July 27, 1954 — J. F. ZALESKI — 2,685,065

MICROWAVE POWER DIVIDER

Filed Feb. 17, 1949 — 2 Sheets-Sheet 1

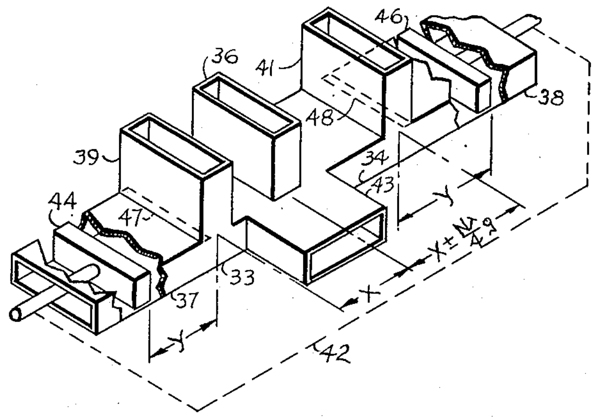

FIG. 3

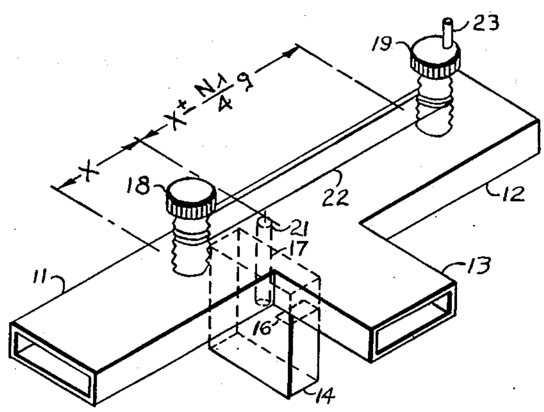

FIG. 1

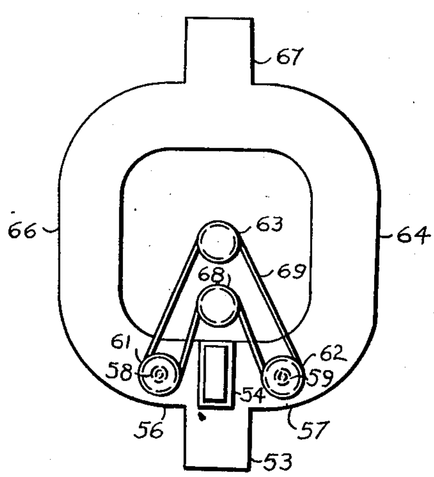

FIG. 6

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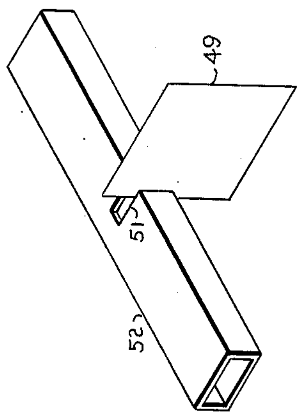

FIG. 4

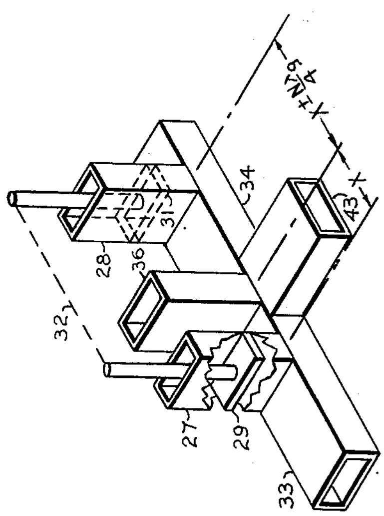

FIG. 2

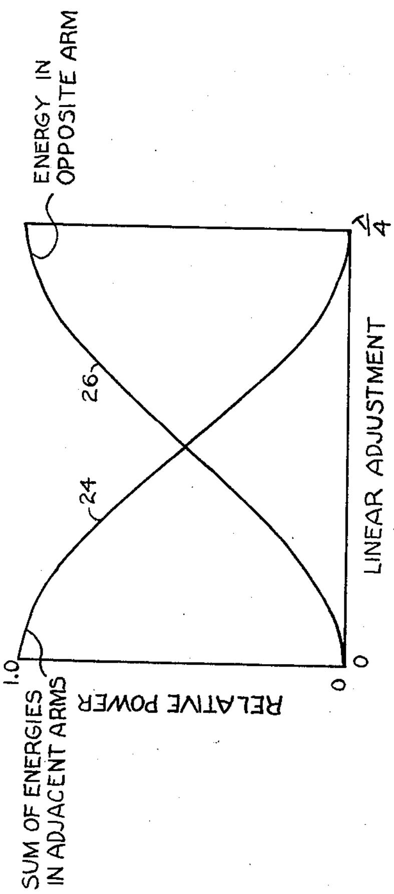

FIG. 5

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MICROWAVE POWER DIVIDER

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5 Claims. (Cl. 333—7)

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This invention pertains to a device for dividing high power electrical microwave energy into several parts.

