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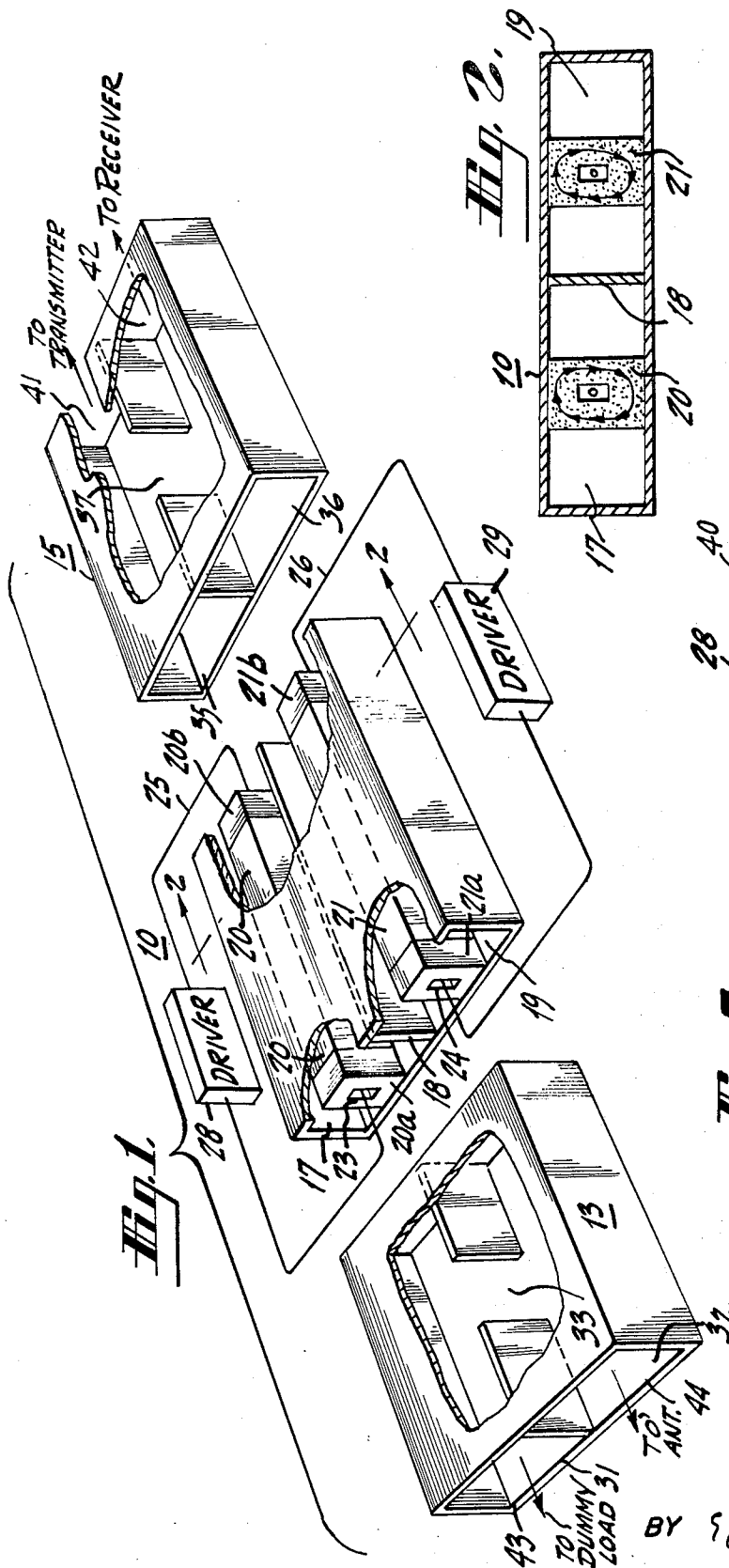
