March 15, 1955 R. H. DICKE 2,704,351

WAVE GUIDE JUNCTION MATCHING DEVICE

Original Filed March 8, 1945 2 Sheets-Sheet 1

Fig. 1.

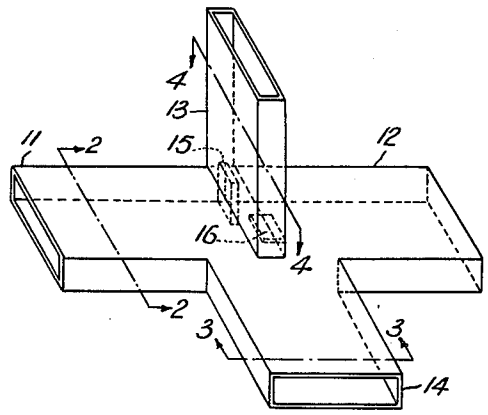


Fig. 2.

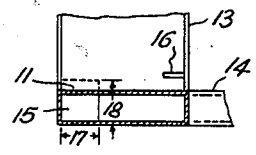


Fig. 3.

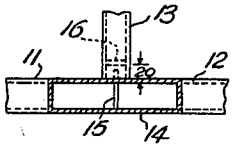


Fig. 4.

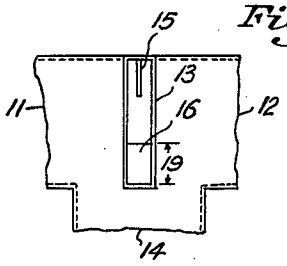


Fig. 5A

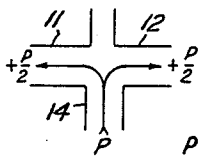
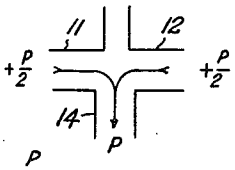


Fig. 5B.



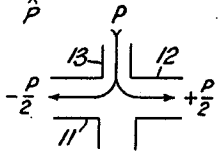


Fig. 5C.

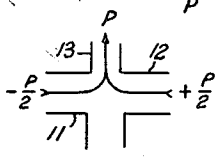


Fig. 5D

INVENTOR.
Robert H. Dicke
BY
Harry M. Saragovitz
ATTORNEY

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Fig. 6.

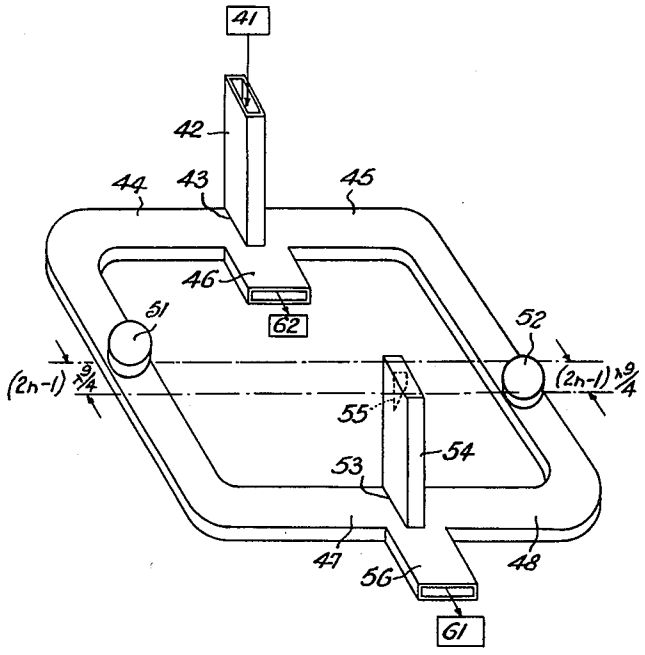


Fig. 8.

