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HIGH POWER MICROWAVE SWITCH

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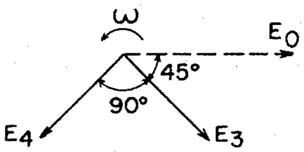

FIG. 1

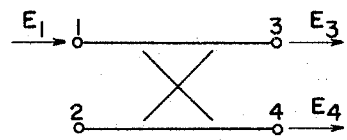

FIG. 2

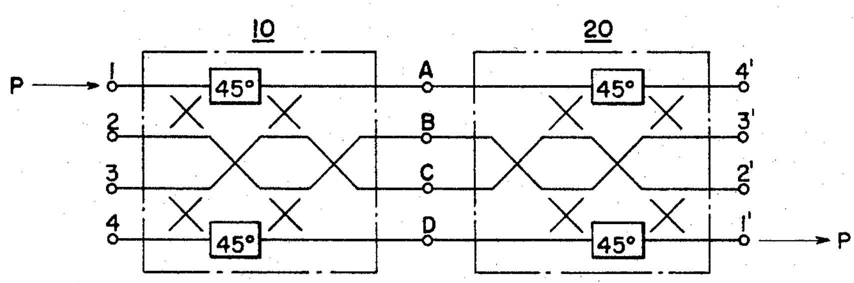

FIG. 3

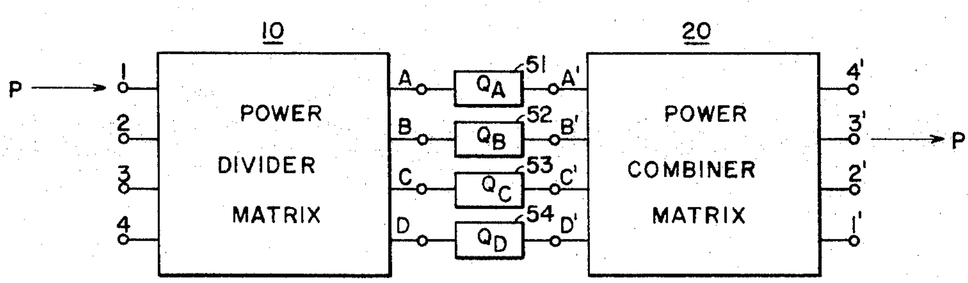

FIG. 4

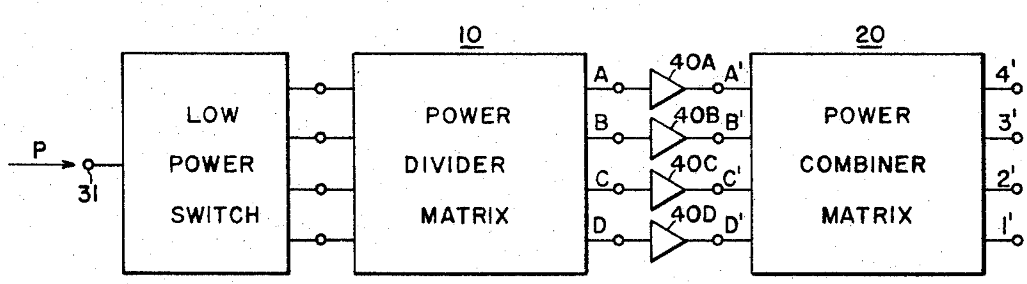

FIG. 5

WITNESSES

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HIGH POWER MICROWAVE SWITCH

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ABSTRACT OF THE DISCLOSURE

A high power microwave multichannel switch wherein a first Butler matrix divides a high power input into lower-power parts, a phase shifter digitally shifting the lower-power parts or levels, and a second Butler matrix recombining the lower-power parts into any one of a number of high power output channels.

The present invention relates generally to high power microwave switches and more particularly relates to such a high power microwave switch utilizing Butler matrixes.

In the present state of the art of microwave switching, there are as yet no available components ideally suited for rapidly switching very high RF power levels from one waveguide channel to another. Ferrite switches have power limitations well below the power handling capability of the waveguides themselves. Gas plasma switches have been reported which can be used in pairs in a balanced duplexer arrangement to form a 3-port switch, but these plasma devices generally have a slow recovery time, and require large power supplies.

An object of the present invention is to provide a high power microwave switch utilizing well known standard components and operating them within their power capabilities.

Another object of the present invention is to provide multichannel switching of very high power levels through the utilization of readily available components of the present state of the art.

Briefly, the present invention accomplishes the above objects and further advantages by providing two Butler matrixes of waveguide hybrids which divide the high input power into a number of separate parts, which parts are then phase shifted at these lower power levels and recombined by the second Butler matrix to exit from any one of a number of the output channels.

