March 28, 1967 A. F. PODELL 3,311,850

LOW LOSS HYBRID CONNECTOR UTILIZING HIGH PERMEABILITY MAGNETIC CORE MATERIAL

Filed Jan. 31, 1964 2 Sheets-Sheet 1

FIG. 1

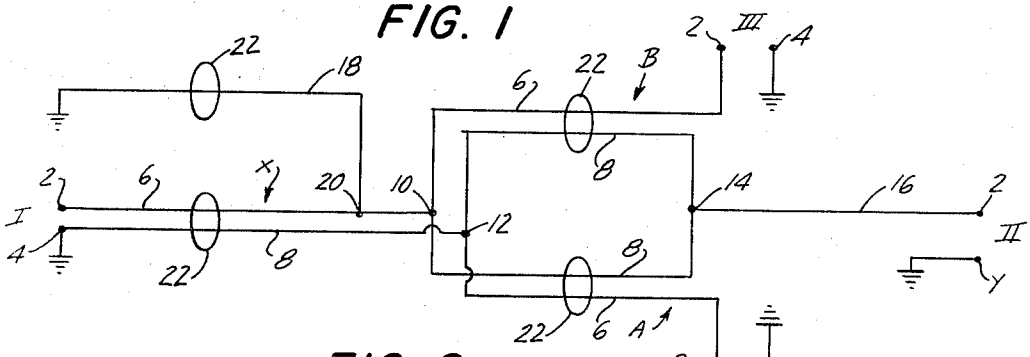


FIG. 2

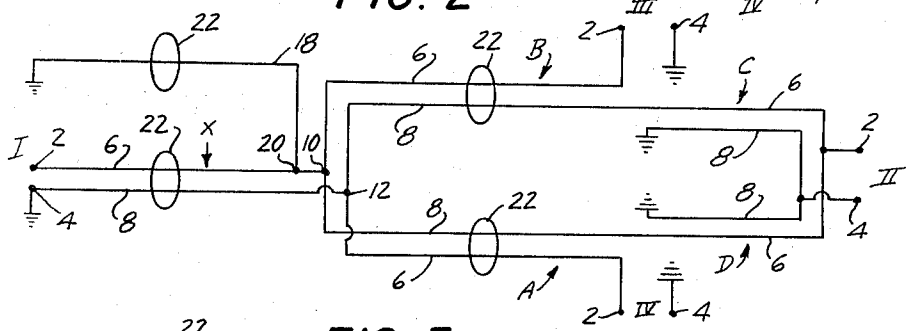


FIG. 3

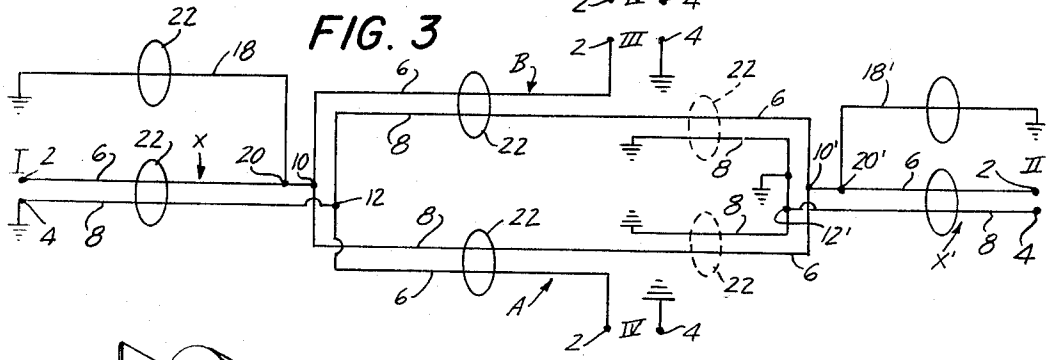
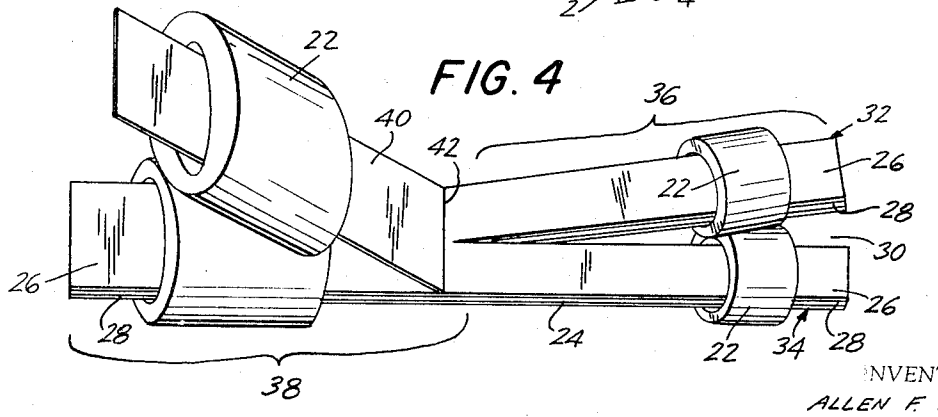


