

Broadband Directional Coupler

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3,426,298

BROADBAND DIRECTIONAL COUPLER

Filed April 19, 1966

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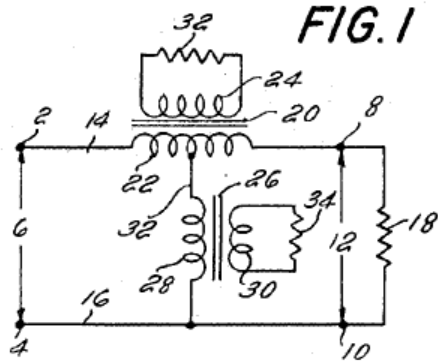


FIG. 1

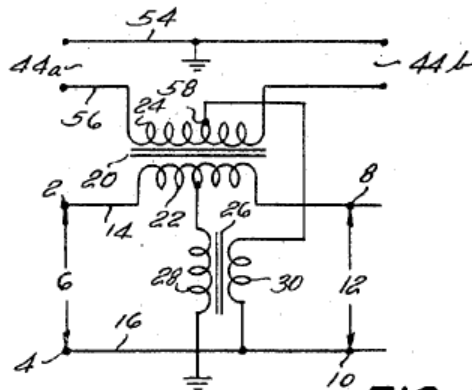


FIG. 4

FIG. 2

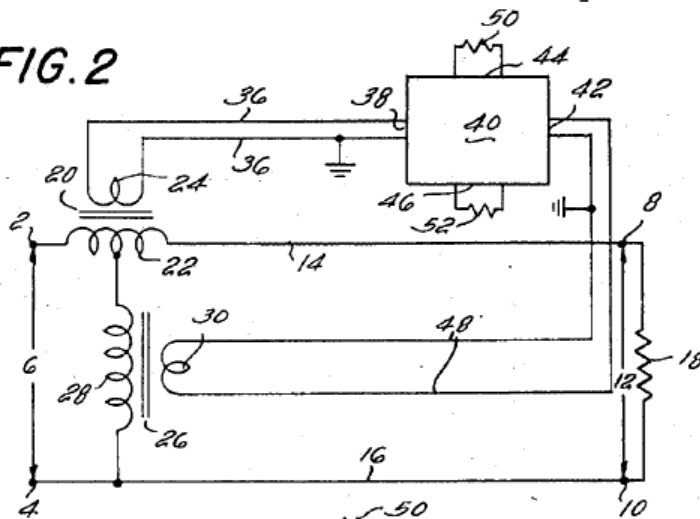
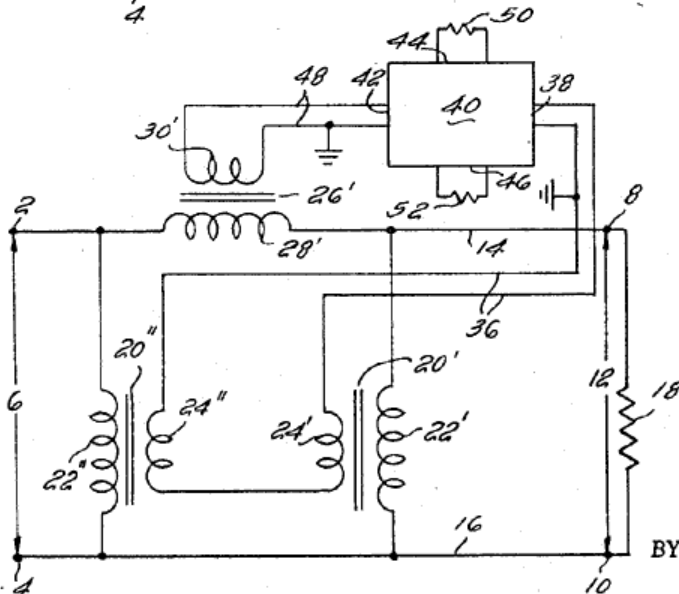


