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[54] CAPILLARY STAGE FOR MICROWAVE TR DEVICES USING STATIC MAGNETIC FIELDS

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[51] Int. Cl. H01j 7/46, H01j 19/80

[58] Field of Search 315/39; 333/13

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Primary Examiner—Eli Lieberman

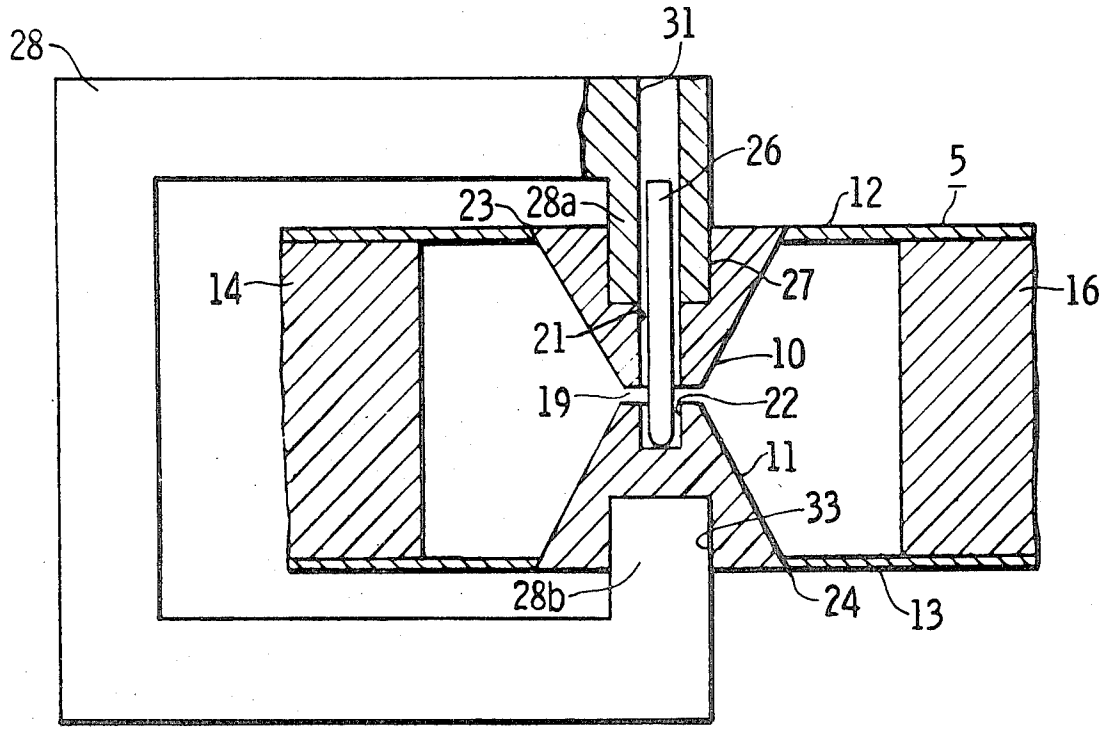
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[57] ABSTRACT

Gaseous discharge TR switch in which two truncated cone electrodes extend inwardly from the broad sidewalls of a waveguide with the truncated ends in juxtaposition to form a discharge gap, the electrodes having a central bore with a capillary tube extending across the gap and including an ionizable gas and a magnetic field being disposed with its flux lines extending parallel to the axis of the tube and to the electric vectors of the microwave in the waveguide.

