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TESTS OF RADIO RECEIVING SETS, II.
(Crystal Detector)

Contents

Note:- This paper and the tests described herein are the result of work done in the Radio Laboratory of the Bureau of Standards by J.L.Preston, Physicist, H.J.Walls, Assistant Electrical Engineer, Bureau of Standards, and H.F.Harmon, Radio Laboratory Assistant, U.S.Department of Agriculture. Acknowledgment is due Mr. L. C. F. Horle for assistance in the development of the methods used in these tests.

1. Purpose of Investigation.

The rapid increase in the use of radio telephony for the broadcasting of entertainment, lectures, market reports, and other material has resulted in the manufacture of a considerable number of types of radio receiving sets and the sale of many thousand such sets. The purchaser who has a desire to make use of the service which can be brought to him by radio broadcasting, but who has not the technical knowledge to make wise selection of his apparatus has been almost entirely without information as to the characteristics which determine the usefulness of a radio receiving set and the way in which these characteristics are expressed.

The Bureau of Agricultural Economics of the Department of Agriculture requested the assistance of the Bureau of Standards of the Department of Commerce on this problem, in connection with the reception of crop, market and weather reports which that Department is sending out through radio stations of the Post Office and Navy Departments and through public and private broadcasting stations.*

*For information as to schedules of transmission of Government reports by radio, reference should be made to the Radio Service Bulletin, a monthly publication of the Radio Inspection Service, Bureau of Navigation, Department of Commerce. This publication may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D.C., for 25 cents per year.

This paper covers part of an investigation of the characteristics and performance of radio receiving sets, which has been under way at the Bureau of Standards for a number of months. All the receiving sets on which tests are herein described use crystal detectors and are believed to be typical of the principal sets of that type which were on the market in May to July, 1922.

In order to make comprehensive tests of radio receiving sets it has been necessary to develop methods of measurement and to formulate statements of the features which should be described as a result of an inspection of the mechanical and electrical design of the apparatus. In developing the methods to be followed and in reporting on the receiving sets tested, it has been the aim to determine the degree in which a set has such desirable features as sensitivity, selectivity, convenience of operation, substantial construction, and effectiveness in covering the particular range of frequencies (wave lengths) which it is desired to receive.

It is not usually possible to secure the maximum of all desirable characteristics in a single piece of apparatus. For example, in order to secure the greatest possible selectivity it may be necessary to use a set which sacrifices some other

desirable features. Commercial questions such as cost are also involved in the selection of apparatus for purchase.

No consideration has been given to the possible existence of any patents which might cover devices or circuits used in any of the apparatus described. The Bureau of Standards can not give authoritative information concerning the patent situation with respect to a particular device.

The particular receiving sets studied are referred to by arbitrary reference numbers rather than by a statement of the manufacturers' names and type or model numbers. It is believed that the methods followed and the examples given in this report on the nine receiving sets included in this part of the investigation will be of assistance to manufacturers in the development of methods of testing and describing their own products and thus improving them. It is believed that purchasers will also be directly aided in deciding what features and characteristics to look for in the selection of apparatus.

It is appreciated that much remains to be done in the improvement of these new methods, and this report and others on receiving sets of other types included in this general investigation are published with the expectation that they will be of assistance in the establishment of standard specifications and testing methods by the radio industry as a whole.

To the various manufacturers and individuals who have helped in this work through furnishing sets for test and in other ways, the Bureau expresses its thanks. Particular acknowledgment is due the Bureau of Agricultural Economics of the Department of Agriculture, which loaned assistants to carry on the laboratory work and cooperated in many other ways.

<u>Receiving Sets Included in this Report</u>.- Nine receiving sets were included in the tests described in this report. These were made by nine different manufacturers. For convenience in reference the following arbitrary numbers are used in designating them.

1922-N	1922-S
1922-O	1922-T
1922-P	1922-U
1922-Q	1922-V
1922-R	

The circuit diagrams and other data on the sets are given below.

3. Outline of Tests Performed.

After a preliminary performance test, to determine whether the receiving set, as received, is in proper operating condition, the following examinations and tests are made:

a. Circuit diagrams.- If diagrams have been submitted by the manufacturer, these are checked. When none are supplied, diagrams are made from the receiving set.

b. Circuit and panel arrangements.- Inspection of the exterior arrangements of the receiving set and circuit is made.

c. Structural details.- The receiving set is examined for ruggedness, quality of material, quality of component parts, and quality of workmanship.

In doing this, the device is given a very close inspection to determine the absolute and relative grades of materials from the mechanical viewpoint, with particular reference to the materials under mechanical strain, the materials and parts which are likely to change because of the effects of moisture and mechanical shock and those which are likely to wear in use.

d. Electrical inspection.- The receiving set is examined to determine the qualities of its component materials from the electrical viewpoint, the care taken in working up these materials into component parts, and their disposition relative to one another. This inspection is made with special attention to the materials that constitute the high-voltage parts of the circuit, those which are under dielectric strain, and the protection of these parts from the effect of time and moisture.

e. Wave frequency (wave length) ranges.- The receiving sets are calibrated when connected to an antenna having constants which are known and are approximately those met with in use. This wave frequency calibration allows the total wave frequency (wave length) range to be determined and also gives approximate data as to the settings of the variable controls for any wave frequency within the range of the set.

f. Vibration test.- This test is designed to obtain information as to mechanical strength and ability to withstand shock in transportation. This information is obtained by fixing the receiving set on a vibrating machine which subjects it to shock and vibration simulating the shocks of transportation. After being subjected to this shaking and vibration for a short time the receiving set is taken from the vibrating machine and carefully inspected as to mechanical condition. This test indicates what weakness, if any, may be expected to develop in transportation or rough usage of the receiving set.

g. Selectivity.- This test is the determination of the ability of the receiving set to differentiate between signals of different frequencies.

h. Sensitivity.- This test is the determination of the magnitude of the response in the telephone receivers of the receiving set for a given voltage applied to the antenna.

i. Notes on operation.- The receiving sets are connected to an antenna of measured constants and put into operation as specified by the manufacturer. The ease of operation, the precision and permanence of adjustment are noted.

3. Manufacturers' Specifications of Antenna, Frequency Range, Detector, and Telephone Receivers.

Receiving Set No. 1922-N.
Antenna specified, single wire, 100 to 150 feet long and 30 to 50 feet high.
Wave frequency (wave length) range stated, 1714 to 445 kilocycles per second (175 to 675 meters).
Galena crystal detector furnished.
Telephone receivers not specified.

Receiving Set No. 1922-O.
Antenna specified, single No. 14 copper wire, 100 to 200 feet long and 30 feet high, - or two wires 60 to 150 feet long and 30 feet high.
Wave frequency (wave length) range stated, 1500 to 100 kilocycles per second (200 to 3000 meters).
Galena drystal detector furnished.
Telephone receivers, -, 3000 ohms resistance, specified.

Receiving Set No. 1922-P.
Antenna specified, single No. 14 copper wire, 100 feet long and 30 feet high.
Wave frequency (wave length) range not stated.
Galena crystal detector furnished.
Telephone receivers, -, 2000 ohms, specified.

Receiving Set No. 1922-Q.
Antenna specified, single wire 100 feet long and 30 feet high.
Wave frequency (wave length) range stated, 2000 to 462 kilocycles per second (150 to 650 meters).
Galena crystal detector furnished.
Telephone receivers, -, 2200 ohms resistance, furnished.

Receiving Set No. 1922-R.
Antenna specified, two wires 70 feet long, spaced two feet apart, and as high as possible.
Wave frequency (wave length) range stated, 1666 to 155 kilocycles per second (180 to 2600 meters).

Galena crystal detector furnished.
Telephone receivers, -, 1000 ohms resistance, furnished.

Receiving Set No. 1922-S.
Antenna specified, one wire 75 to 150 feet between insulators and 25 feet above the ground.
Wave frequency (wave length) ranges stated, 1666 to 750 and 1000 to 429 kilocycles per second (180 to 400 and 300 to 700 meters).
Crystal combination detector furnished.
Telephone receivers, -, 8000 ohms resistance, furnished.

Receiving Set No. 1922-T.
Antenna not specified.
Wave frequency (wave length) range not stated.
Galena detector furnished.
Telephone receivers not specified.

Receiving Set No. 1922-U.
Antenna, single No. 14 copper wire, 100 feet long and 30 feet high.
Wave frequency (wave length) ranges stated, 1500 to 858 and 1000 to 600 kilocycles per second (200 to 350 and 300 to 500 meters).
Crystal combination detector furnished.
Telephone receivers, -, 3000 ohms resistance, furnished.

Receiving Set No. 1922-V.
Antenna, two or four wires, 75 feet long and 20 to 30 feet high.
Wave frequency (wave length) range stated, 1714 to 120 kilocycles per second (175 to 2500 meters).
Galena crystal detector furnished.
Telephone receivers, -, 3000 ohms resistance, specified.

4. Circuit Diagrams.

The circuit diagrams of the nine receiving sets included in this test are given in Figs. 1 to 9 inclusive.

5. Circuit and Panel Arrangements.

The several receiving sets covered by this report differ widely in the arrangement of controls, types of circuits used, method of mounting parts, etc. These characteristics are discussed briefly below.

Receiving Set No. 1922-N.
This receiving set is of the single-circuit type, consisting of a continuously variable inductor, and a fixed condenser. All component parts are mounted on two parallel black laminated phenolic panels, 5 x 5 inches, which in turn are secured into a mahogany finished cabinet 4 3/4 x 4 3/4 x 5 11/16 inches. The panel is of a dull finish.

Controls are provided on the panel for the variation of the continuously variable inductor and the adjustment of the crystal detector stand. The variable inductor is controlled by a knob secured to a black metal dial.

All exposed metal parts such as binding posts, detector, etc., except the control dial, are finished in bright nickel. The binding posts are all back-mounted on a black laminated phenolic panel. Engravings, filled with white, indicate connections to antenna (A), ground (G), telephone receiver (tel.), load and secondary (sec.).

Receiving Set No. 1922-O.

This receiving set is of the single-circuit type, consisting of a continuously variable condenser, tapped inductor, circuit change switch and crystal detector stand, and is supplied with a buzzer and buzzer control switch. All parts are mounted on a highly polished black laminated phenolic panel, 7 x 7 inches, which in turn is set into a polished cabinet 7 3/4 x 7 3/4 x 4 $\frac{1}{4}$ inches. A cover fits over the top of the operating panel and provides space for the telephone receivers. The cover is supplied with a conveniently located carrying strap.

All connectionsterminals are mounted on the panel as are the controls for the continuously variable condenser, for the variation of inductance by a tap switch and for the change of the variable condenser from series to parallel connection.