The advantage of the present invention is that it provides a direct solution to the problem of high power multiple channel microwave switching and circumvents the need for special high power switches of an expensive nature. It can be applied to various high power microwave systems including radar, telemetry and communication systems.

Further advantages and objects of the present invention will be readily apparent from the following detailed description taken in conjunction with the drawing, in which:

FIGURE 1 is a phasor diagram useful in understanding the operation of a Butler matrix;

FIG. 2 is a symbolic representation of a type of short slot hybrid coupler utilized by Butler matrixes;

FIG. 3 is a schematic diagram helpful in understanding the operation of the present invention;

FIG. 4 is a schematic diagram of another illustrative embodiment of the present invention; and

FIG. 5 is a schematic diagram of yet another illustrative embodiment of the present invention.

The Butler matrix is an arrangement of 3 db hybrids and fixed 45° phase shifters which has been applied to multi beam array antennas. Power introduced into any one of its input ports is divided equally among the output ports, but with various phase delays, such that when

the output ports are connected to a linear array of antenna elements, a tilted beam is radiated. A complete description of a Butler matrix is contained in an article by Butler, J., and Lowe, R., "Beam Forming Matrix Simplifies Design of Electronically Scanned Antenna," Electronic Design, April 1961. The device is inherently binary, and can be extended to higher powers of 2. In other words, it can be designed to produce 2, 4, 8, 16 or 2^n beams.

For a clearer understanding of the operation of such a matrix it is desirable to understand the phase properties of the 3 db hybrid couplers which are used. Referring to FIGS. 1 and 2, an input power signal E_1 fed into one of its input ports **1** is split into two equal amplitude components at the opposite output ports **3** and **4** with no coupling of power to the adjacent input port **2**. The outputs E_3 and E_4 are equal in amplitude but differ in phase by 90 degrees. The signal component E_3 at the primary or in-line output terminal **3** experiences a 45° delay relative to the phase of the signal E_0 which would exist at that terminal if there were zero coupling to the secondary or auxiliary line. The other components E_4 experiences a 135° delay, which differs by −90° from the primary output E_3. In other words, a signal which goes straight through a coupler comes out with a 45° delay, while the signal which goes across a coupler comes out with a 135° delay. It is assumed that all coupler matrix paths are made of equal electrical lengths, and therefore the above coupler phase delays are the only significant phase effects.

It is well known that when the output ports of the Butler matrix are connected to a linear array of antenna elements, a tilted beam is radiated. For example, in FIG. 3, power introduced into any one of the input ports **1**, **2**, **3** or **4** is divided equally among the output ports A, B, C and D of a Butler matrix **10** but with various phase delays, as for example the values shown in Table I.

TABLE I.—OUTPUT PHASES FROM 4-PORT BUTLER MATRIX WHEN POWER IS APPLIED TO VARIOUS INPUT PORTS

	Input ports, deg.			
Output phases	1	2	3	4
A	−135	−225	−180	−275
B	−180	−90	−315	−220
C	−225	−315	−90	−180
D	−270	−180	−225	−135

However, the divided output power is not radiated but rather fed into the ports of an identical Butler matrix **20** attached back-to-back so that the power will be recombined in the second matrix and the total power P will appear at a single output port **1′** diagonally opposite the input port **1** as shown in FIG. 4. Input power P at port **2** will be emitted at output port **2′**; input port **3**, at output port **3′** and input port **4** at output port **4′**.

A high power single pole **4** throw microwave switch which allows selection of the output port from which the recombined power will exit is illustrated in FIG. 4. Similar items have been given the like reference characters, of FIG. 3. Each output port A, B, C and D of the first Butler matrix **10**, designated a power divider, is connected to an input port A′, B′, C′ and D′ of the second Butler matrix **20**, utilized as a power combiner matrix. The matrices **10** and **20** are connected in a back-to-back configuration by phase shifters ϕ_A, ϕ_B, ϕ_C and ϕ_D. The power divided by the first matrix **10** will be recombined and directed to exit a selected one of the output ports of the power combiner matrix **20** by properly adjusting the magnitude of phase shift in the phase shifters **51**, **52**, **53** and **54** interconnecting the intermediate terminals A–A′, B–B′, C–C′ and D–D′, respectively.

For the 4-port example shown in FIG. 4, input power to the input port **1** can be recombined into output ports **1′**, **2′**, **3′**, or **4′** by providing the phase shift values ϕ_A, ϕ_B, ϕ_C and ϕ_D given in Table II.

