

Jan. 3, 1939.

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 APPARATUS FOR RECEIVING ELECTROMAGNETIC WAVE  
 SIGNALS THROUGH DIELECTRIC GUIDES  
 Filed Oct. 12, 1935

2,142,159

2 Sheets-Sheet 1

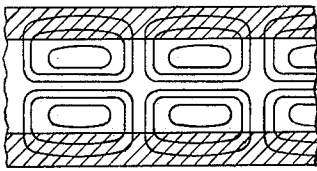


Fig. 1

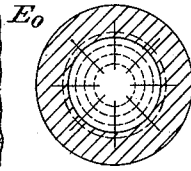


Fig. 2

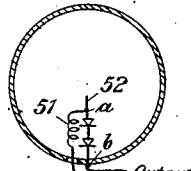


Fig. 9

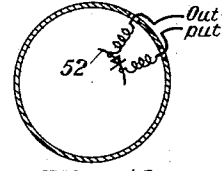


Fig. 10

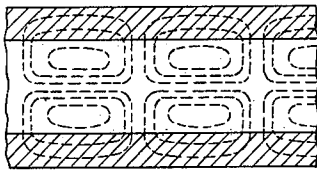


Fig. 3

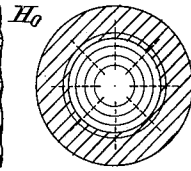


Fig. 4

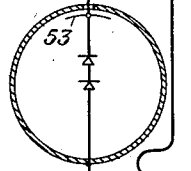


Fig. 11

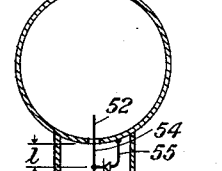


Fig. 12

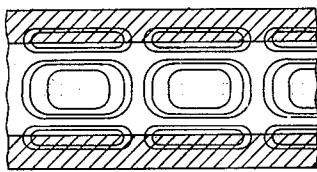


Fig. 5

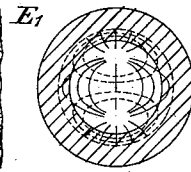


Fig. 6

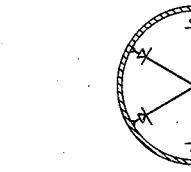


Fig. 13

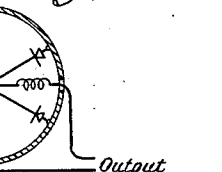


Fig. 14

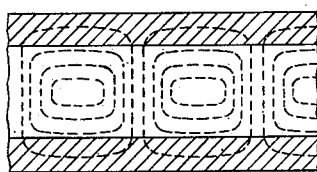


Fig. 7

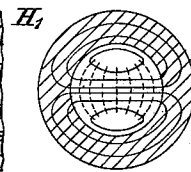


Fig. 8

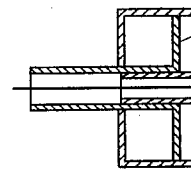


Fig. 15

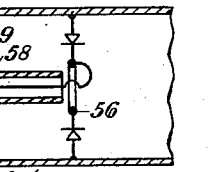


Fig. 16

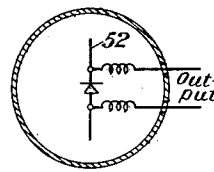


Fig. 17

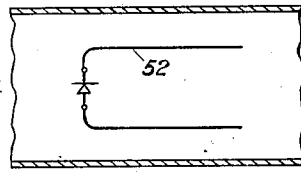


Fig. 18

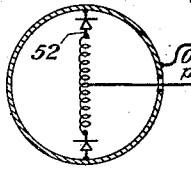


Fig. 19

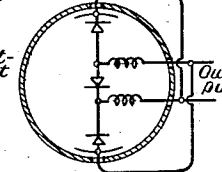


Fig. 20

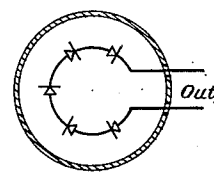


Fig. 21

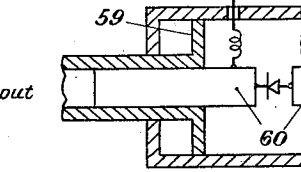


Fig. 22

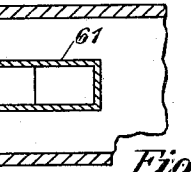


Fig. 23

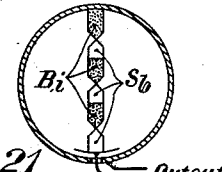


Fig. 24

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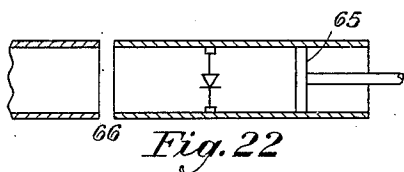