In many applications of microwaves it becomes necessary to divide energy into three or more parts in specified proportions without loss. One such application is in the supplying of three, four or more microwave antennas or radiators from a single transmitter, dividing the energy in specified proportions. This requires a device which is easily adjustable to vary any particular output from zero to substantially one hundred per cent, which has a minimum of adjustments, which is capable of handling the high power of the largest pulse microwave transmitters, and which is ideally lossless.

Variable microwave power dividers have been proposed in the past but in general have divided the power into two parts only, while the device of the instant invention divides the power into two parts, or into three parts with two of them equal, and varies the output proportions by means of a single control device while the input impedance remains constant for all conditions of adjustment. This divider is ideally completely lossless and may handle high powers without flashover. It employs a compensated hybrid junction, also known in one form as a magic tee, having adjustable reflectors in two of its four arms.

A purpose of this invention, therefore, resides in the provision of a mechanism for dividing a single quantity of microwave energy into two or three quantities, the proportions of the magnitudes of which are variable at will while maintaining a constant input impedance.

This invention will be more readily understood from the following detailed description, considered together with the attached drawings in which:

Figure 1 illustrates a hollow wave guide hybrid junction employing screw reflectors.

Figures 2 and 3 illustrate the employment of short-circuited wave guide branches as reflectors.

Figure 4 illustrates the construction of an adjustable iris reflector.

Figure 5 is a graph illustrating the variation of the proportional outputs with adjustment of post or wave branch reflectors.

Figure 6 illustrates a method of adjusting the reflectors in concert.

Fig. 1 illustrates a form of hybrid junction composed of rectangular hollow wave guide having collinear arms 11 and 12 and having in addition an E-plane arm 14 and an H-plane arm 13. Within the junction there are positioned a reflecting iris 16 and post 17 adjusted so that an input arm is nonreflecting when nonreflecting terminations having characteristic impedances are placed on the other arms. Such a junction is well known in the art and its design and properties are described by Smullin and Montgomery in Microwave Duplexers, vol. 14 of the Radiation Laboratory Series, on page 350. When microwave energy of a wavelength suitable for the dimensions employed is led into any one of the four arms of this junction, such as arm 13, and the other arms have nonreflecting characteristic terminations, the energy is divided equally between the two adjacent arms and none enters the opposite arm. No energy is reflected back into the input arm when irises and/or posts are properly placed within the junction.

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For the purposes of this invention the usual hybrid junction thus far described is modified by the addition of two metallic screws 18 and 19 positioned in the center line of one broad side of the collinear arms so that each forms a conductive post with its amount of projection into the hollow interior of the wave guide adjustable by rotation of the screw. The two distances between the screws and the center of the junction are made to be unequal by one-quarter wavelength of the microwave energy within the guide. That is, if the distance from the screw 18 to the electrical center point 21 of the junction be X, and the wavelength in the guide be λ_g, the distance from the other screw 19 to the same point 21 is made to be,

$$X \pm \frac{N\lambda_g}{4}$$

where N is any odd integer including unity. Such a screw acts when inserted into the guide as a shunting reactance, and microwave energy traveling through the guide is reflected when the energy encounters the screw to a degree dependent on the amount of susceptance introduced by the screw. For short insertions the susceptance is capacitive and increases as the screw is inserted until, at a length approximately equal to ¼ wavelength in free spaces, substantially all of the incident wave is reflected. For still greater insertions the screw becomes inductive. In the instant invention operation of screw reflectors in the capacitive region is preferred.

In order to prevent any reflection of energy back into the input arm at any time, it is necessary for the susceptance of the two reflectors to be equal for all conditions of adjustment, which will be the case when they project equal distances into the wave guide. In order to accomplish this conveniently, the two screws are connected by an endless belt **22** composed of flexible stranded steel cable wrapped several times about each screw. One screw **19** has a crank handle **23** for convenient rotation, and when this screw is rotated, it then drives the screw **18** through the belt **22**, so that both screws turn in concert.

