constant wave length when desired or to secure the plates in place during transportation. One set of the fixed plates is grounded on the metal lining of the condenser compartment.

The *detector* is a galena crystal (lead sulphide) in light contact with a brass wire, and is inclosed to keep it dry and clean. The crystal is held in place by a screw on the outside of the detector stand, and the contact wire is adjustable by a ball and socket joint, the pressure on which is controlled by the nut on top of the brass post close to the stand. If desired, a *vacuum tube detector* can be used instead of the crystal detector by making suitable connections to the "Grid" and "Fil" binding posts on the front edge of the panel.

Similarly an external *ammeter* or *thermo-galvanometer* may be used instead of the detector by making suitable connections to the "Meter" binding posts in the upper left corner of the panel which ordinarily are short-circuited by a wide strip of brass. Except when the ammeter, etc., is in use, care must be taken to see that the strip makes good connections as it is in series in the wavemeter circuit.

The *telephones* are of the high impedance type adapted for use either with a crystal or vacuum tube detector. They may be provided

SCHEMATIC DIAGRAM FOR SCR-61

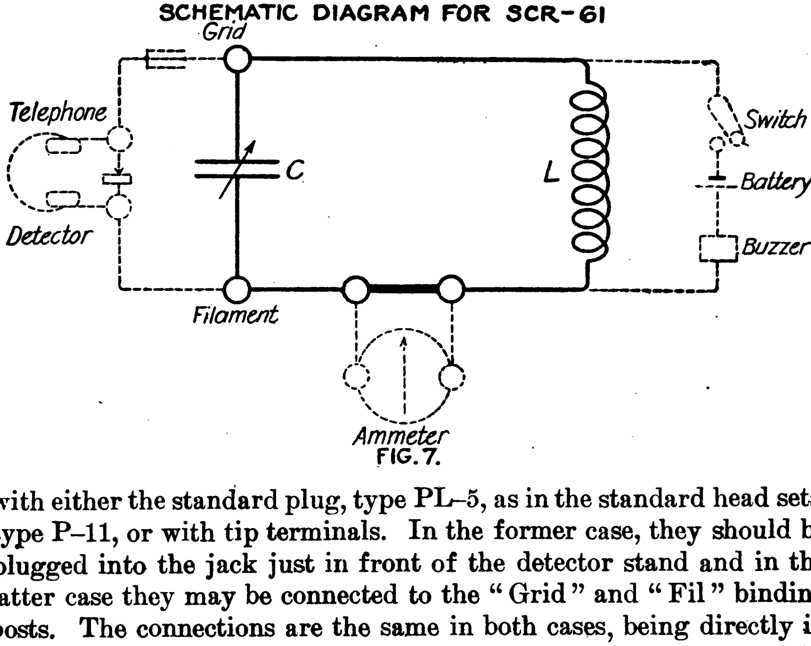

FIG. 7.

with either the standard plug, type PL–5, as in the standard head sets, type P–11, or with tip terminals. In the former case, they should be plugged into the jack just in front of the detector stand and in the latter case they may be connected to the "Grid" and "Fil" binding posts. The connections are the same in both cases, being directly in shunt to the detector, one terminal of which is connected through the metal lining of the box to one side of the variable condenser, and the other terminal through a very small condenser to the other side of the variable condenser. This differs slightly from the usual detector connection which puts the telephones in shunt to a condenser and not a detector. These connections are as shown schematically in figure 7 except that the "Grid" post is at the common terminal of the telephone and detector.

The buzzer exciting circuit comprises the buzzer, battery, and switch, which is connected to the terminals of the condenser with the circuit completed through the metal lining of the box and the inductance coil in circuit. The *buzzer* is mounted on the top side of the panel and is driven by a single dry cell *battery* that is held in spring clips on the underside of the panel just below the buzzer. Access to the battery for its renewal, etc., is through a hinged door opening out into the right-hand compartment of the box. The buzzer *switch* is the black push button on the front edge of the panel, which is in the "Off" position when pulled up and in the "On" position when pushed down.

As the metal lining of the box is used as a part of both the detector and buzzer circuits and as contact is made under three of the four machine screws in the corners of the panel, all of the screws should be kept screwed into place, otherwise the meter may be inoperative both at a receiver and at a transmitter.

44. General instructions.—Before making any measurements with the wavemeter, reference should be made to Sections IV, V, VI, and VII for the various points which must be observed in the care of meters and in their use at a transmitter and at a receiver. When the meter is not in use, or is to be stored away, or made ready for transportation, the three coils should be put in the right-hand compartment; the *condenser plates clamped;* the telephones secured as in paragraph 10, and placed centrally on top of the condenser with the caps between the buzzer and the detector stand; and the cover securely fastened in place.

45. Measuring an unknown wave length at a transmitter.—Connect the coil into circuit, which includes within its range the wave length to be measured; unclamp the condenser plates; and pull up the buzzer switch to its "Off" position. Be sure that the two "Meter" binding posts are firmly short-circuited by the strip of brass. Plug in the telephones and make no other connections to the meter. Loosely couple the wavemeter coil with the *antenna coil* of the transmitter and adjust the detector to a sensitive point. Turn the condenser handle slowly over its scale until the loudest signals are heard in the telephones, thus indicating that the wavemeter is in resonance with the transmitter. Read the wave length in meters on the scale corresponding to the coil in use.

45a. Use of external vacuum tube detector.—If such a detector—which is assumed to be complete and operative—is to be used, instead of the crystal detector, the following directions are to be observed: Open-circuit the detector; remove the telephones; connect the grid and the filament of the tube set respectively to the "Grid" and "Filament" binding posts; make no other connections to the wavemeter; and use the telephones of the tube set. Loosely couple the wavemeter and proceed as in the previous paragraph.

45b. Use of external galvanometer.—If such a detector is to be used, the following directions are to be observed: Connect the coil into circuit which includes within its range the wave length to be measured; pull up the buzzer switch to its "Off" position; open-circuit the detector; remove the telephones; and open the short-circuiting strip at the "Meter" binding posts. Connect the galvanometer into circuit at these posts, being sure to use the shortest possible leads in order to avoid adding inductance into circuit, and thus changing the computed values on the wave-length scales. Make no other connections to the wavemeter. Loosely couple the wavemeter coil with the *antenna coil* of the transmitter; turn the condenser handle slowly over its scale until a maximum reading, etc., similar to above.

46. Setting a transmitter at a predetermined wave length.—Connect the coil into circuit which includes within its range the predetermined wave length; set the condenser at the wave length; pull up the buzzer switch to its "Off" position; connect in the galvanometer or detector and telephones; and do not change the wavemeter adjustments thereafter. Loosely couple the wavemeter coil with the *antenna coil* and tune the transmitter to the wavemeter until the galvanometer or telephones show by the maximum response that the two circuits are in resonance at the predetermined wave length. At a *spark* transmitter it may be more convenient to tune the wavemeter to the transmitter as described in paragraph 22.

47. Calibrating a transmitter.—The procedure is the same as in the previous paragraph, except that the transmitter is set in succession at a series of predetermined wave lengths, etc., as described in paragraphs 19 and 20.

48. Measuring an unknown wave length at a receiver.—Connect the coil into circuit which includes within its range the wave length to be measured; disconnect the telephones; and open-circuit the detector. Be sure that there is a battery in circuit and then push down the buzzer switch to its "On" position, adjusting the vibrator if necessary until the buzzer gives a clear, steady note. Loosely couple the wavemeter coil with the proper receiving circuit coil, as described in paragraph 24. Turn the condenser handle of the wavemeter slowly over its scale until the loudest signals are heard in the telephones of the receiving set, thus indicating that the receiving circuits are in resonance with the wavemeter at the unknown wave length. Read the wave length in meters on the scale in use.

49. Setting a receiver at a predetermined wave length.—Connect the coil into circuit which includes within its range the predetermined wave length; set the condenser at this wave length; disconnect the telephones; open-circuit the detector; pull up the buzzer switch; and do not change the wavemeter adjustments thereafter. Loosely couple the wavemeter with the proper receiving circuit coil, as described in paragraph 24, and tune the receiver circuits to the wavemeter as though it were a distant station, until the telephones of the receiver indicate by the loudest signals that the circuits are in resonance with the wavemeter at the predetermined wave length.

50. Calibrating a receiver.—The procedure is the same as in the previous paragraph except that the wavemeter is set in succession at a series of predetermined wave lengths, etc., as described in paragraph 27.

SECTION XI.

WAVEMETERS—TYPES SCR-95, SCR-111, SCR-125, SCR-125-A, AND SCR-128.

51. Use and range of wave lengths.—These meters are all of the same general type, differing principally in the range of wave lengths and in minor details of construction. They can be used at either a *damped* or a *continuous wave* transmitter and at a receiver for all purposes, except that they can not be used to measure the logarithmic decrement of a transmitter. The ranges of wave lengths for the different meters are given here for the sake of convenient reference:

SCR-95	500 to 1,100 meters.
SCR-111	900 to 1,900 meters.
SCR-125	70 to 560 meters.
SCR-125-A	70 to 560 meters.
SCR-128	50 to 75 meters.

52. Description of meters.—The meters are of the type that use a variometer for the inductance and one or more fixed condensers for the capacity. They are provided with a miniature lamp with rheostat for indicating resonance; a buzzer and battery, etc. All parts are mounted on a panel which can be removed from the set box, and the meter is self-contained. Instructions and a wiring diagram for each type of meter are contained on the inside of its set box cover. A top view of the SCR–95 is shown in figure 8, and an inside view in figure 9. The over-all dimensions of the various meters differ slightly, but do not exceed 5 by 5½ by 5 inches high. The weight is about 4 pounds.

