June 19, 1962 T. S. SAAD 3,040,275

COAXIAL HYBRID

Filed June 27, 1957 3 Sheets-Sheet 1

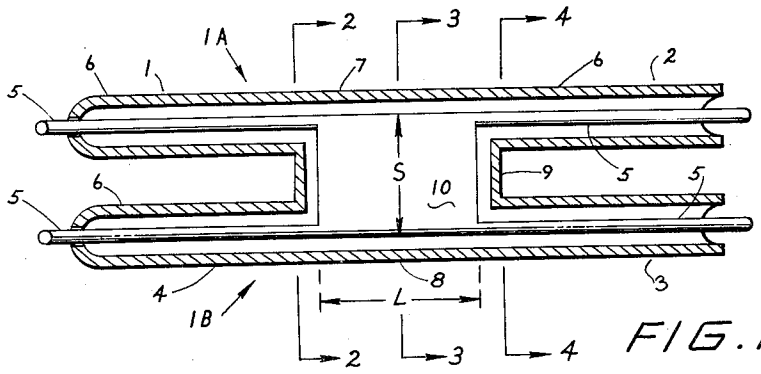


FIG. 1

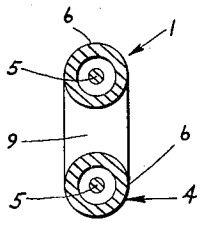


FIG. 2

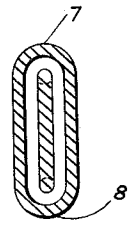


FIG. 3

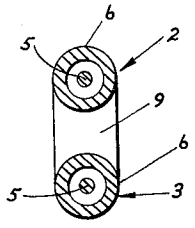


FIG. 4

SYMMETRIC MODE ANTISYMMETRIC MODE

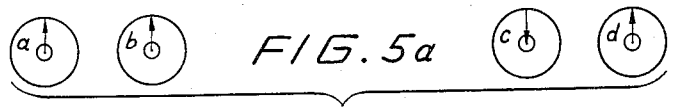


FIG. 5a



FIG. 5b



FIG. 5c

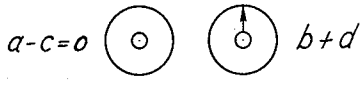


FIG. 6

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COAXIAL HYBRID

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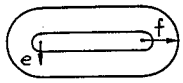


