

Feb. 22, 1966

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3,237,130

FOUR-PORT DIRECTIONAL COUPLER WITH DIRECT CURRENT ISOLATED
INTERMEDIATE CONDUCTOR DISPOSED ABOUT INNER CONDUCTORS

Filed April 17, 1963

2 Sheets-Sheet 1

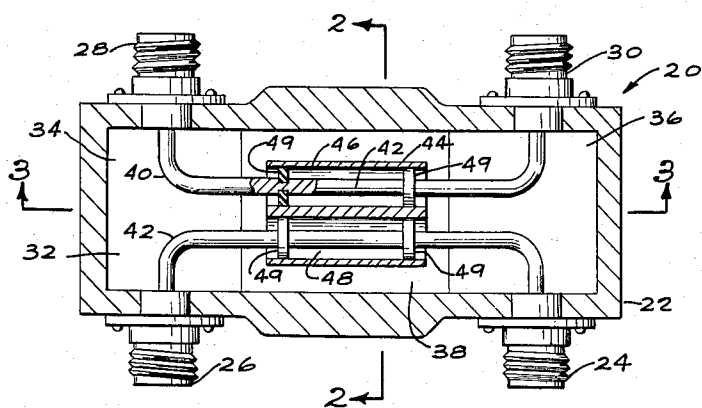


FIG. 1

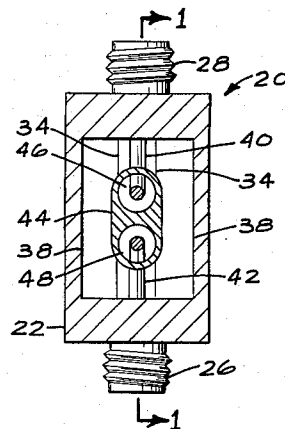


FIG. 2

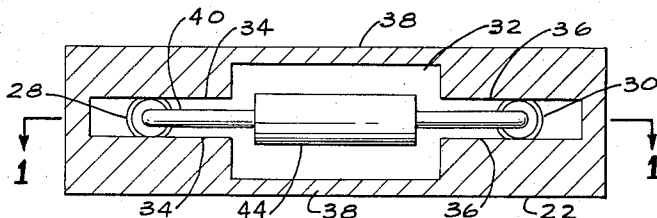


FIG. 3

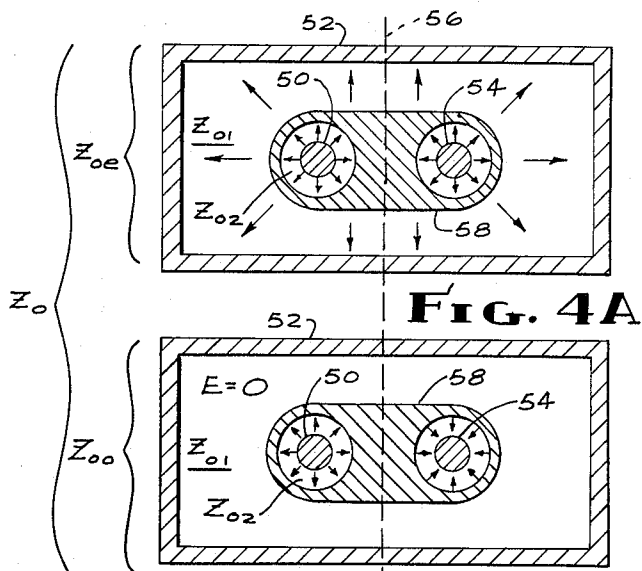


FIG. 4A

FIG. 4B

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2 Sheets-Sheet 2

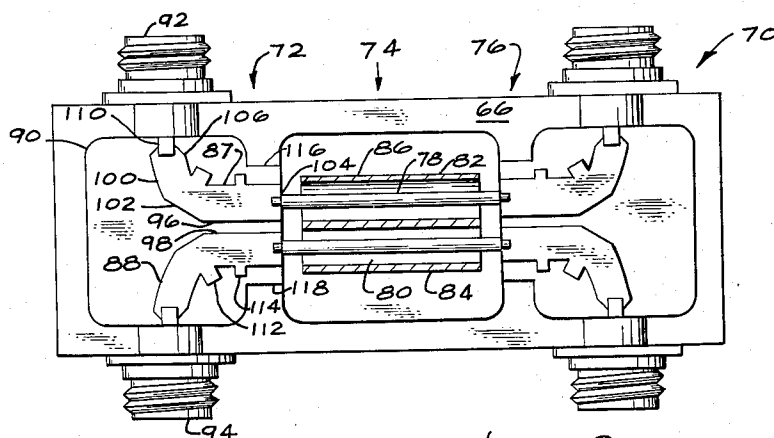


FIG. 6

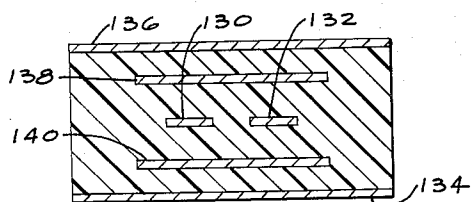


FIG. 8

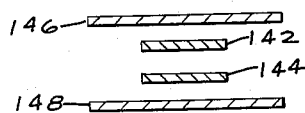


FIG. 9

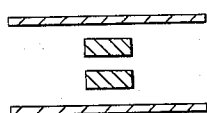


FIG. 10

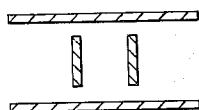


FIG. 11

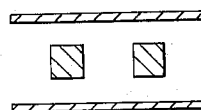


FIG. 12

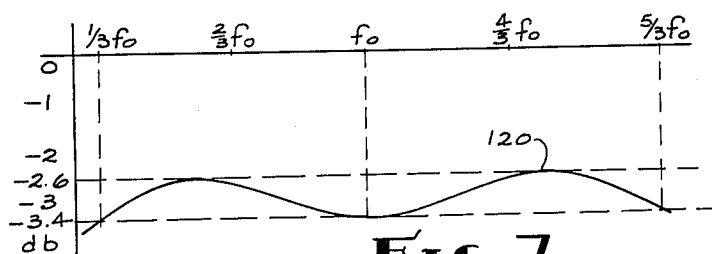


FIG. 7

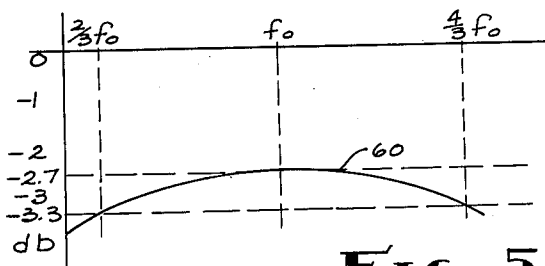


FIG. 5

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FOUR-PORT DIRECTIONAL COUPLER WITH DIRECT CURRENT ISOLATED INTERMEDIATE CONDUCTOR DISPOSED ABOUT INNER CONDUCTORS

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14 Claims. (Cl. 333—10)

This invention relates generally to microwave devices and more particularly to transmission line coupling structures as utilized, for example, in directional couplers, filters, and other components and circuits.

The present invention finds particularly useful application in embodiments thereof which exhibit three-db directional coupling. This class of embodiments, also known as hybrid couplers, are generally four-port devices which divide input microwave energy at one terminal into separate output energies at two other terminals, the output energies having predetermined magnitude and phase interrelationships; namely, equality