

Oct. 20, 1959

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2,909,655

COMBINATION MIXER-DUPLEXER

Filed March 19, 1957

2 Sheets-Sheet 1

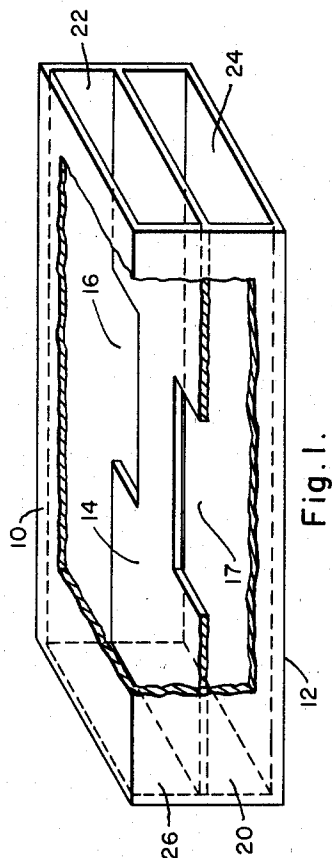


Fig. 1.

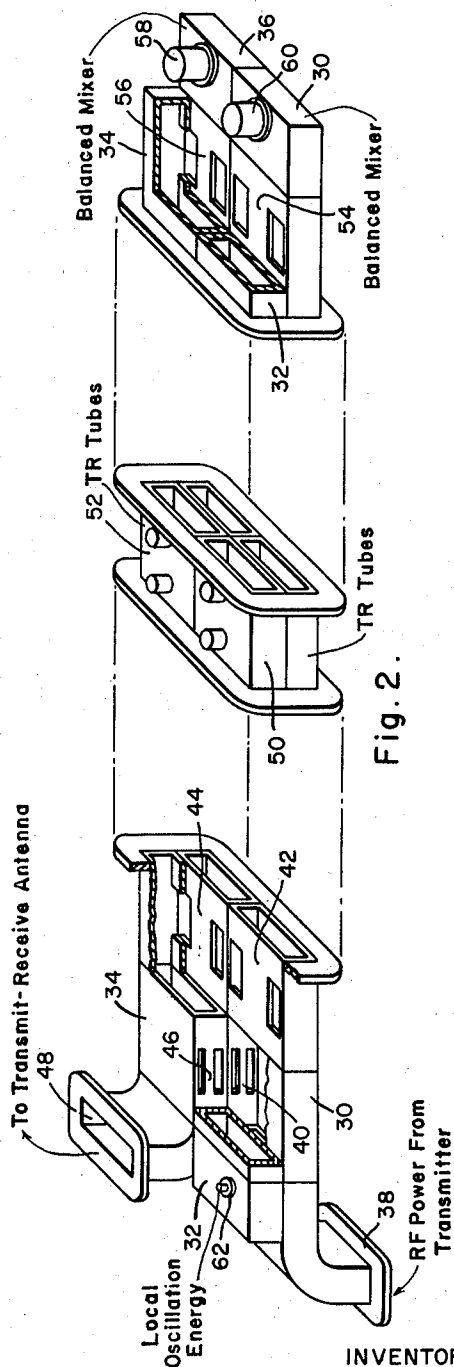


Fig. 2.

WITNESSES

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2 Sheets-Sheet 2

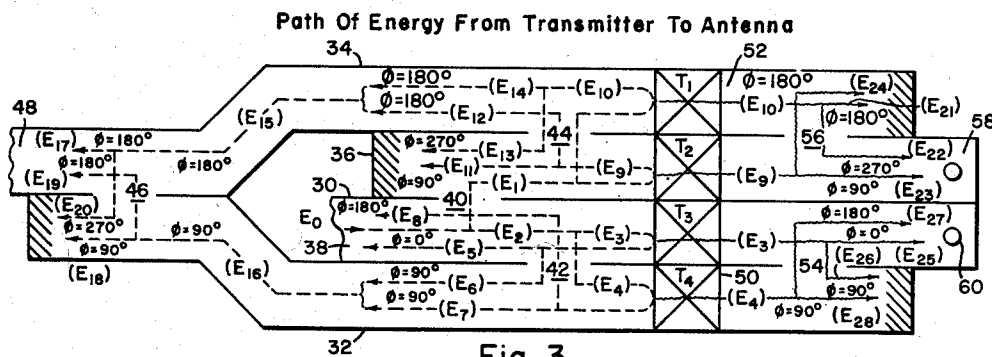


Fig. 3.

