July 8, 1958 M. A. LAMPERT ET AL 2,842,747

SELF-TRIGGERED MICROWAVE ATTENUATOR

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Fig. 1

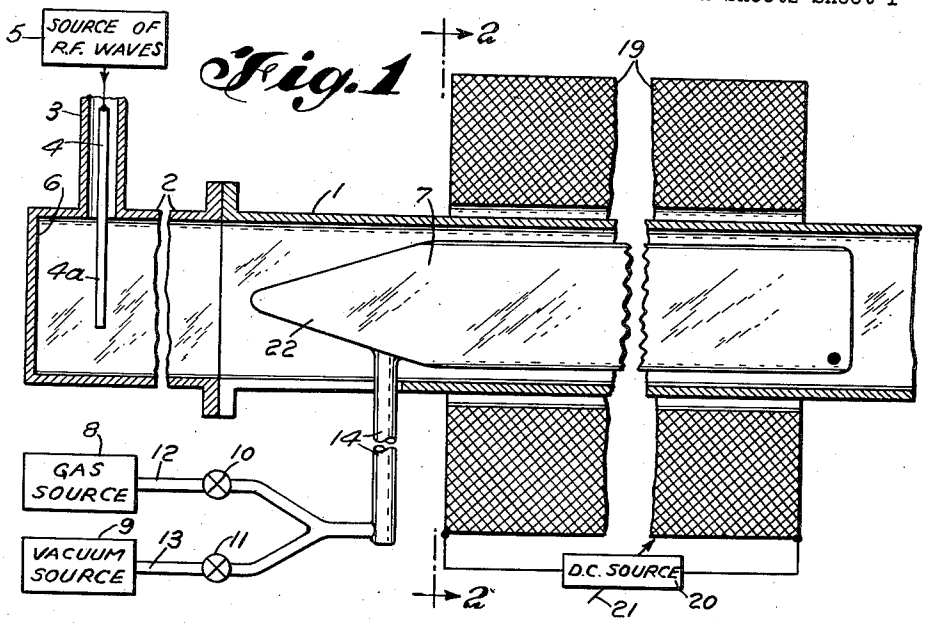
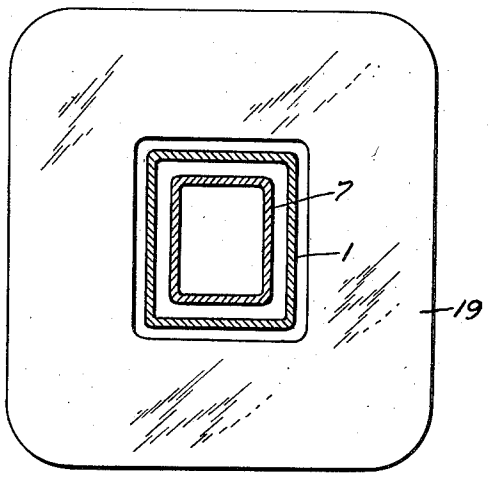


