March 3, 1959 H. J. RIBLET 2,876,421

MICROWAVE HYBRID JUNCTIONS

Filed July 6, 1954

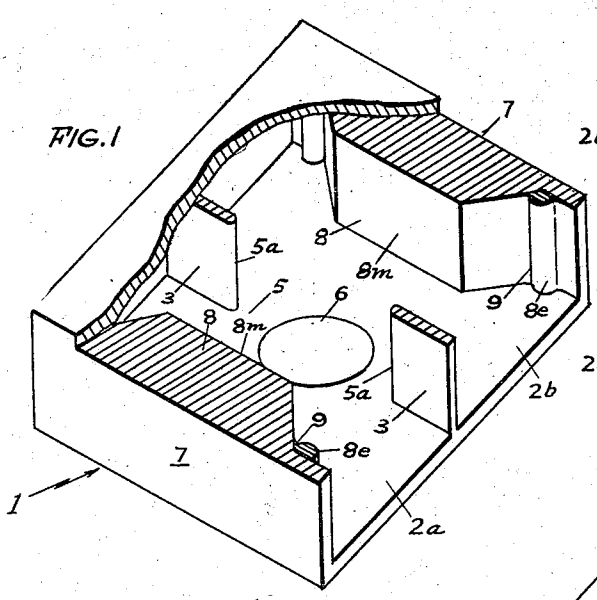


FIG. 1

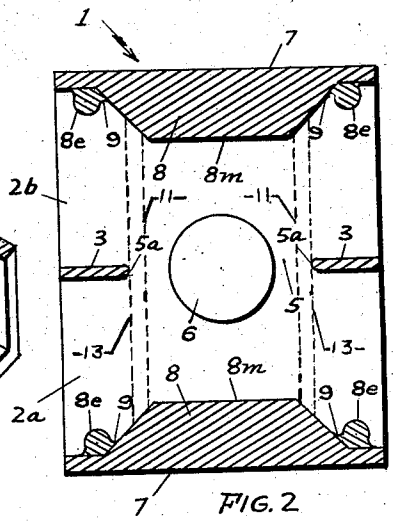


FIG. 2

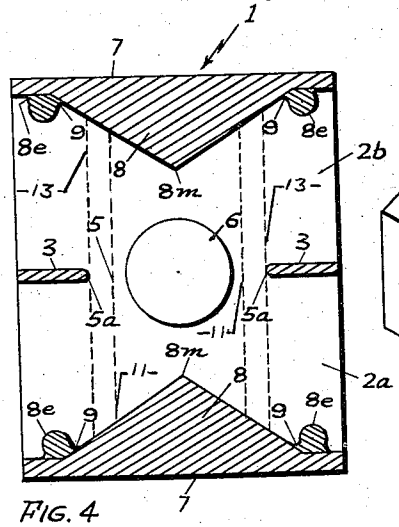


FIG. 4

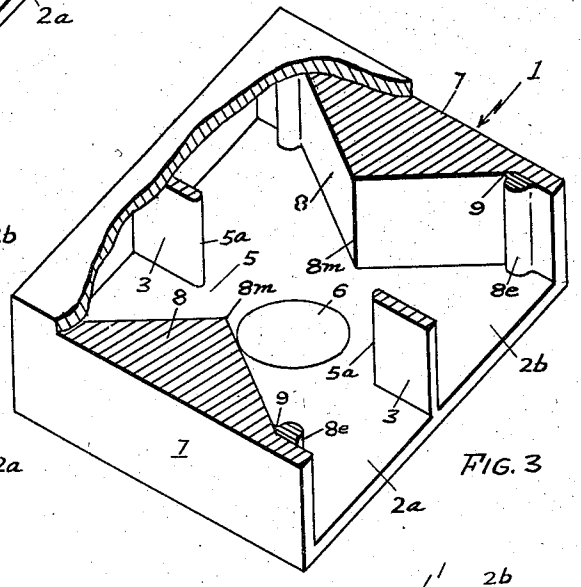


FIG. 3

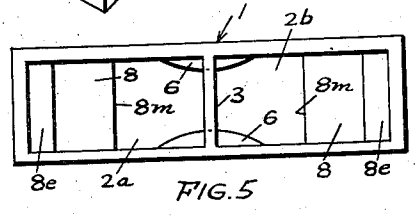


FIG. 5

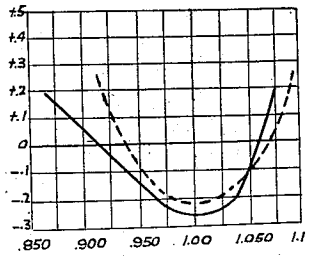


FIG. 6

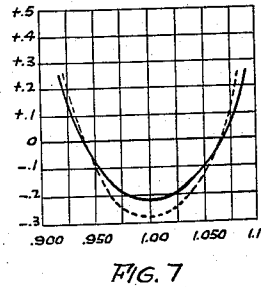


FIG. 7

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MICROWAVE HYBRID JUNCTIONS

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7 Claims. (Cl. 333—11)

The present invention relates in general to microwave waveguide hybrid junctions, and more particularly to improvements in junctions of the character described by applicant, Henry J. Riblet, in the Proceedings of the Institute of Radio Engineers, February 1952. This application is a continuation in part of co-pending applications, Serial Nos. 150,131 and 301,723, now Patents 2,739,287 and 2,739,288 respectively, to which reference is made for background information with respect to the physical configuration, theory of operation, and operational specifications of such hybrid junctions.

For review purposes it is in order to mention briefly that in its most common form the short slot microwave hybrid junction, also known as a side-wall junction, consists of a hollow rectangular conductive structure centrally and symmetrically partitioned by a conductive plane. The effect of the partition is to yield a pair of parallel waveguides of rectangular cross section having a common narrow wall, each guide being proportioned to support microwave energy solely in the fundamental or $TE_{1,0}$ mode at all frequencies through the operating microwave spectrum. As a practical example, if the hybrid is dimensioned for X-band operation, the rectangular cross sections of the waveguides so formed are those normally used for X-band systems and energy would then normally be introduced and withdrawn through commercially available X-band waveguide sections.

