May 8, 1962 — KIYO TOMIYASU — 3,034,076

MICROWAVE DIPLEXER

Filed June 8, 1953 — 2 Sheets-Sheet 1

Fig. 1.

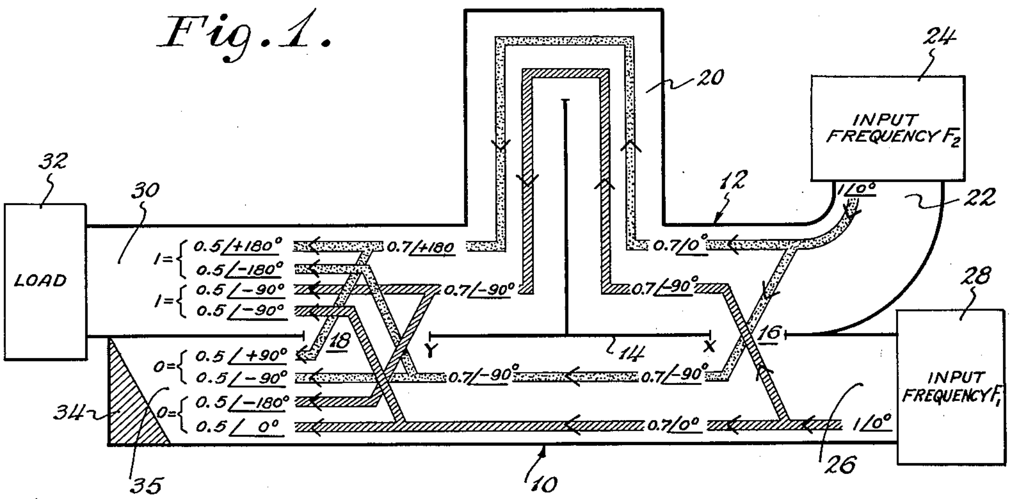


Fig. 2.

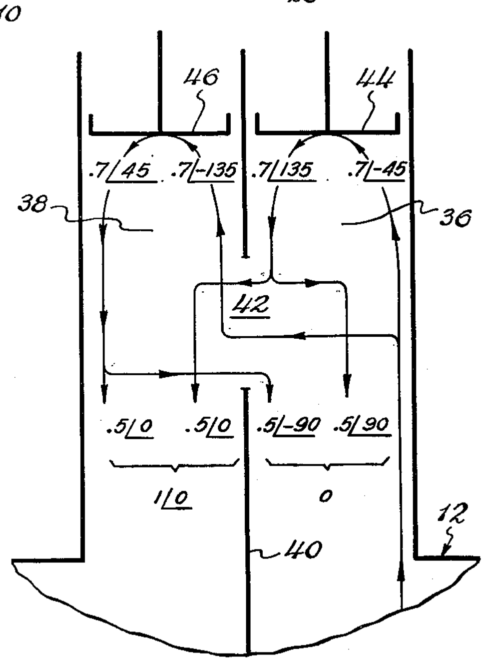
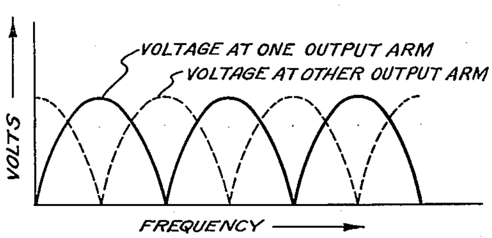


Fig. 5.