Fig. 2



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Fig. 3

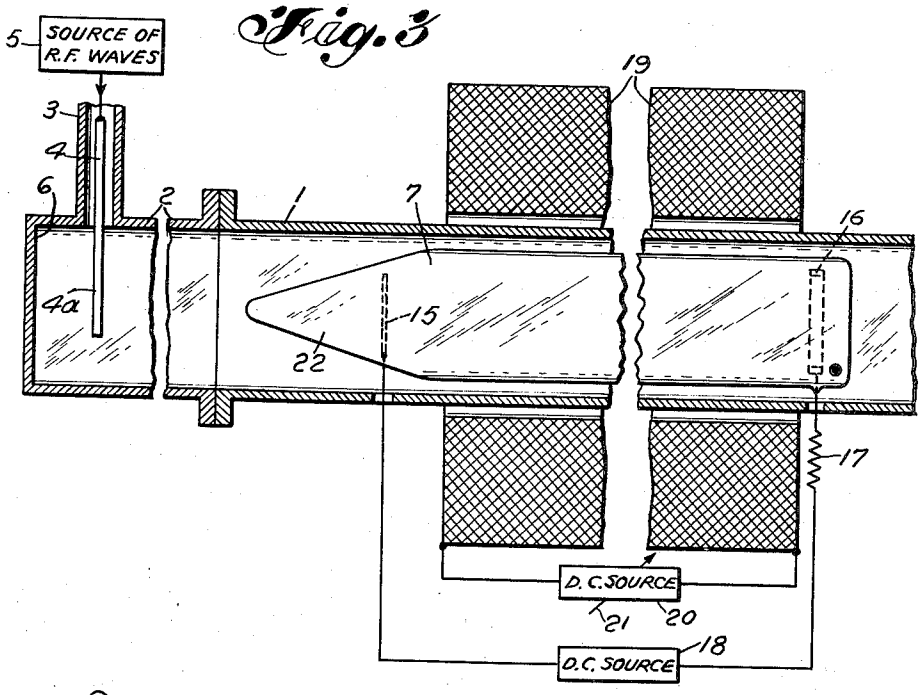
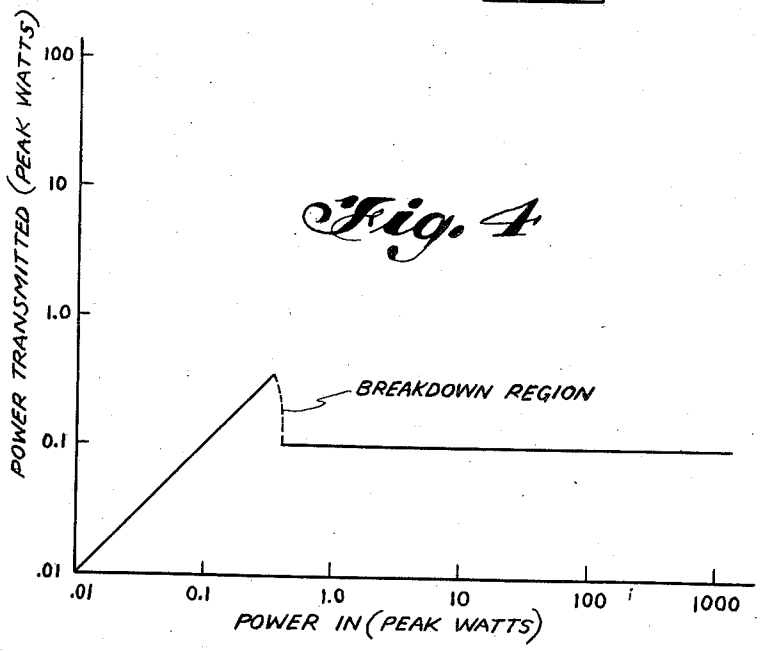


Fig. 4



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SELF-TRIGGERED MICROWAVE ATTENUATOR

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7 Claims. (Cl. 333—81)

This invention relates to radio frequency systems and more particularly to self-triggered attenuators for high power microwave signals.

It is known that the efficiency for absorption of radio frequency power by free electrons present in a gas plasma is very much increased by a gyroresonant magnetic field established therein. So-called gyrator methods and means for shifting the polarization of angularly dependent electromagnetic waves in waveguides of various shapes have been set forth in the copending application of Goldstein, Lampert and Heney, Serial No. 232,148, filed June 18, 1951, now Patent No. 2,773,245. The present invention utilizes the effects of a gyroresonant magnetic field. It is principally concerned with lowering the value of threshold power for gas breakdown by radio-frequency electric fields by use of a gyroresonant magnetic field. It is not concerned with utilization of the phase-shifting effects of polarized waves which may be obtained with magnetic fields at other than at gyroresonance.

It is an object of this invention to provide gas plasma means for use in attenuating high power microwave signals.

It is a further object to provide such a method of attenuation which is simple to accomplish, is relatively broadband in its characteristics and has a long life compared with existing devices used for this purpose.

It is a feature of this invention that an attenuator is provided which is self-triggering and capable of absorbing substantially all of high power microwave signals applied thereto.

It is a further feature that the threshold values required for gas breakdown of radio-frequency electric fields are substantially and significantly reduced by the establishment of a gyroresonant magnetic field.

It is an additional feature that these attenuator devices may also be made partially self-triggered.

As still an additional feature these gyroresonant attenuators may be readily made broadband by use of a tapered magnetic field.

The above-mentioned and other features and objects of this invention and the manner of attaining them will become more apparent by reference to the following description taken in conjunction with the accompanying drawings wherein:

Fig. 1 is a longitudinal sectional view of one form of attenuator device in accordance with the principles of the present invention;

Fig. 2 is a cross-sectional view taken along line 2—2 of Fig. 1;

Fig. 3 is a longitudinal sectional view of another form of attenuator device, one which is partially self-triggered; and

Fig. 4 is a graph of a curve showing the relationship of the input microwave power to the output microwave power in a self-triggered attenuator at the gyroresonant frequency.