6 Claims, 3 Drawing Figures



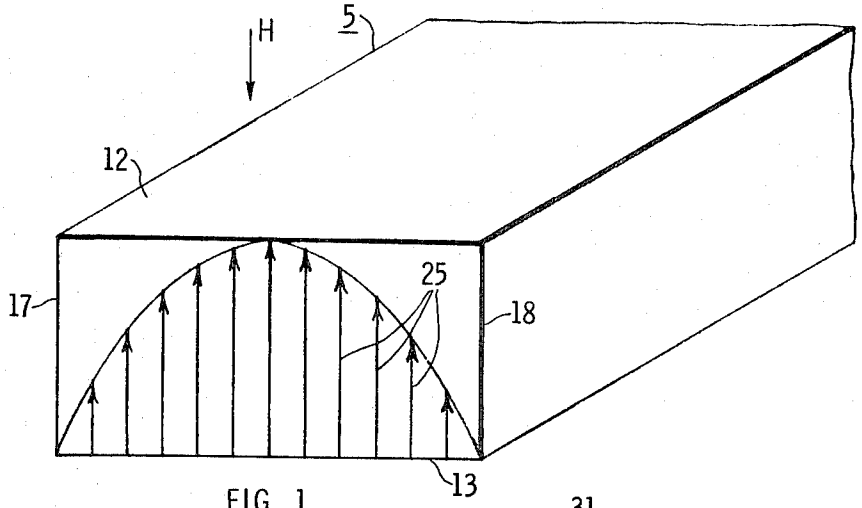


FIG. 1

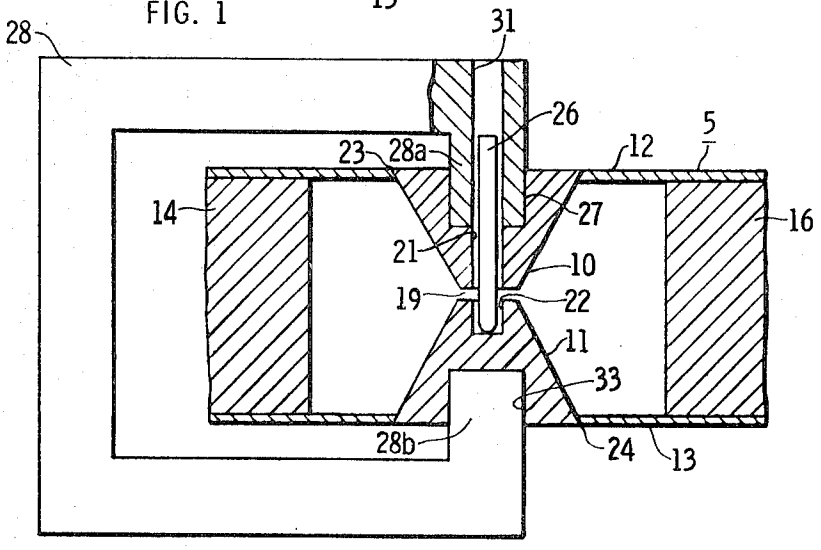


FIG. 2

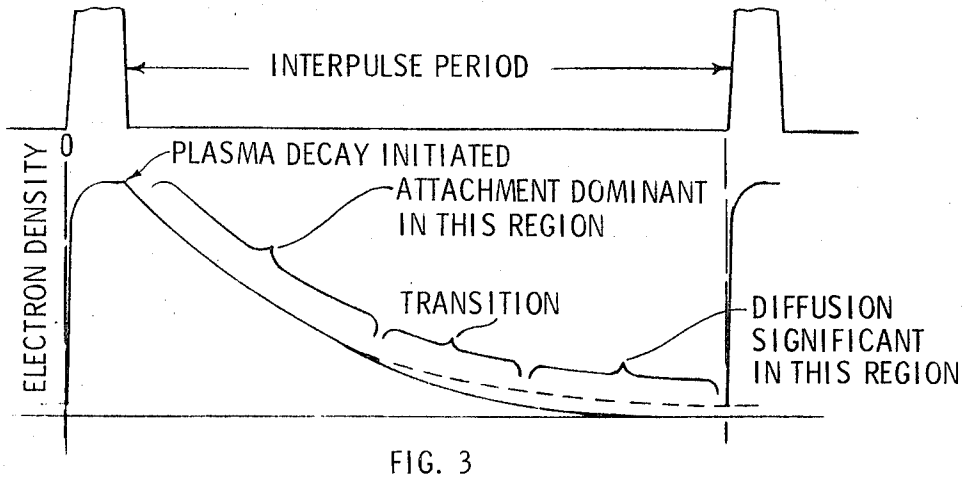


FIG. 3

CAPILLARY STAGE FOR MICROWAVE TR DEVICES USING STATIC MAGNETIC FIELDS

BACKGROUND OF THE INVENTION

This invention relates, in general, to gaseous discharge TR switches which are used in the microwave art for the purpose of permitting the use of a single antenna for transmission and reception. As is well known in the art the letters "TR" stand for transmit and receive, meaning that the gaseous discharge device automatically permits the transmission of high-voltage electromagnetic wave energy in the direction from the transmitter to the antenna while at the same time preventing the transmitted power from reaching and damaging the receiver. Such switches also permit the low-power received signal coming through the microwave guide in an opposite direction to be routed into the receiver.