FIG. 7

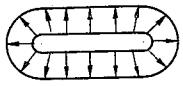


FIG. 9

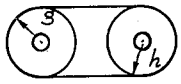


FIG. 8

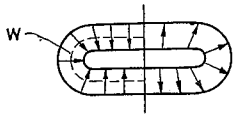


FIG. 10

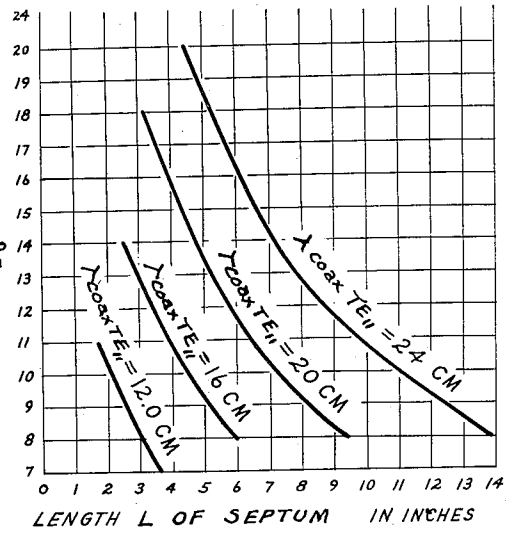


FIG. 12

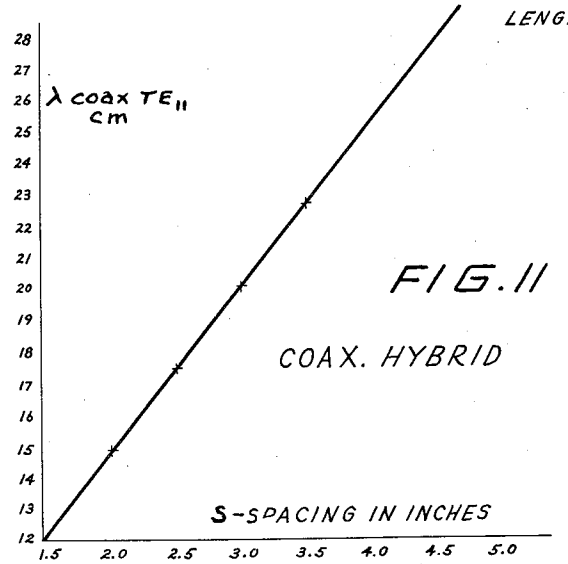


FIG. 11

COAX. HYBRID

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COAXIAL HYBRID

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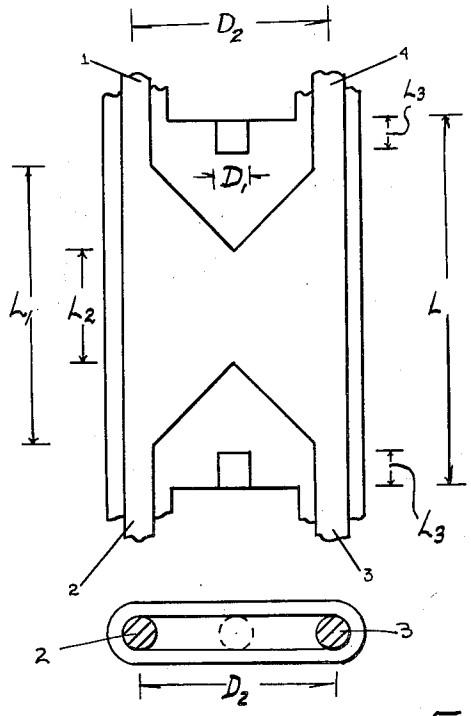


FIG. 13

FIG. 14

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United States Patent Office 3,040,275 Patented June 19, 1962

3,040,275

COAXIAL HYBRID

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Filed June 27, 1957, Ser. No. 668,370
4 Claims. (Cl. 333—10)

The present invention relates to a coaxial waveguide hybrid.

A hybrid is conventionally defined as a circuit having four coaxial terminals with two of these being input terminals and the other two output terminals. The hybrid has the property such that energy incident on one of the input terminals will divide evenly between the two output terminals with only a small incidental fraction of the energy escaping through the other input terminal. Hybrids have been known and used in waveguide transmissions as for example the waveguide hybrid disclosed in United States Patent No. 2,739,288. So far as known, however, a coaxial transmission line hybrid of the type herein disclosed has not previously been constructed.

The present invention provides a coaxial line hybrid in which a pair of coaxial lines are formed parallel to one another with a common aperture in their outer walls, and with a septum interconnecting the inner conductors in this apertured region. This arrangement of structures permits the utilization of the hybrid for broad band transmission and further permits the transmission of the principal TEM and lowest TE_{11} mode associated with the coaxial line inputs simultaneously, provided correct parameters are used in the design of the hybrid.

As is well known in microwave technique, signals which are propagated down two parallel waveguides, having a common apertured wall on the narrow dimension, will be unaffected by the common apertured section if the signals are of the same magnitude and are out of phase. If the signals, however, are in phase, they will, upon reaching the apertured section, behave as a common signal in a single double width waveguide. In an apertured section, the phase of in-phase components advances more rapidly than the phase of out-of-phase components, causing a resultant change in the vector sum of the signals in each guide and consequently a change in the relative power levels in the two guides. This phenomenon may readily be explained by resolving the signal incident to the input terminal into identical in-phase and out-of-phase components at the common apertured section. Thus, as in waveguide hybrids, the incident signal may be resolved into equal resultant power outputs, one in each output terminal with a relative phase dependent upon the length of the apertured section.

The simplicity of this arrangement in waveguide hybrids cannot readily be translated into the field of coaxial line transmission. If a pair of coaxial lines are arranged with a common apertured section in their outer conductors, no unique relationship between the signals in either coaxial line will result. It has been found, by the applicant however, that the resolution of an incident signal in one coaxial terminal into equal output or resultant signals in orthogonal phase may result with the use of a septum interconnecting the inner conductors at the apertured section, with the septum having certain physical dimensions determined by the characteristics of the modes to be transmitted.

