May 5, 1959 J. F. ZALESKI 2,885,677

MICROWAVE DUPLEX SWITCH

Filed July 7, 1955 2 Sheets-Sheet 1

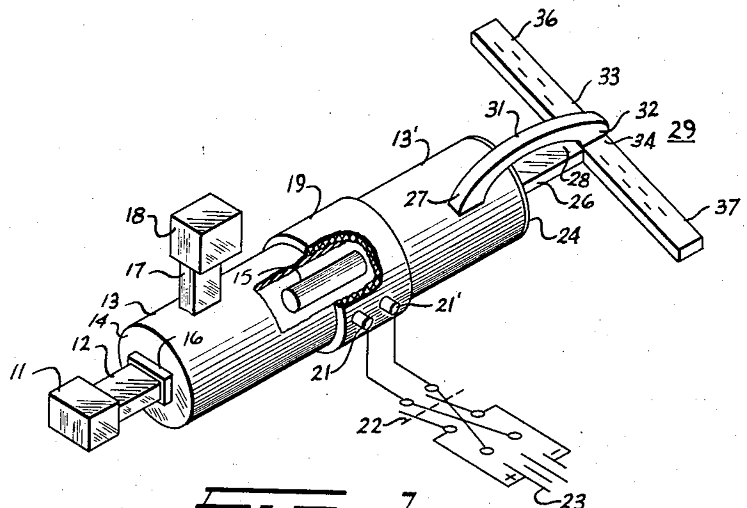

Fig. 1

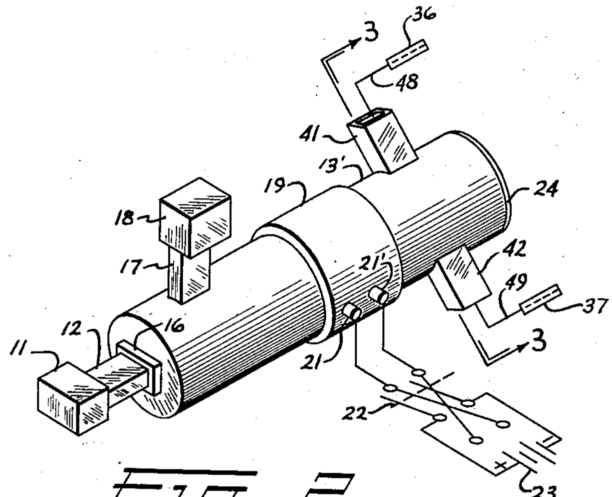

Fig. 2

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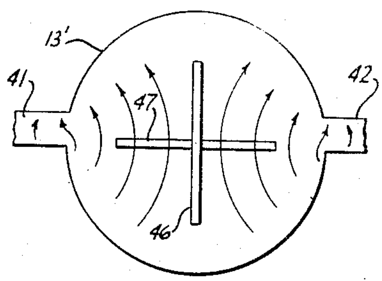
MICROWAVE DUPLEX SWITCH