A coupling aperture of substantially rectangular cross section is centrally positioned in the conductive partition and is of a height equal to that of the narrow walls, that is equal to the full spacing between the broad walls of the device. The effect of the coupling aperture is to define a region common to both parallel waveguides, whose length equals the axial distance between edges of the aperture and whose width equals the spacing between the outer narrow walls.

One of the very important characteristics of the short slot hybrid junction, is its ability to divide incident power equally between two output terminals over an exceptionally wide band, consistent with some given tolerance. As pointed out in the above-identified patents, a requirement for broad band power division in a junction of this type, is that whatever the operating frequency, the third mode, designated as the $TE_{3,0}$, must not be permitted to propagate in the coupling section; that is, in the region of the coupling aperture between the parallel guides forming the junction. In practice, as illustrated in the earlier applications, this has required that the width of the outer narrow walls of the coupling section be reduced so that the combined width of the guides in the coupling section is insufficient to support the third mode; or that some inductive loading be placed at the sides of the hybrid junction to achieve the same result. Of course, obtaining broad band equal power division and high isolation over a wide band of frequencies simultaneously requires critical design and adjustment of the centrally disposed capacitance loading domes in the coupling section; but this feature has been comprehensively

treated in the above-cited patents and consequently will not be discussed further herein.

For purposes of introducing the concepts of the present invention, let us consider an example concerning the application of a short-slot microwave hybrid junction to a particular system. In the microwave art, X-band covers a frequency range roughly from 8500 mc./s. to a maximum of the order of 12,400 mc./s. Ordinarily, it is not necessary to provide microwave components with a bandwidth sufficient to cover this extreme range, and in fact a typical microwave hybrid junction of the character described in the above-cited patents provides a bandwidth of 12 to 16 percent of center frequency as, for example, a band extending between 8500 and 9600 mc./s.