All exposed metal parts as binding posts, detector control stand, switches, and taps, are finished in polished nickel. Labellings stamped into the panel indicate connections to antenna, ground and telephone receivers, and the two connections of the condenser controlled by the series-parallel switch.

Receiving Set No. 1922-P.

This receiving set is of the single-circuit type, consisting of a single continuously variable inductor and a crystal detector. All component parts are mounted on a soft black wooden panel, 9 x 4$\frac{1}{2}$ inches, which in turn is secured into a soft wood cabinet, 9$\frac{1}{2}$ x 9 3/4 x 5 inches. A cover is supplied for the protection of the controls in transportation.

Controls are provided on the panel for the variation of the antenna inductance, crystal detector coupling, and crystal detector adjustment.

All exposed metal parts, as detector control stand, inductor pointers, and scales are of polished nickel. The control knobs and binding posts are of the moulded phenolic type insulating material. The panel carries no markings to indicate the functions of the terminals or controls.

Receiving Set No. 1922-Q.

This receiving set is of the single-circuit type, consisting of a fixed condenser, a single continuously variable inductor, and crystal detector. All component parts of this receiving set are mounted on a highly polished black laminated phenolic panel, $4\frac{1}{4}$ x 7 inches. The overall dimensions of the set are 8 x $6\frac{1}{2}$ x $6\frac{1}{2}$ inches. This receiving set is contained in a metal cabinet which supports the main operating panel and encloses all parts but the detector and terminals. This cabinet is made of heavy brass stampings welded together.

The inductor controls are mounted on the vertical sides of the metal cabinet and consist of levers operating sliding contacts over the inductor turns. These polished nickel plated levers pass over silver enamel scales carried on the sides of the cabinet and are provided with insulating handles for their operation.

All exposed metal parts such as the crystal detector stand and control levers are finished in polished nickel while the case is finished in dull black enamel. No labellings are provided at the terminals but the case carries labels indicating the function of the control levers.

Receiving Set No. 1922-R.

This receiving set is of the single-circuit type, consisting of a variable inductance and crystal detector. All component parts are mounted on a black fiber panel, 3 7/8 x 3 7/8 inches, which in turn is secured into a mission finish oak cabinet, 3 3/4 x $4\frac{1}{4}\frac{1}{8}$x $4\frac{1}{4}$ inches. The panel is of indifferent finish and carries control for the variation of a tapped inductor and the adjustment of the crystal detector stand.

The value of inductance is controlled by a switch and taps. All exposed metal parts, as binding posts, taps, levers, and crystal detector stand are finished in nickel. The binding posts are of metal throughout and are mounted on the operating panel. Stamped engravings, filled with white, indicate connections to antenna, (A), ground (G), and telephone receivers (T).

Receiving Set No. 1922-S.

This receiving set is of the single-circuit type, consisting of a variable inductor, a fixed condenser which may be connected in series with the antenna for short waves, a detector stand, and another fixed condenser shunted across the telephone receivers. All parts are mounted on a laminated phenolic panel $5\frac{1}{2}$ x 9 3/8 inches. The panel is supported by a stamped steel case.

A control is provided on the front of the panel for the variation of inductance of the antenna inductor. This is accomplished by changing the position of a copper disk, the plane of which is perpendicular to the axis of this inductor. The change in inductance is brought about by the reaction of the field produced by the eddy currents in the copper disk, on the

field produced by the inductor. The crystal detector and necessary binding posts are also mounted on the front of the panel.

All metal parts on the front of the panel are finished in unpolished nickel. The knob for controlling the antenna inductor is of moulded composition. A pointer attached to the knob moves over a scale stamped on the panel. The functions of all the terminals are also stamped on the panel.

Receiving Set No. 1922-T.

This receiving set is of the single-circuit type consisting of variable inductor and crystal detector. All component parts are mounted on a black laminated phenolic panel, 5 x 5 inches, which in turn is secured into a soft wood cabinet, 5 5/8 x 5 5/8 x 5$\frac{1}{4}$ inches. The panel is of dull finish.

Controls are provided on the panel for the variation of the inductor and of the connection to the crystal detector circuit, and for the adjustment of the crystal detector. The inductance and coupling control levers are supplied with insulating knobs. No provision is made for noting for record the positions of the control levers.

All exposed metal parts such as binding posts and detector stand, are finished in rather poorly polished nickel-plated brass. The binding posts are mounted on the operating panel; no labels are provided to indicate the functions of the controls or terminals.

Receiving Set No. 1922-U.
This receiving set is of single-circuit type, consisting of a continuously variable inductor and fixed condensers. All component parts are mounted on a soft wood panel, 4 5/8 x 6$\frac{1}{2}$ inches, which is in turn secured into a soft wood cabinet having the overall dimensions of 8 $\frac{1}{2}$ x 7 $\frac{1}{4}$ x 6 3/4 inches in size. A cover makes up the top of this cabinet, protecting the controls when in transportation. The wooden panel is finished in dull black stain.

Controls are provided on the operating panel for the variation of the continuously variable inductor and the adjustment of the crystal detector stand. The variable inductor is controlled by a metal lever containing an insulating arm, and rotating over a dull finish nickel plated metal dial.

All exposed metal parts as binding posts, lever arms, scales and detector stand are finished in nickel plated brass. The binding posts are mounted on the top of the operating panel. There are no engravings to indicate the use of the different controls, although there is a complete direction sheet of operation pasted on the inside of the cover of the cabinet.

Receiving Set No. 1922-V.

This receiving set is of the single-circuit type, consisting of three lattice wound or basket wound inductors, a variable condenser and a crystal detector. All component parts are mounted on a fiber panel $8\frac{1}{2} \times 7\frac{1}{2}$ inches, which is in turn secured into a soft wood cabinet having the overall dimensions of $8\frac{1}{2} \times 7\frac{1}{2} \times 4\frac{1}{2}$ inches. The operating panel is of dull grained finish.

Controls are provided on the operating panel for the variation of the continuously variable condenser, the variation of the inductor by three steps, and the adjustment of the crystal detector stand.

All exposed metal parts are finished in dull nickel plating. The binding posts which are mounted on front of the operating panel are of composition type. Stampings filled with white indicate the connections for antenna (A), ground (E), inductance step increasing 1 to 3, and telephones (Tel).

8. Structural Details.

Receiving Set No. 1922-N.

The dielectric materials of this receiving set are of several types. The panels are constructed of a laminated phenolic type of insulation. The inductor forms are of fibre and the condenser dielectrics are of mica and paraffin paper.

The condensers are of a fixed capacity and in the case of the antenna condenser are of mica and metal pressed tightly together. The heavy copper compression plates give sturdy construction.

The inductor, of the so-called "variometer" type, is wound with solid copper wire which is supported by thin fibre forms having sufficient mechanical strength as long as these supports are in a dry state. The design and construction of the stator and rotor is of a type giving light weight and high mechanical strength. Most of the metal structure is of aluminum. The electrical connections and contacts are made of heavy flexible brass strips. The assembly is carefully and neatly carried out.

The crystal detector stand is built up on two plugs fitting into sockets in the operating panel. The construction is sturdy and well assembled. The small machine screws which hold the detector crystal in a metal cap are of such small size that it is difficult to obtain a screw driver which will fit into their heads.

The cabinet is constructed of Baywood solidly joined together giving sturdy construction.

The component parts of this receiving set are well fitted together. Generous large nuts and screws are provided, some of which are soldered to the connecting wires or studs. Rather heavy solid copper wire, insulated with cambric tubing, serve for interconnections. Most of the electrical connections are well soldered.

Receiving Set No. 1922-O.

Several different dielectric materials are used in this receiving set The panel and inductor form are built up of a laminated phenolic type of insulation. The variable condenser end plates are of moulded shellac composition, and the knobs and dial of moulded phenolic type of insulation. Paraffin paper is used as the telephone condenser dielectric. The continuously variable antenna condenser is constructed of thin zinc plates imbedded in lead supporting columns. The rotating plate system is supported between composition end plates. Contact to the moving plate system is made through a brass spring which presses against the moving plate system and supplies both contact and friction to prevent accidental rotation. The telephone condenser is made of paraffined paper and tinfoil and is only partially compressed, but it is substantially supported between two brass connections.

The inductor is wound with silk insulated solid copper wire. The design and construction of the taps, winding, and supports of this inductor is most substantial. The electrical connection to the different terminals on the inductor is made by a switch arm moving over taps. The switch arm carries a can switch which, on short waves, disconnects a section of the inductor. A two-blade, four point switch allows of the connection of the condenser either in series or in parallel with the inductor.

The detector "cat whisker" control lever is substantially made and well designed to give three-way movements without mechanical difficulty. A small switch, dry cell, and test buzzer are compactly arranged so that sensitiveness of the crystal detector may be tested. The small dry cell can be quickly removed and another substituted. The buzzer is accessible and easily adjusted.

The cabinet is substantially made of soft wood and constructed to withstand rough usage.

All electrical connections are made by heavy copper or brass strips and wire insulated by means of cambric tubing.

Receiving Set No. 1922-P.

The dielectric materials of this receiving set are several. The operating panel is of stained soft wood. The binding posts and control knobs are of the moulded phenolic

type of insulation and the inductor form of the laminated phenolic type of insulation. The telephone condenser dielectric is composed of sheet mica while the plates are of thin copper. This condenser unit, being of the fixed type, is under heavy compression between the two metal supporting plates.

The inductor is wound with about No.20 B & S gage solid enameled copper wire. Contact is made to the various turns by a ball point at the end of a lever arm. The control knob pointer and arm carrying the contact are of unit type, strongly made.

The detector control stand which is directly mounted on the operating panel is composed of two members, one containing the crystal imbedded in Wood's metal and the other providing for a three-way movement of the cat whisker control lever. This lever with the detector crystal is surrounded by a glass cylinder which serves to protect the crystal from moisture and dirt. The glass cylinder is, however, only insecurely held in position and interferes, because of the light reflected from its surface, with the easy observation of the detector adjustment.

The inductor, fixed condenser, and control levers are separately secured to the panel and electrically connected by means of heavily tinned copper wire. Most of the electrical connections are rather roughly soldered to washers or connecting lugs and most of the mechanical connections are provided with lock nuts and are soldered for safety. The assembly of the component parts is carefully and neatly carried out.

Receiving Set No. 1922-Q.

Several different dielectric materials are used in this receiving set. The operating panel is of the laminated phenolic type of insulating material, the binding posts and control lever knobs of the moulded phenolic type of insulating material and the inductor form of cardboard tubing, heavily impregnated with varnish. The dielectric material of the fixed antenna condenser is mica while that of the telephone condenser is paraffined paper. The antenna condenser is highly compressed by two brass compression plates and supported by inductor supporting members. The telephone condenser is composed of tinfoil between paraffin paper rather loosely wrapped around a fibre strip.

