Nov. 20, 1951 H. T. FRIIS ET AL 2,575,804

MICROWAVE HYBRID JUNCTION

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FIG. 1

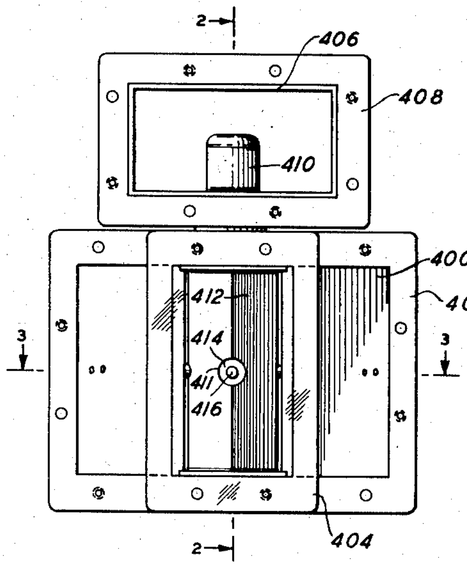


FIG. 2

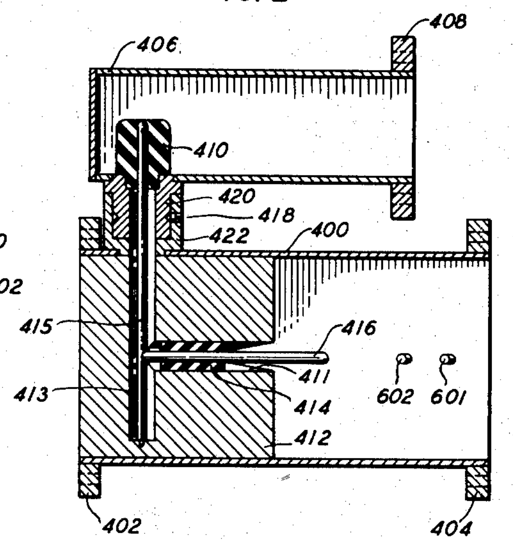
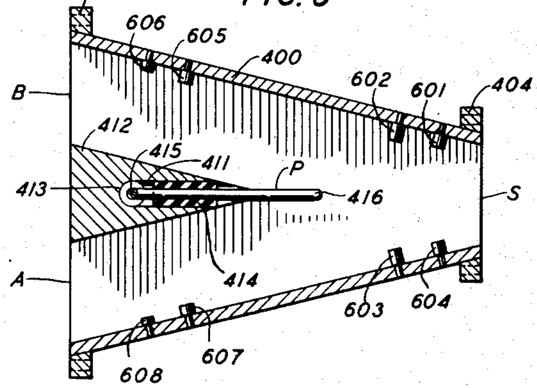


FIG. 3



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MICROWAVE HYBRID JUNCTION

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5 Claims. (Cl. 178—44)

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This invention relates to an improved type of wave guide junction and to an improved wave guide hybrid structure employing the improved type of junction.

Objects of the invention are to provide types of wave guide junctions and wave guide hybrid structures which will have improved electrical impedance characteristics and convenient mechanical structures.

Other and further objects will become apparent during the course of the following description and from the appended claims.

The devices of this invention were especially designed for use as component elements of the hybrid branching filters disclosed and claimed in the copending sole application of W. D. Lewis, Serial No. 789,985, filed December 5, 1947, and assigned to applicant's assignee. This application became United States Patent 2,531,447, granted November 28, 1950.

In accordance with the principles of the invention, the wave guide junction can be more readily understood, if it be considered to be two short sections of identical rectangular wave guide, brought together at an angle of approximately 20 degrees to form an E-plane junction of V shape with the "exterior" or base apex of the V truncated.

