May 5, 1953 A. LONGACRE 2,637,780

PROTECTIVE ELECTRIC BREAKDOWN DEVICE

Filed May 6, 1943 3 Sheets-Sheet 1

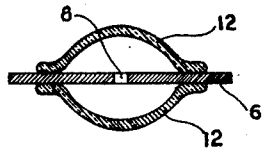


FIG. 5

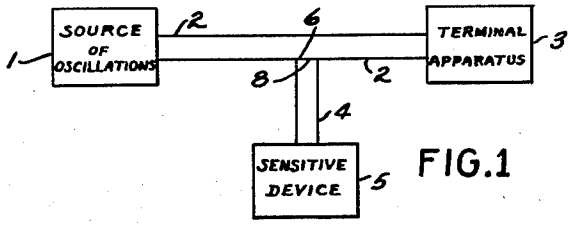


FIG. 1

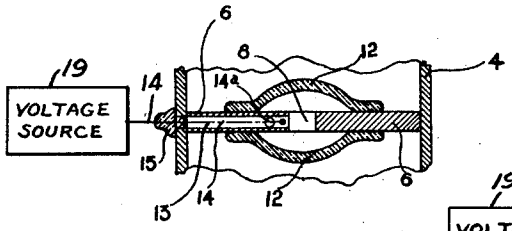


FIG. 6

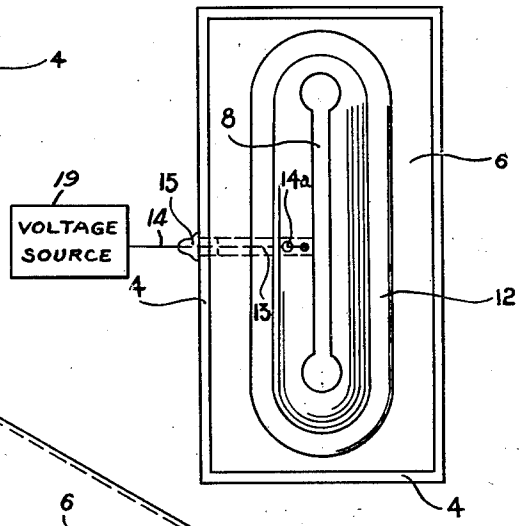


FIG. 7

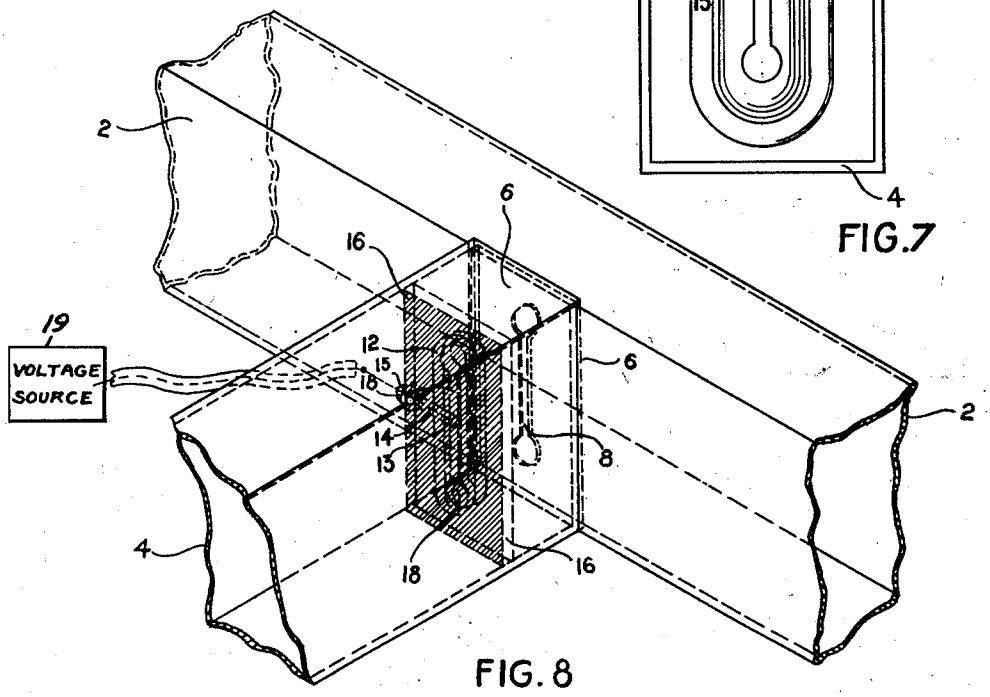


FIG. 8

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PROTECTIVE ELECTRIC BREAKDOWN DEVICE

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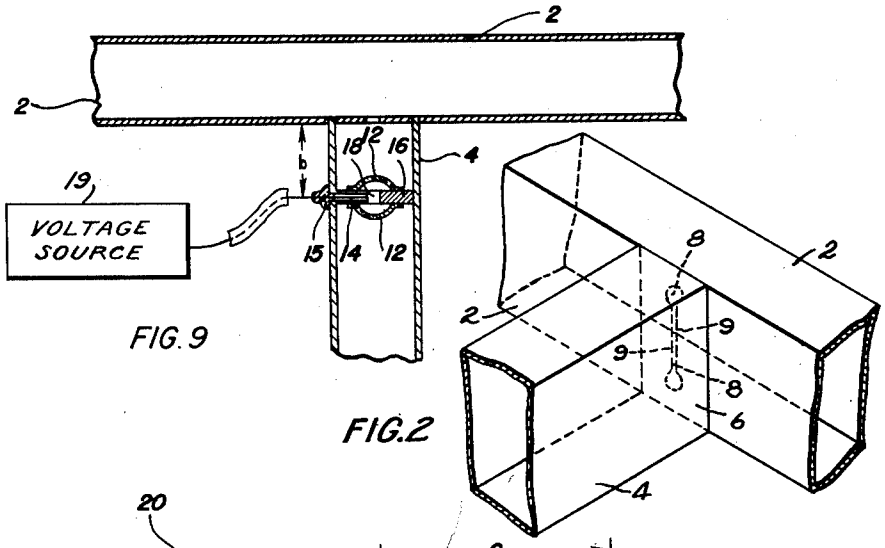