and, usually, quadrature, respectively. Although this form of the invention is particularly useful at present and most of the examples and discussion herein are directed thereto, it is stressed that it is not intended that the invention be limited to three-db directional couplers per se.

In many modern microwave systems such as, for example, radar or communications networks three-db directional couplers form basic and essential components of many sub-systems such as balanced mixers, duplexers, power dividers, ferrite circulators, multiplexing filters, monopulse circuitry and the like. In at least a majority of such systems future developments and achievements have been definitely limited by the quality and other characteristics of hybrid couplers heretofore available for use in practical systems. Typical deficiencies or disadvantages of prior art three-db directional couplers include inadequate bandwidth, directivity, or power handling capability or undesirably large voltage standing wave ratios (VSWR), length and weight, or cost.

Study and development of strip-line techniques have provided improved bandwidth capabilities and good directivity, but strip-line couplers have limited power handling ability and have very close manufacturing tolerances. These become particularly significant disadvantages when tight coupling and reasonable geometries are specified. Multiple section strip-line couplers have been studied because of their desirable theoretical capabilities, that is, their bandwidth and directivity. However, the power handling abilities and tolerance problems, in addition to the discontinuities between the sections which cause excessive VSWR and loss of directivity, pointed out above, are even more severe in the multi-section strip-line case.