In many practical applications employing wave guide transmission lines, a wave guide of rectangular cross-section is employed in which one cross-sectional dimension is greater than the other. With such structures it is the usual practice to employ fundamental mode $TE_{1,0}$ waves, as defined by S. A. Schelkunoff in his book entitled "Electromagnetic Waves," pages 386 to 395, inclusive, with the electric vector parallel with the shorter cross-sectional dimension of the guide. The shorter cross-sectional dimension of the guide is accordingly known as the E-plane dimension and the longer cross-sectional dimension as the H-plane dimension. As employed by those skilled in the art, the terms E-plane and H-plane have collective connotations and include all longitudinal planes within the guide which are parallel with the electric and magnetic vectors, respectively. These connotations follow naturally from the fact that the $TE_{1,0}$ mode wave extends completely across the cross-section of the guide. All planes within the guide parallel with the shorter sides will therefore include an electric vector of the wave. Likewise all planes parallel with the longer sides will include a magnetic vector of the wave. Alternatively, wave guides of square cross-section can be used in

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which case the E and H-plane dimensions are identical in length. With a wave guide of square cross-section, the $TE_{1,0}$ mode wave can be, as is well known to those skilled in the art, introduced into the guide with the electric vector parallel to either pair of opposing sides, so that one can arbitrarily designate either cross-sectional dimension as the E-plane dimension, whereupon the other cross-sectional dimension becomes, of necessity, the H-plane dimension. In connection with wave-guide junctions of the present invention, they are referred to as E-plane junctions because, as is apparent from Figs. 1 to 3, inclusive, of the drawing, the common plane in which the longitudinal axes of the wave-guide sections, forming the junction, lie, is parallel with the direction of the electric vector of a $TE_{1,0}$ wave propagated in the usual manner through these wave-guide sections, i. e. with the electric vector parallel to the shorter sides of the guide. Should wave-guide sections of square cross-section be employed in a wave-guide junction of the invention it will, of course, function as intended only if the electric vectors of the waves in the sections of the junction are parallel with the plane containing the longitudinal axes of both wave-guide arms.

The inner sides of the arm portions of the E-plane wave-guide junction of the invention form the "interior" apex of the V-shaped structure and terminate at the line of intersection of said inner sides, at which point the structure is, of course, substantially twice as wide as the E-plane dimension of one of the wave guides.

The exterior apex, or base, is truncated normally to the longitudinal axis of the structure where the width thereof is substantially the E-plane dimension of one of the wave guides.

The angle between the arms of the V structure is chosen so that the distance from the truncated base, along the longitudinal axis to the line of intersection of the inner sides of the arms of the structure, is substantially one-half wavelength of the lowest frequency of the frequency range to be transmitted through the structure. The portion of the structure included between the truncated base and a plane parallel to the plane of the truncated base, the parallel plane including the line of intersection of the inner sides of the two arms of the structure is defined for the purposes of this application as the throat section or throat of the wave-guide junction.

The outstanding features of this type of wave guide junction are the smooth transition from one to two wave guide widths, introducing only very slight, if any, impedance irregularities, and an impedance transformation of 2 to 1 afforded by the throat section of the structure.

This wave guide junction is then converted into a wave guide "hybrid" structure (so-called, as explained in the above-mentioned sole application of W. D. Lewis, from the analogy of the electrical characteristics of the structure to those of the "hybrid" coil, used for several decades in voice frequency communication systems and in early, comparatively low frequency carrier systems) by coupling a fourth wave guide terminal structure into the throat of the wave guide junction by means of a coaxial line coupling, extending through the center of the line of intersection of the inner sides of the arms of the structure, as shown in Figs. 1 to 3, inclusive.

The outer conductor of the coaxial coupling is terminated at the inner surfaces of the intersecting sides, and the inner conductor is extended into the throat of the structure along its longitudinal axis for a distance of substantially .4 wavelength. At its other end, the coaxial line coupling structure is coupled to a short section of wave guide, closed at one end and provided at the open end with a flange for connecting to another wave guide or to a terminating structure.

The principles of the invention will be more readily understood from the following detailed description of an illustrative embodiment of the invention illustrated in the accompanying drawings in which:

Fig. 1 is a view of a structure of the invention looking into the truncated end of the device;

Fig. 2 is a vertical cross-sectional view taken along the line 2—2 of Fig. 1; and

Fig. 3 is a horizontal cross-sectional view taken along the line 3—3 of Fig. 1.