Fig. 22

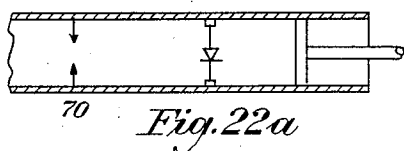


Fig. 22a

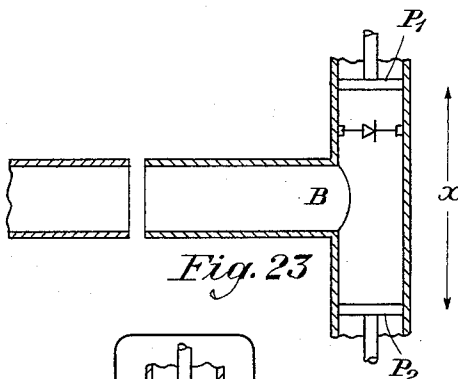


Fig. 23

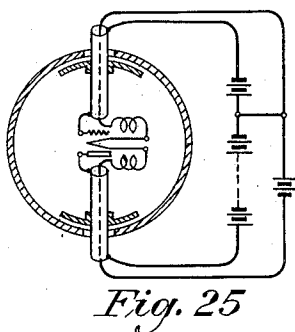


Fig. 25

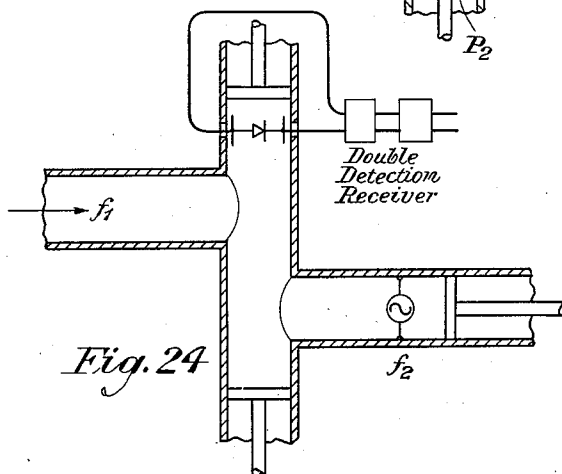


Fig. 24

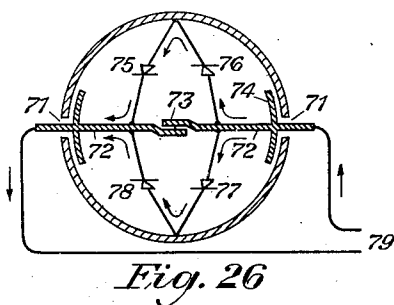


Fig. 26

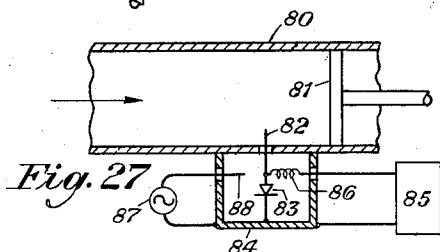


Fig. 27

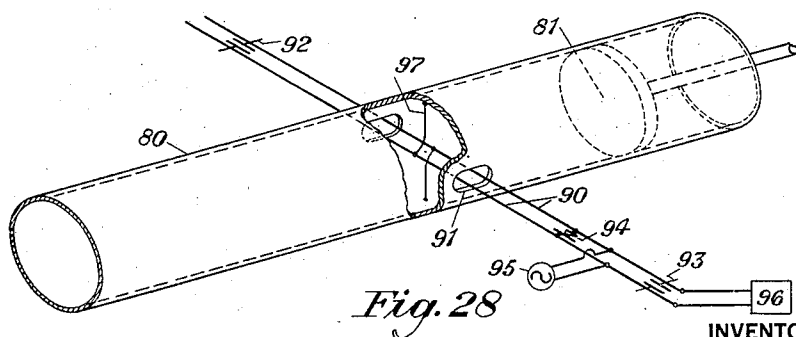


Fig. 28

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## UNITED STATES PATENT OFFICE