53. Component parts.—The *variometer* is mounted on the underside of the panel and is of the type described in paragraph 4b, wound with enamel wire on two forms or frames of an insulating material known as bakelite. The rotation of the inner coil changes the in-

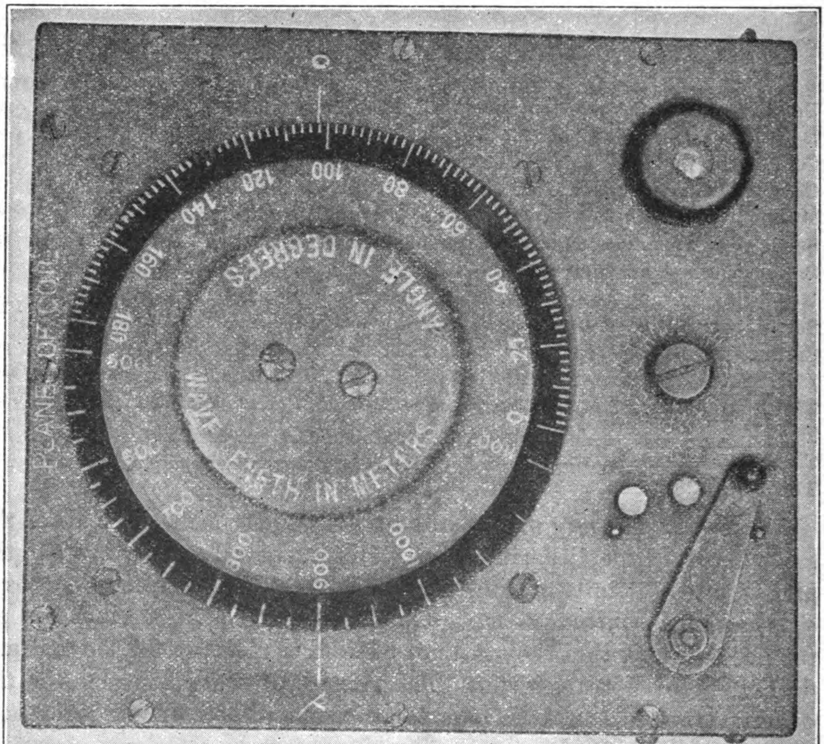

FIG. 8.

ductance in circuit and hence the wave length, and its shaft carries the dial and the wave length scale. The maximum value of the inductance is between 4 and 9 times larger than the minimum value, so that the longest wave length on the scale is between 2 ($\sqrt{4}$) and 3 ($\sqrt{9}$) times longer than the shortest wave length. The "Plane of coil" is indicated by an arrow on top of the meter, and in this case refers to the plane of the larger and fixed variometer coil.

The *condenser* is mounted on the underside of the panel and is of mica, sealed in a waterproof compound to exclude air and moisture.

In some meters three condensers are provided which can be connected into circuit by a *condenser* or *wave length* "*multiplier*" *switch* so as to give three ranges of wave lengths. In this case the capacities are in the ratio of either 1, 4, and 16; or 1, 9, and 81, so that the wave lengths will be as 1, 2, and 4; or 1, 3, and 9. Thus a single direct reading scale of wave lengths may be used, which as the different condensers are put into circuit by the switches, should be multiplied by the corresponding numbers 1, 2, and 4, etc., to give the other wave lengths.

The *miniature lamp* is mounted on top of the panel with a screw base and is protected by a hood which is removable for the renewal of the lamp by rotating it a fraction of a turn. It is permanently

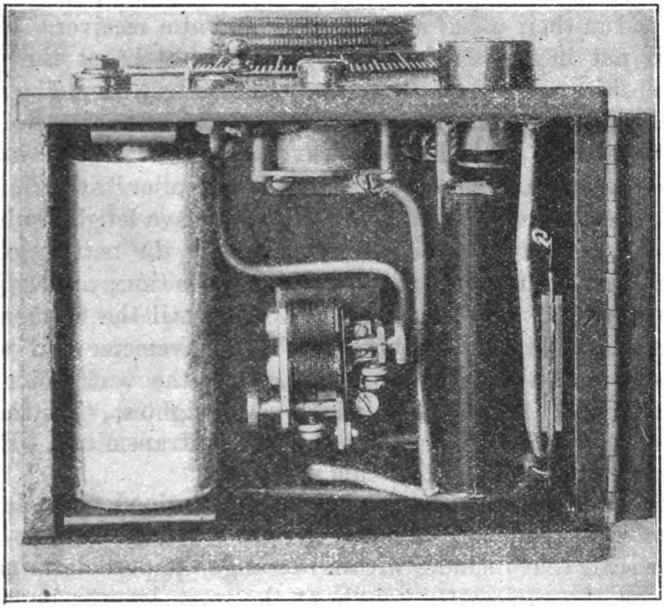

FIG. 9.

connected in circuit in series with the variometer and condenser. The lamp filament is most sensitive in showing any small increase in current when it is lighted to a dull red glow. For this reason the buzzer battery and an adjustable resistance are connected in series across the lamp terminals at the "C" contact at the three-way switch, so that the filament can be brought to its sensitive point. The *resistance* consists of a pile of carbon plates on the underside of the panel, which is adjustable by means of a screw on top of the panel marked "Lamp resistance." A *choke coil* of enamel wire is mounted on the underside of the panel in the front compartment and is used in the lamp and battery circuit to prevent the high frequency oscillations from flowing through that circuit instead of through the lamp. Although the battery is disconnected at the "A" contact of the three-way switch so that the filament is not lighted thereby, yet it is to be noted that the wavemeter is still operative as its circuit is still complete and the filament *may* be lighted at resonance by *strong* signals.

The *buzzer* is connected in circuit at the "B" contact of the three-way switch and is driven by a single dry cell battery that is held in place by spring clips in the front compartment of the set box. The *battery* is cut out of circuit at the "A" or "Off" position of the three-way switch.

54. General instructions.—Before making any measures with the wavemeter, reference should be made to Sections IV, V, VI, and VII, for the various points which must be observed in the care of meters and in their use at a transmitter and at a receiver. When the meter is not in use the battery switch should be at the "A" or "Off" position, and when stored away, the battery should be removed from its compartment.

55. Measuring an unknown wave length at a transmitter.—If there is a condenser or wave length "Multiplier" switch, set it on the scale that includes within its range the wave length to be measured; be sure there is a battery in circuit in the battery clips; set the battery switch on the "C" or "On" position; and adjust the "Lamp resistance" by means of its screw until the filament burns at a dull red glow. Loosely couple the wavemeter coil with the *antenna coil* of the transmitter; and turn the variometer handle slowly over its scale until the lamp glows brightest, thus indicating that the wavemeter is in resonance with the transmitter. Read the wave length in meters on the scale in use.

56. Setting a transmitter at a predetermined wave length.—If there is a condenser or wave length "Multiplier" switch, set it on the scale that includes within its range the predetermined wave length; set the variometer handle at the wave length; be sure that there is a battery in circuit in the battery clips; set the battery switch at the "C" position; adjust the "Lamp resistance" by means of its screw until the filament burns at a dull red glow; and do not change the wavemeter adjustments thereafter. Loosely couple the wavemeter coil with the *antenna coil* and tune the transmitter to the wavemeter until the lamp shows by its brightest glow that the two circuits are in resonance at the predetermined wave length.

At a *spark* transmitter it may be more convenient to tune the wavemeter to the transmitter, as described in paragraph 22.

57. Calibrating a transmitter.—The procedure is the same as in the previous paragraph, except that the transmitter is set in succession at a series of predetermined wave lengths, etc., as described in paragraphs 19 and 20.

58. Measuring an unknown wave length at a receiver.—If there is a condenser or wave length "Multiplier" switch, set it on the scale that includes within its range the wave length to be measured; be sure that there is a battery in circuit at the battery clips; set the battery switch on the "B" contact, adjusting the buzzer if necessary until it gives a clear, steady note. Loosely couple the wavemeter coil with the proper receiving circuit coil as described in paragraph 24. Turn the variometer handle slowly over its scale until the loudest signals are heard in the telephones of the receiving set, thus indicating that the receiver circuits are in resonance with the wavemeter at the unknown wave length. Read the wave length in meters on the scale in use.

59. Setting a receiver at a predetermined wave length.—If there is a condenser or wave length "Multiplier" switch, set it on the scale that includes the predetermined wave length; set the variometer handle at the wave length; set the battery switch on the "B" contact, adjusting the buzzer if necessary until it gives a clear, steady note; and do not change the wavemeter adjustments thereafter. Loosely couple the wavemeter coil with the proper receiving circuit coil, as described in paragraph 24; and tune the receiver circuits to the wavemeter as though it were a distant station, until the telephones of the receiver indicate by the loudest signals that the circuits are in resonance with the wavemeter at the predetermined wave length.

60. Calibrating a receiver.—The procedure is the same as in the previous paragraph except that the wavemeter is set in succession at a series of predetermined wave lengths, etc., as described in paragraph 27.

61. The SCR–95.—This is a *single-scale* wavemeter, with a range of wave lengths from 500 to 1,100 meters. As can be seen from the wiring diagram in figure 10, the 3-point battery switch has contacts as follows: "A" to disconnect the battery; "B" to connect the battery to the buzzer; and "C" to connect the battery to the lamp. The "Plane of coil" is parallel to the back of the set box. The following brief instructions are contained on the inside of the set-box cover:

To measure wave length, set switch on "C" and adjust carbon resistance until lamp glows a dull red. Couple wavemeter by holding near inductance coil of sending set. Rotate dial slowly until lamp lights to maximum brilliancy, when wave length is indicated on wavemeter dial.

To set receiver for given wave length, set switch on "B," adjust buzzer to give a clear note, and turn dial to desired wave length. Couple as above, and tune receiver until buzzer is heard loudest in phones.

CAUTION.—Replace battery when it fails to operate buzzer or lamp. When meter is not in use leave switch on "A" only.