FIG. 3



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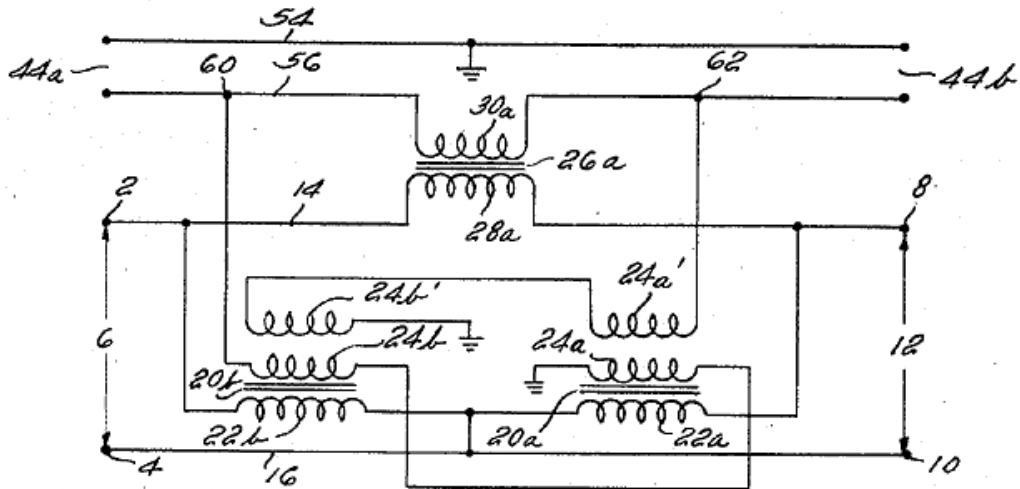