The TR switch functions to short circuit the receiver when a high-power pulse from the transmitter is routed to the antenna and thus prevents a high-energy pulse from damaging the sensitive receiver. In order to accomplish this result a TR switch must change its impedance almost instantly and selectively, depending upon the direction of propagation and amplitude of the signal. The change in impedance must take place with great rapidity from a nearly nonconductive state to a conductive state when the transmitter pulse wave front appears, and must change back again to the nonconductive condition with great rapidity when the transmitted pulse has terminated, to put the circuit in condition for receiving the echo signal. To effect this change, it is necessary that the gaseous medium of the switch shall rapidly ionize so that a space discharge may be initiated by a relatively small voltage rise, that is, it should have a comparatively low breakdown voltage, and it should deionize rapidly when the voltage is removed so the return signal may be admitted to the receiver.

TR switches of the general type to which this invention relates are very well known and may be considered to be represented by the type of switch described and claimed in U.S. Pat. No. 3,208,012, issued to Gerald I. Klein on Sept. 21, 1965. This patent is assigned to the assignee of this application. While the devices of the prior art generally operate at comparatively low firing powers, their recovery time is comparatively long. As is illustrated in the patent, the conventional TR tubes use an ionizable medium having a very fast recovery time, and it is common to use a halogen gas, such as chlorine, in the devices. The chlorine is usually enclosed in a capsule of suitable material, such as quartz, and this is usually in the form of a capillary tube since the tube is usually of very small diameter and it extends through aligned bores in truncated cone members extending inwardly from the block wall to the guide to form a discharge gap. As in the present invention, these TR switches are arranged in a resonant microwave aperture, or iris. This is so that the incidence of a high-power electromagnetic wave will develop a very high voltage between the discharge electrodes thus causing ionization of the gas within the capillary tube. The ionized gas forms a low resistance path between the opposite edges of the iris between which the discharge is established and which, in turn, effectively short circuits the path across the iris and causing reflection of incident radiation. Capillary stages which employ highly attaching halogen gases are used in TR devices to obtain extremely fast recovery periods in the order of tens of nanoseconds. The devices of the prior art are limited in duty cycle range by the almost complete disappearance of free electrons during the interpulse period. Thus when the gas is exposed to a train of RF exciting pulses, whose interpulse period is relatively long, that is, the radar is operating at a very low PRF, the free electrons necessary to facilitate breakdown are absent. This condition leads to an unstable firing power level which, as far as external operating characteristics are concerned, appears as a random amplitude-modulated spikes on the leakage waveform of the TR device, FIG. 3.

The present invention provides an improvement on these prior art devices that substantially eliminates the random AM modulation on the spike pulses and also greatly increases the operating duty cycle range.

SUMMARY OF THE INVENTION

This invention contemplates the immersion of the ionizable halogen gas in a weak static magnetic field with the magnetic field disposed so that the lines of force are parallel to the E vectors of the microwave energy in the waveguide.

It has been found that by the application of a magnetic field in the manner specified, the firing threshold in stability, which is a characteristic of the halogen plasmas when excited at low duty cycles, can be substantially reduced without affecting the recovery time or the leakage power level. Furthermore, the improvement of electrical characteristics of this invention is independent of the signal frequency.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an isometric view, partially broken away, to illustrate the application environment of the present invention;

FIG. 2 is a partial sectional view of the microwave switching device in the embodiment shown in FIG. 1; and

FIG. 3 is a graphical presentation of the relation between the electron density and the interpulse period in a device of the present invention when used in a pulsed microwave system.