62. The SCR–111.—This is a *single-scale* meter, with a range of wave lengths from 900 to 1,900 meters, almost identical with the

SCR–95 except for the wave lengths. The wiring diagram is identically the same as in the SCR–95 (fig. 10). The 3-point battery switch has contacts as follows: "A" to disconnect the battery; "B" to connect the battery to the buzzer; and "C" to connect the battery to the lamp. The "Plane of coil" is parallel to the back of the set box. The following brief instructions are contained on the inside of the set-box cover:

To measure wave length, set switch on "C" and adjust carbon resistance until lamp glows a dull red. Couple wavemeter by holding near inductance coil

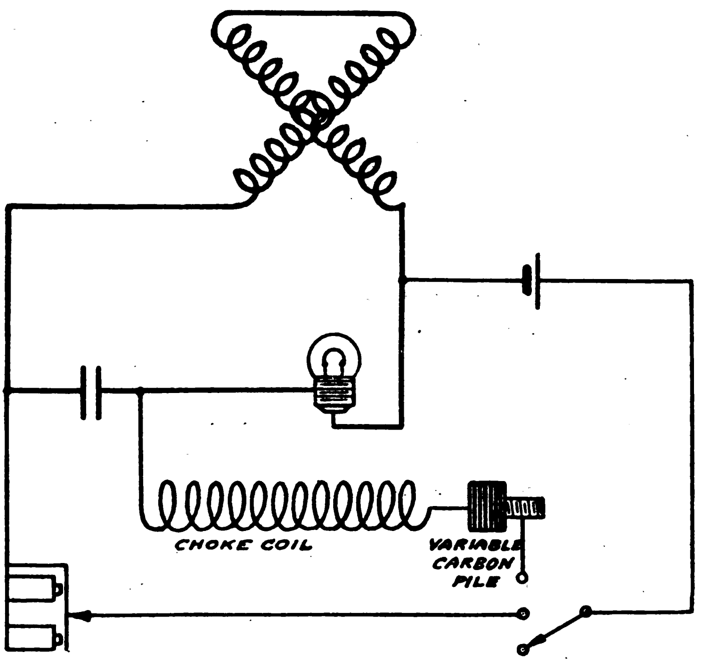

FIG. 10.

of sending set. Rotate dial slowly until lamp lights to maximum brilliancy, when wave length is indicated on wavemeter dial.

To set receiver for given wave length, set switch on "B," adjust buzzer to give a clear note, and turn dial to desired wave length. Couple as above, and tune receiver until buzzer is heard loudest in phones.

Caution.—Replace battery when it fails to operate buzzer or lamp. When meter is not in use leave switch on "A" only.

63. The SCR–125.—This is a *3-scale* meter with a range of wave lengths from 70 to 560 meters. It is direct reading from 70 to 140 meters, and as the multipliers are 1, 2, and 4, the scale also reads from 140 to 280 meters, and from 280 to 560 meters. As can be seen from the wiring diagram in figure 11, the 3-point switch has contacts as follows: "A" to disconnect the battery; "B" to connect the battery to the buzzer; and "C" to connect the battery to the lamp. The "Plane of coil" is parallel to the back of the set box. The following brief instructions are contained on the inside of the set box cover:

This instrument has three wave length ranges obtained by three values of capacity. With the condenser switch on position 1, the wave length range is approximately 70 to 140 meters, the wave length dial reads directly in meters. With the condenser switch on position 2, the wave lengths indicated

SCHEMATIC DIAGRAM FOR SCR-125

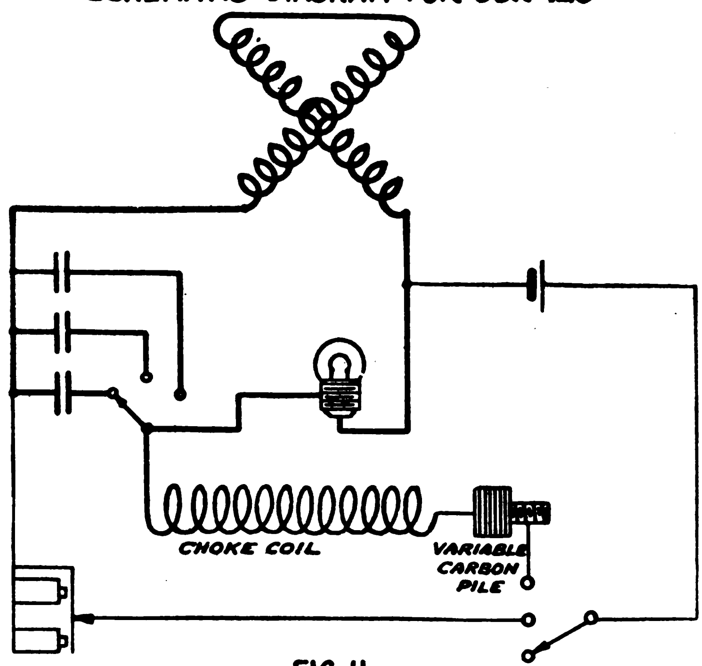

FIG. 11.

on the dial must be multiplied by 2, and correspondingly with the condenser switch on position 4, the dial reading must be multiplied by 4.

To measure wave length, set circuit switch on "C," and adjust carbon resistance until the lamp glows a dull red. Couple the wavemeter by holding it near the inductance coil of the sending set. Rotate the dial slowly until the lamp shows maximum brilliance, the wave length will then be indicated on the wavemeter dial.

To set the receiver for a given wave length, set the "circuit switch" on "B." Adjust the buzzer to give a clear note, and turn the dial to the desired wave length. Couple as above and tune the receiver until the buzzer is heard loudest in the telephone receivers.

Caution.—Leave circuit switch in "A" position when the wavemeter is not in use.

64. The SCR–125–A.—This is a *3-scale* meter, very similar to the SCR–125, with a range of wave lengths from 50 to 1,350 meters. It is direct reading from 150 to 450 meters, and as the multipliers are 1/3, 1, and 3 the scale reads also from 50 to 150 meters, and from 450 to 1,350 meters. As can be seen from the wiring diagram in figure 12, the 3-point switch has contacts as follows: "A" to disconnect the battery, " B " to connect the battery to the buzzer, and " C " to connect the battery to the lamp. The " Plane of coil " is *diagonal* and lies in a vertical plane parallel to a line through the multiplier

SCHEMATIC DIAGRAM FOR SCR-125-A

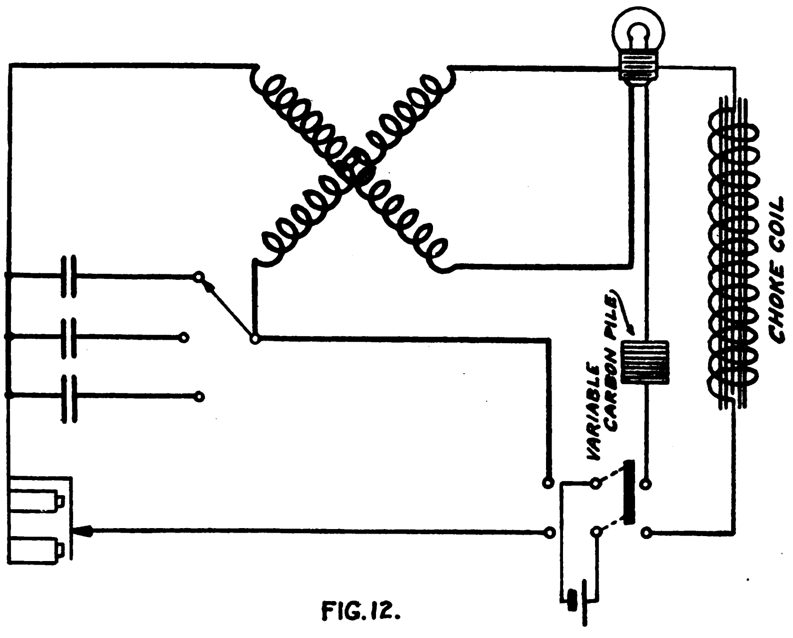

FIG. 12.

switch and the lamp. The following brief instructions are contained on the inside of the set box cover:

This instrument has three wave length ranges obtained by three values of capacity. With the condenser switch on position 1, the wave length range is approximately 150 to 450 meters. The wave length dial reads directly in meters. With the condenser switch on position 3, the wave lengths indicated on dial must be multiplied by 3, and correspondingly with the condenser switch on position 1/3, the dial reading must be multiplied by 1/3.

To measure wave length, set circuit switch on " C " and adjust the carbon resistance until the lamp glows a dull red. Couple the wavemeter by holding it near the inductance coil of the sending set. Rotate the dial slowly until the lamp shows maximum brilliance. The wave length will then be indicated on the wavemeter dial.

To set the receiver for a given wave length, set the circuit switch on "B." Adjust the buzzer to give a clear note, and turn the dial to the desired wave length. Couple as above and tune the receiver until the buzzer is heard loudest in telephone receiver.

65. The SCR–128.—This is a *single-scale* wavemeter for very short wave lengths, with a range from 50 to 75 meters. It is so closely similar to the SCR–95 that the same general instructions, wiring diagram, etc., may be used for both meters.

Section XII.

WAVEMETER; TYPE SCR–137.

66. Use and range of wave lengths.—This wavemeter can be used at either a damped or a continuous wave transmitter, and at a receiver with an oscillating vacuum tube detector for all purposes, except the measurement of the logarithmic decrement of a transmitter. With the equipment that has been provided it can *not* function at a receiver with a crystal or other nonoscillating detector. Its range of wave lengths is from 1,000 to 20,000 meters.