FIG. 5

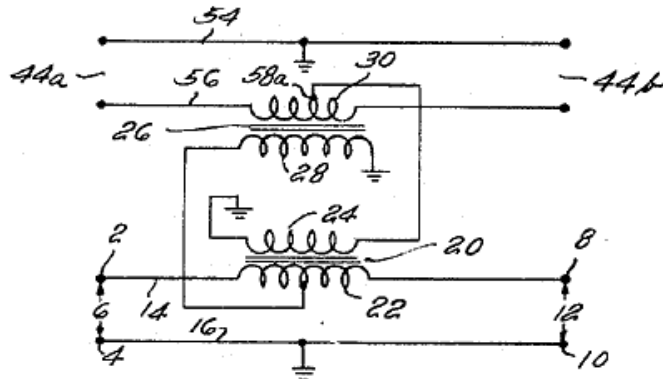


FIG. 6

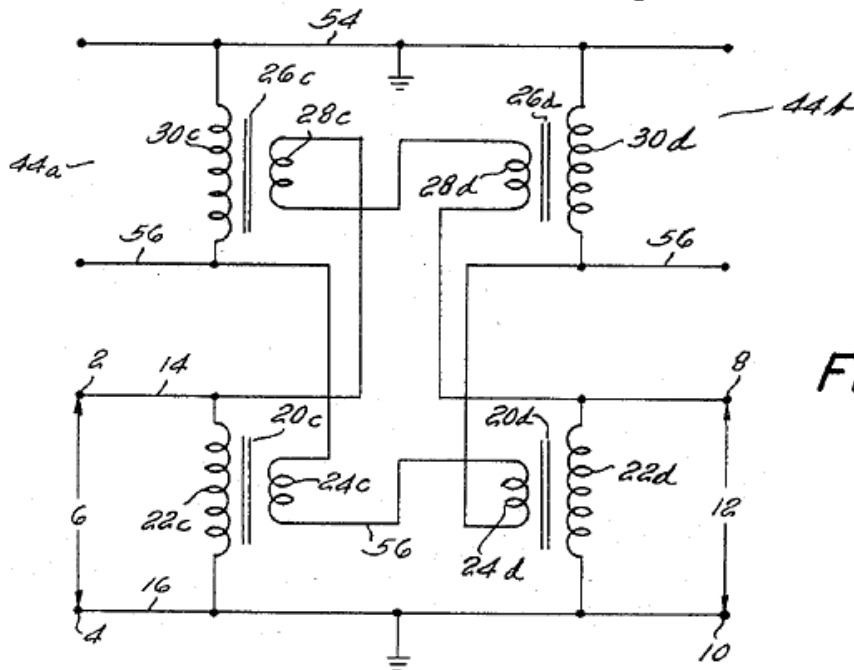


FIG. 7

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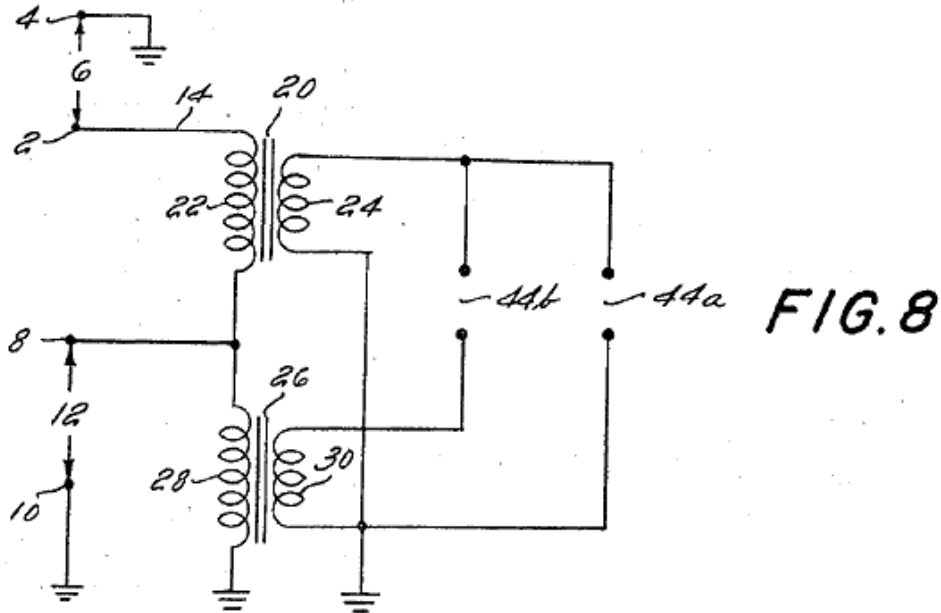


FIG. 8

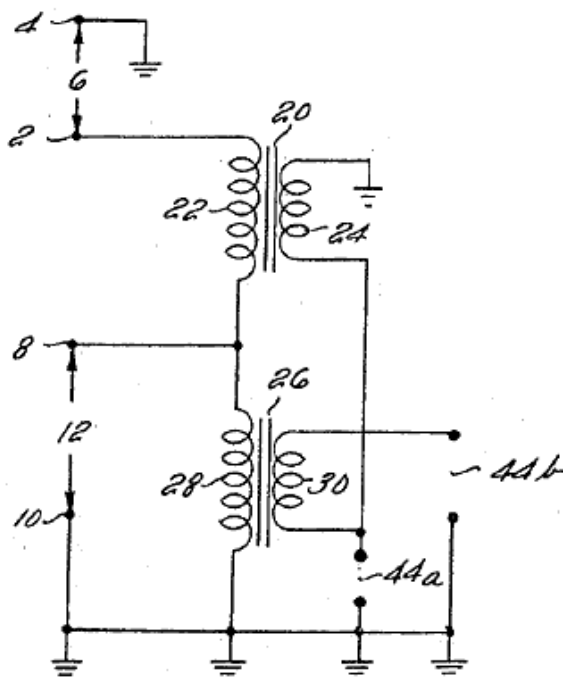


FIG. 9

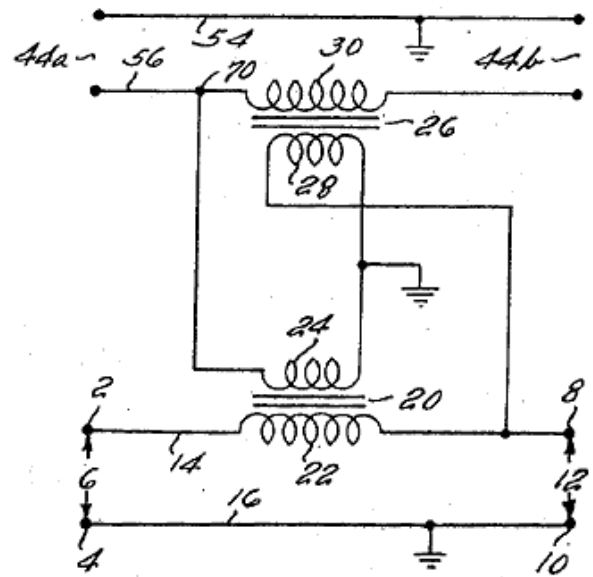


FIG. 10

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BROADBAND DIRECTIONAL COUPLER

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6 Claims

Int. Cl. H01p 5/14

ABSTRACT OF THE DISCLOSURE

A directional coupler having a substantially flat output over a very wide frequency band which is formed of more or less standard circuit elements, such as transmission lines, transformers and 180-degree hybrid junctions, the circuit elements being connected to one another in a fashion particularly well adapted for ready fabrication.

