# United States Patent

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## [54] SINGLE POLE N-THROW MICROWAVE SWITCH

**3 Claims, 4 Drawing Figs.**

[52] U.S. Cl. ..... 333/7, 333/73C
[51] Int. Cl. ..... H01p 1/10
[50] Field of Search ..... 333/7, 17, 31, 73 C, 81, 81 A, 97 S

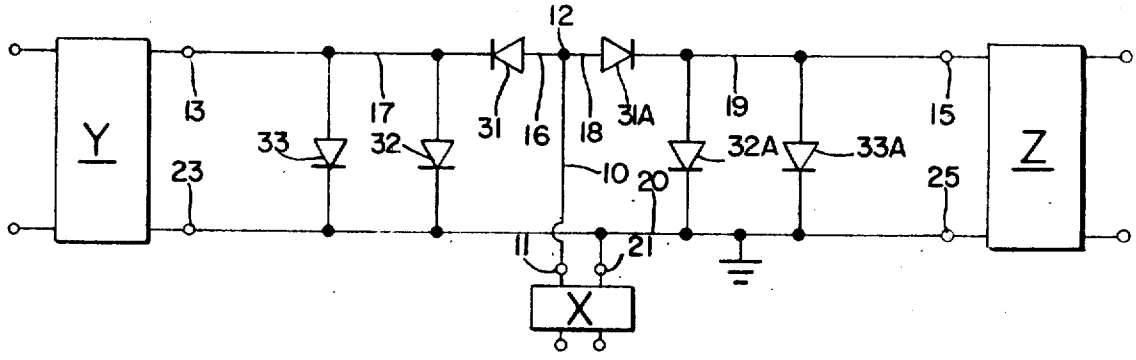
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**ABSTRACT:** A single pole multithrow microwave switch includes a number of terminal pairs, an outer conductor defining a cavity normally maintained at a reference potential intercoupling reference terminals in each terminal pair. Each terminal pair also has a signal terminal. An inner conductor within the cavity intercouples one signal terminal with a common terminal within the cavity. The common terminal is connected to each signal terminal by a circuit containing serially connected and shunt-connector diodes. The shunt-connected diode is coupled to the common terminal by a serially connected unilaterally conducting device in each circuit. The serially connected and shunt-connected diodes in each circuit are polarized so that mutually exclusive conduction occurs upon application of a bias signal. Portions of the inner conductor within the cavity coact with the outer conductor to define substantially inductive transmission line segments. These substantially inductive segments coact with the effective capacitance of the nonconducting diodes to comprise a substantially reflectionless filter circuit.