In order to make clear the operation of this device let it be assumed that the shunt arm **13**, Fig. 1, receives microwave energy at a wavelength for which the wave guide employed is suitable. With screws **18** and **19** both fully retracted, the input energy will be equally divided between the collinear arms **11** and **12** and will emerge at the right and left in the figure to utilizing equipments (not shown) but which it is assumed appear to the junction as each having the impedance characteristic of its attached arm. The emerging energies will be equal in phase at equal distances from the junction center. No energy at all will emerge from the series arm **14**. Now, by turning crank **23** thus rotating screw **19** directly and screw **18** by the belt **22**, the two screws **18** and **19** are inserted in concert to an equal small depth of protrusion within the inner walls of the guide. Each then reflects a small, equal amount of energy which will travel back toward the junction center. These energies start from the junction center in phase, but since the total length of path traversed by one is

$$\frac{\lambda_g}{2}$$

more than that traversed by the other, the reflected energies arrive back at the junction center out of phase by 180°. This is the condition for entrance to the series arm, so that these combined energies pass into the series arm **14** and, if that arm is terminated in its characteristic impedance, they are completely utilized and not reflected. These energies cannot reenter arm **13** because, it being a shunt arm, they are out of phase and cancel each other completely. On a further insertion in concert of the screws **18** and **19** a still greater reflection of energy out the arm **14** is obtained, with a proportional reduction in the energy permitted to pass through the collinear arms **11** and **12**, the amount passing through arm **11**, however, remaining equal to that passing through the arm **12**.

The variation of the proportions of the output energies of the various arms is illustrated in Fig. 5 wherein the variation of the sum of the energies transmitted through adjacent arms with the variable amount of insertion of the screws **18** and **19** is indicated by the curve **24** and the variation of the energy transmitted through the opposite arm with variation of screw insertion is indicated by the curve **26**.

While in the above description the shunt arm **13** has been considered as the input arm for the purposes of analysis, the series arm may be used as the input arm with similar results, if the reflecting screws are moved to the arms which are adjacent to the new input arm. Either of the other two arms may be so used with similar results provided that the reflecting screws **18** and **19** are moved to the arms adjacent to the new input arm. In any case the energy will be reflected to the opposite arm as a direct function of the depth of insertion of the screws while the remaining energy will be transmitted equally through the remaining adjacent arms.

In Fig. 2 there is disclosed a modified form of the invention in which adjustable short circuited lengths of wave guide **27** and **28** forming series arms are substituted for the adjustable screws of the form disclosed in Fig. 1. With the shunt arm **43** selected as the input arm, the series arms **27** and **28** are positioned on either side of the center of the junction in the same manner as described in connection with the adjusting screws of Fig. 1. That is, if the arm **27** is considered as positioned a distance x from the center of the junction, then the arm **28** is positioned a distance

$$X \pm N\frac{\lambda_g}{4}$$

on the other side of the center point, the values for N and λ_g being as given above. Each series arm **27** and **28** contains a plunger **29** and **31**, respectively, and these plungers are adjustable together up and down by any means such as that of Fig. 1, as is indicated schematically in Fig. 2 by the dashed line **32**.

When the distance of a plunger away from the guide collinear arm is one-quarter λ_g, microwaves are prevented from traveling through the collinear arm and are completely reflected. When the distance in a series arm is zero or one-half λ_g all of the energy is transmitted and none is reflected, and between the one-quarter λ_g position and the other positions varying proportions of energy will be reflected and transmitted in accordance with the position of the plunger. It is then clear that if in Fig. 2 the arms **27** and **28** be adjusted to the one-quarter λ_g position, all of the energy entering each collinear arm **33** and **34** will be completely reflected and both energies will combine at the center of the junction to pass out the series arm **36** as a single output. On the other hand, if the arms **27** and **28** be adjusted to the zero or one-half λ_g length, all of the energy entering each collinear arm **33** and **34** will be completely transmitted and none will appear at the output arm **36**. Between these adjustments any other adjustment in concert of the short-circuited guide stubs produces partial equal transmission through the collinear arms **33** and **34** and partial equal reflection to the center of the junction, where the reflected energies combine to form a single reflected output energy at the arm **36**.

In order to insure coverage of a complete quarter-wavelength the plungers may be made adjustable over a range of one-half wavelength. In place of adjustable short-circuited series arms as shown, adjustable short-circuited shunt arms may as well be used.

Any alternative form of plunger well known in the art may of course be used in place of the solid piston plunger illustrated in Fig. 2, as for instance, plungers having spring contacts or forms employing an open-ended quarter-wave trap within the plunger, or a short-circuited end half-wave trap around the periphery, resulting in either case in a high-impedance junction at the point of metallic contact of the forward end of the plunger and the adjacent side wall.