FIG. 4



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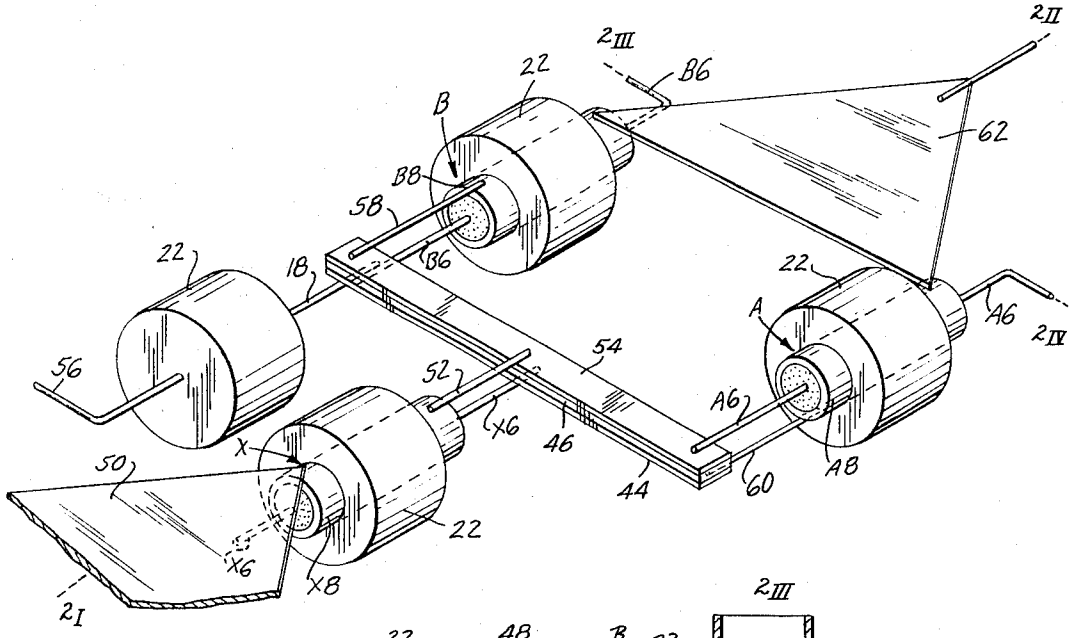
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FIG. 5