67. Description of meter.—The meter is the Bureau of Standards "Long Wave Meter, type L." It uses a set of coils for the inductance and a variable air condenser for the capacity. It is provided with a thermo-galvanometer, and binding posts for connection to an external detector, buzzer, etc. All parts are mounted on a panel in an oak box with a removable cover, and the meter is self-contained. A top view is shown in Fig. 13. The over-all dimensions are approximately 8¼ by 16¾ by 10¼ inches high and the weight about 28 pounds.

68. Component parts.—Four *coils* are provided permanently mounted on the underside of the panel and are connected into circuit in three combinations for the three scales of wave lengths, as follows: (1) For short waves, 1,000 to 5,000 meters, the four coils are all in parallel; (2) for medium waves, 2,000 to 10,000 meters, two coils are connected in series and this combination is in parallel with the other two coils, also in series; and (3) for long waves, 4,000 to 20,000 meters, the four coils are all in series. These various connections are made by means of a switch which is operated by the handle near the rear edge of the meter. This handle can be turned in either direction and at the three points in the revolution where the connections are made, the number of the scale in use is indicated in a circle at the peephole near the handle, and at the same time the index points to the direct reading scale of wave lengths in use. The coils are in the right-hand end of the set box and the axis of the coils is parallel to the right end, as indicated by the legend "Axis of Coils" on the end. The plane of the windings is therefore parallel to the front and rear of the box.

The *condenser* is of the mechanically balanced type with two sets of fixed plates and two sets of moving plates. Owing to the rapid change of capacity as the moving plates are rotated, the motion is geared down about 5½ to 1 and the condenser handle is the one near

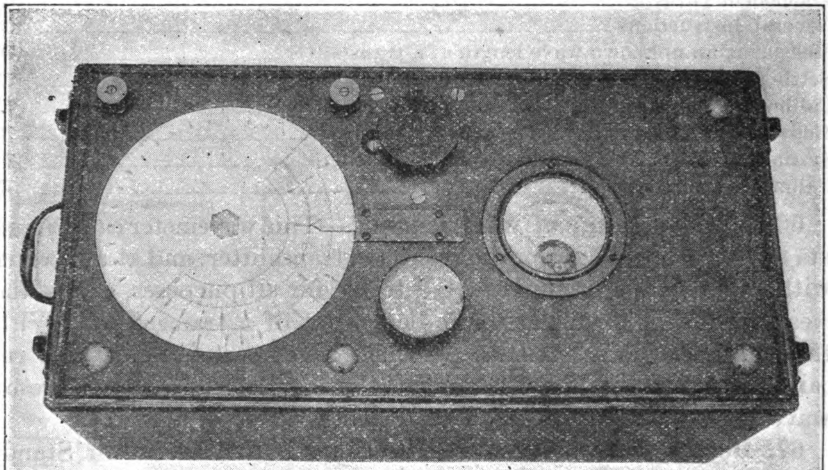

FIG. 13.

the front edge of the panel marked "Press." The condenser compartment is in the left end of the set box shielded by a metal lining.

The *galvanometer* is provided with a small screw extending through the glass cover so that its needle can be adjusted to zero if desired. It is shunted by a resistance and is cut out of circuit by a switch which is closed except when the condenser handle is *pressed down.* This pressure does not change the condenser reading or wave length.

No other auxiliary apparatus has been provided with the meter. There are, however, two binding posts on the rear edge of the panel which are connected to the terminals of the condenser. A detector and telephones, or buzzer and battery can be connected to these if desired for use as described in Section VII. The schematic wiring diagram of the wavemeter is shown in figure 14.

69. General instructions.—Before making any measures with the wavemeter, reference should be made to Sections IV, V, VI, and VII for the various points which must be observed in the care of meters and their use at a transmitter and at a receiver. In making the meter ready for transportation the only step that need be taken is to be sure that the cover is firmly clamped in place.

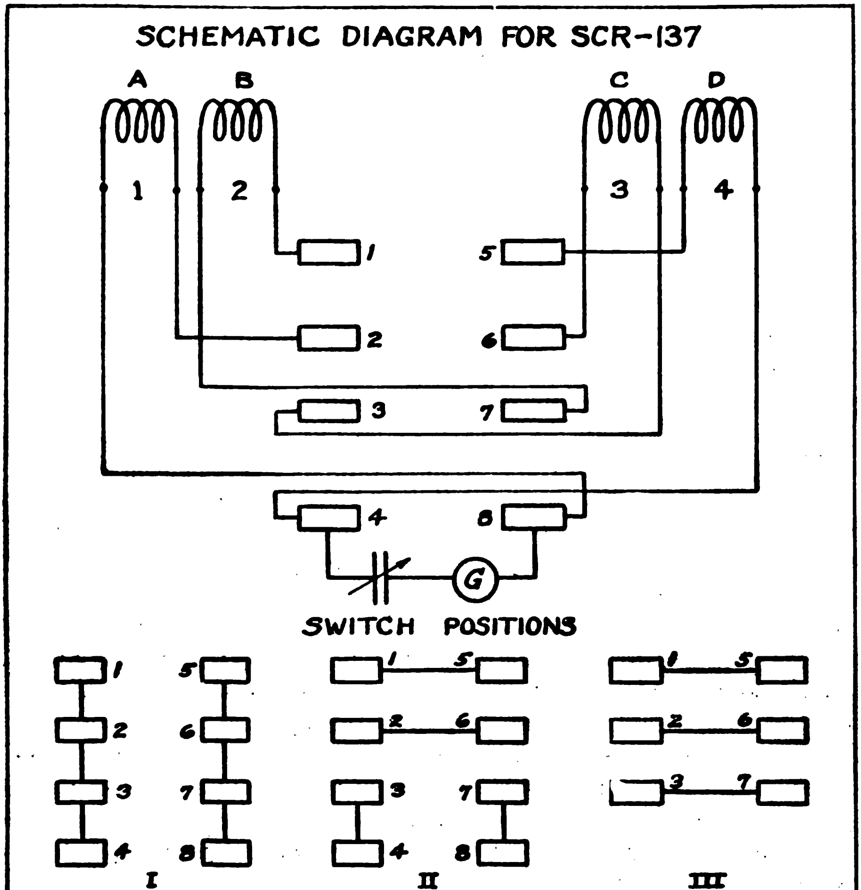

FIG. 14.

70. Measuring an unknown wave length at a transmitter.—Set the coil switch at the rear edge of the meter on the scale that includes within its range the wave length to be measured, taking care that the circle containing the scale number is central in the peephole. Loosely couple the wavemeter coils with the *antenna coil* of the transmitter; press down on the condenser handle on the front edge of the panel; and turn it slowly over its scale until a maximum reading is obtained on the galvanometer, thus indicating that the wavemeter is in resonance with the transmitter. Read the wave length in meters on the scale in use.

If an *external detector* and telephones are to be used (as at a spark transmitter), they should be connected either in series between the two binding posts or in a unipolar connection to the inner post. Then set the coil switch, etc., similar to the previous paragraph.

71. Setting a transmitter at a predetermined wave length.—Set the coil switch on the scale that includes within its range the predetermined wave length; set the condenser at the wave length; make no connections to the wavemeter; press down on the condenser handle; and do not change the wavemeter adjustments thereafter. Loosely couple the wavemeter coils with the *antenna coil* and tune the transmitter to the wavemeter until the galvanometer shows by its maximum reading that the two circuits are in resonance at the predetermined wave length. At a *spark* transmitter it may be more convenient to tune the wavemeter to the transmitter, as described in paragraph 22.

72. Calibrating a transmitter.—The procedure is the same as in the previous paragraph except that the transmitter is set in succession at a series of predetermined wave lengths, etc., as described in paragraphs 19 and 20.

73. Measuring an unknown wave length at a receiver.—If the receiver is provided with an *oscillating vacuum tube detector* (autodyne) two methods may be used, one in which the wavemeter is provided with a buzzer as described in the latter part of this paragraph; and the other with no auxiliary apparatus, which is preferable, as follows: Set the coil switch on the scale that include within its range the wave length to be measured; make no connections to the wavemeter; and loosely couple the wavemeter coils with the proper receiving circuit coil, as described in paragraph 24. Turn the condenser handle of the wavemeter slowly over its scale until a "Resonance click" is heard in the telephones of the receiving set (see paragraph 78), which thus indicates that the wavemeter is in resonance with the receiving circuits at the unknown wave length. Read the wave length in meters on the scale in use.

If the receiver is provided with a *crystal* or *vacuum tube detector* (nonoscillating), the following directions are to be followed: Connect an external buzzer and dry-cell battery in series to the two binding posts at the rear of the panel. Then set the coil switch on the scale that includes within its range the wave length to be measured and adjust the buzzer to a clear, steady note. Loosely couple the wavemeter coils with the proper receiving circuit coil, as described in paragraph 24. Turn the condenser handle of the wavemeter slowly over its scale until the loudest signals are heard in the telephones of the receiving set, thus indicating that the receiving circuits are in resonance with the wavemeter at the unknown wave length. Read the wave length in meters, etc.

74. Setting a receiver at a predetermined wave length.—At a receiver with an *oscillating vacuum tube detector*, set the coil switch on the scale that includes the predetermined wave length, and the condenser on the wave length; make no other connections to the wavemeter; and do not change the wavemeter adjustment thereafter. Loosely couple the wavemeter with the proper receiving circuit coil, as described in paragraph 24; and tune the receiver circuits to the wavemeter as though it were a distant station until a "Resonance click" is heard in the telephones of the receiving set, thus indicating that the circuits are in resonance with the wavemeter at the predetermined wave length. (See paragraph 78.)

At a receiver with a *crystal* or *vacuum tube detector* (nonoscillating), set the coil switch on the scale that includes the predetermined wave length, and the condenser on the wave length; connect the battery and buzzer as in paragraph 73; adjust the buzzer to a clear, steady note; and do not change the wavemeter adjustments thereafter. Loosely couple the wavemeter coils with the proper receiving circuit coil, as described in paragraph 24; and tune the receiving circuits to the wavemeter as though it were a distant station, until the telephones of the receiver indicate by the loudest signals that the circuits are in resonance with the wavemeter at the predetermined wave length.

