

May 25, 1954

C. F. EDWARDS

2,679,582

BALANCED WAVE GUIDE BRANCHING SYSTEM

Filed Dec. 24, 1945

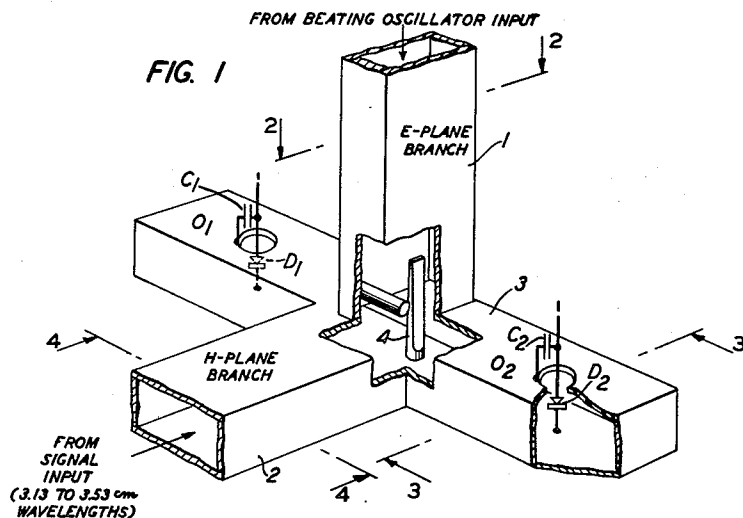


FIG. 2

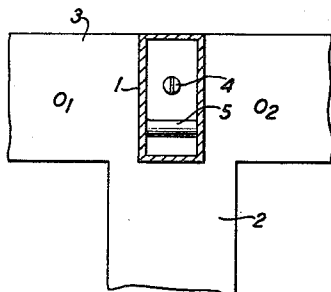


FIG. 3

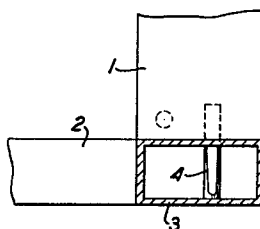


FIG. 4

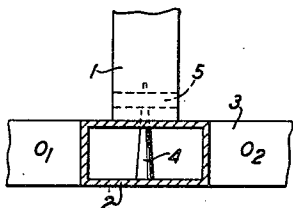
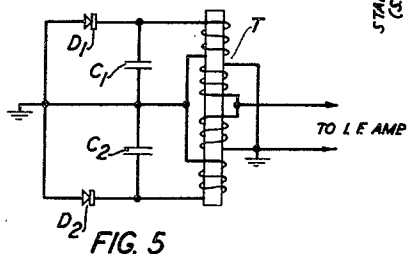
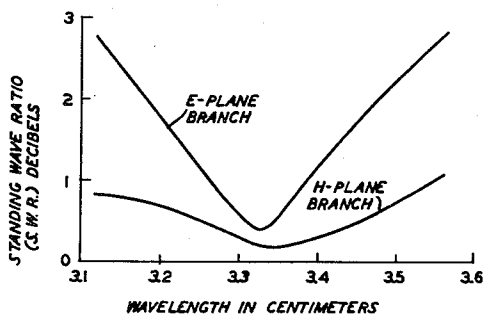


FIG. 6



INVENTOR  
C. F. EDWARDS  
BY  
Earl C. Laughlin  
ATTORNEY

## UNITED STATES PATENT OFFICE

2,679,582

BALANCED WAVE GUIDE BRANCHING  
SYSTEM

Charles F. Edwards, Red Bank, N. J., assignor to  
Bell Telephone Laboratories, Incorporated,  
New York, N. Y., a corporation of New York

Application December 24, 1945, Serial No. 637,124

11 Claims. (Cl. 250—20)

1

This invention relates to a wave transmission system employing a branching arrangement of dielectric wave guide lines and particularly to impedance matching devices for use with such a branching arrangement.