INVENTOR
KIYO TOMIYASU
BY Thomas M. Ferrill, Jr.
ATTORNEY

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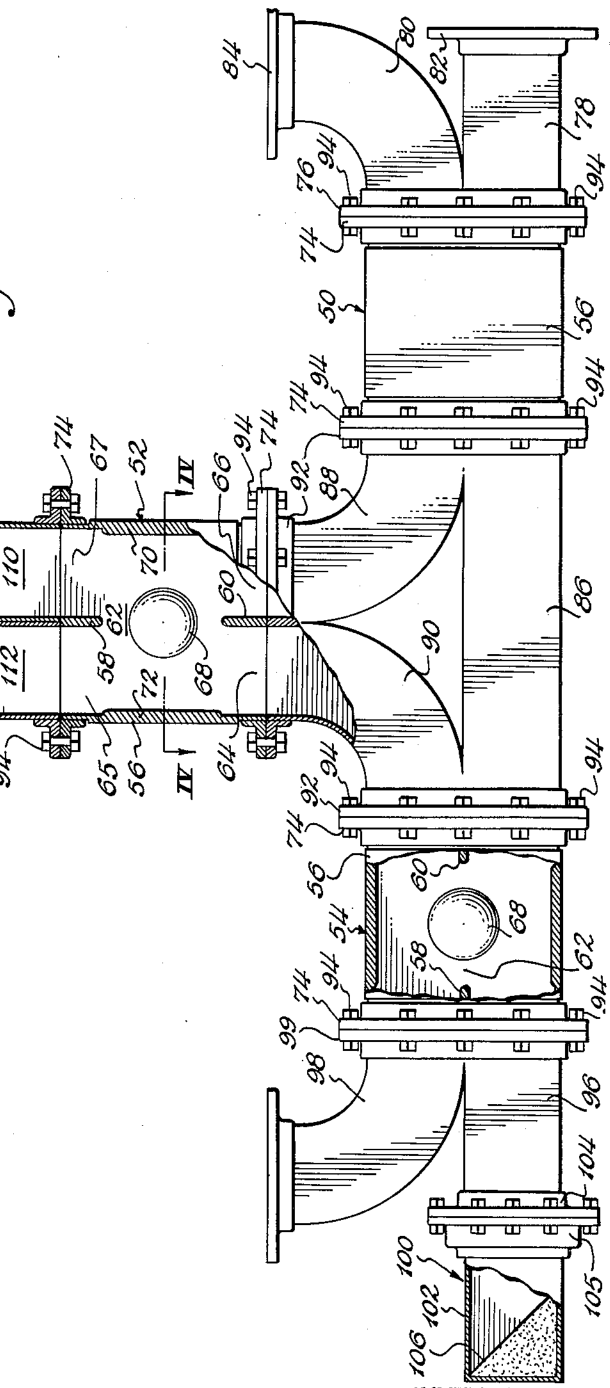

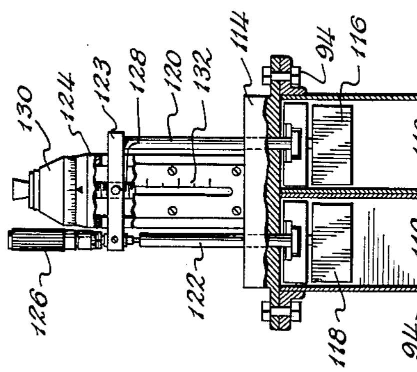

Fig. 3.

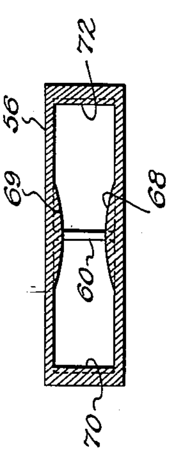

Fig. 4.

INVENTOR
KIYO TOMIYASU
BY
Thomas M. Ferrill, Jr.
ATTORNEY

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MICROWAVE DIPLEXER

Kiyo Tomiyasu, Flushing, N.Y., assignor to Sperry Rand Corporation, a corporation of Delaware

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This invention relates to diplexer systems, and more particularly, is concerned with apparatus for coupling two microwave signals of slightly different frequencies to a single antenna or for separating two microwave signals of slightly different frequencies received by the antenna.

Diplexing systems have been used heretofore for transmitting and receiving two signals of different frequencies utilizing a single antenna. Such systems, however, have been used at lower frequencies in open-line or coaxial transmission lines. Well-known filter techniques have generally been employed to separate the two frequencies.

