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COAXIAL LINE REFLECTOMETER HAVING A RESISTANCE
CONNECTED BETWEEN SECTION OF THE
OUTER CONDUCTOR

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3 Sheets-Sheet 1

Fig. 1

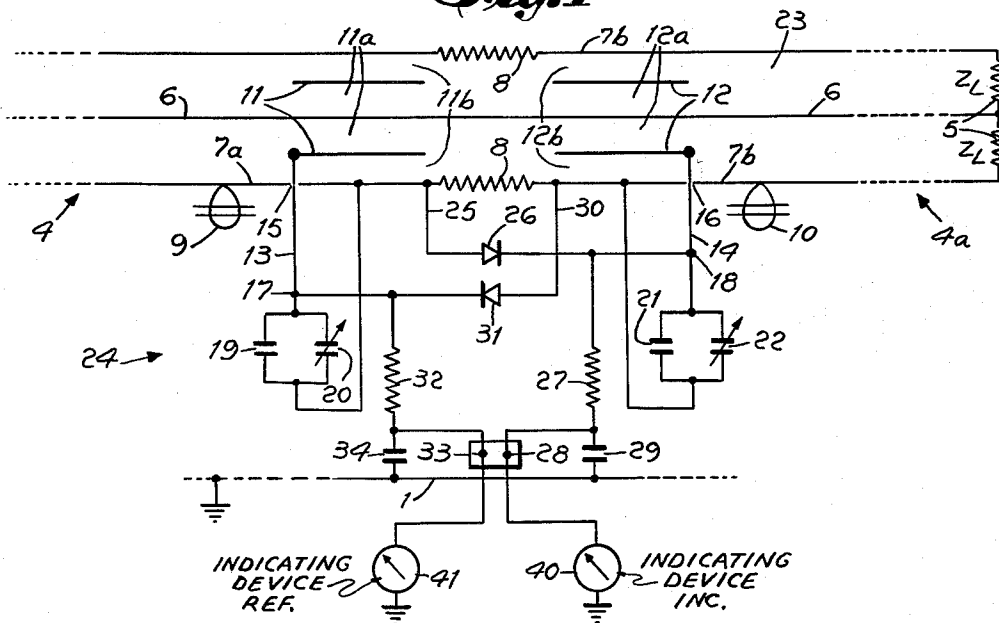
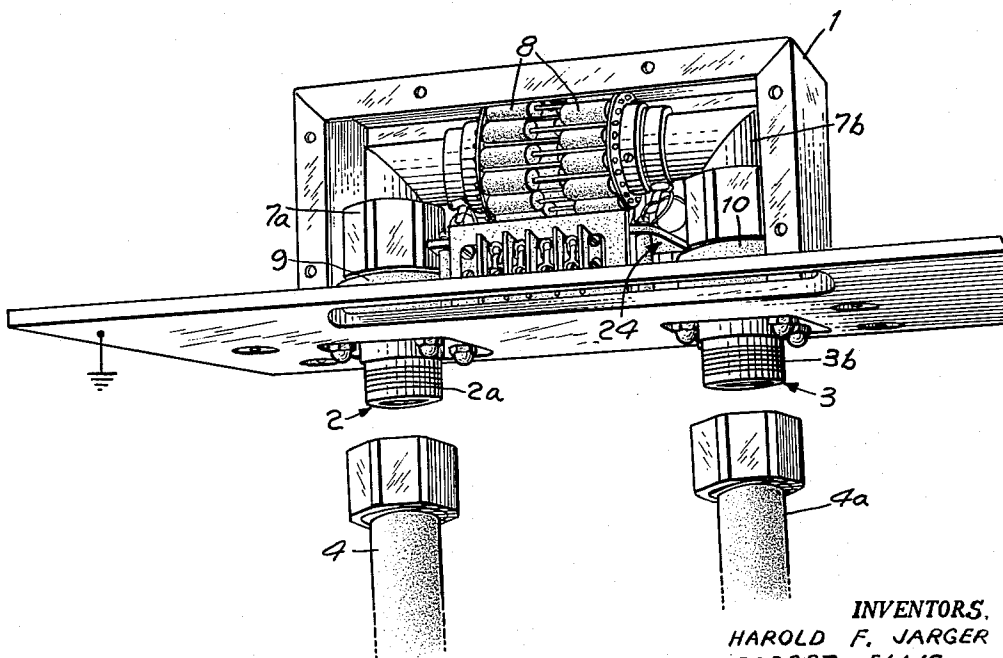