75. Calibrating a receiver.—The procedure is the same as in the previous paragraph except that the wavemeter is set in succession at a series of predetermined wave lengths, etc., as described in paragraph 27.

Section XIII.

HETERODYNES AND AUTODYNES AS WAVEMETERS.

76. Uses.—A heterodyne set calibrated in wave lengths can be used as a wavemeter at a receiving set provided with an oscillating tube detector. Similarly, a receiving set with an oscillating tube detector (autodyne) calibrated in wave lengths can be used as a wavemeter at a continuous wave transmitter. Other uses of heterodynes and autodynes as substitutes for wavemeters may be devised, but will not be described in this pamphlet.

77. Beat note test for resonance.—In all uses of the heterodyne wavemeter, both the heterodyne and other circuits must be oscillating. When the two circuits are oscillating at nearly the same wave length, a "*beat*" note is heard in the telephones of the receiving set. The pitch of the beat note will vary with the tuning adjustments of either circuit. If the tuning adjustments of either circuit are slowly and continuously varied through resonance, the beat note will pass from inaudibly high to high pitch, becoming lower and lower in pitch until it becomes inaudibly low; after which it will reappear as a note of low pitch which becomes higher and higher, finally becoming inaudibly high. The two circuits are in resonance when the beat note is of zero pitch—that is, in the inaudibly low range of tuning. This point is halfway between the points where the low note disappears and reappears as the tuning is varied.

78. "Click" test for resonance.—When a steady current flows through a telephone receiver—as in a vacuum tube detector—any sudden change in the current will produce a click in the receiver. Thus in an autodyne which is oscillating there will be a sudden decrease in the current if a near-by circuit is tuned to the same wave length, as the near-by circuit then draws a large amount of energy from the autodyne circuit and decreases the current in the telephone. When a "click" is produced by this cause it therefore indicates resonance between the autodyne and the external circuit.

79. Autodyne at a transmitter.—A receiving set with an oscillating tube detector and calibrated in wave lengths can be used to measure unknown wave lengths at a continuous wave transmitter. In this case the primary of the receiver is left open circuited and the coupling between the primary and secondary of the receiver made as loose as possible. In general, the secondary of the receiver will pick up energy enough from the transmitter to give a signal without the use of the receiver primary circuit and with no special regard to coupling. Leaving the transmitter circuits unchanged, adjust the receiving circuit to resonance (zero beat note). Similarly a transmitter can be set at a predetermined wave length and calibrated. (See paragraphs 19 and 20.)

80. Heterodyne at a receiver.—A heterodyne set can be used to measure unknown wave lengths, etc., at a receiver in several different ways as follows: It may be connected (1) in the antenna circuit; (2) in the secondary circuit; or (3) loosely coupled with the proper receiving circuit coil but not connected into circuit. In the first case the secondary circuit must remain unchanged and the heterodyne set adjusted to produce zero beat signals as shown by the telephones of the receiving circuit; in the second case, the primary circuit must remain unchanged, etc.; and in the third case, both circuits must remain unchanged, etc. The first and third methods are the most commonly used. The Signal Corps set, type BC-104, may be used for the first method. Similarly a receiving circuit can be set at a predetermined wave length and calibrated according to the directions of paragraphs 26 and 27.

Section XIV.

THEORY OF DAMPING AND ITS MEASUREMENT BY DECREMETER AND WAVEMETER.

81. Damped oscillations and logarithmic decrement.—Whenever a condenser discharges through an inductance and a resistance, the discharge current in general takes place as a train or series of oscillations, the first of which is the most intense, and the following ones of steadily decreasing values as they die away to zero. Such a train of oscillations is said to be *damped*, and the *logarithmic decrement* is the *mathematical measure* of the damping, or the dying away of the oscillations. If the oscillations in a train die away quickly, the decrement is said to be large; and if they die away slowly, the decrement is said to be small. The damping of tube and arc sets is practically zero, and for this reason measures of damping are confined to spark sets.

82. Mathematical definition of decrement.—Mathematically, decrement may be defined as follows: Let figure 15 represent part of a wave train. The largest value in a positive or negative half cycle or alternation is called the *amplitude:* Thus I_0, I_1, and I_2 are the three amplitudes of figure 15, in which I_0 is the largest amplitude and I_1 and I_2 are amplitudes of successive half cycles in the wave train as it dies away. In mathematical language the logarithmic decrement is defined as the natural logarithm of the ratio of any amplitude to the next following amplitude in the same direction.

$$\text{Decrement} = \delta = \log \frac{I_0}{I_2}$$

where δ (read "delta") is the symbol for the decrement. It is constant in any one wave train.

This may be rewritten and restated in other ways as follows:

$$\delta = \log I_0 - \log I_2$$

Thus the decrement is a number which is the *constant difference* between the natural logarithms of any two successive amplitudes in the same direction.

$$\delta = \log I_0 - \log I_2$$

$$\text{And } \log I_2 = \log I_0 - \delta$$

Thus the decrement is the constant number by which the natural logarithm of the amplitude of any oscillation in a train must be decreased to find the natural logarithm of the next following amplitude in the same direction. In other words, it is a constant decrement or decrease in a natural logarithm, whence the name "logarithmic decrement."

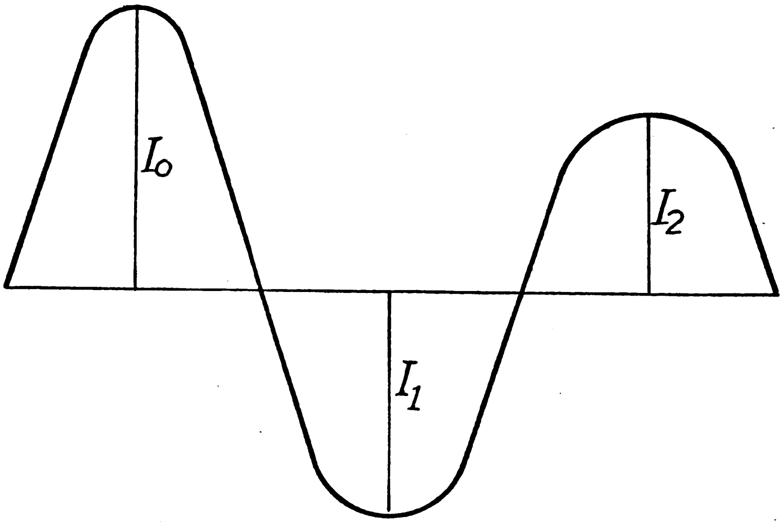

FIG. 15.

If $I_0 = I_2 = I_4$, etc., that is, if the amplitude of all the oscillations in the train is the same, it is evident that the logarithmic decrement is zero, and these oscillations are *undamped.* Reference will be made to this relation later on in the theory of the decremeter.

83. Calculation of decrement in an isolated circuit.—The decrement of any isolated or very loosely coupled oscillating circuit can also be defined by its *electrical constants*, as in the following formula:

$$\delta = \frac{R}{2\,LN}.$$

R=High frequency resistance in ohms.
L=Inductance in henrys.
N=Number of cycles per second at which the circuit is oscillating.

The quantity N is connected to the wave length λ by the following formula:

$$N\lambda = V = 300{,}000{,}000 \text{ meters per second where } \lambda \text{ is in meters.}$$

For example, if the wave length is 754, the value of N is $\frac{300{,}000{,}000}{754}$, or about 398,000 cycles per second.

84. General formulas.—When the decremeter is used to measure the wave length or the decrement of a transmitter, it is loosely coupled with its circuit. Under these conditions it can be shown mathematically that by means of suitably chosen readings the decrement of the transmitter can be determined by the following formula which makes use of the decrement of the meter itself, as well as certain readings of its capacity and current:

$$\delta_1 + \delta_2 = \pi \frac{C_r - C}{C} \sqrt{\frac{I^2}{I^2_r - I^2}}$$

δ_1 is the decrement of the transmitting circuit under measurement.

δ_2 is the decrement of the meter itself.

C_r is the capacity of the decremeter condenser when it is in resonance with the transmitter.

I^2_r is the square of the current in the decremeter circuit at resonance.

C is the capacity of the decremeter condenser when it is slightly off resonance, or detuned.

I^2 is the square of the current in the decremeter circuit at the detuned adjustment.

In order to avoid the necessity of squaring the ammeter current reading to get I^2, the meter actually provided has its scale graduated as I^2 or it is a "current squared" meter. It is a hot wire wattmeter or galvanometer, whose reading depends upon its I^2R value. The resistance "R" of the wire is fixed so that the readings are proportional to the square of the current.

85. Simplified formulas.—In practically all cases where the decrement formula can be correctly used, it is possible to simplify it by a suitable choice of its readings. If the reading I^2 at the capacity C is so taken that $I^2 = \frac{1}{2} I^2_r$, then the quantity under the square root sign becomes unity, and hence

$$\delta_1 + \delta_2 = \pi \frac{C_r - C}{C}$$

where all the quantities are known except δ_1, which can be computed.

If the decremeter is loosely coupled to an undamped wave source, as a vacuum tube oscillator, whose decrement is zero, and if the readings are taken in the usual way, the decrement of the meter can be immediately determined, as δ_1 is now zero, and all quantities are known except δ_2 which becomes

$$\delta_2\pi = \frac{C_r - C}{C}.$$

From formula $\delta = \frac{R}{2LN}$ it is seen that the decrement will vary with N and hence with the wave length, as well as with the high frequency resistance R, and that, therefore, it is not constant for any one decremeter coil. It is the general practice, however, to give an *average* value for each coil over the range of wave lengths for which it is to be used. In some cases for accurate work a curve is supplied showing the variation in decrement for each coil over the entire range of its use.

