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Hudspeth et al.

[11] **3,843,941**

[45] **Oct. 22, 1974**

[54] **TWO-TO-THREE PORT PHASE CONVERTER**

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[21] Appl. No.: **403,368**

[52] **U.S. Cl.** ..... **333/9,** 333/11, 333/31 A, 333/98 R

[51] **Int. Cl.** **H01p 5/12**

[58] **Field of Search** ..... 333/9, 11, 31 R, 31 A, 333/21 R, 98 R, 98 M

[56] **References Cited**

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[57] **ABSTRACT**

A waveguide network is disclosed which provides a simplified means of converting a quadrature phase input signal to a three-phase output signal or vice versa. In the illustrative embodiment two coherent, equal amplitude input signals having a ninety degree relative phase difference are converted to three output signals having progressive phase differences of sixty degrees. The phase progression of the signals at the output ports can be +60°, 0°, −60° or −60°, 0°, +60° depending upon whether the relative phase of the input signals are +90° or −90°. The device comprises a composite structure having a phase correction section and a dual mode impedance transformer section in a unitary housing.

7 Claims, 6 Drawing Figures

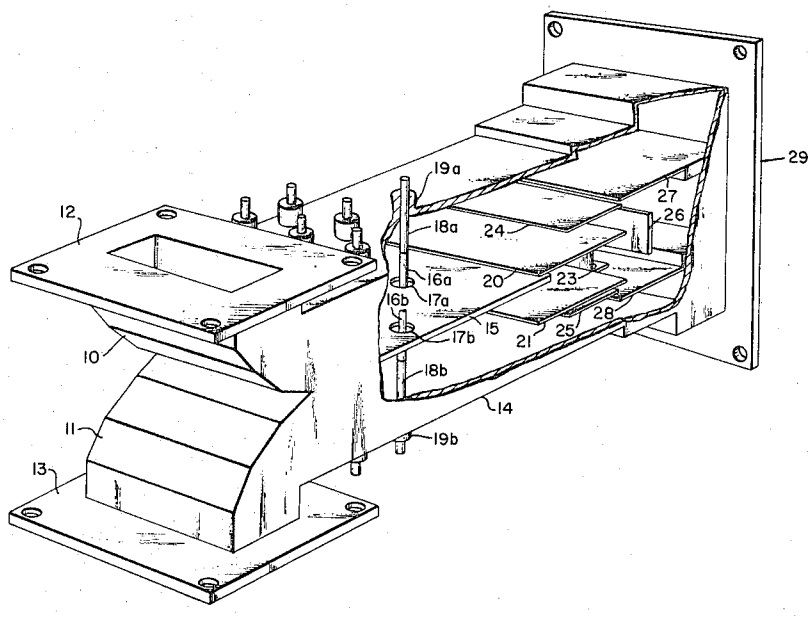


Fig. 1.

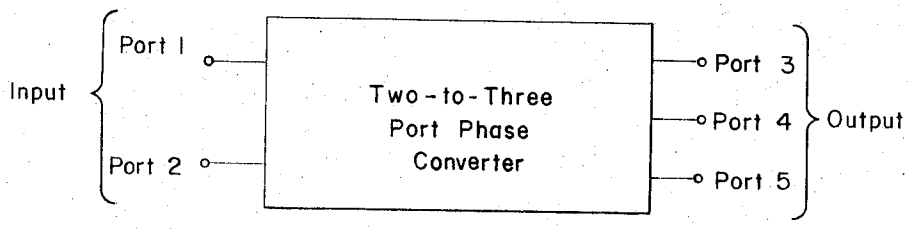


Fig. 5.

