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3,205,493

MICROWAVE SWITCH

Filed May 21, 1963

3 Sheets-Sheet 1

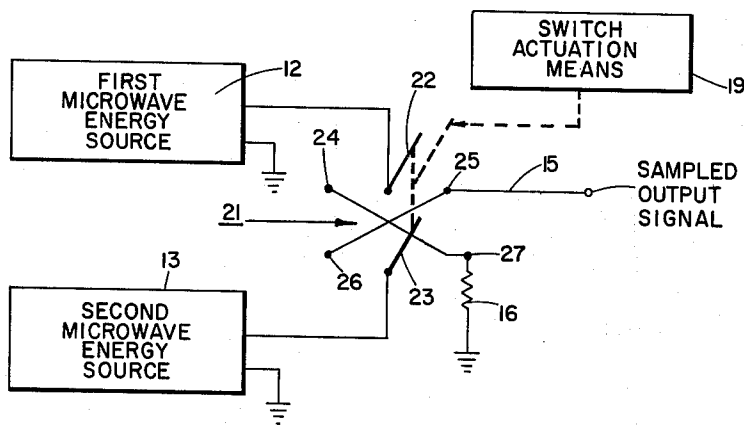


FIG. 1

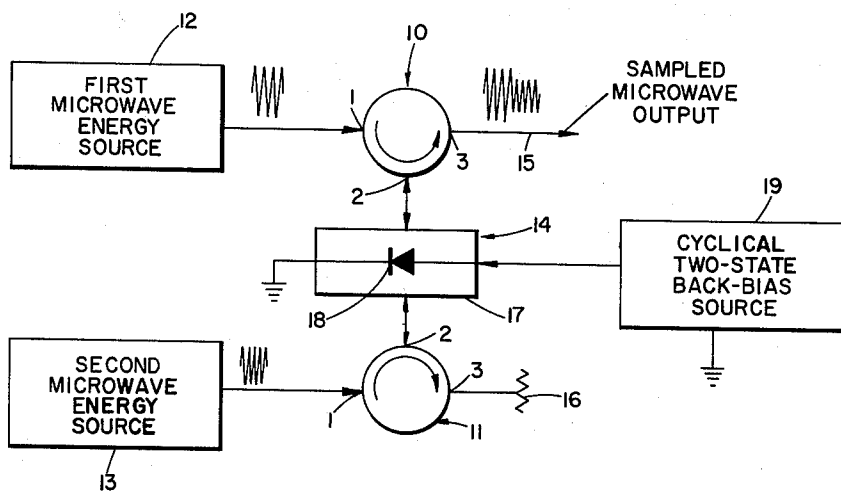


FIG. 2

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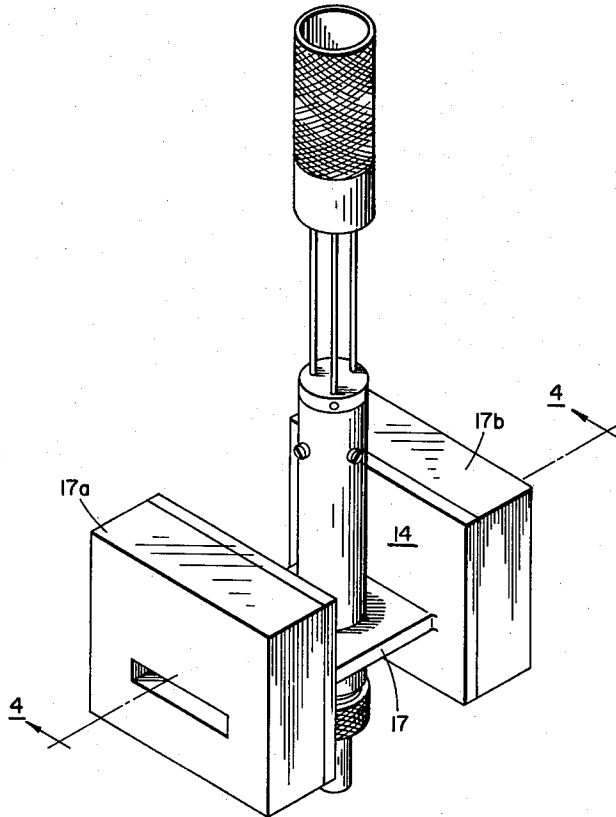