The inductor is wound with heavy cotton covered copper wire and is thoroughly impregnated with varnish. The inductor form is rigidly supported by four heavy brass supports. Electrical contact is made to the turns of the inductor by two long spring phosphor bronze levers fashioned so that one end is pivoted in a large bearing block while the other moves over a path on the inductor which has been scraped free from insulation. Special means are provided for securing the

contact arms at the pivoted end so that good contact is made without the possibility of binding or the loosening of the fastening screws.

The crystal detector stand is constructed of heavy brass strip in the form of an arch. The central portion of the arch carries a ball and socket joint thus affording easy adjustment of the detector. Through the center of the ball passes the crystal contact or arm which carries the cat whisker. The friction on the ball and socket joint can be changed to suit the personal desire of the operator by means of a flat friction spring. The cat whisker of coiled phosphor bronze wire is held in the contact arm by a small screw chuck. An insulating handle provides for the easy manual adjustment of the detector. The crystal, imbedded in the Wood's metal, is securely held in a spring cup centrally located beneath the contact arm. The mechanical operation of the complete unit is excellent.

The cabinet is strongly made of pressed brass sheeting. All mechanical joints are welded giving very sturdy construction. The enameling of the cabinet is of a heavy baked type giving a hard, dull black finish. Pads are provided at the corners of the bottom of the cabinet for the deadening of any accidental shock communicated to the receiver through the supporting table and for the protection of any surface upon which it may be placed.

All electrical connections are made by bare copper wire securely soldered to connecting lugs.

Receiving Set No. 1922-R.

The dielectric materials of this receiving set are several. The operating panel is of fibre. The inductor form is of unvarnished cardboard tubing and the knobs of moulded composition insulation material. The dielectric of the telephones condenser is waxed paper. This condenser is constructed of tinfoil and waxed paper loosely wrapped around a fibre form.

The inductor is wound with very fine enameled copper wire. Fifteen taps are taken off for connection to the inductor switch. These connections are of fine wire, wholly unprotected, against loosening or breakage from careless handling. The construction of the device is such that it makes necessary the manufacturer's precaution, "not to remove the inductor form from its cabinet without the very great possibility of breaking the connections to the inductor." The inductor form is loosely supported in the cabinet by paper packing. The inductance switch arm contact is not securely fastened to its shaft nor to its knob and tends to become loosened quite readily. The electrical connection to the contact arm shaft is made to the head of the brass machine screw which serves rather unsatisfactorilyyas the shaft, by means of a phosphor bronze spring

very insecurely fastened to the panel.

The detector control stand is composed of two members. One is a cup containing the galena crystal imbedded in Wood's metal and the other is a spring socket holding a ball through which passes the cat whisker control. A rather unsatisfactory means of adjustment is provided by this combination.

The cabinet supporting the operating panel and enclosing the inductor is made of oak finished in dark mission. Dovetailed joints and corner ties in which the panel-securing screws are seated, make the cabinet of rather sturdy construction.

All electrical connections are made with small size bare copper wire soldered directly to the terminal screw heads.

Receiving Set No. 1922-S.

A number of different materials are used for dielectrics in this set. The panel is of laminated phenolic insulation. Mica is used in the fixed condensers for dielectric. The inductor is of pancake form held between layers of cloth impregnated with varnish and is securely fastened to the panel. No. 26 copper wire is used for the inductor and its connections. The remaining connections are of substantial strips. The plates of the condensers are of copper. The complete condenser is encased in metal and securely fastened by soldering the plates to their support. The condensers and high potential connections are covered by a piece of hygroscopic material which appears to be hard fibre.

The detector consists of a crystal resembling zincite in contact with a piece of an alloy of dull appearance. The control is designed so as to give one crystal a three-way movement.

The panel is secured to the case by four projecting lugs that fit into four slots in the case. The case is of stamped steel and is enameled.

Receiving Set No. 1922-T.

The dielectric materials of this receiving set are several. The operating panel is of the laminated phenolic type of insulating material, the control lever knobs of the moulded phenolic type of insulating material, the inductor form of varnished pasteboard and the telephone condenser dielectric of paraffined paper.

The telephone condenser is constructed of paraffin paper and tinfoil loosely wrapped around a fibre support.

The inductor form, which is securely supported by the

operating panel, is wound with two parallel strands of enameled solid copper wire. No varnish or impregnation is used. Electrical connection to the turns of wire is made by a ball contact at the end of a spring phosphor bronze contact lever. The contact arm is pivoted at the surface of the panel and extends through the panel. The exposed end is equipped with an insulated knob. This moving contact arm is mechanically well built.

The detector control stand is composed of two members supported vertically by the operating panel. One member consists of a brass cup holding with a set-screw the galena crystal imbedded in Wood's metal. The other member contains a spring ball and socket joint. Through the middle of this ball joint, passes the cat whisker control lever. The contact carrying arm is secured in position by the friction between it and the ball and makes adjustment both difficult and insecure. The mechanical construction and adjustment is rather unsatisfactory.

The cabinet is of soft wood securely joined at the corners and is of fairly rugged construction. The panel is fastened to the cabinet by wood screws.

The electrical connections are made by bare heavy copper wire insecurely soldered to heads of machine screws.

Receiving Set No. 1922-U.

Several dielectric materials are used in this receiving set. The operating panel is built up of a stained soft wood, the inductor forms of the laminated phenolic type of insulating material, and the condenser dielectric is of mica and paraffined paper.

The fixed antenna condenser is composed of copper sheet and mica securely compressed by two supporting plates. The telephone condenser is built up in a metal case protecting it from mechanical shock and atmospheric changes.

The inductor of the so-called "variometer" type is wound, with fine cotton covered copper wire on thin laminated phenolic insulating tubes. The cylindrical stator is solidly secured to the operating panel by two wooden blocks. The rotor, also of cylindrical form, is mounted on two shafts, one of which connects the rotor to the control lever and serves for support and electrical connection. The lever arm controlling the movement of the rotor is solidly constructed but so designed that the rotor may easily become loose from it. The rotor is secured to its shaft by means of metal anchors and set screws. No pins or soldering are used to limit the play on these shafts. The electrical connections to the rotor are soldered to the shaft supports.

The crystal detector stand is rather loosely supported on the operating panel. The two members which compose this stand are of very light spring construction. The member containing the crystal imbedded in Wood's metal uses a clamp to hold the crystal. The support of the lever contains a crystal contact member carrying a ball and socket joint through which the contact member passes. The pressure of this member is controlled by a spring and nut. In general, the operation is satisfactory although mechanical movement is rather crudely worked out.

The cabinet is constructed of soft wood. The operating panel is held to the cabinet by small wood screws. The external appearance is rather neat.

The electrical interconnections in this receiving set are made by rather fine solid copper wire covered with cambric tubing. All connections are thoroughly soldered to connecting lugs which in turn are securely fastened to the metal binding posts.

Receiving Set No. 1922-V.

The dielectric materials of this receiving set are several. The operating panel is built up of black grained fibre, the inductor forms are also of fibre and moulded phenolic type of insulation. The variable condenser and supports are of a moulded insulating material. The variable antenna condenser is constructed of zinc plates spaced with brass spacing washers. The rotating plate element contains no balanced structure but is supplied with a friction member. Because of the heavy weight of the zinc plates, and the lack of balancing, the position of the moving plates will be found to be greatly affected by vibration or minor shocks.

The inductors are of the lattice wound or basket wound type using plugs to insert them in their mountings. The mountings are weak in construction and insecure in operation.

The crystal detector stand, which is supported on the operating panel, is made of spring brass material rather poorly nickel plated. The crystal imbedded in Wood's metal is held in the cup by small screws. The cat whisker control is supplied with a ball and socket joint constructed of thin flexible brass strips and a solid brass ball. The cat whisker control lever passes through this ball and carries on one end a bronze coiled spring cat whisker and on the other, an insulating handle. The pressure adjustment of the cat whisker is obtained by a friction fit of the member through the ball joint. The construction in general is rather light.

The cabinet is rather poorly constructed of soft wood covered with a pebbled paper imitation leather. The operating

panel is fastened to the face of this cabinet with wood screws.

All connections are poorly soldered to the heads of machine screws. Moving contacts such as the inductor sockets and inductor change switch are of unsatisfactory construction.

7. Electrical Inspection

Receiving Set No. 1922-N.

The circuit of this receiving set is shown in Fig. 1. It is the single-circuit type having the crystal detector input connected across the inductance. The inductor, of the so-called variometer type, allows continuous variation of inductance. Binding posts are provided for the connection of loading coils and electron tube detector. The windings are of solid copper covered with silk and enameled insulation. The fibre form which supports these windings is to be criticized because of the fact that this highly hygroscopic material is used in the intense dielectric field of the variometers. This is particularly objectionable and will very seriously reduce the electrical effectiveness of this receiving set in damp weather and in humid climates.

The circuit design of this receiver is of such a type that the detector coupling can not be varied to suit the crystal impedance. For this reason, rather poor selectivity and sensitivity are obtained. The crystal detector stand is supported on a fibre insulating strip which is open to the above mentioned criticisms.

Receiving Set No. 1922-O.

The circuit of this receiving set is shown in Fig. 2. It is the single-circuit type having the detector connected permanently across the total circuit inductance. The short-wave connection allows the variable antenna condenser to be used in series with the tapped inductor while the long wave connection throws this variable condenser in parallel with the tapped inductor. An extra binding post allows connection to be made to an electron tube detector.

The material in the condenser end plates is of low grade and contributes toward making the receiving set one of lower selectivity.

The inductor is built up of rather small wire and has, therefore, a comparatively high resistance. The form upon which it is wound is of exceptionally fine dense material.

The crystal detector is of such a type that a most satisfactory freedom of movement in the adjustment of the detector is possible.

This receiving set is to be criticized because of the great values of series capacity, the small size of wire and insulation thickness and the fact that the detector is connected across across the entire tuning inductance. These several factors account for the rather low selectivity of this receiving set.

Receiving Set No. 1922-P.

The circuit of this receiving set is shown in Fig. 3. The detector input and antenna circuit are controlled by separate control knobs. The former allows the application of a variable radio-frequency voltage tube applied to the crystal and thus allows the adjustment of this voltage to suit the crystal and its adjustment. The wooden panel is to be criticized since it carries metals of widely different radio-frequency potentials and results in considerable loss.