86. Decremeter scale.—It can be shown mathematically that the plates of the decremeter condenser can be so shaped that for any change in capacity from C_r to C, the quantity $\frac{(C_r - C)}{C}$ will be constant. If a scale is attached to the variable condenser whose value is proportional to $\frac{(C_r - C)}{C}$ and whose readings are π times $\frac{(C_r - C)}{C}$, it is evident that the scale will read directly $\delta_1 + \delta_2$ in accordance with the formula of paragraph 85. From the known value of δ_2, δ_1 can be immediately determined. A wavemeter whose condenser is designed to give such readings is called a decremeter. The complete theory of the decremeter is given in Bureau of Standards Scientific Paper No. 235.

87. Use of a wavemeter as a decremeter.—Although the logarithmic decrement can be obtained from a direct reading scale of a decremeter, yet it can also be obtained by computation from readings of certain types of wavemeters. For this purpose, (1) the wavemeter must be of the type using a fixed inductance and variable capacity; (2) its own decrement must be known; and (3) it must be provided with either a current measuring instrument, as an ammeter, or preferably a "current squared" instrument, as a hot wire galvanometer or a thermo-galvanometer.

If the wavemeter coil is loosely coupled with the antenna coil of the transmitter, and if the capacity of its condenser is varied, it will be found that the ammeter or galvanometer will show a maximum reading when the wavemeter is in resonance with the transmitter, and steadily decreasing readings as the condenser is varied more and more from its resonant position on either side of the resonance point. When these results are plotted with the condenser capacities along the horizontal line and the square of the currents along the vertical line, the curve so obtained is one form of a *resonance curve.*

88. Example of a wavemeter used as a decremeter.—Such a resonance curve is shown in figure 16, and from it the logarithmic decrement can be computed as follows: Referring to paragraph 85, it

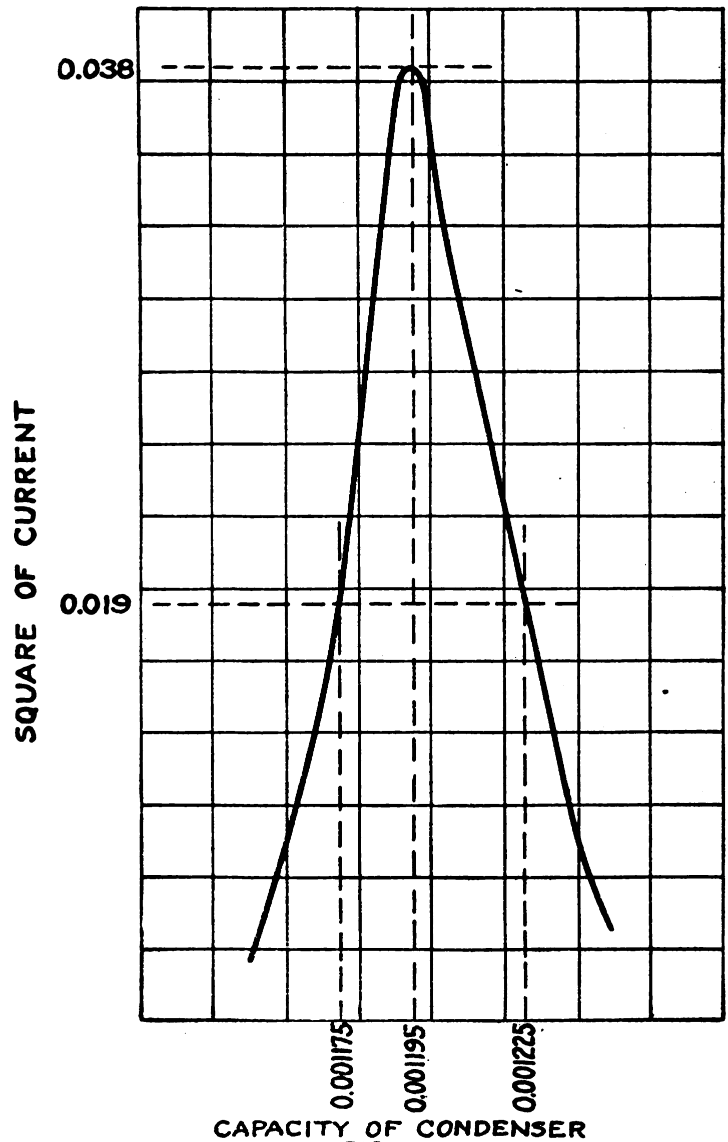

FIG. 16.

is seen that it is necessary to know the capacity at resonance, C_r, where the galvanometer reads I^2_r; and at the detuned position C, where the galvanometer reads $\frac{1}{2}I^2_r$. From the curve, C_r is 0.001195 mfd. at I^2_r=0.038 and C is 0.00117 mfd. at $\frac{1}{2}I^2_r$ Substituting in the formula, the formula

$$\delta_1+\delta_2=3.14\,\frac{0.001195-0.001175}{0.001175}=0.054.$$

If δ_1 is given as 0.016, then δ_2, the decrement of the transmitter is 0.038.

In the computation of the logarithmic decrement in the previous paragraph, the capacity at resonance and at a detuned position on one side of resonance was used. Inasmuch as the curve is not exactly symmetrical, it is best to compute another value, using the capacity at resonance and at the detuned position on the other side of resonance. Thus

$$\delta_1+\delta_2=\pi\frac{C-C_r}{C}$$

where C_r is 0.001195 mfd. at I^2_r=0.038 as before; and C is also 0.001225 mfd. at $\frac{1}{2}I^2_r$. Substituting in the formula, $\delta_1+\delta_2$=0.077 and δ_2=0.061 The average of the two values of δ_1 is therefore 0.049.

Although the method of thus computing the decrement twice and taking its average is strictly correct, yet it is somewhat quicker in practical work to combine the two formulas and methods as follows:

$$\delta_1+\delta_2=\frac{\pi}{2}\times\frac{C_1-C_2}{C_r}$$

where C_1 is the detuned capacity on the large capacity side of resonance at the point where $I^2=\frac{1}{2}I^2_r$;

C_2 is the detuned capacity on the small capacity side of resonance at the corresponding point;

and C_r is the capacity at resonance.

Substituting in the formula $\delta_1+\delta_2$=0.066 and hence δ_2, the decrement of the transmitter=0.050, which agrees closely with 0.049 as obtained above.

In some cases it is more convenient to plot another form of resonance curve, especially where the values of the wavemeter capacities are not given, but only those of the wave lengths in meters. The formula is slightly changed, as follows:

$$\delta_1+\delta_2=\pi\frac{\lambda_1-\lambda_2}{\lambda_r}.$$

where λ_1 is the wave length at the detuned position on the long wave length side of resonance at the point where $I^2=\frac{1}{2}I_r^2$;

λ_2 is the wave length at the detuned position on the short wave side of resonance at the corresponding point;

and λ_r is the wave length at resonance.

89. Notes on the use of a wavemeter as a decremeter.—In the previously described methods of measurement of decrement, a "current-squared" instrument was used to indicate resonance, but the same measures can also be made under certain conditions with an ammeter. In this case another form of resonance curve is drawn, in which the condenser capacities or wave lengths in meters are plotted along the horizontal line and the currents along the vertical line. The values of the capacity or wave length are taken at resonance as before, but the detuned values must be taken where I is at 0.707 I_r and not at $\frac{1}{2}I_r^2$, as will be seen from the following: The relative positions of I_r and 0.707 I_r on the resonance curve of the currents is the same as that of I^2_r and $\frac{1}{2}I_r^2$ on the resonance curve of the squares of the currents, for if each value on the former is squared the latter curve is obtained and I_r and 0.707 I_r become I_r^2 and $\frac{1}{2}I_r^2$. Thus the previous formulas can be used if the detuned capacities or wave lengths are read from the current curve at I_r and 0.707 I_r.

The previously mentioned resonance curves can be more accurately taken and the decrement more accurately computed, the smaller the resistance and decrement of the wavemeter. It is thus seen why the wavemeter or decremeter resistances in coil, condenser, and wattmeter should be kept as low as possible. The sharpness of the peak of the resonance curve depends upon the sum of the decrements of the circuit under measurement and of the wavemeter. In general, the smaller the sum of the decrements the sharper the peak, and vice versa, the larger the sum the broader the peak. It must be noted that a wavemeter with a variable inductance can *not* be used in measuring a decrement.

SECTION XV.

DECREMETER; TYPE SCR-87.

90. Use and range of wave lengths.—This decremeter can be used at either a damped or a continuous wave transmitter and at a receiver for all purposes as a wavemeter as well as a decremeter. It is designed especially for the measurement of the logarithmic decrement of a transmitter, as described at length in Section XIV. Its range of wave lengths is from 75 to 3,000 meters and of decrement from zero to 0.30.