FIG. 3

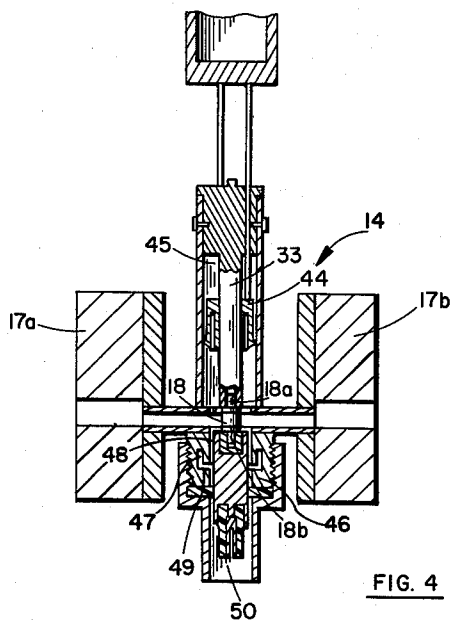


FIG. 4

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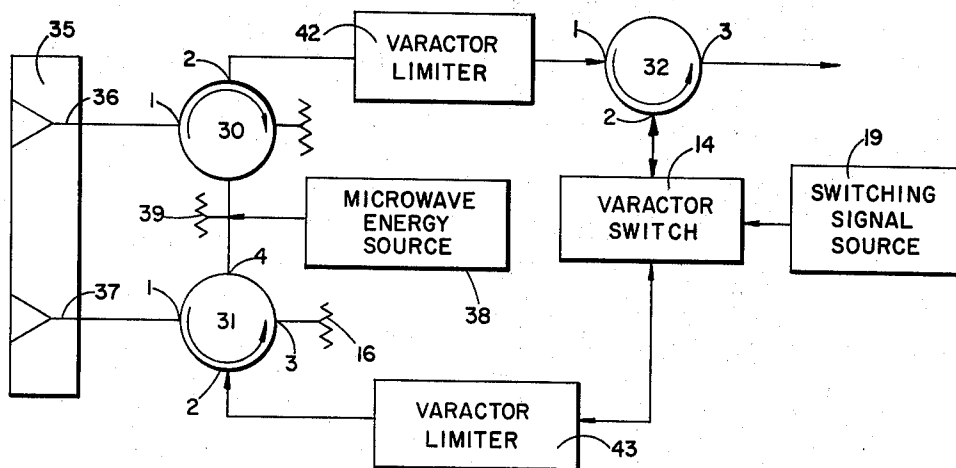


FIG. 5

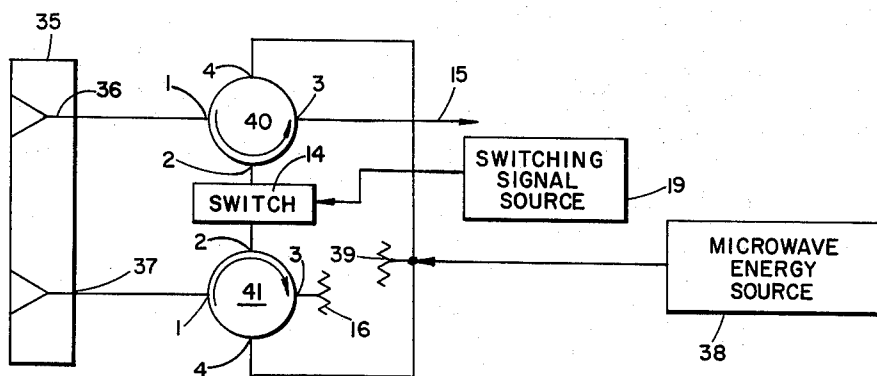


FIG. 6

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MICROWAVE SWITCH

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10 Claims. (Cl. 343—5)

The concept of this invention relates to means for switching microwave energy, and more particularly to improved microwave switch means operable at very high frequencies.