The invention is specifically applicable to a branching arrangement of a type first disclosed in the copending patent application of W. A. Tyrrell, Serial No. 470,810, filed December 31, 1942, now United States Patent 2,445,896, granted July 27, 1948, in which two branch sections of straight hollow pipe wave guide of elongated rectangular cross-section, disposed at right angles to each other, are joined to a main section of similar wave guide at an intermediate, common junction point in the electric plane, equivalent to a series electrical connection, and in the magnetic plane, equivalent to a shunt or parallel electrical connection, respectively. Due to the dissimilarity (one series and one parallel) of the electrical connections of the two wave guide branches with the main wave guide in such an arrangement, these two branches are conjugate or in balanced electrical relation with respect to each other and the two collinear portions of the main wave guide on opposite sides of the common junction point are also conjugate with respect to each other, and are in unbalanced electrical relation with respect to each of the two wave guide branches. If then, a generator is connected to any one of the four branching wave guide portions formed by the two collinear portions of the main wave guide and the two branches thereto at the common junction point so as to cause wave power to be transmitted over that branch towards the common junction point, and suitable loads are connected to the other three branching wave guide portions, this power will be divided equally between the loads connected to the two adjacent wave guide branch portions and substantially no wave power will be developed in the load connected to the fourth, oppositely situated, wave guide portion. These characteristics make the above-described branching wave guide arrangement particularly suitable for use in connection with a balanced modulator or converter to provide the desired distribution of wave energy between its input and output branches, especially with respect to the balanced electrical relation or condition of no wave power transfer which may be caused to exist between the oppositely situated wave guide branches, and to eliminate noise introduced by the associated local oscillator.

An object of the invention is to provide maxi-

2

imum transfer of wave energy over a wide band of frequencies between the input and output branches of such a wave guide branching arrangement.

A more specific object is to provide optimum impedance matching, and thus minimum reflection of wave energy, over a wide band of frequencies between each of two conjugately connected input wave guide branches and each of the two other (output) wave guide branches in the above-described type of wave guide branching arrangement.

These objects are attained in accordance with the invention by the use of two properly dimensioned and located metal rods, one of which is tapered, at the junction of the two branch wave guides with the main wave guide in the above-described branching arrangement. The tapered metal rod, which extends across the interior of the main wave guide at the common junction point into the interior of the particular wave guide branch connected to the main wave guide in the electric plane (series electrical connection), to be referred to hereinafter as the E-plane branch, in the direction of the longitudinal axis of the latter branch, serves to match the wave power from the other wave guide branch, that joined to the main wave guide in the magnetic plane (shunt electrical connection), which will be referred to herein as the H-plane branch, over a wide band of frequencies to the loads connected to the ends of the main wave guide. The second metal rod, which is connected across the interior of the E-plane wave guide branch between the wider faces of the latter at a suitable distance from the junction with the main wave guide and from the axis of that guide, serves to match the wave power from the E-plane wave guide branch over a wide band of frequencies into the loads at the ends of the main wave guide.

A better understanding of the invention will be obtained from the following detailed description when read in conjunction with the accompanying drawings in which:

Fig. 1 shows a perspective view, partially broken away, of a wave guide branching circuit embodying the impedance matching arrangement of the invention, applied to a balanced modulator or converter for use in a signal receiver of the superheterodyne or double detection type operated over a wide band of high frequencies;

Figs. 2 to 4 show sectional views along the lines 2—2, 3—3 and 4—4, respectively, of Fig. 1, drawn full scale, illustrating the detailed con-

struction of the impedance matching arrangement of the invention;

Fig. 5 shows schematically the output electrical connections of the balanced crystal detectors employed in the balanced modulator of Fig. 1; and

Fig. 6 shows curves plotted from experimental data illustrating the improvement attained by the use of impedance matching devices of the invention in connection with the wave guide branching arrangement of Fig. 1.

