

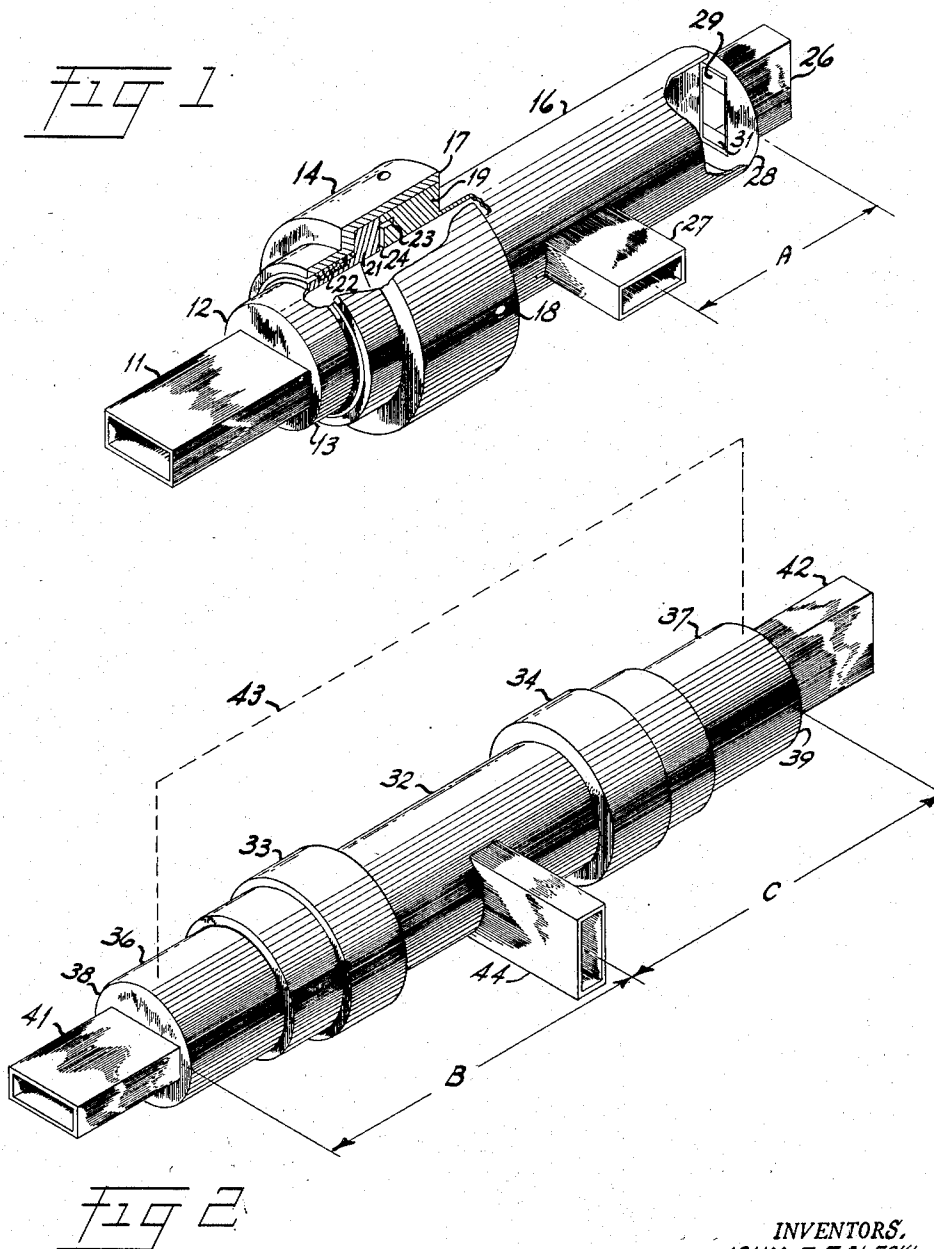
Oct. 30, 1956

J. F. ZALESKI ET AL
MICROWAVE POWER DIVIDER

2,769,145

Filed Aug. 10, 1951

2 Sheets-Sheet 1



INVENTORS,
JOHN F. ZALESKI
GEORGE R. GAMERTSFELDER
BY
H. A. Mackey
ATTORNEY

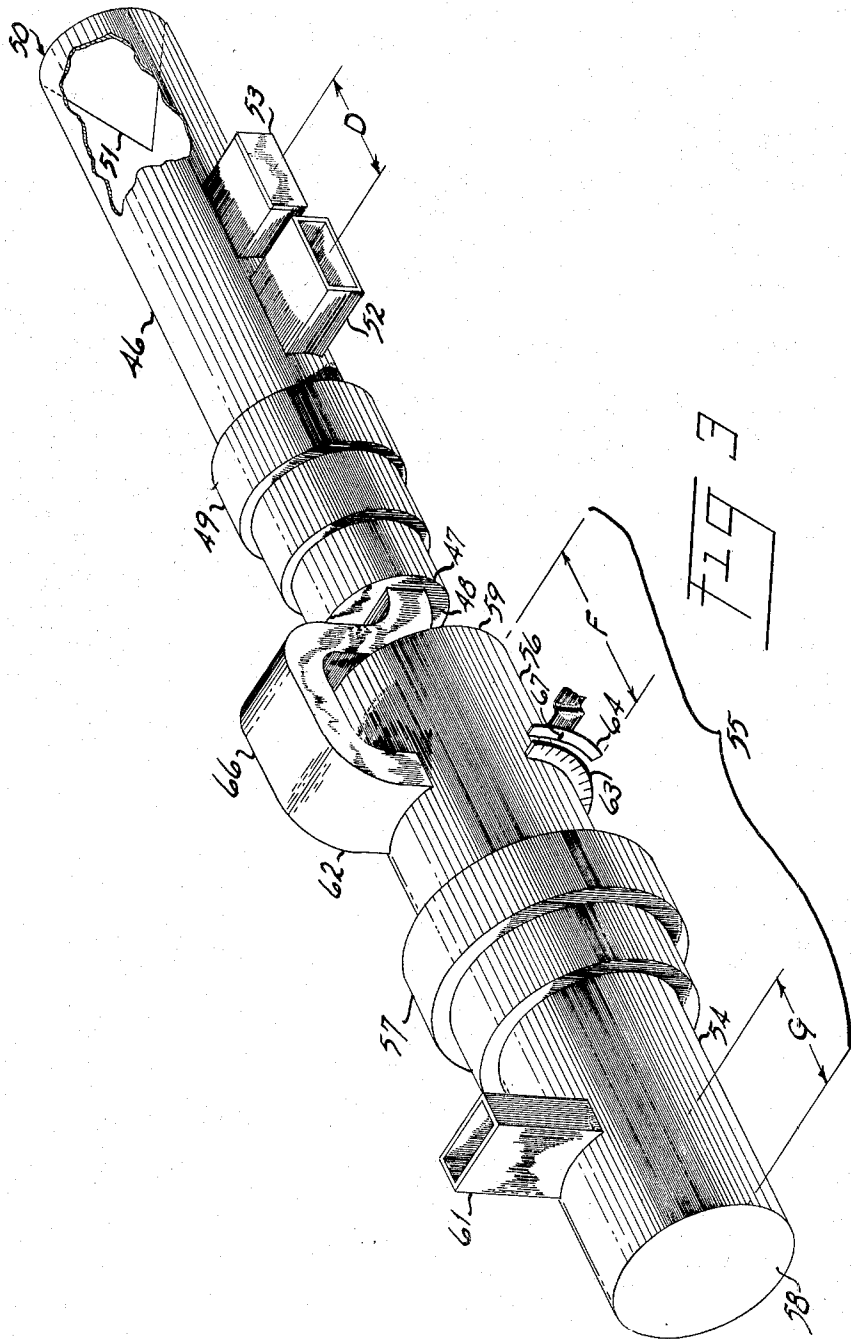
Oct. 30, 1956

J. F. ZALESKI ET AL
MICROWAVE POWER DIVIDER

2,769,145

Filed Aug. 10, 1951

2 Sheets-Sheet 2



INVENTOR.
JOHN F. ZALESKI
BY GEORGE R. GAMERTSFELDER

H. S. Mackey
ATTORNEY

1

2,769,145

MICROWAVE POWER DIVIDER

John F. Zaleski, Valhalla, and George R. Gamertsfelder, Pleasantville, N. Y., assignors to General Precision Laboratory Incorporated, a corporation of New York

Application August 10, 1951, Serial No. 241,222

5 Claims. (Cl. 333-7)

This invention pertains to an adjustable microwave power divider, and more specifically to a device for variably coupling a source of microwave energy to one or more branch utilization circuits while presenting a substantially constant impedance to the source.

In controlling large amounts of microwave energy, the need arises for continuously varying the power output of a microwave generator or other source between zero and a maximum value while maintaining constant output impedance. It is highly desirable that this should be done so as to present a constant impedance to the generator and, for convenience, should be effected by the continuous adjustment of a simple control means. The prior conventional devices employed for low power control, that is, for outputs of less than about 10 watts of average power or 1 kilowatt of pulse power, are not applicable, and the conventional high power attenuators that are known are not readily adjustable.

The instant invention provides a device for apportioning microwave energy in a wave guide between a plurality of output branches, some of which may comprise dissipative loads. It is easily and continuously adjustable, and causes substantially no reflection, so that voltage standing wave ratios under 1.05 are obtainable.

The device is essentially an adjustable, constant-impedance energy divider having in general at least two microwave output branches. If desired one branch may contain an absorption load while others are connected to utilization devices constituting useful loads. Thus by variation of the adjustment of the device the output to the useful loads can be continuously varied from zero to the full capacity of the generator or source. Since the device of the instant invention is a power divider, it can not only be used for the above purpose but also can be used for adjustably dividing a quantity of input power in any desired ratio between a plurality of useful loads, with no substantial variation in the impedance of the load imposed upon the generator or source.