Fig. 2



INVENTORS.
HAROLD F. JARGER
ROBERT ELLIS
BY ROBERT T. ADAMS
Robert Lieber
ATTORNEY

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Fig. 3

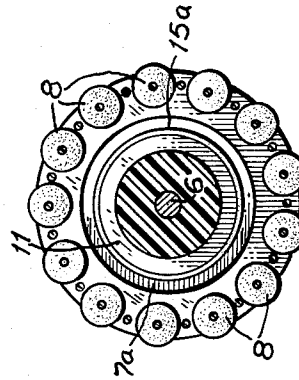
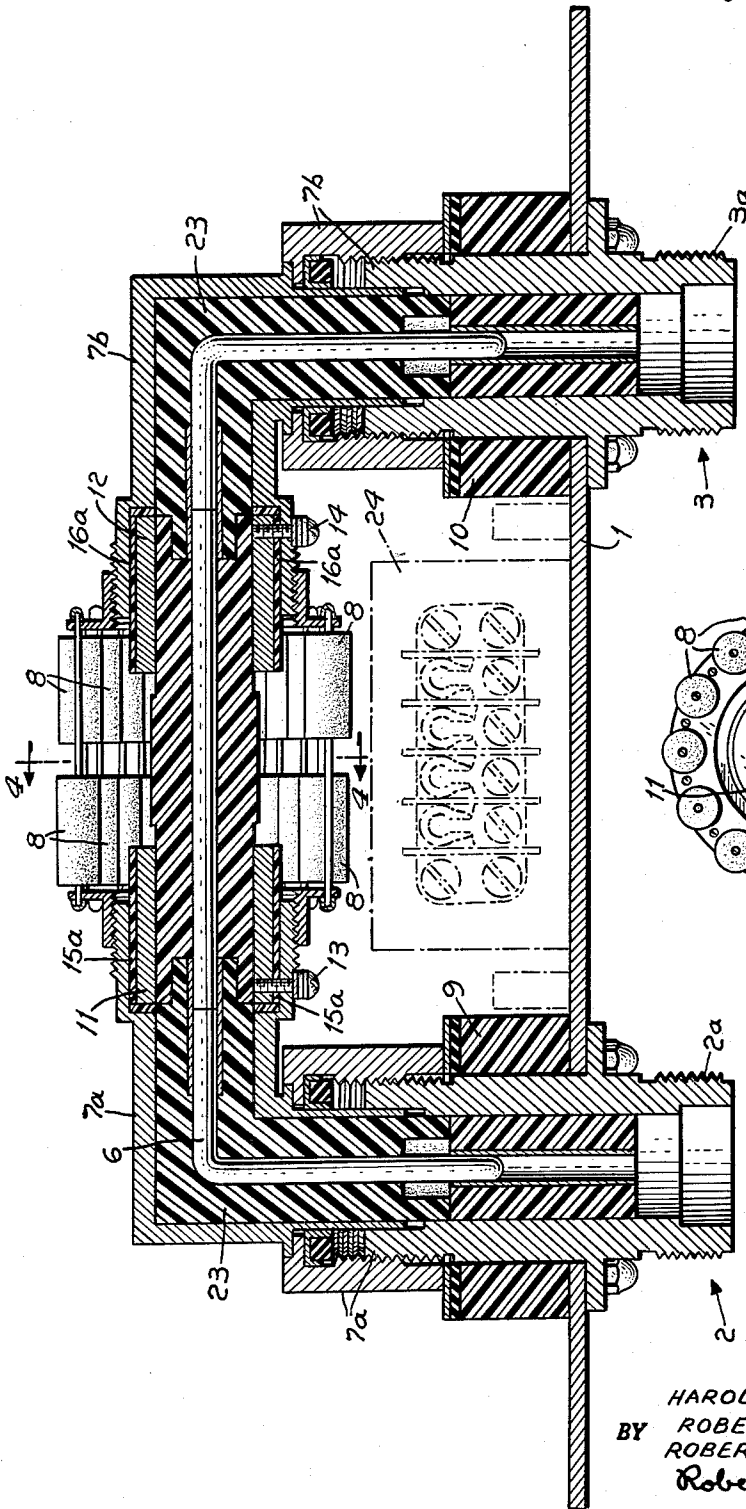


