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WAVEGUIDE SHORTING SWITCH HAVING ASYMMETRICALLY LOCATED CAPACITIVE ELEMENTS AND SHORTING PINS

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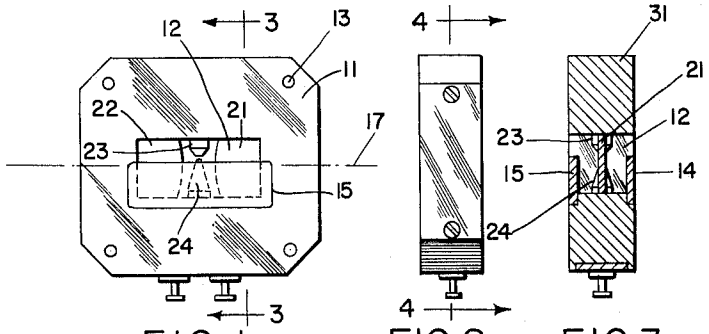


FIG. 1 FIG. 2 FIG. 3

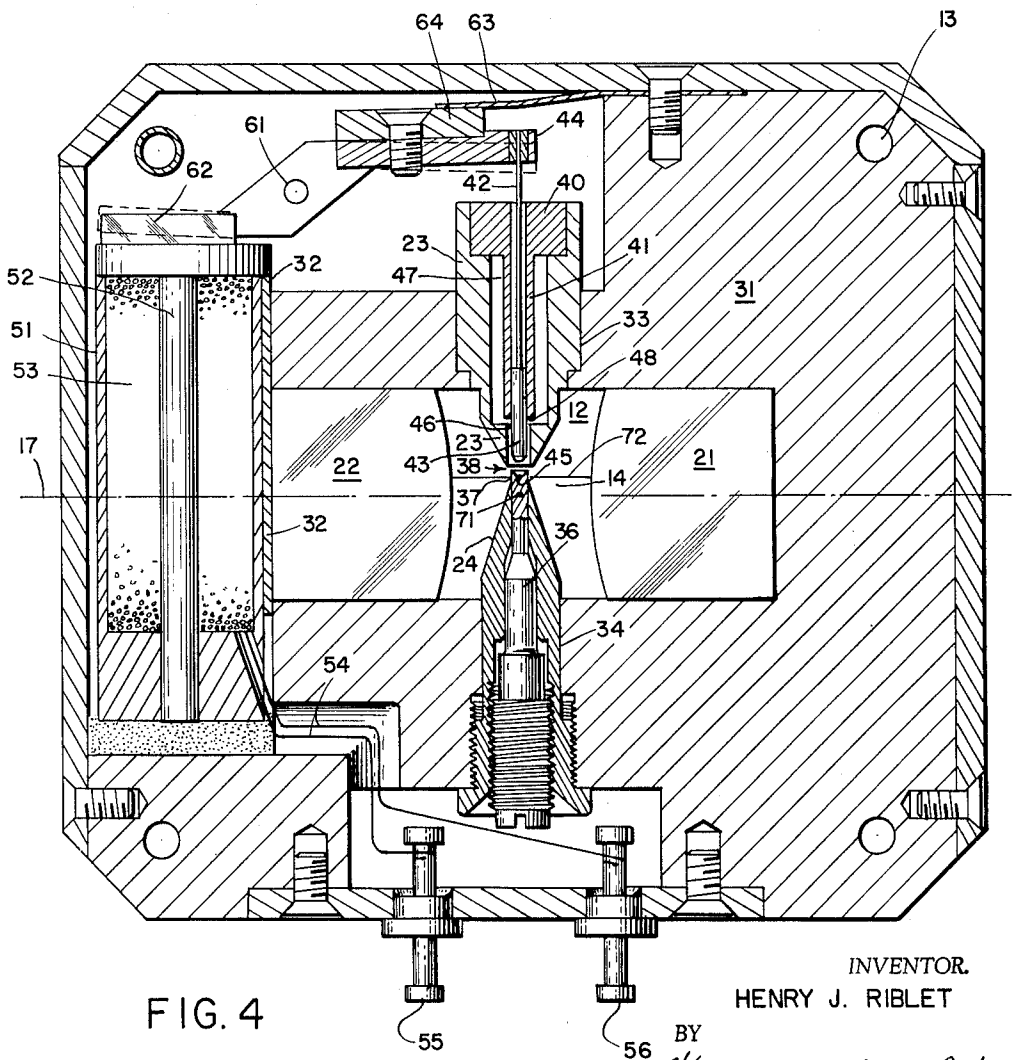


FIG. 4

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WAVEGUIDE SHORTING SWITCH HAVING ASYMMETRICALLY LOCATED CAPACITIVE ELEMENTS AND SHORTING PINS

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The present invention relates in general to the control of microwave energy transmission and more particularly concerns an exceedingly effective, compact, high speed microwave switch.

In many waveguide transmission systems, the flow of microwave energy must be controlled precisely, and typically, microwave switches are used to protect radar crystal rectifiers from possible damage by high intensity signals emanating from other, nearby, high power microwave equipment. In normal radar operation, the crystal detector is protected from both its own transmitter and external high intensity signals by the duplexing action of the TR tube. However, when this equipment is shut down and the TR tube operation ceases, the crystal becomes susceptible to damage from high level stray microwave signals. A shorting switch, which automatically closes when the radar power is turned off, may be used successfully to protect sensitive rectifiers. Microwave switches are also utilized to control microwave power flow through selected waveguide transmission line branches, as in duplexers designed around microwave hybrid junctions.

Numerous microwave switching techniques have been described in the patents and the literature. One form of switch utilizes a shorting plate which effectively shuts off a waveguide at a predetermined location. While such devices are quite effective in limiting the flow of microwave energy, they suffer from the limitation that exceptionally large mechanical movement is required to change the state of the switch from open to shut. Other switches which overcome this particular shortcoming have also been described, and typically, reference is made to applicant's Patent 2,955,268 dated October 4, 1960, which discloses a waveguide-pin switch. Here, switching is accomplished by the relatively limited motion of a large plurality of pins, disposed