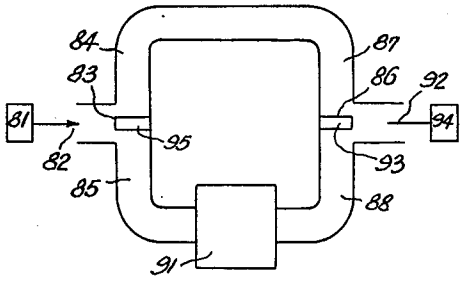
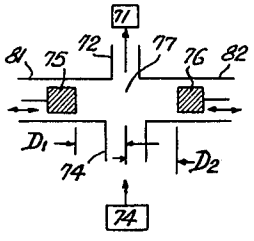


Fig. 7.



INVENTOR.
Robert H. Dicke
BY
Harry M. Saragovitz
ATTORNEY

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WAVE GUIDE JUNCTION MATCHING DEVICE

Robert H. Dicke, Cambridge, Mass., assignor to the United States of America as represented by the Secretary of War

Original application March 8, 1945, Serial No. 581,695, now Patent No. 2,593,120, dated April 15, 1952. Divided and this application March 19, 1952, Serial No. 282,035

1 Claim. (Cl. 333—11)

This application is a division of application Serial No. 581,695 entitled "Transmission Systems," which was filed March 8, 1945, and issued April 15, 1952, as Patent No. 2,593,120.

This invention relates to transmission systems and more particularly to an impedance transformer for use with ultra high frequency energy.

According to conventional theory the dominant mode of operation of a wave guide may be defined as that condition of operation in which the configuration of electric and magnetic lines of force permits the transmission of energy at the lowest possible frequency through a wave guide of a given size and geometric cross-section. It may also be defined with equal accuracy as that condition of operation in which the configuration of electric and magnetic lines of force permits the transmission of energy through the smallest dimensional wave guide of a given cross-section at a given frequency.

In a rectangular wave guide operated in the dominant mode, there exists a sinusoidal distribution of electric lines of force along the major axis of the rectangular cross-section. These electric lines of force or electric field vectors are perpendicular to the major axis of the rectangle.

When a main rectangular wave guide designed to be operated in the dominant mode is joined symmetrically by a wave guide whose axis is parallel to the electric field vectors in the main wave guide, the juncture is said to be a series junction. When the joining wave guide is symmetrical to a main wave guide and the axis of the joining guide is perpendicular to the electric field vectors within the main guide, the junction is said to be a parallel junction. When these two junctures, one series and one parallel, are made in such a manner that the axes of the series and parallel wave guides join the axis of the main wave guide at the same point certain unique properties exist. Broadly, any geometric arrangement of four wave guide branches will also give these unique properties if the following conditions are met. The axes of the four guides must meet at a common point. In a first and second of these guide branches the electric lines of force are perpendicular to each other and the lines of force in one of these first and second wave guide branches must be perpendicular to a plane passing through the axes of the first and second wave guide branches. The third and fourth of these wave guide branches must be symmetrical with respect to the plane passing through the axes of the first and second wave guide branches which was just referred to. These unique properties are explained further in the detailed discussion of the drawings. It will be appreciated, however, by those skilled in the art that where any abrupt change in structure occurs, mismatch and consequent undesirable reflections also tend to occur. This is especially so where one wave guide branches into two or more wave guides. When a wave guide is terminated in its characteristic impedance, no mismatch or reflections will occur. The desirability of the unique properties referred to above render it advisable to eliminate tthe unwanted mismatch and reflections.

In certain radio communication systems a common radiating and receiving device, or antenna, is used for transmitting and receiving and in such systems a part of the channel for transmitted energy is common to a part of the channel for the received energy. There then exists the problem of preventing the transmitted energy,

which is of normally higher level, from being partly spent in the receiver channel and damaging the receiving device. Conversely, there exists the problem of preventing the received energy of normally lower level from being wasted in the transmitter channel. In certain cases it is absolutely essential that the transmitted power be eliminated or at least minimized, from the receiver. A system of transmit-receive or T-R devices were made to achieve this purpose. However, there still existed at least two sources of trouble. The first was that an initial high level transmitted energy spike managed to escape the action of the T-R device and the second was that the T-R device was not capable of excluding from the receiving device a low level or plateau of energy.