It may be stated that there has not heretofore been developed a commercially practicable multi-section three-db directional coupler for utilization in the microwave regions of the electromagnetic spectrum.

It is therefore an object of the present invention to provide a transmission line coupling structure which is not subject to these and other disadvantages of the prior art.

It is another object to provide a three-db directional coupler which has a bandwidth of at least five to one with coupling deviations thereover of less than plus or minus one-half db.

It is another object to provide such a hybrid coupler which has significantly improved directivity and power handling capabilities.

It is another object to provide such a hybrid coupler for microwave utilization which has relaxed tolerances

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and greatly increased repeatability of characteristics as compared to the similar properties of the prior art.

It is another object to provide such a coupler which is light in weight and which is the order of a few inches in overall length.

It is another object to provide an elemental quarter-wave section for a three-db directional coupler, the basic design of which is sufficiently versatile to permit adaptation thereof from either a tight or a loose coupling utilization.

It is another object to provide such a quarter-wave coupler section which is mechanically rugged, has highly repeatable electrical characteristics, and which may be economically mass-produced.

Briefly, in accordance with the structural features of one example of the present invention these and other objects and advantages are achieved in a quarter-wave three-db directional coupler section comprising a pair of parallel, "inner" transmission lines in the form of cylindrical conductors approximately one-eighth inch in diameter and a few inches in length.

Each of the cylindrical conductors is coaxially spaced within an intermediate thin wall conductive tube of approximately three-sixteenths inch inside diameter. The tubes are disposed adjacently and are mechanically and electrically joined along their length. This assembly is then placed within an overall "outer" ground plane conductor.

The ends of the inner rods are coupled to the four ports of the coupler with the outer conductor being connected as the common terminal. The intermediate conductor is left electrically floating and would appear to shield the inner conductors from each other and from the outer conductor. However, the intermediate conductor is in fact in series with the others as are, analogously, the schematically adjacent plates of a plurality of capacitors which are connected in series.

The coupler is a backward wave coupler and, as will be discussed in more detail below, when the characteristic impedances of the various transmission line segments are designed in view of even and odd modes of electromagnetic energy transmission therethrough, the assembly provides an exceptionally large bandwidth of three-db coupling and a high degree of directivity.

The coupler section, designed to have an electrical length of one quarter-wave at the design center frequency, may be employed as a single section three-db directional coupler or it may be incorporated between two other coupler sections with looser coupling to provide a three-quarter wave coupler having even greater advantage of bandwidth. More than two additional coupler sections can be employed as desired to provide still greater bandwidth of operation.

Further details of these and other novel features and their principles of operation as well as additional objects and advantages will become apparent and be best understood from a consideration of the following description taken in connection with the accompanying drawings, which are all presented by way of illustrative example only and in which:

FIG. 1 is a partially plan, partially sectioned, view of a quarter-wave section three-db directional coupler constructed in accordance with the principles of the present invention;

FIG. 2 is a cross-sectional view of the structure of FIG. 1 taken along the lines 2—2 thereof;

FIG. 3 is a longitudinal sectional view of the structure of FIG. 1 taken along the lines 3—3 thereof;

FIG. 4A and FIG. 4B are cross-sectional field vector diagrams for use in discussing the operation of the invention;

FIG. 5 is a graph plotting frequency along the abscissa

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and the degree of coupling along the ordinate for a three-db directional coupler constructed along the lines indicated in the previous figures;

FIG. 6 is a partially plan, partially sectional view of a three-section three-db directional coupler constructed in accordance with the principles of the present invention;

FIG. 7 is a graph relating to the operation of the coupler depicted in FIG. 6 and plotting, as in FIG. 5, frequency versus coupling;

FIG. 8, FIG. 9, FIG. 10, FIG. 11 and FIG. 12 are cross-sectional views of alternative examples of the structure of the present invention.

Referring to the figures in more detail, it is stressed that the particulars shown are by way of example only and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles of the invention. The detailed showing is not to be taken as a limitation upon the scope of the invention which is defined by the appended claims forming a part of this specification.