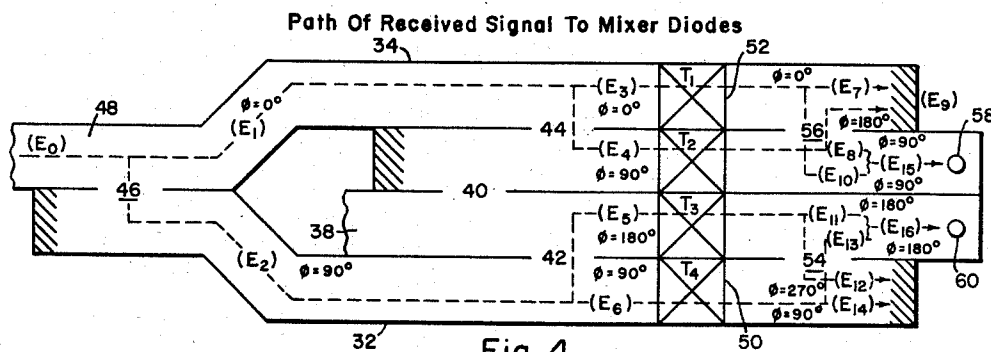


Fig. 4.

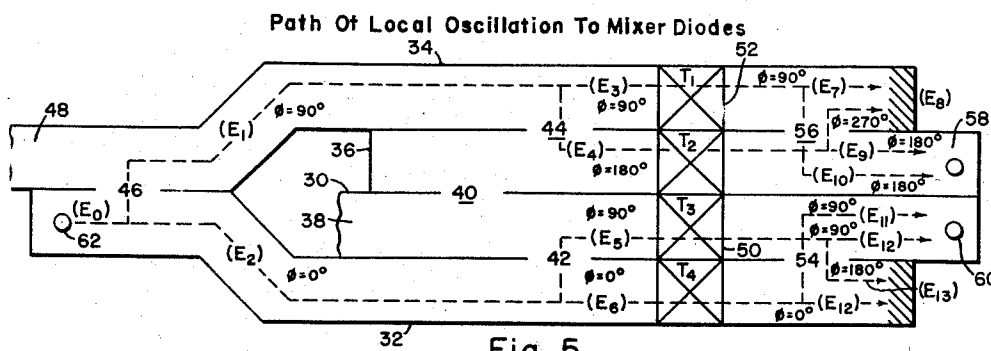


Fig. 5.

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2,909,655

COMBINATION MIXER-DUPLEXER

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9 Claims. (Cl. 250—20)

This invention relates to a combination duplexer-mixer for radar systems and the like, and more particularly to a duplexer-mixer capable of handling relatively high powers.

It is an object of this invention to provide a new and improved microwave duplexer. Although the principle of balanced duplexer operation has been known for many years, its use has been curtailed since it necessitated the use of two perfectly matched TR tubes, a requirement which was extremely difficult to achieve. With the advent of the short slot hybrid junction by H. J. Riblet (U.S. Patent 2,709,241), it became possible for two output waveguide arms to contain a common wall. This common wall enabled two TR tubes to be placed side by side under a common gas atmosphere. In other words, by constructing the tubes in a single common envelope, it is now possible to have a compound dual TR tube in which both cells or tubes are matched and balanced. In the present invention, short slot hybrid junctions and TR tubes in a common envelope are employed to bring about a balanced duplexer circuit having exceptionally good operational characteristics.

Another object of the invention is to provide a balanced duplexer circuit capable of handling relatively large powers. In balanced duplexer circuits previously employed, the limitation to the power handling capability of the duplexer circuit was always the TR tube. It is rather difficult to construct a tube which will operate over an extremely wide range of incident radar power values. For duplexer tubes which are designed to handle peak powers in excess of one megawatt at S-band, for example, it is extremely difficult to make these tubes break down at a low value of power. This is a serious problem since if the TR tube fails to break down the receiver crystal will be damaged. Thus, the greater the peak power level of the tube the higher the minimum breakdown value. In the present invention the power fed into the duplexer is divided into small fractions which are duplexed and then recombined into the total which is presented to its load.