At microwave frequencies where wave guides must be used for transmission, because of the narrow band transmission properties of the wave guide, the diplexing frequencies may be very close together in the frequency spectrum. Filters for separating frequencies so close together in the frequency spectrum must be designed with a very sharp cut-off to effect separation. Although high Q cavity resonators may be designed to have the necessary frequency discrimination to provide isolation between the two narrowly separated diplexing frequencies, any diplexing system using cavity resonators is generally unsuited for high power transmission, since high Q resonators are inherently low power transmission devices, being susceptible to breakdown due to high voltage and/or current concentrations associated with the phenomenon of resonance. Furthermore, resonators give rise to a high VSWR if the frequency shifts only slightly off the design frequency.

It is the general object of the present invention to avoid the foregoing and other difficulties of and objections to the prior art practices by the provision of an improved diplexing system incorporating hollow wave guide transmission lines operating at microwave frequencies.

It is another object of the present invention to provide a diplexing system which achieves substantial isolation between two signals separated by a minimum frequency differential of the order of 5% or less.

Another object of this invention is the provision of a microwave diplexer capable of operating at the high peak powers encountered in a radar transmission system.

Another object of this invention is to provide a diplexer which may be tuned to diplex a large number of frequencies within the operating band of the system.

Another object of this invention is the provision of a diplexing system which is well matched to the source over a broad band of frequencies, so that drift-off frequency does not result in mismatch.

Another object is to provide tuning means for the diplexer in the form of a line stretcher which introduces large phase shifts with minimum adjustment.

These and other objects of the invention which will become apparent as the description proceeds are achieved by providing a microwave diplexer which comprises a pair of four-terminal hybrid junctions which are preferably in the form of directional couplers that effect an even power division of energy coupled in at either of the terminals at one end thereof, the energy being coupled out of the two terminals at the other end. The two terminals at one end of one junction are coupled to the terminals at one end of the other junction by respective interconnecting sections of wave guide transmission line, one of the line sections being of a fixed length and the other of the line sections being of a substantially different and variable electrical length. Means for varying the electrical length

of one of the intercoupling line sections includes a third hybrid junction with two terminals at one end connected in series into the line, the two terminals at the other end of the third hybrid junction having adjustably positioned short-circuiting terminations therein, movement of the position of the shorting terminations varying the length of the line.

For a better understanding of the invention, reference should be had to the accompanying drawings, wherein:

FIG. 1 is a schematic view useful in explaining the operation of the diplexer of the present invention;

FIG. 2 is a schematic showing of a suitable phase shifter or line stretcher used in tuning the diplexer;

FIG. 3 is a plan view partly in section showing a preferred form of the invention;

FIG. 4 is an enlarged cross-sectional view taken on the line 4—4 of FIG. 3; and

FIG. 5 is a graphical showing of the variation of voltage at the two output arms of the diplexer with changes in frequency of either of the two input signals.

Referring to the schematic showing of FIG. 1, the numerals **10** and **12** indicate a pair of rectangular wave guides having a common wall **14** therebetween. The two wave guides **10** and **12** are directionally coupled together at two separate points by suitable coupling slots in the common wall **14**, the coupling slots being indicated at **16** and **18**. Thus, the wave guides **10** and **12** and the coupling slots **16** and **18** define two directional couplers joined in tandem. The path length between the directional couplers along the wave guide **12** is made longer than the path length between the couplers along the wave guide **10** by virtue of a folded portion, indicated at **20**, in the wave guide **12** intermediate the coupling slots **16** and **18**.

The input end **22** of the wave guide **12** is coupled to a source **24** of microwave energy having a frequency F_2, while the input end **26** of the wave guide **10** is coupled to a source **28** of microwave energy having a frequency F_1. The output end **30** of the wave guide **12** is coupled to a load indicated at **32**, which in practice might be an antenna. A suitable non-reflecting energy absorbing termination **34** is provided in the end **35** of the wave guide **10**.