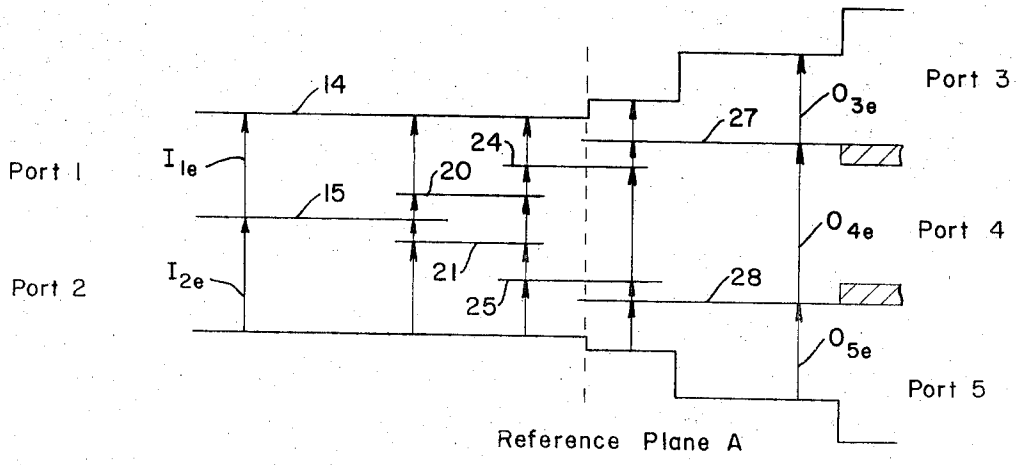
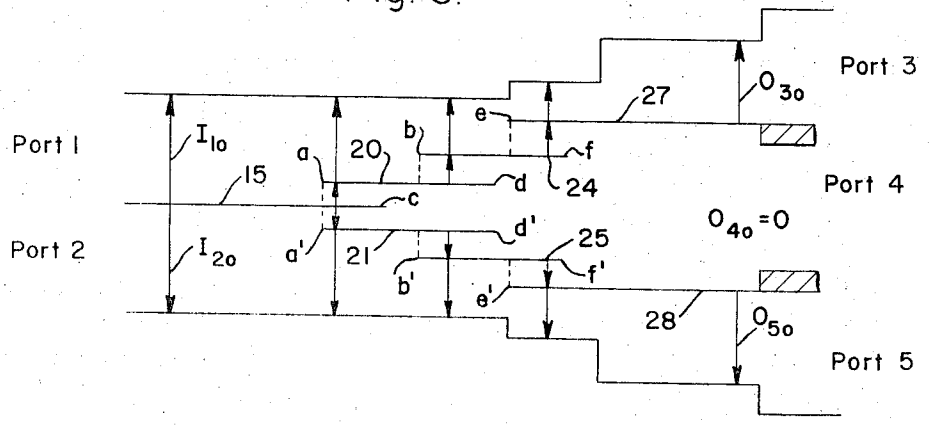


Fig. 6.



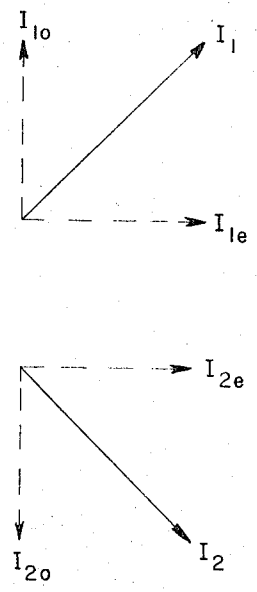


Fig. 2.

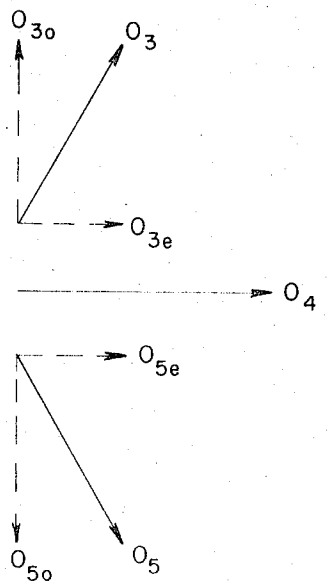


Fig. 3.