Fig. 4

INVENTORS.
HAROLD F. JARGER
BY ROBERT ELLIS
ROBERT T. ADAMS
Robert Lieber
ATTORNEY

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Fig. 5

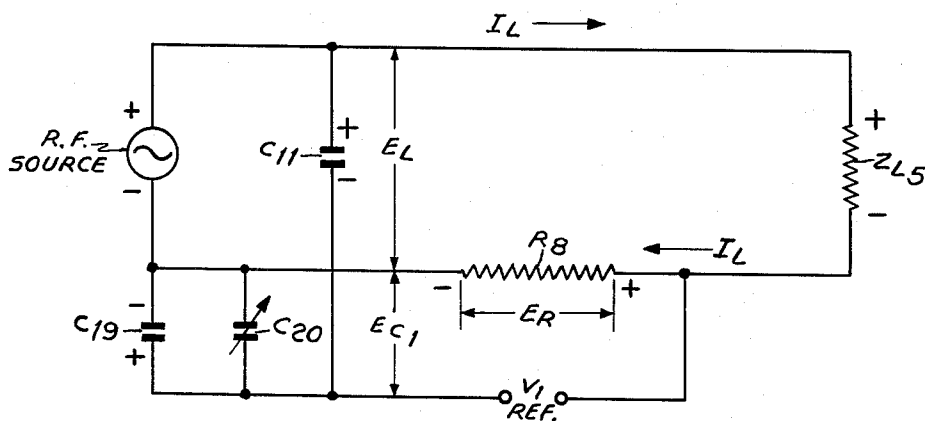
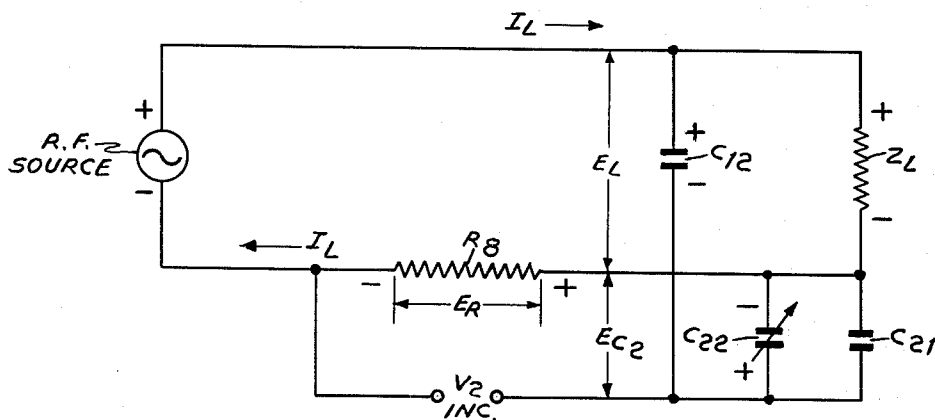


Fig. 6



INVENTORS.
HAROLD F. JARGER
ROBERT ELLIS
ROBERT T. ADAMS
BY
Robert Lieber
ATTORNEY

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COAXIAL LINE REFLECTOMETER HAVING A RESISTANCE CONNECTED BETWEEN SECTIONS OF THE OUTER CONDUCTOR

Harold F. Jarger, Rochelle Park, N.J., Robert Ellis, Jackson Heights, N.Y., and Robert T. Adams, Short Hills, N.J., assignors to International Telephone and Telegraph Corporation, Nutley, N.J., a corporation of Maryland

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7 Claims. (Cl. 324—95)

This invention relates generally to coaxial transmission line directional couplers and particularly to bi-directional couplers commonly termed reflectometers.