As will be clearer from subsequent description the so-called branch waveguides, coupling irises and other electrical equivalents, through which microwave energy is transferred from one guide to another correspond to the two conductors of circuits for currents having frequencies below the microwave range, and therefore such irises or waveguides may be considered to be the equivalent of terminal pairs in the lower frequency field.

One purpose of the instant invention is to provide an improved device for controlling the flow of microwave energy from a microwave source while at the same time presenting a constant impedance to the source.

Another purpose of the instant invention is to provide a constant impedance means for dividing a quantity of microwave energy adjustably into at least two portions having any selected ratio.

One embodiment of the invention chosen for purposes of illustration comprises a hollow round microwave guide having at least two rectangular coupling irises con-

2

stituting output terminals in the walls of the guide connecting with respective output hollow microwave guides. The functioning of the apparatus includes the excitation within the round guide of the $TE_{1,1}$ mode of microwave transmission. The principles of operation basically depend upon the controlled relative rotational position of the electromagnetic field within the round guide with respect to the position of the coupling irises by which variable energy coupling is provided between the electromagnetic field in the round waveguide and the branches connected to the coupling irises. The coupling irises are disposed substantially 90° apart around the axis of the round guide so that there are reciprocal trigonometric function relationships between the coupling of the electromagnetic field in the round guide with the respective branches. The elimination of reflections that would cause losses and variations of impedance loading of the source is effected by conventional means, and any dummy load employed may be of any known type.

A better understanding of the invention will be obtained by reference to the detailed description and the drawings in which:

Figure 1 illustrates one form of the present invention comprising a round hollow wave guide having a shunt rectangular guide side connection and two rectangular guide end connections, one rotatable.

Figure 2 illustrates a second embodiment comprising a round hollow wave guide having a series rectangular guide rotatable side connection and two rectangular guide end connections.

Figure 3 illustrates a third embodiment of the present invention.

Referring now to Fig. 1 a rectangular hollow wave guide 11 constitutes means for introducing microwave energy to a microwave energy divider of the present invention. As regards the present invention the output end of the waveguide 11 where it connects to the disc 12 can be considered the source of microwave energy, be it a generator or a waveguide energized from a generator. The internal width and breadth of waveguides suitable for the conduction of microwave energy of any specific wavelength in a particular mode are well known in the art, and as an example, the rectangular guide 11 and all others in the embodiments of this invention are specified as having internal width and height of 0.9 inch and 0.4 inch, respectively, suitable for the transmission of the 3.3 cm. or X-band of microwave energy. When the waveguide 11 has these dimensions, X-band microwaves are transmitted only in the dominant $TE_{1,0}$ mode. It is to be understood that this invention is applicable to any length of microwave providing, of course, that the components have the appropriate dimensions for the frequencies.

The rectangular guide 11 terminates in a closely fitting rectangular aperture or coupling iris in a metallic disc 12 that constitutes the end of a round hollow wave guide 13. The junction between the rectangular waveguide 11 and the round waveguide 13 is matched by suitable devices to prevent a discontinuity that would reflect energy back into the guide 11. A suitable matching device consists of inductive vanes, which will be described later. It is well known that the dominant $TE_{1,0}$ mode in a rectangular guide corresponds to the dominant mode $TE_{1,1}$ of a round waveguide. By definition, the dominant mode is the one with the longest cutoff wavelength. Accordingly, the dominant mode in a rectangular guide is determined and fixed relative to the inner surface of the guide by the relation of the wavelength and the dimensions of the waveguide. In a rectangular waveguide the position of the transverse electrical field of the $TE_{1,0}$ mode is parallel with the direction of the narrower dimension. On the other hand, in a round waveguide all

points on the inner surface are symmetrically disposed with respect to the axis of the waveguide and accordingly the dominant $TE_{1,1}$ mode (which corresponds to the dominant $TE_{1,0}$ mode of the rectangular guide) can be rotated relative to the inner surface of the round guide. The present invention takes advantage of this phenomenon in a device wherein a dominant $TE_{1,1}$ mode excitation is established in a round waveguide as by means of a rectangular input iris or other known means. By providing suitable coupling irises in the walls of the round guide and varying the angular position of the round guide about an axis collinear with the axis of the fixed $TE_{1,0}$ mode from the input iris, it is possible to vary the amount of microwave energy flowing from the output irises. As would be understood by those skilled in the art suitable output waveguides can be connected to the output irises.