With the increased application of microwave data processing systems, means have been sought for high-speed switching of microwave energy at speeds, for example, above 1 megacycle per second. In this way, microwave data processing equipment such as microwave signal devices may be time-shared between several microwave signal sources or channels, so as to reduce the total amount of signal devices or amplifiers required in a given system or equipment.

Such high-speed switching of microwave energy may be accomplished by means of a device whose capacitive reactance can be varied by an electrical signal such as a varactor diode shunted across the narrow dimension of a waveguide section, and then by applying a suitable bias voltage across the diode. The varactor, or p-n junction semiconductor, when operated as a back-biased junction diode, behaves as a variable capacitance the value of which varies as a function of the applied bias. Hence, by shunting such a device across a waveguide section and adjusting the bias across the diode, an adjustably tuned or conductive microwave switching device can be achieved. By means of the adjustment of the bias across the diode, the microwave combination of waveguide section and back-biased junction diode (or varactor) may be "tuned" so as to transmit microwave energy of a preselected frequency thru the waveguide section in either direction. Also, the bias (and associated capacitance) may be varied as to "de-tune" the microwave combination whereby a reflection of microwave energy is obtained, rather than transmission thereof. Further, the response time of such varactor (to a change in the state of the applied back-bias) is extremely low, response times as low as 10^{-9} second being obtainable. Moreover, such devices are substantially no-loss devices, producing very little attenuation of the microwave energy applied to the waveguide. Hence, it is to be appreciated that high speed microwave switching may be obtained. By combining the microwave switch in novel combination with a plurality of waveguides and multi-port non-reciprocal microwave signal attenuating devices such as ferrite circulators, highly useful multi-function switching may be achieved.

A concept of the invention is to provide efficient solid-state microwave switch means, adapted to function as a high-speed switch for microwave signals such as radar transmitter signals and radar receiver signals.

In a preferred embodiment of the invention there is provided a first and second microwave circulator having at least three ports, a respective first port of which is connected to a first and second source respectively of microwave energy. A microwave switch employing a varactor diode shunted across a waveguide section, interconnects the second ports of the two circulators. The third port of one of the circulators serves as an output port, while the third port of the other circulator may be shorted thru a dummy load impedance.

In normal operation of the above described arrangement, a bias is applied across the varactor to operate the microwave switch whereby alternately the first microwave energy source is connected to the circulator output port while the second source is shorted through the load im-

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pedance, then the second microwave energy source is connected to the circulator output port while the first source is shorted through the load impedance. In this way, the combination of two circulators and microwave switch cooperate as a time-sharing switch, to provide sampling of the two sources of microwave energy.

Accordingly, it is an object of the subject invention to provide high-speed switching of microwave signals.

It is another object of the subject invention to provide means for high-speed sampling of several sources of microwave energy.

It is still another object of the invention to provide microwave sampling means requiring only one varactor for sampling a plurality of received microwave signals.

Yet another object of the invention is to provide an effective microwave switch for use in a time-shared monopulse receiver.

A further object of the subject invention is to provide an efficient multi-function microwave switch useful in a monopulse radar system.

These and other objects of the invention will become apparent from the following description taken in connection with the accompanying drawings in which:

FIG. 1 is a functional block diagram illustrating a concept of the invention.

FIG. 2 is a functional block diagram of one embodiment of the invention.

FIG. 3 is an isometric view showing the construction and arrangement of the microwave switch of FIG. 2.

FIG. 4 is a partial vertical section of the device of FIG. 3.

FIG. 5 is a functional block diagram of an alternative embodiment of the invention.

FIG. 6 is a functional block diagram of another embodiment of the invention.

In the drawings, like reference characters refer to like parts.