longitudinally along the waveguide axis, the pins being operative through relatively small diameter openings in the waveguide wall. In the pin switch, such as shown in this patent, the short-circuit placed across the waveguide reflects essentially all incident power. While effective in many systems, the size and weight of this switch design present problems in airborne and similar equipment.

The present invention is concerned with a waveguide, pin-type shorting switch which is particularly adapted to microwave transmission apparatus requiring highly effective switching characteristics where space and weight are at a premium. As will become apparent from the specifcation which follows, the switch of the persent invention may be inserted into transmission apparatus entirely within the confines of the conventional waveguide flanges normally used for interconnecting waveguide sections without increasing the axial length of the transmission system by more than approximately one quarter wavelength at the frequency of operation. The switch may be electromagnetically operated at exceedingly high speed and arranged to provide a relatively high insertion loss when closed, substantially without loss when open.

In connection with the disclosure set forth in this application, it would be appropriate at this point to make reference to the copending application of Edward Salzberg, Serial No. 731,207, filed, April 28, 1958, and entitled Microwave Frequency Selective Apparatus, now Patent

3,027,525. Broadly speaking, the Salzberg application discloses a microwave quarter wavelength band-pass filter. In one embodiment thereof, the band-pass characteristic is achieved within a rectangular waveguide transmission line by means of a pair of capacitive irises spaced approximately one quarter wavelength apart, as measured along the longitudinal axis of the waveguide. In addition, a microwave resonant element is disposed in a plane transversely of the waveguide longitudinal axis, substantially midway between these capacitive irises. By proper arrangement of the capactive irises and the resonant element, good band-pass and band-rejection characteristics are achieved over a relatively broad microwave frequency spectrum. The precise analytical controlling factors in the design of the Salzberg quarter wavelength filter are set forth in detail in the copending application.