There is no antenna series condenser included in the receiving set circuit and for this reason short wave frequencies are not received to advantage. The fixed condenser shunting the telephone receivers is of mica and copper foil substantially constructed and mounted.

The inductor is wound with solid enameled No. 22 copper wire on an excellent insulating tube. The enameled copper wire is open to the criticism of probable high eddy current losses because of the close proximity of adjacent turns. The method of obtaining electrical contact with the inductance is to be criticized because of the poor rubbing contact and the short circuiting of several turns of the inductor. There is a tendency for the metal dust scraped from the thinly insulated wire to fill the interstices between turns and to short-circuit them. These factors along with the lack of series condenser probably explain the fairly low selectivities obtained with this receiving set, particularly at high wave frequencies.

The design of the detector allows of but little variation in the pressure on the crystal and seriously limits the possible sensitivity. The permanency of contact is fair although the mechanical control of the wave change levers may give sufficient vibration to disturb this adjustment.

Receiving Set No. 1922-Q.

The circuit of this receiving set is shown in Fig. 4. The detector input circuit as well as the antenna tuning circuit are controlled by separate levers, both of which are contactors on the inductor. The operating panel, composed of excellent insulating material, allows very little loss between the different binding posts either in the form of dielectric loss or surface leakage.

The fixed antenna condenser included in this receiving set circuit is of excellent electrical design having low losses. The fixed telephone condenser has varnished paper as a dielectric and is loosely assembled. The paper inductor tube is wound with heavy copper wire, size No. 20, and both are heavily varnished to exclude moisture. The diameter of the inductor form is rather small and while this probably results in a higher resistance for a given inductance than if a large form were used the fact that the inductance per turn is less results in finer tuning. The method of making rubbing contact over the individual turns is rather poor since the control lever will at times short-circuit consecutive turns and thereby increase the resistance of the circuit.

The crystal detector stand which is directly mounted on the insulating panel, is so connected into the circuit that low potential points are nearest to the operator, when making its adjustment. The wave frequency control levers are carefully insulated from the circuit thus reducing the detuning effect of the presence of the operators body or hands. For this reason, low capacity effects shown by small changes of wave frequency (wave length) can be expected. The crystal used in the detector is of an extremely finely granular structure and retains its adjustment under rather serious shocks.

The metal cabinet which surrounds the inductor form will be expected to introduce certain losses into the circuit. This has been reduced to some extent by lowering the inductor proper into a rather large air space at the bottom of the cabinet.

Receiving Set No. 1922-R.

The circuit of this receiving set is shown in Fig. 5. The crystal detector input is connected across the total used inductance.

There is no series antenna condenser included in the circuit of this receiving set. The telephone shunting condenser is a paper condenser loosely assembled.

The inductance is wound of No. 30 enameled copper wire on a small unvarnished pasteboard tube. The size of the wire and its insulation probably results in the high resistance which explains, in part at least, the low selectivity of the set. The pasteboard tube, due to its unvarnished condition, is to be criticized as being rather hygroscopic. Since the only control is that of the inductance switch having only fifteen steps the device can only be exactly tuned to this number at wave frequencies. For this reason, it may be expected that no station received can be correctly tuned to unless the receiving set happens to contain the proper amount of inductance and capacity. The result of this is evident in selectivity and performance tests. It is to be noted, however, that since

the resistance of the device is exceptionally high the effect of this extremely limited frequency adjustment is not as bad as might be expected. This, however, is only a result of the generally low sensitivity of the device.

The panel is made of fibre and is to be criticized because it is hygroscopic and because of the very close proximity of the binding posts, detector terminals and switch points. Since these units are closely adjacent to each other on the small operating panel, dielectric losses are undoubtedly high.

The detector control stand is situated in such a position that it makes necessary the contact of the hand with the telephone receiving binding posts.

The soldered joints have been made with acid paste which already indicates corrosion.

Receiving Set No. 1922-S.

The circuit of this receiving set is shown in Fig. 6. It is the usual single-circuit type with a fixed connection to the detector.

Both the series antenna condenser and the telephone condenser are well made and are protected by a metal case.

The inductor is of pancake form and wound with No. 26 silk covered wire. The inductance is varied by the movement of a copper plate whose plane is mounted perpendicular to the axis of the inductor. The flux, produced by the inductor, cuts the copper plate, setting up eddy currents in it. The flux produced by the eddy currents reacts on the original flux, decreases it, thus decreases the inductance. This method is quite effective but the resistance of the circuit is necessarily somewhat increased.

The detector is designed so as to be easily adjustable. It consists of two materials in surface contact with considerable compression. One element resembles zincite, and the other is an alloy of dull appearance.

The condensers and wiring are covered by a piece of insulating hard fibre board which is hygroscopic. This is in contact with parts of the circuit and it is probable that considerable dielectric and conduction losses are present.

Receiving Set No. 1922-T.

The circuit of this receiving set is shown in Fig. 6, and provides variation of the antenna circuit inductance and coupling to the crystal detector circuit. The operating panel is composed of a good insulating material having on it rather widely separated binding posts, detector stand and control levers.

The material and positioning of these can be expected to give rather low losses between different high potential points.

No antenna series condenser is employed in this receiving set circuit. This design gives rather low efficiency on the reception of signals at high wave frequencies (short wave lengths). The telephone shunt condenser is of rather poor design.

The inductance is composed of two parallel strands of No. 20 enameled copper wire wound on a pasteboard tube only partially varnished. The dimensions of the tube are such that each added turn of inductance increases the wave length by rather large increments. At very high frequencies (short waves), this is most noticeable, and results in serious noises as the controls are moved. The design of winding two parallel wires might be expected to lower the effect of short-circuiting adjacent turns of wire. From the operation of the device it can not be said that this method is effective. The use of enameled wire probably results in the higher losses indicated by the low selectivity of the device. The method of making contact to the different turns of inductance seems to be satisfactory as shown in performance tests and selectivity measurements.

The detector control stand is connected into the circuit in such a way that the high potential points are in contact with or adjacent to the operator's hand. This is likely to introduce capacity effects noticeable in a change of signal intensity or wave frequency. The great care of adjustment required to obtain the most sensitive detector adjustment point makes this detector unsatisfactory.

<u>Receiving Set No. 1923-U.</u>

The circuit of this receiving set is shown in Fig. 7. The crystal detector is connected across a fixed inductance.

The series antenna condenser is well built. The telephone shunt condenser is contained in a metal protecting case and is of very commendable construction.

The inductor, of the so-called variometer type, is constructed of No. 28 cotton covered copper wire wound on a form of high grade dielectric material. All electrical connections are made by soldered coiled springs or soldered to leads running to the different parts of the circuit and assures reliable connections of low resistance. The use of a continuously variable inductance can be commended since it allows a very accurate adjustment to the wave frequency desired. The small wire used in winding this inductance results in rather high resistance.

The operating panel is constructed of soft stained wood. Since the different binding posts, detector stand and condensers are directly screwed to this panel, high dielectric and conduction losses are probably present.

The crystal detector is introduced into the circuit in such a way that the high potential point is next to the operator's hand when adjusting the crystal detector contact. The adjustment of this crystal detector is of a rather permanent nature in that materials having large surfaces are under rather heavy compression.

The electrical connections are made by copper wire covered with varnished tubing and all these connections are most satisfactory.

Receiving Set No. 1922-V.

The circuit of this receiving set as shown in Fig. 8 is that of the usual single-circuit type having the crystal detector input tapped across the total inductance in the circuit. The inductors are of the lattice wound or basket wound type with No. 22 cotton covered copper wire wound on fibre forms and supported by a composition plug. The fibre forms and plugs are to be criticized because of the hygroscopic nature of that material.

The variable antenna condenser is to be criticized for its lack of balance and the friction contact to the moving plate system.

The control of the moving contact position and pressure adjustment of the detector is such that a satisfactory adjustment can only be made with difficulty and can not be maintained without frequent readjustment. The detector is so connected to the circuit that the high potential point is next to the operator's hand when making adjustments.

The insulating panel is of fibre and is to be criticized for its hygroscopic nature and the resultant losses between the binding posts and other high potential points.

8. Wave Frequency (Wave Length) Ranges.

The wave frequency (wave length) ranges of the several receiving sets were determined by operating them in connection with an actual antenna, having the following physical dimensions: one wire totalling approximately 120 ft. in length (flat top of approximately 100 ft.) situated 25 ft. above the ground. The capacity of this is approximately 300 micromicrofarads at 834 kilocycles per second (360 meters). The wave frequency (wave length) ranges of the receiving sets were determined with a buzzer driven wavemeter by coupling the wavemeter to the antenna in such a way that it reacted in no way with the receiving set. Calibrations are obtained for the several combinations of inductance and capacity throughout the wave frequency (wave length) range of the receiving set.

Where the tuning system consists of continuously variable capacity and variable inductance in rather large steps, or a

continuously variable inductance and a capacity variable in rather large steps, a series of wave frequency (wave length) calibrations is obtained.

Tables 1 to 10 give the wave frequency (wave length) ranges and overlaps of the various receiving sets included in this report. The percentage overlap is computed as the ratio of the overlap frequency band to the greater of the two frequencies of which it is the difference.

Table 1

Wave Frequency (Wave Length) Ranges

of

Receiving Set No. 1922-N.

Wave Frequency Inductor Control Position	Wave Frequency in Kilocycles per Second	Wave Length in Meters
Divisions	f	λ
	Short Wave Connection	
5 (minimum)	1765	170
20	1364	220
40	1115	269
60	965	311
80	874	343
95 (maximum)	783	383
	Long Wave Connection	
0	870	343
10	730	411
20	655	458
30	627	478
50	523	574
70	478	628
90	426	703
	Overlap = 87	40

Table 2

Wave Frequency (Wave Length) Ranges

of

Receiving Set No. 1922-0

Short Wave Range

Inductance	Capacity Minimum = 0°		Capacity Maximum = 100°		Overlap of		Percentage Overlap of
Tap	Wave Freq. Kilocycles per second f	Wave Length Meters λ	Wave Freq. Kilocycles per second f	Wave Length Meters λ	Wave Freq. Kilocycles per second f	Wave Length Meters λ	Wave Freq. (wave length) %
1			2140	140			
2			1578	190			
3			1428	210	30	237	14.2
4	1665	180	1250	240	30	178	12.5
5	1428	210	968	310	70	282	22.5
6	1250	240	834	360	60	166	16.6
7	1000	300	652	460	100	182	21.8
8	834	360	546	550	140	186	25.4
9	732	410	462	650	125	109	19.1
10	571	525	387	775	240	173	30.9
11	560	535	343	875	265	149	30.6
12	492	610	300	1000	325	144	32.4
13	444	675	260	1150			

Table 3

Wave Frequency (Wave Length) Ranges

of

Receiving Set No. 1922-O
(Continued)

Long Wave Range

Inductance	Capacity: Minimum = 0° — Wave Freq. Kilocycles per second f	Capacity: Minimum = 0° — Wave Length Meters λ	Capacity: Maximum = 100° — Wave Freq. Kilocycles per second f	Capacity: Maximum = 100° — Wave Length Meters λ	Overlap of — Wave Freq. Kilocycles per second f	Overlap of — Wave Length Meters λ	Percentage overlap of Wave Freq. (wave length) %
1	1665	180	1364	220	136	20	9.1
2	1500	200	1070	280	294	60	21.4
3	1364	220	780	380	290	100	26.3
4	1070	280	582	515	275	165	32.0
5	857	350	445	675	237	235	34.8
6	682	440	353	850	192	300	35.3
7	545	550	286	1050	176	400	38.1
8	462	650	240	1250	135	450	36.0
9	375	800	188	1600	165	750	46.8
10	353	850	167	1800	133	800	44.3
11	300	1000	146	2050	115	900	43.9
12	261	1150	130	2300	184	900	39.1
13	214	1400	107	2800			

Overlap between long wave connection and short wave connection is nearly continuous throughout the wave frequency range of the short wave connection.