Figure 3 illustrates an alternative arrangement of the adjustable short-circuited wave guide tuning stubs illustrated as **27** and **28** in Fig. 2. In Fig. 3 these adjustable stubs constitute terminations **37** and **38** of the collinear arms **33** and **34**, while new output arms **39** and **41** are provided as series tee branches extending at right angles from the collinear arms, one on each side of the hybrid junction series arm 36 at the exact locations formerly occupied by the tuning stubs. One advantage inherent in this modification resides in a gain in design flexibility, since if desired the arms 39, 41 and 36, which may be constituted the output arms, all are in the same plane and extend in parallel directions. The output arms 39 and 41 may equally well be series arms in the opposite broad face of the wave guide and extend in a direction opposite to the direction of the arm 36, or these output arms may be made of the shunt type and extend from either of the narrow faces of the guide. In any case these two output arms are positioned as indicated in Fig. 3 so that the difference of their distances from the electrical center of the hybrid tee is equal to

$$\pm\frac{N\lambda_g}{4}$$

where N is any odd integer including one, and λ_g is the wavelength in guide of the microwave energy employed.

In the employment of the tuning stubs in the positions illustrated in Fig. 3 any type of piston known in the art as mentioned in connection with Fig. 2 may be employed. The distance Y between each piston and the electrical center of the adjacent output arm is adjustable over a range of one-quarter wavelength so that the distance may be made a multiple of

$$\frac{\lambda_g}{4}$$

and variable a quarter wavelength therefrom. As a practical matter the distance should be made adjustable over a range of a half wavelength to insure the accomplishment of this result.

The two pistons are adjustable in concert as is indicated schematically by the dashed line 42 by any convenient method such as those illustrated in Figs. 1 and 6.

In operation, if the shunt arm 43 is made the input arm, the input energy is divided equally and transmitted through the collinear arms 33 and 34. The pistons 44 and 46 in the tunable stubs 37 and 38 being equally adjusted, reflect equal portions of the energies impinging on them to the center of the hybrid tee, and these energies having traversed paths unequal by

$$\frac{\lambda_g}{2}$$

arrive at the center 180° out of phase hence combine perfectly to go out the series arm 36 and are not transmitted out of the shunt input arm 43. The remainders of the energies are reflected out the side output arms 39 and 41, the proportions of these remainders depending on the value to which the equal distances Y have been adjusted. When these distances have been so adjusted that the distance Y provides a perfect match for the adjacent side arm, no reflections occur and all of the energy in the collinear arm passes out the side arm. At an adjustment

$$\frac{\lambda_g}{4}$$

distant from this adjustment the reflection is substantially 100%, and at intermediate adjustments intermediate degrees of reflection take place.

In order to eliminate losses and to permit a complete range of adjustment of reflection from approximately 0% to 100% it is necessary to add irises such as those indicated as 47 and 48 or other well-known matching devices at the junction between each side arm and the collinear arm upon which it is positioned.

When the device has been so constructed, for any adjustment in concert of the pistons 44 and 46 the impedance looking in the input arm 43 will appear constant.

In place of the adjustable stubs of Fig. 1 or the adjustable plungers of Fig. 2, the reactance may be adjustably introduced into the appropriate arms by the use of an iris. In Fig. 4 one form of such an iris is illustrated as consisting of a metal sheet 49 adjustably inserted into a slot 51 cut in the short side of a hollow wave guide 52. When such a device is used the reactance is inductive and the reflectivity is a function of the distance of insertion.

Those skilled in the art will appreciate that other forms of adjustable reflecting obstacles may be employed to perform the functions of those specifically illustrated and described, however, as a matter of convenience it is preferred to employ screw reflectors as illustrated in Fig. 1 except where high power is involved, in which case arms with adjustable plungers as illustrated in Figs. 2 and 3 are deemed preferable to avoid high potential flashover.

Fig. 6 illustrates an employment of the instant invention to secure two output terminals only, having some practical advantages over present conventional methods mentioned supra, one advantage residing in the use of screw post reflectors or of adjustable stub guides in such fashion as to eliminate the need for matching of the individual units to the guide by auxiliary means such as irises.