Many methods have been employed in the past for matching or transforming one impedance to another. At the lower radio frequencies this is done with lumped circuits such as transformers or with line stubs such as the double stub tuner. For radio frequencies sufficiently high to warrant the use of wave guides these stub tuners can still be used but with increasing difficulty. Impedance transformers with greater range of matching and ease of operation are desirable.

Oftentimes in radio work it is desired to variably attenuate or reduce a signal in magnitude. At low radio frequencies the problem is simple, but at frequencies for which wave guides are practical the problem of a variable attenuator becomes quite complex.

One object of this invention is, therefore, to terminate each wave guide at its junction with other wave guides in its characteristic impedance.

A further object of this invention is to provide a system for permitting energy to flow to and from a common element through a common channel with no coupling between the sending and the receiving elements which are located at the same end of the common channel.

Still another object of this invention is to match or transform one impedance into another.

A still further object of this invention is to provide a variable attenuator, capable of handling large amounts of power, using matched wave guide junctions.

In accordance with the present invention there is provided a matched junction formed by three wave guides. One of the three wave guides is joined to a second of the three wave guides in a series junction. The third wave guide joins the second wave guide in a parallel junction. An iris, for matching purposes, is inserted in the second wave guide. It is mounted in such a position as to lie in a plane which also contains the axes of the first and third wave guides. A second iris is located within the first wave guide. The two irises are so adapted that each wave guide sees as its termination at the junction its characteristic impedance.

For a better and fuller understanding of the invention, together with other objects thereof, reference is made to the following detailed description taken in connection with the accompanying drawings in which:

Fig. 1 shows an improved wave guide junction;

Figs. 2, 3, and 4 show views looking into different wave guides making up the junction of Fig. 1 to show the position of matching irises;

Figs. 5A, 5B, 5C, and 5D facilitate describing some of the unique properties of the matched junction shown in Fig. 1;

Fig. 6 shows an improved transmission system;

Fig. 7 shows an improved impedance transformer; and

Fig. 8 shows an improved variable attenuator system.

Referring now more particularly to Fig. 1, there is shown a matched junction formed by three wave guides. A first wave guide with two branches **11** and **12** is joined by a second wave guide **13**, symmetrically in a series connection. A third wave guide **14** is joined symmetrically and in a parallel connection to the first wave guide **11—12**. The series and parallel junctions are so made that the axes of the first, second, and third wave guides meet in a point. Fig. 1 shows the wave guides **13** and **14** as being perpendicular to the wave guide **11—12**. While this is a preferred embodiment, it is not desired to limit the invention here described to this geometric arrangement. Two irises **15** and **16**, preferably in the form of thin plates of conducting material, are inserted at the

junction to permit matching of all four wave guide branches, that is to say, looking from any one of the four wave guide branches toward the junction each of the wave guide branches will be terminated by its characteristic impedance. Fig. 2 shows the iris **15** partially closing off wave guide branch **11** as it is viewed from line **2—2** in Fig. 1. In Fig. 3 this same iris **15** is shown as it is viewed from line **3—3** in Fig. 1. Fig. 4 again shows the iris **15** as it is viewed from line **4—4** in Fig. 1. Figs. 2, 3, and 4 taken together show the iris **15** to be within the wave guide **11—12** and to lie in a plane which includes the axes of wave guides **13** and **14**. By variation of the length **17** and the depth **18** of the iris **15** shown in Fig. 2, the iris **15** is adjusted empirically so that the third branch **14** is terminated in its characteristic impedance. Fig. 4 also shows the position of the iris **16**. Figs. 2 and 4 taken together show the iris **16** to be within the wave guide **13**. By variation of the length **19** of the iris **16** (Fig. 4) and the axial distance **20** of the iris **16** from the junction (Fig. 3), the iris **16** is adjusted empirically so that the second branch **14** is terminated in its characteristic impedance.