Such an arrangement provides a very convenient device for controlling the transmission of microwave energy from a source, which may be represented by the waveguide 11 or its rectangular terminating iris, to output branches represented by the rectangular waveguides 26 and 27. The significant feature of the inventive concept is the establishment of a dominant mode such as the $TE_{1,0}$ mode, which has a fixed physical relation to one physical component of the device such as a rectangular iris or waveguide, and introducing this excitation into another physical component, such as a round waveguide section in which all points on the inner surface thereof are symmetrical with the axis thereof. Because of the symmetry of the round waveguide, the $TE_{1,0}$ mode in the rectangular guide when introduced into the round guide becomes the corresponding dominant $TE_{1,1}$ mode in the round guide and the polarization (the E vector position) is determined by the polarization of the $TE_{1,0}$ mode. Since the round guide can be rotated relative to this predetermined polarization, a microwave energy controlling device is provided which is substantially analogous in its action to that of a faucet or spigot.

The round metal guide 13 has an internal diameter of $1\frac{1}{16}$ inch, which is a suitable size to transmit X-band microwave energy in the $TE_{1,1}$ mode. When microwave energy in the $TE_{1,0}$ mode is transmitted by the rectangular guide 11 to the round guide 13, it induces only the $TE_{1,1}$ mode in the latter, the direction of the E vector of the field thereof being parallel to the direction of the electric field in the rectangular guide, that is, perpendicular to the broad sides thereof.

The round guide 13 is connected by a rotary joint 14 to a round guide 16 which is of the same size as the round guide 13 and may be considered as a continuation thereof. The rotary joint 14 permits free relative rotation of the round guides 13 and 16 around their common axis, has low impedance for microwaves, and contains a wave trap to prevent the escape of microwave energy. The two round guides 13 and 16 therefore behave with respect to microwaves as if they were a single continuous guide. The construction of this rotary joint is shown in Fig. 1. An external shell 17 is secured by screws 18 to a ring 19 that is integral with the guide 16, the shell 17 being separated by a packing ring 22 from a metal ring 21 that is integral with the guide 13. The ring 19 is provided with a cylindrical slot 23 having a depth of one-quarter wave length, and a communicating annular slot 24 also having a depth of one-quarter wave length makes a total depth of one-half wave length for the two slots 23 and 24. The junction of the two slots is therefore a high impedance point, preventing escape of microwave energy from entering the annular slot 24 at the interior surface of the round guide so that no impedance discontinuity is presented to microwaves passing from the guide 13 to guide 16. Relative mechanical rotation is thus possible between the guide 13 and guide 16, so that any microwave field in the $TE_{1,1}$ mode induced in the round guide 13 and transmitted into the guide 16 may be rotated in the latter relative to the inside of the wall thereof. In 75

use, either guide 13 or 16 may be fixed and the other rotated. In this example the guide 16 is fixed and the guide 13, together with the attached rectangular guide 11, is rotatable. In order to permit this rotational motion the guide 11 may be connected to a source of microwave energy (not shown) by a conventional flexible rectangular guide, or, alternatively, a microwave generating device, such as a klystron tube or a magnetron may be fixed to the guide 11 and rotate therewith.

From the foregoing it will be seen that microwave energy can be variably extracted from the wave guide 16 through suitable coupling irises when the guide 16 is rotated relative to the dominant $TE_{1,0}$ mode which is set up in the guide 13 by the guide 11. Such irises are provided between the guide 16 and rectangular guides 26 and 27.

The two rectangular wave guides 26 and 27 are so positioned as to be electrically spaced 90° apart around the axis of the round guide 16. One of these rectangular wave guides 26 is fastened to a metal disc 28 forming an end of the round guide 16 so that microwave energy may pass from the round guide 16 into the rectangular guide 26 when the microwave field is properly oriented with relation to the attitude of the intervening coupling iris. This occurs when the direction of the E vector of the electric field of the microwave transmitted in the $TE_{1,1}$ mode within the round guide 16 is perpendicular to the broad faces of the rectangular guide 26. When this orientation exists there is a minimum impedance. When the junction between the guides 16 and 26 is properly matched substantially no microwave energy is reflected. A good match may be made in several ways, as is well understood in the art, but for the purposes of this example the match is effected by means of an iris consisting of two inductive vanes 29 and 31 at the entrance to the rectangular guide 26. In all of the examples described in this specification it is to be understood that all junctions between round and rectangular guides are so matched. When the field is properly oriented, this iris prevents all reflection, but when the direction of the E vector of the electric field within the round guide 16 is not exactly perpendicular to the broad faces of the rectangular guide 26, some energy is reflected from the metal end 28, regardless of the matching iris, and when the electric field is parallel to the broad faces, no microwave energy enters the rectangular guide 26 and all is reflected as though the disc 28 was solid. This is the case when the relative orientation of the guide 11 and guide 26 is as depicted in Fig. 1; in order to reduce to a minimum the impedance at the coupling iris 29, 31 between the end of the guide 16 and the guide 26, the latter would have to be rotated 90° in either direction.