Referring to FIG. 1, there is illustrated a simplified schematic diagram of a concept of the invention. There is provided a double-pole double-throw switch 21 for switching microwave signals, and having a first and second armature 22 and 23. First and second armatures 22 and 23 are connected to a first and second microwave energy sources 12 and 13, respectively. Also provided are first and second switching terminals 24 and 25 associated with first armature 22, and first and second switching terminals 26 and 27 associated with second armature 23. A first switching terminal associated with each of the two armatures is interconnected with a second terminal associated with the other of the two armatures. In other words, terminals 24 and 27 are interconnected, and terminals 25 and 26 are interconnected. Terminal 27 is also shorted to ground by means of a shorting impedance 16, and terminal 25 serves as an output terminal connected to an output line 15. As illustrated in FIG. 1, the pair of armatures 22 and 23 are shown positioned intermediate the two switching positions employed.

There is further provided switch actuation means 19 in cooperation with switch 21 for alternately switching the armatures from engagement with one to the other of the associated first and second switching terminals.

In normal operation of the above described arrangement, first one microwave signal source is connected to output line 15, while the other microwave signal source is shorted thru shorting impedance 16; and then the other microwave signal source is connected to source terminal 15, while the first source is shorted thru impedance 16. In this way, output line 15 is made to sample alternately the two microwave energy signal sources 12 and 13 in FIG. 1.

It is to be appreciated that the switch 21 of FIG. 1 is

only a functional schematic representation of means for sampling a plurality of signal sources. Switching means more suitable for cooperation with a plurality of microwave energy sources is shown in FIG. 2.

Referring to FIG. 2, there is illustrated a functional block diagram of one embodiment of the invention. There is provided a first and second microwave circulator 10 and 11 having at least three ports. A respective first port of circulators 10 and 11 is connected to a first and second source 12 and 13, respectively, of microwave energy. A microwave switch 14 interconnects the second ports of first and second circulators 10 and 11. A third port of first circulator 10 provides an output to line 15, and the third port of second circulator 11 is shorted by a dummy load impedance 16. Such load impedance is a matched termination which may comprise a waveguide section, having a piece of tapered microwave absorptive or lossy dielectric inserted therein parallel to the longitudinal axis thereof, whereby microwave attenuation without reflection is achieved, as is well understood in the art.

Microwave circulators 10 and 11 are multiport non-reciprocal or unidirectional microwave attenuators which demonstrate a low impedance between adjacent ports to signals transported in the direction indicated by the curved or circularly shaped arrows in FIG. 1. The circulators demonstrate a relatively high impedance between adjacent ports to signal transport in a direction opposite that indicated by the curved arrows. Also, a large impedance is exhibited between non-adjacent ports. Hence, in first circulator 10 of FIG. 1, for example, signals may flow from microwave source 12 to the first port of circulator 10 and then out the second port of circulator 10 to switch 14 without significant attenuation. However, such applied signals will not be transmitted from microwave source 12 to output port 15 without substantial attenuation. Similarly, an input applied to the second port of circulator 10 will appear substantially unattenuated at the third port of circulator 10 (e.g., at output line 15).

Microwave circulators 10 and 11 are similarly constructed and arranged, preferably being of the ferrite type and similar, for example, to Model CX-405 manufactured by Rantec, Inc., of Calabasas, California.

Microwave switch 14 is comprised of a microwave section 17 adapted to provide microwave communication between circulators 10 and 11, and a varactor diode 18 shunted across waveguide section 17 and connected to a source 19 of switching signals. The switching signals provided by source 19 are two-state signals one of which adjusts the back-bias upon, and hence the capacitive effect of, diode 18 within waveguide section 17 so as to allow microwave communication between the ends of waveguide section 17. The second state of the switching signal is selected to adjust the capacitive effect of diode 18 within waveguide section 17 whereby the combination 14 substantially reflects, rather than conducts, microwave signals applied at either end of waveguide section 17.

The construction and arrangement of microwave switch 14 is shown in detail in FIGS. 3 and 4.

Referring to FIGS. 3 and 4, there is illustrated, respectively, an isometric view and vertical center section (the vertical center section being taken along the longitudinal waveguide axis shown in the isometric view) of a preferred embodiment of microwave switch 14. There is provided a rectangular waveguide section 17 of preferably reduced height, the height being adequate to accommodate no more than the longitudinal dimension of the ceramic or reactive element of a varactor diode 18, which is placed across the narrow dimension of waveguide section 17 so as to present a microwave shunt impedance. It is preferable to use a varactor diode of relatively small dimensions or small over-all geometry, in order to achieve efficient high-speed switching. Such a diode may be of any commercially available reactive type such as, for example, type MA 4352, Style D, manufactured by Micro-

wave Associates, Inc. (Semiconductor Division), of Burlington, Mass. Accordingly, the use of a waveguide of reduced height is preferred, in order to maximize the switching effect of the diode upon the impedance of the waveguide section, as is explained more fully hereinafter.