Another object of the invention is to provide a new and improved balanced microwave mixer. As is well known, mixers are basically of the balanced or single-ended type. One of the most objectionable features of the single-ended or conventional mixer is the presence of local oscillator noise. Various types of filter cavities have been constructed for the purpose of suppressing this noise. However, this is done without frequency selective circuits in the balanced mixer circuit. A balanced mixer utilizes two separate mixer circuits driven in shunt by the local oscillator signal and in push-pull by the received signal. This results in a balanced push-pull signal at intermediate frequency, and the IF amplifier input is designed to give response only to such a signal. Any IF output signals derived from noise accompanying the local oscillator power appear in the same phase at the output terminals of each mixer unit and are, therefore, rejected by the IF amplifier circuitry. The present in-

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vention provides proper power division of the incoming RF signal into components with such relative phase and amplitude requirements that optimized balanced mixing occurs. Inasmuch as local oscillator energy is needed at the crystal mixers for proper mixing, the present invention also provides proper power division of the local oscillator energy into the required components which, when incident upon the mixer crystals, will provide optimized mixing.

A still further object of the invention is to provide a combination mixer-duplexer arrangement in which the functions described in the foregoing objects (mixing, duplexing, and local oscillator power division) are all accomplished by the same common components.

Another object of the invention is to provide a combination multiplexer-duplexer which is extremely compact and which provides a circuit that is electrically optimized since it is constructed as one composite unit.

A still further object of the invention is to provide a combination mixer-duplexer having the ability to duplex very high powers with low power tubes.

The above and other objects and features of the invention will become apparent from the following detailed description taken in connection with the accompanying drawings which form a part of this specification, and in which:

Figure 1 is a illustration of an E-plane top wall hybrid junction;

Fig. 2 is an exploded perspective view of the present invention showing its component parts;

Fig. 3 is a schematic diagram illustrating the operation of the present invention in conveying wave energy from a transmitter to a directional antenna or other similar device;

Fig. 4 is a schematic diagram illustrating the operation of the present invention in conveying wave energy from a directional antenna to a pair of receiver crystals, and

Fig. 5 is a schematic diagram showing the path of local oscillator energy introduced into the present invention to accomplish a mixing function.

Referring to Fig. 1, there is shown one type of hybrid junction used in the present invention. Although the hybrid junction forms only a part of the invention, its operational characteristics should be understood before proceeding with a detailed description of the entire invention. In Fig. 1, it can be seen that a pair of substantially rectangular waveguide portions 10 and 12 are separated by a wall portion 14. Cut out of wall portion 14 are a pair of short slots 16 and 17 which lie adjacent the side walls of waveguides 10 and 12. This junction belongs in a large class of symmetrical hybrids at whose equidistant output terminals the voltages are always in quadrature. For a complete and detailed description of the theory of operation of this type of hybrid, reference may be had to "Transactions of the I.R.E.," vol. MTT-1, No. 1, pages 29-30, March 1953. For purposes of the present invention, however, it will be sufficient to state that if power is fed into the junction through the left end 20 of waveguide portion 12 and if ends 22 and 24 of waveguide portions 10 and 12, respectively, are terminated in matched loads, then there will be an absence of wave energy appearing at the left end 26 of waveguide portion 10. In addition, equal amounts of wave energy will be present at ends 22 and 24, and the wave energy at end 24 will be 90° out of phase with respect to that at end 22 which received zero phase shift with respect to the incident wave energy entering end 20. When wave energy passes through the hybrid junction, the power is always split an even 3.0 db. That is the power is always split evenly

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in half. Hence, each time power passes through a hybrid junction, the output is 3.0 db down from the input.

The hybrid junction shown in Fig. 1 is an E-plane top wall type. Short slot hybrid junctions of this type however may also be used to interconnect the side walls of waveguides, in which case the operation of the junction is identical to that of a top wall junction.

Referring to Fig. 2, it can be seen that the present invention comprises four parallel waveguide sections 30, 32, 34 and 36 all arranged in juxtaposition. Input RF energy from a transmitter or signal generator, not shown, enters the left end of waveguide section 30 at 38. This input energy from the transmitter enters a side wall short slot hybrid junction 40 having a pair of output arms which feed the input arms of two top wall hybrid junctions 42 and 44, respectively. An output arm of each of the top wall junctions again feeds a side wall hybrid 46, the output of which feeds an antenna, not shown, through the open end of waveguide section 34 at 48. On the other side of a pair of dual TR tubes 50 and 52, two top wall hybrids 54 and 56 combine their outputs into the inputs of two crystal mixers 58 and 60 located at the right ends of waveguide sections 30 and 36, respectively. Local oscillator energy from a frequency generator, not shown, is fed into the left end of waveguide section 32 through a probe 62 so that the local oscillator energy will be combined with the received RF energy at the crystal mixers 58 and 60.