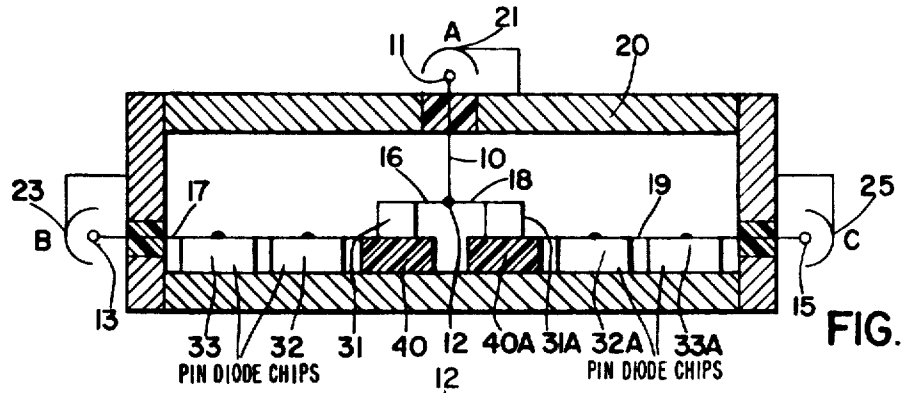



FIG. 1

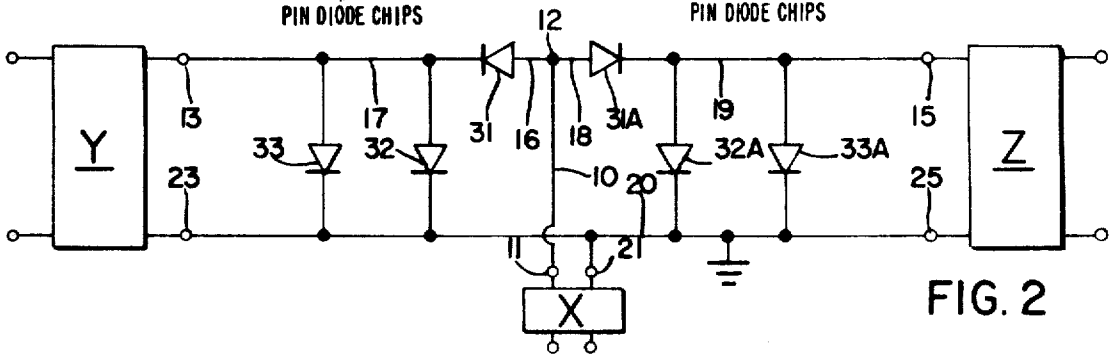



FIG. 2

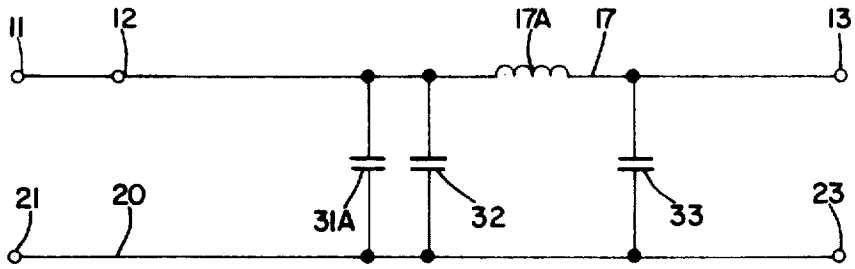



FIG. 3

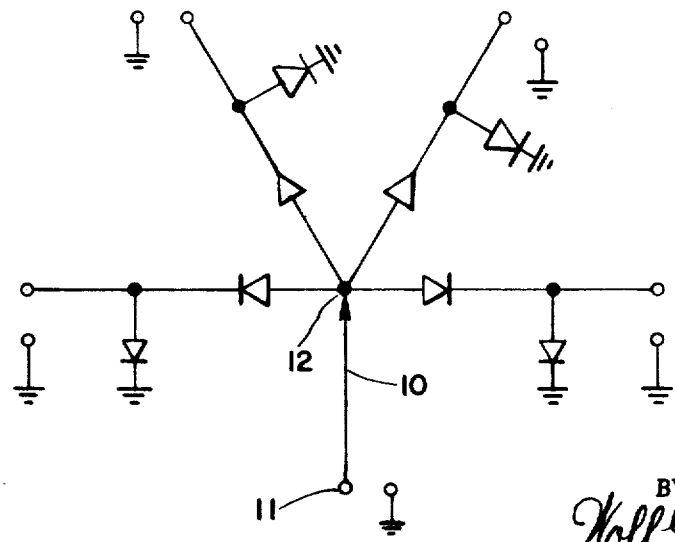



FIG. 4

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# SINGLE POLE N-THROW MICROWAVE SWITCH

## BACKGROUND OF THE INVENTION

The present invention relates in general to microwave switches and more particularly concerns a novel microwave switch of high electrical performance and small physical form which is relatively easy and inexpensive to fabricate in large and small quantities with uniformly high quality.

One well-known type of microwave switch comprises an inner conductor within a cavity which is capacitively coupled to coaxial terminals and having cartridge or case type diodes connected thereto. Cartridge crystals require a crystal holder and elaborate spring mechanism to create proper contact between the crystal and the inner conductor. Moreover, these large crystals need elaborate biasing circuits, introducing further fabrication problems and unwanted reflections in microwave frequencies.

While these techniques have not foreclosed satisfactory diode switch operation, they do introduce mechanical and electrical problems which are disadvantageous. The mechanical and electrical structures heretofore known are not only complex but also present considerable problems in connection with *r–f* impedance matching, particularly when broadband operation is desired.

These problems are caused mainly by the relatively large size of the crystals and their inherent mismatch with respect to the standard impedances found in the microwave field (i.e. 50 ohms).

Until recently, diode switch designs at microwave frequencies were limited to a maximum of 8 GHz., for example, axial lead glass switching diodes. Although these diodes work well up to approximately 6 GHz., the diode package parasitics degrade the switch performance above 8 GHz.

It is an important object of the invention to overcome limitations of the prior art and provide a broadband microwave switch of relatively small size that is adapted for utilization of standard miniature diode chips which introduce relatively little reflection at microwave frequencies.

It is another object of the invention to provide a broadband multiple throw microwave switch using standard miniature diode chips which introduce relatively little reflection at microwave frequencies.