It is essential to the operation of the present invention as a diplexer that the directional couplers be of a type which functions as a hybrid junction, that is, which can be so dimensioned that power that is incident upon a terminal at one end is evenly divided and appears in equal quantities at both terminals at the other end of the directional coupler. A preferred directional coupler having the properties of a hybrid junction is described in the Proceedings of the I.R.E., February 1952, page 180. This type of directional coupler couples energy in the forward direction, and in addition, is electrically symmetrical in that a wave being coupled encounters the same electrical conditions on either side of the coupler. One of the properties of such a directional coupler is that the phase of the coupled wave lags by 90° the phase of the direct wave at the output terminals of the coupler, so that a quadrature phase shift is effected between the two output signals derived from the directional coupler. In addition, there is a 45° phase lag of the direct wave due to the coupling slot.

Operation of the diplexer in its schematic form as above described will now be considered. The polar form of the electric vector of the two input signals F_1 and F_2 at various points along the wave guides is shown in FIG. 1 to indicate the changes in phase and amplitude which take place. In the following analysis, the 45° phase lag of the direct wave due to the coupling slot in the hybrid coupler is neglected since it produces no net effect in the operation of the diplexer. The phase angles indicated are merely assigned values which indicate the relative phases of the various waves at a common transverse plane.

The signal F_1 from the source 28, indicated by the cross-hatched line in FIG. 1, is coupled to the wave guide 10 and on reaching the coupling slot 16 is divided equally between the wave guide 10 and the wave guide 12. By virtue of the power split at the coupling slot 16, the direct wave from the source 28 at the point X in the wave guide 10 has an electric vector having a reduced magnitude of .707 at an assigned phase of zero. (It should be noted that only an approximate figure of 0.7 is used to indicate the magnitude in the drawings.) The energy from the source 28 coupled into the wave guide 12, however, is reduced in magnitude and shifted in phase by the coupling slot, so that the electrical vector at the point X in the wave guide 10 is .707 with a phase angle of −90° relative to the direct wave, due to the phase quadrature shift effected by the directional coupler as described above.

If it is assumed that the additional path length in the wave guide 12 introduced by the folded section 20 is equal to an integral number of guide wavelengths at the frequency F_1, the phase relationship between the direct wave in the wave guide 10 and the coupled wave in the wave guide 12 will be the same at point Y as it is at point X. The energy of the direct wave is evenly split at the coupling slot 18 so that the electric vector of the wave continuing on down the wave guide 10 is again reduced in magnitude to .5 at the same assigned phase angle of zero. The electric vector of the wave coupled into wave guide 12 at the slot 18 is changed in both magnitude and phase by the coupling slot 18, so that it has a magnitude of .5 and a relative phase angle of −90°, again as the result of the quadrature phase shift introduced by the directional coupler.

Similarly, the coupled wave from the source 28 in the wave guide 12 is evenly split at the coupling slot 18, the energy continuing directly on down the wave guide 12 to the load 32 being reduced in magnitude with an assigned phase angle of 90°. The portion of the coupled wave in the wave guide 12 from the source 28 which is coupled back into the wave guide 10 is both reduced in magnitude and shifted in relative phase by 90°, so that it is equal in magnitude to the direct wave from the source 28 but 180° out of phase by virtue of the two 90° phase shifts at each of the coupling slots 16 and 18. Thus, the two waves of energy cancel each other in the region of the termination 34, while the two waves reinforce each other in the region of the load 32.

In a similar manner, the signal F_2 from the source 24 is coupled to the input end 22 of the wave guide 12. The coupling slot 16 effects an even energy split of the signal F_2, so that at the point X the electric vector of the direct wave in the wave guide 12 has a magnitude of .707 at zero phase angle while the coupled wave in the wave guide 10 has a magnitude of .707 at a phase angle of −90° relative to the direct wave.

Now assuming that the folded portion 20 of the wave guide 12 introduces an additional path length between the points X and Y of an odd number of half wavelengths at the frequency F_2, the relative phase of the direct wave at the point Y will be shifted by a half wavelength or 180°, so that the electric vector at the point Y has a magnitude of .707 at a phase angle of +180°. This direct wave is split by the coupling slot 18, the direct portion continuing on to the load with a magnitude of .5 at an assigned phase angle of +180°. The wave coupled into the wave guide 10 is reduced in magnitude to .5 but with the phase angle shifted 90° by virtue of the quadrature phase shift of the directional coupler.