On the other hand, when the side arm guide 27 is in the position depicted in Fig. 1, there is a minimum impedance at the coupling junction between the guide 16 and the side arm guide 27 and microwave energy is received by it since it is an H-line arm. The $TE_{1,0}$ electric field in the input guide 11 being vertical in the figure, produces a vertical electric field in the $TE_{1,1}$ mode in the round guides 13 and 16, which in turn produces a vertical electric field, again in the $TE_{1,0}$ mode, in the output guide 27. However, when the input guide 11 is in a position exactly 90° from that shown, the E vector of the $TE_{1,1}$ mode of the electric field in the round guide 16 will be in such a position that it cannot enter the guide 27, and in fact to this field the guide 27 appears to be absent and the wall of the round guide 16 appears to be continuous. When the $TE_{1,1}$ field in the round guide has any intermediate orientation, the microwave energy is divided between the waveguides 26 and 27. In order for this to be true, the distance A between the electrical center of the guide 27 and the end plate 28 must be one-fourth of a wave length in the guide, or

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

5

This is because it is necessary that all microwave energy arriving at the guide 26 and not accepted thereby because of the orientation thereof, and hence reflected by the end 28, must return to the guide 27 so as to be in phase with energy approaching at the same instant from the guide 11. This condition exists only when the distance is as specified or is an odd integral multiple M thereof, expressed as

$$\frac{M\lambda g}{4}$$

The energy-dividing action of the apparatus described may be more clearly understood when it is considered that the E vector of the TE_{1,1} mode induced in the round guides 13, 16 by the TE_{1,0} mode of the rectangular guide 11, is along a diameter of the round guides and may be resolved into two voltage vectors along any two mutually perpendicular directions in a plane perpendicular to the axis of the guides 13 and 16. The values of each of these vectors will be proportional to the cosine, of the angle it makes with the resultant. These vectors then will represent the proportions of voltage received by the guides 26 and 27 as the input guide 11 is rotated relative to the guide 16. The energy received by each of the guides 26 and 27 will be proportional to the squares of the respective voltages, and their sum will equal the input energy. In all cases the effect of the variation of the impedance of the total load upon the generator, as observed from the generator, or the input end of guide 11 will be substantially zero, usually less than 1%. This is one of the salient features of this invention.

It is obvious that if the arm 11 be fixed and the round guide 16 together with its output arms 26 and 27 be rotatable, it will be necessary in general to make connections to the arms 26 and 27 by flexible guide or equivalent means.

The output arms 26 and 27 may be connected respectively to two useful respective loads, or as previously mentioned, one may be connected to a useful load, such as a transmitting antenna, while the other may be connected to a dummy load of any known type suitable for the amount of power to be dissipated. In this case either the arm 26 or the arm 27 may be connected to the useful load, as the characteristics of the output arms 26 and 27 are quite similar.

Since operationally, the arms 26 and 27 are similar, it is obvious that the end arm 26 may be replaced by a shunt side outlet of rectangular waveguide identical to the guide 27 and located like it a distance of

$$\frac{Xg}{4}$$

or odd multiple thereof, from the end plate 28, which should be solid and without any aperture. The replacing arm would be positioned 90 mechanical degrees from the arm 27 around the round guide axis in either direction, and the description of its operation would be similar to that given for the case of the end and side outlet arms.

Referring now to Fig. 2, a round waveguide 32 is connected by means of two rotary joints 33 and 34, similar to the rotary joint 14, Fig. 1, to two round wave guides 36 and 37 respectively, the guides 36, 37 may be of a size suitable for the transmission of a microwave in the TE_{1,1} mode; for example, $\frac{1}{4}$ inch in diameter for X-band microwaves of 3.3 cm. in length. The round guides 36 and 37 are terminated by metal disc ends 38 and 39, to which are connected rectangular wave guides 41 and 42 of dimensions suitable for supporting the TE_{1,0} mode of the X-band. The broad sides of the respective guides 41 and 42 are oriented at right angles with respect to each other and are mechanically connected by any suitable means so as to be rotated together around their common axis, this connection being schematically indicated by the dashed line 43. The round guide 32 has a series side arm 44 consisting of a rectangular wave guide of a size suit-

6

able for supporting the TE_{1,0} mode for X-band transmission. The distances B and C from the electrical center of this arm to the guide ends 38 and 39 must each be one-half of the wave length λg in the guide or an integral multiple N thereof, expressed as

$$\frac{N\lambda g}{2}$$

for reasons which will presently appear. Theoretically, the use of a series side arm can be made the electrical equivalent of a shunt side arm by appropriately changing the dimensions B and C.