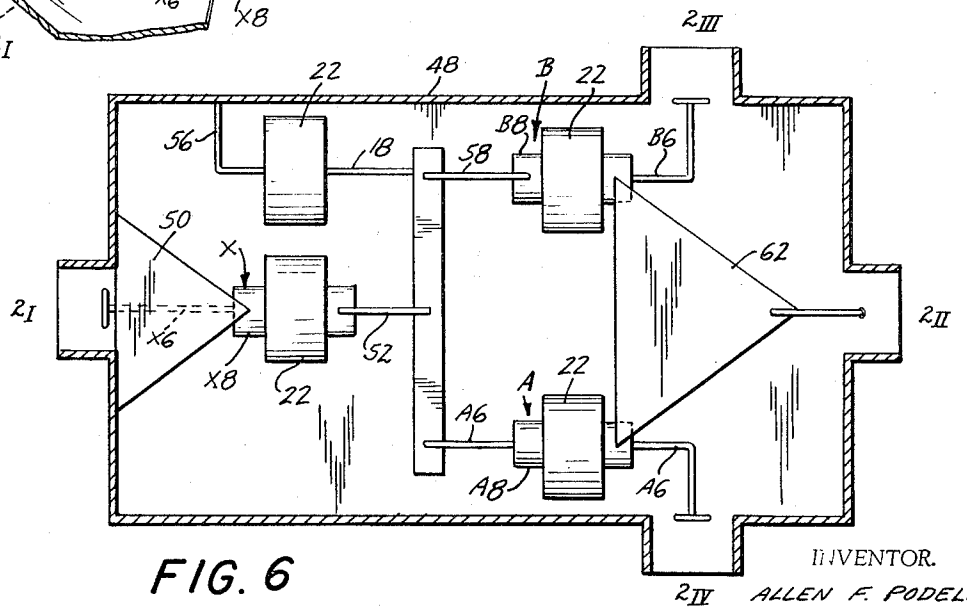


FIG. 6

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LOW LOSS HYBRID CONNECTOR UTILIZING HIGH PERMEABILITY MAGNETIC CORE MATERIAL

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12 Claims. (Cl. 333—11)

The present invention relates to a hybrid connector characterized by a very high band width, good isolation between input and output ports, a low phase shift between ports which is substantially linear throughout the pass band, and an exceedingly low insertion loss.

Hybrid connectors are utilized in a wide variety of relatively high frequency electrical systems to connect two pairs of circuits to one another. For purposes of discussion one pair of circuits can be denominated "input circuits" and the other pair "output circuits." The function of the hybrid is to connect one or both input circuits so as to equally feed both output circuits, the input circuits being isolated from one another and the output circuits being isolated from one another. Thus, if two input circuits (a transmitter and a receiver) are to be connected to a pair of loads (antennas) it is desired that both antennas function together and equally for the receiver and transmitter, but that the transmitter not affect the receiver and vice versa.

In my prior application Ser. No. 246,121 of December 20, 1962, entitled, "Hybrid Connector," now Patent No. 3,239,781, I disclose a hybrid circuit which provides substantially fully reciprocal isolation as between the input and output ports—the isolation of the circuits of each pair from one another is substantially equal and is virtually independent of the frequency, and it is a matter of indifference which pair of ports are connected to the input circuits and which to the output circuits. This result is there accomplished through the use of a network comprising a pair of input ports and a pair of output ports (the designation "input" and "output" are arbitrarily and interchangeably applied), the ports of each pair being diagonally opposed to one another to define the corners of a four-sided network, the sides of the network comprising electrical connections between the terminals which include transmission lines, the two transmission lines extending from the first port being so electrically constructed and modified that at least one wire of each of them is enabled to electrically float relative to a reference potential. As a result of the construction there disclosed isolation between terminals is accomplished with a high degree of efficiency over an extremely wide range of frequencies.

However, the basic circuit there disclosed was less effective at low frequencies than at high frequencies, because at the lower frequencies the floating of certain of the transmission lines became less effective. In order to minimize this effect, certain connections were employed within the four-sided network.

It is a prime object of the present invention to improve the operating characteristics of a hybrid connector circuit of the type disclosed in aforementioned application Ser. No. 246,121, particularly with regard to the amount of signal loss produced by the connector circuit and to the degree of isolation produced at the lower end of the wide frequency band over which the circuit is designed to operate. The less the loss produced in the signal by the circuit, the more sensitive is the overall connection. The more uniform the isolation effect of the circuit over a wide range of frequencies, the more useful is the device. A particular feature of the present invention

resides in the fact that the circuitry by means of which these advantageous effects are produced is simple, reliable, and easily incorporated into a workable structure.

The devices employed for causing certain of the transmission lines forming a part of the hybrid network to float are usually ferrite tubes which surround portions of those transmission lines. Imperfections in these tubes, particularly with regard to frequency response, may tend to cause different branches of the network to function differently. It is a characteristic of the circuitry of the present invention that the ferrite tubes are symmetrically located and are equally loaded, thereby producing an inherent self-compensating effect which maintains isolation between ports over the full frequency range.

The losses in the ferrite tube contribute markedly to the overall insertion loss of the circuit. Such tube losses are directly related to the voltage drop from one end to the other of the tubes. The circuitry of the present invention approximately halves this voltage drop across the tubes, when compared to the circuit of application Ser. No. 246,121, and therefore greatly reduces the insertion losses.