Referring now to Figs. 5A, 5B, 5C, and 5D specifically, there is shown four novel ways in which the matched junction of Fig. 1 operates. Although there are other novel modes in which a junction, such as is illustrated in Fig. 1, operates, the modes illustrated in Figs. 5D–5D inclusive are deemed sufficient for explanatory purposes. In Fig. 5A energy P, which enters the parallel connected wave guide **14**, divides at the junction into the two branches **11** and **12** of main wave guide. The energy divides equally, and the two parts are in phase with each other as indicated by the designation $+(P/2)$ at the ends of each of wave guide branches **11** and **12**. In Fig. 5B the converse of the condition illustrated in Fig. 5A is shown. If energies of equal magnitude and similar phase $+(P/2)$ enter the two branches **11** and **12** of the main wave guide, these energies combine at the junction, and all of this energy enters the parallel connected wave guide **14** and is designated by P. In Fig. 5C is shown the condition where energy P enters the series connected wave guide **13**. This energy divides equally and passes into the two branches **11** and **12** of the main guide. The two energies will be in 180° phase opposition as shown by the designation $-(P/2)$ at the end of guide branch **11** and the designation $+(P/2)$ at the end of guide branch **12** in this figure. Fig. 5D shows the converse of the condition shown in Fig. 5C. If energies of equal magnitude and in 180° phase opposition as indicated by $-(P/2)$ and $+(P/2)$, the energies will combine and will all enter the series connected wave guide **13**. This energy is designated by P. To those skilled in the art, it will be obvious that energies which enter the two brancahes of the main guide but which are neither in phase nor in phase opposition will be combined and will divide going into both the series and the parallel connected wave guides. The relative division into the series and parallel connected wave guides will be a function of the phase relation existing between the two energies. This will be readily seen when one considers that either energy may be resolved into two components, one component in phase and one component in phase opposition to the other energy.

In Fig. 6 there is shown a novel apparatus employing the matched junction of Fig. 1 in a wave guide circuit. This is the preferred arrangement. However, the circuit will function if unmatched junctions are used. A transmitter or transmitting device **41** is connected to a wave guide **42**. Wave guide **42** comprises the series connected branch of a first matched junction **43**. The parallel connected wave guide **46** of this junction **43** is connected to a radiating device **62**. The branches **44** and **45** of the junction **43** are connected, respectively, to the branches **47** and **48** of a second matched junction **53**. The electrical length of wave guide **44—47** from the junction **43** to the junction **53** differs from the electrical length of wave guide **45—48** from the junction **43** to the junction **53** by an integral number of wave lengths. "Integral number" is taken to include zero. The series connected wave guide **54** of the second matched junction **53** is terminated in an absorptive load **55**. The parallel connected wave guide **56** of the second matched junction **53** goes to a receiving device **61**. Two T-R devices **51** and **52** are inserted in the two wave guides **44—47** and **45—48**. Their electrical distances from the junction **43** differ by an odd number of quarter wavelengths. A transmit-receive (T-R) device may be defined for the purposes of this invention as a device operative only by high level energy and which when operative will cause a maximum of reflection of the high level energy to occur. Low level energy such as received signals will not operate the T-R device and so will continue past the device unaltered.

A detailed description of the operation of the apparatus of Fig. 6 follows. The transmitter **41** is connected to feed energy into the apparatus through wave guide **42**. Referring to Fig. 5C, we note that this energy will divide at the matched junction **43** equally, going into wave guide **44** and wave guide **45** in 180° phase opposition with no energy passing directly into wave guide **46**. The energy of high level transmission will break down the T-R devices **51** and **52**, but both relatively short high level energy and relatively long low length energy which escapes the action of the T-R devices continue past the T-R devices **51** and **52** with no phase change and reach the matched junction **53**. The path from junction **43** through wave guide **44—47** to junction **53** being equal in electrical length to the path from junction **43** through wave guide **45—48** to junction **53**, and since the energy in these two paths leaves junction **43** in 180° phase opposition, the energy in these two paths arrives at the matched junction **53** in 180° phase opposition. Referring to Fig. 5D, we note that this energy will all pass into wave guide **54** and be absorbed by the matched load **55**. It is to be noted that no energy from either the relatively short high level portion or the relatively long low level portion passes into the wave guide **56** and receiving device **61**. The energy which does not pass the T-R devices **51** and **52** is reflected back toward the matched junction **43**. However, when energy travels from junction **43** through wave guide **45** to T-R device **52** and back to junction **43**, it travels an odd number of half wavelengths farther than energy that travels from the junction **43** through wave guide **44** to T-R device **51** and back to junction **43**. The two energies which are reflected from the T-R devices **51** and **52** arrive at junction **43** in phase. This is true because the two energies leave junction **43** in 180° phase opposition, and then the energy in wave guide **45** experiences an extra delay of an odd number of half wavelengths, and, therefore, the two energies are again in phase. Referring to Fig. 5B, it is noted that this reflected energy will pass into wave guide **46** and thence to radiating device **62**. Energy which enters junction **43** from the radiating device **62** by means of guide **46** divides equally and with no phase difference between the guides **44** and **45**. None of this energy enters wave guide **42**. Normally the energy from the radiating device **62** is not sufficient in quantity to operate the T-R devices **51** and **52**, and thus it will all continue on to the junction **53**. The energies arrive at junction **53** in phase, since they start from junction **43** in phase and travel equal electrical distances. At junction **53** this energy passes on into wave guide **56** and thence to receiving device **61**.