FIG. 9

FIG. 2

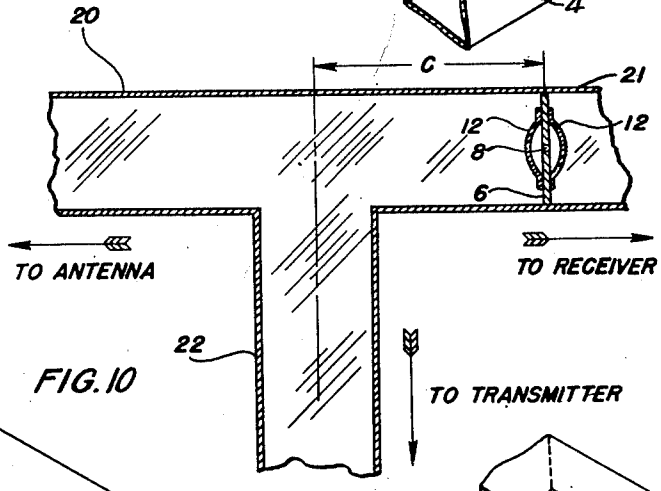


FIG. 10

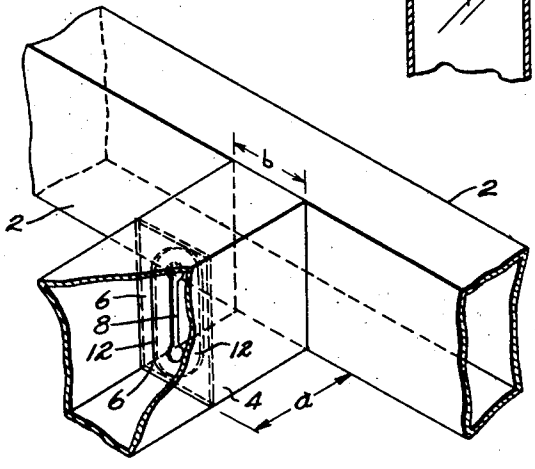


FIG. 4

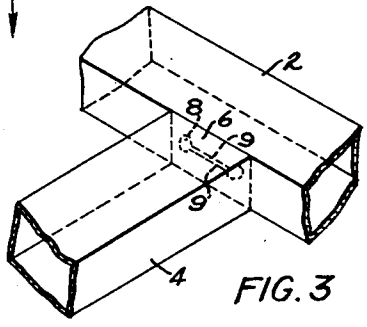


FIG. 3

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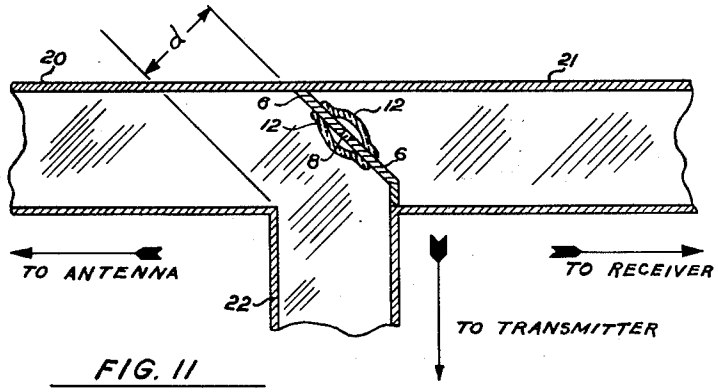


FIG. 11

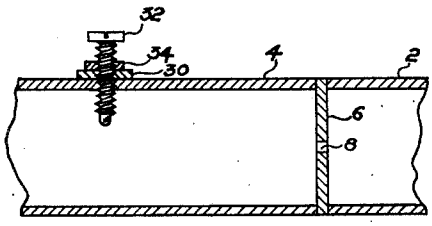


FIG. 12

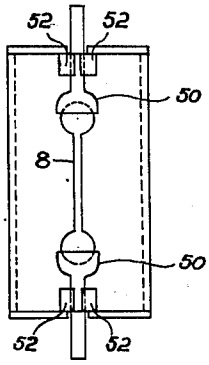


FIG. 14

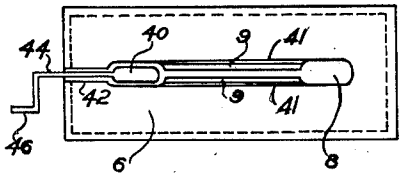


FIG. 13

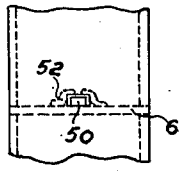


FIG. 15

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UNITED STATES PATENT OFFICE

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PROTECTIVE ELECTRIC BREAKDOWN DEVICE

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Application May 6, 1943, Serial No. 485,933

25 Claims. (Cl. 178—44)

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This invention relates to switches of the automatic breakdown type for association with an electrical transmission line or "wave guide" for the purpose of protecting a sensitive apparatus connected to said transmission line. More particularly, this invention relates to automatic breakdown switches adapted for use in "wave guides" having the form of hollow pipes.

Because of the modern emphasis on phenomena in the space surrounding a transmission line as contrasted with the phenomena within the conductor, the term "wave guide" is now frequently used to refer to a transmission line, especially one used at high frequencies. This term is frequently applied to transmission devices in the form of a hollow pipe, which are practical only for high frequency applications. Properly speaking, any transmission line is a wave guide. Modifying phrases are therefore liberally used in this specification to make it clear that the type of wave guide in conjunction with which the breakdown switch of this invention is particularly concerned is the form of wave guide constructed as a hollow pipe. In conformance with the terminology of the high frequency art, the term "wave guide" will generally be used herein in place of the term "transmission line."

When intermittent trains of oscillations are being transmitted from a source of oscillation of relatively high amplitude, such as a generator of high frequency electromagnetic oscillations, to a terminal apparatus, such as an antenna system, over a wave guide and it is desired to connect with said wave guide a sensitive device such as a receiver for such high-frequency oscillations, it is desirable to protect the receiver against damage from oscillations of great amplitude by providing a switch or a protective gap between said receiver and said wave guide which will short circuit oscillations exceeding a predetermined amplitude across the receiver input. It is an object of this invention to provide a protective breakdown discharge device which will occupy very little space when associated with a hollow pipe wave guide system and which is simple in construction. It is a further object of this invention to provide such a device for use in hollow pipe wave guides which will take advantage of the symmetrical nature of hollow pipe wave guides and will take advantage of the symmetrical and essentially two-dimensional nature of resonant circuit constituted by an elongated aperture in a sheet of metal.