As disclosed on page 896 of "Techniques of Microwave Measurements," volume 11, MIT Laboratory series edited by C. G. Montgomery, a reflectometer normally comprises two directional couplers which are insertable into a test transmission line—one to measure incident R.F. power and the other to measure reflected R.F. power at the point of insertion—to provide a measure of the reflection coefficient, or the voltage standing wave ratio, of the line.

Prior art coaxial transmission line directional couplers generally employ a bulky arrangement involving either a resistor in series with the center conductor of the coaxial line with appropriate leads brought out through high voltage insulated openings in the outer conductor of the coaxial line, or a chamber in which is placed a transformer type coupling which extracts the energy to be measured. These structures are generally inadequate because of the aforementioned bulkiness and also because of the necessity for complex high voltage insulating structures or complex current transforming structures, or other design complications.

These and other disadvantages found in prior art apparatus are avoided by means of the present inventive arrangement wherein a relatively low voltage, with respect to the outer coaxial conductor, is developed across a resistor placed in series between separated portions of the outer conductor, the thus developed low voltage being compared to the voltage developed across a capacitive voltage divider network running between the center conductor and one of the separated outer conductor portions. This arrangement has been found to result in an overall structure of considerably reduced size, of convenient accessibility for adjustment of the strength of the signal extracted from the main line, and also of improved performance characteristics.

A problem arising with this type of arrangement, however, is that, because of its position in series with the outer conductor, it is difficult to enclose the above-mentioned series resistor and outer conductor portions in a metal housing, for shielding and packaging purposes, without, in effect, shorting out the signal to be measured. This problem has been solved by providing a ferrite core structure between the outer housing shield of the apparatus and the outer conductor of the coaxial structure, to which the series resistance is connected, so that a relatively high impedance is presented to energy propagating between the outer surface of the outer conductor and the housing shield.

It is therefore a general object of this invention to provide an improved directional coupler apparatus.

A more specific object is to provide an improved coaxial line reflectometer.

A still more specific object is to provide a coaxial line reflectometer in which signals coupled out of a coaxial line are maintained at a low voltage with respect to the outer conductor of the coaxial line.

Another specific object is to provide coaxial line re-

flectometer apparatus wherein signals are extracted from a coaxial line at a relatively low voltage with respect to the outer conductor of the line, by means of a relatively small resistance which is connected in series between separated portions of the said outer conductor, and which is contained within a metal shielding housing which is isolated from signals developed across the said series resistance.

These and other objects and features of the present invention may be more fully understood and appreciated from the following detailed description of exemplary reflectometer apparatus designed to accommodate one kilowatt of energy in the main coaxial line while dissipating only about 10 watts of energy in the VSWR monitoring structure, said description to be read in association with the accompanying drawing wherein:

FIGURE 1 is a schematic drawing illustrating the electrical circuit configuration corresponding to the reflectometer structure of the present invention,

FIGURE 2 is a plan view illustrating the actual physical structure of the present reflectometer apparatus,

FIGURE 3 is a sectional view taken through the axis of the coaxial structure within the reflectometer apparatus illustrated in FIGURE 2,

FIGURE 4 is a view of a section through the apparatus of FIGURE 3 taken along the lines 4—4 transverse to the axis of the coaxial structure shown in FIGURE 2, and

FIGURES 5 and 6 are partial schematics for explaining the theory of operation of the present apparatus.