The present invention relates to a directional coupler network capable of functioning over an exceptionally wide frequency range.

A directional coupler is a circuit which may be considered as having a pair of main or input ports and a pair of auxiliary or output ports, the distribution of output power as between the output ports varying in accordance with the direction of flow of current from one main port to the other. Usually, but not necessarily, substantially all of the output power is delivered to one output port or the other, depending upon the aforesaid direction of current flow between the main ports.

One problem which has arisen in connection with circuits of this type is that they are highly frequency-sensitive. The degree of coupling between the input and output ports, and the degree to which the output is directionally sensitive, will depart markedly from design values unless the input power frequency is within a 2 to 1 frequency band approximately.

It is the prime object of the present invention to devise a directional coupler circuit the coupling of which is substantially independent of frequency over a larger band width than previous circuitry designed for the same purpose, even at high frequencies in the multi-megacycle per second range. It is another prime object of the present invention, applicable to some but not all of the embodiments here specifically disclosed, to devise such a directional coupler circuit which can be matched at all ports, that is to say, in which the input standing wave ratio is unitary at all ports. It is a further prime object of the present invention to devise a directional coupler circuit which can employ more or less standard circuit elements, and which therefore can be constructed relatively inexpensively.

The directional coupler circuit of the present invention has other important advantages. It retains its excellent standing wave ratio even when very tightly coupled. The output or outputs are either in phase with or 180 degrees out of phase from the input power. It may be used in conjunction with such relatively standard circuitry as 180 degrees hybrid junctions. Since the devices of the present invention can be built of matched transmission lines and conventional or transmission line transformers, its construction is simple and economical; in addition, it may be constructed extremely compactly and will exhibit very low electrical losses, thereby being capable of handling large amounts of power for its size.

These results are achieved by connecting the two main ports by means of a line, preferably but not necessarily a transmission line, which has first and second transformers connected thereto, each of said transformers comprising a primary and a secondary. The primary of the first trans-

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former is connected in series in the line between the main ports, while the primary of the second transformer is connected in shunt across said line. The secondaries of the two transformers have signals produced therein in accordance with the voltages active on, and the currents passing through, their respective primaries. The outputs from the two secondaries are differently combined and connected to the output ports, the connections being such that when the outputs from the two secondaries are in phase a given distribution of power output to the output ports will result, and when the outputs from the two secondaries are 180 degrees out of phase, a different power distribution will result. The phase of the output from the second transformer, connected in shunt across the input line, will remain the same whether current is flowing through that line in one direction or the other. The phase of the output from the secondary of the first transformer, connected in series in the input line, however, will vary by 180 degrees depending upon the direction of current flow in the input line. As a result, the distribution of output as between the output ports will be dependent upon the direction of current flow in the input line, and that distribution will be substantially accurately maintained over a frequency band width in excess of 100:1.

In some disclosed embodiments the outputs from the two secondaries have the same magnitude, and they are used as the inputs to two opposed ports of a phase-sensitive network such as a 180 degree hybrid junction, the other two ports of the hybrid junction defining the output ports of the overall system. In other disclosed embodiments the outputs from the two secondaries are different in magnitude (preferably one is twice the other), and the two secondaries are connected to the output ports of the system in such a way that their output signals will cancel wholly or partially in traveling toward one output port and will add wholly or partially when traveling toward the other output port, the cancellation direction and the addition direction being dependent upon the phase relationship between those two outputs.

By means of these arrangements circuitry which is normally not directionally sensitive but which is not particularly frequency-sensitive is combined and interconnected so as to produce an overall system which is highly directionally sensitive but which substantially retains its characteristic frequency insensitivity.

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

FIG. 1 is a circuit diagram of representative input circuitry and the transformer arrangements from which output signals are derived;

FIG. 2 is a circuit diagram showing the input circuitry of FIG. 1 connected to a conventional hybrid junction in order to produce directionally sensitive outputs;

FIG. 3 is a diagram of a circuit similar to FIG. 2 but which is in effect the dual of that disclosed in FIG. 2;

FIG. 4 is a diagram of a circuit in which the output ports are connected to one another in a difference fashion;

FIG. 5 is a circuit diagram similar to FIG. 4 but which in effect is the dual of that shown in FIG. 4;

FIG. 6 shows another arrangement for the type of circuit disclosed in FIG. 4;

FIG. 7 shows a circuit similar to FIG. 6 but which in effect is the dual of that shown in FIG. 6;

FIG. 8 is a circuit diagram of yet another embodiment of the present invention;

FIG. 9 is a circuit diagram of a modification of the circuit of FIG. 8; and

FIG. 10 is a circuit diagram of yet another modification of the circuit of FIG. 8.