Table 4

Wave Frequency (Wave Length) Ranges

of

Receiving Set No. 1922-P.

Wave Freq. Control Degrees	Coupling Control Degrees	Wave Freq. Kilocycles per second f	Wave Length, Meters λ
0	90	2000	150
10	90	1500	200
20	80	1070	280
30	80	770	390
40	80	652	460
50	75	572	525
62	70	492	610
70	65	435	690
90	65	380	790

Table 5

Wave Frequency (Wave Length) Ranges

of

Receiving Set No. 1922-0.

Tuning Control Divisions	Coupling Control Divisions	Wave Freq. Kilocycles per second f	Wave Length Meters λ
Short wave connection			
1	2.0	2140	140
2	2.0	1935	155
3	2.0	1430	210
4	2.0	1250	240
5	2.0	1034	290
6	2.5	938	320
7	2.5	858	350
8	3.0	811	370
10	3.0	760	395
Long wave connection			
1	1.5	1364	220
2	2.0	1110	270
3	2.5	857	350
4	3.0	715	420
5	3.5	632	475
6	4.0	546	550
7	4.0	500	600
8	4.0	462	650
10	5.0	445	675

Overlap of short and long wave frequency range is 604 kilocycles per second (175 meters).

Table 6

Wave Frequency (Wave Length) Ranges

of

Receiving Set No. 1922-R

Inductor Tap	Wave Freq. Kilocycles per second f	Wave Length Meters λ
1 (Dead Tap)		
2	1665	180
3	1052	285
4	619	485
5	545	550
6	469	640
7	414	725
8	364	825
9	324	925
10	300	1000
11	261	1150
12	222	1350
13	188	1600
14	167	1800
15	143	2100

Table 7

Wave Frequency (Wave Length) Ranges

of

Receiving Set No. 1922-S

Tuner Control Setting	Wave Freq. Kilocycles per second f	Wave Length Meters λ	Overlap of Kilo-cycles f	Overlap of Meters λ	Overlap of %
		180-400 meter tap			
0	1240	242			
5	691	434			
10	628	478			
		300-700 meter tap			
0	711	422	83	56	11.7
5	433	692			
10	364	824			

The inductor was continuously variable and not tapped. The controls were equipped with indicators moving over a scale.

Table No. 8

Wave Frequency (Wave Length) Ranges

of

Receiving Set No. 1922-T

Tuner Control Setting	Wave Freq. Kilocycles per second f	Wave Lengths Meters λ
Minimum	1, 817	165
Maximum	540	556

The inductor was continuously variable and not tapped. The controls were not equipped with indicators.

Table No. 9

Wave Frequency (Wave Length) Ranges

of

Receiving Set No. 1922-U.

Tuner Control Setting Divisions	Wave Freq. Kilocycles per second f	Wave Length Meters λ
Short wave connection		
0	1500	200
2	1364	220
4	1110	270
6	938	320
8	834	360
10	790	380
Long wave connection		
0	1035	290
2	938	320
4	770	390
6	638	470
8	588	510
10	545	550

Overlap between short wave connection and long wave connection is 245 kilocycles (90 meters).

Table 10

Wave Frequency (Wave Length) Ranges

of

Receiving Set No. 1922-V.

Inductor	Capacity Minimum = 0°		Capacity Maximum = 100°		Overlap of		Percentage overlap of
Turns	Wave freq. Kilocycles per second f	Wave Length Meters λ	Wave Freq. Kilocycles per second f	Wave Length Meters λ	Wave Freq. Kilocycles per second f	Wave Length Meters λ	Wave Freq and Wave Length λ
25	1195	251	735	408			0
50	679	442	377	798	286	324	40.6
25 + 50	663	474	343	876			0
50	238	1260	124	2425	109	1140	47.0
25 + 150	233	1285	122	2470	110	1180	47.8
50 + 150	232	1290	121	2480	109	1175	47.4
25 +50 +150	230	1305	118	2555			

9. Vibration Test.

The vibration test is designed to obtain information as to the mechanical strength and ability to withstand shock in transportation. This data is obtained by fixing the receiving set on a vibrating machine, and operating for a period of fifteen minutes. At the end of this time, the receiving set is taken from the vibrator and carefully inspected as to mechanical condition. If parts of the receiving set have been misplaced in any way, the condition is noted. From this test, it is possible to judge whether the condition of the apparatus after transportation will be satisfactory.

At the end of a fifteen-minute shipping test, it was found that receiving sets Nos. 1922-N, 1922-O, 1922-S and 1922-T were in the same mechanical and electrical condition as before the test was begun.

Receiving Set No. 1922-Q.

At the end of a fifteen-minute shipping test, this receiving set was found to be in good condition except for a very slight loosening of the detector inductance control lever.

Receiving Set No. 1922-P.

At the end of a fifteen-minute shipping test, this receiving set was found to be in good condition except for the loosening of a binding post and a nut on the inductance support.

Receiving Set No. 1922-R.

At the end of a fifteen-minute shipping test, it was found that three taps had broken off where connection was made to the inductor. It was necessary to re-solder the taps before the set could be operated satisfactorily.

Receiving Set No. 1922-U.

At the end of a fifteen-minute shipping test, it was found that a fine wire leading from the inductance to the detector had broken and a screw holding the detector adjusting control support had loosened. It was necessary to repair the instrument before it could be used.

Receiving Set No. 1922-V.

At the end of a fifteen-minute shipping test, it was found that the bearing nut on the dial end of the variable condenser had loosened, the variable condenser was short-circuited for several positions, the plate stop, which was imbedded in the insulating ends had broken out of the insulating material and one of these ends was cracked in two places. It was necessary to repair the condenser before the set could be operated satisfactorily.

10. Sensitivity Measurement

The practical usefulness of a receiving set may be measured by the extent of its ability to convert a desired incoming radio signal into sound as well as its ability to select a desired signal from among a number. The factors governing this may be the circuit used, the characteristics of the crystal detector or electron tube detector, the characteristics of the telephone receivers used and the mechanical arrangement of the tuning devices.

The extent of ability to make radio signals audible might be expressed as the ratio of the sound power delivered by the telephone receivers to the radio-frequency power produced in the antenna by the received radio wave. However, it is more convenient to measure the induced radio-frequency voltage in the antenna and the telephone receiver current, and define sensitivity as,

$$\text{Sensitivity} = \frac{I_t}{E_a} \times 10^5 \quad \text{- - - - - - - - - - - - - - -} \quad (2)$$

where I_t is the telephone receiver signal current in amperes and E_a is the induced emf in the antenna in volts. The factor, 10^5, is introduced arbitrarily for the sake of the convenience of comparing the results as whole numbers instead of small fractions. When telephone receivers were neither specified nor furnished by the manufacturers, a pair of telephone receivers having a total resistance of 2000 ohms was used.

While the selectivity whose measurement is described earlier in this paper is a single-valued quantity only when the detector operates with output current proportional to the square of the input voltage, this definition of sensitivity gives a single number for sensitivity with various input radio-frequency voltages, only when the detector shows linear rectification. Neither do these many crystal rectifiers appear to follow neither of these simple laws of rectification over the rather wide ranges of signal voltages impressed on the receiving set by transmitters of varying powers and distances.

A number of determinations are therefore made of the signal currents obtained in the telephone receivers of crystal detector receiving sets with radio-frequency signal voltages of 30, 50, and 100 millivolts induced in the receiving antenna. These voltages correspond roughly to weak, loud and powerful signals when a crystal detector is used. These sensitivities are also obtained with rather low and high values of antenna resistance, indicating the effect of this variable on the signal strength obtained.

The crystal detectors were adjusted to use points of approximately a large sensitivity for these measurements.

It is difficult to state the degree of distortion due to crystal detector rectification but it can be said in general that the detector having a sensitivity figure most nearly constant for the three input radio-frequency voltages will give the least distortion.

Test Procedure.- Fig. 10 shows the arrangement of apparatus for measuring the sensitivity of crystal detector receiving sets. The receiving set is connected to a phantom antenna having the desired constants. A predetermined radio-frequency voltage E_a at a definite radio frequency is induced in the phantom antenna. The crystal detector is adjusted to average sensitiveness and the receiving set accurately tuned to resonance. The telephone receiver current in microamperes is read on the meter and compared with the induced voltage in the phantom antenna as shown by equation 8. Similar data are obtained for various radio frequencies, antenna resistances and antenna voltages. The results of such measurements are shown in Tables 11, 12 and 13.

Table 11

Sensitivity at Wave Frequency, 1500 Kilocycles per Second (Wave Length, 200 meters).

Receiving Set No.	Antenna Input Milli-volts	Sensitivity Antenna Resistance 6.0 ohms	18.0 ohms	Antenna Capacity micro-micro-farads	Control setting of receiving set
1922-N	50 100	6 9	6 8	450	Short wave connection Control - 13°
1922-O	30 50 100	73.4 56 60	53 42 49	450	Short wave connection Inductor tap 3 Condenser 50°
1922-P	30 50 100	82 103 98	48 56.6 62	450	Tuner 6 Detector 90
1922-Q	30 50 100	40 40 58	33 30 47	450	Short wave connection Tuner 2.8 Detector 1.0
1922-R	100	2	2	450	Inductor tap - 2
1922-S	30 50 100	7 6 11	5 5 9	450	Short wave connection Control - 0
1922-T	30 50 100	140 110 123	60 50 67	450	No indicator on control levers
1922-U	30 50 100	11.7 12 22	7.7 9 16	390	Tuning control - 0 Constants of circuit not suitable for tuning to 200 meters with specified antenna
1922-V	50 100	--	--	190	Constants of circuit not suitable for tuning to 200 meters with specified antenna

Table 12

Sensitivity at Wave Frequency, 834 Kilocycles per second (Wave Length, 360 meters).