In the annexed drawings:

Fig. 1 is a diagram showing the location of the protective breakdown discharge device of this invention in a radio system employing hollow pipe wave guides;

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Fig. 2 is a perspective view of one form of the protective breakdown device of this invention together with associated portions of hollow pipe wave guides;

Fig. 3 is a perspective view showing another form of protective breakdown device according to this invention, and also showing associated portions of wave guides;

Fig. 4 is a perspective view of still another form of protective breakdown device according to this invention together with associated portions of wave guides;

Fig. 5 is a cross section showing a modified form of protective breakdown device;

Figs. 6 and 7 show, in cross section and in elevation, respectively, a modification of the protective breakdown device according to this invention;

Fig. 8 is a perspective view of a compound form of protective breakdown device in which two cooperating breakdown elements are provided at different parts of the hollow pipe wave guide system;

Fig. 9 is a median horizontal cross section of the apparatus shown in Fig. 8;

Fig. 10 shows in cross section another arrangement of the protective breakdown device of this invention in a wave guide system associated therewith;

Fig. 11 shows in cross section still another arrangement of the protective breakdown device of this invention in a wave guide system associated therewith;

Fig. 12 shows in cross section an arrangement for adjusting the resonant frequency of the protective breakdown device—that is, for "tuning" the device;

Fig. 13 shows, in elevation, an alternative arrangement for tuning the protective device, and

Figs. 14 and 15 show, in elevation and in plan respectively, still another arrangement for tuning the protective breakdown device.

In the protective breakdown device of this invention, there is used as a circuit adapted to promote breakdown when subjected to oscillations exceeding a predetermined amplitude, a sheet of conducting metal transversely closing the hollow pipe wave guide leading to the sensitive device (as shown in Fig. 1) and provided with an aperture of elongated contour so dimensioned and shaped that the metal sheet, in the neighborhood of said aperture, constitutes a res-

onant circuit which is resonant at a frequency corresponding closely to that of the oscillations desired to be transmitted in said hollow pipe wave guide. Such an aperture has the advantageous property that in the absence of breakdown it produces little if any interference with transmission of oscillations therethrough at its resonant frequency, having low losses and presenting zero shunt susceptance across the wave guide. The long dimension of the aperture is oriented perpendicularly to the direction in which currents tend to flow in the wave guide walls, so that the resonant circuit will be excited by oscillations in the guide and a high voltage gradient will appear across the middle part of said aperture. The aperture is constructed with a very narrow clearance in its middle portion so that when the oscillations reach a predetermined amplitude, a breakdown will occur across the narrow portion of said aperture. The resulting short circuit will in effect electrically close off the hollow pipe wave guide leading to the sensitive device or receiver. At the same time, if the apertured metal partition is properly located in the hollow pipe wave guide leading to the receiver, as hereinafter described, the wave guide leading from the source of oscillation to the terminal apparatus (see Fig. 1) will, when breakdown occurs as aforesaid, act electrically like an essentially uninterrupted wave guide.

Fig. 1 shows the general type of system in which the breakdown switch of this invention finds its particular utility and shows the general location of such a breakdown switch in such a system. The block 1 indicates in a general manner a source of high amplitude, which could be a vacuum tube oscillator. The wave guide 2 is a transmission apparatus of the hollow pipe type which is preferably rectangular in cross section (though the invention is equally applicable to systems with wave guides of circular cross section) and of such dimensions that it readily sustains and transmits oscillations of the frequency of those generated in the source 1 which are so polarized in said wave guide that the electric vector of such oscillations lies in the direction of the short dimension of said wave guide, but does not readily sustain or transmit other modes of oscillation at said frequency. The wave guide 2 serves to transmit oscillations from the source 1 to a terminal apparatus generally indicated at 3, which may be an antenna system. Intermediate the ends of the guide 2 at a suitable point determined by methods known to those skilled in the art, another hollow pipe wave guide 4 is joined to the guide 2. The guide 4 likewise functions to transmit oscillations of which the electric vector is parallel to its shorter cross-sectional dimension. The guide 4 serves to lead or transmit oscillations taking place in the guide 2 to a sensitive device generally indicated at 5, which may be a receiver for detecting and amplifying high-frequency signals. In the guide 4, in this case at its extremity where it joins the guide 2, there is placed a transverse barrier 6 of a thin conducting material, preferably copper or brass, provided with an elongated aperture, appearing in cross section at 8. When so positioned, the barrier 6 forms a continuation of the wall of the guide 2 across the mouth of the guide 4.

As above described, the aperture is so dimensioned and shaped as to produce resonance at the frequency of the oscillations desired to be transmitted in the guide 2, and its width is so dimensioned, at least in the middle portion of its length, so that breakdown will readily occur when oscillations of such amplitude as might damage the sensitive device 5 occur in the guide 2. Oscillations of such amplitude might, for instance, occur whenever the source of oscillation 1 is delivering energy to the guide 2, if this source is a source of relatively high-amplitude oscillations. When oscillations of such amplitude are present in the guide 2 and a breakdown occurs across the narrow portion of the aperture in the barrier 6, the guide 2 electrically acts as if it were completely cut off from the pipe 4 by a continuous conducting barrier, except for the relatively low and practically negligible resistance associated with the breakdown discharge. When oscillations of sufficient amplitude to cause a breakdown across the aperture are not present, however, the aperture will readily permit the transmission therethrough of oscillations of frequencies in the neighborhood of the frequency at which the circuit surrounding the aperture resonates so that the sensitive device 5 is effectively connected with the terminal apparatus 3 for receiving electromagnetic oscillations of such frequencies.

In a system such as that of Fig. 1 it may be desirable to vary the length of the guide 2 between the transmitter and the junction with the guide 4 in order to obtain an adjustment that minimizes absorption of received signals in the transmitter and its associated guide. Such adjustment may be readily determined experimentally. Absorption of received signal by the transmitter may also be prevented by other means, such as by a resonant side stub which acts as a choke while the apparatus is used for receiving and which is adapted to be short circuited out of the system by a gap discharge occurring while the apparatus is used for transmission.