The present invention further contemplates the provision of a coaxial line hybrid capable of handling substantial amounts of power over a wide range of frequencies. The specific parameters of the hybrid are of course dependent upon the frequencies to be transmitted. The important parameters relative to the aperture area are the width of the septum defining the distance between the

two inner conductors, hereinafter termed S and the length of the septum, hereinafter termed L. The width or spacing S is determined by the maximum distance between the outer edges of the inner conductors while the length L, includes a correction factor to account for the regions between the ends of the common wall joining the outer conductors and the beginning of the septum.

While the invention hereinafter described will be considered in connection with coaxial lines circular in cross section and while the septum will be described in connection with a single embodiment of a specific shape, it should be understood that other types of cross section coaxial lines and septums are considered within the scope of this invention.

The invention will be more clearly understood when considered in connection with the accompanying drawings, in which:

FIGURE 1 is a schematic cross sectional plan of a hybrid of the present invention.

FIGURE 2 is a cross sectional view taken substantially along the line 2—2 of FIGURE 1.

FIGURE 3 is a cross sectional view taken substantially along the line 3—3 of FIGURE 1.

FIGURE 4 is a cross sectional view taken substantially along the line 4—4 of FIGURE 1.

FIGURES 5*a* to 5*c* are schematic vector representations used in connection with explaining the operation of my invention,

FIGURES 6, 7 and 8 are also schematic theoretical vector representations of modes at various points of the hybrid.

FIGURES 9 and 10 schematically illustrate the electric fields for even and odd modes at the center of the septum in the present invention.

FIGURE 11 is a chart useful in determining the width S of the septated area.

FIGURE 12 is a chart useful in determining the length L of the septated area, and,

FIGURE 13 and FIGURE 14 are diagrammatic top and end views of a specific embodiment of the invention.

Referring to FIGURE 1, there is illustrated a pair of parallel coaxial lines 1*a* and 1*b*, each having an inner conductor 5 and an outer conductor 6. These lines 1*a* and 1*b* form respectively, coaxial terminals or sections 1 and 2, and 3 and 4. These conductors may be made of any conventional material utilized in the manufacture of coaxial transmission lines. Further, the inner and outer conductors may be separated by solid or air dielectric means in accordance with any of the well known practices. The free ends of these coaxial terminals may be adapted to be inter-engaged with other coaxial transmission lines also by well-known means, as for example, by providing type N terminals at the free ends of these coaxial line sections.

The coaxial line sections 1 and 2 as well as the line sections 3 and 4, are respectively provided with common outer conductors as indicated respectively at 7 and 8. Aligned aperture sections are provided in each of the continuous sections 7 and 8. A continuous conductive well section 9 interconnects the peripheral portions of the apertures with one another. The apertures preferably have a width equal to the outer diameter of the coaxial lines, which lines preferably should be all of equal dimensions. The length of the aperture as well as the spacing between the parallel line sections may be determined in a manner hereinafter described. Interconnecting the inner ends of the inner conductors 5 is the septum 10. The septum 10 is formed of a continuous conductive material extending in width to at least the maximum distance between the parallel inner conductors 5 and with each outer edge of this septum being continuous with the aligned outer edges of the inner con-

ductors 5. The length L of the septum is defined by the length of the apertures, that is the distance between the wall sections 9 or alternately, the length of the apertures may be considered as being defined by the length of the septum 10 in a manner hereinafter described.

In considering the operation of this device, reference is made to FIGS. 5–8. As a preliminary to understanding the operation of the device, it must first be presumed that the reflected voltages in both the input terminals, as for example, terminals of lines 1 and 4, add up to zero. It therefore follows that the reflected voltages of both symmetrical or in phase modes and anti-symmetrical, or out-of-phase modes must both be zero. This may be obtained by making the apertured sections matched for the incident symmetric voltages, or even modes.