In this embodiment the side arm 44 is adapted to serve as an input for microwave energy and the end arms 41 and 42 are adapted as output terminals. Energy entering the round guide 32 from the rectangular series side arm guide 44 divides, with one-half passing toward the guide 41 and the remainder toward the guide 42. The microwave energy in the round guides 32, 36 and 37 is transmitted by fields in the TE_{1,1} mode, these fields having, in a guide positioned as depicted in Fig. 2 their E vectors in the horizontal plane. The orientation of the E vectors is determined by the polarization of the rectangular input guide 44. Such fields are accepted by rectangular guides oriented like guide 42 because, as mentioned above, the dimensions of this guide are such as to support a TE_{1,0} mode of the X-band which mode corresponds to the TE_{1,1} mode of the round guide. Accordingly, the guide 42 presents a minimum impedance to the microwave energy in round guide 32 of the polarization mentioned while guide 41 presents a maximum impedance as if the round guide end 38 were solid. The distance B being equal to

$$\frac{N\lambda g}{2}$$

the reflected energy is returned to the location of the guide 44 at such phase as to reinforce waves travelling toward the right, so that all of the energy introduced at the guide 44 is received by the guide 42.

By similar reasoning, it is readily seen that if the guides 41 and 42 be turned about the axis of the round guide 32 through an angle of 90° all of the energy will be emitted from the guide 41 and none from the guide 42. Likewise, at intermediate positions of the guides 41, 42 the energy transmitted by each guide will be a function of the angle between the broad faces of the respective guides 41, 42 and the E vector in round guide 32, which vector is fixed by the position of guide 44 as described in connection with Fig. 1. In all cases the substantial constancy of the impedance of the device as reflected to the generator or input terminal 44 is of the greatest practical utility.

It is obvious that in place of either or both output terminal guides 41 and 42 there may be substituted side arm output rectangular guides, either of the shunt type 27, described in connection with Fig. 1, or of the series type identical with the input arm 44, Fig. 2. In either case the adjacent round guide ends may be solid and the distances between the ends and the respective output side arms would be

$$M\frac{\lambda g}{4}$$

for the shunt type and

$$N\frac{\lambda g}{2}$$

for the series type.

As a further corollary, more than two outlets may be provided with the microwave energy dividing in accordance with the principles described, to the outlets in accordance with the respective orientation of the outlets

7

with respect to the polarization of the field in the round guide.

In Fig. 3 a $TE_{1,1}$ field is excited in a $1\frac{5}{16}$ inch diameter round guide 46 by the introduction through an end plate 47 of microwave energy in the $TE_{1,0}$ mode from a rectangular waveguide 48, the field in the round guide 46 being rotatable through rotation of the input guide 48 and the end plate 47 relative to the round guide 46. Rotational movement between the waveguide 48 and the round guide 46 is permitted by the provision of a connecting rotary joint 49 which is similar in construction to joint 14 shown in Fig. 1. A side outlet terminal in the form of rectangular guide 52 is provided. So far the power divider is similar to that described in connection with Fig. 1. However, in Fig. 3 the end output terminal 50 is of the circular cylinder guide type and consists of an absorptive load. This dummy load may be of any one of a number of known types suitable for the power required to be dissipated and in the form shown is a wood cone 51 having a resistive skin of colloidal graphite. The apex of the cone is pointed toward the power input and is long enough to prevent the effect of a discontinuity that would cause reflections. Its length in any case should not be less than one and one-half times the diameter of its base.

The rectangular guide shunt side arm 52 is positioned at a convenient distance from the input end 47. Since the round guide 46 is not reflective at its loaded end 50, a reflective quarter-wave closed stub 53 is provided to cause proper functioning of the side arm 52. This stub 53 is of the shunt type and is positioned on the round guide 46 in longitudinal alignment with the arm 52, on the side away from the power input guide terminal 48. The electrical distance D between the electrical center of the stub 53 and the electrical center of the arm 52 must be

$$\frac{\lambda g}{4}$$

or an odd multiple thereof in instances, both where the shunt and series types of arms and stubs are used.

A mode transformer 55 is provided to permit all input and output branches of the complete device to remain stationary, and yet provide for the adjustable rotation of the guide 48 about the axis of the power divider to vary the orientation of the field within the guide 46 with relation to the side outlet terminal arm 52. The mode transformer 55 consists of two round guides 54 and 56 connected by a rotary joint 57 similar to that described in connection with Fig. 1. The guides 54 and 56 have an internal diameter of $1\frac{5}{16}$ inches and are closed by respective solid metal disc ends 58 and 59. An input branch or terminal in the form of a rectangular guide 61 connected to the guide 54 as a series side arm is positioned a distance G, equal to one-half of a $TM_{0,1}$ mode wavelength and

$$\frac{\lambda g}{4}$$

of a $TE_{1,1}$ mode wavelength in the guide from the disc end 58, and an output branch in the form of a rectangular guide 62, also connected to the guide 56 as a series side arm, is positioned a distance F equal to one-half of a $TM_{0,1}$ mode

$$\left(\frac{\lambda g}{4} \text{ of a } TE_{1,1} \text{ mode wavelength} \right)$$

in the guide from the disc end 59. An orientation scale 63 fixed to the guide 56 is associated with a fixed index plate 64 to determine the relative position of the guide 56 and the guide 54. The output terminal 62 is connected by a length of curved rectangular waveguide 66 to the rotatable input waveguide 48 of the power divider.