Filed July 7, 1955 2 Sheets-Sheet 2

Fig-5



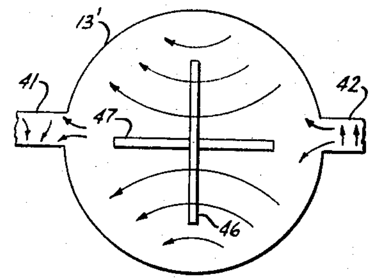


Fig-6

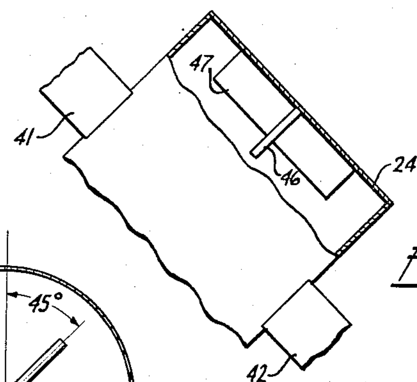


Fig-4

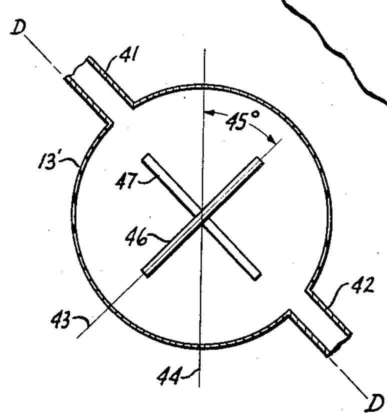


Fig-3

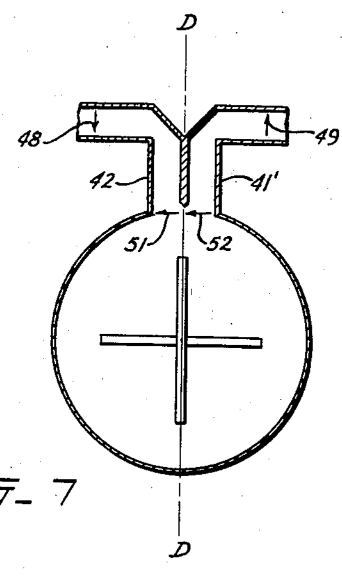


Fig-7

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MICROWAVE DUPLEX SWITCH

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Application July 7, 1955, Serial No. 520,506

3 Claims. (Cl. 343—777)

This invention relates to a combined microwave duplexer and microwave switch. More specifically the invention relates to a microwave field rotator of the magnetically energized type which provides duplex operation and reverses the phase of the output.

The invention provides a microwave guide structure having a generator arm and a receiver arm at one end and a pair of load arms at the other end. The structure contains a microwave field rotator capable of rotating the microwave field in the Faraday magneto-optical sense under the influence of a reversible magnetic field and so designed that the microwave field rotation produced thereby is exactly 45°. Generator energy passing through the rotator to the load and there reflected is returned to the receiver and not to the generator, the device thus serving as a duplexer. The phase relations in the load arms are either in phase equality or in phase opposition depending upon the direction of the magnetic field in the rotator. The device is therefore a phase reverser, and both the duplexing and phase-reversing functions are performed by the same microwave field rotator simultaneously.

The magnetic field may be generated by means of a coil, the circuit of which can be reversed either by a mechanical switch or by connecting the coil to an alternating source having a square, sinusoidal or any other wave form. The invention thus provides a duplexer in combination with a phase reversing switch which may have no moving parts and which therefore may be operated at high frequencies limited only by the distributed capacitance of the coil. Moreover, the switching device is distinguished from switches requiring moving parts in the microwave field space by the fact that this device presents constant impedance to the radio frequency power source during the switching operation.

One purpose of this invention is to combine the functions of a microwave duplexer and a microwave switch in a single component.

Another purpose is to combine the functions of a microwave duplexer and a microwave phase-reversing switch in a single component.

Still another purpose is to provide a microwave circuit containing a switched field rotator of the magnetically energized type for simultaneous duplex transmission and reception, control of the microwave energy at dual outlets being governed by the switching of the field rotator.

A further understanding of this invention may be secured from the detailed description and drawings, in which:

Figure 1 depicts a microwave guide system embodying the invention.

Figure 2 depicts another embodiment of the invention including a phase-reversal switch integral with a duplexer.

Figure 3 is a cross section of Fig. 2 taken on the line 3—3.

Figure 4 is a side view of Fig. 3, partly in section.

Figures 5 and 6 schematically illustrate microwave field distributions within the embodiment of Fig. 2.

Figure 7 depicts a modified form of the embodiment of Fig. 2.

Referring now to Fig. 1, a microwave generator **11** applies energy through a rectangular guide **12** to the end of a round guide **13**. The transition between the rectangular guide **12** and the end of the round guide may comprise a quarter-wave transformer **16** as illustrated, or alternatively a tapered junction or any of the other well-recognized matching means for providing transition from rectangular to circular waveguide. The dominant TE_{10} mode of microwave transmission in rectangular guide **12** thus efficiently excites the dominant TE_{11} mode in the round guide **13**, the average direction of the lines of electric force therein being parallel to those in guide **12**.