2,142,159

## APPARATUS FOR RECEIVING ELECTROMAGNETIC WAVE SIGNALS THROUGH DIELECTRIC GUIDES

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Application October 12, 1935, Serial No. 44,640

5 Claims. (Cl. 178-44)

A principal object of our invention is to provide new and improved apparatus and a corresponding method for the effective reception of electromagnetic wave signals, especially when such signals have been transmitted to the space of their reception along a dielectric guide. Another object of our invention is to combine one or more sensitive receiving elements with a dielectric guide in such relation to the lines of force of received waves therein, that the energy of the received signals shall be applied in an effective manner. Another object of our invention is to modify the receiving end of a dielectric guide appropriately for the combination therewith of sensitive receiving elements. All these objects and other objects and advantages of our invention will become apparent on consideration of a limited number of examples of the invention which we have chosen for presentation in this specification. It will be understood that the following disclosure relates principally to these particular embodiments of the invention and that the scope of the invention will be indicated in the appended claims.

Referring to the drawings, Figures 1, 3, 5 and 7 are diagrammatic longitudinal sections of a dielectric guide showing the lines of force of respective different wave types therein; Figs. 2, 4, 6 and 8 are corresponding cross-sections; Fig. 9 is a cross-section of a dielectric guide showing crystal detectors adapted especially for waves of asymmetric magnetic and certain other types; Fig. 10 shows crystal detectors adapted for the reception of symmetric magnetic waves; Fig. 11 shows another arrangement for receiving asymmetric magnetic waves; Fig. 12 shows a receiving crystal associated externally with the receiving end of a dielectric guide; Fig. 13 shows crystals in multiple for the reception of symmetric electric waves; Fig. 14 is a longitudinal section showing a modification with facility for adjustment; Fig. 15 shows a crystal associated with a dipole receiver in a dielectric guide; Fig. 16 is a longitudinal section showing a modification of Fig. 15; Fig. 17 shows an alternative disposition of the crystals for the same type of wave as compared with Fig. 15; Fig. 18 shows a combination of the principles involved in Figs. 15 and 17; Fig. 19 shows a plurality of crystals in series adapted for receiving symmetric magnetic waves; Fig. 20 shows a crystal associated with a section of a coaxial conductor system tuned with respect to a dielectric guide so as to produce optimum received signals; Fig. 21 shows a modification in which thermoelectric junctions take the place of

the crystal or crystals in Fig. 11; Fig. 22 is a longitudinal section of a dielectric guide at its receiving end, with an adjustable piston for a purpose which will be explained; Fig. 22a shows a modification as compared with Fig. 22; Fig. 23 shows an impedance matching chamber termination at the receiving end; Fig. 24 shows such a chamber with a beating oscillator; Fig. 25 shows a suitable oscillator for use in this connection; Fig. 26 is a cross-section showing the use of rectifiers for two-way rectification; Fig. 27 is a longitudinal section of a dielectric guide at its receiving end showing the use of a beating oscillator; and Fig. 28 is a perspective view of a dielectric guide at its receiving end showing a beating oscillator in combination with a Lecher wire system.

For the purpose of transmitting electromagnetic waves from one place to another place, a dielectric guide may be provided comprising a body of dielectric extending from the one place to the other place and bounded laterally by a dielectric discontinuity. A dielectric guide may take various forms, for example, a cylindrical body of air or empty space bounded by a metallic sheath. In Figs. 1 to 8, cylindrical sheaths are shown in longitudinal and transverse section with the sheath wall thickness greatly exaggerated to facilitate the diagrammatic representation.