TABLE II.—VALUES OF PHASE SHIFT REQUIRED TO SWITCH INPUT 1 INTO FOUR OUTPUTS

	1′	2′	3′	4′
ϕ_A	0	−90°	−45°	−135°
ϕ_B	0	+90°	−135°	−45°
ϕ_C	0	−90°	+135°	+45°
ϕ_D	0	+90°	+45°	+135°

Since adding a constant value to all four phases does not alter their relative relationships, the phase shift values can be further simplified as shown in Table III.

TABLE III.—VALUES OF PHASE SHIFT REQUIRED TO SWITCH INPUT 1 INTO FOUR OUTPUTS

Outputs	1′	2′	3′	4′
ϕ_A	0	−180°	−180°	−270°
ϕ_B	0	0	−270°	−180°
ϕ_C	0	−180°	0	−90°
ϕ_D	0	0	−90°	0

It is to be noted that all the phase shifts indicated in Table III are negative or of additional delay and are in discrete multiples of 90°, which conveniently allows the variable phase shifters to be digital rather than analog devices. Each variable phase shifter is exposed to only one-fourth the total power being switched from input terminal **1** to any of the four output terminals. By extending the principles, illustrated in this 4-channel example to higher-order devices, such as an N-channel switch (where $N=2^n$), the variable phase shifters are exposed to only one-Nth the total power.

Thus, it can be seen that very high RF power levels can be switched by means of medium power phase shifters together with Butler matrices. Of course, the fixed phase shifters of 45° positioned in the Butler matrices must be capable of handling half of the total power being switched but such shifters with high power capability are readily available.

FIG. 5 illustrates a high power microwave switch without the interconnecting phase shifters ϕ. A low power switch **30** has a single input terminal **31** for receipt of the power to be switched and a plurality of output terminals to which the input power can be directed for entry into the first Butler matrix via the input ports **1**, **2**, **3**, or **4**. The lower power amplitude components appearing at the output ports A, B, C and D of the divider matrix **10** are each individually amplified by power amplifiers **40** which interconnect the two Butler matrices **10** and **20** in a back-to-back configuration.

The low power single pole **4** throw switch **30** can be a diode or ferrite device, depending upon the input power levels involved. The power amplifiers **40** must have adequate phase and gain stability control to provide good isolation of output power from the unswitched ports. However, the high power microwave switch illustrated in FIG. 5 eliminates the need for variable phase shifters yet still allows the combined power of many power amplifiers to be switched to a chosen single output port **4′**, **3′**, **2′** or **1′** of the high power switch.

While the present invention has been described with a degree of particularity for the purposes of illustration, it is to be understood that all modifications, substitutions and variations within the spirit and scope of the present invention are herein meant to be included. For example, while a 4-port microwave switch has been illustrated, a multiple port high power microwave switch having a higher power of the binary number 2 ports, such as an N-port device, can be readily fabricated. The total power which can be switched as N times the power handling capability of the individual variable phase shifters. While the invention has been described using wave-guides, stripline or coaxial channels may be utilized when desirable.

I claim as my invention:

1. A high power microwave multichannel switch comprising, in combination, first and second Butler matrices each having a like plurality of channels; each channel having an input port and an output port; means intermediate said first and said second Butler matrices connecting said matrices in a back-to-back combination with the resulting intermediate output port of a respective channel of said first matrix connected to a resulting intermediate input port of a respective channel of said second matrix; said means including a phase shifter between each pair of channels so coupled.

2. A high power microwave multichannel switch comprising, in combination, first and second Butler matrices each having a like plurality of channels; each channel having an input port and an output port; means intermediate said first and said second Butler matrices connecting said matrices in a back-to-back combination with the resulting intermediate output port of a respective channel of said first matrix connected to a resulting intermediate input port of a respective channel of said second matrix; said means including a phase shifter between each pair of channels so coupled; each said phase shifter being operable in 90 degree steps.

3. A high power microwave multichannel switch comprising, in combination; first and second Butler matrices each having a like plurality of channels, each channel having an input port and an output port; and means interconnecting said first and said second Butler matrices back-to-back for selectively shifting the phase of the power exiting each output port of said first Butler matrix and entering an output port, now input port, of the reversely connected second matrix in 90 degree steps.

4. A high power microwave multichannel switch comprising, in combination; first and second Butler matrices each including a like plurality of channels, each channel having an input port and an output port; a low power switch for receiving input power and directing such power to a predetermined input port of said first Butler matrix; means intermediate said first and second matrices connecting said matrices in a back-to-back combination with the resulting intermediate output port of a respective channel of said first matrix connected to a resulting intermediate input port of a respective channel of said second matrix; said means including a power amplifier between each pair of channels so coupled.

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