Operation of the invention may best be understood by reference to Figs. 3-5 which schematically illustrate the path of wave energy traveling through the mixer-duplexer during the transmit and receive periods of operation.

In Fig. 3 of the operation of the invention is shown during a transmit pulse as energy is propagated through the waveguide sections from the transmitter input at 38 to the antenna output at 48. In explaining the operation of the device, it should be understood that during the transmit pulse the dual TR tubes 50 and 52 will fire and act as short circuits in the waveguide sections whereas, during the receive portion of the cycle, wave energy may pass through the TR tubes.

During the transmit pulse, energy enters the mixer-duplexer at 38 as shown in Fig. 3. If we denote this energy as E_0 , it is evident that it will split into equal components E_1 and E_2 at the first side wall hybrid junction 40. Following the component E_2 through the circuit, it again splits evenly at junction 42 into two equal components E_3 and E_4 . It is immediately evident from Fig. 3 that the power represented by components E_3 and E_4 are 6.0 db down from the transmitter power level. The TR tube windows T_3 , T_4 in dual TR tube 50 break down and reflect E_3 and E_4 , respectively. Following E_3 , we find that it now approaches top wall hybrid junction 42 from the reverse direction and immediately splits into components E_5 and E_6 . E_5 is propagated in waveguide 30 and E_6 is propagated in guide 32. E_5 now has a phase of 0° over the input energy at 38 since this component has at no time entered a hybrid junction coupling slot. E_6 , however, passes through junction 42 once and, therefore, has a phase shift of 90° . At this time, E_4 has a relative phase shift of 90° since it passed through junction 42 once. E_4 breaks down TR tube T_4 , is reflected, and approaches junction 42 in the opposite direction. At 42, E_4 divides evenly into energies E_7 and E_8 . E_7 remains in waveguide 32 with a relative phase shift of 90° where it adds in phase with E_6 to form the component E_{16} which has a relative phase shift of 90° . E_8 , however, is coupled back through the hybrid junction 42 and thereby receives an additional 90° phase shift to gain a total of 180° relative to the incident input energy. The result is that E_8 cancels completely with E_5 and no input energy results in waveguide 30 as a result of the original energy vector E_2 .

Returning to side wall junction 40, we shall now pick up vector E_1 which is coupled through the side wall junction

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into waveguide 36. E_1 is propagated across the second top wall hybrid junction 44 where it is divided evenly into E_9 and E_{10} . Following through on energy E_9 , it strikes TR tube T_2 , breaks it down, and is reflected across the top wall hybrid junction 44 where E_9 is further divided into E_{11} and E_{12} . E_{11} has passed through the top wall hybrid junction 40 once and has a phase shift of 90° . E_{12} , however, passes through junction 44 also and ends up in guide 34 with a phase shift of 180° . Going back and picking up E_{10} , which was the other part of E_1 , split at junction 44, it is seen that E_{10} breaks down TR tube T_1 , is reflected, and arrives at junction 44 where it splits evenly into components E_{13} and E_{14} . E_{14} remains in guide T_1 with a relative phase shift of 180° since it has passed through junctions 40 and 44. E_{13} , however, is propagated back through the hybrid junction 44 into channel 36 with a total relative phase shift of 270° . The result is that E_{11} and E_{13} cancel completely in channel 36 since there is a total phase shift between them of 180° . E_{12} and E_{14} , however, are of equal phase shift and add up vectorially in guide 34 as E_{15} with a total relative phase shift of 180° .

Referring now to hybrid junction 46, it can be seen that E_{16} approaches the junction 46 where the energy divides into E_{18} and E_{19} . E_{18} retains its phase shift of 90° while E_{19} passes through the hybrid junction 46 and arrives in the antenna output arm with a total phase shift of 180° . E_{15} , however, arrives at the second side wall hybrid junction 46 where it is split evenly into components E_{20} and E_{17} . The component E_{20} passes through the junction 46 to gain a total relative phase shift of 270° . E_{17} remains in the antenna output arm with a total phase shift of 180° .

The result is that E_{20} and E_{18} cancel out completely into the terminated arm as shown in Fig. 3 since there is a total of 180° phase difference between these two vectors. However, components E_{17} and E_{19} add up in phase in the antenna arm. Since these vectors add up to unity in the output arm, this represents full power in this arm.