Of the various types of dielectrically guided waves which may be propagated in a dielectric guide, the present disclosure has relation more especially to certain of the simpler types which may be named and symbolized as follows: They are symmetric if they have symmetry on all sides around the axis, but they are asymmetric if the lines of force lie in great part parallel with a single plane containing the axis. Also, the waves are electric if they have a substantial component of electric force in the direction of propagation, but they are magnetic if they have a substantial component of magnetic force in that direction. In Figs. 1 to 8, continuous lines represent lines of electric force and dotted lines represent lines of magnetic force. Accordingly, symmetric electric waves ( $E_0$ ) are represented in Figs. 1 and 2, symmetric magnetic waves ( $H_0$ ) in Figs. 3 and 4, asymmetric electric waves ( $E_1$ ) in Figs. 5 and 6, and asymmetric magnetic waves ( $H_1$ ) in Figs. 7 and 8.

For the purposes of this specification it is to be understood that "dielectrically guided waves" comprehends any waves that may be propagated along a dielectric guide as hereinbefore defined

and that are characterized in one or more of the following respects: the velocity of propagation, and, therefore, the wave-length, is a function of the transverse dimensions of the guide; propagation along a given dielectric guide is possible only above a critical frequency; and current flow in at least one longitudinal path is confined to the dielectric medium comprising the guide, or, in other words, the presence of a pair of conductors for the "go and return" flow of current is not essential.

Assuming that waves of one of the types shown in Figs. 1 to 8 are to be transmitted over a dielectric guide, the present disclosure has to do more particularly with obtaining optimum response from such waves for a given incident signal at the receiving end. It will be obvious in many cases that the configuration and relation of parts at the receiving end will be similarly advantageous at the transmitting end upon the substitution of wave generators for wave energy receivers.

In the disclosures that follow, a suitable wave frequency that may be held in view by way of example will be of the order of 2,000 megacycles per second, corresponding to a wave length in free space of about 15 centimeters. For such a wave length the diameter of the wave guide when it has an air core may advantageously be about 5 inches. The devices described herein are applicable by suitable scale modifications to higher and lower frequencies than that mentioned. In nearly all of the arrangements herein disclosed the receiver or detector elements are connected in circuits with the coupling leads lying along the lines of force of the electric field of the received waves. In most of the receivers disclosed herein the received electric wave energy is applied directly in this way, instead of being applied to develop electromotive forces in conductive circuits and thereby convey the electromagnetic forces along the conductors to the detector or receiver elements at a greater or less distance.

Crystal detectors or receivers are examples of a number of well-known materials and devices which respond non-linearly to impressed voltages; that is, with varying applied voltage the resulting current increments are not proportional to the voltage increments. Such devices have the useful property of modulating or demodulating the various frequencies that have been impressed upon them; they may either produce several harmonics of any one frequency that is impressed, or in the more general case, they may produce demodulation products corresponding to the sums and the differences of all the various frequencies that are present. When an intelligence bearing band of relatively low frequencies is combined with a higher frequency carrier to form a side band, the process is known as modulation. When the components of such a combination are reproduced therefrom, the process is known as demodulation or detection. As is well known, these two processes are not essentially different. Thus it is that many of the devices herein described are applicable substantially alike for modulation or demodulation, that is, for transmitters as well as for receivers.

As examples of crystals possessing the non-linear property that has been mentioned, there are galena, silicon, iron-pyrites, carborundum, as well as copper oxide plates; also, gases at certain pressures have similar properties, and two-electrode and three-electrode vacuum tubes may have such properties.

For the detection of asymmetric magnetic waves, several crystals may be connected in series along a diametral line as between the two points *a* and *b* of Fig. 9. A choke coil is introduced at 51 so that there will be no high frequency counterelectromotive force in the lead from the inner point at *a*. The conductor is continued from the point *a* along the diameter in the form of a probe or pick-up 52. The high frequency electric forces impressed along the line *ab* are rectified, but prevented from entering the output circuit directly. Only the rectified and integrated current effect goes to the output circuit. The length of the pick-up 52 may be adjusted for the maximum amount or any lesser desired amount of energy absorption.

The waves transmitted along the guide and received as in the apparatus of Fig. 9 may have been modulated with speech, television signals or other forms of intelligence which are reproduced by demodulation in the output circuit.