In the balanced modulator of Fig. 1, two straight sections 1 and 2 of  $\frac{1}{2}$ " x 1" rectangular wave guide of any length are joined as branches to a main straight section 3 of  $\frac{1}{2}$ " x 1" rectangular wave guide, the three wave guides 1 to 3 being relatively disposed so that their longitudinal axes extend in mutually perpendicular directions from a common junction point. The wider (1") faces of the branch wave guide 1 are normal to the direction in which the main wave guide 3 extends, and the narrower ( $\frac{1}{2}$ ") faces of branch guide 1 are parallel to that direction. This is a connection in the electric plane, that is, the plane parallel to the lines of electric intensity produced in both joined wave guides when dominant waves are propagated over one of them towards the junction between the two guides, and is equivalent to a series electrical connection of the two guides. The narrower ( $\frac{1}{2}$ ") faces of the branch wave guide 2 are normal to the direction in which the main guide 3 extends and the wider (1") faces of branch guide 2 are parallel to that direction. This is a connection in the so-called magnetic plane, that is, the plane perpendicular to the lines of electric intensity produced in both joined guides when dominant waves are propagated over one of them towards the junction between the two guides, which is equivalent to a shunt or parallel electrical connection. The branch guide 1 connected to the main wave guide 3 in the electric plane will be referred to as the E-plane branch and the branch wave guide 2 connected to the main wave guide 3 in the magnetic plane as the H-plane branch.

The two branch portions O<sub>1</sub> and O<sub>2</sub> of the main wave guide 3 respectively extending on opposite sides of the common junction with the branch wave guides 1 and 2 are of equal length and are closed at their outer ends by reflecting plates, as indicated. Equivalent crystal detectors D<sub>1</sub> and D<sub>2</sub> utilized in the balanced modulator or detector are connected in series with the condensers C<sub>1</sub> and C<sub>2</sub>, respectively, between the wider faces of the respective branch portions O<sub>1</sub> and O<sub>2</sub> of the main wave guide 3 at points equidistant from the common junction with the branch wave guides 1 and 2, near the closed ends of the main wave guide 3.

The high frequency incoming signal power is applied to the balanced modulator through the H-plane wave guide branch 2 and the local beating oscillator power is applied to the modulator through the E-plane wave guide branch 1. Because of the conjugate relation of these two branches and the equal resistance terminations of the two branch portions O<sub>1</sub> and O<sub>2</sub> of the main guide, the signal wave power from the H-plane branch will be divided at the junction with the main guide 3 between the portion O<sub>1</sub> and O<sub>2</sub> of that guide, and none of this power will enter the E-plane branch. Similarly, the beating oscillator power from the E-plane branch will be divided at the junction with the main wave guide 3 between the two main guide branches O<sub>1</sub> and O<sub>2</sub> and none

of this power will be fed into the H-plane branch. The loss of signal power into the beating oscillator branch and the transmission of beating oscillator power to the signal branch are thereby effectively eliminated. The portions of the signal and beating oscillator power entering the branches O<sub>1</sub> and O<sub>2</sub> of the main wave guide 3 will be combined in the crystal detectors D<sub>1</sub> and D<sub>2</sub>, respectively to produce waves of intermediate frequency. The phase relationship of the intermediate frequency waves so produced in the two detectors is such that the two detector outputs must be connected in series in order that the two waves may combine in phase. The phase relationship of intermediate frequency waves produced by two sources of power in the same branch are such that they may be balanced against one another by such a series connection to give no output, and, therefore, noise components introduced by the beating oscillator can be effectively balanced out in balanced windings of a three-winding transformer T coupling the outputs of the two crystal detectors D<sub>1</sub> and D<sub>2</sub> through condensers C<sub>1</sub> and C<sub>2</sub>, respectively in parallel to the input of the intermediate frequency amplifier of the superheterodyne signal receiver (Fig. 5).

To obtain maximum transfer of wave energy over a wide band of high frequencies between the input and output branches of such a balanced modulator, impedance matching devices in accordance with the invention are utilized at the common junction of these branches.