Fig. 2 shows a perspective view of the junction of the guides 2 and 4 of Fig. 1, thus illustrating in detail the form of one embodiment of this invention. The conducting barrier 6 which closes off the end of the guide 4 is shown as constituting a portion of the wall of the guide 2. These guides, 2 and 4, are manufactured in the form of thin-walled rectangular metallic pipe, preferably of copper or brass. The aperture in the barrier 6 is shown at 8. Although for the purposes of this invention any of a variety of shapes, usually elongated in some manner, will serve for this aperture, I prefer the shape shown in Fig. 2 which is essentially that of a long narrow slit terminated at its end by rounded openings of a diameter somewhat wider than the said slit.

When oscillations exceeding a predetermined amplitude occur in the guide 2, a breakdown occurs across the jaws 9 of the slit forming a part of aperture 8.

Fig. 3 shows an alternative arrangement of the protective breakdown discharge device of this invention. In Fig. 3 the junction between the wave guides 4 and 2 is made in one of the narrow sides of the wave guide 2 instead of in one of the broader sides as in Fig. 2. The junction shown in Fig. 2 is known as an "electric plane" junction while the junction shown in Fig. 3 is known as a "magnetic plane" junction. In general the type of junction shown in Fig. 2 is at present believed to be preferable.

It will be noted that in the apparatus of Fig. 3 the aperture 8 is oriented lengthwise of the wave guide 2, although in the apparatus of Fig. 2 the aperture 8 is oriented perpendicular to the axis of the wave guide 2. In each case, however, the

aperture 8 is oriented so that potential differences will appear across its narrow dimension. In both Fig. 2 and Fig. 3 the aperture 8 has the same orientation with respect to the branch wave guide 4. It is oriented at right angles to the direction of the electric vector in the branch wave guide 4, the electric vector in a rectangular wave guide as normally used being perpendicular to the broad sides of the wave guide and parallel to the narrow sides.

Fig. 4 shows a modified arrangement of the invention employing an improved type of protective breakdown aperture. In Fig. 4 the conducting barrier 6 is not, as in Figs. 1, 2 and 3, flush with the wall of the wave guide 2 so as to form a continuation thereof, but is instead at a position farther down the guide in the direction of the sensitive device, an arrangement which I prefer in practice to that of Fig. 2. The distance between the transverse barrier 6 and the nearer wall of the wave guide 2 should be approximately equal to an integral number of half-wave lengths of the oscillation in the guide 4. A single half-wave length is preferred because greater lengths introduce undesired amounts of frequency sensitivity. In practice the distance will be somewhat less than that just defined, presumably on acount of the "end effect" associated with the junction of the two wave guides and the electrical characteristics of the breakdown discharge.

This distance is shown on Fig. 4 by the dimension a, and in the case of the electric plane junction shown in Fig. 4 its preferred magnitude depends to some extent on the ratio b/λ_g, in the manner illustrated in Table I, b being the narrower cross-sectional dimension of the guides (indicated on Fig. 4) and λ_g being the wave length of the oscillations in the guide. The distance in question may conveniently be referred to as an "electrical half-wave length from the junction." The valus given in Table I may be regarded as defining the effective center of the junction, since they correspond to half-wave lengths corrected for "end effects" of the junction.

b/λ_g	a/λ_g
0.22	0.463
0.25	0.458

The wave length of the oscillations in the guide is ordinarily different from the wave lengths of oscillations of the same frequency in free space, and is in the usual case considerably longer than the free space wave lengths. The wave length of oscillations of a given frequency in a wave guide of given dimensions may be calculated without difficulty from the guide dimension by known methods or may be determined experimentally by known techniques.

The barrier 6 and its aperture 8 as shown in Fig. 4 are provided with means comprising a glass envelope 12 for maintaining a partial vacuum in the aperture 8 and thereby promoting electrical breakdown discharges in said aperture at voltages lower than those which would be necessary to produce breakdown across the same aperture filled with air and atmospheric pressure. In this manner a greater degree of protection can be furnished to the sensitive device because protective breakdown will take place at a lower amplitude level.

The residual gas inside the envelope 12 may be air, or it may be composed of a gas or a mixture of gases adapted to be ionized more readily than air by the alternating electric field set up across the narrow part of the aperture 8. Water vapor or hydrogen might, for instance, be used. Neon and argon have slow de-ionization time characteristics and are therefore suitable only where relatively slow recovery (several microseconds or so) can be tolerated, as in the case of long-range radio-echo locating equipment.

Various degrees of partial vacuum might be used, depending on the desired amplitude level of oscillations at which it is intended the breakdown should begin to take place. A suitable partial vacuum for a sensitive gap, for instance, is one in which the pressure corresponds to a 7 mm. column of mercury. In general I prefer pressures between 1 mm. and 25 cm. of mercury. If long service life is more important than the ultimate in sensitivity, a relatively high pressure gap should be used which, if properly constructed, will provide satisfactory sensitivity for all practical purposes. In the construction of such a gap great care should be taken to clean thoroughly the metal surfaces in the neighborhood of the discharge gap. If then an inert gas, such as nitrogen, is used for the gap atmosphere, the discharge will be in the nature of a gas discharge rather than a metallic arc, and the sensitivity of the gap will be great even at relatively high pressures, such as 10 cm. of mercury, which I believe to be preferable. This discharge, because of the relatively high pressure will tend to remain confined to the space defined by the discharge aperture, even in apparatus operating at high power levels, which is a great advantage, since spread-out discharges may interfere with power transfer between transmitter and antenna. The service life of the type of discharge element just described is very great because the metal parts are practically unaffected by the type of dicharge obtained.

One way in which the means for maintaining partial vacuum may conveniently be associated with the conducting metal wall 6 is more clearly illustrated in the cross-sectional view shown in Fig. 5 of the metal wall 6 of Fig. 4 and its associated glass structure. The glass envelope 12 is preferably formed of two parts, one on each side of the metal sheet 6. Each part is sealed to the metal wall 6 by a metal-to-glass seal about the circumference of the envelope, surrounding the aperture 8. The envelope 12 extends slightly away from the metal sheet 6 in its middle portion in order that the breakdown discharge shall not be interfered with.