By proper adjustment of the pick-up length 52, the system of Fig. 9 may be made applicable for receiving either symmetric electric or asymmetric electric waves as well as for asymmetric magnetic waves.

By disposing the crystals along a transverse arc centered on the axis as shown in Fig. 10, the system may be adapted for receiving symmetric magnetic waves in which the lines of force are circles about the axis. The pick-up projecting at 52 may be adjusted to get the optimum impedance matching effect.

Instead of ending the diametrically disposed assembly in an interior pick-up as at 52 in Fig. 9, the conductor can be carried the whole length of the diameter as in Fig. 11. Here the plate 53 serves as one plate of a condenser, its other plate being the metallic shell of the guide, so that the diametral conductor is effectively connected across the guide for high frequencies, but is connected at only one end for the low frequency output demodulation currents. In Fig. 11 the detector or detectors may be placed at any point along the length of the diametral conductor, the most advantageous position being determined experimentally. One or several detectors in series may be employed.

Another plan is, as in Fig. 12, to have a pick-up 52 projecting into the guide through a little hole in its side, with the crystal connected externally between this pick-up and the metal shell of the guide. This external circuit is shielded by the cylindrical cover cap 8. To reduce the variable reaction of the crystal due to its impedance variation with amplitude change, the pick-up probe 52 may be isolated by connecting the crystal through a short section of two-wire line, the two wires 54 and 55 being of suitable length *l*. If this length is made equal to a quarter wave length, then looking from the detector, one sees a comparatively low impedance; therefore the variation of the higher crystal detector impedance will develop at the probe 52 a greatly diminished impedance variation. This scheme of connection is applicable with other types of detectors and with other types of waves. To meet practical operating conditions, the length from the crystal to the side wall of the guide in Fig. 12 may be varied somewhat from the quarter wave length value in accordance with experimental determination. The systems of Figs. 9 and 12 can be

used either for detecting or measuring the intensity of the symmetric electric wave.

A plurality of detector units may be mounted radially as shown in Fig. 13, with one or more crystal detectors in each spoke of the radial structure. Here the elements are connected together at the center and the output is brought out through a radio frequency choke coil as shown. An alternative procedure is shown in Fig. 14. Here the radial elements are connected at their inner ends to a conductive ring 56 which is adjacent to, but insulated from, the end of the coaxial inner conductor pipe 58. The annular piston 59 is adjustable longitudinally. The inner cylinder 58 and the outer shell of the dielectric guide form a coaxial conductor system extending to the left from the array of radially disposed crystals. The radii may have the proper ratio to give impedance match between the dielectric guide and the coaxial conductor system. Symmetric electric waves incoming from the right are converted into coaxial conductor current waves which go on to the annular piston 59 and are reflected back therefrom toward the crystals. The adjustment of the piston 59 is made to bring the direct and reflected waves in the most advantageous phase relation at the crystals.

Referring to Figs. 5 and 6, one sees that the electric forces in the midpart of a vertical diameter may be opposed to those near its ends. Only the forces along the intermediate part of the diameter will be impressed upon the dipole shown in Fig. 15. The lengths of the pick-ups 52 may be adjusted within limits and if they need to be made longer, they may be bent over, with the extended parts parallel to the axis as shown in Fig. 16. This will be understood by reference to Figs. 5 and 6. Fig. 15 is adapted for the reception of waves of either of the types asymmetric electric or asymmetric magnetic. Fig. 16 is adapted for the reception of asymmetric electric waves.

As shown in Fig. 17, the crystals may be exposed to the received forces near the ends of the diameter, and if the pick-ups 52 need to be extended, this can be accomplished by bending them parallel to the axis in like manner as shown in Fig. 16.

Fig. 18 combines the principles of Figs. 15 and 17, connecting the three detectors in parallel. Similarly, other detectors may be disposed at advantageous places in the entire field of electric force and connected all in parallel.

For the detection of a symmetric magnetic wave, the detector units may be disposed in series as shown in Fig. 19. One or more of these lines of detector units may be employed and the outputs may be connected in series or parallel to the external circuit according as the best impedance match is secured.