A further object of this invention is to provide a broadband multiple throw switch of relatively low SWR suitable for sealed or unsealed operation.

A further object of this invention is to provide a broadband multiple throw switch characterized by relatively low insertion loss in the on path and high isolation in the off paths.

Another object of the invention is to achieve one or more of the preceding objects while keeping costs relatively low.

## SUMMARY OF THE INVENTION

According to the invention there are at least first and second terminal pairs each having a signal terminal and a reference terminal and an outer conductor defining a cavity. The outer conductor, normally maintained at a reference potential, intercouples the reference terminals in each terminal pair. An inner conductor within the cavity intercouples the signal terminal of the first terminal pair with a common terminal within the cavity. Circuits containing serially connected and at least one shunt-connected unilaterally conducting device intercouple the common terminal with each of the remaining signal terminals. The at least one shunt-connected unilaterally conducting device is coupled to the common terminal by the serially connected unilaterally conducting device and has its other terminal connected to the outer conductor defining the cavity. The serially connected and shunt-connected unilaterally conducting devices are poled for mutually exclusive conduction. The mutually exclusive conduction is dependent upon the polarity and the potential of the bias signal applied on the signal terminal of the first terminal pair relative to that on the signal terminal of the remaining terminal pairs and that on the outer conductor. The inner conductors within the cavity coact with the outer conductor to define substantially inductive transmission line segments. These substantially inductive transmission line segments coact with the effective capacitance of the unilaterally conducting devices in their nonconducting states to comprise a substantially reflectionless filter circuit.



In a modification of the present invention, there are a plurality of circuits containing unilaterally conducting devices extending from the common terminal to a plurality of signal terminals. Each circuit comprises at least two unilaterally conducting devices. Each circuit selectively passes *r–f* signal upon proper application of the bias signal. Proper application of bias, again, is dependent upon the polarity and potential of the signal applied to the signal terminal of the first terminal pair relative to that applied to the signal terminals of the remaining terminal pairs and that on the outer conductor. Again the inner conductors within the cavity comprise substantially inductive transmission line segments coacting with the effective capacitance of the unilaterally conducting devices in their nonconducting states to comprise a substantially reflectionless filter circuit.

These and other objects and advantages of the present invention will be more clearly understood when considered in conjunction with the accompanying drawings in which:

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a longitudinal sectional view of the single pole N-throw microwave switch according to the invention;

FIG. 2 is a schematic circuit diagram of the embodiment of FIG. 1 showing all the unilaterally conducting devices as diode elements and further showing the biasing networks connected to the switch;

FIG. 3 is a schematic representation of the circuit of FIG. 2 when biased to transmit between terminals 11 and 13, representing the nonconducting diodes as capacitors; and

FIG. 4 is a schematic circuit diagram of a modification of the invention with more throws and a single shunt diode per throw.

## DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Corresponding reference symbols will be used throughout the drawings to indicate corresponding elements where applicable.

With reference now to the drawings and more particularly FIG. 1 thereof, there is shown a longitudinal section view of the embodiment of the invention in which three terminal pairs A, B and C of a broadband single-pole double-throw microwave switch are diagrammatically represented. Outer conductor casing **20** defines a cavity and intercouples reference terminals **21**, **23** and **25** in terminal pairs A, B, and C respectively. Signal terminal **11** of terminal pair A is coupled to the common terminal **12** within the cavity by conductor **10**. Common terminal **12** is coupled to signal terminal **13** of terminal pair B by serially connected conductor **16**, unilaterally conducting device **31** and conductor **17**. Serailly connected unilaterally conducting device **31** is insulated from outer conductor casing **20** by insulating means **40**. Unilaterally conducting devices **32** and **33** are each connected by one terminal to conductor **17** and by the other to outer conductor casing **20**. Common terminal **12** is also coupled to signal terminal **15** of terminal pair C by serially connected conductor **18**, unilaterally conducting device **31A**, and conductor **19**. Serially connected unilaterally conducting device **31A** is insulated from outer conductor casing **20** by insulating means **40A**. Unilaterally conducting devices **32A** and **33A** are each connected by one terminal to conductor **19** and by the other terminal to outer conductor casing **20**.