A shunt rectangular side arm **17** is connected and matched to the round guide **13** with its axis at a distance

$$\frac{(2N+1)\lambda_g}{4}$$

from end **14**, N being any integer including zero and λ_g being the microwave length in guide. The axis of side arm **17** is in the described average TE_{11} field direction. These described locations of the connections of arms **12** and **17**, together with the axial orientations of these arms, provide mutual isolation between them, so that a field in round guide **13** so oriented as to couple fully to one does not couple at all to the other. A microwave receiver **18** is connected to guide **17**.

The round guide **13** is connected beyond side arm **17** to a microwave field rotator having an internal magnetizable rotating element such as a ferrite element **15** and having a magnetizing coil **19** concentric with the round guide **13**. One form of such a device capable of rotating microwave energy in the Faraday magneto-optical sense is described in Patent No. 2,644,930, of C. H. Luhrs et al., issued July 7, 1953. The two terminals **21**, **21′** of coil **19** are connected through a reversing switch **22** to a source of direct current represented by battery **23**.

As is well known, certain forms of such rotators rotate the plane of polarization of microwave energy passing therethrough by an amount proportional to the magnitude of coil current, and the rotational sense is dependent upon the direction of current flow in the coil, i. e., the direction of magnetic field, and is independent of the direction of microwave energy flow, the direction of rotation of the plane of polarization being described as clockwise or counterclockwise as seen by an observer at a fixed location looking in the direction from the gentrator.

To illustrate, let it be assumed that when terminal **21** is positive, microwave energy passing through the rotator from left to right is rotated clockwise. It is an experimental fact that when microwave energy in transmitted from right to left it is likewise rotated clockwise, the observer's position, of course, remaining fixed looking from left to right. When terminal **21′** is positive, microwave energy passing from left to right is rotated counterclockwise and likewise rotated counterclockwise when transmitted from right to left. The amount of rotation is independent of the strength of the microwave field.

The rotator is connected to a round guide **13′**, which may be considered to be a continuation of guide **13**. Guide **13′** is terminated at the end **24** by a metal short-circuiting plate. The plate **24** is provided with a rectangular guide outlet **26**, the round-to-rectangular transition being matched in any desired way such as described for the transition between guides **12** and **13**. The rectangular guide **26** is rotationally positioned at a 45° angle to guide **12**, so that microwave energy in the round guide **13/13′** can most efficiently enter guide **26** only after it has been given a clockwise rotation of 45°. Round guide **13′** is also provided with an impedance matched shunt rectangular side arm **27** spaced from end **24** similarly to the spacing of arm **17** from end **14**, that is, at a distance

$$\frac{(2N+1)\lambda_g}{4}$$

Side arm **27** is rotationally displaced from the median plane of the round guide taken through arm **17** so that, looking from the arm **17** at the left to arm **27** at the right, the position of the latter is displaced by 45° in a clockwise direction. The arms **26** and **27** are thus mutually isolated by their positions and orientations.

The output end guide **26** is connected to the shunt arm **28** of a magic tee **29**, and the output side guide **27** is connected by a gradually curved guide **31** to the series arm **32** of the same magic tee **29**. The other two arms of the magic tee, being the conjugate pair of collinear arms **33** and **34**, are connected to non-reflective microwave loads of any form requiring selected relative phasing of the microwave energization. For example, these loads may consist of cooperating linear antenna arrays, depicted by arrays **36** and **37**, the individual antennas or space radiators being of any type but here consisting of longitudinal slots in the broad faces of the arrays. In certain configurations of such cooperating arrays it is desired to operate the arrays with in-phase microwave energy to secure one condition of operation, and to operate them with opposed-phase energy to secure another condition of operation. The arrays **36** and **37** are assumed to have such configuration in order to serve as an example of loading utilizing the output of the described microwave system.

In the operation of this device the current passed through coil **19** in either direction is of such strength as to rotate microwave energy passing through the rotator by 45°. It is understood that the antenna arrays **36** and **37** are employed in some form of echo-generating apparatus so that echo energy received at the antenna is applied to the right end of round guide **13'** and passes through the rotator from right to left. The generator **11** may generate either pulsed or continuous wave microwave energy, both being equally suitable for use with this invention.