As shown in Figs. 1 to 4, one of these impedance matching devices comprises a tapered metal rod 4 having its larger end affixed to the lower one of the wider faces of the main wave guide 3 at a point equidistant from the two narrower faces of the H-plane wave guide branch 2 and nearer one of the narrower faces of the E-plane branch 1 than the other, and its tapered end extending to a given point into the interior of the E-plane wave guide branch 1 in the direction of the longitudinal axis of the latter. In the case of the particular junction shown utilizing  $\frac{1}{2}$ " x 1" wave guide, the optimum dimensions and location of the rod 4 as experimentally determined are as follows:

|                                                                                   | Inches         |
|-----------------------------------------------------------------------------------|----------------|
| Diameter of rod 4 at larger end.....                                              | $\frac{1}{8}$  |
| Thickness of rod 4 at tapered end.....                                            | $\frac{1}{64}$ |
| Length of rod 4.....                                                              | 0.730          |
| Distance of center line of rod 4 from one narrower face of main wave guide 3..... | 0.354          |

The tapered rod 4 serves to match over a wide range of high frequencies the signal power from the H-plane wave guide branch 2 into the two crystal loads D<sub>1</sub> and D<sub>2</sub> connected to the branches O<sub>1</sub> and O<sub>2</sub>, respectively, of the main wave guide 3 at points equidistant from the common junction point. When no impedance matching devices were present, the measured value of the standing wave ratio (SWR) looking into the H-plane branch 2 was found to be 9.8 decibels and that looking into the E-plane branch 1.0 decibels for input energy of 3.33 centimeters wavelength with the load branches O<sub>1</sub> and O<sub>2</sub> terminated as shown. By means of the tapered rod 4 with the optimum dimensions and location specified above, the measured value of the standing wave ratio in the H-plane branch was reduced to 0.2 decibel for input energy of 3.33 centimeters wavelength and was made less than 1 decibel at all wavelengths between 3.13 and 3.53 centimeters, as shown by the lower curve of Fig. 6. The rod 4 has only a small effect on the standing wave ratio

in the E-plane branch, and the purpose of the taper shown is to minimize this effect.

The cylindrical metal rod 5 was provided to match over a wide band of frequencies the beating oscillator wave power from E-plane wave guide branch 1 into the crystal loads D<sub>1</sub> and D<sub>2</sub> connected to the branches O<sub>1</sub> and O<sub>2</sub> respectively, of the main wave guide 3 at points equidistant from the common junction point. The rod 5 extends from one of the wider faces of the E-plane wave guide branch 1 to the other in a direction perpendicular to the longitudinal axis of that branch (and therefore parallel to the longitudinal axis of the main guide 3) at the proper distance from its junction with the latter guide and at the proper distance from the wall of wave guide 1. After rod 4 had been filed to the correct dimensions given above, the standing wave was measured at various points along the E-plane branch. From these measurements it was possible to determine the point where the resistive component of the impedance was equal to the characteristic impedance. It was observed that the reactive component of the impedance at this point was capacitive. The rod 5 was located at this point and in effect served as an inductive iris to cancel this capacitive reactance. In matching the E-plane and H-plane branches to the output wave guide, it is very helpful from an experimental standpoint to have the two procedures independent since the problem is greatly complicated by interaction effects.

For the junction utilizing 1/2" x 1" wave guide illustrated, the optimum dimensions and location for the rod 5 as determined experimentally are:

|                                                                               | Inches |
|-------------------------------------------------------------------------------|--------|
| Diameter of rod 5.....                                                        | 1/8    |
| Distance of rod 5 from junction of E-plane branch with main wave guide 3..... | 0.200  |
| Distance of rod 5 from one narrower face of E-plane branch.....               | 0.149  |

By means of the rod 5 having the optimum dimensions and location specified above, the standing wave ratio in the E-plane wave guide branch was reduced to 0.4 decibel at 3.33 centimeters wavelength and its variation with wavelength is shown by the upper curve of Fig. 6.

In converter and modulator applications of the above-described type of wave guide junction employing the impedance matching devices of the invention, it is preferable to employ the H-plane branch as the branch to which signals are applied since it provides somewhat better impedance matching over a wide band of high frequencies. The 3-decibel standing wave ratio obtained in the E-plane branch is negligible when this branch is used for introducing the beating oscillations.

It is understood, of course, that the device may be used at other wavelengths by the use of different size wave guide or at the same wavelengths using different size wave guide than those disclosed in the specific embodiment and that the dimensions and locations of the impedance matching elements may be varied to match other wave guide sizes and to operate at other wavelengths.