In order to promote the breakdown discharge by establishing a partial vacuum in the aperture of the barrier 6, it is of course not necessary that a partial vacuum should be maintained in all parts of the aperture and a glass envelope could be arranged to maintain a partial vacuum only in the narrow part of the aperture. This, however, would put part of the glass wall directly across the narrow part of the slit, which would tend to cause dielectric losses, so that such a form of the protective discharge device is not preferred.

Figs. 6 and 7 show a further modified and preferred form of the protective breakdown device of this invention. Fig. 6 is a sectional view in the median "electric" plane of the wave guide 4. Fig. 7 is an elevation transverse to the axis of the wave guide 4.

In Figs. 6 and 7, as in Figs. 4 and 5, the part of the barrier 6 in which the aperture 8 is cut is

provided with a glass envelope of two parts 12, 12 which maintain a partial vacuum in the aperture and in the space neighboring the aperture. In addition, passage 13 is drilled inside the metal sheet 6 parallel to the surfaces of the sheet 6 and leading to the narrow part of the aperture 8. Preferably the hollow passage 13 is centrally located as shown in Figs. 6 and 7. Inside the passage 13 is provided an electrode 14 which is insulated from the metal sheet 6 by a spacing bead 14a on the electrode 14. The electrode 14 extends almost to the point where the passage 13 reaches the aperture 8, but it is terminated within the passage 13. A glass seal 15 is provided at the end of the passage 13 which communicates with the outside of the wave guide in which the sheet 6 is located, the electrode 14 passing through the seal 15. The seal 15 serves to cooperate with the envelope 12, 12 to maintain a partial vacuum in the space defined by the aperture 8. An electric potential, preferably a constant voltage, is impressed upon the electrode 14 with respect to the wave guide 4 and the sheet 6 (which are electrically connected) from a source of voltage schematically indicated by block 19. Preferably, a high voltage is impressed upon the electrode 14 through a high resistance, so that when a discharge begins to take place, the voltage will automatically be reduced. For example, a voltage of 1000 volts may be impressed upon the electrode 14 through a high resistance of approximately 5 or 10 megohms.

The electric potential between the electrode 14 and the walls of the passage 13 will cause a small amount of ionization to take place in the passage 13 which, like the space in the aperture 8, is maintained under partial vacuum conditions. Certain of the ions formed in this manner will migrate into the aperture 8, so that when a high voltage appears across the aperture 8, a breakdown will readily occur. In this fashion the voltage necessary to cause a breakdown is made considerably lower than if there were no ions present in the aperture 8.

When the apparatus of Figs. 6 and 7 is used in a system similar to that of Fig. 1 and in which the source of oscillations is a generator of high frequency oscillations which transmits such oscillations in the form of short pulses or other intermittent wave trains of high amplitude of oscillation, the potential applied on the electrode 14 in the apparatus of Figs. 6 and 7, instead of being a continuous constant potential, might be an intermittently applied potential applied only during the period during which the said source of oscillations is transmitting energy. Such a potential may readily be applied by locating a synchronized rapidly-operating electronic switch in the circuit of voltage source 19 and the electrode 14, the switch being operated in a well-known manner by circuits associated with the source of oscillation and the apparatus controlling it. Constant potential operation of the electrode is, however, preferred.

Apparatus maintaining a partial vacuum for the discharge space has the disadvantage at high power operation that the discharge tends to broaden out from the plane of the aperture 8 and to fill the rest of the space in which a partial vacuum is maintained. This operates to make the location of the short-circuited termination in the wave guide 4 indefinite and makes it difficult to obtain the desired reduction of energy acceptance by the wave guide 4. In order to avoid this difficulty, apparatus may be built as shown in Fig. 8, with a first discharge aperture operating at higher pressure which is adapted to keep its discharge substantially confined to the plane of the aperture, and a second discharge gap adapted to operate upon such energy as is passed down the guide 4 as a result of the relatively high voltage discharge at the first gap. The second discharge, since it operates at a lower power level of incident oscillation may operate at low gap voltage without spreading substantially beyond the plane of the gap aperture, thus furnishing a high degree of protection to the sensitive device in question while permitting desirable conditions to hold at the wave guide junction.

Fig. 8 is a perspective view and Fig. 9 is an "electric plane" section of one form of the compound type of device just referred to. In this arrangement there are located in the guide 4 two conducting transverse barriers 6 and 16. The barrier 6 has an aperture 8 and is arranged and located exactly as in Fig. 2. The barrier 16 is located in the guide 4 between the barrier 6 and the sensitive device to which the guide 4 leads but which is not shown in the figure. The distance along the guide 4 between the barriers 6 and 16, indicated by the dimension *b* on Fig. 9, should be approximately equal to an odd number of electrical quarter-wave lengths in the guide 4 of the oscillations to which the system is designed to respond. For purposes of simplicity and economy of space I prefer a spacing of one quarter-wave length between the barriers 6 and 16. The barrier 16 is provided with an aperture 18, an envelope 12 and an electrode 14, corresponding fully to the aperture 8, the envelope 12 and the electrode 14 of Figs. 6 and 7. As in the latter figures, a partial vacuum is maintained in the immediate neighborhood of the aperture 18. It is to be noted that a great deal of the total breakdown energy in the compound device is consumed in the aperture 8 which is more resistant to damage and more readily and economically replaceable than the more sensitive element (the barrier 16 and aperture 18) of the device.

It is not necessary for this invention that the wave guide T-junction should be so arranged that the branch leg of the T leads towards the receiver while the cross-arm leads in one direction to the antenna and in the other direction to the transmitter although that configuration is preferred. This preference is based on observations indicating that the most complete energy transfer between two legs of a T-junction of which the third leg has been short-circuited is obtained when the short-circuited leg is the branch guide rather than part of the cross-arm of the T. Consequently a straight path past the T-junction is preferably established for the transmitting operations (corresponding to the existence of breakdown in the aperture 8). In some cases, however, it may be found advantageous to provide a straight-through path for receiving, permitting transmission to take place around the wave guide corner of the T-junction. Arrangements of this type are shown in Figs. 10 and 11, the connections to the transmitter and receiver being indicated on the figures.