In X-band work, whatever the operating frequency, it is customary to use waveguide having certain standardized dimensions; a typical example being rectangular guide one-half inch high and one inch wide. When making a short-slot microwave hybrid junction for use in the lower end of the X-band, no serious problem has been encountered in narrowing the combined waveguides in the coupling section to preclude the passage of the $TE_{3,0}$ mode simply because the minimum dimension required to support this third order mode is not much less than the combined width of two X-band guides in parallel. Thus as shown in the earlier cited patents, it was possible to obtain third order mode suppression by simply constricting the waveguide junction outer side walls by a relatively small amount. If, on the other hand, the design criterion was the upper end of X-band, namely 11,500–12,400 mc./s., then the minimum dimension required for suppressing the third mode would be considerably less than the combined width of two parallel X-band waveguides of the standard dimensions previously set forth. In other words, if one imposes the requirement that commercial X-band waveguide be used as both input and output lines to a short-slot microwave hybrid junction operating throughout the high end of X-band, then the constriction of the waveguide in the coupling section required to suppress the third mode would be so great that highly undesirable reflections and mismatch would be the result. In fact, it has been found impractical merely to scale the dimensions for the standardized short-slot hybrid junction normally used in the 8500 to 9600 mc./s. range for use in the higher frequency range noted.

In one approach to the problem of providing a parallel guide microwave hybrid junction for the high end of X-band with conventional X-band input and output waveguides, it is proposed that third order mode suppression be accomplished by gradually tapering inwardly the outer sidewalls of the waveguide until the minimum dimension required was achieved. Although this tapering arrangement would prevent serious mismatch and undesirable reflection, it has been found that the proposal when carried into practice requires an inordinately long junction.

In accordance with the concepts of the present invention, a microwave hybrid junction of no greater physical dimension than those ordinarily used for the lower end of a given frequency band, may be made for operation at the high end of the same frequency band. It has been observed that relatively sharply tapered indentations could be used when suitably matched inductive elements placed outside the coupling aperture, so long as the third mode is allowed to propagate in the coupling aperture to a limited extent. As is clearly supported by experimental data, permitting short regions of the coupling section near the ends of the coupling aperture to propagate the third mode, a coupling characteristic becomes available which is flatter than hitherto obtainable, that is power division is more nearly equal over wider frequency bands.

In general then, by permitting limited propagation of the third mode in the coupling region between parallel guides, rather than complete suppression thereof, a more desirable short-slot microwave hybrid is attainable.

The present invention will be more clearly understood with reference to the accompanying drawing in which:

Figure 1 presents a broken perspective view, partly in section, of a preferred embodiment of this invention,

Figure 2 is a cross sectional view of the structure illustrated in Figure 1 showing in detail the internal configuration of the hybrid junction,

Figure 3 is a broken perspective view, partly in section, of another embodiment of the present invention,

Figure 4 is a cross sectional view of the structure illustrated in Figure 3,

Figure 5 is an end view of the hybrid junction of Figs. 3 and 4 showing the relative position and approximate relative dimensions of the capacitive domes and the sidewall indentations for mode suppression,

Figure 6 is a graphical illustration of the coupling characteristics of the present microwave hybrid junction as illustrated in Figures 1 and 2, presented in comparison with data characteristic of previous hybrid designs, and

Figure 7 is a graphical display of coupling data for the hybrid illustrated in Figures 3 and 4 with a similar comparison to earlier available data.

Similar numerals refer to similar parts throughout the several views in which:

The numeral **1** designates a short-slot waveguide hybrid formed of two waveguides **2***a* and **2***b* symmetrically joined along their common narrow wall **3**. A coupling aperture **5** is formed between waveguides **2***a* and **2***b* by removing substantially all of the common wall for an axial distance of approximately one free space wavelength. The ends of the aperture are denoted by **5***a*. The center of aperture **5** is provided with a pair of opposed wavelength reducing capacitive projections **6**, each consisting of a somewhat flat, rounded dome extending into the central portion of the coupling aperture of hybrid **1**. The outer sidewall **7** of the hybrid are provided with wavelength increasing inductive indentations **8** which are parallel to aperture **5** as shown in Figs. 1, 2, 3, and 4. The indentation begins in the region of **8***e* and tapers to its narrowest point at **8***m*. The present invention depends for performance on the fact that this constriction does not increase uniformly from **8***e* to **8***m*, but rather is formed with a recess **9** cut at both ends in the general region of the ends **5***a* of the coupling aperture **5**. In the fabrication of a practical junction as shown in the drawing, the protrusions **8***e* are directly cast in place or may be formed by suitably soldering or brazing conductive rods into the junction in the areas shown. It will be noticed that the recesses **9** are not of such magnitude as to cause the total width of the junction in this region to be greater than the combined width of the parallel waveguides **2***a* and **2***b*. In Figures 1 and 2, the inductive wavelength increasing indentations **8** are flat along their narrowest regions **8***m*, whereas in Figures 3 and 4, the inductive wavelength increasing indentations **8** gradually taper down to a well-defined minimum at **8***m*.