Referring to FIGURES 1 through 4, exemplary reflectometer apparatus, having a flat output response within the frequency range 2–30 megacycles, and constructed in accordance with the teachings of this invention, comprises a metal shield and housing 1 having coaxial connectors 2 and 3 connected thereto for respectively making output and input terminal connections to separated sections 4 and 4a, of a coaxial line, so that R.F. energy propagating down the line 4 enters the housing at 2, passes through apparatus to be described within the housing, emerges from the housing at 3 and continues down the coaxial line section 4a to a load termination 5, at which the energy is either fully absorbed or partially reflected back towards the terminal 3 through the housing, out of the terminal 2 and back through the line section 4. The function of the reflectometer apparatus within the housing 1 is to provide minimal interference with the above mentioned energy propagation while utilizing a portion of the propagating energy to produce a signal or signals representative of the VSWR (voltage standing wave ratio) at the point of insertion of the apparatus in the line 4, 4a, the dimensions of the housing 1 being small in relation to a quarter wavelength of the propagating signal.

A center conductor 6 extends along the axis of the connector 2 and through the housing 1 to the connector 3. The corresponding outer conductor of the coaxial structure comprises the outer portion 2a of the conductor 2, a hollow conductive section 7a connected thereto, a cylindrically arranged resistance indicated generally at 8, in series with the section 7a, and a hollow conductive section 7b connected to the resistance 8, and to the outer portion 3a of the connector 3. Toroidal ferro-electric cores 9 and 10 are placed in corresponding grooves located between the outer surfaces of the outer conductor sections 7a and 7b and the respective connections between the connectors 2 and 3, and the housing 1 to isolate R.F. signals propagating along the outer surfaces of the sections 7a and 7b from the grounded shield 1, for purposes discussed hereinafter, it being noted at this point that R.F. energy entering the reflectometer via either connector 2 or connector 3 will be confined to the interior of the coaxial structure until it reaches the resistor 8 at which point some of the energy may "leak out" of the coaxial

enclosure and propagate along the outer surface of section 7a or section 7b to the inner surface of the housing 1, thereby bypassing resistance 8. It is this outer propagation which is impeded by the ferroelectric cores 9 and 10, which, in effect, act as R.F. chokes. The impedance offered to currents flowing on the outer surfaces of the coaxial connector is increased by the placing of the ferrite cores. This portion of the circuit can be represented as a toroidal inductor of one turn. The inductive reactance of a toroid can be expressed as:

$$X_L = KN^2 \frac{A_C \mu_C}{l_C \mu_0}$$

where

A_C = cross sectional area of core
 l_C = average flux path length
 N = number of turns
 μ_0 = permeability of free space
 μ_C = permeability of core
 K = constant of proportionality

In this device $N=1$, $A_C/l_C \approx .5$, but μ_C/μ_0 may be in the order of several hundred to a thousand, resulting in a marked increase in inductive reactance.

On either side of the resistance 8, the coaxial structure contains hollow tubular conductive members 11 and 12 which provide a predetermined amount of distributed capacitance extending from the center conductor 6 to the tubular members, and also extending from the said respective tubular members to the respective outer conductor sections 7a and 7b. The distributed capacitances between the center conductor 6 and the tubular members 11 and 12 are designated respectively 11a and 12b while those between the said members 11 and 12 and the corresponding outer conductor sections 7a and 7b, are respectively designated 11b and 12b.

Conductive connections 13 and 14 are brought out through respective openings 15 and 16, in the outer conductor sections 7a and 7b—which openings are suitably insulated by means of dielectric spacers 15a and 16a, respectively—from the respective tubular members 11 and 12, to respective terminals 17 and 18. Fixed and variable capacitors, 19 and 20, respectively, are connected in parallel between terminal 17 and outer conductor section 7a, while a symmetrically disposed pair of fixed and variable capacitors, 21 and 22, respectively, are connected in parallel between terminal 18 and section 7b. The interior of the coaxial structure is filled with an insulating dielectric such as polyethylene or Teflon, indicated generally at 23, in which the tubular metal members are embedded.