In Fig. 10 is shown the parts of a wave guide system which are located near the junction of the wave guides leading to the antenna, receiver and transmitter. The wave guides shown are, as before, in the form of rectangular hollow conducting pipes. The wave guide 20 leads toward the antenna, the wave guide 21 leads toward a receiver and the wave guide 22 leads toward a

transmitter. In the wave guide 21 is interposed an electrical breakdown device similar to that shown in Figs. 4 and 5, and comprises a metallic barrier 6, an elongated aperture 8, and a glass envelope 12 for maintaining a partial vacuum in the aperture 8. As in previous instances, the glass envelope 12 may be omitted if desired. The distance between the barrier 6 and the T-junction of the wave guides 20, 21 and 22 should, in accordance with the principles previously outlined, be approximately an integral number of electrical half-wave lengths. Although the effective location of the junction with respect to the branch wave guide of a T-junction, as, for instance in Fig. 4, lies approximately at the nearer wall of the cross-arm wave guide of the said T-junction, the effective location of the junction with respect to apparatus located in one of the cross-arm wave guides is in the neighborhood of the median plane of the branch wave guide, or, otherwise stated, the end effects are different in the leg and in the cross-arm of a T-junction. The desired dimension c indicated on Fig. 10 is slightly more than half the wave length of oscillations in the guide on account of the end effects at the junction. For a guide in which $b/\lambda_g=0.22$, a preferred value for the dimension c is 0.52 times the wave length in the guide. Even with the preferred value of the dimension c a mismatch will occur at the junction unless further measures are taken, on account of the reel (conductance) component of the junction admittance as seen from the transmitter branch. For maximum energy transfer upon transmission, therefore, a matching device is necessary in the guide 22, which may be a pair of capacitive loads located about a quarter-wave length in the guide from each other.

Fig. 11 shows an arrangement similar to Fig. 10, except that the protective electrical breakdown device is located at the T-junction instead of some distance down the wave guide 21 away from the T-junction. In such a case the barrier 6, as shown in Fig. 11, is preferably so located that when a breakdown occurs in the aperture 8 a conducting wall electrically substantially continuous appears across the wave guide 21 in such a position as is most conductive for transmission of energy from the wave guide 22 around a right angle corner and down the wave guide 20. In view of this consideration I prefer a diagonal arrangement of the barrier 6 as shown in Fig. 11. The diagonal part of the barrier 6 is very slightly removed from the central diagonal of the T-junction in the direction which permits a slightly greater clearance around the corner of the wave guides 22 and 21, in accordance with the practice for making right angle bends in rectangular wave guides. For an electric plane junction, such as that shown in Fig. 11, I prefer arrangements in which the dimensions shown at d on Fig. 11 lie between 85 and 90% of the cross section of the wave guide in the direction of the electric vector. For a magnetic plane junction I prefer a slightly wider corner, with a dimension corresponding to the dimension d of approximately 95% of the cross section of the wave guide in the magnetic plane. These preferences apply particularly to rectangular wave guides for which b/λ_g as heretofore defined is equal to about 0.25.

For the best operation of the breakdown switch of this invention, it is important that the aperture 8 should be rather accurately tuned to the frequency of the oscillations which are desired to be handled in the guides 2 and 4. Means for adjusting this tuning of the aperture 8 without removing the barrier 6 from the inside of the pipe system are therefore desirable, both for adjusting the breakdown switch to the particular frequency of oscillations transmitted, and for correcting any change in the dimension of the aperture 8 caused by the subjection of the narrow part of the aperture to repeated electric breakdown discharges.

A few of the many possible methods for accomplishing such tuning are shown in Figs. 12 to 15 inclusive. In Fig. 12 a threaded stud 30 is shown fastened to one of the walls of the wave guide 4. The surface of the wall to which the stud 30 is fastened is perpendicular to the electric vector of the oscillations in the pipe. It is preferable to place the threaded stud 30 centrally with respect to the wave guide wall in order to locate it at or near the maximum electric field. The wall of the wave guide is perforated so that a screw 32 may be inserted into the pipe through the stud 30. A locking nut 34 serves to preserve the adjustments and to maintain firm electrical contact at the screw threads. Instead of providing actual contact at the wave guide wall between the wall and the screw 32, other arrangements providing effective energy transfer at radio frequencies by the use of suitable small resonators around the screw, with or without direct electrical contact, may be employed.

The distance between the screw 32 and the barrier 6 has an important influence upon the effect of the screw 32 upon the resonant structure of the barrier 6 and its aperture 8. If this distance is about one-half of the wave length in the wave guide of the oscillations in question, the effect of the screw will be that of an adjustable capacitance in parallel across the jaws of the aperture 8. If the distance between the screw 32 and the barrier 6 is approximately one-quarter of a wave length of the oscillations in question, in the wave guide the adjustable screw, as it affects the aperture 8, will act as a variable inductance across the width of the aperture 8. The effect of the screw 32 when placed at positions intermediate of those just mentioned is somewhat more complicated, and consequently I prefer either quarter-wave or half-wave spacing or both.

A similar screw introduced into the guide in a direction perpendicular to the electric vector of transmitted oscillations might also be used for tuning. Such a screw usually has an inductance effect at the place of its insertion. Another possible tuning arrangement is a branch or "stub" guide having a short-circuiting termination which is adjustable in position. These various tuning arrangements may be located at some distance from the barrier 6, preferably one or more quarter-wave lengths, and yet effectively provide an adjustable susceptance in shunt with the tuned circuit constituted by the barrier 6 and its aperture 8.