The teachings of the present invention can be employed not only with hybrid networks in which each set of ports is isolated from the other, but also in a simplified network providing only one-way isolation. In the latter instance extremely simplified physical embodiments may be employed the cost of which is greatly minimized without sacrifice in desired electrical characteristics.

To accomplish these ends the basic four-port hybrid network with floating transmission lines is preceded by a balancing transformer, the latter being connected to one of the input ports. It is preferred that this balancing transformer take the form of a floating transmission line. For the highest degree of frequency insensitivity insofar as isolation is concerned, one conductor of that line is preferably connected to a reference potential by means of an electrical conductor which also is permitted to float. The action of the balancing transformer is such as to cause a voltage drop to occur therein, thereby reducing the voltage drop in the floating transmission lines forming a part of the four-port hybrid circuitry per se. As a further result, the voltage drops across the ferrite tubes which produce the floating of the transmission lines in the hybrid network per se are the same, and those transmission lines are symmetrically located within the network, thereby producing inherent compensation over the entire range of frequencies. This in turn ensures that the desired degree of isolation is maintained throughout that range of frequencies.

To the accomplishment of the above, and to such other objects as may hereinafter appear, the present invention relates to a hybrid connector circuit as defined in the appended claims and as described in this specification, taken together with the accompanying drawings, in which:

FIG. 1 is a schematic circuit diagram of one embodiment of the present invention in which only one-way isolation is achieved;

FIG. 2 is a schematic circuit diagram of a second embodiment of the present invention in which two-way isolation is achieved;

FIG. 3 is a schematic circuit diagram illustrating a third embodiment of the present invention in which completely symmetrical two-way isolation is achieved;

FIG. 4 is a three-quarter perspective view of a simplified structural embodiment of the circuitry of FIG. 1;

FIG. 5 is a perspective view of an alternative physical embodiment of the circuitry of FIG. 1; and

FIG. 6 is a top plan view of the physical embodiment of FIG. 5 mounted within a casing, the casing being shown in horizontal cross section.

Turning first to the simplified embodiment of FIG. 1, there is there schematically disclosed a circuit comprising a pair of "input" ports I and II and a pair of "output" ports III and IV, the input ports I and II being diametrically opposed to one another and the output ports III and IV being diametrically opposed to one another. First and second transmission lines, generally designated A and B respectively are provided, line A extending between ports I and IV and line B extending between ports I and III. Another transmission line generally designated X is interposed between port I and lines A and B, lines A and B being directly connected respectively between their respective ports IV and III and the end of line X remote from port I. Each port is provided with a pair of terminals designated **2** and **4** respectively. Each transmission line comprises what may be electrically considered as, and are schematically illustrated as, inner conductors **6** and outer conductors **8**. The outer terminals **4** of each of the ports are, as indicated, connected to a reference potential such as ground. The inner conductor X_6 (conductors are hereinafter designated by the letter representing the transmission line of which they form a part, and by the sub-number **6** or **8** depending upon whether they are electrically inner or outer conductors) is connected between the inner terminal 2_I of the port I (terminals will be thus designated in a manner analogous to conductors) and point **10**. Conductor X_8 is connected between terminal 4_I and point **12**. Conductor B_6 is connected between point **10** and terminal 2_{III}. Conductor B_8 is connected between point **12** and point **14**. Line A_8 is connected between points **10** and **14**. Line A_6 is connected between point **12** and terminal 2_{IV}. Point **14** is connected by conductor **16** to terminal 2_{II}. Terminals 4_{II}, 4_{III} and 4_{IV} are grounded.

Conductors forming parts of the lines A, B and X are designed to float electrically relative to a reference potential such as ground, and to that end those lines pass through tubes **22** (schematically represented in FIGS. 1–3) formed of highly magnetic permeable material of high electrical efficiency, such as ferrite. Ideally, the electrical impedances of lines A, B and X are the same.

It will be seen that the network defined by the line X constitutes a balancing transformer or "balun," and that the remainder of the circuitry of FIG. 1 comprises a four-port network, two sides of which are defined by the lines A and B respectively and the other two "sides" of which are defined by the conductor **16** and the connections to ground of the terminals 4_{II}, 4_{III} and 4_{IV}.