The terminals 17, 18 and components 19–22 are all mounted on a terminal board indicated generally at 24. From FIGURE 1 it is clear that the capacitors 19 and 20 are in parallel with distributed capacitance 11b, and likewise that capacitors 21 and 22 are in parallel with distributed capacitance 12b.

An incident R.F. signal detection network comprises the series combination of a conductor 25—which is connected to outer conductor section 7a at one end of resistance 8—a crystal rectifier 26, terminal 8, a resistor 27, and an output terminal 28 all mounted on board 24. A bypass capacitor 29 is connected between the ground of housing 1 or any other suitable ground, and terminal 28.

Similarly, a reflected R.F. signal detection network comprises the series combination of a conductor 30—which is connected to the outer conductor section 7b at the opposite end of resistance 8 relative to conductor 25—a crystal rectifier 31, terminal 17, resistor 32, and output terminal 33, all mounted on board 24, with a bypass capacitor 34 connected between terminal 33 and the housing ground.

It will be shown that the series combination of capacitance 11a, and the parallel capacitances 11b, 19 and 29, represents an adjustable voltage divider which transfers

a signal proportional to the incident R.F. signal appearing across coaxial conductors 6 and 7a to terminal 17, and similarly, that capacitance 12a in series with the parallel capacitances 12b, 21, and 22, represents an adjustable voltage divider for reflected signals with respect to terminal 18.

The theory of operation is as follows:

This device makes use of the phenomenon relating to the existence of a current, on the inner surface of the outer conductor of a coaxial transmission line, which is equal and opposite to the current flowing in the center conductor. This current on the outer conductor produces a voltage E_R (FIGS. 5, 6) across R(8) (FIGS. 5, 6) which is proportional to the current I_L on the line.

The voltage and current on the transmission line can be expressed as:

$$\begin{aligned} E_L &= E_i + E_r \\ I_L &= 1/Z_0 (E_i - E_r) \end{aligned}$$

where

E_L = voltage at any point on the line
 E_i = incident voltage
 E_r = reflected voltage
 I_L = current at the point of observation on the line and

Z_0 = surge (characteristic) impedance of the transmission line

Referring to FIG. 5

The voltage across the capacitor divider can be expressed as:

$$E_{c1} = \frac{C_{11}}{C_{11} + C_{19} + C_{20}} (E_L) = \left(\frac{C_{11}}{C_{11} + C_{19} + C_{20}} \right) (E_i + E_r)$$

The voltage across the resistor R_8 can be expressed as:

$$E_R = I_L R_8 = \frac{R_8}{Z_0} (E_i - E_r)$$

If the polarities of the voltages due to an R.F. source are as shown in FIG. 5, then it can be seen that V_1 is the difference voltage between E_{c1} and E_R .

If E_{c1} is adjusted to be equal to E_R when E_r is equal to zero, as is the case when the line is terminated in Z_0 , then for any other value of Z_L , V_1 becomes:

$$V_1 = 2 \frac{R_1}{Z_0} (E_r)$$

whence V_1 is a function of the reflected voltage on the line and will be equal to zero for a properly terminated transmission line. When used with a suitable metering circuit, such as that indicated at 41 in FIG. 1, the output will be an indication of reflected power.

Referring to FIG. 6 the voltage and current on the line are, as previously mentioned:

$$E_L = E_i + E_r$$

$$I_L = \frac{1}{Z_0} (E_i - E_r)$$

The voltage E_{c2} across the voltage divider can be expressed as:

$$E_{c2} = \frac{C_{12}}{C_{12} + C_{21} + C_{22}} (E_{L2}) = \frac{C_{12}}{C_{12} + C_{21} + C_{22}} (E_i + E_r)$$

The voltage E_R is, as previously mentioned:

$$E_R = I_L R_8 = \frac{R_8}{Z_0} (E_i - E_r)$$

It can be seen in FIG. 6, that V_2 is equal to the sum of E_{c2} and E_R . If E_{c2} is adjusted to be equal to E_R when E_r is equal to zero, i.e. when the transmission line is terminated in Z_0 , then for any other value of

$$Z_L, V_2 \text{ becomes } = \frac{2R_1}{Z_0} (E_i)$$

whence V_2 is a function of the incident voltage and with a suitable metering circuit will indicate incident power.