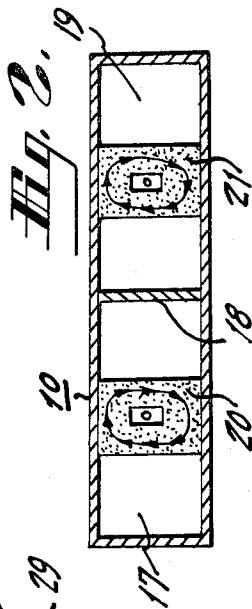
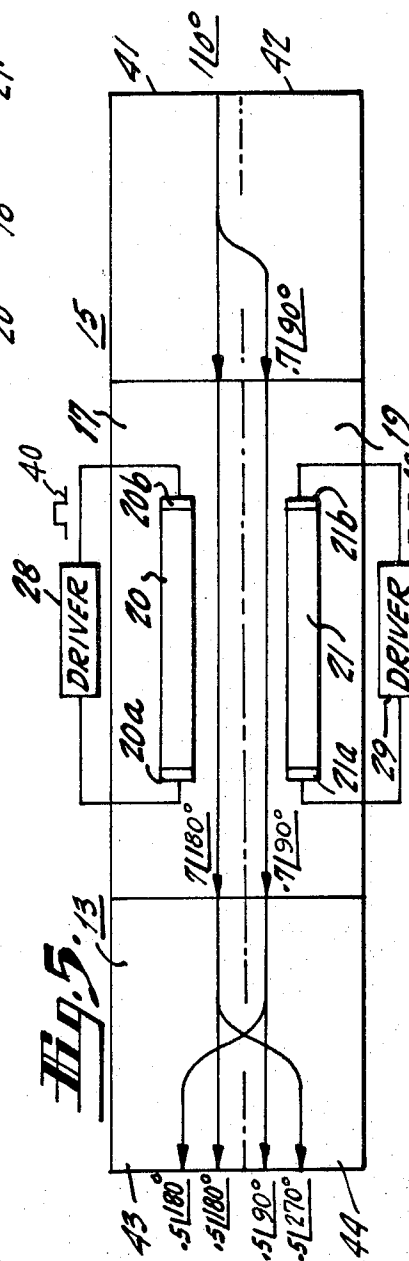
W. W. SIEKANOWICZ ET AL