To analyze the effect of the network thus disclosed, let us assume that the output ports III and IV are equally loaded and that a voltage E is applied as an input across the terminals of input port I. A similar voltage E will be produced at the output ports III and IV, terminal 2_{III} being at a value of $+E$ and terminal 2_{IV} being at a voltage $-E$ when terminal 2_I is at a voltage E. At such an instant point **10** will be at a voltage of $+E/2$ and point **12** will be at a voltage of $-E/2$. Thus the voltage drop from one end of the ferrite tube **22** on line X to the other will be $E/2$, and the same voltage drop will exist from one end to the other of each of the tubes **22** on the lines A and B respectively. The right hand ends of conductors B_8 and A_8, and hence point **14**, will be at zero potential, thereby isolating input port I from input port II.

From this it will be appreciated that the tubes **22** on the lines A and B are equally loaded. Hence they will function similarly over the entire range of operating frequencies. As a result for any given frequency, and insofar as the action of lines A and B are concerned, output port III will be coupled to input port I to the same degree as is output port IV, and input port I will be isolated from input port II. As a result, frequency compensation is inherently achieved, particularly at the higher frequencies.

Moreover, the loading on each of the tubes **22** is dependent upon the voltage drop from one end thereof to the other, and the losses produced in those tubes are more or less directly related to the core loading. Since the voltage drop across each tube **22** is equal to $E/2$, whereas in the hybrid embodiment disclosed in application Ser. No. 246,121 the corresponding voltage drop was equal to E, it will be appreciated that the losses involved in the instant circuit are considerably less than those involved in the prior circuit of application Ser. No. 246,121.

The effect of the ferrite tube **22** in permitting the conductors, and particularly the outer conductors **8**, of the lines A, B and X to float electrically is well defined at high frequencies, such as those above 100 megacycles per second, and is exceptionally well defined at even higher frequencies on the order of 1000 megacycles per second. However, as the frequency drops the floating effect produced by the ferrite tubes **22** decreases in effectiveness, and this results in a failure or deterioration of isolation. The close coupling between the inner and outer conductors **6** and **8** of the respective lines, as those conductors are received within the ferrite tubes **22**, will, at such lower frequencies, cause voltages in the one conductor **6** or **8** to be reflected into the other conductor **8** or **6**, thereby producing a voltage at port II and reducing isolation.

The conductor **18** is provided in order to restore isolation at low frequencies when the ferrite tubes **22** on the lines A, B and X do not perform their desired functions in an optimum manner, that conductor **18** being connected at one end to ground and at the other end to the inner conductor **6** of the line X at point **20**, point **20** being located at the end of the line X remote from port I and at the near ends of the lines A and B. The inductance of the conductor **18** is substantially equal to the inductances of the conductors **6** and **8** of the lines A, B and X, all of those lines being substantially similar to one another. The ferrite tube **22** which surrounds the conductor **18** is preferably closely the same as the ferrite tubes **22** which surround the lines A, B and X. The conductor **18** provides an additional conductive path to ground. Voltages induced in the conductors A_8, B_6 and X_6 at low frequency feed through the conductive path defined by the conductor **18**, and the currents which flow in conductors A_8, B_6 and X_6 by reason of this conductive path to ground in turn induce voltages in the corresponding conductors A_6, B_8 and X_8 respectively which tend to nullify the isolation-destroying effect previously set forth.

While the conductor **18** is particularly needed at low frequencies on the order of 100 mc. or less, because it is in that range that the ferrite tubes **22** surrounding the transmission lines A, B and X are particularly inadequate, it has been found that the inclusion of the conductor **18** even at high frequencies is desirable. At such higher frequencies the hybrid network without the conductor **18** works satisfactorily, but an even higher isolation is achieved when the conductor **18** is operative. The conductor **18** and its associated ferrite tube **22** compensates for the losses in and the finite permeability of the ferrite tubes **22** associated with the lines A, B and X.

Purely by way of example, a commercial embodiment of the circuit of FIG. 1 will function over a range of frequencies from 5–900 mc., has an insertion loss, from port I to either of ports III or IV, no greater than 0.7 db over a frequency range from 30–900 mc., provides a 40 db minimum isolation over a range from 5–300 mc. between ports I and II when ports III and IV are equally terminated, with a 30 db minimum isolation over a range from 5–900 mc. This commercial device is capable of carrying a maximum of 5 watts power input, and is entirely encompassed within a volume of 1¼" x 1¼" x 2½", less than 4 cubic inches.