Receiving Set No.	Signal Strength Milli-volts	Sensitivity Antenna Resistance 4 ohms	Sensitivity Antenna Resistance 16 ohms	Antenna Capacity micro-micro-farads	Control Settings of Receiving Set
1922-N	50	3	3	290	Short wave connection
	100	4	4		Control - 83°
1922-O	30	31.6	25	290	Long wave connection
	50	36	30		Inductor tap 4
	100	41	38.5		Condenser 20°
1922-P	30	43	23	290	Tuner 25
	50	60	36		Detector 90
	100	60	52		
1922-Q	30	18.3	15	290	Short wave connection
	50	28	23		Tuner 7
	100	40	34		Detector 1.2
	30	57	33	290	Long wave connection
	50	71	42		Tuner 3
	100	82.5	56		Detector 1
1922-R	100	2	2	450	Inductor tap 4 Not resonant to 360 meters with 290 μμf antenna capacity
1922-S	30	10	7	290	Short wave connection
	50	11	8		Control - 5.2
	100	22	19		
	30	3	3	290	Long wave connection
	50	6	5		Control - 2.8
	100	9	7		
1922-T	30	80	33	290	No indicator on control levers
	50	94	47		
	100	93.5	60		
1922-U	30	6.6	5	290	Short wave connection
	50	1.2	10		Tuning control 7.4
	100	20	17		
	30	14	6.6	290	Long wave connection
	50	27	9.6		Tuning control 2.3
	100	45	25		
1922-V	50	20	16	290	25 turn inductor
	100	31	25		Condenser - 54°

Table 13

Sensitivity at Wave Frequency, 625 Kilocycles per Second (Wave Length, 485 meters).

Receiving set No.	Signal Strength Milli-volts	Sensitivity Antenna Resistance 3.4 ohms	15.4 ohms	Antenna Capacity Micro-micro-farads	Control settings of receiving sets.
1922-N	50	18	16	280	Long wave connection
	100	18	16		control - 16°
1922-O	30	36	28	280	Long wave connection
	50	38	32		Inductor tap - 6
	100	40	35		Condenser - 3°
1922-P	30	47	23	280	Tuner - 37°
	50	60	32		Detector - 90°
	100	82	51		
1922-Q	30	45	22	280	Long wave connection
	50	63	44		Tuner - 4.5
	100	76	55		Detector - 1
1922-R	50	20	18	280	Inductor tap 4
	100	30	28		
1922-S	30	10	7	280	Long wave connection
	50	12	8		Control 4.7
	100	24	17		
1922-T	30	87	43	280	No indicator on
	50	96	58		control levers
	100	113	69		
1922-U	30	17	7	280	Tuning control - 5.7
	50	30	17		
	100	44	31		
1922-V	50	18	14	280	Inductor - 50 turn
	100	30	27		Condenser - 7°

11. Selectivity Measurements

It has been necessary to devise a special method for determining the selectivity of radio receiving sets. The primary requirement of any radio receiving set is that it shall be capable of receiving clear signals from a desired radio transmitting station to the exclusion of signals from all stations transmitting on different wave frequencies (wave lengths). That is, if two signal voltages of comparable magnitude but of slightly different wave frequency (wave length) be simultaneously or successively impressed on the same receiving antenna, the receiving set should, by proper manipulation of the controls, give response in the telephones from either signal voltage in much greater volume than from the other signal voltage.

If the percentage difference of the telephone currents which cause responses in the telephones to the two voltages impressed on the antenna, to one of which the receiving set is carefully tuned, is determined and compared to the percentage difference in frequency of the two signal voltages the resultant ratio is a measure of the ability of the receiving set to distinguish between signals of different frequencies.

Selectivity is in these tests indicated by the quantity, sharpness of resonance, S, determined in accordance with the formula,

$$S = \frac{\sqrt{\dfrac{I_{tr}-I_t}{I_t}}}{\dfrac{\pm(f^2-f_r^2)}{f_r\, f}} = \frac{\sqrt{\dfrac{I_{tr}-I_t}{I_t}}}{\dfrac{\pm(\lambda_r^2-\lambda^2)}{\lambda_r\, \lambda}} \qquad \text{- - - - - - - - - - (1)}$$

I_{tr} is telephone receiver signal current at resonance, I_t is its value off resonance, and f_r and f are the corresponding values of frequency, and λ_r and λ are the corresponding values of wave length of the exciting emf. The origin and applicability of this formula are discussed further in another paper, "Tentative Methods of Testing Radio Receiving Sets."

For the application of this expression to actual receiving set measurements, it is necessary to connect to the receiving set an antenna (real or artificial), detector and such necessary accessory equipment as telephones, to induce in the antenna a voltage of constant magnitude but of varying frequency (wave length), and to observe the values of the frequencies (wave lengths) and telephone receiver signal currents. The values of the frequencies (wave lengths) are determined by wavemeter measurements while the telephone receiver signal currents are determined by the measurements of the direct current passing through the telephone receivers as a result of the signal voltage induced in the antenna circuit by the incoming radio wave.

The arrangement of apparatus for this measurement is given in Fig. 11.

Test Procedure.- In this case a sensitive microammeter is used in the telephone receiver circuit to indicate the rectified radio-frequency signal current received from the antenna. Equation (1) applies rigorously only if the crystal rectifier operates with output current proportional to the square of the input voltage and when this relation is departed from correction may be made by determining the law of rectification of the detector. In the detectors considered in this report the square law of rectification did not hold, except in a very few cases. For this reason sharpness of resonance was obtained at varying signal strengths, which correspond to loud and weak signals.

The necessary data for the determination of sharpness of resonance is obtained by connecting the receiving set to a phantom antenna having the constants specified by the manufacturer or those commonly met with in the field. The receiving set is then adjusted to resonance with the voltage applied to the antenna circuit; the telephone current is noted; and the wave frequency (wave length) varied until the telephone receiver signal current is reduced to one half of its value at resonance. These data are used in equation (1). The values of sharpness of resonance obtained at several wave frequencies (wave lengths) are given in Tables 14, 15, 16, 17 and 18.

Table 14

Sharpness of Resonance at Wave Frequency, 1500 kilocycles per second, (Wave Length, 200 meters).

Receiving Set No	Weak Signals Telephone receiver current = 20 microamp.			Loud Signals Telephone receiver current = 100 microamp.			Control Settings of Receiving sets.
	Antenna Capacity micro-micro-farads	Sharpness of Resonance		Antenna Capacity micro-micro-farads	Sharpness of Resonance		
		Antenna Resistance 6.0 ohms	Antenna Resistance 18.0 ohms		Antenna Resistance 6.0 ohms	Antenna Resistance 18.0 ohms	
1922-N	450	7.3	6.4	450	7.3	6.4	Short wave connection = 13°
1922-O	450	12.5	12.5	450	6.7	5.7	Short wave connection Inductor tap=3, Cond.=54°
1922-P	450	6.7	5.0	450	6.7	5.0	Antenna inductor =6°. Detector inductor = 90°
1922-Q	450	25.0	20.0	450	25.0	13.3	Short wave connection. Antenna inductor=2.5 Detector inductor= 1.0
1922-R	450	5.9	5.9	450	5.9	5.9	Inductor tap = 2
1922-S	450	6.9	6.1	450	5.4	5	Short wave connection control=0
1922-T	450	18.2	10.0	450	12.5	7.2	No setting indicator on controls

1922-U	390	40.0	40.0	390	25.0	25.0	(Constants of circuit not suitable for tuning to 200 meters with specified antenna
1922-V	190	---	---	190	---	---	

Table 15

Sharpness of Resonance at Wave Frequency, 834 Kilocycles per second (Wave Length, 360 meters).

Receiving Set No.	Weak Signals Telephone receiver current =20 microamperes			Loud Signal Telephone receiver current = 100 microamp.			Control Settings of Receiving set
	Antenna Capacity micro-micro-farads	Sharpness of Resonance		Antenna Capacity micro-micro-farads	Sharpness of Resonance		
		Antenna Resistance 4.0 ohms	Antenna Resistance 16.0 ohms		Antenna Resistance 4.0 ohms	Antenna Resistance 16.0 ohms	
1922-N	290	4.0	4.0	290	4.0	4.0	Long wave connection Control=0
1922-O	290	11.6	9.8	290	9.2	6.3	Long wave connection Inductor tap=4. Cond.=20°
1922-P	290	20.0	14.7	290	14.4	11.2	Antenna inductor=25° Detector inductor =90°
1922-Q	290	31.0	30.0	290	23.3	16.2	Short wave connection Antenna inductor=7.0 Detector inductor =1.5
		27.7	15.0		22.5	11.8	Long wave connection Antenna inductor=3.0 Detector inductor = 1.0
1922-R	290	--	--	290	--	--	At resonance. Tap 2=285 m. Tap 3= 480 m.
1922-S	290	14.4	13.8	290	10.3	10.3	Short wave connection Control= 5.2
		10	9.5		7.6	6.3	Long wave connection Control = 3.1

1922-T	290	31.3	16.0	290	36.0	11.6	No setting indicator on controls
1922-U	290	44.2	31.6	290	29.6	22.4	Short wave connection Control = 7.0 Long wave connection Selectivity not so great
1922-V	290	15.7	13.8	290	12.0	10.4	Inductor = 25 turn Condenser =54°

Table 16

Sharpness of Resonance at Wave Frequency, 625 Kilocycles per second, (Wave Legnth, 480 meters).

Receiving Set No.	Weak Signals, Telephone Receiver Current = 20 microamp. Antenna Capacity micro-micro-farads	Weak Signals: Sharpness of Resonance, Antenna Resistance 3.5 ohms	Weak Signals: Sharpness of Resonance, Antenna Resistance 16.0 ohms	Loud Signals, Telephone receiver current =100 microamp. Antenna Capacity micro-micro-farads	Loud Signals: Sharpness of Resonance, Antenna Resistance 3.5 ohms	Loud Signals: Sharpness of Resonance, Antenna Resistance 16.0 ohms	Control Settings of Receiving Sets.
1922-N	290	12.0	10.2	290	12.0	10.2	Long wave connection control =17°
1922-O	290	8.4	7.8	290	4.6	4.3	Long wave connection Inductor tap =6. Condenser = 2°
1922-P	290	32.0	26.7	290	26.7	18.5	Antenna inductor=37° Detector inductor =90°
1922-Q	290	35.6	23.4	290	25.2	17.5	Long wave connection Antenna inductor=4.5 Detector inductor =1.0
1922-R	290	7.0	7.0	290	7.0	7.0	Inductor tap = 3
1922-S	290	18.5	16.5	290	13.7	13	Long wave connection Control=4.7
1922-T	290	48.0	21.8	290	37.0	22.0	No setting indicator on controls
1922-U	290	60.2	50.6	290	40.6	32.6	Long wave connection Control=5.5
1922-V	290	9.0	9.0	290	9.0	9.0	Inductor = 50 turns. Condenser = 7°

Table 17

Sharpness of Resonance at Wave Frequency, 400 Kilocycles per second, (Wave Length, 750 meters).