Various other modifications of the arrangements illustrated and described, which are within the spirit and scope of the invention, will occur to persons skilled in the art.

What is claimed is:

1. In combination with a wave transmission network consisting of three branching hollow

pipe wave guides each of elongated rectangular cross-section, extending longitudinally in mutually perpendicular directions from a common junction point with the wider faces of two of said guides normal to one of said directions and the wider faces of the third guide normal to another of said directions, one of said two guides extending longitudinally to each side of said common junction point, means to cause electromagnetic wave energy to be propagated over the other of said two guides towards said junction point, and a load connected near each end of said one guide, impedance matching means including a metal rod at the common junction of said three guides extending across the interior of said one guide to a given point in the interior of said third guide in the direction of the longitudinal axis of the latter guide.

2. The combination of claim 1 in which the dimensions of said metal rod and its location with respect to said three guides are selected so as to obtain an optimum impedance match between said other guide and the portions of said one guide on each side of said junction point over a wide frequency range.

3. The combination of claim 1 in which the dimensions and relative location of said metal rod with respect to said three guides are selected so as to match the wave power from said other wave guide into the load connected near each end of said one wave guide over a wide frequency range.

4. The combination of claim 1 in which the largest lateral dimension of said metal rod is small compared to the dimension of the shortest side of the cross-section of any one of said three guides, and its length is substantially one and one-half times the dimension of the shortest side of the cross-section of said one wave guide.

5. The combination of claim 1 in which said metal rod is located nearer to one of the two narrower faces of said one wave guide than to the other and substantially equidistant from the two narrower faces of said other guide and from the two wider faces of said third wave guide.

6. The combination of claim 1 in which said metal is tapered in the direction towards the interior of said third guide to minimize the effect of this rod on the standing wave ratio in said third guide.

7. In combination, a main hollow pipe wave guide and two other wave guides branching out therefrom at a common intermediate junction point, the three wave guides having elongated rectangular cross-sections with the same corresponding dimensions, and extending longitudinally in mutually perpendicular directions with the wider faces of the main wave guide and one of said branch guides normal to one of said directions and the wider faces of the other of said branch guides normal to another of said directions so that said one branch guide and said other branch guide are connected in parallel and in series electrical relation, respectively, with said main guide, means for causing electromagnetic wave energy to be propagated over each of said branch guides toward said common junction point, a load connected to the portion of said main wave guide on each side of said common junction, and means for causing a maximum transfer of wave energy over a wide range of frequencies between each of said branch wave guides and the portions of said main wave guide on each side of said common junction point, comprising a tapered metal rod extending across the interior of said main wave guide at said common junction point into

7

the interior of said other branch guide in the direction of the longitudinal axis of the latter guide, and a second cylindrical metal rod extending across the interior of said other guide between the wider faces thereof at a given distance from its junction with said main wave guide.

8. The combination of claim 7 in which the distance of said second metal rod from the junction of said other branch guide with said main guide is approximately equal to one-fifth the length of the longest side of the rectangular cross-section of each of said guides and its distance from one of the narrower faces of said other branch guide is approximately equal to one-seventh of the length of the longest side of the cross-section of said other guide.

9. The combination of claim 7 in which said wave energy propagated over each of said branch wave guides toward said common junction point comprises signal oscillations and beating oscillations, respectively, the loads connected to the portions of said main wave guide on each side of said common junction point comprise matched

8

crystal detectors for deriving an intermediate frequency output from the applied signal and beating oscillations.

10. A wave-guide assembly comprising: a main wave-guide section having a non-linear impedance at each of the opposite ends thereof; one side of each of said impedances being capacitively coupled to said main wave-guide section; and a pair of branch wave-guide sections, perpendicular to said main wave-guide section and to each other, extending outwardly from said main wave-guide section.

11. A wave-guide assembly comprising: a main wave-guide section having a crystal detector at each of the opposite ends thereof; one side of each of said crystal detectors being capacitively coupled to said main wave-guide section; and a pair of branch wave-guide sections, perpendicular to said main wave-guide section and to each other extending outwardly from said main wave-guide section.

No references cited.