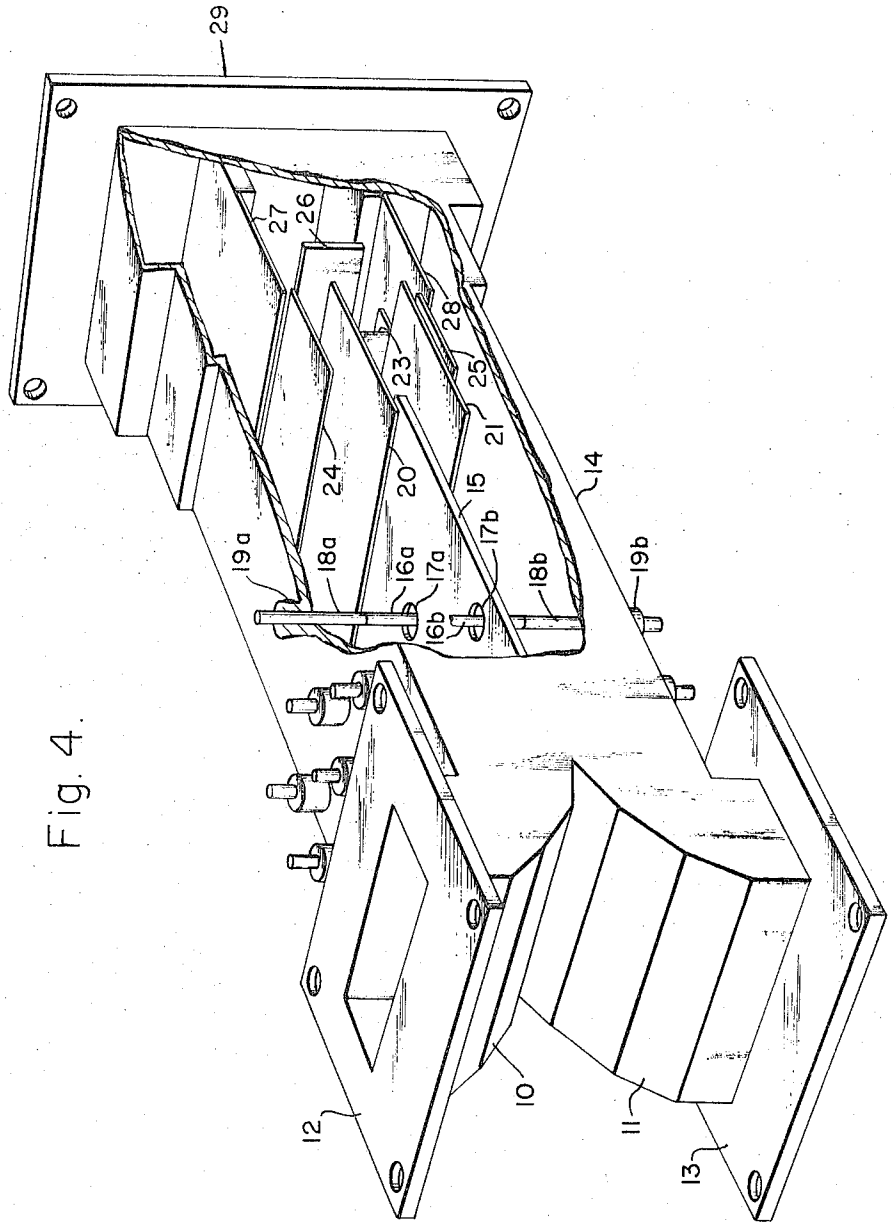

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25
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15
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19a
18a
16a
17a
17b
18b
19b
16b
12
10
11
13

Fig. 4.

TWO-TO-THREE PORT PHASE CONVERTER

FIELD OF THE INVENTION

This invention relates to microwave devices and more specifically to waveguide networks and phase transforming devices.

DESCRIPTION OF THE PRIOR ART

In many microwave applications it is necessary to convert input signals of one phase to output signals of a different phase. In many cases straightforward phase shift networks of common design can be successfully employed. As the number of input signals and/or output signals increase, however, such networks tend to become more and more complex. Moreover, in some cases it is necessary to convert from two inputs to three outputs or vice versa and simultaneously maintain the relative phase of the signals at predetermined values.