In the circuit disclosed in FIG. 1, the terminals 2 and 4 define between themselves a main or input port 6, and the terminals 8 and 10 define between themselves a main or input port 12. Conductors 14 and 16, connected respectively between the terminals 2 and 8 and the terminals 4 and 10, define a transmission line having a characteristic impedance Z_0 . As here disclosed port 12 is terminated by an impedance 18 having the impedance value Z_0 , and a suitable voltage V is applied across the terminals 2 and 4 at the port 6. Under these circumstances a traveling wave may be considered as passing through the transmission line 14, 16 from the port 6 to the port 12, from left to right as viewed in FIG. 1. It will be understood, of course, that the terminating impedance 18 could be applied across the port 6 and the input voltage V could be applied across the port 12, in which case power would be considered as flowing through the line 14, 16 from port 12 to port 6, from right to left as viewed in FIG. 1. A transmission line transformer or other broad band transformer 20 has a primary 22 and a secondary 24. The primary 22 is connected in series in the conductor 14. The primary:secondary turns ratio of the transformer 20 is 1: n . A second transmission line transformer or other broad band transformer 26 is provided, it having a primary 28 and a secondary 30. The primary 28 is connected between the conductor 16 and a center-tap 32 on the primary 22 of the transformer 20. The primary:secondary turns ratio of the transformer 26 is n :1. In FIG. 1 impedance 32, having a value of Z_0 , is connected across the secondary 24 of the transformer 20, and impedance 34 having the value Z_0 is connected across the secondary 30 of the transformer 26.

Circuit analysis reveals that with the circuitry of FIG. 1 the input impedance (the impedance looking into the circuit from the port 6) is constant and equal to Z_0 for all values of n . The same would, of course, be true if the impedance 18 were connected across the port 6 and one looked into the circuit from port 12. It further can be demonstrated that the power dissipated in the resistor 34 is the same as that dissipated in the resistor 32, that power being represented by the expression $n^2/(n^2+1/2)^2$. From this it follows that the magnitude of the voltages across the resistors 32 and 34 will be the same. The phase of the voltage across the resistor 34 will be the same whether power enters the system from port 6, as illustrated, or from port 12. However, the phase of the voltage across resistor 32 will vary by 180 degrees depending upon which of the ports 6 and 12 has power fed thereinto.

Thus it may be said that the voltage across resistor 34 (the output from the secondary 30) is determined solely by the magnitude of the voltage input to the system, whereas the voltage across the resistor 32 (the output from the secondary 24) is determined both by the magnitude of the voltage input and the direction of current flow (or, more properly, traveling wave movement) between the ports 6 and 12.

FIG. 2 illustrates one way in which the differing characteristics of the output voltages from the secondaries 24 and 30 respectively can be utilized to produce a network having directional coupling characteristics. The output from secondary 24 is connected by leads 36 to port 38 of a phase sensitive coupling network of known type, represented in the circuit diagram by the block 40. It may, for example, take the form of a 180 degree hybrid junction. The hybrid junction has other ports 42, 44 and 46, and all four of its ports preferably exhibit an input impedance of Z_0 . The output from the secondary 30 is connected by leads 48 to port 42. The ports 44 and 46 of the hybrid junction 40 are shown as terminated by impedances 50 and 52 respectively, each of which preferably has a value of Z_0 . The signals applied to the ports 38 and 42 of the hybrid junction 40 will have the same magnitude,

and they will either be in phase or 180 degrees out of phase, depending upon the direction of traveling wave movement through the transmission line 14, 16 (or direction of current flow in the conductor 14). As a result, and as is characteristic of hybrid junction circuits, all of the input power will appear at one or the other of the output ports 44, 46, depending upon the phase relationship which exists at any given time between the inputs to the ports 38 and 42.