91. Description of meter.—The meter is of the type that uses a set of coils for the inductance; and a special variable air condenser for the capacity. It is provided with a thermo-couple galvanometer; crystal detector and telephone; and with battery and buzzer, etc. Some of the parts are mounted on a panel and the rest are carried in

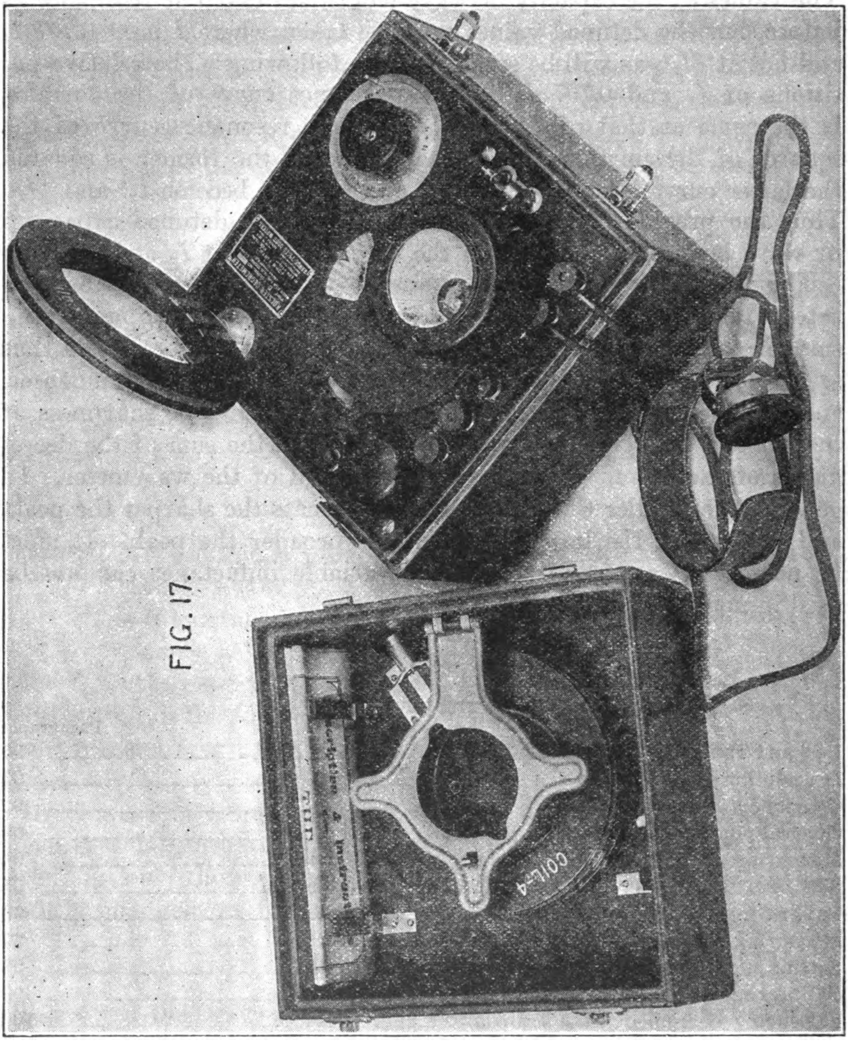

FIG. 17.

the cover. The meter is self-contained in a leather case with hinged cover and carrying strap. It is shown assembled in figure 17, and with an interior view in figure 18. The over-all dimensions are $10\frac{1}{4}$ by $10\frac{3}{4}$ by $9\frac{3}{4}$ inches high, and its weight is about 20 pounds.

92. Component parts.—Four *coils* are provided, numbered 1 to 4, which are stored away in the cover of the case under a clamp which also holds the galvanometer in place. Each coil is provided with a special plug to which the coil terminals are connected. A coil is connected into a circuit by plugging it into the jack in the upper right corner of the panel and pressing it down until it is seated. This automatically sets a pointer to read on a scale of wave lengths at the condenser corresponding to the coil in use, as follows: (1) 60 to 200 meters; (2) 150 to 480 meters; (3) 400 to 1,300 meters; and (4) 1,000 to 3,200 meters.

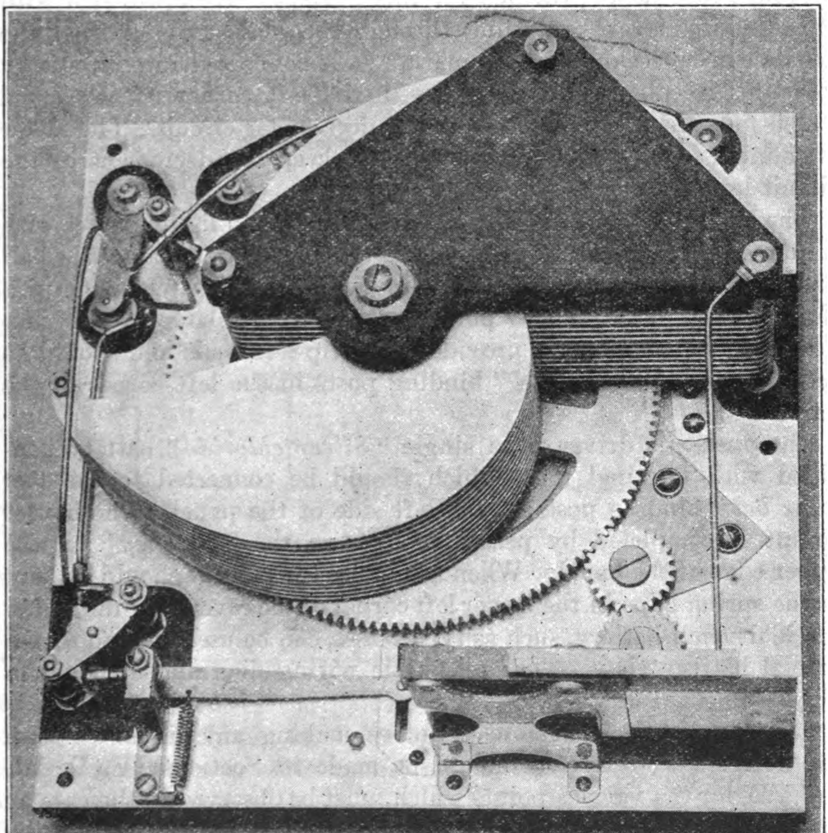

FIG. 18.

The *condenser* is a variable air condenser with specially shaped fixed and moving plates. The moving plates can be clamped by turning the "Lock" switch on the left edge of the panel so that the arrow points in toward the meter, and should always be *so clamped* for transportation. The rotation of the plates is geared down so as to be able to get a fine adjustment and for this reason the condenser handle is off center and in the lower right-hand corner of the panel. The moving plates are grounded on the metal lining of the condenser compartment. The condenser handle carries the scale of decrements, 0.00 to 0.30; and the condenser shaft carries the four wave-length scales and a depressed scale of degrees which can be read through a slot near the top of the panel. There is a small fixed air condenser in parallel with the variable condenser.

Resonance may be indicated either by (1) a thermo-galvanometer or (2) crystal detector and telephones. The *galvanometer* is stored away on the cover of the case in the center of the coils by inserting its plugs into jacks provided for this purpose. It is provided with an adjusting screw extending through the glass cover so that the needle can be set on the zero mark. It is connected into circuit by inserting its plugs into the jacks in the left corner of the panel which puts the meter in series in the decremeter circuit. The meter is shunted by a low resistance so as to keep the decrement of the circuit low.

The *crystal detector* is galena (lead sulphide) in light contact with a fine wire, the pressure of which is adjustable by means of a ball and socket joint. It is connected in series with the telephone in a shunt circuit between two points on the fixed plates of the condenser. The *telephone* is provided with tip terminals and should be connected to the two "*Tel*" binding posts in the left corner of the panel.

The *buzzer* is driven by a single "*Silver chloride*" battery provided with terminal lugs, which should be connected to the two "*buz bat*" binding posts on the left side of the panel. The buzzer circuit is completed by pressing down on the "*buz key*" on the upper edge of the panel. When not in use the battery should be kept in the spring clips in the upper left corner of the cover. If desired, a single dry-cell battery, such as type BA-4, can be used instead of the special batterv above. The schematic wiring diagram is shown in Figure 19.

93. General instructions.—Before making any measures with the decremeter, reference should be made to Sections IV, V, VI, and VII for the various points which must be observed in the care of the meter and its use at a transmitter and at a receiver. When the meter is not in use, or is to be stored away, or made ready for transportation, the following component parts should be secured in their proper places in the cover: Galvanometer, four coils, battery, telephone, and instruction sheets. The condenser plates should be clamped in place by turning the "Lock" switch so that its arrow points toward the center of the meter.

94. Measuring an unknown wave length at a transmitter.—Connect the coil into circuit which includes within its range the wave length to be measured; unclamp the condenser plates; open-circuit the detector; disconnect the telephone; open the buzzer switch; and connect the galvanometer into circuit. Make no other connection to the decremeter. Loosely couple the decremeter coil with the *antenna coil* of the transmitter and turn the condenser handle of the decremeter slowly over its scale until a maximum reading is indicated on the galvanometer, thus indicating that the decremeter is in resonance with the transmitter. Read the wave length in meters on the scale corresponding to the coil in use.

If a crystal detector is to be used at a *damped wave* (*spark*) transmitter, the following directions are to be followed: Connect the coil into circuit which includes within its range the wave length to be

SCHEMATIC DIAGRAM FOR DECREMETER TYPE SCR-87

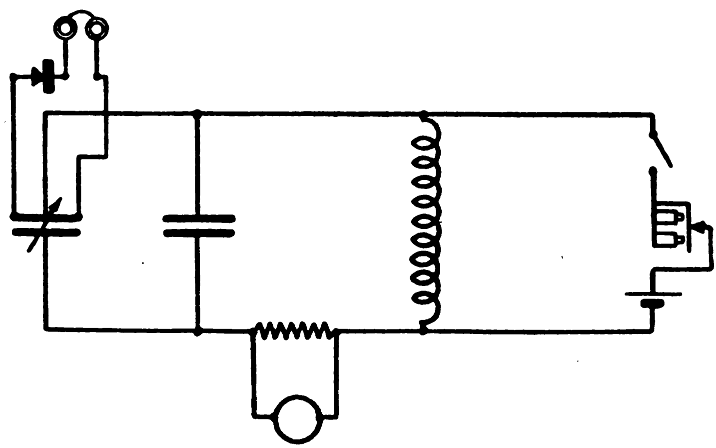

FIG. 19.

measured; disconnect the galvanometer; open the buzzer switch; connect the telephones to the two "Tel" binding posts in the left corner; and make no other connections to the meter. Loosely couple the decremeter coil with the antenna coil and adjust the detector. Turn the condenser handle of the decremeter slowly over its scale until the loudest signals are heard, etc.