The cooperation of diode 18 shunted across the narrow dimension of waveguide section 17 is designed to provide a parallel-tuned tank of infinite shunt impedance to microwave signals of a preselected frequency, including frequencies as high, for example, as 9.3 kilomegacycles per second. Such tank is of an extremely high Q because the varactor diode is essentially a capacitive or reactive diode (as distinguished from resistive diodes), the reactive effect of which is varied by adjustment of a bias potential applied across the electrode terminals (18a and 18b) thereof. Because of the small overall geometry of varactor 18, the associated inductive parameter is minimized. Hence, the response time of the diode is minimized, whereby high speed switching of the diode may be achieved. Diodes of the type described may be switched at switching frequencies at least as high as 100 megacycles per second, the actual speed in practice being limited mainly by the speed of the driver circuit.

Because of the small overall geometry (in addition to essentially reactive nature) of varactor 18, the resistive (or energy dissipative) parameter thereof is minimized. Further, where a reduced height waveguide is employed, dissipative or lossy structure (such as the electrical terminals at either end of the diode and associated supporting structure for supporting the diode) are exterior to, or excluded from, the waveguide section 17. Because the lossy structure is excluded from the waveguide section 17, essentially loss-less transmission may be effected thru the waveguide, when the bias potential applied across terminals 18a and 18b of diode 18 is adjusted to provide a tuned shunt tank. Accordingly, when the tank is detuned (relative to the preselected frequency of interest) by switching or adjusting the bias potential to another value, the detuned or reduced shunt impedance is essentially reactive in nature, whereby microwave energy reflection occurs (rather than dissipation), the energy applied to either end of the waveguide being reflected back to such end. The range of voltages employed in switching diode 14 are on the order of about 1 to 10 volts.

In FIG. 4, an adjustable tuning slug 44 is shown slidably mounted vertically above diode 18 in the upper mounting cavity 45 exterior to waveguide section 17, and is provided for adjustment of the tuning of the tank to a desired tuning frequency, as is well understood in the art. The cavity 46 vertically below diode 18 and external to waveguide section 17 is a half wavelength section, comprising two mutually concentric quarter wavelength sections 47 and 48 connected by annular aperture 49, whereby a half-wavelength choke impedance is provided, as is well understood in the microwave art. The purpose of such choke is to prevent leakage of microwave energy out of the switch to the synchronous switching signal source 19 (in FIG. 2) along a switching line (not shown) connected to connector 50.

Upper diode terminal 18a is grounded to the waveguide structure by means of electrical contact with mechanical mounting post 33. Lower diode terminal 18b is electrically connected to connector terminal 50 by means of electrical contact with the mechanical mounting provisions at the upper end of connector terminal 50 which connector terminal is electrically insulated from the waveguide structure. Hence, switching signals may be applied across diode 18 by connecting a source of such signals to the waveguide section and connector terminal 50.

Because of the reduced height waveguide employed, quarter wave transition sections or microwave step transformers 17a and 17b are employed at either end of waveguide section 17 in order to achieve impedance matching

with the microwave sources connected thereto, as is well understood in the microwave art.

Hence, it is to be appreciated that the structure illustrated in FIGS. 3 and 4 cooperate to provide alternately transmissive and reflective states to microwave energy of a preselected frequency, in response to high-speed switching signals of switching frequencies as high as 10 megacycles per second.