In FIG. 1 there is illustrated a quarter-wave section re-entrant three-db directional coupler 20 which includes a body member 22 having four coaxial connectors 24, 26, 28, 30. The interior of the body member 22 is relieved to define a stepped cavity 32 which comprises a shelf 34, 36 at either end, respectively, joined by a more deeply relieved central region 38. A pair of transmission lines, 40, 42 are each interconnected between a different pair of the coaxial connectors as illustrated.

In the volume defined by the central region 38, the segments of the transmission lines 40, 42 are substantially parallel with each other and spaced by a distance comparable to their diameter. The conductive walls of the central region 38 form an "outer" conductor which in a radial sense surrounds the inner transmission lines 40, 42 in that portion of the coupler. An intermediate "floating" conductor 44 is provided between the inner transmission lines and the outer conductor which consists, in this example, of an elongated tubular member having a pair of cylindrical bores 46, 48 within which are disposed concentrically the central parallel segments of the transmission lines 40, 42. Alternatively, the intermediate conductor 44 may be a right parallelepiped, not shown, from which the bores 46, 48 have been removed. As implied above the intermediate conductor 44 is electrically insulated from the outer conductor defined by the central region 38 of the body member 22. The conductor 44 is similarly insulatively spaced from the transmission lines 40, 42 upon which it may be mechanically rigidly supported by means of dielectric spacer rings 49, which are disposed between the inner transmission line segments and the intermediate conductor 44. The spacer rings 49 may be disposed in shallow peripheral channels, as shown, to secure their axial position and to tend to maintain Z (see below) constant along the length of the re-entrant section. Additional dielectric spacers, not shown, have been used to support the center conductor assembly symmetrically within the outer conductor structure.

The shelves 34, 36 of the body portion 22 are spaced from the end, transitional portions of the transmission lines 40, 42 by a distance which provides a satisfactory impedance match between an external line and the central portion of the coupler. The central region 38 of the coupler is relieved to a deeper extent to provide mechanical clearance between the intermediate conductor 44 and the body member 22 and to provide the desired characteristic impedance between 44 and 22.

Referring to FIG. 2 a cross-sectional view of the structure depicted in FIG. 1 illustrates the lateral symmetry of the coupler 20. Again the body member 22 is illustrated as being internally relieved to form a central region 38 and stepped end portion shelves 34. The inner transmission lines 40, 42 are shown, where sec-

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tioned in the figure, as being disposed concentrically within the cylindrical bores 46, 48, respectively, of the intermediate conductor 44.

The longitudinal sectional view of FIG. 3 illustrates the continuity of the inner transmission line 40 from the coaxial connector 28, through the impedance transitional region formed by the shelves 34, through the intermediate conductor 44, and through the transition region formed by the shelves 36 to the connector 30. The symmetrical location of the intermediate conductor 44 and its spacing from the central region 38 of the body member 22 as well as its longitudinal spacing from the inner ends of the shelves 34, 36 is illustrated.

In a typical mode of utilization of the re-entrant coupler 20, the connector 26 may serve as the "input" port, the connector 24 as the "transmitted" output port, the connector 28 as the "coupled" output port, while connector 30 is the "isolated" port. The general object of this class of device is, as indicated above, to divide the input power at connector 26 into two equal power portions available at connectors 28 and 24, respectively. In this case, the coupling is nominally three-db.

Referring to FIG. 4A and FIG. 4B, a schematic cross-section of the central section of a re-entrant coupler in accordance with the present invention is illustrated with a plot of the electrical field distribution between the different conductors for the even mode (FIG. 4A) and the odd mode (FIG. 4B) of electromagnetic transmission through the coupler. As in the case with conventional directional couplers, it is considered that this re-entrant line coupler may be best analyzed in terms of its even and odd mode characteristic impedances. The even mode characteristic impedance Z_{oe} occurs between the inner conductor 50 and the outer conductor 52 when the radio frequency currents and voltages on the inner conductors 50, 54 are respectively equal in magnitude and phase. In this mode it may be seen that a theoretical "magnetic" wall may be disposed coincident with the line of symmetry 56 since the H field components are everywhere perpendicular to the plane of symmetry and E field components lie in this plane. The odd mode characteristic impedance Z_{oo} occurs when the radio frequency currents and voltages on the inner transmission lines 50, 54 are respectively equal in magnitude but are 180 degrees out of phase, causing the electromagnetic field intensities between the intermediate conductor 58 and the outer conductor 52 to be everywhere zero. In this mode it may be seen that the overall structure may be bisected through its vertical plane of symmetry 56 by an imaginary "electric" wall.