The coupled wave from the source 24 in the wave guide 10 is also split at the coupling slot 18, the direct portion continuing towards the termination 34 with a reduced magnitude of .5 with an assigned phase angle of −90°. Thus, the two portions of the energy at frequency F_2 in the wave guide 10 have the same magnitude but they are 180° out of phase, so that they cancel each other.

The other portion of the coupled wave which is coupled back into the wave guide 12 has a magnitude of .5 but is shifted in phase by an additional −90°, giving it a phase angle −180° in the wave guide 12. Thus, the direct and coupled waves from the source 24 reinforce each other in the wave guide 12 and continue on to the load 32.

It will be seen from the above discussion that under certain circumstances, namely, where the difference in path length between the points X and Y via the wave guides 10 and 12 is equal to an even number of guide half wavelengths at the frequency F_1 and equal to an odd number of half wavelengths at the frequency F_2, all the energy from both sources is transmitted to the load 32 with none of the energy reaching the termination 34.

These conditions, necessary to effect diplexing in the manner above described, may be expressed mathematically as

$$l = m\lambda g1 \qquad (1)$$

and

$$l = (n \pm 1/2)\lambda g2 \qquad (2)$$

where l is the difference in path length between the points X and Y via the two wave guides 10 and 12, $\lambda g1$ and $\lambda g2$ are the guide wavelengths at the two frequencies F_1 and F_2 and m and n are integers. For instance, if $\lambda g1$, the guide wavelength of energy from the source 28, is fixed, l may be any one of a number of discrete values which provide complete transfer of energy at frequency F_1 to the load 32. With $\lambda g1$ fixed, there are a number of discrete wavelengths $\lambda g2$ of energy from the source 24 for each of the discrete values of l which produce complete transfer of energy at the frequency F_2 to the load 32, that is, there are a number of discrete values of F_2 for each of the discrete values of l which result in diplexing.

From the above discussion it will be apparent that a large number of frequencies F_1 and F_2 can be made to diplex by changing the value of l in Equations 1 and 2. A preferred means of varying the value of l is the phase shifter shown schematically in FIG. 2 and includes a hybrid coupler with two sliding short circuit terminations. The hybrid coupler is substituted for the folded line portion 20 in the wave guide 12 of FIG. 1. The hybrid coupler includes a pair of wave guide sections 36 and 38 having a common narrow wall 40 therebetween. A coupling slot 42 in the common wall 40 directionally couples energy between the wave guide sections 36 and 38 in the manner of the hybrid couplers described above in connection with FIG. 1. Sliding short-circuiting pistons, indicated at 44 and 46, are positioned in the same plane in the ends of the wave guide sections 36 and 38, respectively.

The electric vector relationships that exist in the phase shifter portion of the diplexer at various points are indicated in FIG. 2. For this analysis, the 45° phase lag of the direct wave due to the coupling slot is included in the assigned phase angles. It will be seen that the incident energy having an initial assigned phase of zero at an amplitude 1 is split at the coupling slot 42 and reflected by the shorts 46 and 48. Each of the reflected waves in turn is again split by the coupling slot 42, the two waves reflected back along the wave guide 36 in the direction of the incident energy being 180° out of phase with each other so as to effect cancellation, while the two waves reflected along the output portion of the wave guide section 38 again combine to have an amplitude of 1.

Thus, there is no resultant phase shift introduced by the phase shifter due to intercoupling, the only phase shift being due to the path length as determined by the position of the shorts 44 and 46. Since the additional path length introduced in the wave guide 12 is twice the incremental movement of the shorts 44 and 46, it will be seen that the hybrid coupler with two sliding shorts is capable of introducing large values of phase shift.