Fig. 13 shows another method for varying the tuning of the aperture 8. In this case, as shown in the drawing, the broadened ends of the aperture are made to occupy a somewhat greater part of the length of the aperture than in the aperture previously described, such as that shown in Fig. 2. The jaws 9 bordering the narrow part of the aperture may advantageously be formed of pieces or slugs 41 of a refractory metal such as tungsten (as shown in Fig. 13) in good electrical and physical contact with the highly conducting metal of the barrier 6, which is preferably copper. The slugs 41 form a facing along

the narrow portion of the aperture, in the region where breakdown discharges occur. Since tungsten or other similar refractory metal will withstand the high temperatures present in an arc discharge without corrosion or disintegration, the facing greatly lengthens the useful life of the barrier. In one of the broadened ends of the aperture 8 is provided a swinging vane 40. A channel is cut in the metal of the barrier 6 in a direction parallel to the long dimension of the aperture 8 and preferably located centrally with respect to the short dimension thereof. In the channel is laid a shaft 44 which is fastened to the vane 40 and serves to rotate the vane 40 in the aperture 8. The shaft 44 is provided with a manipulating and indicating means, such as the crank 46, in any well-known manner. Other mechanical arrangement could also be employed for actuating a vane similar to the vane 40 in the aperture 8.

Figs. 14 and 15 show, in elevation and plan respectively, still another way of tuning the aperture 8. In this arrangement, sliding shutters 50, 50 made of metallic conducting material may be moved so as to short-circuit the ends of the aperture 8 at an adjustable location. The sliding shutters 50, 50 are guided by the lugs 52, 52, 52, 52 which are suitably fastened to the barrier 6, as by soldering. The ends of the shutters 50, 50 are brought outside of the wave guide through suitable holes in the wave guide wall. It is important that the shutters 50, 50 should make good electrical contact with the barrier 6, and for that purpose spring pressure may be applied by suitable means (not shown).

It is believed to be desirable to keep the thickness of the metal barrier 6 down to fairly small proportions, in order to minimize losses. The dimensions of the aperture 8 suitable for operation at any particular frequency will of course depend upon the shape of the aperture. For a given shape the desired dimensions may readily be determined by experimental procedures. In general, it may be pointed out that narrowing the aperture in the direction of the electric vector in the wave guide across which the barrier 6 is located has an effect similar to an increase of capacitance in a tuned circuit, while shortening the aperture in the direction perpendicular to the said electric vector has an effect similar to the addition of a shunt inductance (that is, a lowering of the inductance). In the case of a rectangular slot, the length of the slot will be approximately equal to one half of the free space wave length for the resonant frequency.

The protective breakdown device of this invention is particularly well suited for simple incorporation into wave guides of the hollow pipe variety. The resonant aperture 8 is an essentially two-dimensional system, and, moreover, a symmetrical one, so that a minimum of mechanical construction is necessary to arrange such an electrical breakdown discharge device in a wave guide system. The two-dimensional resonant aperture has, in comparison with other resonant cavities that might be used for electrical breakdown switches in wave guide systems, the advantage of mechanical compactness and the further advantage of extreme simplicity in the method of connecting the resonant aperture electrically in such a way as to respond to the oscillations transmitted by the wave guide system.

What I desire to claim and secure by Letters Patent is:

1. In a system for the transfer of high frequency electromagnetic waves including a pipe wave guide, a protective electrical breakdown device which includes a metallic conducting barrier located transversely of said wave guide and having an aperture of elongated contour said aperture being so dimensioned that said barrier constitutes a tuned circuit adapted to resonate at a frequency substantially equal to that of oscillations desired to be transmitted through said wave guide system, said aperture being at least for part of its length so narrow that when oscillations in said pipe exceed a predetermined amplitude an electrical breakdown discharge will occur across said aperture.

2. In a system for transmitting and receiving by means of the same antenna and which includes pipe wave guides adapted to transfer electromagnetic waves and leading respectively toward a transmitter, a receiver and an antenna, the combination of a suitably located junction of said wave guides, a barrier of conducting metal in that one of said wave guides leading from said junction to said receiver, said barrier having an aperture of elongated contour with its long dimension oriented perpendicularly to the electric vector of oscillations transmitted in said wave guide, the width of said aperture being sufficiently small, at least for a part of its length, to permit the establishment of an electrical breakdown discharge across said aperture when oscillations in said wave guide exceed a predetermined amplitude, said aperture being dimensioned and shaped to resonate at a frequency substantially equal to that employed for said transmitting and receiving, said apertured barrier being located at a distance from said junction approximately equal to an integral number (including zero) of half wave lengths of the oscillations in said wave guides.

3. In a system for the transfer of high frequency electromagnetic waves including a pipe wave guide, a protective electrical breakdown device which includes a metallic conducting barrier of relatively thin cross section located transversely of said wave guide and having an aperture of elongated contour with its long dimension perpendicular to the electric vector of oscillations transmitted in said wave guide, the width of said aperture being sufficiently small at least for a part of its length to permit the occurrence of an electric breakdown discharge across said aperture when oscillations in said pipe exceed a predetermined amplitude, said aperture being dimensioned and shaped so that said apertured barrier resonates at a frequency substantially equal to that of oscillations transmitted through said wave guide system, and means associated with said barrier and said aperture to maintain a partial vacuum in the space defined by said aperture for promoting ionization and electrical breakdown therein.

4. In a system for the transfer of high frequency electromagnetic waves including a pipe wave guide, a protective electrical discharge device including a metallic conducting barrier of relatively thin cross section located transversely of said wave guide having an aperture of elongated contour with its long dimension perpendicular to the electric vector of oscillation transmitted in said wave guide, the width of said aperture being sufficiently small at least for a part of its length to permit the occurrence of an electric breakdown discharge across said aperture when oscillations in said pipe exceed a predeter-

mined amplitude, said aperture being dimensioned and shaped so that said apertured barrier resonates at a frequency substantially equal to that of oscillations transmitted through said wave guide system, means associated with said barrier to maintain a partial vacuum in the space defined by said aperture, an auxiliary electrode associated with said means and electrically separated from said conducting barrier for maintaining a relatively low intensity electric discharge in the immediate neighborhood of said aperture, and means for impressing a voltage on said auxiliary electrode with respect to said conducting barrier during periods when electrical breakdown of said aperture is desired to be promoted.

5. In a system for the transfer of high frequency electromagnetic waves including a pipe wave guide, a protective electrical discharge device including a metallic conducting barrier of relatively thin cross section located transversely of said wave guide and having an aperture of elongated contour with its long dimension perpendicular to the electric vector of oscillations transmitted in said wave guide, the width of said aperture being sufficiently small at least for a part of its length to permit the occurrence of an electric breakdown discharge across said aperture when oscillations in said pipe exceed a predetermined amplitude, said aperture being dimensioned and shaped so that said apertured barrier resonates at a frequency substantially equal to that of oscillations transmitted through said wave guide system, means associated with said barrier to maintain a partial vacuum in the space defined by said aperture and means located within said last-mentioned means for constantly maintaining ionization in the immediate neighborhood of said aperture.