Hence the overall circuit of FIG. 2 constitutes a directional coupler, since the output power will appear either at port 44 or port 46 depending upon the direction of traveling wave movement between the ports 6 and 12 (or, to put the matter in different words, depending upon whether power is fed into the system at port 6 or at port 12), and that coupler will have an extremely wide band width, since all of its components are of essentially frequency-insensitive character.

The fraction of the total power abstracted from the line 14, 16 and appearing either at the port 44 or 46 may be represented by the expression $2n^2/(n^2+1/2)^2$, and consequently the coupling coefficient of the device is the reciprocal thereof, to wit, $(n^2+1/2)^2/2n^2$.

As will be understood by those skilled in the art, the ports 38, 42, 44 and 46 of the hybrid junction need not all have an input impedance of Z_0 ; if they do not it is desirable, for matching purposes, that coupling transformers be interposed between them and their outputs or inputs, as the case may be, or that the turns ratios of the transformers 20 and 26 be changed accordingly.

FIG. 3 discloses a circuit similar to FIG. 2, which is in effect the dual thereof. It comprises a series transformer 26' having primary 28' and secondary 30', which represents the dual of the shunt transformer 26 with its primary 28 and secondary 30 in the embodiment of FIG. 2. The embodiment of FIG. 3 is provided with a pair of shunt transformers 20' and 20'', each with primaries 22' and 22'' respectively and with secondaries 24' and 24'' respectively, which constitutes the duals of the center-tapped series transformer 20 in the embodiment of FIG. 2, with its primary 22 and secondary 24. The turns ratio between the primary 28' and the secondary 30' of the transformer 26' is 1: n , and the turns ratios between each of the primaries 22', 22'' and each of their corresponding secondaries 24', 24'' is $2n$:1. The secondaries 24' and 24'' are connected in series with one another and, by leads 36, to the port 38 of the hybrid junction 40, while the output from the secondary 30' is connected by leads 48 to the port 42 of the hybrid junction 40.

Comparable results can be achieved with other connections between the outputs of the transformers 20 and 26 of the output ports of the system. One such embodiment is disclosed in FIG. 4, where the outputs ports, there designated 44a and 44b, are connected by conductors 54 and 56 which define a transmission line having a characteristic impedance which is preferably equal to Z_0 . The secondary 24 of the transformer 20 is connected in series in the conductor 56. One end of the secondary 30 from the transformer 26 is grounded, and the other end is connected to a center-tap 58 on the secondary 24. In this embodiment the transformers 20 and 26 are so designed that the impedance in series in the transmission line 14, 16 is $2Z_0/n^2$. The current through the primary 22 is $Vn^2/Z_0(n^2+1)$, where V is the amplitude, taken positive with respect to ground, of a traveling wave entering at port 6 or 12. The voltage across the primary 22 is therefore $2V/(n^2+1)$, and the voltage across the secondary 24 is $2nV/(n^2+1)$. The transformer impedance across the line 14, 16 is $Z_0n^2/2$, and the current through the primary 28 of the transformer 26 is $2V/Z_0(n^2+1)$. The voltage across primary 28 is $Vn^2/(n^2+1)$, and the voltage across the secondary 30 of the transformer 26 is $nV/(n^2+1)$.

Comparing the voltage developed across the secondary 24 of the transformer 20 with that developed across the secondary 30 of the transformer 26, we find that the former

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(the voltage across the secondary 24 of the transformer 20) is twice the latter. As a result, when the secondary voltages are connected as shown in FIG. 4, zero voltage will be developed at one output port, and a voltage having the value of $2nV/(n^2+1)$ will be developed at the other output port. For one phase relationship between the outputs of the secondaries 24 and 30 all of the power will be delivered to the output port 44a, and for the opposite phase relationship all of the power will be delivered to the output port 44b.

It can be demonstrated that all of the ports 6, 12, 44a and 44b are matched to Z_0 . The fraction of the total input power applied at port 6 or 12 which appears at the appropriate output port 44a or 44b is $4n^2/(n^2+1)^2$, and consequently the coupling coefficient thereof is

$$(n^2+1)^2/4n^2$$

FIG. 5 discloses a circuit similar to FIG. 4, which is in effect the dual thereof. The series connected transformer 26a, with its primary 28a, and its secondary 30a, is the dual of the shunt-connected transformer 26 of FIG. 4. The shunt-connected transformers 20a and 20b, with their primaries 22a and 22b respectively, and with their individual secondaries 24a, 24a' and 24b, 24b', constitute the dual of the series connected transformer 20 in FIG. 4. One end of the secondary 24a is connected to ground and its other end is connected, with secondary 24b in series therewith, to point 60 in conductor 56 to one side of the secondary 30a. One end of the secondary 24b' is connected to ground and its other end is connected, in series with the secondary 24a', to point 62 in conductor 56 on the other side of the secondary 30a from the point 60. The turns ratio between each of the primaries 22a, 22b and each of the secondaries 24a, 24a', 24b and 24b' is $2n:1$. The turns ratio between the primary 28a and the secondary 30a is $1:n$.