The characteristic impedance of the transmission line consisting of an inner transmission line 50 or 54 and the intermediate conductor 58 is designated Z_{o2} , while the characteristic impedance of the transmission line represented by the outer conductor 52 and the inner conductor 58 is designated Z_{o1} . The proper terminating impedances for the entire combination is designated Z_o .

From the above simplification afforded by the theoretical electrical and magnetic walls along the bisecting plane, it may be seen that for the even mode, Z_{oe} is equal to the series combination of $Z_{o2} + 2Z_{o1}$. For the odd mode, Z_{o1} is short-circuited by the electric wall so that Z_{oo} (the characteristic impedance for the odd mode) equals simply Z_{o2} .

The new structure being a parallel transmission line directional coupler is as indicated above a backward-wave coupler and when discontinuity reactances are neglected, the isolation and input match are substantially perfect when

$$Z_o = \sqrt{Z_{oe} Z_{oo}}$$

where Z_o is the characteristic impedance of the terminating or external lines. The mid-band coupling factor k defined as the ratio of the coupled voltage magnitude to that of the input voltage is related to the even, and

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odd mode characteristic impedances by the relationship, which holds at center frequency:

$$k = \frac{Z_{oe} - Z_{oo}}{Z_{oe} + Z_{oo}}$$

In the particular design of a directional coupler constructed in accordance with the principles of the present invention the desired value of mid-band k is chosen; then Z_{oe} and Z_{oo} may be calculated as follows:

$$Z_{oe} = Z_o \sqrt{\frac{1+k}{1-k}}$$

$$Z_{oo} = Z_o \sqrt{\frac{1-k}{1+k}}$$

The necessary values of the Z_{o1} and Z_{o2} from the relationships given earlier above are:

$$Z_{o1} = \frac{1}{2} (Z_{oe} - Z_{oo})$$

$$Z_{o2} = Z_{oo}$$

In a practical example of a re-entrant quarter-wave section directional coupler constructed along the lines of the devices shown in the previous figures, a coupling value of -2.7 db at the center frequency was chosen. The corresponding coupling factor k was then 0.734 , and the usual Z_o of 50 ohms was selected. Z_{oe} then equaled 127.8 ohms and Z_{oo} equaled 19.6 ohms. The characteristic impedances in the re-entrant line cross section were $Z_{o2} = 19.6$ ohms and

$$Z_{o1} = (\frac{1}{2}) (127.8 - 19.6) = 54.1 \text{ ohms}$$

The outer conductor of the two inner coaxial lines consisted of two pieces of quarter-inch outer diameter tubing joined lengthwise and soldered together with solder filling the spaces between the tubes. Thus the width of the cross section of the intermediate conductor was one-quarter inch and its length was one-half inch. The wall thickness of the tubing was $.022$ inch so that the inner diameter of the intermediate conductor was $.206$ inch. The ratio of conductor diameters to provide the required 19.6 ohms was, by conventional methods, found to be 1.386 , giving an inner-conductor diameter of 0.149 inch. The gap between the conductors was therefore approximately 0.024 inch. The inner-conductor rods were supported by annular Teflon rings $\frac{1}{16}$ of an inch long.

In FIG. 5 the results obtained with the above described practical example are illustrated. Over an octave range from 340 to 680 megacycles ($\frac{2}{3}$ f_o to $\frac{4}{3}$ f_o on the graph **60**, where f_o is the mid-band frequency), the coupling was found to be three-db plus or minus 0.3 db. The measured directivity, that is, the relationship between the power at the coupled output terminal compared to that at the isolated or terminated terminal was greater than 30 db over the indicated band.