If an incident voltage is introduced into one of the inputs, as for example, input 4, it will travel or propagate down the line to the septated area at which point there will be a power transfer into the other side of the hybrid. This power transfer may be best understood in connection with FIGS. 5*a* to 8. In these figures, the vector arrows *a* and *b* theoretically represent even or symmetric modes introduced simultaneously into each input terminal 1 and 4, and vector arrows *c* and *d* theoretically represent anti-symmetric or odd modes introduced simultaneously into each input terminal. The vectors indicate incident voltage in relative magnitude and phase at various locations in the hybrid. These rotating vectors, *a*, *b*, *c* and *d*, are illustrated in FIGS. 5*a*, 5*b* and 5*c* respectively, at sections 2—2, 3—3 and 4—4, of FIG. 1. In this manner the effect of power incident on a single input terminal only may be considered by the resolution of this signal in that line into indentical in-phase and out-of-phase components in that line and in the other input line. Such a theory is fully explained and well known in the art (see for example, Patent No. 2,739,288). In accordance with this theory, radial vectors *a* and *b*, in FIGURE 5*a*, represent the symmetric or in-phase modes appearing at section 2—2 of terminals 1 and 4 respectively. Radial vectors *c* and *d* represent the anti-symmetrical or out-of-phase modes, at section 2—2 of terminals 1 and 4 respectively. These radial vectors are propagated down the coaxial hybrid towards the terminals 2 and 3. Radial vectors *a* and *b* however, being in phase components, will, in the septated area combine and propagate as a principal TEM mode and will therefore be of a shorter wave length than radial vectors *c* and *d*, which in the septated area combine to propagate in the TE_{11} mode. The vectors *a* and *b*, therefore advance relatively more rapidly than the out-of-phase vectors *c* and *d* as will be further explained below. This results in a change in the vector sum of the signals in each half of the hybrid as the signal advances down the hybrid towards the terminals 2 and 3. At, for example, section 3—3, the vectors may take the relative phase positions illustrated in FIG. 5*b*. It will be noted, however, that vectors *a* and *b* are still in phase with one another, while vectors *c* and *d* are still 180° out-of-phase with one another. At section 4—4 of FIG. 1, vectors *a* and *b* have advanced in phase to a point where they are now 90° in advance of their original phase position and the phase position with respect to vectors *c* and *d* at section 2—2. The vectoral sum of the voltage vectors in each half of the hybrid at lines 2, 3 and 4 of FIG. 1 are illustrated respectively in FIGS. 6, 7 and 8. At section 2—2 the voltage vectors *a* and *c* combine to produce a zero net vector at terminal 1. The vectors *b* and *d* add together and represent the incident voltage applied at the input terminal 4, this being a maximum voltage. At point 3—3, the vectors *a* and *b* have advanced more rapidly than the vectors *c* and *d*. When combined, the vectors *a* and *c* are represented by the resultant vector *e* and the vectors *b* and *d* are represented by the resultant vector *f*. The vector *f* is relatively greater in magnitude than the vector *e*. At section 4—4, vectors *a* and *c* add to the resultant vector *g*, while vectors *b* and *d* add to the resultant vector *h*. At this point, the vectors *g* and *h* are equal in magnitude and are 90° out-of-phase with one another. It will be clear from a consideration of this explanation that the relative phases of the resultant vectors are fixed during the propagation of energy through the terminal sections of the hybrid, but that the energy in the half through which the power is introduced goes from a maximum to one-half maximum in the septated area, while the power in the other half of the hybrid is initially zero at the beginning of the septated area and increases to one-half the power at the end of the septated area. Once the septated section has been passed and the power propagated in either half of the hybrid is isolated, the relative phase of the even and odd modes remains fixed, and therefore, there is no possibility for further power transfer.

Consider further the distribution of the electric field, particularly in the septated region where the incident voltage has been resolved into odd and even modes. Under these circumstances, the resultant even mode as illustrated in FIG. 9 appears very much like the principal TEM mode as indicated above, with the field entirely radial from the center conductor. This field is uniform and orthogonal to the symmetric conductors. The resultant odd mode, however, as illustrated in FIG. 10, has a zero field at its center which results from the adjacent modes on either side of the coaxial line being out-of-phase with one another. This is in fact the next higher mode, that being the TE_{11} mode of a coaxial line.