FIG. **2** is a schematic circuit diagram of the embodiment of FIG. **1** further showing biasing networks connected to the broadband switch. FIG. **2** also illustrates how common ter-

minal 12 is connected to the signal terminals of terminal pairs B and C respectively by circuits containing serially connected and shunt-connected unilaterally conducting devices. In the circuits, unilaterally conducting devices 31 and 31A are serially connected and unilaterally conducting devices 32 and 33, 32A and 33A are shunt-connected. Biasing networks X, Y, and Z are respectively connected to terminal pairs A, B and C. The serially connected and shunt-connected unilaterally conducting devices are thus arranged so that they are poled for mutually exclusive conduction dependent upon the relative polarity and potential of the bias signal applied by biasing networks X, Y and Z.

FIG. 3 is a schematic circuit diagram of the embodiment of FIG. 2 showing one path on. The unilaterally conducting devices within the cavity are poled so that signal passes from signal terminal 11 to signal terminal 13. In this operating mode the series and shunt-connected unilaterally conducting devices are poled for mutually exclusive conduction. Unilaterally conducting devices 32A and 33A are in their conducting states while unilaterally conducting device 31A is nonconducting. Conversely, unilaterally conducting devices 32 and 33 are in their nonconducting states while unilaterally conducting device 31 is operating in a conducting mode.

The unilaterally conducting devices in their nonconducting states are represented by capacitors 31A, 32 and 33 in FIG. 3. In their conducting states, the unilaterally conducting devices pass substantially all of the *r-f* signal. Thus, one terminal of nonconducting unilaterally conducting device 31A is maintained substantially at *r-f* ground potential by conducting unilaterally conducting device 32A. Conducting unilaterally conducting device 31 passes substantially all the *r-f* signal from terminal 12 to nonconducting unilaterally conducting device 32. The segment of inner conductor 17 interposed between nonconducting unilaterally conducting devices 32 and 33 coacts with the outer conductor 20 forming the cavity to define a substantially inductive transmission line segment 17A. Thus, unilaterally conducting devices 31A and 32 are effectively maintained in parallel combination. Nonconducting unilaterally conducting devices 31A, 32 and 33 coact with the substantially inductive transmission line segment 17A to form a substantially reflectionless filter circuit.

FIG. 4 is a schematic circuit diagram of a modification of the invention in which four circuits extend from common terminal 12 to signal terminals of four terminal pairs. These circuits as, is illustrated in FIG. 2, are comprised of serially connected and shunt-connected unilaterally conducting devices. In this modification there is only one shunt-connected unilaterally conducting device in each circuit. Again the serially connected and shunt-connected unilaterally conducting devices are poled for mutually exclusive conduction dependent upon the relative potential and polarity of bias signal applied to the various signal terminals of the switch. Again, portions of the inner conductors within the cavity coact with the outer conductor to define substantially inductive transmission line segments. These substantially inductive transmission line segments coact with the nonconducting unilaterally conducting devices to form a substantially reflectionless filter circuit.

In the specific embodiment of the invention 50 ohm type axial terminals were used with an outer conductor casing of Kovar type material, 0.650 inches long. The cavity formed within the outer conductor was 0.450 inches in diameter. 0.015 diameter type Kovar wire was used as the inner conductor extending the first signal terminal to the common terminal within the cavity. 0.001 diameter wire was used to connect the common terminal with the serially connected unilaterally conducting devices and 0.005 inches by 0.001 inches gold ribbon was used to connect the serially connected unilaterally conducting device to the signal terminals. Si PIN type diode chips were used within the cavity as unilaterally conducting devices. Air dielectric insulated the serially connected unilaterally conducting device from the outer conductor casing. The diode chips required a bias current of 50 MA in order to switch the diodes to their conducting states. The broadband five-throw switch operated over a frequency range of 0.5 to 12.4 GHz. with an insertion loss of 2.5 db. and 2.0 maximum SWR. The isolation of the switch was 60 db.

An important feature of the invention is the adaptability of the structure to accommodating a variety of switching speeds. Switching speed, in general, is a function not only of the semiconductor devices used but of the drive pulse and the bias circuits. The switching speed of the semiconductor device itself is related to the power handling capability of the device. In low power semiconductor devices, relatively fast switching may be achieved while in the higher power devices, substantially slower switching inherently occurs. Thus, the types of unilaterally conducting devices utilized in the invention necessarily depend upon the design criteria. For fast switching, relatively low power handling capability semiconductor devices may be used. If high power handling capability is the requirement, then relatively low switching speeds can result.