Thus, by adjusting capacitances 20 and 22, the signals at terminals 28 and 33, taken with respect to ground, are,

respectively proportional to the incident and reflected signal levels. These signals may then be monitored by suitably calibrated D.C. microammeters, as shown at 40 and 41, respectively.

A table of specific dimensions and component values used in the construction of the above discussed reflectometer structure is given in table 1 below:

TABLE 1

Item	Description
2, 3,-----	Male connectors, LC type UG287/U.
7a, 7b,-----	Metal elbow joints, LC type UG208/U.
9, 10,-----	Ferroelectric cores, 1 1/4" I.D., 2" O.D., 3/4" length.
11, 12,-----	Tubular capacitance plates approximately 1 inch in length by 3/4 inch in mean diameter, by 1/4 inch thick.
11a, 12a,-----	Distributed capacitances between center conductor 6 and plates 11 and 12; approximately 3 μf.
11b, 12b,-----	Distributed capacitances between plates 11 and 12, and corresponding outer conductor sections 7a, and 7b; approximately 45 μf.
19, 21,-----	Lumped capacitors; approximately 200 μf.
20, 22,-----	Lumped variable capacitors, approximately 7-45 μf.
26, 31,-----	Crystal rectifiers, type 1N270.
27, 32,-----	Lumped resistors; approximately 1,000 ohms.
29, 34,-----	Lumped bypass capacitors; approximately 01 μf.
8,-----	26 lumped resistors, each 13 ohms, 2 watts, all connected in parallel between sections 7a and 7b to provide a total resistance of 0.5 ohms.

It is noted that while for the present purposes it has been found expedient to construct the resistance 8 out of a plurality of lumped resistors cylindrically disposed, those skilled in the art will appreciate that under certain circumstances a deposited film resistor might provide an even more effective structure, and that such deposition of a resistor is easily within the skill of those familiar with this art. Accordingly, the construction indicated above is not to be construed as a limitation on this invention.

While we have described above the principles of our invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of our invention as set forth in the objects thereof and in the accompanying claims.

We claim:

1. Coaxial transmission line directional coupler apparatus comprising:

- (a) A first hollow outer conductor section,
- (b) A second hollow outer conductor section,
- (c) A central conductor coaxially disposed within said first and second sections,
- (d) A resistance connected in series electrical circuit between said first and second sections,
- (e) A first voltage divider network connected between said central conductor and said first section,
- (f) A second voltage divider network connected between said central conductor and said second section,
- (g) A first signal detection network, coupled between said second section and said first voltage divider network,
- (h) A second signal detection network coupled between said first section and said second voltage divider network,
- (i) And means coupled to said first and second signal detection networks for monitoring output signals therefrom.

2. A coaxial line reflectometer comprising:

- (a) A first hollow outer conductor section,
- (b) A second hollow outer section axially aligned with said first section,
- (c) A central conductor coaxially disposed within said first and second outer sections,
- (d) A coupling resistance connected between said first and second sections,
- (e) A first voltage divider network connected between said central conductor and said first section,
- (f) A second voltage divider network connected between said central conductor and said second section,