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DUPLEXER HAVING TWO NON-RECIPROCAL PHASE SHIFTING MEANS

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2 Sheets-Sheet 1



INVENTORS
WIESLAW W. SIEKANOWICZ
DONALD J. BLATTNER &
THOMAS E. WALSH

BY Edward J. Norton
ATTORNEY

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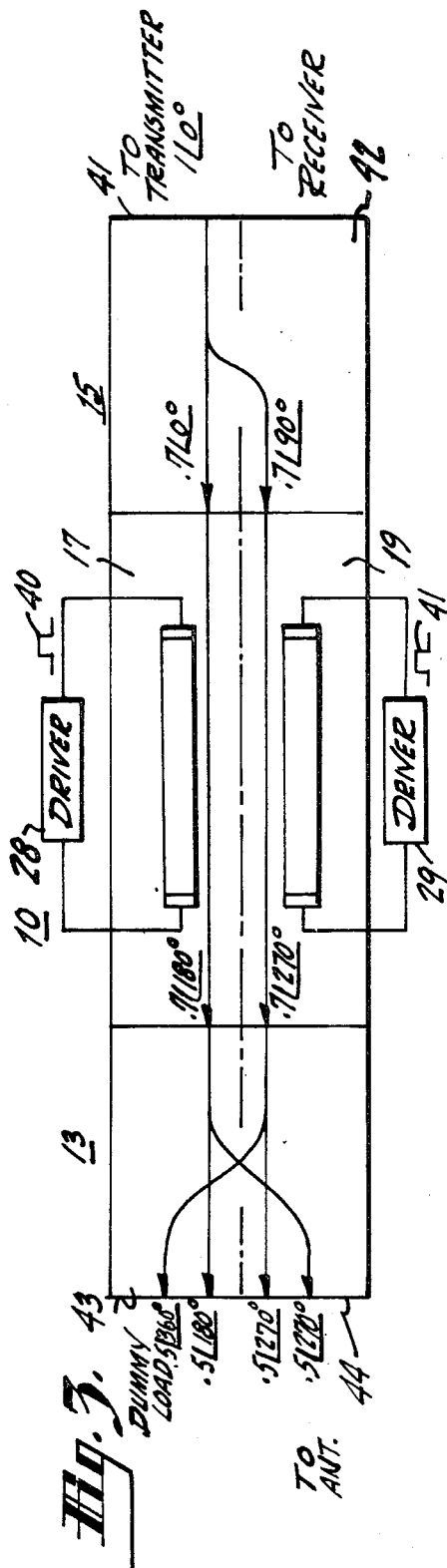
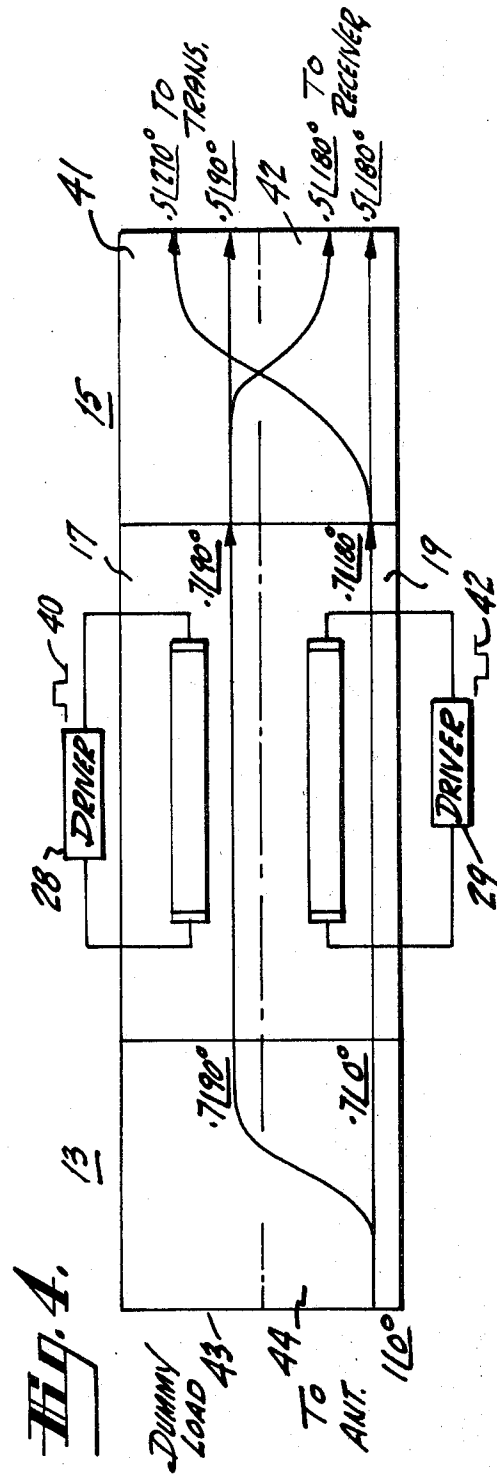
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WIESLAW W. SIEKANOWICZ
DONALD J. BLATTNER &
THOMAS E. WALSH

BY Edward J. Norton
ATTORNEY

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DUPLEXER HAVING TWO NON-RECIPROCAL PHASE SHIFTING MEANS

Wieslaw W. Siekanowicz, Trenton, Donald J. Blattner, Princeton, and Thomas E. Walsh, Kearny, N.J., assignors to RCA Corporation, a corporation of Delaware