One specific use for phase converters of the latter type is in an antenna feed network for shaped beam antennas. An example of an antenna which utilizes such a shaped beam is disclosed in U.S. Pat. No. 3,680,143 which issued to J. S. Ajioka, et al. on July 25, 1972. With such antenna structures a shaped beam is realized by a plurality of linearly disposed offset feeds at the focal region of a reflector. The feeds are energized in a manner to produce different senses of phase progression across the aperture. The resulting patterns are sufficiently close so as to overlap. Because of the phase progression, the overlapping patterns add vectorially to produce an overall saddle or flat beam pattern rather than a pattern with a peak in the center of the plane of the linearly disposed feeds. In an exemplary antenna having three feeds the relative phase progression across the adjacent horns in one mode might be +60°, 0° and −60° and in another mode −60°, 0° and +60°.

The waveguide network which was formerly required to obtain such phase progressions with two orthogonal input signals was quite complex—consisting of several waveguide sections with twists and bends and a plurality of waveguide coupling devices.

It is therefore an object of the present invention to provide a waveguide two-to-three port phase converter of simplified design.

SUMMARY OF THE INVENTION

In keeping with the principles of the present invention this object is accomplished in a unique unitary structure by combining a two-to-three port dual mode impedance transformer and a phase correction network. The operation of the two-to-three port phase converter is advantageously viewed from the standpoint of its "even mode" and "odd mode" behavior. That is, the device operates in different ways on the so-called "even" and "odd" mode components of the progagating wave energy. A superposition of the two modes of operation represents the resultant operation.

BRIEF DESCRIPTION OF THE DRAWINGS

In order that the invention may be clearly understood and readily carried into effect it will now be described with reference by way of example to the accompanying drawings, wherein like reference numbers correspond to like structural elements and, in which:

FIG. 1 is a generalized block diagram of a two-to-three port phase converter;

FIG. 2 is a graphical representation, in vector form, of the input signals to the two-to-three port phase converter;

FIG. 3 is a graphical representation, in vector form, of the output signals from the two-to-three port phase converter;

FIG. 4 is a pictorial view, partially broken away, of a preferred embodiment of the present invention;

FIG. 5 is a simplified cross-sectional view of the dual mode impedance transformer portion of the embodiment of FIG. 4 for even mode transmission; and

FIG. 6 is a simplified cross-sectional view of the dual mode impedance transformer portion of the embodiment of FIG. 4 for odd mode transmission.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring more specifically to the drawings, FIG. 1 is a generalized block diagram of a two-to-three port phase converter useful in understanding the principles of the present invention. The two-to-three port phase converter is characterized by a pair of input ports denoted port 1 and port 2 and three output ports labeled port 3, 4 and 5, respectively. In a preferred embodiment coherent input signals having a phase quadrature relationship are applied in equal amplitude to input ports 1 and 2. These input signals are converted in the two-to-three port phase converter into three output signals having a relative phase progression from output port 3 to output port 5 of +60°, 0° and −60°. As noted hereinabove, however, this phase progression can be reversed by the reversal of the quadrature input signals.

For the sake of clarity, the input signals to ports 1 and 2 are shown in vector notation in the graphical representation of FIG. 2. In FIG. 2 the vector I_1 represents the input signals to port 1 and the vector I_2 represents the input signal to port 2. For reasons which will become apparent in connection with the description given hereinbelow, the input signals have been further broken down into their even mode and odd mode components. That is, input signal I_1 has an even mode component represented by dashed line vector I_{1e} and its odd mode component I_{1o}. In a similar manner the input signal to port 2 has an even mode component I_{2e} and odd mode component I_{2o}. The quadrature phase input signals can be conveniently obtained, for example, from the output ports of a 90° 3-db hybrid network, not shown.

In the graphical representation of FIG. 3 the output signals from ports 3, 4 and 5 of the two-to-three port phase converter are similarly shown in vector notation. The output signal from port 3 comprises the vector combination of dashed line vector O_{3o} and O_{3e}, which are the odd mode and even mode components, respectively. The output signal from port 4 comprises a vector O_4 which has no odd mode compenent. Similarly, the output from port 5 corresponding to vector O_5 is made up of its even and odd mode components O_{5e} and O_{5o}, respectively.