Referring to FIG. 6 an example of the invention is illustrated in which an even greater bandwidth may be achieved. In the view of FIG. 6, a half of an unassembled body **66** of a three-quarter wave section three-db directional coupler **70** is illustrated. Assembled within the body half is shown a first end coupler section **72**, a re-entrant coupler section **74**, and a second end coupler section **76**. The central coupler section **74** may be similar in most important respects to the coupler section illustrated in the previous figures in that it comprises a pair of inner transmission lines **78**, **80** which are elongated cylindrical rods disposed concentrically within tubular bores **82**, **84**, respectively which are relieved in parallel through an intermediate tubular conductor **86**.

Each of the end coupler sections **72**, **76** include a pair of strip-line segments **87**, **88** and a ground plane element **90**. Each of the strip-line segments is interconnected between a respective one of the inner-transmission lines of the re-entrant coupler section **74** and an external connector **92**, **94**. Coupling between the pair of strip-line segments **87**, **88** is achieved by disposing extended portions of their edges **96**, **98** in a juxtaposed

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spaced relationship as illustrated. The elongated coupling gap provided thereby may readily afford a relatively loose degree of coupling between the two segments. It has been found, as will be indicated below, to be an easily repeatable parameter because the gap width is neither particularly close nor critical. Discontinuities at the ends of the strip-line segments as well as along their length are minimized by providing curved and tapered edges **100** and **102**, respectively, along their lengths. In addition, transition sections **104** and **106** are provided where the strip-line segments are joined to other elements of the combination.

Foil tabs **112**, **114** may be added along the edge of the strip-line segments either as separately applied structure or they may be formed integrally with the conductive strip-line. Their function is to improve significantly the impedance match and directivity of the strip-line coupler section.

The inner end portion **116** of the strip-line ground plane element **90** is formed with a reduced width in the region of the ends of the strip-line segments toward their junction with the inner transmission line elements of the central coupler section. This narrowing of the ground plane is provided for the purpose of precluding higher order of modes of electromagnetic transmission or oscillation which if not so precluded may deleteriously affect the desired coupling operation. It is also to be noted that the extreme inner end **118** of the ground plane element **90** is spaced from the end of the intermediate conductor **86** of the re-entrant coupler section **74** to minimize coupling therebetween and to preclude the possibility of a direct current short from a direct contact between the two elements. The corresponding ground plane element or outer conductor for the re-entrant coupler section **74** is formed by a rectangular parallelepiped depression **119** in the surface of the body **66**.

In a constructed example of the embodiment of the invention illustrated in FIG. 6, the mid-band coupling factor k for the re-entrant or central section **74** was chosen to be 0.8612 while k' for the end, strip-line coupler sections, was chosen to be 0.2337 . With Z_o of 50 ohms the even and odd mode characteristic impedance of the sections were, respectively, $Z_{oe} = 183$ ohms; $Z_{oe}' = 63.5$ ohms; $Z_{oo} = 13.66$ ohms and $Z_{oo}' = 39.4$ ohms, where the primed figures refer to the indicated quantities for the end coupler sections. It may be noted by one skilled in the art that the indicated characteristic impedances and coupling factors for the end coupler sections are advantageously and readily achieved with parallel coupled strip-line.

The center section characteristic impedances which are obtained from the equations given above in the discussion relating to the previous figures are

$$Z_{o1} = \frac{1}{2} (183 - 13.7) = 84.7 \text{ ohms}$$

$Z_{o2} = 13.66$ ohms. In this example the tubing outer diameter for the intermediate conductor **86** was 0.1875 inch and its inner diameter was 0.143 inch. The coaxial center conductors **78**, **80** had diameters of 0.114 inch. The spacing from the intermediate conductor **78** to the outer conductor, not shown, was 0.956 inch.

The end sections **72**, **76** were constructed from copper clad Tellite 3A dielectric material which has a dielectric constant of 2.32 . The thickness of each board was 0.125 inch so that the ground plane spacing was 0.250 inch. The copper thickness was 0.0014 inch. In the coupling region of the strip-line segments, that is along the edges **96**, **98**, the strip width of the segments was 0.173 inch and the gap was 0.0253 inch. The 50 -ohm terminating transition strips **106** were 0.194 inch wide.

The graph **120** of FIG. 7 illustrates the coupling response of the example described above. Over a 5 to 1 frequency range, $\frac{1}{3}$ f_o to $\frac{5}{3}$ f_o , the degree of coupling remained within three-db plus or minus 0.4 db. In an "equal ripple" character of response, as shown, the directivity was better than 25 db throughout the indicated bandwidth.