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10 Claims

ABSTRACT OF THE DISCLOSURE

A duplexer includes a center dual waveguide section. A ferrite toroid is placed along the length of one waveguide section, and a fixed 180° differential phase shift is provided along the length of the second waveguide section. A first and a second short-slot hybrid coupler respectively terminates each end of the center dual waveguide section. A latching wire is passed through the ferrite toroid in the first section and coupled to a current driver. Upon the application of a pulse from the driver in one direction, an additional 180° relative phase shift is provided for signals traveling in a first direction along the length of the first waveguide section than for signals traveling in the opposite or second direction through the waveguide section. Upon the application of a pulse from the driver in the opposite direction, an additional 180° relative phase shift is provided for signals traveling in the second or opposite direction through the first waveguide section than for signals traveling in the first direction through the section.

BACKGROUND OF THE INVENTION

This invention relates to duplexers and more particularly to duplexing systems employing ferrite elements.

Duplexing systems utilizing ferrite elements for coupling a transmitter and a receiver to a common antenna and providing isolation between the receiver and the transmitter are known in the art. One common method utilizes a ferrite junction circulator. A single circulator does not, however, provide adequate isolation for the relatively high power during the transmission from a transmitter such as used in airborne radar systems. Additional isolation is therefore needed and may be provided by a series of serially connected latching circulators which, upon command from a current driver, change their direction of circulation. In addition to the number of circulators required to meet the required isolation, the circulators are sensitive to temperature changes and the isolation is dependent upon the level of RF power. Also, if the current driver fails while the circulator is in the receiving condition, the transmitter power will not be isolated from the receiver causing breakdown of the receiver.

It is therefore an object of the present invention to provide an improved duplexer which is relatively insensitive to temperature changes and operates at a relatively high level of RF power, providing better receiver protection by absorbing the reflected power during transmission by the transmitter and by providing a fail-safe operation in the event of current driver failure.

This and other objects of the present invention are accomplished by the use of two independent phase shifters having two conditions of adjustment. The phase shifters are coupled between two hybrid sections wherein power splitting and a 90° relative phase shift between the waveguide sections occurs. In one condition of adjustment, a 180° relative phase difference occurs between signals traveling in a given direction through one of the waveguide sections and signals traveling in the one direction

through the other waveguide section. In a second condition, both waveguide sections provide an equal amount of phase shift for signals traveling in the opposite direction through the waveguide sections.

A more detailed description follows in conjunction with the following drawings wherein:

FIG. 1 shows a perspective exploded view of one embodiment of a duplexer in accordance with the invention, FIG. 2 is a cross sectional view of the center section of waveguides 17 and 19,

FIGS. 3 and 4 respectively are diagrams used to illustrate the operation of the duplexer in the signal transmitting and signal receiving conditions respectively, and

FIG. 5 is a diagram illustrating the operation of the duplexer when the duplexer is in the receive condition and the transmitter signals are applied.

Referring to FIG. 1, the duplexer comprises a center waveguide section 10 between two similarly constructed waveguide hybrid sections 13 and 15. The center section is made up of two adjoining rectangular waveguides 17 and 19 which may have a common wall 18 extending the entire length of center section 10. A first ferrite toroid 20 has adjoining matching dielectric pieces 20a and 20b on either end. The toroid 20 and the dielectric pieces 20a and 20b are centered along waveguide 17. The ferrite toroid 20 and dielectric pieces 20a, 20b have an aperture 23 along the length thereof. The toroid 20 and dielectric pieces 20a and 20b are mounted between the broad walls of the waveguide 17. A latching wire 25 is looped through the toroid 20 and dielectric pieces 20a and 20b by passing the wire through the aperture 23. A driver 28 is coupled to the latching wire 25 and provides a fixed differential phase shift of 180° through the waveguide section 17 upon the application of D.C. current pulses in one direction along the wire 25. Because of the closed magnetic flux path in the ferrite toroid 20, as shown by the arrows in FIG. 2, the toroid operates at a remanent magnetization after termination of the current pulse. The phase shift through the ferrite is determined by the properties and dimensions of the ferrite, and by the orientation of the magnetization with respect to the direction of RF propagation. The length of the ferrite toroid section 20, 20a, 20b is adjusted such that, for the direction of D.C. magnetization shown in FIG. 2, the phase shift through the waveguide section 17 will be 180° greater for a wave traveling from the transmitter to the antenna than for a wave traveling in the opposite direction.