The foregoing description of operation has been given, neglecting the leakage of energy through the TR tubes 50 and 52. It is well known that no TR tube can be constructed with an infinite direct coupled attenuation on the transmit pulse. It follows directly, therefore, that there will be leakage power from these TR tubes. These four energies are shown in Fig. 3 as E_{10} from T_1 , E_9 from T_2 , E_3 from T_3 and E_4 from T_4 . E_{10} in passing through TR tube T_1 will gain zero phase shift. We may assume this to be true since all tubes will contribute the same phase shift and, therefore, we may neglect it in this explanation. E_{10} is propagated down the right side of waveguide section 34 and arrives at the third top wall hybrid junction 56 where E_{10} is divided evenly into components E_{21} and E_{22} . E_{10} originally possessed a relative phase shift of 180° . E_{21} will, therefore, arrive at the terminated load, past junction 56 in guide 34, with a total relative phase shift of 180° . E_{22} , however, gains a 90° phase shift in passing through junction 56 and arrives at the terminated load in guide 36 with a total relative phase shift of 270° . Consider now E_9 which leaks through TR tube T_2 with a phase shift of 90° . E_9 arrives at junction 56 where it splits into components E_{23} and E_{24} . E_{23} will retain its 90° phase shift while E_{24} will add another 90° since it has passed through junction 56. The total phase shift of E_{24} will therefore be 180° . The result is that vectors E_{21} and E_{24} will add up in phase into the matched load terminating waveguide section 34. Vectors E_{22} and E_{23} will add up 180° out of phase and cancel completely into the crystal diode terminating guide 36.

E_3 , which leaks through TR tube T_3 , will have a relative phase shift of 0° when it arrives at the fourth top wall hybrid junction 54 and divides equally into components E_{25} and E_{26} . E_{25} will retain its zero phase shift while E_{26} will assume a 90° relative phase shift since it has passed through the hybrid junction 54 only once.

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Energy E_4 , however, leaks through the TR tube T_1 and arrives at hybrid junction 54 with a relative phase shift of 90° . E_4 then divides equally into components E_{27} and E_{28} . E_{27} receives an additional phase shift of 90° and arrives in waveguide 30 with a total phase shift of 180° . It is obvious that E_{25} and E_{27} then add up 180° out of phase and cancel completely. E_{28} and E_{26} , however, each have a relative phase shift of 90° and, therefore, add up in phase into the matched load which terminates the waveguide 32.

From this description of operation, it is obvious that the circuit offers exceptional crystal protection to the transmitter leakage energy since all of the leakage energy is terminated in matched loads.

As was pointed out previously, one required function of the combination mixer-duplexer is to channel all of the received echo energy into the crystal diodes 58 and 60 without losing any of this energy to the transmitter arm. Another way of saying this is that the received branching loss of the mixer-duplexer must be low. It is obvious that this circuit affords an extremely low branching loss to the received echo. This is shown in Fig. 4 where the received echo pulse from the antenna, not shown, enters the left end of waveguide section 34 as E_0 and is propagated down the guide to the hybrid junction 46 where it divides into two portions E_1 and E_2 , both of which are equal. E_1 propagates in guide 34 until it reaches hybrid junction 44 where it splits into energy portions E_3 and E_4 which are again equal. E_3 passes through the TR tube T_1 and suffers only the insertion loss of this tube since the tube is not firing during the receive pulse. In like manner E_4 also passes through TR tube T_2 where it is attenuated only by the insertion loss of the tube. E_3 which has passed through no hybrid junctions then arrives at junction 56 with 0° relative phase shift. E_4 , however, passes through the junction 44 and arrives at junction 56 with a relative phase shift of 90° . At junction 56, E_3 divides into equal components E_7 and E_{10} . E_7 arrives at the load terminating waveguide section 34 with zero phase shift. E_{10} , however, receives a 90° phase shift in passing through the junction 56. E_4 arrives at the junction 56 and splits into two equal portions E_8 and E_9 . E_8 retains its 90° phase shift and adds up with E_{10} which also has a relative phase shift of 90° , to form E_{15} which is incident on the crystal diode 58. E_9 enters the junction 56, receives a phase shift of 90° , and adds up with E_7 180° out of phase. Hence, no received energy remains in waveguide section 34.