For a given difference l in path length, by varying either $\lambda g1$ or $\lambda g2$, or both, the proportion of each appearing at the output arms varies. This is illustrated graphically in FIG. 5. Thus, the apparatus as defined may be used as a power divider, the division of power being a function of wavelength or frequency. At discrete frequencies diplexing occurs, that is, all the power from two sources of different frequency combine in one output. However, at intermediate frequencies there is a division of power between the two output arms depending on the frequency.

While a 50% power split of the energy at the directional couplers is essential to get diplexing, where it is merely desired to get a particular power division, the coupling slots may be proportioned to give other ratios of power division. This provides a useful design parameter where a particular ratio of power division is desired at selected frequencies.

FIGS. 3 and 4 illustrate a practical embodiment of the diplexer of the present invention. The numerals **50**, **52**, and **54** indicate generally three identical hybrid couplers, each of which is cast as a single unit including a hollow rectangular pipe section **56** with septums **58** and **60** extending between the broad walls to form a coupling slot **62** and four wave guide terminals indicated at **64**, **65**, **66**, and **67**. Spherical segments **68** and **69** project into the interiors of the hybrid couplers and are symmetrically positioned at the centers of the coupling slots **62**. These spherical segments, together with the reduced cross section provided by the thickened wall portions **70** and **72** of the pipes **56**, improve the isolation and bandwidth characteristics of the couplers. Flanges **74** are provided at each end of each of the hybrid couplers.

Connected to one end of the hybrid coupler **50**, by means of the flanges **74** and **76**, are the input wave guide sections **78** and **80**, the latter being in the form of an H-plane bend. Flanges **82** and **84** provide convenient means of connecting the input wave guide sections **78** and **80** of the diplexer to any desired wave guide transmission system.

The hybrid couplers **50** and **54** are directly connected by a section of rectangular wave guide **86**, which is preferably cast as an integral unit with two H-plane wave guide bends **88** and **90** that couple the hybrid couplers **50** and **54** to the third hybrid coupler **52**. Suitable flanges, indicated at **92**, are provided for joining the various wave guide sections to the respective hybrid couplers. Suitable means, such as bolts **94**, may be used to secure the flanges together.

Output from the hybrid coupler **54** is provided by means of wave guide sections **96** and **98**, the latter being an H-plane bend. The output wave guide sections are secured to the hybrid coupler **54** by means of a flange **99** secured to the flange **74** of the coupler. A non-reflecting termination for the wave guide **96**, indicated generally at **100**, includes a section of wave guide **102** secured to the wave guide section **96** by means of coupling flanges **104** and **105**. Energy absorbing material, such as Polyiron or the like indicated at **106**, is inserted in the wave guide **102** to provide a non-reflecting energy absorbing termination.

The adjustable short circuit terminations for the phase shifter include a pair of rectangular wave guide sections **110** and **112** coupled at one of their ends to the hybrid coupler **52**, the other end of the wave guide sections **110** and **112** being terminated in a cap **114**. Short circuits are provided by plungers or pistons within the wave guides **110** and **112**, the plungers being indicated at **116** and **118** respectively. The plungers are separated from the walls of the wave guides to form a wave trap type of short circuit, such as described in Patent No. 2,503,256, issued to E. L. Ginzton et al.

The plungers are secured to the lower ends of parallel rods **120** and **122**, which extend through holes in the cap **114**. The upper end of the rod **120** is secured to a yoke **123** which is slidably supported in slots provided in the guide member **124**. The upper end of the rod **122** is adjustably secured to the yoke **123** by means of a micrometer type of adjusting element, indicated at **126**, which provides for relative adjustment of the two plungers **116** and **118**.

The yoke **123** is positioned along the guide member **124** for varying the position of the short-circuiting plungers **116** and **118** by means of a micrometer screw **128** which threadedly engages the yoke **123**. A calibrated dial **130** on the end of the micrometer screw **128** together with a linear scale **132** provide means for positioning the short-circuiting plungers **116** and **118** at any predetermined positions within the wave guide **110** and **112** respectively.