A second toroid 21 centered along waveguide 19 also has adjacent matching dielectric sections 21a and 21b on either end of the toroid. The ferrite toroid 21 and dielectric pieces 21a, 21b have an aperture 24 along the length thereof. The toroid 21 and dielectric pieces 21a, 21b are mounted between the broad walls of the waveguide 19. A latching wire 26 is looped through the toroid 21 and dielectric pieces 21a, 21b by passing the wire through the aperture 24. A driver 29 is coupled to the latching wire 26 and provides switching of the toroid 21 by applying unidirectional pulses of D.C. current in opposite directions along the wire 26. The driver 29 may in practice be the same driver as driver 28 wherein a diode is placed in the latching wire 25 and suitably poled to prevent reversing of the phase shift through toroid 20. Because of the closed magnetic flux path in the ferrite toroid 21 as shown in FIG. 2, the toroid operates at a remanent magnetization after termination of the current pulse. The phase shift through the ferrite is determined by the properties and dimensions of the ferrite and the orientation of the magnetization with respect to the direction of RF propagation. The ferrite toroid 21 provides along the length of the ferrite a 180° differential phase shift between signals traveling in opposite di-

rections through waveguide 19. By applying D.C. current pulses of one direction (positive going from driver 29) signals passing on one direction, i.e., from transmitter to antenna undergo an additional 180° phase shift whereas signals passing in the opposite direction from the antenna to the receiver or transmitter undergo 0° additional phase shift. By applying upon command D.C. pulses of opposite direction (negative going, for example) from driver 29, signals passing in the opposite direction from the antenna to the receiver or transmitter undergo an additional 180° phase shift through that section.

On either side of the center waveguide sections 17 and 19 are located end hybrid waveguide sections 13 and 15. These are identical directional couplers which are conventional broad-band, short-slot hybrids whereby power splitting and 90° relative phase shifting occurs between waveguide sections 31 and 32 of hybrid 13 with passage of signals through slot 33 in the common wall of hybrid waveguide section 13. Likewise, 90° relative phase shifting and power splitting between waveguide sections 35 and 36 of hybrid 15 is provided with passage of signals through slot section 37 in the common wall of waveguide section 15. While the hybrid sections are symmetrically bidirectional, the ends thereof adjacent the central waveguide 10 may be considered the inputs of the hybrids and their other ends may be the outputs thereof.

In the described arrangement the transmitter, not shown, is located at terminal 41 which is the outboard end of waveguide section 35 and the receiver, not shown, is coupled to terminal 42 which is the outboard portion of waveguide section 36. The inboard section of waveguide 35 joins with waveguide section 17 and the inboard section of waveguide 36 joins with waveguide section 19. The outboard portion of waveguide section 31 is coupled to a dummy load (not shown) at terminal 43 and the outboard portion of waveguide section 32 is coupled to antenna terminal 44.

The operation of the duplexer of the invention, as shown in FIG. 1, will be described in connection with the diagrams of FIGS. 2 and 3 which indicate by the arrowed straight and curved lines the distribution of the signal energy as it appears in the duplexer in the signal transmitting or receiving condition respectively of the associated system coupled thereto.

Turning now to the transmitting condition, the relative phase shift through the various regions of the duplexer are indicated in FIG. 3. The RF signal from the transmitter at terminal 41 undergoes a power split and 90° relative phase shift between the split signals in passing through the short-slot hybrid coupler in section 15. In passing through center section 10, an additional 180° phase advance is provided in passing through the ferrite loaded waveguide sections 17 and 19. Signal energy passing through waveguide section 17 and coupled through the short-slot of hybrid 13 undergoes an additional power split and 90° relative phase shift when passing through this hybrid section.