The present invention contemplates and has as a primary object the provision of a waveguide shorting switch which in the switch-open condition comprises a quarter wavelength band-pass filter. More particularly, a rectangular waveguide section having an axial dimension of approximately a quarter wavelength within the frequency band of operation is arranged with first and second capacitive elements positioned respectively at the input and output rectangular openings of the waveguide. A resonant element is placed in a transverse plane substantially midway between these capacitive elements, the resonant element in turn comprising a pair of symmetrically disposed coplanar inductive irises and a pair of confronting conductive posts extending inwardly, in closely spaced but noncontacting relationship, from the opposed broad walls of the rectangular waveguide. One of these two posts is generally hollow and contains a relatively thin coaxially slidable conductive pin which may be displaced into conductive short-circuiting contact with the oppositely positioned post. For minimum pin travel, it is desirable to have the two posts relatively close together, for example, the order of .010". This implies a large capacity and a high-Q resonant element. Under conditions where such short-circuiting contact is achieved, the microwave waveguide filter section is sharply detuned, and will thus reflect substantially all incident microwave energy. With the pin withdrawn, the switch waveguide section functions in a desirable manner as a band-pass filter with exceptionally low insertion loss and with a highly satisfactory VSWR.

In order to obtain the low VSWR together with minimal pin motion, the present invention utilizes capacitive elements at the input and output openings of the waveguide switch which are asymmetrically disposed with reference to the waveguide longitudinal axis and the waveguide rectangular cross-section. For the same reasons, the gap between the conductive posts of the resonant element is also asymmetrically disposed with respect to the longitudinally axis of the waveguide section. In a preferred embodiment, the aforementioned capacitive irises comprise relatively thin conductive plates extending upwardly from one of the broad walls slightly above the longitudinal axis of the waveguide section while the gap between the conductive posts is even further displaced from the waveguide axis in the same direction. The specific advantages achieved by this configuration will be set forth at a later point in the specification.

An additional significant feature of the present invention comprises the technique for achieving a highly effective microwave short-circuit between the conductive posts of the resonant element, when electrically connected by the shorting pin. As will be seen, this is achieved by hollowing-out the conductive post enclosing the shorting pin and its guide to define a generally cylindrical volume, short-circuited at one end and communicating with the waveguide section at the other end in the region of the

innermost portion of the oppositely disposed conductive post. This hollow region and pin guide serve as a choke dimensioned to enhance the effective reflecting properties of the two posts when the pin is displaced into short-circuiting contact.

Apart from the features and advantages enumerated above in connection with the switch as a microwave component, the present invention permits a geometry so that a solenoid actuator may be disposed in a relatively small volume within the switch structure, externally adjacent to the rectangular waveguide section. The solenoid actuator, for which external electrical terminals are provided, is coupled to the shorting pin by means of a relatively small, dynamically balanced, spring-loaded linkage. Ordinarily, when the solenoid is de-energized, the spring-loading drives the shorting pin into short-circuit connection. When the solenoid is energized, the light-weight linkage operates almost instantaneously to drive the pin in a relatively linear manner to a position out of engagement with the opposite post.

Other objects, features and advantages of the present invention will become apparent from the following specification when read in connection with the accompanying drawings in which:

FIG. 1 is an external front view of the novel waveguide switch of the invention;

FIG. 2 is an external side view of the waveguide switch shown in FIG. 1;

FIG. 3 is a general cross-sectional view of the waveguide switch, taken along the plane 3—3 of FIG. 1; and

FIG. 4 is an enlarged cross-sectional view of the waveguide switch taken along the plane 4—4 of FIG. 2.

With reference now to the drawing, and more particularly to FIGS. 1, 2, and 3, the broad outlines of the microwave switch of the present invention are illustrated. When viewed from the front, as in FIG. 1, the switch is seen to comprise a generally rectangular structure **11** formed with a conductive rectangular waveguide section **12** in the central portion thereof. The exterior dimensions of the body portion **11** preferably correspond with customary waveguide flange couplings characteristic of the band of waveguide **12**, and a plurality of mounting holes **13** are provided for attachment of the switch to waveguide flanges in the transmission system.