The circuitry of FIGS. 6 and 7 is similar to that of FIGS. 4 and 5 respectively, except that the action of the series and shunt transformers 20 and 26 respectively are reversed. Thus in FIG. 6 the series-connected transformer 20 has a primary 22 and a secondary 24 with a turns ratio of $1:n$, and the shunt-connected transformer 26 has a primary 28 and a secondary 30 with a turns ratio of $n:1$, but it is the secondary 30 of the second transformer 26 which is connected in series in the conductor 56 of the transmission line 54, 56 between the output ports 44a and 44b, and it is the secondary 24 of the series-connected transformer 20 which has one end thereof connected to ground and the other end thereof connected to center-tap 58a on the secondary 30 of the shunt-connected transformer 26. Under these circumstances the signal produced across the secondary 30 of the transformer 26 is twice the signal produced across the secondary 24 of the transformer 20, thereby to produce the desired directional characteristic. In the dual circuit of FIG. 7 the series-connected transformer which is the dual of the shunt-connected transformer 26 of FIG. 6 is in two sections 26c and 26d, the section 26c having a primary 28c and a secondary 30c, the section 26d having a primary 28d and a secondary 30d. The turns ratio of each primary 28c or d to its secondary 30c or d is $1:2n$. The shunt-connected transformer in FIG. 7 which is the dual of the series-connected transformer 20 of FIG. 6 is defined by two sections 20c and 20d. The section 20c has a primary 22c and a secondary 24c. The section 20d has a primary 22d and a secondary 24d. The turns ratios between the primaries 22c, 22d and their respective secondaries 24c, 24d is $2n:1$. The primaries 22c and 22d are connected across the transmission line 14, 16 to either side of the primaries 28c, 28d of the transformer 26c, 26d. The secondaries 24c and 24d of the transformer 20c, 20d are connected in series with one another and in series with the conductor 56 of the transmission line 54, 56, which extends between the output ports 44a and 44b. The secondaries 30c and 30d of the transformer 26c,

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26d are connected across the line 54, 56 to either side of the secondaries 24c, 24d of the transformer 20c, 20d.

FIG. 8 discloses another embodiment of the present invention to which reference numerals corresponding to those used in the preceding figures have been applied where applicable. Thus input port 6 is defined between 2 and 4 and input port 12 is defined between terminals 8 and 10, the terminals 4 and 10 being grounded, with line 14 connecting ports 2 and 8. Series-connected transformer 20 has its primary 22 connected in series with the line 14 and has a secondary 24, the turns ratio between the primary 22 and the secondary 24 being $1:n$. The shunt transformer 26 has its primary 28 connected between line 14 and ground and has a secondary 30. The primary:secondary ratio of the transformer 26 is $n:1$. The output port 44a is connected between ground and the ungrounded end of the secondary 24. The other output port 44b is connected between the ungrounded ends of the secondaries 24 and 30 respectively. With this arrangement equal length paths are provided to the two output leads in both directions, thus presenting operational advantages over the previously described embodiments. In the system of FIG. 8, when power is fed from input port 6 to input port 12 the voltages generated at the transformer secondaries 24 and 30 are equal. Thus there will be no output at port 44b and there will be an output at port 44a. On the other hand, when current is fed from port 12 to port 6 it can be shown that a current will pass through the load connected across the output port 44b, flowing upwardly as viewed in FIG. 8, which will, when the load across port 44b equals the load across port 44a, be equal and opposite to the current induced in the secondary 24. As a result, there will be no output at port 44a, while there will be an output at port 44b. Thus a directional coupler effect is produced. In this embodiment, and in the embodiments of FIG. 9 and 10, the coupler cannot be matched at all ports. It can, and preferably should, be matched at the ports 12, 44 and 44b, but the impedance looking into port 6 will be different from the impedance looking into the other three ports.