From the above description it will be seen that the various objects of the invention have been achieved by the provision of a diplexing system suitable for operation at microwave frequencies using hollow wave guide transmission lines. In theory, a large number of discrete frequencies may be diplexed by varying the path length of one or both of the wave guide sections between the hybrid couplers. The longer the folded section of of wave guide is made, i.e., the greater the difference in path length of the two wave guide sections, the closer together in frequency may be the signals which will diplex. Practical considerations, however, limit the distance over which the shorts may be adjusted and the extent to which the wave guide may be lengthened by movement of the shorts, the principal limiting factor being the frequency sensitivity of the system which is greatly increased as the difference in path length is increased.

It was seen that, in theory, for a given frequency setting of one of the signals, only discrete values of frequency of the other signal would diplex. In practice, however, it has been found that diplexing occurs for bands of finite width. These finite frequency bands are determined by the tolerable insertion loss, which for design purposes has been set at 0.5 db. It has been found that a phase shift of $\pm 25°$ at the output of the second hybrid coupler is permissible without exceeding the 0.5 db insertion loss figure. The allowable change in frequency (and hence the bandwidth) at the input of the first hybrid coupler, which limits this phase shift to $\pm 25°$, is a function of the path length in terms of guide wavelengths between the two hybrid couplers. Hence, the larger the difference in path lengths between the points X and Y of FIG. 1, the greater is the phase sensitivity between the two lines with consequent sharper rise in insertion loss. For this reason the phase shift introduced by the shorted hybrid coupler section is limited to a maximum of 8 or 9 wavelengths.

Although a drift away from the discrete diplexing frequencies causes greater insertion loss because there is not complete cancellation in the one output arm, the match is not affected. If the hybrid couplers are well matched, and the source and load are well matched, the shift in frequency does not affect the impedance of the diplexer, as in the case of ordinary filter-type systems.

It should be noted that while the diplexer has been described in terms of two input signals of different frequency being coupled to a single antenna load, the diplexer is bilateral in operation, so that it may be used, for example, to receive two signals of different frequencies at a single antenna and separate them to provide two output signals. Thus, the diplexer may be used to receive as well as transmit two signals of different carrier frequencies.

Also, it should be noted that while the diplexer has been described as having a phase shifter in one of the wave guide lines, a second phase shifter may be inserted in the other wave guide line to provide an additional adjustment parameter.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A diplexer transmission system for isolating two microwave signals of different frequencies at one point and combining them at another, said diplexer comprising a first hollow rectangular wave guide, a second hollow rectangular wave guide ending in a non-reflecting energy absorbing termination, the first and second guides having a common narrow wall portion at two separated positions along the guides, each of the common narrow wall portions having an elongated opening therein, the opening having a width extending the width of the common narrow wall and having a length such as to couple half the incident power, and frequency-sensitive phase shifting means positioned in one of the wave guides intermediate said common wall portions, said means including first and second hollow rectangular wave guide sections having a common narrow wall portion therebetween with an elongated opening therein, the opening having a width extending the width of the common narrow wall and having a length such as to couple half the incident power, and shorting means adjustably positioned in each of the wave guide sections, the ends of the wave guide sections opposite the shorting means being connected into said one of the wave guides, whereby changes in position of the shorting means varies the electrical length of said one of the wave guides.

2. A diplexer transmission system for isolating two microwave signals of different frequencies at one point and combining them at another, said diplexer comprising a first hollow rectangular wave guide, a second hollow rectangular wave guide ending in a non-reflecting energy absorbing termination, the first and second guides having a common narrow wall portion at two separated positions along the guides, means in each of the common wall portions for directionally coupling the two wave guides, said means at each common wall portion coupling substantially half the energy propagated in one direction in one of the wave guides into the other wave guide, and frequency-sensitive phase shifting means positioned in one of the wave guides intermediate said common wall portions, said means includng first and second hollow rectangular wave guide sections having a common narrow wall portion therebetween, means in said common wall portion for directionally coupling the wave guide sections, said means coupling substantially half the energy propagated in one direction in one of the sections into the other section, and shorting means adjustably positioned in each of the wave guide sections, the ends of the wave guide sections opposite the shorting means being connected into said one of the wave guides, whereby changes in position of the shorting means varies the electrical length of said one of the wave guides.