FIGS. 1 and 3 illustrate the arrangement whereby the rectangular input and output openings of waveguide section **12** are partially covered by recessed, conductive, capacitive irises **14** and **15**, and it should be observed that the uppermost edge of the respective iris falls above the center line **17** which passes through the longitudinal axis of waveguide **12**.

Disposed midway between the capacitive irises **14** and **15**, in a plane perpendicular to the longitudinal axis of waveguide **12**, are a pair of inductive irises **21** and **22**. The latter irises symmetrically encompass a pair of posts **23** and **24** which extend inwardly of the waveguide **12** from the opposite broad walls thereof. As shown in FIG. 1, a small gap exists between the innermost ends of these two posts, and further, it should be noted that this gap is not only upwardly displaced from the longitudinal axis of waveguide section **12**, but also displaced somewhat more than the upper edges of the capacitive irises **14** and **15**.

Waveguide **12**, as shown in FIG. 3, has a relatively short dimension measured along its longitudinal axis. As will be further discussed below, the axial distance between the outer faces of capacitive irises **14** and **15** is approximately one quarter wavelength taken at a frequency within the normal band of operation of waveguide **12**. Thus, within the quarter wavelength guide section, there are the two capacitive elements **14** and **15** and a central resonant structure made up of the inductive irises **21** and **22** and the posts **23** and **24**.

Taken as a passive waveguide structure, with the gap between posts **23** and **24** open, as shown in FIG. 1, the device represents a quarter wavelength filter generally as disclosed in the aforementioned Salzberg copending patent application. By distinction, however, capacitive elements **14** and **15** and posts **23** and **24** are asymmetrically disposed with reference to the longitudinal axis of waveguide **12**, as noted earlier.

In FIG. 4, the details of the waveguide switch of the present invention are shown in enlarged cross-sectional form. Specifically, a machined conductive block **31** forms the core of the device, which with conductive side plate **32**, defines the broad and side walls of rectangular waveguide section **12**. Capacitive iris **14** shown in FIG. 4 is recessed into the block structure **31** in the manner shown for both such irises in FIG. 3. It will be understood that firm electrical contact between conductive microwave elements, such as capacitive irises **14** and **15**, inductive irises **21** and **22**, and the like, may be established by conventional silver soldering or brazing.

Conductive posts **23** and **24** are generally cylindrical members with conical tips, and these extend into waveguide **12** through suitable cylindrical openings **33** and **34** in the block **31**. The vertical axis of these conductive posts is midway between the side walls of rectangular waveguide **12** and substantially midway between capacitive irises **14** and **15**. The vertical axis of the posts also intersects the longitudinal axis of waveguide section **12**.

It will be observed in FIG. 4 that the lower post **24** includes a solid, central conductive member **36**, which at its lower end threadably engages the conductive post **24**, to permit vertical adjustment of the projection of the tip **37**. This in turn permits critical adjustment of the gap **38** between the upper and lower posts, the gap dimension for X-band operation being of the order of 0.010 inch.

The upper post **23** is of hollow construction and includes a conductive upper cap **40** having a smaller diameter cylindrical extension **41**, which in turn freely guides thin cylindrical actuator rod **42**. The latter in turn supports and actuates shorting pin **43**, which is chamfered at its lower end and extends almost to the gap **38**, as shown. Cylindrical extension **41** is approximately a quarter wavelength long.

The shorting pin **43** is conductive and arranged for free, rapid axial movement in guide **41**. The upper end of rod **42** is engaged by one end of a rocker arm **44**, the function of which will be described later. In the position of the rocker arm shown, however, the lowermost end of pin **43** is withdrawn into post **23** slightly above gap **38**. A small chamfered bore **45** in the upper end of post tip **37** is arranged to receive conductive pin **43** when displaced downwardly.

A small annular gap **46** communicates at its lower end with the waveguide **12** in the region of gap **38**, and at its upper end with the enlarged annular region **47** within the post **23**, through the choke gap **48**. This region **47** functions as a microwave choke, as will be further mentioned below, but it should be observed here that the choke gap **48** lies within the waveguide section **12**.