The embodiment of FIG. 2 is similar to that of FIG. 1, except that transmission lines C and D are connected between input port II and output ports III and IV respectively, the four-sided circuitry per se thus being

brought into conformity with the disclosure in application Ser. No. 246,121. As there disclosed, when the lines A and C are substantially the same electrical length and the lines B and D are substantially the same electrical length, and when the impedances of lines A and B are the same and the impedances of lines C and D are the same, ports I and II will be reciprocally isolated from ports III and IV when the ports are properly terminated, and that high degree of isolation will be effective over an increased frequency range. As pointed out in said prior application, the aforementioned impedance relationship among the lines is desirable primarily in order to minimize the effect of reflections in the event that the lines are not terminated in their characteristic impedances. The relationship as to electrical length is significant particularly with regard to the frequency sensitivity of the network. The effects of the balancing transformer defined by the line X and the conductor **18** are the same in the embodiment of FIG. 2 as in the embodiment of FIG. 1.

The embodiment of FIG. 3 is similar to that of FIG. 2 except that a balanced transformer defined by transmission line X' is connected between port II and the four-sided network, a conductor **18'** corresponding to conductor **18** is provided, and floating-producing cores **22** are located on lines C and D. This produces a completely balanced network with excellent loss characteristics.

FIG. 4 illustrates a simple structural arrangement capable of producing the network of FIG. 1. A strip or sheet **24** of insulating material is provided with conductive layers **26** and **28** on opposite sides thereof, the thickness of the sheet **24**, and consequently the spacing between the conductive layers **26** and **28**, being such as to place the conductive layers **26** and **28** in transmission line relationship. The sheet **24** and the layers **26** and **28** are longitudinally slit, at **30**, thereby producing first and second separated arms generally designated **32** and **34**, those arms **32** and **34** extending along what may be termed a first longitudinal portion **36** of the assembly and leaving a second longitudinal portion **38** of the assembly unslit. Appropriately dimensioned ferrite tubes **22** are slipped over the arms **32** and **34** respectively, and a ferrite tube **22** is slipped over the second longitudinal portion **38**. A conductive strip **40** of substantially the same width as the strip **24** is electrically connected, as by soldering, to the conductive layer **26** along line **42**, and ferrite tube **22** is slipped thereover. The arms **32** and **34** comprise the transmission lines A and B of FIG. 1, the second longitudinal portion **38** comprises the transmission line X, and the strip **40** comprises the conductor **18**. The other electrical connections shown in FIG. 1 may readily be made by simple soldering connections to conventional electrical conductors.

The physical embodiment of FIGS. 5 and 6, which also corresponds electrically to the circuit of FIG. 1, is composed of more conventional circuit elements. The transmission lines X, A and B are formed of conventional concentric line segments having outer and inner conductors spaced from one another in any appropriate manner. The inner conductor X_6 is connected at one end to terminal 2_I and is connected at its other end to the conductive layer **44** on the bottom of insulating strip **46**. The outer conductor X_8 is connected at one end to the casing **48** by means of an appropriately shaped sheet of conductive foil **50**, and is connected at its other end, by conductive strip **52**, to the upper conductive layer **54** on insulating strip **46**. The conductor **18** is connected between the casing, at point **56**, and the lower conductive layer **44**. The left hand ends of the inner conductors B_6 and A_6 are connected to the lower and upper conductive layers **44** and **54** respectively, while the corresponding ends of the outer conductors B_8 and A_8 are connected by conductive strips **58** and **60** respectively to the upper and lower conductive layers **54** and **44** respectively. The right hand ends of the inner conductors B_6 and A_6 extend respectively to the terminals 2_{III} and 2_{IV}, while the right hand ends of the outer conductors B_8 and A_8 are connected to one another and to terminal 2_{II} by means of an appropriately shaped strip **62** of conductive material. The ferrite tubes **22** may readily be slid over the concentric line segments and the conductor **18** prior to the time that they are electrically connected into the assembly. By virtue of the construction disclosed in FIGS. 5 and 6 sturdy commercially available components may be assembled within a minimal space to produce circuitry having the desired operating characteristics.

While but a limited number of embodiments of the present invention have been here specifically disclosed, it will be apparent that many variations may be made therein, all within the spirit of the invention as defined in the following claims.