Receiving Set No.	Sharpness of Resonance Antenna 0 ohms	Resistance 16 ohms	Antenna Capacity in micro-micro-farads	Control setting of receiving set
1922-N	4.0	4.0	280	Long wave connection control = 86°
1922-O	4.9	4.1	280	Long wave connection Inductor = tap 6 Condenser = 7°
1922-P	46.6	18.0	280	Short wave connection Tuning control = 67° Coupling = 90°
1922-R	1.7	0.7	280	Inductor tap = 11
1922-V	15.0	12.7	280	Inductor = 50 turns Condenser = 62°

Table 18

Sharpness of Resonance at Wave Frequency, 261 Kilocycles per second, (Wave Length, 250 meters)

Receiving Set No.	Sharpness of Resonance Antenna 0 ohms	Resistance 16 ohms	Antenna capacity in micro-microfarads	Control Setting of receiving set
1922-O	3.35	3.35	275	Long wave connection Inductor tap =11 Condenser = 9°
1922-R	1.67	1.67	275	Inductor tap = 11

12. Notes on Operation

Receiving Set No. 1922-N.

The mechanical arrangement of tuning controls is most simple in that all wave frequency (wave length) variation is provided for by a single knob and dial centrally located with respect to the operating panel.

The crystal detector is conveniently placed in the upper left corner of the tuner panel allowing its adjustment by the left hand while tuning it with the right. The adjustment of the crystal detector is rather difficult owing to the lack of effective three-way adjustment. It is not suited to those types of crystals needing a very light contact. No buzzer is provided for testing the sensitiveness of the detector. The manipulation of the wave -frequency (wave length) control is such that the detector may lose its best adjustment.

Body capacity effects produce no noticeable change of wave frequency (wave length) tuning.

Receiving Set No. 1922-O.

The arrangement of the tuning controls of this receiving set is not logical and is somewhat crowded, convenience of adjustment being sacrificed for compact construction. The wave frequency (wave length) tuning circuit is changed by the use of a short throw switch, tapped inductors, and a continuously variable air condenser.

The crystal detector provides a light three-way adjustment for galena crystals. Its operation is satisfactory in that it allows a quick, rather stable, and sensitive adjustment, although its position relative to the complete receiving set makes it rather inconvenient to operate. A high-grade test buzzer and battery allows a good detector adjustment to be quickly and easily obtained.

Receiving Set No. 1922-P.

The mechanical arrangement of tuning controls of this receiving set is fair from the standpoint of radio operation. The tuning adjustments (two in number consisting of knobs with pointers moving over engraved scales) are, (1) variation of antenna inductance, and (2) crystal detector connection. By the proper use of the coupling control, either broad or rather selective tuning can be obtained throughout the wave frequency (wave length) range of the receiving set. This arrangement gives a minimum of adjustment with a maximum result, but the method of design of these controls is poorly carried out. This is most marked by the audible noises due to the mechanical sliding contact and the electrical telephone receiver noises due to the short circuiting of the various inductor turns.

This short circuiting of the inductor turns also produces high losses in the circuits, causing a weak telephone receiver signal. For this reason, the best of results are obtained only by the careful adjustment of these tuning controls.

The crystal detector, employing a galena crystal embedded in Wood's metal is handily adjusted by a three-way movement, but has the disadvantage of a constant cat-whisker pressure which in this case is much too heavy. Due to this, the receiving set as a whole lacks much of the sensitivity that it should otherwise have. On the other hand, this arrangement allows a rather sturdy adjustment of the detector undisturbed by the mechanical movement of the tuning controls. No test buzzer is supplied to facilitate the detector adjustment.

Receiving Set No. 1922-Q.

The mechanical arrangement of the tuning controls of this receiving set is somewhat unusual but well positioned, allowing quick adjustment to any wave frequency (wave length) within the range of the set. The tuning adjustments (being in the form of two levers moving over scales) vary the antenna inductance and the detector connection. Since these can be simultaneously operated by the both hands of the operator, it is possible to obtain the desired wave frequency (wave length) and selectivity in a minimum of time. The method of varying the inductance produces noises in the telephone receivers, due to the sliding contacts. These electrical noises are not disturbing, however, unless the receiving set is used with an audio-frequency amplifier. There is also a certain amount of short-circuiting of inductor turns which produces high loss in the circuits. For this reason, the best results are obtained only after careful adjustment of these tuning controls.

The crystal detector stand is well situated allowing easy access to the cat-whisker control handle. When the receiving set is in the best position for the manipulation of the tuning controls the crystal is hidden from the view of the operator by the crystal stand. The adjustment of the three-way movement of the cat-whisker control and the pressure of contact on the crystal, is ingeniously obtained, giving an excellent control which results in a stable and sensitive detector.

Receiving Set No. 1922-R

The tuning control of this receiving set is most simple, being a rotating switch moving over taps, centrally located with respect to the tuner panel. Since the wave frequency (wave length) control is not continuous, only those stations happening to have approximately the same wave frequency (wave length) that the tuner does can be received to best advantage. Since there are fifteen different tuning positions in the tuner, only that number of different wave frequencies (wave lengths) can be accurately tuned to, which fact seriously limits the

usefulness of the receiving set. This arrangement is entirely unsatisfactory as far as control of reception of signals is concerned, especially in view of the large total inductance.

The detector control stand does not facilitate the light stable contact necessary for the type of crystal employed. The position of the cat whisker control is such that a binding post obstructs free access to its adjustment. Since the receiving set proper is of such light weight that any slight vibration is carried to the detector contact, satisfactorily stable adjustment can not be held for any length of time.

Receiving Set No. 1922-S.

The tuning control of this receiving set consisting of a knob with pointer attached moving over a scale is conveniently located, and allows a quick adjustment to any wave frequency (wave length) within the range of the set. The wave frequency (wave length) range is divided into two continuously variable and overlapping ranges.

The adjustments required for receiving with this set are two in number, - the tuning control and the detector adjustment. These adjustments are very simple. The wave frequency (wave length) adjustment is permanent since no body capacity effects are noted.

The detector stand which holds a crystal combination is conveniently located and easily adjusted. It is designed to give one crystal a three-way movement with a satisfactory method of adjusting the contact pressure.

Receiving Set No. 1922-T.

The mechanical arrangement of the tuning and detector adjustment control levers of this receiving set is very inconvenient from the standpoint of radio operation. In any case, if the handiest position for adjustment of the wave frequency (wave length) controls is obtained, the detector control, antenna ground leads, and telephone cords are in the way. The wave frequency (wave length) is varied by a lever which has no method of calibration to allow a reset. The detector connection is also controlled by a similar lever. By the proper use of these two control levers, the wave frequency (wave length) and selectivity can be controlled. The moving inductor contacts produce noises, as well as occasional short circuiting of the inductor turns.

The crystal detector stand is not well positioned for satisfactory adjustment, and provides no good pressure adjustment. Due to this and to the vertical position of the face of the crystal, it is most difficult to obtain and keep a satisfactorily sensitive point. This difficulty is further increased by the vibration and shock due to the adjustment of the tuning controls.

Receiving Set No. 1922-U.

The wave frequency tuning control of this receiving set is in the form of a quiet rotating lever, moving over a 180° circular scale. The wave frequency (wave length) range of the receiving set is divided into two overlapping ranges, controlled by the same tuning lever and a changing antenna connection. The tuning control is very easily manipulated.

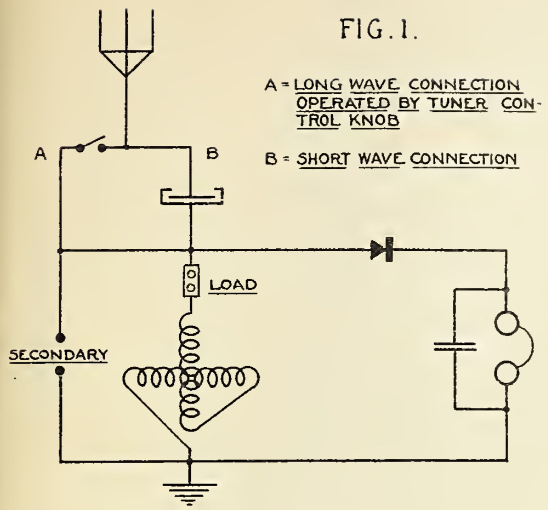
The detector control stand uses as elements a straw-colored mineral and an alloy of dull appearance and is well situated with respect to operation of tuning control. An adjustment of pressure and a three-way movement allows any desired pressure contact to be obtained.

Receiving Set No. 1922-V.

The mechanical arrangement of the tuning controls is very simple in that all wave frequency (wave length) variation is obtained by a three-point switch and a conveniently located knob with dial. Some tuning may also be done by changing the position of the inductors.

The crystal detector is located on the right of the panel where it may be readily adjusted with the right hand. The detector is very easily adjusted as the cat-whisker has three-way motion. No buzzer is supplied to aid in finding a sensitive spot on the crystal.

Department of Commerce,
Washington, D.C.



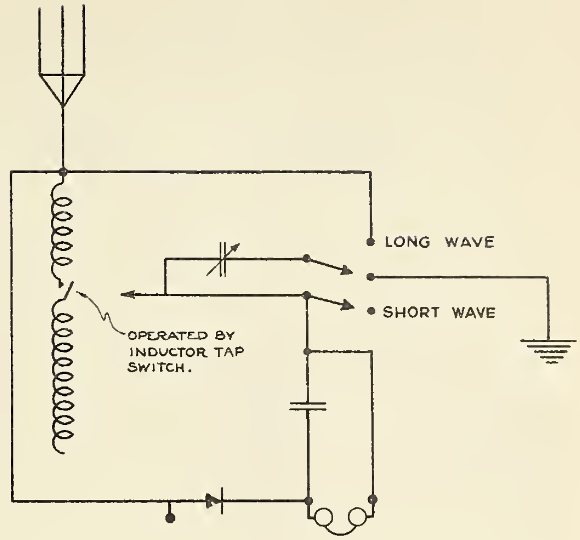


Fig. 2.