A small solenoid **51** having a magnetic core **52** is positioned within the switch structure, but externally of the waveguide section **12**. The cylindrical coil **53** of this solenoid is connected by a pair of wires **54** to external electrical terminal **55** and **56**, for energization from a suitable D.C. source, not shown.

The rocker arm **44** is pivoted at a substantially central point **61** and on the left-hand end terminates in the magnetic button **62**. A small leaf spring **63** rigidly fixed at the right-hand end, as shown, bears down upon the rocker arm in the region **64** thereof, and as a consequence tends to normally drive the rocker arm **44** into the position shown in the dotted lines. This, it should be observed, will drive the lowermost portion of pin **43** into the small bore **45**, for short-circuiting contact therewith. Hence, the rocker arm, as shown in solid lines in FIG. 4, is in the position assumed when solenoid **51** is energized. De-energization will automatically set up the short-cir-

cuit condition between posts **23** and **24**, previously mentioned.

In view of the detail of FIG. 4, it would be appropriate here to re-emphasize some of the structural features previously discussed in connection with FIGS. 1 and 3. The longitudinal axis of the waveguide section **12** is represented by the dot at **71**. The upper edge **72** of capacitive iris **14** and the corresponding upper edge of capacitive iris **15**, not shown in FIG. 4, are arranged to be asymmetrically above the longitudinal axis **71**. The gap **38** is even further displaced, that is, even more asymmetrically disposed with respect to axis **71**. The asymmetrical posts **23** and **24** together with inductive irises **21** and **22** are arranged to be resonant at a frequency substantially less than the pass-band of the quarter wavelength filter which is formed by the aforesaid resonant element and the two capacitive irises.

In operation, with the pin **43** in the position shown, the filter structure formed within waveguide section **12** passes a relatively broad band of signals within the normal transmission band for waveguide of the specific dimensions utilized. When, however, the solenoid **51** is de-energized and the pin **43** is abruptly driven into short-circuiting contact with the lower post **24**, this filter is sharply detuned and the short-circuit effectively introduces substantial reflection for microwave energy within the pass-band incident thereon. The switch is thus closed.

Rapidity of operation of the switch shown in the drawings is assured by arranging rocker arm **44** for dynamic balance. When the solenoid is de-energized, spring **63** displaces a relatively small mass for a comparatively short distance. The solenoid when energized corrspondingly actuates a relatively small mass against the force of spring **63**. In considering the operation of the short-circuiting pin **43**, it is to be noted that the pin is slidably fitted within guide **41**, thus permitting freedom of action while maintaining some electrical contact therewith. Microwave leakage through cylindrical extension **41** is insignificant due to the open circuit presented at the choke gap **48** by the choke **47**. When the pin **43** is displaced downwardly into bore **45**, the choke formed by the annular region **47** presents an open circuit at such a position at the pin **43** so as to provide an exceedingly effective microwave short-circuit. The axial dimension and location of choke **47** is empirically selected for the band of frequencies of operation to provide maximum microwave short-circuiting effect.

The combination shown of a movable pin slidable within a choke is effective to permit an exceptionally high insertion loss in the contacting condition. Typically, for the switch shown, dimensioned for X-band operation, as for example, a frequency band extending from 9.2 to 10.0 kmc., the insertion loss with the switch closed is 35 db, or greater, while the identical device, with the pin withdrawn as shown in FIG. 4, has an insertion loss of less than 0.15 db with a VSWR of no more than 1.10. For a device of these characteristics the resonant frequency of the resonant element is approximately 8.5 kmc.

The rapidity of action permitted by the dynamically balanced rocker arm permits switching times of 10 milliseconds or less upon the application and removal of the appropriate D.C. signal at terminals **55** and **56**. The significance of this invention is perhaps best illustrated by noting that the approximate weight of an X-band switch as shown with the characteristics enumerated above, is less than two ounces.