Before describing the operation of the two-to-three port phase converter in detail it is desirable to describe the preferred waveguide embodiment of the present invention. This embodiment is shown in the pictorial view of FIG. 4.

There is shown in FIG. 4 a partially broken away pictorial view of the preferred embodiment of the present invention. The structural features of the invention will be explained in connection with this figure. The electrical operation of the invention, however, will be more readily understood in connection with the description of the simplified cross-sectional views of FIGS. 5 and 6.

In FIG. 4 a pair of rectangular waveguide sections 10 and 11 comprise the two input ports of the two-to-three port phase converter. These ports are termed the "input ports" although, since the device is a reciprocal device, this designation is for convenience only. Waveguide sections 10 and 11 are provided with flanges 12 and 13, respectively, to facilitate connection to other apparatus with which the device is utilized. Both waveguide sections 10 and 11 make a ninety degree bend in the E-plane and thereafter merge into a rectangular conductive waveguide housing 14. A common conductive wall 15 is disposed between the side walls of conductive housing 14 and forms a structural part of the phase correction portion of the embodiment as will be discussed in greater detail hereinbelow.

A plurality of conductive rods 16*a*, 16*b*, ... etc., extend through corresponding circular apertures 17*a*, 17*b*, ... etc., in common wall 15 also for the purpose to be discussed in greater detail hereinbelow. For ease in mounting, rods 16*a*, 16*b*, ... etc., are bonded to dielectric support rods 18*a*, 18*b*, ... etc., respectively. Conductive rods 16*a*, 16*b*, ... etc., can be of copper, brass, or any other suitable high conductivity material. Dielectric support rods 18*a*, 18*b*, ... etc., can be advantageously fabricated of any suitable low loss dielectric material known in the art. Support rods 18*a*, 18*b*, ... etc., project through appropriately located bushing 19*a*, 19*b*, ... etc., disposed on and extending through the top and bottom walls of waveguide housing 14.

Conductive rods 16*a*, 16*b*, ... etc., are mounted in the manner shown for ease of replacement in the tuning process. These support rods and their corresponding bushings are not indispensable elements of the device but rather illustrative means for providing interchangeability and a degree of adjustability. Other mounting techniques can be readily employed for this purpose.

A first pair of substantially identical conductive septa 20 and 21 extend across the width of conductive waveguide housing 14 between the side walls thereof. Septa 20 and 21 overlap common conductive wall 15 in the longitudinal direction to a small extent, as will be explained hereinbelow. A second pair of substantially identical conductive septa 24 and 25 also extend across the width of conductive housing 14 beginning further along the longitudinal direction. Septa 24 and 25 also overlap to a small extent septa 20 and 21. Finally, a third pair of substantially identical conductive septa 27 and 28 are disposed across conductive housing 14 beginning from the mid-region of septa 24 and 25 and extending longitudinally to the second end of the device.

A first vertically extending transverse septum 23 extends across conductive housing 14 between septa 20 and 21 near the far end region thereof. Finally, a second vertically extending transverse septum 26 extends across conductive housing 14 between septa 24 and 25 in the region of their furthermost ends. All of the above-mentioned conductive septa 20 through 28, as well as plate 15, are mechanically and conductively joined to the sidewalls of housing 14 such as by soldering, brazing or other techniques well-known in the art.

Additionally, the top and bottom walls of conductive housing 14 are stepped from the region of septa 27 and 28 for impedance matching purposes as is known in the art. A coupling flange 29 is provided at the second end of the device of FIG. 4 to facilitate connection to output waveguide means, not shown. Stepped transition sections are also provided on the facing surfaces of septa 27 and 28 at their furthermost ends also to facilitate impedance matching for the center output port.

The function of the two-to-three port phase converter of FIG. 4 therefore is to transform input signals such as shown in FIG. 2 to output signals as shown in FIG. 3. The operation of the device can be more readily understood by considering its even and odd mode transmission characteristics. As previously noted in connection with the diagrams of FIGS. 2 and 3, each of the input and output signals can be separated into its constituent even and odd mode components. When this is done and the operation of the device is considered separately for the two transmission modes, the principle of superposition is applied to furnish the net result.