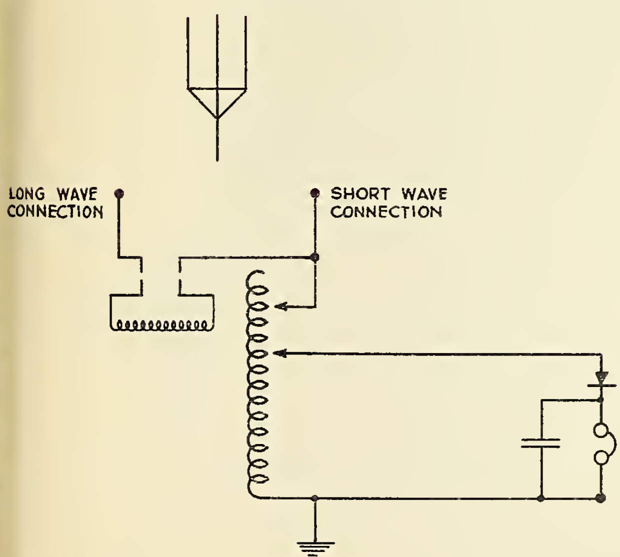


Fig. 3.

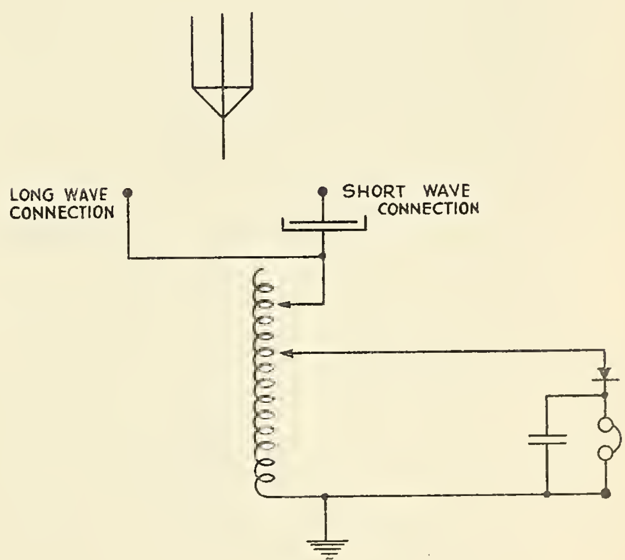


Fig. 4.

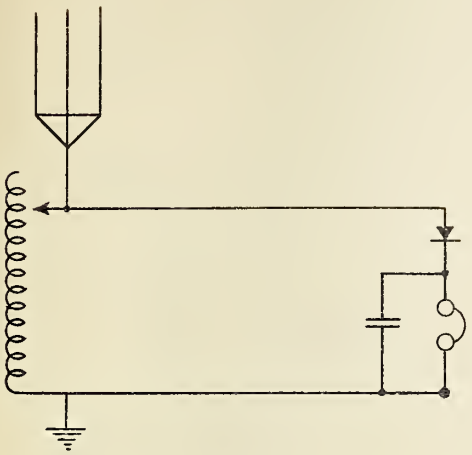


FIG. 5.

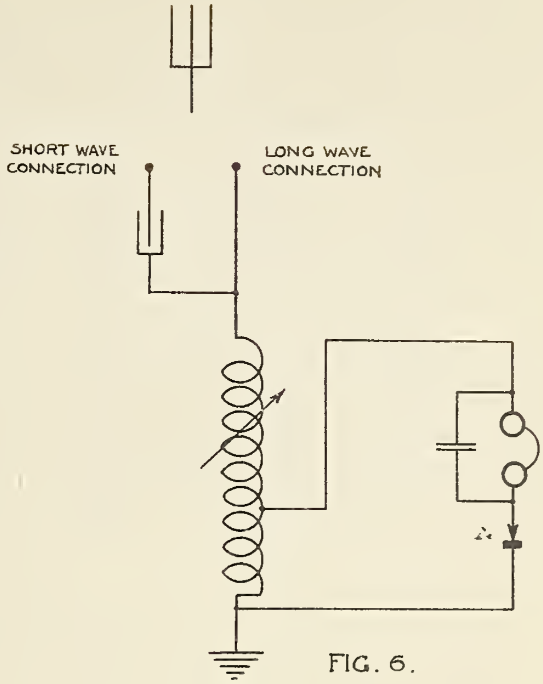


FIG. 6.

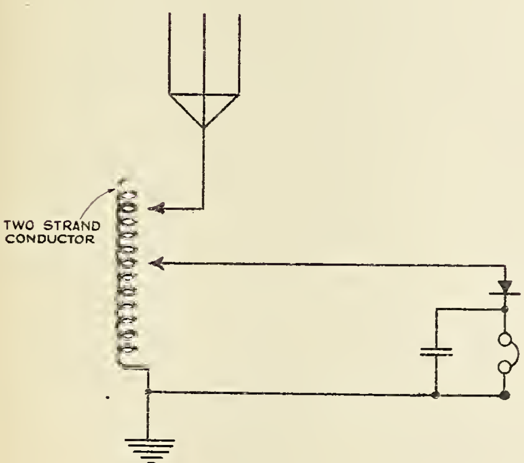


FIG. 7.

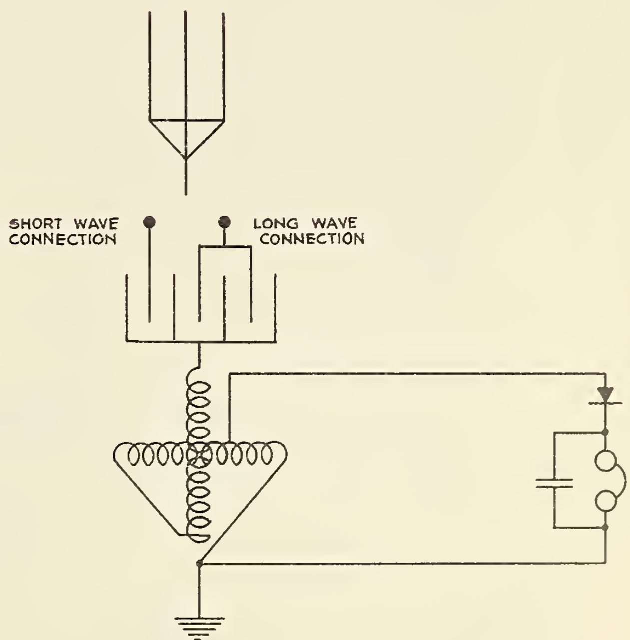


FIG. 8.

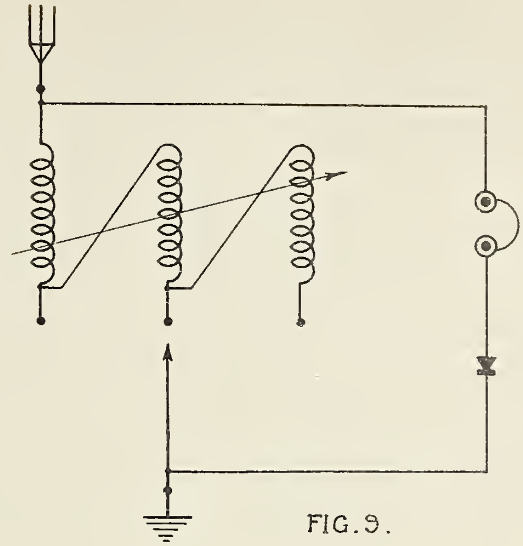


FIG. 9.

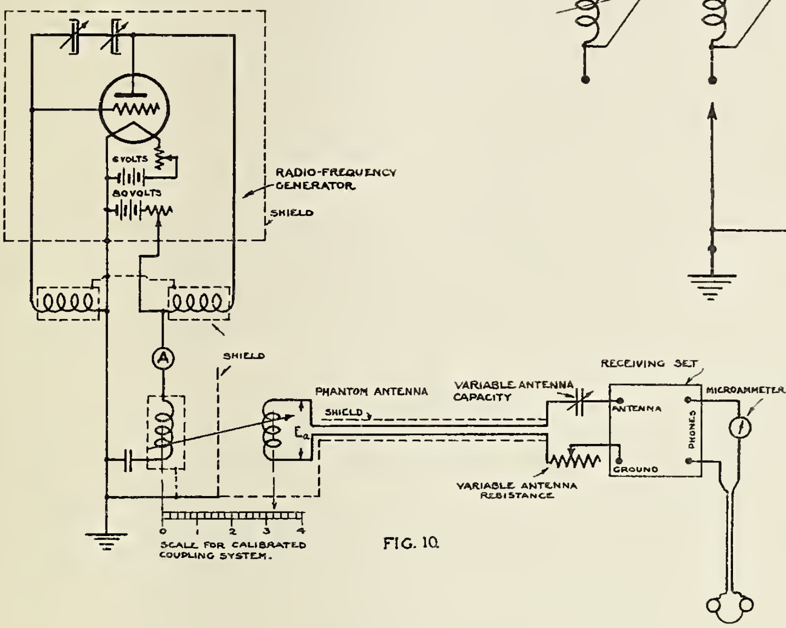


FIG. 10.

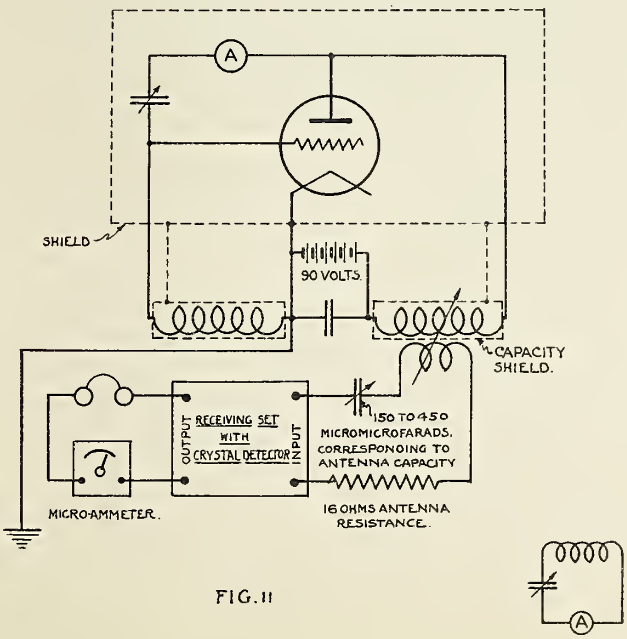


FIG. 11