The following definitions of terms and symbols are provided for convenient reference:

(1) Coupling aperture—the aperture **5** cut in the common wall **3**. The length of the coupling aperture is measured lengthwise of the hybrid between the edges **5***a* of the dividing partition. As noted above this aperture is of the order of one free space wavelength measured at mid-band frequency.

(2) Apertured section—the portion of the hybrid **1** within the axial span of coupling aperture **5** which is capable of supporting the fundamental mode, namely, $TE_{1,0}$, together with the second mode, namely, $TE_{2,0}$. In the drawing this region is shown in Figure 2 as lying within the broken lines **13—13**. In this region, the width between indentations **8***m* will not permit third mode propagation between broken lines **11—11**. In Figure 4, this apertured section is correspondingly bounded by broken lines **13—13**.

(3) Third mode sections—the portions of the hybrid **1** included within the axial span of aperture **5** which are capable of supporting the first, second, and third order modes, namely, the $TE_{1,0}$, the $TE_{2,0}$, and the $TE_{3,0}$, for the highest operating frequencies of the hybrid junction. In Figures 2 and 4, these regions are axially bounded by broken lines **11** and **13**. The axial length of each third mode section is in the range of 0.06–0.20 free space wavelength for the highest operating frequency.

(4) The height of the apertured section is the maximum distance between the top and the bottom surfaces of the apertured section, preferably the full height of the input and output waveguides.

(5) The minimum width of the apertured section is the distance between the narrow sidewalls of the apertured section measured perpendicular to the common wall **3** at the center of the coupling aperture. For a hybrid as in Figure 1, this width is preferably of the order of 1.33 free space wavelength measured at midband frequency.

(6) The terminal width of the apertured section is the distance between the narrow sidewalls of the apertured section, measured perpendicular to the common narrow wall **3**, at the ends **5***a* of the coupling aperture.

(7) The gap spacing is the minimum distance measured between the opposed capacitive projections **6**. This has been fully treated in the copending applications.

(8) The indentation length is the distance measured axially along the length of the apertured section between the beginning and ends of the inductive loading **8***e* at the sidewalls of the hybrid. In a practical junction this length is of the order of 1.25–1.50 free space wavelength measured at midband frequency.

(9) The terminal indentation width is the width of the projection **8***e*. Widths of between 0.125 and 0.150 freespace wavelength at midband frequency are typical.

(10) Midband frequency is the center frequency in the microwave spectrum throughout which the hybrid performs within the specifications set down for power division equality in the output arms and isolation of the fourth arm.

In Figure 6, the performance of an improved hybrid junction made as shown in Figure 1 and 2 is compared with the performance obtainable from a conventional sidewall hybrid junction in which no provision is made for the propagation of the $TE_{3,0}$ mode in the vicinity of the ends **5***a* of the coupling aperture. Specifically in Figure 6 the solid line is a plot of the difference in db between the power in the output arms as a function of frequency normalized with respect to center frequency for the hybrid junction shown in Figures 1 and 2, while the broken line is a corresponding characteristic curve for a hybrid in which the third order mode is suppressed throughout the region of coupling aperture. In Fig. 7 the solid line depicts a corresponding plot for the hybrid junction shown in Figures 3 and 4, while the broken line again is representative of a junction in which the third mode is suppressed throughout the region of the coupling aperture. If maximum operating frequency is defined as the highest frequency at which the energy out of waveguide **2***b* exceeds the energy out of waveguide **2***a* by 0.25 db, with input energy applied to but one of the opposite waveguide terminals, it is apparent from Figures 6 and 7 that the present hybrids shown in the drawing provide substantially equal division of the input power over a considerably broader frequency range than heretofore attainable.

Although the precise reasons for the improvements in performance noted are not yet known, a reasonable explanation is believed as follows:

In general, the performance of a sidewall hybrid junction, insofar as constant power division at the two ad-

jacent output terminals is concerned, is limited at the high frequency edge of the band by the fact that the $TE_{3,0}$ mode can propagate, and at the low frequency edge of the band by the fact that the width of the waveguide approaches cutoff. In the present invention advantage is taken of the fact that this limitation can be relieved to some extent at the low frequency edge of the band by widening the combined waveguides at the ends of the aperture, as by recesses 9, and that this widening does not lead to excessive difficulty with the $TE_{3,0}$ mode propagation, so long as the propagation of this mode is strictly restricted to the ends of the coupling aperture.