I claim:

1. In combination, a hybrid connector comprising first, second, third and fourth ports each having first and second terminals, first and second transmission lines connected between said first port and said third and fourth ports respectively and each comprising first and second wires, said first wires of said first and second lines being connected at one end to said first and second terminals of said first port respectively and at their other ends to said second terminals of said third and fourth ports respectively, said second wires of said first and second lines being connected at one end to said second and first terminals of said first port respectively and at their other ends to said second terminal of said second port, electrical connections between said first terminal of said second port and said first terminals of said third and fourth ports respectively, a balancing transformer having an input and an output, and means electrically connecting said balancing transformer output to said first port, said balancing transformer input being adapted to be connected to external circuitry, said balancing transformer comprising a transmission line comprising first and second wires, means active on said line for permitting it to float relative to a reference potential, an electrical connection between one of the wires of said line and said reference potential, and a high permeability magnetic core surrounding said electrical connection.

2. In combination, a hybrid connector comprising first, second, third and fourth ports each having first and second terminals, first and second transmission lines connected between said first port and said third and fourth ports respectively and each comprising first and second wires, said first wires of said first and second lines being connected at one end to said first and second terminals of said first port respectively and at their other ends to said second terminals of said third and fourth ports respectively, said second wires of said first and second lines being connected at one end to said second and first terminals of said first port respectively and at their other ends to said second terminal of said second port, electrical connections between said first terminal of said second port and said first terminals of said third and fourth ports respectively, first and second balancing transformers, each having an input and output, means electrically connecting said output of said first balancing transformer to said first port, and means electrically connecting said input of said second balancing transformer to said second port, said input of said first balancing transformer and said output of said second balancing transformer being adapted to be connected to external circuitry, each said balancing transformer comprising a transmission line comprising first and second wires, means active on said line for permitting it to float relative to a reference potential, an electrical connection between one of the wires of said transmission line and said reference potential, and a high permeability magnetic core surrounding said electrical connection.

3. A hybrid network having first, second, third and fourth ports arranged in diagonally opposed pairs and electrical connections therebetween to produce isolation between said first and second ports while connecting said first and second ports to said third and fourth ports, said electrical connections comprising transmission lines at least between said first port and said third and fourth ports, and means active on said transmission lines for permitting them to float relative to a reference potential, and, in combination therewith, a balancing transformer having an input and an output, and means electrically connecting said balancing transformer output to said first port, said balancing transformer input being adapted to be connected to external circuitry, said balancing transformer comprising a transmission line comprising first and second wires, means active on said line for permitting it to float relative to a reference potential, an electrical connection between one of the wires of said line and said reference potential, and a high permeability magnetic core surrounding said electrical connection.

4. A hybrid network having first, second, third and fourth ports arranged in diagonally opposed pairs and electrical connections therebetween to produce isolation between said first and second ports while connecting said first and second ports to said third and fourth ports, said electrical connections comprising transmission lines at least between said first port and said third and fourth ports, and means active on said transmission lines for permitting them to float relative to a reference potential, and, in combination therewith, first and second balancing transformers each having an input and an output, means electrically connecting said output of said first balancing transformer to said first port, and means electrically connecting said input of said second balancing transformer to said second port, said input of said first balancing transformer and said output of said second balancing transformer being adapted to be connected to external circuitry, each said balancing transformer comprising a transmission line comprising first and second wires, means active on said line for permitting it to float relative to a reference potential, an electrical connection between one of the wires of said line and said reference potential, and a high permeability magnetic core surrounding said electrical connection.

5. A hybrid network having first, second, third and fourth ports arranged in diagonally opposed pairs and electrical connections therebetween to produce isolation between said first and second ports while connecting said first and second ports to said third and fourth ports, said electrical connections comprising transmission lines between each of said third and fourth ports and each of said first and second ports respectively, and means active at least on said transmission lines electrically connected to said first port for permitting them to float relative to a reference potential, and, in combination therewith, a balancing transformer having an input and an output, and means electrically connecting said balancing transformer output to said first port, said balancing transformer input being adapted to be connected to external circuitry, said balancing transformer comprising a transmission line comprising first and second wires, means active on said line for permitting it to float relative to a reference potential, an electrical connection between one of the wires of said transmission line and said reference potential, and a high permeability magnetic core surrounding said electrical connection.