In considering the even mode transmission characteristics of the device, reference is now made to the simplified cross-sectional view of FIG. 5 showing the dual mode impedance transformer section of the composite structure of FIG. 4. The succession of arrows shown in the figure represents the direction of the electric field for each of the wave components. As shown in FIG. 5, the electric fields for the even mode components of the input signals I_{1e} and I_{2e} extend in the same direction. The electric fields of the odd modes, however, extend inopposite directions, as will be seen in the cross-sectional view of FIG. 6.

In the preferred embodiment, the characteristic impedances of the waveguide sections formed by the conductive housing 14 and the various conductive septa are proportional to the waveguide heights (in FIGS. 5 and 6, the vertical dimension). In the illustrative embodiment, the characteristic impedances of the input waveguide sections at ports 1 and 2 are defined as Z_o. At Reference Plane A, the top and bottom output waveguides have characteristic impedances defined as Z_1 and the center output waveguide has a characteristic impedance Z_2. As noted, these characteristic impedances are obtained by a proper choice of the waveguide height dimensions. It can readily be seen that for reflectionless transformation in the even mode, the sum of the characteristic impedances of the output waveguides at Reference Plane A is equal to the sum of the characteristic impedances of the two impedances of the two input waveguides, or in other words, $Z_1 + Z_2 + Z_1 = 2Z_o$.

It is noted in the illustrative embodiment that extending to the right from Reference Plane A the conductive housing 14 is stepped to provide greater waveguide heights for output ports 3 and 5. Conversely, the height of the center output waveguide formed by septa 27 and 28 and housing 14 is reduced by conductive steps, as previously mentioned. The height variations are for impedance matching purposes so that all three of the output waveguide ports have characteristic impedances which match those of the apparatus to which the ports are coupled. If desired, these characteristic impedances

can be made equal to Z_o, or any other convenient value.

Ideally, conductive septa **20, 21, 24, 25, 27** and **28** should have zero thickness. In a practical embodiment, however, there is a small finite thickness of the septa which, in turn, causes a small departure from ideal performance. In order to correct for this non-ideal power distribution within the output waveguides, it has been found useful to employ the vertically extending transverse septa **23** and **26** shown in FIG. **4**. For the sake of clarity, these septa have been omitted from the simplified views of FIGS. **5** and **6**.

As the input signals in the even mode propagate to the structure they are relatively undisturbed by the presence of conductive septa **20, 21, 24, 25, 27** and **28**. In other words, since the direction of the electric field vectors are the same at every point within the device a power division takes place, as is well-known in the art, to furnish the desired even mode power distribution. The relative magnitudes of the power in the even mode components at output port **3** through **5** is graphically illustrated in FIG. **3** by the even mode vector O_{3e}, O_{4e} and O_{5e}.

Referring now to the simplified cross-sectional view of FIG. **6**, the arrows depict the electric field corresponding to the odd mode components of the wave energy propagating through the device. The odd mode components of the input signals I_{1o} and I_{2o} are of opposite polarity, as are output components O_{3o} and O_{5o}. The height of the waveguide sections formed by the conductive housing **14** and septa **20** and **21**; setpa **24** and **25**; and septa **27** and **28** are chosen low enough to prevent the propagation of wave energy which can be launched by the odd mode. Therefore, within these waveguide sections at points *c*, *d*—*d'* and *f*—*f'*, respectively, the waveguides present substantially an open circuit to the wave energy in the odd mode. In practice, there is found a small fringing capacitance at these points. The reactance at points *c*, *d*—*d'* and *f*—*f'* are reflected back through the respective waveguide sections to appear as short circuits at the planes shown by the dotted lines at *a*, *a'*, *b*, *b'*, *e* and *e'*. Thus the length of septa **20** and **21**; **24** and **25**; and **27** and **28** between points *a*, *a'* – *c*, *b*, *b'* – *d*, *d'* and *e*, *e'* and *f*, *f'* are substantially equal to one-quarter wavelength at the signal frequency. In general, these lengths will depart from one-quarter wavelength by a small amount depending upon the value of the aforementioned fringing capacitances.