Returning now to hybrid junction 46, E_2 has passed through this hybrid and arrives at junction 42 with a relative phase shift of 90° . At junction 42, this energy splits into components E_5 and E_6 . E_5 passes through the junction 42, receives a phase shift of 90° , passes through TR tube T_3 , and arrives at hybrid junction 54 with a relative phase shift of 180° . E_6 , however, receives no additional phase shifts and after passing through TR tube T_4 arrives at the junction 54 with a relative phase shift of 90° . At junction 54, E_5 splits evenly into components E_{11} and E_{12} . E_{11} remains in waveguide section 30 with a relative phase shift of 180° . E_{12} passes through the junction 54 into guide 32 and arrives at the terminating load with a relative phase shift of 270° . E_6 splits at junction 54 into components E_{13} and E_{14} . E_{14} adds up in the load terminating guide T_4 with E_{12} 180° out of phase since its relative phase shift is only 90° . E_{13} , however, passes through junction 54 and adds up in phase with E_{11} to form E_{16} since both E_{13} and E_{11} have a total relative phase shift of 180° . E_{16} is incident on the other crystal diode 60.

It can thus be seen that the received signal is entirely in waveguide sections 30 and 36. E_{15} in section 36 is incident on the crystal diode with a relative phase shift of 90° as compared to the received RF signal. E_{16} , however, is directly incident on the other crystal diode and possesses a relative phase shift of 180° with respect

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to the input RF signal. Hence, there is a total phase difference of 90° between the RF signals incident on the two diode mixers. This, of course, is the proper phase relationship for RF mixing.

The mixing function of the invention is shown in Fig. 5. The local oscillator signal is injected into the left end of waveguide section 32 through probe 62 as E_0 . This signal is propagated down waveguide section 32 to the junction 46 where it undergoes a 3.0 db split into branches E_1 and E_2 which are 90° out of phase. The energy E_1 receives a 90° phase shift since it has passed through the hybrid junction 46. E_1 continues down waveguide section 34 until it reaches hybrid junction 44 where it splits again evenly into E_3 and E_4 . E_3 remains in waveguide section 34 with a relative phase shift of 90° while E_4 is propagated in waveguide section 36 with a relative phase shift of 180° . E_3 passes through the TR tube T_1 and arrives at hybrid junction 56 where it splits further into components E_7 and E_9 . E_4 passes through TR tube T_2 and arrives at hybrid junction 56 where it splits into components E_8 and E_{10} . Since E_7 retained its relative phase shift of 90° and E_8 has obtained a total phase shift of 270° , these two components will cancel completely in waveguide section 34. E_9 , however, arrives at one of the balanced crystal diodes 58 with a total relative phase shift of 180° as does E_{10} . These two components then add up in phase into the crystal diode mixer 58 which terminates waveguide section 36. This local oscillator energy then has a total phase shift of 180° over the input signal E_0 .

Returning to Fig. 4, it is immediately apparent that the proper phase relationship exists between the received RF energy (E_{15} in Fig. 4) and the local oscillator energy (E_9 and E_{10} in Fig. 5) at the balanced mixer 58 to result in balanced mixing.

Referring now to Fig. 5, it is seen that E_2 is propagated through waveguide section 32 to hybrid junction 42 with a relative phase shift of 0° . At the junction 42 this energy splits evenly into E_5 with a relative phase shift of 90° and E_6 with a relative phase shift of 0° . E_5 passes through TR tube T_3 and splits into components E_{12} and E_{13} at hybrid junction 54. E_6 passes through TR tube T_4 and arrives at hybrid junction 54 where it splits evenly into components E_{11} and E_{14} . E_{13} has a relative phase shift of 180° , and E_{14} has a relative phase shift of 0° when they arrive at the load terminating waveguide section 32. Consequently, these vectors cancel and no energy remains in section 32. E_{12} has a relative phase shift of 90° and E_{11} also has a relative phase shift of 90° when they arrive at the crystal mixer terminating waveguide section 30. Consequently, vectors E_{11} and E_{12} will add in phase.

Returning to Fig. 4, it is immediately apparent that the proper phase relationship exists between the received RF signal energy (E_{16} —Fig. 4) and the local oscillator energy (E_{11} and E_{12} in Fig. 5) at the diode mixer 60 terminating waveguide section 30 to produce balanced mixing. This is true since the relative phase difference between the two mixer crystals is 90° .