The generated microwave energy is applied by rectangular guide **12** to the left end of round guide **13**, setting up the TE_{11} field mode therein. The electric orientation of this mode being in the direction of the axis of side arm **17**, no energy can enter this arm. The energy passes toward the right through the rotator, the switch **22** being in the position to make terminal **21** positive. Accordingly the field polarization is rotated 45° clockwise as it enters guide **13'**. It therefore cannot enter side arm **27** but is properly polarized to enter end arm **26**. It therefore is applied to the magic tee shunt arm **28** and excites the collinear arms **33** and **34** and their connected arrays **36** and **37** in the same phase.

Echo microwave energy returns to the arrays in phase, so excites the shunt arm **28** and not the series arm **32**. The shunt arm **28** applies the echo energy through guide **26** to the round guide **13'**, exciting the TE_{11} mode therein. The microwave flow through the rotator being from right to left, the field is rotated clockwise, looking from left to right by 45°. The energy therefore arrives at arm **17** at such orientation that it passes into the arm and to the receiver **18**, and does not enter the end arm **12**.

When the switch **22** is thrown to the position to make terminal **21'** positive, energy applied from guide **12** is rotated counterclockwise by 45°. This energy cannot then enter end guide **26** but is properly oriented to enter side arm **27**, which it does, and enters the magic tee **29** through the series arm **32**. The energy therefore excites the collinear arms **33** and **34** and arrays **36** and **37** in opposed phase. The echo of the antenna beam excites oppositely-phased microwave echo energy in antenna arrays **36** and **37**, so that the echo energy returns through guides **32** and **31** and not through guides **28** and **26**. The returning energy is rotated counterclockwise 45° by the rotator, so that it enters side arm **17** and not end arm **12**.

During the travel time of switch **22**, and in general during excitation of the rotator in any degree or sense, the impedance presented to the microwave field by the arms **26** and **27** remains constant, so that at no time is any discontinuity reflected from the arms during and due to the switching operation.

To recapitulate, the rotator serves as a duplexer, whichever way switch **22** is thrown, so that echo energy enters receiver **18** and not generator **11**, while the positions of receiver arm **17** and generator arm **12** are such that generator energy from arm **12** cannot enter receiver arm **17** directly. Additionally, the microwave energizations of array loads **36** and **37** are either in phase or in opposed phase in accordance with the position of the direct-current direction-changing switch **22**, which controls the rotator coil. The switched rotator in combination with the round guides **13** and **13'** and their arms thus serves as both a duplexer and as a high speed constant impedance microwave switch having no moving microwave parts. The combination of these elements with a hybrid junction serves as a duplexer, as a constant impedance switch and as a phase reverser.

It is obvious that the above-described functions do not depend upon the type of switch **22** or upon its speed of operation. Therefore this switching function may be done by an electro-magnetic relay, an electrical square-wave or sinusoidal-wave dynamoelectric generator, an electronic oscillator, or by any other component applying reversing or alternating current to coil **19**.

It is obvious that in place of the magic tee **29** any four-arm hybrid junction having conjugate pairs of arms may be used. It is also obvious that in place of the end arm **12** and side arm **17** any two arms coupled to round guide **13** and electrically isolated for the TE_{11} mode may be employed. The same comment applies to arms **26** and **27**.

It is also obvious in accordance with the above statement generalizing the characteristics of the output arms, that if the device be considered as terminated at arms **26** and **27**, with any forms of microwave loads applied thereto, the application of the device is broadened because the switching function is no longer restricted to phase-reversing, but is a generalized microwave switcher comparable to a double-throw switch in wire circuits, and may be applied to any microwave switching use of this type.

A second form of the invention is depicted in Fig. 2 which dispenses with the hybrid junction **29**, Fig. 1, but which nevertheless accomplishes the phase-reversing function performed thereby.