Briefly, this invention accomplishes the objectives of the present invention by providing a gas discharge TR switch which includes a section of hollow waveguide operating in the dominant TE_{10} wherein the electric vectors are parallel to the narrow sidewalls of the waveguide.

Referring specifically to the drawings it will be noted that there are a pair of frustoconical electrodes **10** and **11** which are attached in good electrical conducting relation to the upper and lower broadwalls **12** and **13**, respectively, of the waveguide section **5**. The waveguide section **5** is of a suitable electrically conducting material, such as copper, as is standard practice in the art. A pair of electrically conducting vanes **14** and **16** extend inwardly from each of the narrow sidewalls **17** and **18**, respectively, and are positioned in a plane which is perpendicular to the major or longitudinal axis of the waveguide section. These vanes constitute a tuned iris, the center plane of which passes through the centers of the frustoconical electrodes **10** and **11**.

The two electrodes **10** and **11** form the capacitive portion of the tuned circuit of which the two side vanes **14** and **16** constitute the inductive portions. This is clearly indicated in the drawings, where the smaller ends of the electrodes **10** and **11** define a discharge gap **19** between their adjacent extremities.

The upper electrode **10** is provided with a centrally extending bore **21** which is in alignment with a circular recess **22** in the lower electrode **11**. The base end of the electrode **10** is electrically attached to the edges of an aperture **23** in the upper broad wall **12** of the waveguide. Likewise, the lower electrode **11** is electrically attached to the edges of an aperture **24** in the lower broad wall **13** of the waveguide.

A capillary tube **26** of very small diameter is disposed within the bore in the upper electrode **10**, extends across the discharge gap **19** between the extremities of the electrodes **10**, **11** and extends into the recess **22** in the lower electrode **11**. The capillary tube **26** is preferably of a material, for example, quartz, capable of withstanding very high temperatures and having a low dielectric constant and dielectric loss. Other materials, such as sapphire, may be used to make the capillary tube. The tube **26** is filled with a readily ionizable medium, which has a very fast recovery rate, for example, a halogen gas, and preferably chlorine or hydrogen chloride, which may be mixed with small amounts of other gases to make it more readily ionizable with an enhanced recovery rate characteristic. The gaseous medium is at a pressure in the range of from 1 to 30 torrs and typically in the range of about 5 to 15 torrs. Although the capillary tube **26** is illustrated as being similar to a small rod it will be readily apparent to those skilled

in the art that the upper end of the capillary tube may be sealed to some type of reservoir which may be in the nature of a bulbous enlargement of the tube. Such a reservoir would serve to increase the total volume of ionizable medium available to the capillary tube, and help to maintain a more uniform internal pressure and also help to increase the life to the device.

The device as so far described is a typical example of prior art structure. The novel feature of the present invention resides in the combination of means with the structure already described for immersing the ionizable gas in the capillary tube **26** in a static magnetic field, the lines of force of which are substantially parallel to the axis of the tube **26** and thus also parallel to the E vectors **25** of the dominant mode in the waveguide section **5**.

To this end, the upper electrode **10** is provided with the central annular recess **27** in which is disposed one leg **28***a* of a magnet or electromagnet **28**. It will be obvious that with this construction the leg of the magnet must have a bore **31** which is in alignment with and constitutes an extension of the bore **21** in the upper electrode **10**. To accommodate the other leg **28***b* of the magnet the lower electrode **11** has a suitable recess **33** in which the leg **28***b* is disposed.

The addition of the static magnetic field has a very marked effect on stabilizing the breakdown threshold of the ionizable gas and in decreasing the electron loss in the plasma formed by the discharge. Such previous devices, without the static magnetic field, are limited in duty cycle range by the fast rate of disappearance of the free electrons during the interpulse period of pulse transmission. Thus, when the gas in the capillary tube is exposed to a train or RF exciting pulses whose interpulse period is relatively long, that is, low PRF rate, the remanent free electrons necessary to facilitate breakdown of the next pulse are absent. This condition leads to an unstable firing power level which, as previously mentioned, appears as an amplitude modulated spike on the leakage waveform of the TR device. The magnetic field decreases the radial diffusion of the free electrons to the walls of the capillary tube, and therefore reduces the rate of decay of the plasma and aids in electron pulse-to-pulse carryover. In addition to diffusion loss there is an attachment loss but the attachment coefficient that contributes to this loss is not easily calculable. However, it is known that the attachment loss is independent of the magnetic field as it has been experimentally observed and proven at low electron densities. This would in general correspond to the decaying part of the interpulse periods where the diffusion loss is very significant. The results accomplished by this invention are a substantial improvement over the prior devices in that electron carryover is achieved by use of the magnetic field.