As will be understood, the invention accomplishes high power duplexing with lower power conventional TR tubes. Consequently, it is extremely simple and economical in construction since it requires no special or expensive parts. Only four TR tubes are required and the received signal passes through the TR tube only once, after which the components add up in phase once more. Hence, the received signal suffers insertion losses only once. Since no ATR tubes are used as in a conventional branching duplexer, there are no ATR cavity losses in addition to the savings in such tubes. Since both the antenna and the transmitter look into short slot hybrid junctions instead of the infinite discontinuity of a non-linear device as in branching duplexer circuits, both low and high level VSWR are reduced, thus de-

creasing reflection losses on the receive portion of the cycle and magnetron pulling on the transmit cycle.

The invention also has various other advantages. It is apparent from the foregoing description that there is a complete cancellation of leakage loss in the receiver arm during the receive portion of the cycle. In addition, since the leakage loss adds up in matched terminations, the magnetron in the transmitter always sees either the antenna or a matched load. In addition to balanced duplexing, the invention also provides balanced mixing. There is a complete cancellation of local oscillator noise in the output signal. The circuit provides for 30 db isolation between diode mixers which results in prevention of interaction. Since local oscillator energy is fed into the mixer-duplexer at the end opposite the crystal mixers, there results a proper local oscillator power division through the use of the same common hybrid components as are used for duplexing. In addition, the composite mixer-duplexer provides an extremely compact package having the advantages of both balanced mixing and balanced duplexing for relatively high microwave powers.

Although the invention has been shown in connection with a certain specific embodiment, it will be readily apparent to those skilled in the art that various changes in form and arrangement of parts may be made to suit requirements without departing from the spirit and scope of the invention.

I claim as my invention:

1. A duplexer for microwave energy comprising, in combination, a first wave energy transmission line having one end adapted for connection to a source of radio frequency energy, wave energy detecting means at the other end of said first transmission line, a second wave energy transmission line arranged in juxtaposition to said first line end having its opposite ends terminated in matched loads, two spaced hybrid junctions interconnecting said first and second transmission lines, a wave energy switch device in each of said first and second transmission lines between the spaced hybrid junctions, a third wave energy transmission line having one end terminated in a matched load, wave energy detecting means located at the other end of said third transmission line, a hybrid junction connecting said one end of the first transmission line to the said one end of the third transmission line, a fourth wave energy transmission line arranged in juxtaposition to said third transmission line, said fourth transmission line having one end open to convey wave energy from the duplexer and another end terminated in a matched load, a pair of spaced hybrid junctions interconnecting the third and fourth transmission lines, a wave energy switch device disposed in each of said third and fourth transmission lines between the spaced hybrid junctions, and a hybrid junction interconnecting one end of said second transmission line with the said one end of the fourth transmission line.

2. A duplexer for microwave energy comprising in combination, a first rectangular waveguide section having one end adapted for connection to a source of radio frequency energy, wave energy detecting means at the other end of said first waveguide section, a second rectangular waveguide section having its opposite ends terminated in matched loads, two wave energy coupling devices interconnecting said first and second wave guide sections, a wave energy switch device disposed in each of the first and second waveguide sections between the spaced coupling devices, a third rectangular waveguide section having one end terminated in a matched load, wave energy detecting means at the other end of said third waveguide section, wave energy coupling means connecting said one end of the first waveguide section to the said one end of the third waveguide section, a fourth waveguide section having one end open to convey wave energy from said duplexer and its other end terminated in a matched load, a pair of spaced wave energy coupling devices interconnecting the third and fourth waveguide

sections, a wave energy switch device disposed in each of the third and fourth waveguide sections between the spaced coupling devices, and a wave energy coupling device interconnecting one end of said second waveguide section and the said open end of the fourth waveguide section.

3. In combination, a first wave energy transmission line having one end adapted for connection to a source of radio frequency energy, wave energy detecting means at the other end of said first transmission line, a second wave energy transmission line having its opposite ends terminated in matched loads, means for feeding wave energy into one end of said second transmission line, two spaced wave energy coupling devices interconnecting said first and second transmission lines, a wave energy switch device disposed in each of the first and second transmission lines between the spaced wave energy coupling devices, a third wave energy transmission line having one end terminated in a matched load, wave energy detecting means at the other end of said third transmission line, wave energy coupling means connecting said one end of the first transmission line to the said one end of the third transmission line, a fourth wave energy transmission line having one end open to discharge wave energy and its other end terminated in a matched load, a pair of spaced wave energy coupling devices interconnecting the third and fourth transmission lines, a wave energy switch device disposed in each of said third and fourth transmission lines between the spaced wave energy coupling devices, and wave energy coupling means interconnecting said one end of the second transmission line to the open end of the fourth transmission line.