Those parts which function similarly to parts of Fig. 1 are denoted by the same reference characters and include the microwave generator **11** which applies microwave energy to round guide **13**, and the receiver **18** connected to round guide **13** through side arm **17**. The rotator coil **19** is switched by switch **22** and the microwave field, after rotation, passes to the right into round guide **13'**. This guide **13'** terminates in a conductive plate **24** forming a closed and short-circuited end. Two side arms **41** and **42** of the shunt type branch from round guide **13'** at a distance of approximately

$$\frac{(2N+1)\lambda_g}{4}$$

from the closed end **24**. These arms are connected to the round guide **13'** at points which are angularly equidistant from a diametral longitudinal plane indicated in Fig. 3 by the center line **43** and are not diametrically opposite, their axial intersections with the round guide wall being less than 180° apart. Arms **41** and **42** are depicted in Figs. 2 and 3 as collinear, but equal results will be attained by arms opening into the round guide **13'** at the same locations but making any other desired angles therewith. The diametral longitudinal plane **43** makes an angle of

45° with diametral longitudinal plane of round guide 13, Fig. 2, which comprehends the axes of arms 12 and 17, this latter plane being indicated in Fig. 3 by center line 44.

In place of the shunt arms 41 and 42, two series arms may be employed similarly placed on round guide 13′ with similar results.

Two coupling-matching vanes 46 and 47, Figs. 3 and 4, are provided, one in the plane 43, and the other in a plane perpendicular thereto. These vanes are preferably conductive, although they may alternatively be dielectric, and are secured and joined to the end plate 24. The coupling-matching properties of these vanes are dependent upon the vane length, breadth and thickness, and these dimensions are designed to produce equal coupling between the pair of arms 41 and 42 and the round guide 13′ in the two transmitting field orientations, as will be described later. It is desirable, however, that each of these vanes be so thin that the vane has negligible effect upon a microwave field having its average electric field direction perpendicular thereto. This requirement is generally satisfied if the metallic vane has a thickness of not over 1/64 inch at a frequency of 10,000 megacycles.

In order to provide an example of loading which requires the application of alternative inphase and antiphase microwave energy, two microwave antenna arrays 36 and 37 are schematically indicated as connected to the arms 41 and 42 by circuits schematically indicated at 48 and 49.

In the operation of this device, when switch 22 is operated so that the terminal 21 is positive, the microwave field applied from generator 11 cannot enter side arm 17 (Fig. 2). The field is rotated 45° clockwise by the rotator and reaches the arms 41 and 42 with its average electric field direction at right angles to their common axis, which is the polarization most favorable for exciting them and the arms 41 and 42 are excited in phase. This action is illustrated in Fig. 5. The echo energy returned from antennas 36 and 37, Fig. 2, in phase reenters round guide 13′ and is rotated clockwise 45° by the rotator, entering receiver 18.

When switch 22 is operated to make terminal 21′ positive the generator energy is rotated counterclockwise, so that the average field direction at the arms 41 and 42 is oriented at 90° from its previous orientation, as indicated in Fig. 6. Since the microwave field distribution varies across the entrance to each of the side arms 41 and 42, each is coupled to the field and is excited. However, due to the direction of polarization of the TE_{11} field, these couplings are opposite in sense, with the result that the phases in the arms are in 180° opposition. The echo energy returned from antennas 36 and 37, Fig. 2, in antiphase relation reenters round guide 13′ and excites therein a field oriented as indicated in Fig. 6. It is rotated counterclockwise by the rotator and enters receiver 18. Thus the two antennas 36 and 37, Fig. 2, are excited in the same phase or in opposed phase depending upon the position of switch 22. The impedance presented to the microwave field is constant during switching.

The coupling of arms 41 and 42 to round guide 13′, as depicted in Figs. 3, 5 and 6, is near maximum for a field as indicated in Fig. 5, and consequently the coupling is near minimum for a field 90° thereto as indicated in Fig. 6. However, high coupling to a field as indicated in Fig. 6 is possible by appropriate impedance matching, and if equal excitation of the antennas in the inphase and antiphase senses is desired, these couplings must be made equal. This may be done in either of two ways or by a combination of them. The two arms 41 and 42 may be changed in their positions on the round guide by being moved toward or away from each other until the couplings are equal, or end vanes 46 and 47 may be employed. It is evident that vane 47, Fig. 5, has no effect

upon the indicated field but the vane 46 does have, and that the latter, by modifying the field configuration, controls the coupling of arms 41 and 42 to a field so oriented. It is also evident that vane 46, Fig. 6, has no effect upon that field but that vane 47 does. Thus the two vanes independently affect the arm couplings in the two field orientations, so that by appropriate design of these vanes the couplings may be independently adjusted to be equal.