Referring to Figs. 1 and 2 of the drawings, the device therein shown includes a waveguide section 1 which preferably is rectangular in cross section. Coupled to this section of the waveguide is an input waveguide section 2 to which is coupled a coaxial line 3, 4, or another waveguide section, which launches electromagnetic waves from source 5 into the waveguide section 2. The section 2 includes a conductive short 6 appropriately one-quarter wavelength of the guide back of the antenna 4a extending from the inner conductor 4. The waves are launched by the antenna 4a in a mode appropriate to the waveguide used. A mode such as $TE_{1,0}$ may be used. The dimensions of the waveguide, of course, are determined by the frequency of the waves to be propagated.

Contained in the waveguide section 1 is an envelope 7, preferably made of glass, into which gas may be introduced under controlled pressure from a gas source 8. A vacuum pump 9 is shown for evacuating other gases from the envelope prior to sealing it with the desired gas or gas mixture. The gas source 8 and pump 9 are connected by valves 10 and 11 and tubular connections 12 and 13 to a tube 14 and thence to envelope 7. In practice, the envelope would be sealed with the desired gas contained therein prior to insertion in the waveguide.

Referring to Fig. 3, it is seen that for purposes of partial self-triggering a cathode 15, suitably a cold-cathode type in view of the small current required, is provided. The envelope 7 contains an anode 16 which is connected to the cathode through a current-limiting resistor 17 and an appropriate voltage source 18. These electrodes serve only as "keep alive" electrodes to maintain an auxiliary discharge in the gas tube, and do not serve as the means for providing the principal ionized plasma discharge of the gas tube.

Referring to Figs. 1 and 3, there is concentrically disposed about the waveguide and envelope 7 an electromagnet coil 19 to which a source of current 20 is applied as indicated. This source of current which preferably is direct current may be varied as indicated at 21 to control the magnetic field intensity. Pulsed direct current may also be used, depending upon the effects desired. The forward portion 22 of the envelope 7 is preferably tapered to minimize wave disturbance due to boundary discontinuities.

Where the magnetic field or a part theerof is to be held at a given intensity, the field may be supplied by a permanent magnet of cylindrical or other suitable form. Also, an additional coil may be used in conjunction with the permanent magnet or other main coil, or any appropriate combination of the permanent magnet and electromagnet may be used. Magnetic field intensities to 3500 gauss are suitable. The magnetic field may be oriented in a manner either transverse or longitudinal to the principal axis of the waveguide. The section of waveguide may be smooth or corrugated. Most commonly and preferably, it will be of rectangular cross section. It is particularly desirable that the lowest mode of propagation in the waveguide be non-degenerate in nature. The sealed-off tube containing the gas fills all or part of the guide cross section. The guide wall itself may be part of the envelope. Suitable gases are appropriate pure gases or gas mixtures, preferably of the non-electronegative type, such as neon, helium, argon, krypton and nitrogen. Gas pressures between 0.1 and 100 millimeters of mercury may be used. The presence of a radioactive gas such as radon or tritium as part of the gas filling of the envelope is considered desirable, particularly for the embodiment shown in Fig. 1, in that the need for keep-alive electrodes is eliminated. Thus the radioactive gas will substantially aid the operation of the attenuator by providing a steady supply of electrons in the gas. Also, part of the inside surface of the envelope may be coated with a convenient radioactive

substance such as radiocobalt. The radioactive decay occurring will provide the steady supply of electrons which will both lower and stabilize the breakdown threshold.

In Fig. 4 is shown a graphical comparison of the transmitted microwave power as a function of the microwave power input in the practice of this invention. As the microwave power is fed into the waveguide, the output power correspondingly increases in a linearly dependent manner. This continues until the threshold breakdown voltage is reached, whereupon the gas tube becomes self-triggered and the output power drops to a substantially constant value, almost all of the power being absorbed by the gas. Thus attenuations as high as 50 decibels may be obtained for a peak pulse input of one kilowatt. In order to stabilize and lower the breakdown threshold and possibly increase the absorption efficiency, an auxiliary discharge of a pulsed or continuous nature may be provided as shown in Fig. 3. This auxiliary discharge is of an extremely low value, of the order of approximately a few milliamperes, and is similar in purpose to the "keep-alive" discharge in transmit-receive, i. e., T–R, tubes. Thus, with the keep-alive discharge present, the attenuator is partially self-triggered. The gyroresonant attenuator can be broadbanded relatively simply by use of a tapered magnetic field. The magnetic field has a uniform gradient along the axis of the waveguide so that some region of the gas tube is in a field gyroresonant with the signal frequency anywhere in the band. Since the purpose of this device is to act as an attenuator of transmitted high power, it is operated at the gyroresonant frequency, for it is at this frequency that the maximum absorption of power occurs.