There are, of course, numerous modifications and extensions of the principles of this invention which may be made without departing from the spirit thereof. For example, the solenoid actuator, while shown as an internal element, may be mounted externally to enhance cooling. It should be apparent that it is possible to reverse the function of the solenoid, so that the switch may be normally open when the solenoid is de-energized. Accordingly, the present invention should not be deemed to be limited to the embodiment shown in the drawing, but rather, by the scope of the appended claims.

What is claimed is:

1. A microwave switch for controlling the flow of microwave energy within a predetermined band of frequencies comprising, a rectangular waveguide section having an axial dimension of substantially one quarter wavelength of said microwave energy, resonant means asymmetrically arranged within said waveguide section and including a pair of spaced conductive posts, means within said quarter wavelength waveguide section for tuning said waveguide section including said resonant means for operation as a band-pass filter within said predetermined frequency band, said resonant means being resonant at a frequency outside said filter pass band, and means for abruptly and substantially detuning said resonant element.

2. A microwave switch for controlling the flow of microwave energy within a predetermined band of frequencies in accordance with claim **1**, wherein said tuning means includes a pair of capacitive elements asymmetrically disposed with reference to the longitudinal axis of said waveguide section.

3. A microwave switch for controlling the flow of microwave energy within a predetermined band of frequencies in accordance with claim **2** wherein said asymmetrical capacitive elements comprise capacitive irises disposed respectively at opposite ends of said waveguide section.

4. A microwave switch for controlling the flow of microwave energy within a predetermined band of frequencies in accordance with claim **3** wherein said resonant element comprises, in addition to said spaced conductive posts a pair of inductive irises disposed oppositely of said conductive posts in a plane through said posts substantially perpendicular to said waveguide axis.

5. A microwave switch for controlling the flow of microwave energy within a predetermined band of frequencies in accordance with claim **4**, wherein the gap between said spaced conductive posts is asymmetrically disposed with reference to said axis of said waveguide.

6. A microwave switch for controlling the flow of microwave energy within a predetermined band of frequencies comprising, a rectangular waveguide section formed of spaced confronting pairs of relatively broad and relatively narrow conductive walls dimensioned for transmission of microwave energy within said frequency band, said waveguide section having an axial dimension between input and output rectangular openings of substantially one quarter wavelength of said microwave energy, resonant means disposed substantially at the center of said waveguide section axis including a pair of spaced coaxial posts extending inward from respective ones of said broad walls and a pair of conductive inductive irises disposed oppositely of said resonant posts in a plane substantially perpendicular to said axis and extending through said posts, a pair of capacitive irises asymmetrically disposed in the planes of said input and output rectangular openings respectively, said capacitive and inductive irises and said posts being arranged whereby said waveguide section is operative as a band-pass filter within said predetermined band of frequencies, said posts and said inductive irises being resonant at a frequency outside said filter pass-band, and means for abruptly short-circuiting said posts in said spacing therebetween.

7. A microwave switch for controlling the flow of microwave energy within a predetermined band of frequencies in accordance with claim **6**, wherein said spacing between said posts is asymmetrically disposed with respect to said axis of said waveguide section.

8. A microwave switch for controlling the flow of microwave energy within a predetermined band of frequencies in accordance with claim **7**, wherein said means for short-circuiting said posts comprises a coaxial pin extending through a first of said posts from a point at

the inner face thereof to a point external of said rectangular waveguide section, electromagnetic means externally adjacent said waveguide section, and dynamically balanced means coupling said electromagnetic means to said pin, whereby in response to said electromagnetic means said pin may be axially displaced into contact and out-of-contact with the second of said posts.

9. A microwave switch for controlling the flow of microwave energy within a predetermined band of frequencies in accordance with claim **8**, wherein said pin extending through said first post is enclosed in a conductive tube, said first post being formed with an internal opening whereby the region therein surrounding said tube communicates with said waveguide section in the area adjacent the innermost end of said second post, said region serving as a microwave choke.

10. A microwave switch in accordance with claim **9** wherein said choke is substantially one quarter wavelength long and is conductively terminated at its end opposite said pin.

11. Apparatus in accordance with claim **10** wherein

the end of said choke in the region of said pin lies within the cross-section of said waveguide.

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