In the operation of this modified form the input ter-

8

terminal 61 may be fixed to a microwave generator, or other input equipment, and the output terminal 52 may be fixed to stationary output or utilization equipment. The part between the rotary joint 57 and the rotary joint 49 may be rotatably adjusted and its orientation is indicated by the position of the scale 63 attached to the round guide 56 in relation to the index mark 67 carried by the fixed index plate 64.

The specific diameters of the guides 54 and 56 are such as to support both the $TM_{0,1}$ mode and the $TE_{1,1}$ of propagation of microwave energy one in resonance and the other in anti-resonance therein. The introduction of microwave energy in the $TE_{1,0}$ mode through the rectangular guide 61 to the round guide 54 tends to cause both modes $TE_{1,1}$ and $TM_{0,1}$ to be established in the round guide 54 and 56. However, because the distance G is

$$\frac{\lambda g}{2}$$

of $TM_{0,1}$ mode and

$$\frac{\lambda g}{4}$$

$TE_{1,1}$ mode (resonant to $TM_{0,1}$ and anti-resonant to $TE_{1,1}$), the $TE_{1,1}$ mode may be said to be "tuned out," and its elimination leaves the mode $TM_{0,1}$ as the sole means of propagation of all of the input energy without reflection through the guides 54 and 56 to the rectangular output guide 62 where the transformation to the $TE_{1,0}$ mode recurs without harmful reflection because of the termination of the round guide 56 by the end plate 59 at the particular distance F from the longitudinal center of the rectangular guide 62. The $TM_{0,1}$ mode solely existing in the round guides 54 and 56 is symmetrical about the axis of the guides, so that the relative axial rotation of the guides 54 and 56 causes no change whatever in the phase or orientation of the microwave energy entering the branch or terminal 62. This energy is delivered to the terminal 48 without substantial loss or reflection regardless of its angular position. The angular position of the terminal 48 does determine, however, the orientation of the $TE_{1,1}$ mode in the round guide 46 and therefore determines the division of energy between the output arm 52 and the dummy load 51, in exactly the way that field orientation determines energy division in the embodiment described in connection with Fig. 1.

As a result, the mode transformer 55 provides the means for carrying out the purposes of this invention yet obviates the necessity for employing flexible guides or other adjustable coupling attachments to the input and output end terminals. The impedance of the load on the generator (or other source) remains constant for all orientations of the rotatable portion of the device, a fact of the greatest utility.

It is obvious that the mode transformer 55 of Fig. 3 can be applied to any input or output microwave terminal connection in the end of a round guide that may be required in any of the embodiments of this invention. It is also obvious that the side arm and end arm input and output terminal connections and all other components described may be associated in a great many combinations, but in most cases each of such components and each of their interrelations should preferably be as have been herein described in connection with the embodiments of the invention.

Within the broad aspects of the present invention the rectangular guides may be considered as polarizing irises and it will be clearly understood by those skilled in the art that the rectangular guides could be replaced by other interconnecting waveguides or coaxial lines so long as they are capable of transmitting the desired frequencies. The important thing is that either the interconnecting device or the coupling device be capable of polarizing or of being sensitive to electric fields of a definite polarization. Also the mode transformer 55 interposed between

the input 61 and output terminal 52 in Fig. 3 may be considered merely illustrative of a component for transmitting or carrying circularly polarized microwave energy at the desired frequency.

Any of the rectangular guide input and output arms or terminals described in the example can be replaced by any other well-known device by which the $TE_{1,1}$ mode can be induced in a round guide, or which can be excited by the $TE_{1,1}$ mode in a round guide while being sensitive to the orientation of the electric field thereof. Common examples of such well-known devices include an antenna or probe extending a suitable distance into the side wall of a round guide, and a side or end aperture of generally elongated shape. Any of such devices may be employed so as to be electrically the equivalent of the described rectangular wave guide input and output arms. Each of the side arms and other branch guides by which the microwave energy is transmitted corresponds effectively to the two conductors of an electrical circuit for frequencies below the microwave region. Accordingly, for convenience, the word "terminal" is used in such sense in the appended claims and in the specification.

What is claimed is:

1. A microwave power controlling device comprising a waveguide section capable of supporting independently at orthogonal positions in said section only the dominant TE_{11} non-circular mode of wave transmission at a given frequency, said section having an impedance discontinuity for reflecting wave energy in at least one plane of polarization, input means for establishing incident wave energy in said non-circular mode in said section with the transverse electric vector at a selected plane of polarization, a plurality of output means connected to said section at position orthogonally related electrically around the axis of said section, at least one of said output means being connected at an in-phase position for incident and reflected wave energy, said output means being connected to said section through respective oblong polarizing coupling apertures having their planes of polarization orthogonally related, the major axes of said apertures being of such dimension as to support only the dominant TE_{10} mode corresponding to the TE_{11} mode in said section, the minor axes of said apertures being of such dimension as not to support a dominant mode corresponding to the TE_{10} mode in said section and means for changing the plane of polarization of the incident wave relative to said polarizing output coupling apertures.