Therefore, it is to be understood that, in the exemplary application in FIG. 2, the periodic operation of switch 14 in response to periodic switching signals, alternately reflects and transmits energy applied thereto, whereby alternately (1) the output energy from the second port of circulator 10 is reflected to the third or output port thereof, while the output energy from the second port of circulator 11 is reflected to the shorting impedance 16 across the third port thereof; and (2) the output energy of the second port of circulator 10 is transmitted thru the second and third ports of circulator 11 to shorting impedance 16, while the output energy from the second port of circulator 11 is transmitted thru the second and third ports of circulator 10 to output line 15.

An alternate embodiment of the device of FIG. 2, and which employs three circulators, is shown in FIG. 5.

Referring to FIG. 5, there is illustrated a block diagram of a pulsed radar system employing an alternate embodiment of the invention. There is provided a source 38 of pulsed microwave energy and a transmitting and receiving radar antenna 35 having at least two apertures 36 and 37. Antenna 35 is operatively coupled for radiating or transmitting microwave energy generated by source 38. Antenna 35 will also provide at apertures 36 and 37 microwave echoes (of the transmitted microwave energy) or other microwave signals received thereby, as is well understood in the art. Microwave energy source 38 may be of any type usual in the art for providing microwave energy. Such source might be adapted, for example, for providing pulsed microwave energy having a pulsewidth and further having a pulsing interval substantially in excess of the duration of the pulsewidth.

The construction and arrangement of multi-aperture antenna 35 and microwave generator 38 are well-known in the art, as is indicated by FIG. 3 of U.S. Patent 2,933,980, issued on April 26, 1960 to J. R. Moore et al. for an Integrated Aircraft and Fire Control Autopilot. Accordingly, elements 35 and 38 are shown in block form only.

There is also provided a first, second and third ferrite four-port circulator 30, 31 and 32. Such four-port circulators may be of any commercially available type, such as for example, the ferrite type Model 90CR manufactured by Microwave Development Laboratories, Inc., of Natick, Massachusetts. A respective first port of first and second circulators 30 and 31 is connected to a first and second source 36 and 37, respectively, of received microwave energy. Such sources might be comprised for example, of the several apertures of monopulse receiving antenna 35. Magic tee 39 (or like microwave energy divider means) interconnects the output of microwave energy source 38 with the last port of each of circulators 30 and 31.

A second port of each of circulators 30 and 31 is operatively connected to a first and second port respectively of third circulator 32. Interposed between the second and third circulators 31 and 32 is a microwave switch 14 of the type described in connection with FIGS. 2, 3 and 4, and adapted to be operated (e.g., switched) by source 19 at a frequency representing a periodicity of no more than one-half the pulsewidth of the pulsed energy from source 38.

If desired, microwave signal-limiters 42 and 43 may be interposed between microwave energy source 38 and switch 14, in order to protect the switching varactor from damage or malfunction due to possible energy leakage of high level microwave energy from the circulators

during the duty cycle of source 38. Such limiter devices are well known in the art and may be comprised, for example, of a self-biasing varactor diode shunted across a waveguide section, whereby high energy levels of applied microwave energy result in an induced voltage or bias across the varactor which causes energy reflection, thereby protecting circuit elements between which such limiters are interposed. Such reflected energy is shunted to ground by means of the shorting impedances shown at the conductive adjacent parts of the four-port configuration of circulators 30 and 31 of FIG. 5.

By means of the above described arrangement, efficient and reliable solid state multi-function switching means is provided for the switching of microwave signals, including the switching of transmitted and received signals and the alternate sampling of several sources of received microwave signals.

In normal operation of the device of FIG. 5, pulsed microwave energy generated by source 38 travels via energy divider 39 to the last ports of first and second circulators 30 and 31, thru those circulators to the adjacent conductive or first ports thereof in substantially unattenuated form, and thence from the first ports of circulators 30 and 31 to apertures 36 and 37 respectively of antenna 35, where the energy is radiated or transmitted, as is well understood in the art. The echoes of the transmitted energy, reflected by radar targets, are received by apertures 36 and 37 of antenna 35, and transmitted to a first port of circulators 30 and 31 respectively. The received energy applied to the first port of each of circulators 30 and 32 appears as an output of the corresponding adjacent conductive or second port of circulators 30 and 31.

Now, varactor switch 14 is periodically switched from a conductive state to a reflective state and back again to a conductive state, in a like manner as was explained in connection with the description of switch 14 in FIG. 2.