Like parts are given like designation numbers in all three figures. These figures correspond to Figs. 4, 5 and 6, respectively of the above-mentioned sole application of W. D. Lewis and an effective use of the device of the invention is illustrated in said sole application.

Basically the structures of Figs. 1, 2 and 3 is of the general type shown in Fig. 31 of the copending application of W. A. Tyrrell, Serial No. 470,810, filed December 31, 1942. This application became United States Patent 2,445,895, granted July 27, 1948.

However, it embodies extensive modifications which substantially eliminate the appreciable impedance irregularities arising from abrupt changes in the direction of the energy paths between the series termination S and the two output terminations A and B (Fig. 3), usually encountered in all prior art structures of this general type, including those of the Tyrrell application. Also the throat section, (i. e. the portion between the line of intersection of the inner surfaces of arms A and B and the orifice S) and the coaxial line coupling to the throat, introduce impedance transformations so that all terminations can be of the same impedance.

In more detail, in Figs. 1, 2 and 3, member **400** can more readily be understood as representing an E-plane junction of two wave guides placed so that their longitudinal axes intersect at an angle of approximately 20 degrees in a common horizontal plane, the H-planes of both guides being vertical, the dimensions of both guides in both planes being, respectively, identical.

For the system and frequency range suggested in the above-mentioned sole application of W. D. Lewis, by way of example, guides having an H-plane dimension of 2.290 inches and an E-plane dimension of 1.145 inches have been found satisfactory.

For member **400**, therefore, the single rectangular opening at the smaller (or truncated) end and the two rectangular openings at the larger end, all can have the same H-plane (vertical) dimension (2.290 inches) and the same E-plane (horizontal) dimension (1.145 inches).

A small V-shaped member **412** forms the inner vertical surfaces of the two guides from the larger end of member **400** to their line of intersection. As was mentioned above, this line of intersection should be at a distance along the longitudinal axis of the structure of substantially one-half wavelength of the lowest frequency of the frequency range to be employed, from the smaller end of member **400**. The throat section of the junction so formed provides, as stated above, a 2-to-1 impedance transformation so that all three terminations, S, A and B (Fig. 3) have the same impedance.

The horizontal dimension, or width of member **400** at the position of this line of intersection should obviously be substantially twice the E-plane dimension of either of the two wave guides considered as being convergent on each other to form member **400**. A flange **404** is provided at the smaller end of member **400** and a second flange **402** is provided at the larger end of member **400** to facilitate the joining of wave guides having suitable dimensions (preferably as given above) at the three wave guide orifices of member **400**.

Provision is made for connecting a fourth wave guide of like dimensions to the junction, by a coaxial line type of coupling built into the smaller centrally located V-shaped member **412**.

A vertical cylindrical passage **413** and a horizontal cylindrical passage **411**, the latter centered vertically and perpendicular to the opposite base of member **412**, are formed in member **412** as shown in the cross-sectional view of Fig. 2 and constitute the inner surfaces of the outer conductors of the coaxial line coupling. Cylindrical conductors **415** and **416** are the inner conductors of the coaxial line coupling and are centered in the holes by insulating bushings **410** and **414**, respectively. The lower end of inner conductor **415** is conductively fastened centrally to the lower end (closed end) of passage **413** and the left end of inner conductor **416** conductively connects to conductor **415** at a point one-quarter wavelength, of the median frequency of the frequency range employed, from the lower end.

The short circuit at the lower (closed) end of the vertical bit of coaxial line is transformed by the one-quarter wavelength, just described, so that the impedance of the above-described lower end of the vertical bit of coaxial line, at the point of connection of **416** is very high, i. e., substantially that of an open circuit.

The upper end of member **415** extends sufficiently into the short section of wave guide **406** to afford an effective coupling therewith. This coaxial coupling arrangement, as described above, also affords a 2-to-1 impedance transformation from the throat portion of member **400** to the member **406** so that a wave guide transmission line of the same impedance as those connecting to terminations A and B can be connected to member **406**. Alternatively, any other desired impedance transformation within wide limits can be introduced by appropriate design of the coaxial coupling as is well known in the art, if desired, so that in such a case a wave guide transmission line of a different impedance can be connected to member 406.