2. A microwave power controlling device comprising a hollow waveguide section capable of supporting independently at orthogonal positions in said section only the dominant TE_{11} non-circular mode of wave transmission at a given frequency, said section having one end terminated in an impedance for reflecting wave energy in at least one plane, input means for establishing incident wave energy in said non-circular mode in said section with the transverse electric vector at a selected plane of polarization, a first output means connected to said terminated end of said round section, a second output means connected to the side of said first section at an in-phase position for incident and reflected wave energy reflected from said terminated end of said section, said output means being connected to said section through respective oblong polarizing coupling apertures orthogonally related electrically about the axis of said section, the major axes of said apertures being of such dimension as to support only the dominant TE_{10} mode corresponding to the TE_{11} mode in said section, the minor axes of said apertures being of such dimension as not to support a dominant mode corresponding to the TE_{10} mode in said section and means for changing the plane of polarization of the incident wave relative to said polarizing output coupling apertures.

3. An adjustable microwave power controlling device comprising a round hollow waveguide section having such internal diameter as to support only the TE_{11} mode of

wave transmission at a given frequency, a polarizing oblong input guide rotatably attached in coaxial relation to one end of said round section, the other end of said round section having terminating means for reflecting wave energy in at least one plane, a first hollow polarizing oblong output arm coupled in coaxial relation to the other end of said round section at a fixed orientation therewith to accept microwave energy in a plane of polarization orthogonal to that reflected by said terminating means, a second hollow oblong polarizing output arm connected to the side of said round guide at an in-phase position along the axis of said round section with its plane of polarization orthogonally related about the axis of said round section to the plane of polarization of said first output arm, the major axes of said oblong guides being of such dimension as to support only the dominant TE_{10} mode corresponding to the TE_{11} mode in said round section, the minor axes of said arms being of such dimension as not to support a dominant mode corresponding to the TE_{10} mode in said section and means for rotating said input arm about its axis whereby the wave energy entering said round section through said oblong input arm will be divided between said output arms as functions of the angular position of E vector in said round section with respect to the respective planes of polarization of the respective output arms.

4. An adjustable microwave power controlling device comprising a round hollow waveguide section having such internal diameter as to support only the TE_{11} mode of wave transmission at a given frequency, said section having its ends terminated in impedances for reflecting wave energy in respective orthogonal planes, an input arm fixed to one side of said section and coupled through a polarizing aperture, a plurality of output means connected to said round section through respective rotatably adjustable walls having polarizing coupling apertures, said output arms being connected to said round section at in-phase positions spaced along the axis of said round section, the major axes of said apertures being of such dimension as to support only the TE_{10} mode corresponding to the TE_{11} mode in said section, the minor axes of said apertures being of such dimension as not to support the dominant mode in said section, means connecting said rotatably adjustable walls for rotating them in unison about the axis of said round guide while maintaining the major axes of said output apertures in a relatively fixed orthogonal relation, whereby the wave energy in the TE_{11} mode in said round section will be divided between said output arms as respective functions of the position of the E vector in said round section with respect to the respective planes of polarization of the TE_{10} mode in the respective output arms without substantially affecting the total impedance at said input arm.

5. An adjustable microwave power controlling device comprising a round hollow waveguide section having such internal diameter as to support only the TE_{11} mode of wave transmission at a given frequency, said section being terminated in an impedance for reflecting wave energy in one plane, a rectangular input arm and a plurality of rectangular output arms connected to said round section, said input arm being fixed to the side of said round section with its axis perpendicular to the axis of said round section, the broad walls of said input arm being perpendicular to the axis of said round section, the broad walls of said output arms being parallel to the axis of said round section and perpendicular to each other, said output arms being rotatably connected to the opposite ends of said round section, means for simultaneously rotating said output arms in unison about the axis of said round guide while maintaining their orthogonal relation to each other, said output arms being connected to said round section at in-phase positions along the axis of said round section whereby wave energy in said round section will be divided between said output arms as functions of the respective

11

positions of the E vector in said round section with respect to the respective planes of polarization of the TE₁₀ mode in the respective output arms without substantially affecting the total impedance at said input arm.

References Cited in the file of this patent

UNITED STATES PATENTS

2,129,712 Southworth ----- Sept. 13, 1938

2,257,783

2,425,345

2,438,119

2,606,248

12

Bowen ----- Oct. 7, 1941

Ring ----- Aug. 12, 1947

Fox ----- Mar. 23, 1948

Dicke ----- Aug. 5, 1952

OTHER REFERENCES

Ragan: Microwave Transmission Circuits, vol. 9, M. I. T. Rad. Lab. Series, published by McGraw-Hill, pages 368-69. Copy in Patent Office Library.