Therefore, at the signal frequency, the dual mode impedance transformer section is equivalent to a quarter-wave stepped transformer. With this equivalent circuit in mind a straightforward analysis based on transmission line theory yields the desired characteristic impedances and therefore height dimensions of the waveguide sections formed between the conductive septa.

Returning now to the phase correction portion of the embodiment illustrated pictorially in FIG. **4**, since the odd mode components are subjected to the various steps and reactances described above they incur more phase shift than the even mode components. The function of the phase correction section of the device is to compensate for the greater phase shift of the odd mode components. This phase correction is accomplished by introducing a phase shift substantially only affecting the even mode components. The phase shift is accomplished by means of the conductive rods **16***a*, **16***b*, etc., which extend through the apertures in the common wall **15**. For the evne mode, the apertures are equivalent to the solid conductor. The rods, however, present an equivalent shunt susceptance to the even mode components. The length of the rods and their transverse locations are selected to provide a phase, phase slope, and rate of change of phase slope with respect to frequency, correction for the device.

In practice, it has been found convenient to dispose three rods, as shown, in two transverse planes separated by substantially one-quarter wavelength at the signal frequency. The first and second rows of rods are followed by a single rod **16***a* centrally located within the common wall **15** at a distance also substantially equal to one-quarter wavelength. By adjusting the lengths of the conductive rods **16***a*, **16***b*, etc., phase, phase slope and curvature of the phase versus frequency characteristics of the phase compensating section can be optimized.

In all cases it is understood that the above-described embodiment is merely illustrative of but one of the many possible specific embodiments which can represent applications of the principles of the present invention. Numerous and varied other arrangements can be readily devised in accordance with these principles by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A microwave network comprising, in combination:

a pair of input ports,

means for coupling signal energy to said input ports, said signal energy at said input ports having components which are mutually in-phase and mutually out-of-phase;

at least three output ports;

means for coupling said input ports to said output ports, said means comprising the serial combination of a phase correction network and an impedance transformer;

said phase correction network being adapted to shaft the phase of said in-phase components with respect to the phase of said out-of-phase components; and

said impedance transformer being adapted to transform the in-phase components of the phase-corrected signal energy into three in-phase output components and to transform the out-of-phase components of the phase-corrected signal energy into two out-of-phase output components.

2. The microwave network according to claim **1** wherein signal energy to one of said input ports is in phase quadrature to the signal energy to the other of said input ports.

3. A five port waveguide network comprising, in combination:

a hollow conductive housing;

a conductive common wall extending longitudinally within said housing to form a pair of substantially identical rectangular waveguide sections;

a first pair of conductive septa extending longitudinally within said housing parallel to said common wall and spaced therefrom, said first pair of septa and said common wall having a first longitudinal overlap;

a second pair of conductive septa extending longitudinally within said housing parallel to said first pair

of septa and spaced therefrom, said second and first pair of septa having a second longitudinal overlap,

and a third pair of conductive septa extending longitudinally within said housing parallel to said second pair of septa and spaced therefrom, said third and second pair of septa having a third longitudinal overlap;

input means including first and second ports coupled to the waveguide sections formed by the conductive housing and said common wall; and

output means including third, fourth and fifth ports coupled to the waveguide sections formed by the conductive housing and said third pair of conductive septa.

4. The network according to claim **3** wherein said common wall defines a plurality of apertures, a plurality of reactive elements, and means for supporting said reactive elements in a spaced relationship in said apertures.

5. The network according to claim **4** wherein said reactive elements comprise conductive rods extending transversely through said apertures.

6. The network according to claim **3** wherein said waveguide sections are capable of supporting propagating microwave energy of a given frequency and wherein said first, second and third longitudinal overlaps are substantially equal to one-quarter wavelength at said given frequency.

7. The network according to claim **3** wherein said hollow conductive housing is of substantially square cross-section over a first portion of its length and is stepped in at least one cross-sectional dimension over a second portion of its length.

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