Referring to Fig. 20, the detector shown is interposed in the axial conductor 60 of the coaxial conductor system whose outer conductor is the shell of the dielectric guide. The length of the axial conductor is made adjustable by means of the telescopic cap 61 at its right-hand end. The diameters of the inner and outer conductors of the coaxial conductor system are chosen at a suitable ratio to afford impedance match with the cylindrical dielectric guide at the right. A movable annular piston 59 is provided at the left by which a suitable standing wave system may be set up on the coaxial conductor system, and a proper impedance match may be established.

Referring to Fig. 21, this shows a sequence of thermoelectric junctions lying along a diameter of a wave guide. The metals of one kind are designated B<sub>1</sub> and those of the other kind are designated S<sub>b</sub>. The thermoelectric effects are generated in greater intensity at the smaller junctions between the diverse metals. The whole assembly lies along a line of force of a received asymmetric magnetic wave; the thermoelectric currents developed in the composite diametral conductor are effective as signal indications in the output circuit. Somewhat similarly, various substitutions of thermoelectric couples may be made for the crystals of the foregoing figures.

To adjust and perhaps intensify the effect of the received waves upon the detector, they may be reflected, as by the piston 65 in Fig. 22. The gap 66 may be adjusted in width to secure the optimum degree of coupling. Between the gap 66 and the piston 65, properly adjusted, a system of standing waves will be set up. Then the detector may be adjusted along the length of the guide to bring it to the place of most effective intensity in the standing wave system. Thus if the detector is of low impedance it may go at or near a voltage node, but if it is of high impedance it may go at or near a voltage loop. In the modification shown in Fig. 22a, there is an iris at 70 which is made adjustable, to control the admission of wave energy to the chamber between it and the piston.

A system for the more effective development and localization of standing waves at the receiving end is shown in Fig. 23. The pistons P<sub>1</sub> and P<sub>2</sub> are adjusted so that the distance  $x$  between them is approximately a half wave length or an integral multiple of half wave lengths. By shifting the pistons alike the intermediate standing wave is displaced until its amplitude is such at the place E of connection to the incoming wave guide that there is an impedance match and no reflection of wave energy back into the guide. The detector is then shifted to its optimum place as explained above for the detector of Fig. 22. But the reaction of the detector may be enough to require a little further readjustment of the pistons P<sub>1</sub> and P<sub>2</sub> to get an impedance match.

Beating oscillators for use in multiple detection reception may be associated with wave guides, for example, in the manner shown in the system of Fig. 24. The beating oscillator frequency  $f_2$  is set in relation to the received frequency  $f_1$  so  $f_1 - f_2$  or  $f_2 - f_1$  is equal to a suitable intermediate frequency. Although it is preferable for the two frequencies  $f_1$  and  $f_2$  to be of the same type of wave, this is not essential. The beating oscillator may take the same form as the signal generator or be of the Barkhausen, magnetron, or the negative grid type. One form of the latter is illustrated (for asymmetric magnetic waves) in Fig. 25. The position of the triode along the diameter should preferably be adjustable, since experience indicates maximum output at a particular position. To facilitate this adjustment the sliding tube scheme of Fig. 25 is suggested. The arrangement of Fig. 25 has given good results as an oscillator.

By varying the tube position and/or the operating parameters the circuit of Fig. 25 may be adjusted just below oscillation and operated as a regenerative detector. In an analogous manner Barkhausen and magnetron oscillators may be adjusted to oscillate feebly or just below the threshold of oscillation and act regeneratively.

The superregenerative receiver has the sim-

plicity and high gain of the regenerative receiver without the critical adjustments usually associated with the latter. To the oscillating detector circuit a second oscillator adds a quenching frequency. This is usually at a lower frequency and during a portion of its cycle the detector is in an oscillating condition and the signal builds up to a large value. Before the overload limit is reached, the quenching frequency voltage reverses in phase and the building up of the signal is definitely limited. The quenching frequency may be due to another oscillator circuit associated with the same tube or it may employ a separate tube and a separate circuit. The system of Fig. 25 may be used as a super-regenerative receiver.