It will be obvious to those skilled in the art that the functions performed by the parallel and series connected branches **46** and **42** and **56** and **54** may be interchanged if the interchange is made at both junctions **43** and **53**. The functions of the wave guide branches **46** and **42** and **56** and **54** may also be interchanged at either junction **43** or **53** by properly adjusting the relative lengths of the wave guides **44—47** and **45—48**.

Fig. 7 shows a device employing a matched junction in a wave guide circuit as an impedance transformer. Because of the desirability of the matched junction, it is preferred for use in this circuit. However, the circuit will function with junctions like the one shown in Fig. 1 if the matching irises are omitted. The impedance **71** to be transformed is connected to a series connected wave guide **72** of a junction **77**. The impedance **73** to which impedance **71** is to be transformed is seen when looking into a parallel connected wave guide **74**. Two plungers **75** and **76** are inserted in wave guides **81** and **82** and are adapted to be adjusted in their relative positions. These two plungers are located at distances D_1 and D_2, respectively, from the junction as shown in Fig. 7.

The method for determining the distances D_1 and D_2 is explained in the following part of the specification.

In a wave guide such as wave guide **72** which is terminated by an impedance **71**, which is equal to Z_1, other

than its characteristic impedance Z_c there exists standing waves and associated therewith a standing wave ratio SWR. The SWR is defined as the ratio of the maximum amplitude of signal along the wave guide to the minimum amplitude of signal along the wave guides. The maximum and minimum amplitudes normally exist one fourth wavelength apart. If the impedance **71** or Z_1 is divided by Z_c, the resulting quotient which is a complex notation locates a point on an impedance circle diagram known as the Smith chart. A circle passing through this point with $1+j0$ as the center will describe the loci of all impedances existing along wave guide **72**. Since we normally desire a matched system, we wish to transform Z_1 to Z_c. By variation of D_1 and D_2 it is possible to match any impedance Z_1 to the wave guide **72** i. e. to transform it to Z_c. D_1 and D_2, the distances from the center of the T-junction to the plungers **75** and **76**, can be thought of as being determined by two parameters X and Y which are functions of the two impedances Z_1 and Z_c considered. The following relation holds:

$$D_1=X+Y \tag{1}$$

$$D_2=X-Y \tag{2}$$

It is normally possible to calculate or determine experimentally the SWR. If the terminating impedance Z_1 and the characteristic impedance Z_c are known and both are pure resistances, then the reflection coefficient A is given by

$$A=\frac{Z_1-Z_c}{Z_1+Z_c} \tag{3}$$

and if the SWR is determined experimentally, the reflection coefficient A is given by

$$A=\frac{SWR-1}{SWR+1} \tag{4}$$

The following expression derived from a consideration of the junction described above gives a relationship between the reflection coefficient A and D_1 and D_2.