Since the signal energy that would emerge from terminal 43 at the dummy load suffers destructive interference, namely one is $0.5 \angle 360^\circ$ and the other being $0.5 \angle 180^\circ$, all the power ($0.5 \angle 270^\circ + 0.5 \angle 270^\circ$ or amplitude=1) emerges from port 44 or the antenna port. Any reflected signals at the antenna terminal 44 undergo zero additional relative phase shift through waveguides 17 and 19 and consequently these reflected signals will suffer destructive interference at the receiver ($0.5 \angle 0^\circ$ and $0.5 \angle 180^\circ$). The reflected signal will therefore be reflected back to the transmitter terminal 41 ($0.5 \angle 90^\circ$ and $0.5 \angle 90^\circ$) and will not be reflected to the receiver, thereby providing isolation of the receiver from the transmitted signals.

This isolation of the receiver from transmitter power is insensitive to temperature because the two ferrite elements, toroids 20 and 21, perform identical functions in

the transmit condition. Thus, if a temperature change caused the phase shift through 17 to change, the phase shift through 19 would undergo the same change. Also, any power reflected from antenna terminal 44 would still have destructive interference at the receiver; similarly, all power from the transmitter emerges at the antenna, thereby providing full isolation at the receiver.

Turning to the receive condition, the relative phase shift through the various regions of the duplexer are as indicated in FIG. 4. To switch to the receive condition, a D.C. pulse of opposite direction (negative going) is provided from driver 29 which reverses the differential phase shift through waveguide section 19 so that signals traveling from the antenna to the receiver have an additional phase shift of 180° and signals from the receiver to the antenna have 0° additional phase shift. The signal from the antenna is power split and 90° relative phase shift is provided by hybrid section 13. The signals when passing through waveguide section 17 from the antenna undergo no additional relative phase shift. The signal passing through waveguide section 19 undergoes 180° additional relative phase shift. The signal energy coupled through the short-slot hybrid section 15 undergoes additional power split and 90° relative phase shift. Signals passing through waveguide section 19 have 180° additional relative phase shift. The signal energy adds up ($0.5 \angle 180^\circ$ and $0.5 \angle 180^\circ$) at the receiver terminal 42. Since the signal energy at transmitter terminal 41 suffers destructive interference, i.e. $0.5 \angle 270^\circ$ and $0.5 \angle 90^\circ$, all the power (or amplitude =1) emerges at the receiver terminal 42.

A third important advantage of this described arrangement has to do particularly with the condition wherein, if the driver fails in the receive condition, the receiver is still protected during transmission.

As illustrated in FIG. 5 the described duplexer is adjusted to receive and yet the transmitter is operating. Then a power split of the transmitter signal and a 90° relative phase shift therebetween is provided by short-slot hybrid waveguide section 15. The passing of the signals through waveguide section 17 provides 180° additional relative phase shift and the passing of the transmitter signals through waveguide section 19 provides no additional relative phase shift. Power split and 90° relative phase shift of the transmitter signals is provided at hybrid 13. At the antenna port 44 these signals ($0.5 \angle 270^\circ$ and $0.5 \angle 90^\circ$) suffer destructive interference and the signal energy adds up ($0.5 \angle 180^\circ$ and $0.5 \angle 180^\circ$) at the dummy load terminal 43. All the power (amplitude =1) is applied to the dummy load which absorbs most of the power applied thereto. Any reflections from the dummy load add up at the transmitter terminal and suffer destructive interference at the receiver, it being remembered that for signals passing in towards the receiver through waveguide 17, the phase shift is zero, and for signals passing through the waveguide 19 towards the receiver, the phase shift is 180° . Therefore, the receiver is protected even though the system has failed in the receive position.