It will be seen from Figures 2 and 4 that the third mode is permitted to propagate for a short distance (note definition of the third mode section above). In experimental models of the devices illustrated, the axial lengths of the third mode sections are as noted earlier of the order of one-tenth wavelength measured at the highest frequency of the microwave spectrum over which the hybrid junction is operable; where once again the maximum frequency is defined as the frequency at which an 0.25 db power difference exists between the energy crossing over from the input side of the hybrid junction and the energy passing directly through.

It is known that many variations on dimensions of the coupling section may be made without seriously impairing the performance characteristics of these hybrids. For example, complete symmetry is not absolutely essential, nor must the capacitive projections be placed centrally in the coupling aperture. Such changes, however, do not depart from the spirit of this invention in which there is claimed:

1. A hybrid junction operative over a relatively broad microwave spectrum centered at a predetermined midband frequency comprising, a hollow generally rectangular conductive structure having pairs of opposed broad and narrow walls, a conductive partition extending longitudinally through said structure coextensively with and substantially intermediate said narrow walls, said partition thereby dividing said structure into first and second like waveguides of substantially rectangular cross-section having a common narrow wall each dimensioned for normal propagation of microwave energy only in the $TE_{1,0}$ mode over said microwave spectrum, said partition being provided with a lengthwise aperture coupling said first and second waveguides and defining an apertured section whose width at any point is determined by the spacing of said narrow walls, said apertured section being capable of propagating microwave energy in the $TE_{1,0}$ $TE_{2,0}$ and $TE_{3,0}$ modes throughout said microwave spectrum, means associated with said apertured section for effectively precluding propagation of microwave energy in said $TE_{3,0}$ mode throughout said microwave spectrum in a portion of said apertured section less than the axial length thereof substantially without effect on the propagation therein of said $TE_{1,0}$ and $TE_{2,0}$ modes, said aperture having a height equal to the spacing between said broad walls, and centrally disposed means for capacitively loading said aperture, said aperture length, capacitive loading, and apertured section configuration being mutually arranged whereby for all frequencies throughout said microwave spectrum, the electrical length of said apertured section for said $TE_{1,0}$ mode is substantially ninety degrees greater than the electrical length thereof for said $TE_{2,0}$ mode and further, whereby substantially no microwave energy is reflected by said apertured section, including said ends of said aperture, said capacitive loading means and said means for limiting propagation of said $TE_{3,0}$ mode, in the transmission of microwave energy therethrough in said $TE_{1,0}$ and $TE_{2,0}$ modes throughout said spectrum.

2. A hybrid junction in accordance with claim 1 wherein said portion of said apertured section less than the axial length thereof is substantially symmetrically and centrally disposed whereby said $TE_{3,0}$ mode may be propagated throughout said microwave spectrum in relatively small areas in the regions of the edges of said aperture.

3. A hybrid junction in accordance with claim 2 wherein said means associated with said apertured section for effectively precluding propagation of microwave energy in said $TE_{3,0}$ mode in said portion of said apertured section comprises a pair of tapered indentations extending into said apertured section from said narrow walls.

4. A hybrid junction in accordance with claim 3 and including conductive rods disposed in the junctions of said tapered indentations and said narrow walls.

5. A hybrid junction in accordance with claim 3 wherein said indentations each taper to a planar conductive surface parallel to said conductive partition, the spacing between opposed planar surfaces being less than that required to support propagation of said $TE_{3,0}$ mode in said apertured section throughout said microwave spectrum.

6. A hybrid junction in accordance with claim 3 wherein said areas in said apertured section capable of supporting said $TE_{3,0}$ mode of propagation are each of an axial length in the range of 0.06–0.20 free space wavelength for the highest frequency of said spectrum.

7. A hybrid junction in accordance with claim 3 wherein said indentations each taper to a sharply-defined edge centrally positioned with respect to said apertured section, the spacing between opposed edges of said indentation being less than the minimum dimension required to support propagation of said $TE_{3,0}$ mode in said apertured section throughout said microwave spectrum.

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