The output guide arms of Fig. 3 may be disposed in a slightly different manner, as depicted in Fig. 7, yet will operate the same. If it be considered that the arm 41, Fig. 3, be transferred to a position 180° displaced from that shown, it will then occupy the position of 41′, Fig. 7, adjacent to arm 42 but on the opposite side of the diametral plane D—D from it. Obviously such a change will not affect operation either in a field oriented as in Fig. 5 or in one perpendicular thereto as in Fig. 6, or in a field at any intermediate orientation. However, due to the inclusion of the 90° elbows in Fig. 7, the field directions as indicated by arrows 48 and 49 at the exits of arms 42 and 41′ have opposite directions relative to each other, differing from arrow directions 51 and 52 at the entrances of the guides for the field of Fig. 5. Similarly, when the field is oriented as in Fig. 6 the graphic indication of output phase in Fig. 7 differs from that of Fig. 6 merely because of the inclusion of the elbows.

To recapitulate, a single microwave rotator serves simultaneously in three capacities: as a duplexer, as a microwave switch presenting constant impedance during switching and having no moving parts within the microwave field and which may be operated at high speed, and as a microwave phase reverser.

What is claimed is:

1. A microwave duplexer and phase-reversing switch comprising, a round waveguide section, a pair of mutually isolated arms connected to one end thereof, a microwave energy source connected to one arm of said pair of arms propagating a microwave field in the TE_{11} mode in said round waveguide, a microwave receiver connected to the other of said pair of arms, a second pair of arms connected to the other end of said round waveguide section, microwave field rotating means active in the Faraday magneto-optical sense positioned in said round waveguide section intermediate said pairs of arms, means for impressing a magnetic field on said field rotating means, said magnetic field having a magnitude sufficient to cause said field rotating means to rotate the TE_{11} microwave field by an angle of 45° in a direction dependent on the direction of said magnetic field, means for periodically reversing said field, and means including said second pair of arms for securing a pair of microwave outputs of phase equality or opposition dependent on the polarization of the microwave field at said second pair of arms.

2. A microwave duplexer and switch adapted to be energized by a microwave field comprising, a round waveguide section having a first pair of mutually isolated arms connected to one end thereof, a second pair of mutually isolated arms connected to the other end thereof, said second pair of arms being displaced 45° as respects said first pair of arms, microwave field rotating means active in the Faraday magnetooptical sense positioned in said round waveguide section intermediate said first and second pair of arms, means for impressing a magnetic field of such intensity on said field rotating means as to rotate said microwave field by an angle of 45° in a direction dependent on the direction of said magnetic field, means for periodically reversing said field, and a hybrid microwave four-arm junction having the respective arms of one conjugate pair of arms thereof connected to respective arms of said second pair of mutually isolated arms and the respective arms of the

other conjugate pair of arms connected to the respective ones of a pair of microwave antennas.

3. A microwave duplexer and phase-reversing switch comprising, a round microwave guide having a first pair of mutually isolated arms connected to one end thereof, a microwave source connected to one arm of said first pair of arms propagating a microwave field in the TE_{11} mode in said round guide, a microwave receiver connected to the other arm of said first pair of arms, a second pair of mutually isolated arms connected to the other end of said round guide having an orientation differing by 45° from the orientation of said first pair of arms, an electromagnetically energized microwave field rotator in said round guide intermediate said two pairs of arms, said rotator being energized by a reversible direction current supply source of a magnitude such that the TE_{11} microwave field in said round guide is rotated thereby by 45° in a sense dependent upon the direction of said current, and a hybrid microwave four-arm junction having the respective arms of one conjugate pair of arms thereof connected to the respective arms of second pair of mutually isolated arms, whereby energy applied at one arm of said first pair of mutually isolated arms when reflected and returned through said hybrid junction goes to said receiver, said rotator causing said source and said receiver to operate in duplex, and whereby the microwave energy from said source is emitted from the other conjugate pair of arms of said hybrid junction in equal or opposed phase depending upon the polarization of said TE_{11} microwave field.

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