When switch 14 is in the conductive state, received microwave energy (from antenna aperture 36) is applied to the first port of third circulator 32 from the second port of first circulator 30, and thence from circulator 32 thru switch 14 and circulator 31 to shorting impedance 16. Concurrently, received microwave energy (from aperture 37 of antenna 35) occurring as an output at the second port of second circulator 31, is transmitted thru microwave switch 14 to the second port of third circulator 32, thence thru the adjacent conductive or third port of third circulator 32 to output line 15. In other words, in the conductive state of switch 14, microwave signals received at antenna aperture 36 are shorted thru shorting impedance 16, while microwave signals received by antenna aperture 37 are transmitted to output line 15.

When switch 14 is in the reflective state, received microwave energy (from aperture 36), which is applied to the first port of third circulator 32 from the second port of first circulator 30, is again transmitted thru the second port of third circulator 32 to switch 14. However, because of the reflective state of switch 14, this energy is reflected back to the second port of circulator 32 and is transmitted thru the adjacent conductive or third port to output line 15. Concurrently, received microwave energy (from aperture 37), occurring as an output at the second port of second circulator 31, is transmitted to switch 14, is reflected therefrom back to the second port of circulator 31, and thence thru the third or adjacent conductive port to shorting impedance 16. In other words, in the reflective state of switch 14, microwave signals received at antenna aperture 36 are transmitted to output line 15, while microwave signals received by antenna aperture 37 are shorted thru shorting impedance 16.

An alternative embodiment of the invention, which provides the performance features of FIG. 5 and employs no more than two circulators, is shown in FIG. 6.

Referring to FIG. 6, there is illustrated an alternative embodiment of the invention. There is provided an antenna 35, microwave energy source 38, and microwave switch 14, similar to like referenced elements of FIG. 5. There is also provided a first and second four-port circulator 40 and 41 constructed and arranged similarly as the four-port circulators of FIG. 5. A first port of circulators 40 and 41 is operatively connected to apertures 36 and 37 respectively of antenna 35; the second ports of circulators 40 and 41 being interconnected by microwave switch 14. The third port of second circulator 41 is shorted by means of a shorting impedance 16, while the third port of first circulator 40 serves as an output port in cooperation with output line 15.

The last or fourth ports of circulators 40 and 41 are commonly connected to microwave source 38 by means of energy divider 39, in a like manner as was explained in connection with the divider of FIG. 5.

The normal operation of the device of FIG. 6 may be deduced from the operational modes explained in connection with FIGS. 2 and 5. The energy from source 38, as fed to the fourth or last ports of circulator 40 and 41, appears as an output at the conductive adjacent or first ports of circulators 40 and 41, whence it is conducted to antenna 35, in a similar manner as was explained in connection with the cooperation of the antenna 35 and source 38 of FIG. 4.

A conductive state of switch 14 in FIG. 6 causes received energy from aperture 36 to be shorted by impedance 16, and causes received energy from aperture 37 to appear at output line 15; while a reflective state of switch 14 causes received energy from aperture 37 to be shorted by impedance 16 and causes received energy from aperture 36 to appear at output line 15. Hence, a sampling of received energy from apertures 36 and 37 is provided by the alternately reflective and transmissive states of switch 14 (in cooperation with switching signal source 19), in a manner similar to that explained in connection with the device of FIG. 2.

While the illustrated embodiments of the invention have described structure useful for achieving duplexing and time-sharing of signals, particularly microwave signals, it is to be understood that the concept of the invention is equally useful to multiplexing or switching of signals including microwave signals in a computer or other data processor employing a plurality of such signals.

Thus, the device of the present invention provides a novel and efficient combination for effecting switching of electrical signals.

Although the invention has been described and illustrated in detail it is to be clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of this invention being limited only by the terms of the appended claims.

I claim:

1. The combination comprising

A first and second microwave circulator, each having at least three ports,

A respective first port of said circulators being adapted to be connected to a first and second source respectively of microwave energy,

A microwave switch interconnecting the second ports of said circulators, and adapted to be operatively connected to a source of switching signals,

A third port of one of said circulators being shorted through a load impedance, and a third port of the other of said circulators providing a sampled output.