6. A hybrid network having first, second, third and fourth ports arranged in diagonally opposed pairs and electrical connections therebetween to produce isolation between said first and second ports while connecting said first and second ports to said third and fourth ports, said electrical connections comprising transmission lines between each of said third and fourth ports and each of said first and second ports respectively, and means active at least on said transmission lines electrically connected to said first port for permitting them to float relative to a reference potential, and, in combination therewith, first and second balancing transformers each having an input and an output, means electrically connecting said output of said first balancing transformer to said first port, and means electrically connecting said input of said second balancing transformer to said second port, said input of said first balancing transformer and said output of said second balancing transformer being adapted to be connected to external circuitry, each said balancing transformer comprising a transmission line comprising first and second wires, means active on said line for permitting it to float relative to a reference potential, an electrical connection between one of the wires of said transmission line and said reference potential, and a high permeability magnetic core surrounding said electrical connection.

7. A network assembly comprising a strip-like body comprising conductive layers with an insulating layer therebetween and defining a transmission line, said body having first and second longitudinal portions and being longitudinally divided along said first longitudinal portion to form first and second separated arms, first and second high permeability magnetic tubes through which said first and second arms pass, a third high permeability magnetic tube through which said second longitudinal portion of said body passes, a conductor electrically connected to one of said conductive layers on said second longitudinal portion, said connection being at a point between said third tube and said first longitudinal body portion, and a fourth high permeability magnetic tube through which said conductor passes.

8. The assembly of claim 7, in which said conductor comprises a strip-like member of essentially the same width as said body and connected to said one of said conductive layers along substantially the entire width thereof.

9. A network assembly comprising a conductive housing means having first and second substantially opposed terminal means and third and fourth substantially opposed terminal means mounted thereon, each of said terminal means comprising two terminals, one terminal of each of said terminal means being electrically connected to said housing means and another terminal thereof being insulated from said casing, first and second concentric transmission lines each having inner and outer conductors, the outer conductors of said transmission lines being at one end electrically connected to said other terminal of said second terminal means, the inner conductors of said transmission lines being at said one end electrically connected to said other terminals of said third and fourth terminal means respectively, a unit in said housing means comprising a pair of conductive strips separated by insulation, said first and second transmission lines being located in said housing means between said unit and said second, third and fourth terminal means with their inner and outer conductors at said other ends thereof connected respectively to said conductive strips in opposite senses respectively, a third concentric transmission line having inner and outer conductors, said third transmission line being positioned in said housing means between said unit and said first terminal means and having its inner and outer conductors connected at one end respectively to said conductive strips on said unit, said inner conductor of said third transmission line, at the other end thereof, being electrically connected to said other terminal of said first terminal means, said outer conductor of said third transmission line being electrically connected to said housing means.

10. The network assembly of claim 9, in which said first, second and third transmission lines are oriented in said housing substantially parallel to one another and said unit is oriented in said housing substantially at right angles thereto.

11. A network assembly comprising a conductive housing means having first and second substantially opposed terminal means and third and fourth substantially opposed terminal means mounted thereon, each of said terminal means comprising two terminals, one terminal of each of said terminal means being electrically connected to said housing means and another terminal thereof being insulated from said casing, first and second concentric transmission lines each having inner and outer conductors, the outer conductors of said transmission lines being at one end electrically connected to said other terminal of said second terminal means, the inner conductors of said transmission lines being at said one end electrically connected to said other terminals of said third and fourth terminal means respectively, a unit in said housing means comprising a pair of conductive strips separated by insulation, said first and second transmission lines being located in said housing means between said unit and said second, third and fourth terminal means with their inner and outer conductors at said other ends thereof connected respectively to said conductive strips in opposite senses respectively, a third concentric transmission line having inner and outer conductors, said third transmission line being positioned in said housing means between said unit and said first terminal means and having its inner and outer conductors connected at one end respectively to said

conductive strips on said unit, said inner conductor of said third transmission line, at the other end thereof, being electrically connected to said other terminal of said first terminal means, said outer conductor of said third transmission line being electrically connected to said housing means, and an auxiliary conductor connected at one end to that one of said conductive strips on said unit to which said inner conductor of said third transmission line is connected, and said auxiliary conductor being connected at its other end to said housing means.

12. The network assembly of claim 11, in which said first, second and third transmission lines are oriented in said housing substantially parallel to one another and said unit is oriented in said housing substantially at right angles thereto.

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