By gyroresonance or the gyromagnetic resonant region reference is made to that state or region wherein the gyromagnetic frequency of electrons produced in the gaseous medium contained in the magnetic field is approximately equal to the frequency of the electromagnetic waves propagated through the gaseous medium. The gyromagnetic resonant region is readily calculated from the following formula: $0.357f_s=H$, where f_s represents the incoming signal frequency in megacycles and H represents the magnetic field intensity in gauss. Thus, from the foregoing, it will be readily understood that the gyroresonant frequency is readily established from a knowledge of the frequency of the input microwave signal source and by adjustment of the variable magnetic field. The present invention finds application in an extremely wide frequency range, from below 100 megacycles per second to above 100,000 megacycles per second, and preferably in the range from 1,000 to 20,000 megacycles per second.

As will be recognized by those skilled in this art, the waveguide section of an attenuator device of this type may either have fast or slow wave propagating characteristics and may either be closed or open. For fast propagation, the guide should have smooth boundaries, although they may be ridged. For slow propagation the guide may be periodically corrugated or provided with helical, foraminous or grid-like walls. The length of the gas envelope may be widely varied depending on the magnitude of the effect desired. Roughly speaking, this effect is proportional to the length of the electron gas medium.

By means of this attenuator device operating at a magnetic field adjusted to the gyroresonant frequency, a very high efficiency in coupling microwave power into the gas is obtained. As a result, considerably broader bands of frequency may be transmitted than is possible in T–R tubes. These devices are considerably cheaper to build than such T–R tubes inasmuch as the resonant cavity structure of the T–R tube is readily replaced by the more convenient magnetic field of this attenuator. Also, the problems of gas clean-up present in T–R tubes because of their predominantly metallic construction are eliminated in these simpler preferably glass-built envelopes. Thus the additional advantages over existing devices of simplicity of construction, long life and broadbanded operation are provided by these gyroresonant attenuators. These attenuators being able to absorb large amounts of microwave power are useful in very-high-powered radar equipment. Thus, ordinarily, in such equipment, the transmitter leakage power from the duplexer can deteriorate or destroy the receiver mixer crystal. The attenuator if placed in front of the crystal will absorb the leakage power and thereby protect the crystal. Similar applications will be apparent to those working in this field.

While we have described above the principles of our invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of our invention as set forth in the objects thereof and in the accompanying claims.

We claim:

1. A power limiting attenuator comprising an electromagnetic waveguide, a body of ionizable gaseous medium having a given ionization level contained within said waveguide, means to launch electromagnetic energy in only a single mode in said waveguide and through said gaseous medium, said electromagnetic energy having a power level at least equal to said given ionization level to ionize said gaseous medium, and means to produce a magnetic field in said gaseous medium having a value to establish gyroresonant absorption of said electromagnetic energy in said ionizable gaseous medium to limit said electromagnetic energy passing therethrough to a given power.

2. An attenuator according to claim 1 wherein said gaseous medium includes a radioactive gas.

3. An attenuator according to claim 2 wherein said radioactive gas is radon.

4. An attenuator according to claim 1 wherein the walls of the container of said gaseous medium are coated with an electron-emitting radioactive substance.

5. An attenuator according to claim 1 wherein said attenuator further includes a pair of electrodes disposed within said medium and a source of potential coupled to said electrodes to maintain a discharge therebetween to maintain said gaseous medium primed for rapid ionization breakdown by said electromagnetic energy.

6. An attenuator according to claim 1 wherein said magnetic field has a uniform gradient along the axis of said waveguide.

7. A power limiting attenuator comprising an electromagnetic rectangular waveguide, a body of ionizable gaseous medium having a given ionization level contained within said waveguide, means to launch electromagnetic energy in only a single mode in said waveguide and through said gaseous medium, said electromagnetic energy having a power level at least equal to said given ionization level to ionize said gaseous medium, and means to produce a magnetic field in said gaseous medium having a value to establish gyroresonant absorption of said electromagnetic energy in said ionizable gaseous medium to limit said electromagnetic energy passing therethrough to a given power.

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