A device as described above was constructed and tested and provided a minimum of 40 db of isolation and operated over a frequency range of 5400 ± 50 megahertz and over a temperature range of -40°C. to $+75^\circ \text{C.}$ This device had the following characteristics:

The length of the dual center waveguide section 10 is $4\frac{1}{2}$ inches. The length of the hybrids are each $3\frac{1}{4}$ inches. The length of the ferrite sections 20 and 21 is 3.6 inches. The length of each dielectric matching section 20a, 20b, 21a and 21b is 320 mills.

The ferrite material has a dielectric constant of 15; and the dielectric matching sections 20a, 20b, 21a and 21b have a dielectric constant of 6.

While what has been described herein is one embodiment of the present invention using short-slot hybrids and differential phase shifters, it is understood that the present embodiment is only by way of example. Numerous other changes such as magic tees in place of short-slot hybrids

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may be used, and also other phase shifters such as adjustable reciprocal phase shifters may be used rather than differential phase shifters to provide the 180° additional relative phase shift in one phase shifter than the other phase shifter for signals traveling in a first direction in both phase shifters and to provide no additional relative phase shift in one phase shifter than the other phase shifter for signals traveling in the second direction opposite the first direction through both phase shifters.

What is claimed is:

1. In combination,
 - a central dual waveguide having first and second sections,
 - first means coupled to each end of said dual waveguide and providing at each end power splitting with 90° relative phase shift of signals applied thereto,
 - second adjustable means having two conditions of adjustment,
 - in one condition of adjustment, said second means providing an additional 180° relative phase shift of signals propagating in one direction through one waveguide section than for signals propagating in said one direction in the other waveguide section of said dual waveguide and,
 - in said second condition of adjustment said second means providing virtually no difference in relative phase shift of signals propagating in the opposite direction through said one waveguide section than for signals propagating in said opposite direction in the other waveguide section of said dual waveguide.
2. The combination as claimed in claim 1 wherein said second means includes at least one ferrite toroid in at least one of said waveguide sections and further includes a pulse driver and a latching wire coupled to the pulse driver and passing through the center of the toroid.
3. The combination as claimed in claim 2 wherein said first means includes two short-slot hybrids, one coupled to each end of said dual waveguide.
4. The combination as claimed in claim 1 wherein said second means includes a differential phase shifter in said one waveguide section and a second differential phase shifter in said other waveguide section.
5. The combination as claimed in claim 4 wherein said first means includes two short-slot hybrids, one coupled to each end of said central waveguide.
6. The combination as claimed in claim 4 wherein said phase shifters include ferrite toroids.
7. The combination as claimed in claim 5 wherein said second means includes a ferrite toroid in said one waveguide section.

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8. The combination as claimed in claim 7 wherein said second means includes a pulse driver and a latching wire coupled to the pulse driver and passing through said second ferrite toroid in said one waveguide section.

9. A duplexer comprising,
 - a pair of hybrid means each having two input portions and two output portions, a wave applied to either one of said input portions appearing in equal amplitudes and 90° out of phase at said output portions, while the wave applied to either one of said output portions appears in equal amplitude and 90° out of phase at said input portions,
 - a pair of reversible phase shifters through which waves may travel in both directions, said phase shifters each providing a phase shift in one direction of wave travel therethrough that is equal to a constant value plus 180° and providing a phase shift in the other direction of wave travel therethrough that is equal to said constant value, and
 - means to reverse one of said pair of phase shifters whereby a wave traveling therethrough in said one direction is shifted in phase by said constant value and a wave traveling therethrough in the opposite direction is shifted in phase by said constant value plus 180°,
 - each of said shifters being arranged to receive waves from and to transmit waves to a respective output portion of one of said hybrid means and to transmit waves to and receive waves from a respective output portion of the other of said hybrid means.
10. The combination as claimed in claim 9 wherein said phase shifters include toroids.

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HERMAN KARL SAALBACH, Primary Examiner
P. L. GENSLER, Assistant Examiner

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