The end of member 406 nearer the coaxial coupling is closed, as shown clearly in Fig. 2, and the coaxial coupling member 415 is centered horizontally in member 406 at a distance of approximately an eighth wavelength from the closed end of member 406.

By means of a housing member 422 affixed to member 400 and a bushing 420 affixed to member 406 the latter can be rotated about the vertical center line of member 415 and can be fixed at any angle by tightening set screw 418, which registers with a small groove in the side of bushing 420.

The open end of member 406 is provided with a flange 408 to facilitate coupling to another wave guide transmission line, or to a terminating device of suitable impedance.

The internal dimensions of member 406 are preferably those of the wave guides to which member 400 is also adapted to be connected, i. e. 2.290 inches (H-plane) and 1.145 inches (E-plane).

The member 412 can obviously be simply a hollow or open V-shaped member and the coaxial coupler can be constructed in the usual manner, i. e. using cylindrical tubing for the outer conductors, if so desired.

Minor impedance irregularities can be eliminated by inserting small pins 601 to 608, inclusive, in the sides of member 400 spaced along the center line of their respective sides by approximately one-eighth wavelength of the median frequency of the frequency range employed. In many instances these can be omitted and in most cases only four, such as 601 to 604, inclusive, near the smaller end of member 400 will be found entirely sufficient. These pins introduce impedance irregularities of such character as to compensate for those introduced by other apparatus to which the junction is connected when in use. (For example the filters of the above mentioned Lewis application.)

Member 416 extends into member 400 approximately .4 wavelength from the right end of bushing 414, and being positioned along the longitudinal axis of member 400, as shown, it constitutes a "parallel" coupling to the two arms A and B of the truncated V-shaped member 400. Alternatively the coupling conductor comprising the portion of member 416 extending to the right of bushing 414 can be supported by a vertical rod, the rod being parallel with the E-plane of the wave guide junction and connecting at its upper end to a short section of coaxial line coupling. To preserve the symmetry of the arrangement the coupling conductor 416 or its equivalent should be situated along the longitudinal axis of the throat portion of the wave guide junction.

Because of the symmetry of the arrangement, the coupling afforded by member 416 and the associated coaxial coupling members described in detail above, is conjugate with respect to the "series" coupling which the opening at the small end S of member 400 affords to the two arms A and B of the larger end of member 400.

To summarize, the device illustrated in Figs. 1, 2 and 3 is a "hybrid" microwave junction device in which the terminations A and B (Fig. 3) are conjugately related and terminations S and P (Fig. 3) are also conjugately related. This means that with the other three arms properly terminated, energy introduced into any one of the four terminations will not appear in its conjugately related termination but will divide equally between the other two terminations. If the input termination "P" is used, since it has effectively a "parallel" connection with the two output terminations A and B, the portions (halves) of the total input voltage wave energy transmitted to A and B will travel away from the junction in phase. If the input termination "S" is used, since it has effectively a "series" connection, the portions (halves) of the total input power or voltage wave energy in the two output terminations will be precisely opposed in phase. In each instance, reciprocal relations exist, i. e. if equal powers (voltage wave energies) are introduced in phase into terminations A and B of the junction, the voltage wave energies will combine in the one of the other pair of terminations (i. e. P and S) which has effectively a "parallel" connection (i. e. termination P) with the terminations A and B. If equal powers (voltage wave energies) are introduced out of phase into the pair of conjugate terminations A and B, the powers will combine in the termination of the other pair which has effectively a series connection (i. e. termination S) with the terminations A and B.

A number of other arrangements within the spirit and scope of the invention will readily occur to those skilled in the art. A more detailed discussion of the properties of hybrid junctions and illustrations of their utility are given in the above-mentioned copending application of W. D. Lewis. The scope of the invention is defined in the following claims.