2. The combination of claim 1 in which said microwave switch comprises

A waveguide section,

A varactor diode shunted across said waveguide section and adapted to cooperate therewith alternatively as a tuned waveguide circuit and as a reflector of microwave energy applied at either end of said wave-

guide section, in response to signals applied across said diode.

3. Microwave switching means comprising

A first and second microwave circulator having at least three ports,

A first port of said first and second circulators being connected to a mutually exclusive one of two sources of microwave energy,

A third port of said second circulator being shorted through a shorting impedance,

Microwave means interconnecting the respective second ports of said first circulator and said second circulator for alternately reflecting microwave energy received from one of said sources through said shorting impedance and transmitting microwave energy received from the other of said sources through said shorting impedance, whereby the received energy of alternate ones of said mutually exclusive sources of microwave energy is transmitted to a third port of said first circulator as an output thereof.

4. The device of claim 3 in which said microwave means comprises

A source of a two-state control voltage, and

A voltage-controlled microwave impedance interconnecting a second port of said first and second circulators for alternately providing microwave communication therebetween and reflection of microwave signals in response to a respective state of said two-state control voltage.

5. The microwave combination comprising

A first ferrite circulator having at least three ports;

A second and third ferrite circulator, each having at least four ports;

A respective first port of said second and third circulator connected to a first and second source, respectively, of received microwave energy;

A respective second port of said second and third circulator being connected to a first and second port, respectively, of said first circulator, and a third port of said third circulator being shunted by a dissipative shunt impedance;

A microwave switch interposed between said first and third circulator,

A third source of pulsed microwave energy having a preselected pulsewidth and a pulsing interval substantially in excess of the duration of said pulsewidth,

Energy divider means operatively connected to divide said pulsed microwave energy between a third and fourth port of said second and third circulator, respectively,

Said microwave switch being adapted to be operated at a frequency representing a periodicity of no more than one-half the pulsewidth of said pulsed energy.

6. The device of claim 5 in which there is further provided signal limiting means interposed between said first and second circulators and between said third circulator and said microwave switch.

7. The device of claim 6 in which said signal limiting means is comprised of a varactor diode shunted across a waveguide section.

8. Microwave-switching means comprising

A first and second microwave circulator having at least three ports,

A third circulator having at least four ports,

A first port of said first and third circulators being connected to a mutually exclusive source of microwave energy,

A third port of said third circulator being shorted through a shorting impedance,

Microwave means including a first and second port of said second circulator and interconnecting the second ports of said first and third circulators for alternately reflecting said microwave energy received by said third circulator through said shorting impedance and transmitting said microwave energy received by

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said first circulator through said shorting impedance whereby the received energy of alternate ones of said first and third circulators is transmitted to an output port of said second circulator, the last ports of said first and third circulators being adapted to be connected to a third source of microwave energy to be transmitted.

9. The device of claim 8 in which said microwave means further includes

A reduced height waveguide section interconnecting the second port of said second and third circulators,

A second port of said first circulator and a first port of said second circulator being interconnected for microwave communication therebetween,

A varactor diode shunted across the narrow dimension of said reduced height waveguide and responsively connected to a source of two state signal for making said reduced height waveguide section alternately conductive and reflective of microwave signals.

10. Microwave switching means comprising
An antenna having at least two apertures for transmitting and receiving microwave energy,

A source of microwave energy to be transmitted,
Unidirectional microwave means for severally coupling said source of microwave energy to said two apertures, and

Sampling means including said unidirectional means for sampling received echoes of said microwave energy received by alternate ones of said apertures,

Said unidirectional microwave means comprising a first

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and second ferrite microwave circulator having at least three and four ports respectively, a first port of each of which is connected to a mutually exclusive one of said apertures, a last port of each of which is commonly responsively connected to said source of microwave energy;

Said sampling means further including microwave switch means having alternatively conductive and reflective states and interconnecting a respective second port of said circulators, and a dissipative shunt impedance shunting a third port of said second circulator.

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