Referring to FIG. 8 an example of the structure of the re-entrant coupler section is illustrated which is different from the previously described examples. In this example the space between the different electrodes is filled with a solid, supporting dielectric substance instead of air. The structure may be constructed by a lamination process of thin film metals on layers of solid dielectric substances. The combination can be substantially smaller and more compact because the dielectric constant of the solid dielectric may be readily in the range of 2 to 3.

In particular, with reference to the figure, a pair of inner-transmission lines 130, 132 are elongated thin film strips disposed parallel to each other and having a width and spacing to provide the characteristic impedances discussed above in connection with the earlier figures. Similarly an outer conductor consisting of a pair of thin film plates 134, 136 are provided which are spaced transversely from the inner-transmission lines 130, 132. Interposed between the outer conductive plates 134, 136 and the inner-transmission lines 130, 132 are a pair of parallel conductive plates 138, 140 which may also be thin film in construction.

As in the above examples of the invention, the intermediate conductors are electrically floating and are disposed in a manner to be in a series, electrically, relationship between the inner and the outer conductors. In the example of FIG. 8 the thin films making up the combination for the re-entrant coupler section shown in cross section are all in parallel planes with the inner conductive strips 130, 132 being substantially coplanar.

In FIG. 9 an example of the invention is illustrated showing an alternative arrangement for the inner and intermediate conductors. The outer conductor, not shown, for simplicity, may be as shown in FIG. 8. A pair of inner conductors 142, 144 are disposed in a juxtaposed relationship in spaced parallel planes between the similarly juxtaposed intermediate thin film conductive plates 146, 148.

In FIG. 10 an example of the invention is illustrated in which the inner conductive elements 150, 152 are "thick slab" elements instead of the thin film form of the previous two examples. The thick slab elements are disposed in a juxtaposed relationship, as illustrated, between similarly juxtaposed plates 154, 156 of an intermediate conductive means. Again the design criteria, namely the required relationships of characteristic impedances, are the same as for the previous examples. Again the outer conductors 134, 136 are not shown in the figure.

In FIG. 11 an example of the invention is depicted in which a pair of inner-conductive transmission lines 160, 162 are in a parallel juxtaposed relationship with each other and are spaced between a pair of intermediate conductive plates 164, 166, with an outer conductor understood, as before. In this case, however, the planes of the inner conductive transmission lines 160, 162 are orthogonal with respect to the planes of the intermediate conductive plates 164, 166. Again the extension of the intermediate conductive plates laterally is beyond the region of the volume bounded by the inner conductive transmission lines 160, 162.

In FIG. 12 an example of the invention similar in most respects to that shown in FIG. 11 is illustrated in which the inner conductive transmission lines 168, 170 are thick slab conductive elements disposed in a juxtaposed parallel relationship with a direction of spacing which is parallel to the intermediate conductive plates 172, 174. Again the outer conductor elements are not shown; and the design criteria relating to the characteristic impedances may be understood as being the same as those presented in connection with the earlier examples of re-entrant coupler sections.

There have thus been disclosed a number of examples of a microwave hybrid coupler which achieve the objects and exhibit the advantages enumerated above.

What is claimed is:

1. A four-port microwave directional coupler comprising: a pair of spaced, parallel inner conductors having a length approximately $\frac{1}{4}$ wavelength long at midband; an outer, hollow conductor disposed about said inner conductors; and an intermediate conductor means disposed about said inner conductors within said outer conductors and between said inner conductors, said intermediate conductor means being direct current isolated from the other said conductors.

2. A four-port microwave directional coupler comprising: a pair of parallel, spaced, inner conductors, having a length of approximately one quarter wavelength at midband; outer conductor means substantially shielding said inner conductors; electrically floating intermediate conductor means interposed between said outer conductor means and said inner conductors.