- (g) A first signal detection network connected between said second section and said first voltage divider network,
 - (h) A second signal detection network connected between said first section and said second voltage divider network,
 - (i) And means coupled to said first and second signal detection networks for jointly monitoring the outputs thereof.
3. A coaxial line directional coupler comprising:
- (a) A first hollow outer conductor section,
 - (b) A second hollow outer conductor section axially aligned with said first section,
 - (c) A central conductor coaxially disposed within said first and second outer sections,
 - (d) A coupling resistance connecting said first and second sections,
 - (e) Capacitive voltage divider means connected between said first section and said central conductor,
 - (f) Signal detection means coupled between a tap point on said capacitive voltage division means and said second section,
 - (g) A metal housing shield surrounding said coupling resistance,
 - (h) And means interposed between the end of said coupling resistance connected to said first section, and the said metal housing for preventing leakage of R.F. currents between the outer surface of said first section and the inner surface of the said housing.
4. Coaxial line reflectometer apparatus comprising:
- (a) A first hollow outer conductor section,
 - (b) A second hollow outer conductor section coaxially aligned with said first section,
 - (c) A cylindrically disposed hollow resistance connected between said first and second sections,
 - (d) A central conductor coaxially disposed within the enclosure defined by said first section, said connected resistance, and said second section,
 - (e) A capacitive voltage divider network connected between said central conductor and said first section, including a hollow conductive tubular member disposed coaxially intermediate said first section and said central conductor, which tubular member provides a predetermined distributed capacitance between the said central conductor and the said member and also a predetermined distributed capacitance between the said member and the said first section,
 - (f) A signal detection network connected between the said second section and the said tubular conductive member,
 - (g) Means connected between said tubular conductive member of said first section for varying the voltage division ratio associated with said voltage divider network,
 - (h) And means coupled to said tubular member for monitoring the signals appearing thereat.
5. Coaxial line reflectometer apparatus comprising:
- (a) A central conductor,
 - (b) A first hollow outer conductor section coaxially surrounding said central conductor,
 - (c) A second hollow outer conductor section axially aligned with said first section, and coaxially surrounding said central conductor,
 - (d) A resistance disposed in hollow tubular fashion around said central conductor, and electrically connecting said first and second sections,
 - (e) A first tubular shaped hollow conductive member coaxially disposed intermediate said central conductor and said first section,
 - (f) A second tubular shaped hollow conductive member coaxially disposed intermediate said central conductor and said second section,
 - (g) A first signal detection network coupled between said second section and said first tubular member,
 - (h) A second signal detection network coupled between

- said first section and said second tubular member,
- (i) Means coupled between said first tubular member and said first section for varying the impedance presented by said tubular member to incident R.F. energy propagating in said first section, 5
 - (j) Means coupled between said second tubular member and said second section for varying the impedance of said second tubular member to reflected R.F. energy propagating in said second section, 10
 - (k) A conductive housing enclosing all of the above-mentioned items and having electrical connections to the outer surfaces of said first and second sections at given regions thereof, 15
 - (l) And means intermediate said given connection regions to said first and second sections and said resistance for impeding leakage of R.F. currents between the exterior of said hollow resistance and said conductive housing. 20
6. Apparatus according to claim 5 wherein:
- (a) The outer surfaces of said first and second sections are inwardly grooved between said connecting region and said resistance, 25
 - (b) And said leakage impeding means includes first and second ring-shaped ferroelectric core members respectively mounted in said input and output sheath section grooves. 30
7. Coaxial transmission line reflectometer apparatus comprising:
- (a) A first hollow outer conductor section,
 - (b) A second hollow outer conductor section having an axis in line with an axis of said first section,
 - (c) A cylindrically disposed resistance connected between said first and second sections,

- (d) A central conductor threading said first and second sections and said resistance,
- (e) First and second capacitive voltage divider networks connected between said central conductor and said respective first and second sections,
- (f) First and second R.F. signal detection means coupled between said respective first and second voltage divider networks and said respective second and first sections,
- (g) First and second voltage adjustment means connected to said respective first and second voltage divider means for independently adjusting the respective outputs thereof to be equal to the voltage drop across said resistance, when the coaxial line containing said sections, said resistance, and said central conductor, is terminated in its characteristic impedance, over a wide band of input frequencies,
- (h) and first and second indicating means respectively coupled to said first and second signal detection means for indicating the levels of respective reflected and incident signals passing thru said resistance.

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WALTER L. CARLSON, *Primary Examiner.*R. V. ROLINEC, *Assistant Examiner.*