An important feature of the invention is adaptability of the structure to accommodating terminals at different locations. FIG. 1 shows the output terminals being on the opposite points of the longitudinal axis of the diode switch. But the invention operates equally well with output terminals in space quadrature at other suitable angles. Also, the input terminal is shown orthogonal to the longitudinal axis of the switch. But the invention operates equally well with the input terminals in the same plane as the output terminals or at any suitable angle.

Another important feature of the invention is the adaptability of the switch to operation in various frequency ranges. The unilaterally conducting devices have substantially capacitive characteristics, varying with their composition, structure, and the frequency of interest. The conductors within the cavity may be chosen so they represent a substantially inductive characteristic in the frequency range of interest when coacting with the outer conduct or casing. Thus, the switch operates as a filter circuit whose bandwidth and frequency range may be determined by the type of unilaterally conductive devices and size of conductors within the cavity.

The invention is illustrated with a rectangular cavity formed by the outer conductor casing. The cavity may be cylindrical or in any other suitable shape. The broadband n-throw microwave switch may be constructed with two parallel plates forming a transmission line with the unilaterally conducting devices being mounted on one or both of the plates. The switch also may be constructed in microstrip or any other TEM waveguide configuration.

The serially connected and shunt-connected unilaterally conducting devices may be mounted within the cavity in such polarity as to conduct when either positive or negative bias is applied to the signal terminals of the switch. The invention is illustrated with 2 and 4 circuit arms respectively containing 2 and 1 shunt-connected unilaterally conducting devices. But the invention operates equally well with one or more circuit arms containing a plurality of unilaterally conducting devices. Also any number of shunt-connected unilaterally conducting devices may be used. Furthermore, a multiplicity of unilaterally conducting devices may be connected in parallel with one another to form a series portion of the circuit.

Other modifications and uses of and departures from the specific embodiments described herein may be practiced by those skilled in the art without departing from the inventive concepts. Consequently, the invention is to be construed as embracing each and every novel feature and novel combination of features present in or possessed by the apparatus and techniques herein disclosed and are limited solely by the spirit and scope of the appended claims.

What I claim is:

1. A broadband microwave switch operative within a predetermined microwave frequency range comprising,

means defining at least first, second and third terminal pairs each having a signal terminal and a reference terminal,

an outer conductor defining a cavity normally maintained at reference potential intercoupling said reference terminals,

means defining an inner conductor within said cavity coupled at one end to the first signal terminal,

the other end of said inner conductor defining a common terminal within said cavity,

first circuit means including a first unilaterally conducting device intercoupling said second signal terminal with said common terminal,

said first circuit means also having at least second and third unilaterally conducting devices in parallel each having one terminal coupled to said common terminal by means including said first unilaterally conducting device and the other terminal of each connected to said outer conductor with a conducting segment between each of the latter one terminals comprising an inductance that coacts with the capacitances of unilaterally conducting devices in said cavity and other inductances in said cavity to form a substantially reflectionless band-pass filter within said predetermined microwave frequency range in a selectable transmission path between said first and second terminal pairs,

said first and the parallel second and third unilaterally conducting devices being poled for conduction during first and second mutually exclusive time intervals respectively dependent upon the polarity of the potential on said second signal terminal relative to that on said first signal terminal and that on said outer conductor for allowing and preventing the transfer of *r–f* energy between said first and second terminal pairs during said first and second time intervals respectively,

second circuit means including a fourth unilaterally conducting device intercoupling said third signal terminal with said common terminal,

said second circuit means also having at least fifth and sixth unilaterally conducting devices in parallel each having one terminal coupled to said common terminal by means including said fourth unilaterally conducting device and the other terminal of each connected to said outer conductor with a conducting segment between each of the latter one terminals comprising an inductance that coacts with the capacitances of unilaterally conducting devices in said cavity and other inductances in said cavity to form a substantially reflectionless band-pass filter within said predetermined microwave frequency range in a selectable transmission path between said first and third terminal pairs,

said fourth and the parallel fifth and sixth unilaterally conducting devices being poled for conduction during third and fourth mutually exclusive time intervals respectively dependent upon the polarity of the potential on said third signal terminal relative to that on said first signal terminal and that on said outer conductor for allowing and preventing the transfer of *r–f* energy between said first and third terminal pairs during said third and fourth time intervals respectively.

2. A broadband microwave switch according to claim 1 wherein said unilaterally conducting devices include diode chips.

3. A broadband microwave switch in accordance with claim 1 and further comprising means for establishing transmission between said first terminal pair and said second terminal pair and between said first terminal pair and said third terminal pair during mutually exclusive time intervals.