3. A re-entrant microwave directional coupler comprising: a pair of parallel-spaced, inner transmission lines having a length of approximately $\frac{1}{4}$ wavelength at the midband frequency; outer conductor means disposed about and spaced from said inner transmission lines; intermediate conductor means disposed in an electrically floating relationship between said transmission lines and said outer conductor means, the characteristic impedances Z_{01} , between said intermediate conductor means and said outer conductor means, being approximately

$$\frac{1}{2}(Z_{0e}-Z_{0o})$$

and Z_{02} , between one of said transmission lines and said intermediate conductor means, being approximately Z_{0o} , where Z_{0o} and Z_{0e} are the characteristic impedances between an inner said transmission line and said outer conductor means for odd and even mode transmission, respectively, and are so related to the midband coupling factor k of the coupler and the characteristic impedance Z_0 of its terminating lines that

$$Z_{0e} = \sqrt{\frac{1+k}{1-k}}$$

and

$$Z_{0o} = \sqrt{\frac{1-k}{1+k}}$$

4. The invention according to claim 3 in which said inner transmission lines comprise elongated conductive rods which are disposed parallel to each other and to said outer conductor means and said intermediate conductor means.

5. The invention according to claim 3 in which said inner transmission lines are strip conductors disposed with their flat surfaces mutually parallel.

6. The invention according to claim 5 in which said outer conductor means comprises a first pair of juxtaposed substantially congruent flat plates, said intermediate conductor means comprises a second pair of parallel, spaced, flat plates, said inner transmission lines being substantially contained within the volume defined by the boundaries of said second pair of spaced flat plates, said second pair of flat plates being substantially contained within the volume defined by the boundaries of said first pair of flat plates; and solid dielectric means substantially filling said volume, but for the space of said inner and intermediate conductors.

7. A three-db directional coupler comprising: a body member and four connectors supported thereon, a central portion of said body member being relieved to define an outer conductor, the latter being connected to a common terminal of each of said four connectors; a pair of transmission lines interconnected between different ones of said four connectors and disposed parallel to each other within said central portion of said body member; intermediate conductor means disposed in said central region radially between each of said transmission lines and said body member; electrically insulative means for supporting

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said intermediate conductor in an electrically floating relationship between said transmission lines and said body member.

8. The invention according to claim 7 in which said intermediate conductor comprises a tubular member internally relieved to form two parallel bores therethrough and each of said transmission lines in said central portion being disposed substantially coaxially with a respective one of said bores.

9. The invention according to claim 7 which further includes at least one additional quarter-wave coupling section interposed between said central portion and a pair of said connectors.

10. The invention according to claim 9 in which said additional quarter-wave coupling section comprises a pair of intercoupled microwave strip-line segments, each of which is coupled between a respective one of said transmission lines and a respective one of said connectors; an electrical transmission means interposed at each end of said strip-line segments.

11. A microwave coupling structure comprising: a pair of spaced, parallel inner conductors having a length equal approximately to $\frac{1}{4}$ wavelength at midband; an outer, hollow conductor disposed about said inner conductors; and intermediate conductor means disposed about said inner conductors, within said outer conductors, and between said inner conductors, said intermediate conductor means being direct current isolated from the other said conductors.

12. The invention according to claim 11 which further comprises at least one additional quarter-wave coupling section disposed adjacently to and coupled electromagnetically to said conductors.

13. A microwave coupling structure comprising: a pair of spaced, parallel transmission lines; outer conductor means disposed about and spaced from said inner transmission lines; intermediate conductor means disposed in

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an electrically floating relationship between said transmission lines and said outer conductor means, the characteristic impedances Z_{01} , between said intermediate conductor means and said outer conductor means, being approximately $\frac{1}{2} (Z_{0e} - Z_{0o})$ and Z_{02} , between one of said transmission lines and said intermediate conductor means, being approximately Z_{0o} , where Z_{0o} and Z_{0e} are the characteristic impedances between an inner said transmission line and said outer conductor means for odd and even mode transmission, respectively, and are so related to the coupling factor k of the coupler and the characteristic impedance Z_0 of its terminating lines that

$$Z_{0e} = Z_0 \sqrt{\frac{1+k}{1-k}}$$

and

$$Z_{0o} = Z_0 \sqrt{\frac{1-k}{1+k}}$$

14. A microwave coupling structure as set forth in claim 13 which further includes at least one additional quarterwave section disposed adjacently to and coupled electromagnetically to said spaced, parallel transmission lines.

References Cited by the Examiner

UNITED STATES PATENTS

3,025,480 3/1962 Guanella 333—26

OTHER REFERENCES

Shimizu, "Strip-Line 3-db Directional Couplers," 1957, Wescon Convention Record, vol 1, part 1, pages 4 to 15.

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