FIG. 9 represents a modification of FIG. 8 in which the interconnected transformer secondary circuit is grounded at a different point. In effect, the lowermost end of the secondary 30 is conductively connected to one of the terminals of the output port 44a, and the system is grounded at a point corresponding to the upper end of the transformer secondary 24 in FIG. 8. The advantage of the arrangement of FIG. 9 is that it permits all leads to be grounded at one end, this being beneficial for high frequency work particularly in facilitating the use of better terminations, and the use of strip line techniques to feed the unit.

The embodiment of FIG. 10 is similar to that of FIGS. 8 and 9, except that it is disclosed in accordance with a transmission line approach to the problem, and the configuration is particularly well adapted for commercial manufacture. The series-connected transformer 20, having primary 22 and secondary 24 with a turns ratio of $1:n$, and the shunt transformer, with its primary 28 and secondary 30 having a turns ratio of $n:1$, have their secondaries conductively connected as shown, with the secondary 30 of the shunt transformer 26 connected in series in the line 56, which forms a part of the transmission line 54, 56 extending between the exit ports 44a and 44b. The secondary 24 of the series-connected transformer 20 has one end connected to ground and the other end to point 70 on the line 56.

Circuits of the type disclosed in FIGS. 8, 9 and 10 have been constructed covering a frequency range of 10-1500 megacycles, with 30 db directivity, 1.5 db main line loss, and a coupling variation of less than 0.8 db over the frequency range specified.

Although the circuit diagrams here disclosed show the use of conventional transformers, transmission line transformers may be employed if desired. The circuits here specifically disclosed are typical, and many equivalent cir-

uits could be employed in their place with equivalent results.

We claim:

1. A directional coupler comprising a line having ports at either end, a first transformer comprising a primary connected in series in said line between said ports and a secondary associated with said primary, the primary-secondary turns ratio of said first transformer being $1:n$, a second transformer comprising a primary connected in shunt across said line and a secondary associated with said primary, the primary-secondary turns ratio of said second transformer being $n:1$, n being any number, third and fourth ports, and means conductively connecting said third and fourth ports and said secondaries of said first and second transformers, said connecting means including means for sensing phase changes in the output of one of said secondaries relative to the other and for modifying the transmission of said outputs from said secondaries to said third and fourth ports in accordance with such sensing, in which said connecting means comprises a hybrid junction having two pairs of opposed ports, one such pair comprising said third and fourth ports, the ports of the other such pair being connected respectively to said secondaries of said first and second transformers respectively.

2. The directional coupler of claim 1, in which said secondaries of said first and second transformers produce signals of equal voltage magnitude.

3. A directional coupler comprising a line having ports at either end, a first transformer comprising a primary connected in series in said line between said ports and a secondary associated with said primary, the primary-secondary turns ratio of said first transformer being $1:n$, a second transformer comprising a primary connected in shunt across said line and a secondary associated with said primary, the primary-secondary turns ratio of said second transformer being $n:1$, n being any number, third and fourth ports, and means conductively connecting said third and fourth ports and said secondaries of said first

and second transformers, said connecting means including means for sensing phase changes in the output of one of said secondaries relative to the other and for modifying the transmission of said outputs from said secondaries to said third and fourth ports in accordance with such sensing, in which said connecting means comprises a conductive connection between given ends of said secondaries, one of said third and fourth ports is connected between the other ends of said secondaries, and the other of said third and fourth ports is connected between the other end of said secondary of said first transformer and the given end of said secondary of said second transformer.

4. The directional coupler of claim 3, in which the given end of said secondary of said first transformer is connected to a reference potential.

5. The directional coupler of claim 4, in which said secondaries of said first and second transformers produce signals of equal voltage magnitude.

6. The directional coupler of claim 3, in which said secondaries of said first and second transformers produce signals of equal voltage magnitude.

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UNITED STATES PATENT OFFICE CERTIFICATE OF CORRECTION

Patent No. 3,426,298

February 4, 1969

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It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

In the heading to the printed specification, lines 4 and 5, "assignors to Anzac Electronics, Inc., Norwalk, Conn., a corporation of Connecticut" should read -- Adams-Russell Co., Inc., a corporation of Massachusetts --.

Signed and sealed this 17th day of March 1970.

(SEAL)

Attest:

Edward M. Fletcher, Jr.

Attesting Officer

WILLIAM E. SCHUYLER, JR.

Commissioner of Patents