3. A microwave diplexer comprising three hybrid junctions, each junction including a pair of wave guide sections with a common wall between and means for directionally coupling said sections together, said means coupling substantially half the energy propagated in one of said sections into the other of said sections, wave guide means for coupling one end of one wave guide section of the first of the hybrid junctions to one wave guide section of the second of the hybrid junctions, wave guide means for coupling one end of the other wave guide section of the first hybrid junction to one wave guide section of the third of the hybrid junctions, means for coupling together the remaining wave guide sections of the second and third hybrid junctions, and short-circuiting means adjustably positioned in the two wave guide sections of one of the hybrid junctions at the ends of said sections remote from said wave guide means.

4. A microwave diplexer comprising three power-dividing directional couplers, each coupler including two adjacent intercoupled transmission line sections, means for coupling one end of one line section of the first of said couplers to one line section of the second of said couplers, means for coupling one end of the other of the line sections of the first of said couplers to one line section of the third of said couplers, means for coupling together the remaining line sections of the second and third of said couplers, and energy reflecting means terminating the ends of the line sections of the first coupler opposite the ends coupled to the second and third couplers.

5. Apparatus as set forth in claim 4, wherein the energy reflecting means is longitudinaly movable with respect to the line section of the first coupler.

6. A microwave diplexer comprising at least two hybrid junctions, each junction including a pair of wave guide sections with a common wall between and means for directionally coupling said sections together, said means coupling substantially half the energy propagated in one of said sections into the other of said sections, wave guide means for coupling one wave guide section of one of the hybrid junctions at one end thereof directly to one wave guide section of the other hybrid junction, and variable length wave guide means for coupling one end of the other wave guide section of said one hybrid junction to one end of the other wave guide section of said other hybrid junction.

7. A microwave diplexer comprising three hybrid junctions each having four wave guide terminals, wave guide means for coupling one wave guide terminal of one of the hybrid junctions directly to one terminal of one of the other hybrid junctions and another of the wave guide terminals of said one of the hybrid junctions directly to one terminal of the remaining hybrid junction, means for coupling a second terminal of said other hybrid junction directly to a second terminal of said remaining hybrid junction, and adjustable lengths of short-circuited wave guide sections coupled respectively to the remaining two terminals of one of the hybrid junctions.

8. In combination, a source of first and second signals of different frequency and a wave guide channeling system for differently directing said first and second signals of different frequency, said channeling system comprising first and second wave guide directional couplers, each of said directional couplers having two input waveguides and two output wave guides, the characteristics of said directional couplers being such that energy introduced into either input wave guide divides equally between the two output waveguides with the energy in one output wave guide shifted 90° in phase with respect to energy in the other output wave guide, a first wave guide section coupling an output wave guide of said first directional coupler to an input wave guide of said second directional coupler, and a second wave guide section coupling the other output wave guide of said first directional coupler to the other input waveguide of said second directional coupler, said second wave guide section having an electrical length which is an even integral number of half wavelengths longers than that of said first wave guide section at the frequency of said first signal and an odd integral number of half wavelengths longer than the electrical length of said first waveguide section at the frequency of said second signal.

9. A diplexer transmission system for isolating two microwave signals of different frequencies at one point and combining them at another, said diplexer comprising a first hollow rectangular wave guide, a second hollow rectangular wave guide, a source of microwave signals at a first frequency coupled to said first wave guide, a source of microwave signals at a second frequency coupled to said second wave guide, the first and second wave guides having a comon wall portion at two separated positions along the guides, means in each of the common wall portions for directionally coupling the two wave guides, said means at each common wall portion coupling substantially half the energy propagated in one direction in one of the wave guides into the other wave guide, and phase

shifting means positioned in one of the wave guides intermediate said common wall portions, said phase shifting means introducing a difference in the path lengths in said wave guides between said common wall portions of substantially an even number of half wavelengths at one of said frequencies and of substantially an odd number of half wavelengths at the other of said frequencies.

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