Referring to FIG. 10, this TE_{11} mode of the coaxial line resembles a pair of identical TE_{10} modes in two sections of identical rectangular guides surrounding the septum 10, with the width of each waveguide being equal to the length of the broken line *w*. The wave length in coaxial line for the principle symmetric, or even mode or TEM mode in the septated area is substantially equal to the wave length in air of the incident voltage. Thus, $\lambda_{\text{coax TEM}}=\lambda_0$, where $\lambda_{\text{coax TEM}}$ is a wave length in coaxial line and λ_0 is a wave length in air. On the other hand, the wave length in coaxial line for the odd or TE_{11} mode in the septated area is determined by the formula

$$\lambda_{\text{coax TE}_{11}}=\frac{\lambda_0}{\sqrt{(1-\lambda_0/\lambda_c)^2}}$$

where λ_c is equal to $2w$ and λ_0 is equal to the wave length in air. $\lambda_{\text{coax TE}_{11}}$ is determined as λ_g is determined in a rectangular guide for the TE_{10} mode. From a comparison of these equations it will be seen that the wave length $\lambda_{\text{coax TEM}}$ for even modes is less than the wave length $\lambda_{\text{coax TE}_{11}}$ for odd modes and thus the relative phase velocity in the septated area is greater for the even mode than for the odd mode.

In determining the parameters of the coaxial line, the length and width of the septated region is determined for the frequency band in which the hybrid may be used. Of course, the coaxial terminals should be such as to handle the incident and resultant voltages.

In determining the parameters of the hybrid, the wave length in air λ_0 is first determined and converted to wave length in coaxial line $\lambda_{\text{coax TEM}}$ for the TEM mode. In this case, $\lambda_0=\lambda_{\text{coax TEM}}$. A wave length λ_{ac} greater than cut-off wave length λ_c is then calculated. This wavelength λ_{ac} should be about 20% to 40% longer than the desired wavelength λ_c for which the hybrid is designed. The percentage by which it may exceed λ_c is of course determined by the consideration of whether or not a third mode will be propagated. Thus, the 20% to 40% range set forth above is suggestive rather than definitive. In order to determine $\lambda_{\text{coax TE}_{11}}$ in inches from the chosen value of $S=2\lambda_{ac}$, reference is made to FIG. 11. Thus, if the wave length in line $\lambda_{\text{coax TEM}}$ is 15 cm., λ_c is two inches in length and *w* and *s* (see FIG. 10) should equal at least one inch. L may be determined empirically or by the formula $2\pi L(1/\lambda_s-1/\lambda_a)+\phi_e+\phi_0=\pi/2$, L being the length of the apertured section, λ_s and λ_a being the guide wave-

lengths of the symmetric and antisymmetric modes, respectively, and ϕ_e and ϕ_0 being the phase shift in radians imparted to the even and odd modes, respectively.

In FIG. 12, there is a chart prepared for determining the length L empirically. After $\lambda_{coax\ TE_{11}}$ is determined from the chart of FIG. 11, a corresponding $\lambda_{coax\ TE_{11}}$ is selected or interpolated from the chart shown in FIG. 12. If, for example, an S of 1.5 inches was selected corresponding to a $\lambda_{coax\ TE_{11}}$ of 12.4 cm., reference is then made to the $\lambda_{coax\ TE_{11}}$ curve shown in FIG. 12 for 12.0 cm. Actually a curve should be determined for $\lambda_{coax\ TE_{11}}=12.4$ cm., but for approximation purposes, the curve for $\lambda_{coax\ TE_{11}}=12.0$ cm. is satisfactory.

If now, λ_0 corresponds to a wave length below 12.4 cm., as for example at 8 or 9 cm., the length of the septated sections must be equal to approximately 3 inches. It has been found by actual experimentation that a hybrid with 7/8 coaxial terminals (0.813" outer conductor O.D. x 0.375" inner conductor O.D.) and having S=1.5 inches and L=3 inches, will operate over a bandwidth of 3200 to 4000 megacycles corresponding to a wavelength range of from 7.5 cm. to about 9.4 cm.

The present invention contemplates modifications in which the septated area, for example, need not be formed of a substantially rectangular cross section. Thus, the septated area may have its ends tapered towards the inner conductors. Similarly, the well section 9 may be V-shaped and tapered toward a point to conform with the angle of the septated area. These and other modifications of the present invention will, however, be obvious from a consideration of the invention as set forth above.