In the device illustrated in this figure a hybrid junction is composed of a shunt arm 53, series arm 54 and collinear arms 56 and 57. Screws 58 and 59 are inserted in the collinear arms 42 and 57 at distances from the center of the junction differing by

$$\frac{\lambda_g}{4}$$

Each screw is headed by a grooved wheel 61 and 62. A grooved adjusting knob 63 and grooved idler 68 are connected with both screws by a belt 69 so that rotation of the adjusting knob 63 rotates both screws equally and in the same sense. The collinear arms 56 and 57 are continued by curved and straight wave guide sections 64 and 66 to a shunt tee having shunt arm 67. Employing appropriate dimensions which may easily be calculated by anyone skilled in the art, when microwave energy is introduced at arm 53, and partly transmitted past the screws 58 and 59, the equal energies at equal phases from the collinear arms 56 and 57 will combine without appreciable loss and emerge as a single combined magnitude of energy from the shunt arm 67, and if the arm is terminated in its characteristic impedance no reflections will occur. The energies reflected by the screws 58 and 59 will combine and emerge at arm 54, as described in connection with Fig. 1. Thus the instant invention is directed to the lossless production of two output energies, that from arm 54 and that from arm 67, and the proportions thereof are inversely variable at will by means of a single adjustment 63.

By combining devices as illustrated in Fig. 6

in tandem with devices as illustrated in Fig. 1, an output arm of one feeding the input arm of another, equipment having any number of output arms adjustable in any proportions may be built up.

While for the purposes of description a magic tee form of hybrid junction has been disclosed other forms of hybrid junctions are equally adapted to the purposes of the present invention. Likewise any one of the four arms of the hybrid junction may constitute the input arm, in which case the two adjacent arms are provided with the adjustable elements and constitute the coequal output arms.

The hybrid junction may be associated with a Y or tee fitting to produce two outputs, or two or more hybrid tees may be connected in tandem to produce four or more output energy fractions. In each case the sum of the energies of all fractions will be closely equal to the input energy. By appropriate combinations it will be possible to produce any number of outputs in any desired proportions with less equipment and greater effectiveness than has heretofore been possible.

What is claimed is:

1. A microwave power divider comprising, a hybrid junction having an input arm, a first output arm and second and third output arms electrically adjacent said input arm, a single conductive post projecting into each said second and third arms, said conductive posts being positioned in said second and third arms at such distances on either side of the electrical center of said junction that the difference between said distances is equal to

$$\frac{N\lambda_g}{4}$$

where N is any odd integer including unity and γ_g is the wavelength of the input energy in the junction and means for simultaneously adjusting the amounts by which said conductive posts project into said second and third arms.

2. A microwave power divider comprising, a first rectangular wave guide section, a second rectangular wave guide section joined to said first section intermediate the ends thereof and extending in a direction at right angles thereto, a third rectangular wave guide section joined to said first section at the junction of said first and second sections and extending in a direction at right angles to said second section, forming a side-arm tee having four arms one of which constitutes an input arm for the introduction of microwave energy and the remainder of which constitute output arms for the extraction of the energy so introduced, a single conductive post projecting into one of said output arms electrically adjacent said input arm, a single conductive post projecting into the other of said output arms which is electrically adjacent said input arm, said first and second mentioned conductive posts being positioned at such points that the distance between the first mentioned post and the junction of the wave guide sections exceeds the distance between the second mentioned post and the junction of the wave guide sections by an odd number of quarter wavelengths of the microwave energy in the wave guide sections and means for simultaneously adjusting the amounts by which said first and second mentioned conductive posts project into said output arms.

3. A microwave power divider comprising, a hybrid junction having an input arm, a first output arm and second and third output arms electrically adjacent said input arm, a first wave guide section connected to said second output arm, a second wave guide section connected to said third output arm, said first and second wave guide sections being connected to the respective output arms at such points that the distance from the first wave guide section to the electrical center of the hybrid junction exceeds the distance from the second wave guide section to the electrical center of the hybrid junction by an odd number of quarter wavelengths of the microwave energy in said hybrid junction, a short circuiting plug in each of said wave guide sections and means for simultaneously adjusting the positions of the short circuiting plugs in their respective wave guide sections.

4. A microwave power divider comprising, a hybrid junction having an input arm and three output arms, reflecting means electrically associated with each of two of said output arms for reflecting only a part of the energy of a selected frequency existing therein and for transmitting the remaining unreflected portion of the energy of said selected frequency through said two arms, said reflecting means being so located with respect to each other and the third arm that all of the energy reflected thereby is transmitted through said third output arm and means for adjustably varying the position of said reflecting means by equal amounts in unison so that equal amounts of energy are reflected by each of said reflecting means.

5. A microwave power divider comprising, a hybrid junction having an input arm and three output arms, reflecting means electrically associated with each of two of said output arms for reflecting only a part of the energy of a selected frequency existing therein and for transmitting the remaining unreflected portion of the energy of said selected frequency through said two arms, means for varying the portion of the energy reflected relative to the portion of the energy transmitted, said reflecting means being so located with respect to each other and the third arm that all of the energy reflected thereby is transmitted through said third arm.

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