4. In combination, a first waveguide section having one end adapted for connection to a source of radio frequency energy, wave energy detecting means at the other end of said first waveguide section, a second waveguide section having its opposite ends terminated in matched loads, two spaced hybrid junctions interconnecting said first and second waveguide sections, a third waveguide section having one end terminated in a matched load, wave energy detecting means located at the other end of said third waveguide section, a hybrid junction connecting said one end of the first waveguide section to said one end of the third waveguide section, a fourth waveguide section having one end open to discharge wave energy and its other end terminated in a matched load, a pair of spaced hybrid junctions interconnecting the third and fourth waveguide sections, and a hybrid junction interconnecting one end of said second waveguide section to the open end of the fourth waveguide section.

5. A duplexer for microwave energy comprising, in combination, a first wave energy transmission line having one end adapted for connection to a source of radio frequency energy and its other end terminated, a second wave energy transmission line having its opposite ends terminated, two spaced wave energy coupling devices interconnecting the first and second transmission lines, a wave energy switch device disposed in each of the first and second transmission lines between the spaced coupling devices, a third wave energy transmission line having its opposite ends terminated, wave energy coupling means interconnecting said first and third transmission lines, a fourth wave energy transmission line having one end open to discharge wave energy and its other end terminated, a pair of spaced wave energy coupling devices interconnecting the third and fourth transmission lines, a wave energy switch device disposed in each of the third and fourth transmission lines between the spaced coupling devices, and wave energy coupling means interconnecting said second transmission line and said fourth transmission line.

6. In combination, a first wave energy transmission line having one end adapted for connection to a source of radio frequency energy and its other end terminated, a second wave energy transmission line having its opposite

ends terminated, two spaced wave energy coupling devices interconnecting said first and second transmission lines, a third wave energy transmission line having its opposite ends terminated, wave energy coupling means interconnecting said first and third transmission lines, a fourth wave energy transmission line having one end open to discharge wave energy and its other end terminated, a pair of spaced wave energy coupling devices interconnecting said third and fourth transmission lines, and a wave energy coupling device interconnecting said second and fourth transmission lines.

7. Means for detecting wave energy received by a directional antenna or the like comprising, in combination, a first wave energy transmission line having one end adapted for connection to a directional antenna and its other end terminated in a matched load, a second wave energy transmission line having its opposite ends terminated in matched loads, a wave energy coupling device interconnecting the said one end of the first transmission line to one end of the second transmission line, a third wave energy transmission line having a wave energy detecting device located at one end thereof, a pair of spaced wave energy coupling devices interconnecting said first and third transmission lines, a fourth wave energy transmission line having a wave energy detecting device located at one end thereof, and a pair of spaced wave energy coupling devices interconnecting said second and fourth transmission lines.

8. Means for mixing wave energy received by a directional antenna or the like with local oscillator wave energy and comprising, in combination, a first waveguide section having one end adapted for connection to an antenna or the like and its other end terminated in a matched load, a second waveguide section having its opposite ends terminated in matched loads, a wave energy coupling device connecting the said one end of the first

waveguide section to one end of the second waveguide section, a third waveguide section, a pair of spaced wave energy coupling devices interconnecting said first and third waveguide sections, a fourth waveguide section, a pair of spaced wave energy coupling devices interconnecting said second and fourth waveguide sections, wave energy detecting means located in each of said third and fourth waveguide sections, and means for feeding local oscillator wave energy into the said one end of the second waveguide section.

9. In combination, four parallel waveguide sections each of which is rectangular in cross section, means for feeding wave energy into an end of a first of said sections, wave energy detecting means at the other end of said first section, a pair of spaced top wall hybrid junctions interconnecting the first section with a second of said sections, a wave energy switch device in each of said sections interposed between the hybrid junctions, matched loads terminating the opposite ends of the second waveguide section, a side wall hybrid junction interconnecting the first section with a third of said sections, a matched load terminating one end of said third section and a wave energy detecting device disposed at the other end of said third section, a pair of spaced top wall hybrid junctions interconnecting the third section with a fourth of said sections, a wave energy switch device disposed in each of said third and fourth sections between the spaced hybrid junctions, a matched load terminating one end of the fourth section, and a side wall hybrid junction interconnecting the second and fourth sections.

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