Largely for simplification of the disclosure, one-way rectifiers have been shown in many of the figures that have been discussed heretofore. In numerous cases two-way rectification may be practiced, as for example, in the reception of asymmetric magnetic waves by means of the apparatus of Fig. 26. The lines of force of the received asymmetric magnetic waves are vertical, as viewed in the cross-section shown in Fig. 26. Two flat metal plates 72, overlapping one another at 73, are placed in a diametral, equipotential plane. At the sides they project, without metallic contact, through the longitudinal slots 71. The plates 72 also carry flanges 74 in capacity relation to the metal sheath of the wave guide. Four copper oxide rectifiers 75, 76, 77 and 78, each in itself a one-way rectifier, are disposed and connected as shown in the drawings. The circuits of the high frequency electromotive forces on the individual rectifiers are completed through the capacities 74 and the metal sheath of the guide. The circuit 79 for the lower frequency rectified currents is indicated by the little arrows. During one half-period, when the lines of electric force of the incoming wave are directed down, the signal current gets its electromotive force at 75 and 77; on the other half wave when the lines of electric force are directed up, the signal current gets its electromotive force at 76 and 78.

In the system of Fig. 27 the piston 81 is adjusted within the receiving end of the dielectric guide 80 so that in the resultant standing wave system the probe 82 will be at the proper place of intensity for optimum operation. The probe 82 connects through the crystal detector 83 to the wall of the housing 84 which is electrically connected with the shell of the guide 80. A beating oscillator 87 is connected as shown, with a probe 88 projecting into the chamber within the housing 84. The signal indicator 85 is connected across the crystal detector 83 through a choke coil 86. The received current waves through the dielectric guide 80 and the output of the beating oscillator 87 are superposed in the detector 83 according to well-known principles so as to get a signal indication in the device 85.

In the system of Fig. 28 the piston 81 is adjusted along the receiving end of the dielectric guide 80 to bring the standing wave system at a place of proper intensity on the two aligning

diametral wires 87. These two wire conductors 87 are bent aside at their meeting ends and connected respectively to the two conductors of the Lecher wire system 90, which extends across through holes 91 in the wall of the dielectric guide sheath 80. It will readily be seen that the electromotive forces of received waves are applied through the conductors 87 to the Lecher wire system 90. The two condenser bridges 92 and 93 are adjusted along the Lecher wire system 90 to set up a standing wave system thereon. Then the crystal detector 94 is adjustably bridged on the Lecher wire system to get the optimum effect therein and a beating oscillator 95 is also bridged across, as shown. The signal indicator 96 takes off the rectified current due to the received signal current and the superposed beating oscillator current in the crystal detector 94.

#### We claim:

1. In combination, a cylindrical metal-sheathed dielectric guide for asymmetric electric waves, three sensitive one-way detecting elements in series along a diameter of the guide, the extreme elements being oppositely directed to the intermediate element, and a signal indicating circuit comprising said elements in parallel and directed alike therein.

2. In combination, a wave guide comprising a metallic pipe, means for transmitting signal-modulated dielectrically guided waves there-through and a receiver for said waves comprising a plurality of rectifying devices disposed at different places in the path of said waves and a receiving circuit common to a plurality of said devices for carrying the rectified currents derived therefrom.

3. In combination, a wave guide comprising a metallic pipe carrying signal-modulated dielectrically guided waves of asymmetric electric type, two rectifying devices disposed within said pipe at separated points near the periphery thereof, and means connecting said devices together to a common signal output circuit.

4. In combination, a wave guide comprising a metallic pipe and means for transmitting signal-modulated dielectrically guided waves there-through, a multiplicity of detectors disposed in the path of said waves at a receiving point, and means connecting said detectors to a common signal output circuit, said connecting means having relatively high impedance at the frequency of said signal-modulated waves.

5. In combination, a wave guide comprising a metallic pipe carrying signal-modulated dielectrically guided waves therein, and a receiver for said waves comprising several asymmetrically conducting devices disposed within said guide at separate points in substantially the same transverse plane, said devices being differently oriented with each in substantial alignment with the incident electric field of said waves, an output circuit, and means connecting said devices in electrically aiding relation to said output circuit.

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