$$A=\tfrac{1}{2}\left(1+\cos\frac{4\pi(D_1-D_2)}{\lambda}\right) \tag{5}$$

However, since from Equations 1 and 2

$$D_1-D_2=2Y \tag{6}$$

Equation 5 may be solved for Y. From any arbitrary value of X, Y may be set by a system of levers arranged to move the two plungers **75** and **76** equally in opposite directions from the center of the junction **77** or Y may be set for each plunger separately. This will set up the proper SWR in the wave guide containing the impedance Z_1. If now we vary X, we can effectively move the standing waves until the actual impedance Z_1 agrees with the value of the standing wave existing at the termination. Varying the parameter X can be thought of as rotating the Smith diagram or as effectively lengthening the wave guide between the point of matching and the terminating impedance Z_1. A system of levers may be set up which will move the two plungers **75** and **76** in the same direction from the center of the junction and hence automatically set both plungers to conform to X.

It can be shown that any electrically symmetrical impedance transformer which will match any impedance to a wave guide will also match any impedance to any other impedance. As shown in the case above, if both plungers **75** and **76** are changed in position by the parameter Y, the SWR only is changed and the movement on the Smith chart is radial. If, however, we move only one plunger, the movement on the Smith chart will be circular. If we move the other plunger, we move along another circular path. It is possible, therefore, by altering the two plungers individually to transform any impedance to any other.

Referring now particularly to Fig. 8, there is shown a novel wide range variable attenuator designed for use in the ultra high frequency range and employing the matched junctions shown in Fig. 1. These matched junctions are preferred for use in this attenuator circuit. However, the circuit will function with junctions in which the matching irises are omitted. A power source **81** is connected to a parallel connected wave guide **82** of a first matched junction **83**. A series connected wave guide **95** is terminated in an absorptive load, not shown, preferably a matched sand load. The branches **84** and **85** of the first junction **83** are connected, respectively, to branches **87** and **88** of a second matched junction **86**. A variable line stretcher **91** is adapted to be a part of the energy path through guide branches **85—88**. A variable line stretcher may be described as a section of line or wave guide whose electrical length is variable. A series connected wave guide **93** of the second junction **86** is terminated in an absorptive load, not shown, preferably a matched sand load. A parallel connected wave guide **92** of the junction **86** is connected to an active load **94**.

In the operation of the apparatus shown in Fig. 8, energy from power source **81** enters wave guide **82**. At the junction **83** the energy divides into wave guides **84** and **85** equally. Energy in wave guide **84—87** continues on to junction **86** where it is combined with energy which travels by means of the wave guide **85—88**. The energy in wave guide **85—88**, however, passes through the variable line stretcher **91** so that when it reaches the junction **86**, its phase with respect to the energy arriving through wave guide **84—87** may differ anywhere from 0° to 360°. The division of energy between wave guide **92** and wave guide **93** depends upon the relative phases of the two energies arriving at the junction **93**. It is evident, therefore, that the amount of energy going into either wave guide **92** or **93** can be controlled by adjusting the relative phases of the two energies arriving at the junction **86** by means of the line stretcher **91**. The power source **81** and the sand load terminating guide **95** may be interchanged without affecting the operation of the attenuator. It is also to be understood that the line stretcher **91** may be located in either wave guide **84—87** or wave guide **85—89** or it may be located in both wave guides **84—87** and **85—89**. Further it is understood that power source **81** and active load **94** may be interchanged if desired without departing from the true intent of this invention.

While there has been described what is at present considered the preferred embodiments of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made thereon without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

I claim:

An electrical device comprising a first rectangular wave guide; a second rectangular wave guide connected in series to a first broad wall in said first guide; a third rectangular wave guide connected in parallel to the first narrow wall of said first wave guide and in such a manner that the axes of said first, second and third wave guides meet in a common point; a first thin conducting plate attached to the second narrow wall and second broad wall of said first wave guide and extending in a plane containing the axes of said second and third wave guides and a second thin plate of conducting material located in said second wave guide and extending between the broad walls thereof and adjacent the narrow wall which is co-planar with the first narrow wall of the first wave guide, said plates being physically proportioned in size and so arranged in the junction of said first, second and third wave guides for establishing a characteristic impedance termination for both branches of said first wave guide, for said second wave guide and for said third wave guide at their junction.

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