While the septated area is described as being of a thickness equal to the thickness of the inner conductors, it has been found that this area may in fact be greater or smaller in thickness than that of the two inner conductors.

It should be understood that the hybrid may be adapted for various purposes and functions without departing from the scope of the invention by incorporating into the structure tuning devices, such as inductive rods, capacitive posts, etc.

Referring to FIGURES 13 and 14, there is illustrated a specific embodiment of the present invention having the following dimensions: overall length L=3" (the length of the common apertured section). L_1=2.55", L_2=1", L_3=.425", D_1=.375", D_2=1.5". Inside diameter of the outer conductor .813". Outside diameter of the inner conductors .375".

It will be noted in the modification illustrated that there is provided a tuning device at each end of the septated area.

The performance of this particular device illustrated in FIGURES 13 and 14 is as follows: With an input at terminal 1, the power at terminal 2 relative to the power at terminal 3 is within plus or minus .25 DB in a 3200 to 3800 mc. frequency range. With an input at terminal 1, the power at terminal 4 relative to the power at terminal 1 is at least 15 DB less in a 3200 to 3800 mc. frequency range.

Having now described my invention, I claim:

1. A coaxial hybrid comprising at least four coaxial terminals each having inner and outer conductors with the inner conductors coupled together by a substantially solid unitary conducting plate coacting therewith to comprise a hybrid junction whose length and width are greater than the thickness of said inner conductors, and with the outer conductors all connected by a conductive casing enclosing and insulatedly spaced from said conducting plate intercoupling said outer conductors, said conducting plate being dimensioned to support propagation of symmetric and antisymmetric modes corresponding respectively to TEM and TE_{11} modes propagated through said coaxial terminals while imparting a relative phase shift between said symmetric and antisymmetric modes providing operation as a hybrid junction.

2. A hybrid junction operable over a broad spectrum centered about a predetermined high frequency comprising, first, second, third, and fourth coaxial input terminal pairs each having an inner terminal and an outer terminal, said outer terminal being maintained at reference potential, a thin substantially solid unitary conducting plate intercoupling said four inner terminals and coacting therewith to comprise said hybrid junction, first, second, third and fourth points on said plate defining a quadrilateral having a first dimension generally parallel to a first line joining said first and second points and a second line joining said third and fourth points and a second dimension generally parallel to a third line joining said first and third points and a fourth line joining said third and fourth points, said first and second dimensions being greater than the thickness of said inner terminals, means for coupling said first, second, third and fourth inner terminals to said first, second, third and fourth points respectively to maintain the latter points at the potential of the respective inner terminals, a conducting shield insulatedly separated from and surrounding said plate to form with said conducting plate a parallel plate wave transmission conduit between said first and second lines, said first dimension being of a length which results in said parallel plate conduit supporting propagation of symmetric and antisymmetric modes of energy within said spectrum between said first and second lines corresponding respectively to the TEM and TE_{11} modes propagated through said terminal pairs, said second dimension being of a length to establish a prescribed difference in electrical length between said first and second lines for said symmetric and antisymmetric modes providing operation as a hybrid junction, and means for coupling said outer terminals to said conducting shield to maintain the latter substantially at said reference potential.

3. A hybrid junction in accordance with claim 2 wherein said conducting plate is rectangular, said four points are at the corners of said plate, and said prescribed difference in electrical length corresponds to a relative phase shift between said symmetric and antisymmetric modes of substantially an odd multiple of 90 electrical degrees after propagation between said first and second lines.

4. High frequency apparatus comprising, four coaxial terminal pairs each comprising an inner terminal and an outer terminal, means defining a substantially solid conducting plate intercoupling said four inner terminals, means defining a conducting surface surrounding but insulatedly separated from said conducting plate defining means and intercoupling said four outer terminals, said conducting plate defining means being dimensioned to support propagation of symmetric and antisymmetric modes corresponding respectively to TEM and TE_{11} modes propagated by said coaxial pairs while introducing a relative phase delay between said modes to provide hybrid junction operation.

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