6. In a wave guide system, a protective device comprising a conducting barrier of a shape which corresponds to the internal dimensions of said wave guide, said barrier being positioned transversely of said guide and having an elongated aperture adapted to resonate at a predetermined frequency, said aperture being sufficiently small for a part of its length that an electrical breakdown discharge will occur across said aperture at a predetermined potential, means associated with said barrier and said aperture to maintain a partial vacuum in the space defined by said aperture, and means for maintaining a region surrounding said aperture in an ionized state, said last-mentioned means comprising an opening in said conducting barrier communicating with said aperture, an electrode extending through said opening to said aperture, said electrode being insulated from said conducting barrier, and means for applying a voltage to said electrode.

7. In a wave guide energy transmission system, a protective device which includes a conducting barrier positioned transversely of said guide and being formed with a centrally disposed elongated aperture, said aperture being dimensioned for resonance at the frequency of oscillations transmitted by said system, and being further dimensioned for incurring electrical discharge thereacross when the oscillations in said system exceed a predetermined energy level.

8. In a wave guide system, a protective device which includes a conducting barrier positioned transversely of the direction of propagation of electromagnetic energy in said wave guide and having an aperture located in said barrier, said aperture being so dimensioned in a direction parallel to the direction of the electric field of oscillations in said guide that a breakdown will occur across said aperture in said direction when the amplitude of said oscillations exceeds a predetermined value, said aperture being further dimensioned whereby said aperture is resonant at the frequency of said oscillations.

9. In a wave guide system, a protective device which includes a conducting barrier positioned transversely of the direction of propagation of electromagnetic energy in said wave guide and having an elongated aperture located in said barrier, said aperture being so dimensioned, at least in part, in a direction parallel to the direction of the electric field of oscillations in said guide that an electrical breakdown will occur across said aperture in said direction when the amplitude of said oscillations exceeds a predetermined value, the dimension of said aperture in a direction perpendicular to said breakdown direction being arranged whereby said aperture is resonant at the frequency of said oscillations.

10. Apparatus in accordance with claim 9, wherein said aperture includes enlarged openings at the ends thereof.

11. In a wave guide system having a junction of first and second wave guides, a protective device which includes a conducting barrier located at said junction and positioned transversely of the direction of propagation of waves through said second wave guide, said barrier having a tuned aperture therein, said aperture being so dimensioned that it is resonant at the frequency of oscillations transmitted by said system and that a discharge will occur across said aperture when the oscillations in said system exceed a predetermined amplitude.

12. Apparatus in accordance with claim 11, wherein said tuned aperture comprises within said barrier a centrally disposed elongated slit oriented perpendicularly to the direction of the electric field of oscillations in said second wave guide.

13. Apparatus in accordance with claim 11, wherein said tuned aperture comprises within said barrier a centrally disposed elongated slit having enlarged openings at the ends thereof, said slit being oriented perpendicularly to the direction of the electric field of oscillations in said second wave guide.

14. In a wave guide system having first and second wave guides wherein said second wave guide forms a junction with said first wave guide at a wall of said first wave guide, a protective device comprising a tuned aperture in the said wall of said first wave guide being oriented centrally of the area of said first wave guide enclosed by the end of said second wave guide at said junction.

15. Apparatus in accordance with claim 14, wherein said tuned aperture comprises an elongated slit oriented perpendicularly to the direction of the electric field of oscillations in said second wave guide.

16. Apparatus in accordance with claim 14, wherein said tuned aperture comprises an elongated slit having enlarged openings at the ends thereof, said slit being oriented perpendicularly to the direction of the electric field of oscillations in said second wave guide.

17. In a wave guide system having first and second rectangular wave guides wherein said second wave guide forms a junction with said first wave guide along a broad wall of said first wave guide, a protective device comprising a tuned aperture in the said broad wall of said first wave guide, said aperture being oriented centrally of

the area of the broad wall of said first wave guide enclosed by the end of said second wave guide at said junction.

18. Apparatus in accordance with claim 17, wherein said tuned aperture comprises an elongated slit oriented perpendicularly of the direction of the electric field of oscillations in said second wave guide.

19. Apparatus in accordance with claim 17, wherein said tuned aperture comprises an elongated slit having enlarged openings at the ends thereof, said slit being oriented perpendicularly of the direction of the electric field of oscillations in said second wave guide.

20. Apparatus in accordance with claim 7, which includes, in addition, means associated with said barrier for maintaining a partial vacuum in the space defined by said aperture for promoting ionization and electrical breakdown therein.

21. Apparatus in accordance with claim 7, which includes in addition, an envelope secured to said barrier and enclosing said aperture for maintaining a partial vacuum in the space defined by said aperture to promote ionization and electrical breakdown therein.

22. Apparatus in accordance with claim 7, including means associated with said aperture for establishing in the immediate vicinity thereof a region of charged electric particles.

23. Apparatus in accordance with claim 7, including means associated with said barrier and said aperture to maintain a partial vacuum in the space defined by said aperture, and means associated with said aperture for establishing in the immediate vicinity thereof a region of charged electric particles.

24. Apparatus in accordance with claim 7, including means for maintaining a partial vacuum in the space defined by said aperture, and means for establishing a region of charged electric particles in the immediate neighborhood of said aperture, said last-mentioned means comprising an electrode extending into said aperture, and means for applying a voltage to said electrode.

25. In combination, a dielectric wave guide of the hollow-pipe type, exciting means for establishing electromagnetic waves within said guide, a metallic wall associated with said guide and lying in a plane substantially transverse to the direction of wave propagation therethrough and provided with an aperture having an appreciable dimension perpendicular to the electric component of the waves propagated through said guide and tuned to the frequency of the exciting means, and means for enclosing said aperture in an atmosphere at low pressure comprising a pair of bulbous vitreous members mounted on opposite sides of said wall and sealed thereto.

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