95. Setting a transmitter at a predetermined wave length.—Connect the coil into circuit which includes within its range the predetermined wave length; set the condenser on the wave length; open the buzzer switch; connect in the galvanometer or the detector and telephones; and do not change the decremeter adjustments thereafter. Loosely couple the decremeter coil with the *antenna coil* and tune the transmitter to the decremeter until the galvanometer or telephone shows by its maximum response that the two circuits are in resonance at the predetermined wave length. At a *spark* transmitter, it may be more convenient to tune the wavemeter to the transmitter, as described in paragraph 22.

96. Calibrating a transmitter.—The procedure is the same as in the previous paragraph, except that the transmitter is set in succession at a series of predetermined wave lengths, etc., as described in paragraphs 19 and 20.

97. Measuring an unknown wave length at a receiver.—Connect the coil into circuit which includes within its range the wave length to be measured; disconnect the telephones; open-circuit the detector; connect the battery into circuit; and close the buzzer switch. Loosely couple the decremeter coil with the proper receiving circuit coil, as described in paragraph 24. Turn the condenser handle of the decremeter slowly over its scale until the loudest signals are heard in the telephones of the receiving set, thus indicating that the receiving circuits are in resonance with the decremeter at the unknown wave length. Read the wave length in meters on the scale in use.

98. Setting a receiver at a predetermined wave length.—Connect the coil into circuit which includes within its range the predetermined wave length; set the condenser on the wave length; disconnect the telephones; open-circuit the detector; close the buzzer switch, and do not change the decremeter adjustment thereafter. Loosely couple the decremeter coil with the proper receiving circuit coil, as described in paragraph 24; and tune the receiver circuits to the decremeter as though it were a distant station, until the telephones of the receiver indicate by the loudest signals that the circuits are in resonance with the decremeter at the predetermined wave length.

99. Calibrating a receiver.—The procedure is the same as in the previous paragraph except that the decremeter is set in succession at a series of predetermined wave lengths, etc., as described in paragraph 27.

100. Measuring decrement at a transmitter.—Connect the coil into circuit whose range includes the wave length at which the decrement is to be measured; open-circuit the detector and the buzzer; disconnect the telephones; put the galvanometer into circuit; and make no other connections to the meter. Adjust the galvanometer needle to zero by means of the small screw extending through the glass cover. This must be carefully done as the measures of the decrement depend in part at least on the correctness of this adjustment. Loosely couple the meter coil with the *antenna coil* of the transmitter; tune the meter to resonance with the transmitter, in which case the deflection of the galvanometer should preferably be about full scale and not less than half scale. If the transmitter is of low power it is best to work with not more than half scale deflection at resonance in order to be certain that the coupling is loose.

As soon as these approximate adjustments have been made, the meter should be firmly put in place on some stand and the coupling varied slightly by turning the meter coil until at resonance the needle of the galvanometer is on some convenient scale marking as full scale or half scale. In any case, it is preferable that this reading be on an even scale division so that the half scale deflection can be quickly and easily obtained. After these two adjustments have been made, *neither the position of the meter nor the coupling should be changed.* Having noted the galvanometer deflection at resonance, turn the condenser knob in the right-hand corner so that the wave length is decreased and until the galvanometer deflection is reduced to one-half the value at resonance. Keeping the condenser knob fixed, turn the ring outside the decrement scale by means of the pin until either of the two index marks rests on the zero mark of the decremeter scale. Keeping the ring fixed, turn the condenser knob back toward resonance and continue on the other side of resonance until the galvanometer reading is again one-half the value at resonance. Read the value on the decremeter scale opposite the same index mark of the ring. This gives one value of $\delta_1+\delta_2$ A second value of $\delta_1+\delta_2$ should be obtained as follows: Set the meter at resonance as before, and noting the scale deflection turn the condenser knob so that the wave length is increased and until the galvanometer deflection is reduced to one-half the value at resonance. As in the previous case, keep the condenser knob fixed; turn the ring by means of the pin until either of its index marks rests on the zero mark of the decremeter scale. Keeping the ring fixed, turn the knob back toward resonance and continue on the other side of resonance until the galvanometer reading is again one-half the value of resonance. Read the value on the decremeter scale opposite the index mark of the ring. This gives a second value of $\delta_1+\delta_2$. Take the average of the two measures of $\delta_1+\delta_2$; subtract the value of δ_1 for the given coil, which gives the decrement, δ_2, of the transmitter at the given wave length.

Detailed instruction sheets are provided with each decremeter which give additional information, calibration curves, decrements of each coil, etc.

Measures of decrement are of value only when a single wave length or "hump" is noted in tuning. The meter can not be correctly used when two waves or "humps" are observed.

Section XVI.

PARTS LISTS OF SETS.

101. Wavemeter, type SCR-60-C.—This comprises:

Battery, type BA-4 (1).
Crystal, type DC-1 (1).
Set box, type BC-50 (1).

102. Wavemeter, type SCR-61.—This comprises:

Battery, type BA-4 (1).
Coil, type C-13 (1).
Coil, type C-14 (1).
Coil, type C-15 (1).
Crystal, type DC-1 (1).
Head set, type P-11 (1).
Set box, type BC-37 (1).
Strap, type ST-5 (1).

103. Wavemeter, type SCR-95.—This comprises:

Battery, type BA-4 (1).
Lamp, type LM-4 (1).
Set box, type BC-40 (1).

104. Wavemeter, type SCR-111.—This comprises:

Battery, type BA-4 (1).
Lamp, type LM-4 (1).
Set box, type BC-49 (1).

105. Wavemeter, type SCR-125.—This comprises the wavemeter set box and the following:

Battery, type BA-4 (1).
Lamp, type LM-4 (2); 1 in use, 1 spare.

106. Wavemeter, type SCR-125-A.—This comprises the wavemeter set box and the following:

Battery, type BA-4 (1).
Lamp, type LM-4 (2); 1 in use, 1 spare.

107. Wavemeter, type SCR-128.—This comprises the wavemeter set box and the following:

Battery, type BA-4 (1).
Lamp, type LM-4 (2); 1 in use, 1 spare.

108. Wavemeter, type SCR–137.—This is self-contained in its box and has no spares nor accessories.

109. Decremeter, type SCR–87.—This is self-contained in its case and cover. The following detachable parts are carried in the cover:

Set of 4 coils (1).
Thermo-galvanometer, Weston (1).
Battery, silver chloride, with clips (1).
Instruction leaflet (1).
Head set, single (1).

SIGNAL CORPS PAMPHLETS.

[Corrected to February, 1922.]

RADIO COMMUNICATION PAMPHLETS.

[Formerly designated Radio Pamphlets.]

No.

1. Elementary Principles of Radio Telegraphy and Telephony (edition of 4–28–21). W. D. D. 1064.
2. Antenna Systems.
3. Radio Receiving Sets (SCR–54 and SCR–54–A) and Vacuum Tube Detector Equipment (Type DT–3–A).
5. Airplane Radio Telegraph Transmitting Sets (Types SCR–65 and 65–A).
9. Amplifiers and Heterodynes. W. D. D. 1092.
11. Radio Telegraph Transmitting Sets (SCR–74; SCR–74–A).
13. Airplane Radio Telegraph Transmitting Set (Type SCR–73).
14. Radio Telegraph Transmitting Set (Type SCR–69).
17. Sets U. W. Radio Telegraph (Types SCR–79–A and SCR–99). W. D. D. 1084.
20. Airplane Radio Telephone Sets (Types SCR–68; SCR–68–A; SCR–114; SCR–116; SCR–59; SCR–59–A; SCR–75; SCR–115).
22. Ground Radio Telephone Sets (Types SCR–67; SCR–67–A). W. D. D. 1091.
23. U. W. Airplane Radio Telegraph Set (Type SCR–80).
24. Tank Radio Telegraph Set (Type SCR–78–A).
25. Set, Radio Telegraph (Type SCR–105). W. D. D. 1077.
26. Sets, U. W. Radio Telegraph (Types SCR–127 and SCR–130) (edition of Nov., 1921). W. D. D. 1056.
28. Wavemeters and Decremeters. W. D. D. 1094.
30. The Radio Mechanic and the Airplane.
40. The Principles Underlying Radio Communication (edition of May, 1921). W. D. D. 1069.

WIRE COMMUNICATION PAMPHLETS.

[Formerly designated Electrical Engineering Pamphlets.]

1. The Buzzerphone (Type EE–1).
2. Monocord Switchboards of Units (Type EE–2 and EE–2–A) and Monocord Switchboard Operator's Set (Type EE–64). W. D. D. 1081.
3. Field Telephones (Types EE–3; EE–4; EE–5).
4. Laying Cable in the Forward Area (formerly designated Training Pamphlet No. 3).
6. Trench Line Construction (formerly designated Training Pamphlet No. 6–a).
7. Signal Corps Universal Test Set (Type EE–65) (edition of Dec., 1921). W. D. D. 1020.
10. Wire Axis Installation and Maintenance within the Division. W. D. D. 1068.

TRAINING PAMPHLETS.

No.
1. Elementary Electricity (edition of Jan. 1, 1921). W. D. D. 1055.
4. Visual Signaling.
5. The Homing Pigeon, Care and Training. W. D. D. 1000.
7. Primary Batteries (formerly designated Radio Pamphlet No. 7).
8. Storage Batteries (formerly designated Radio Pamphlet No. 8).

FIELD PAMPHLETS.

1. Directions for Using the 24–CM Signal Lamp (Type EE–7).
2. Directions for Using the 14–CM Signal Lamp (Type EE–6).

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