The approximate electron loss during the interpulse period is shown graphically in FIG. **3**. The dashed portion of the curve indicates the decreasing rate of electron loss that is present when the magnetic field is not used.

Although it is not intended to limit the present invention by stating categorically how the present invention accomplishes its improved results, it is believed that the interaction between the fields of the individual electrons and the static magnetic field causes the electrons to travel in helical paths concentric with the axis of the capillary tube. Thus, the electrons take a longer time to reach the walls and as a result their collision rate with the walls is lower. However, there are no resonance effects so long as there are no transverse components of the magnetic field. The energy absorption is independent of the microwave frequency and dependent upon the ratio of the static magnetic field density to the gas pressure in the capillary tube. This would appear to indicate that the increase in gas pressure may increase the collision rate between ions due to the increase in the total length of the helical paths. The best results observed were obtained by weak magnetic field.

The radial diffusion coefficient is modified by the static magnetic field in the following manner:

$$\frac{Dm}{D} = \left[1 + \frac{\omega_b^2}{\nu_c^2}\right]^{-1}$$

where Dm is the radial diffusion coefficient with the magnetic field applied; D is the diffusion coefficient without the magnetic field; ω_b (electron angular frequency of magnetic rotation) $= eB/m$, where e is the electric charge, B is the magnetic field density and m is the mass of the electrons; and ν_c is the frequency of the collisions between the electrons and the atoms and/or molecules of the walls.

In the operation of this device, radiofrequency energy incident upon the tuned iris in the waveguide section **5** creates a very high electrical field between the two electrodes **10** and **11** at the discharge gap **19**. This high electrical field creates a discharge between the two electrodes and the discharge takes the path of the least resistance. In this case the path of least resistance is through the ionizable medium within the capillary tube **26**. Because of the relatively close spacing of the electrodes **10** and **11** and because of the readily ionizable medium within the capillary tube **26** only low firing power is required to initiate a discharge at gap **19**. A very small amount of radiofrequency power is required to ionize the gas beyond plasma resonance density. As discussed above in instances where the PRF rate is very low, and therefore the interval between pulses is very long, the magnetic field as described above contributes to reduction of the loss of the electrons in the interpulse period to maintain a suitable plasma density so that upon the next pulse of microwave energy the arc discharge will form again very readily.

I claim:

1. A microwave switching device comprising a section of waveguide, a pair of electrodes ohmically connected to and extending inwardly from the walls of said waveguide to define a discharge gap between them, a closed container having walls substantially transparent to microwave energy, said container disposed adjacent said discharge gap, an ionizable halogen gas within said container and means for immersing said container in a static magnetic field of strength less than that required for cyclotron resonance of electrons in said discharge gap with the magnetic flux lines parallel to the electric vectors of microwave energy propagated in said microwave waveguide section.

2. The combination as set forth in claim **1**, in which each of said electrodes have a recess in which a portion of said container is disposed.

3. The combination as set forth in claim **3**, in which said recesses in said electrodes are bores and in which said container is an elongated capillary tube extending across said discharge gap.

4. The combination as set forth in claim **1**, in which said electrodes are frustoconical in shape with their bases forming a part of the ohmic contact with said walls.

5. The combination as set forth in claim **1**, in which said discharge gap is located in a tuned iris of said waveguide section.

6. The combination as set forth in claim **1**, in which said waveguide section has a rectangular cross section and is operating in the dominant $TE_{0,1}$ mode and said electrodes are connected to the broad walls of said waveguide section.

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