What is claimed is:

1. An E-plane wave guide junction for use in the transmission of high frequency electromagnetic wave energy of the $TE_{1,0}$ fundamental mode, said junction being adapted to join three like wave guides of rectangular cross section, having predetermined E-plane and H-plane dimensions, said junction comprising a V-shaped structure having a throat section and two like arms symmetrically joined to said throat section, the interior or base apex of the V being truncated, said structure being formed by upper and lower truncated V-shaped parallel plane surfaces separated by the H-plane dimension of said wave guides, said upper and lower surfaces being joined by four plane side surfaces perpendicular to said upper and lower surfaces, respectively, two of said side surfaces enclosing the throat portion and forming the outer sides of the two arms respectively, the remaining two of said side surfaces forming the inner sides of the two arms, respectively, and joining each other at the junction plane between said throat portion and said arms, the side surfaces at the truncated end of said V structure and throughout the length of the arms of the V structure being spaced apart by the E-plane dimension of said wave guides, the said truncated end of said V structure and the free ends of the arms of the V structure being open and adapted to be connected to said wave guides, respectively, the distance from the truncated end of said structure to the surface at which said arms join the throat portion of said V structure being at least one-half wavelength of the lowest frequency to be transmitted through said wave guides.

2. A microwave hybrid junction comprising the

E-plane wave guide junction as defined in claim 1 and a coaxial line connecting centrally and perpendicularly through the line of juncture between the inner sides of the arms of the V structure, the outer conductor of said coaxial line terminating at the inner surfaces of said juncture, the inner conductor of said coaxial line extending into said structure to afford equal parallel electrical coupling with the two arms of said wave guide junction and substantially zero electrical coupling with the orifice at the truncated end of said wave guide junction.

3. A truncated V-shaped wave guide junction for use in the transmission of high frequency electromagnetic wave energy of the $TE_{1,0}$ fundamental mode, said junction being adapted to join three identical uniform wave guides of rectangular cross-section, having predetermined E-plane and H-plane dimensions, said junction having a throat section and two like arms symmetrically joined to said throat section, said junction comprising upper and lower plane parallel truncated V-shaped surfaces spaced apart by the H-plane dimension of the wave guides to be joined, the sides of the junction being plane surfaces perpendicularly positioned with respect to said upper and lower surfaces and joining the outer longitudinally extending edges of said upper and lower surfaces, said side surfaces being inclined at equal angles with respect to the longitudinal axis of the junction, the truncated end of the V being open and having cross-sectional dimensions identical with those of said wave guides, the arms of the junction having uniform cross-sectional dimensions identical with those of said wave guides the inner sides of said arms being plane surfaces perpendicularly positioned with respect to said upper and lower surfaces and joining the inner longitudinally extending edges of said upper and lower surfaces, said inner sides of said arms joining and terminating at a transverse line normal to the V-shaped sides of the junction at a point on the longitudinal center line of said structure at which the distance between the inclined outer side surfaces of the junction are separated by a distance equal to twice the E-plane dimension of said wave guides, the distance from said last-mentioned point and the truncated end of the junction being substantially one-half wavelength of the lowest frequency to be transmitted through said junction.

4. A wave guide junction for use in the transmission of high frequency electromagnetic wave

energy of the $TE_{1,0}$ fundamental mode, said junction comprising two like sections of wave guide of rectangular cross-section having predetermined E-plane and H-plane dimensions, said wave guides being oriented with their H-plane dimensions parallel and their longitudinal axes in a common horizontal plane, said wave guides intersecting at an angle of approximately 20 degrees, the adjacent or innermost sides of said wave guide sections terminating at their common line of intersection, the outermost sides of said wave guides continuing past said common line of intersection for approximately one-half wavelength of the lowest frequency to be employed with the device, to a point where they are separated by a distance equal to the E-plane dimension of said wave-guide section, the upper and lower surfaces of said guide sections merging between said line of intersection and the extremities of the extensions of the outermost sides to form together with the said outer sides of said waveguide sections, an enclosed throat portion of said junction.

5. A wave guide hybrid junction comprising the wave guide junction of claim 4 and coaxial coupling means coupling into the throat portion of said junction, the coupling member comprising a linear conductor situated along the longitudinal axis of said throat portion and connecting to the center conductor of said coaxial coupling means, the outer conductor of said coaxial coupling means terminating at the surface of said throat portion.

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