Dec. 23, 1958 H. L. STEELE, JR 2,866,164

CYCLIC MICROWAVE SWITCHING TUBE

Filed Dec. 31, 1953 2 Sheets-Sheet 1

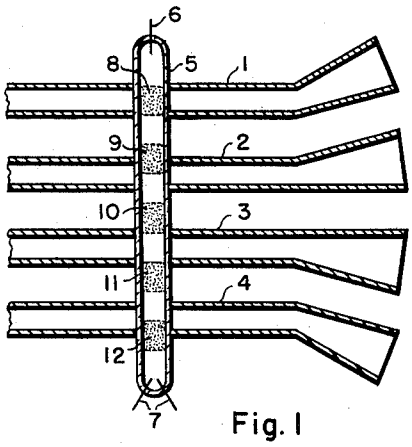


Fig. 1

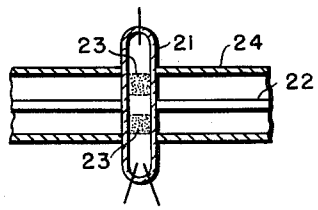


Fig. 3

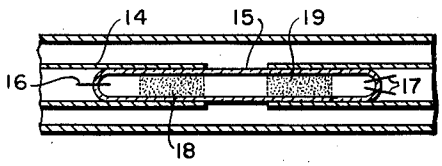


Fig. 2

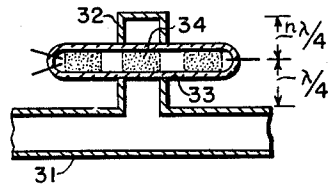


Fig. 4

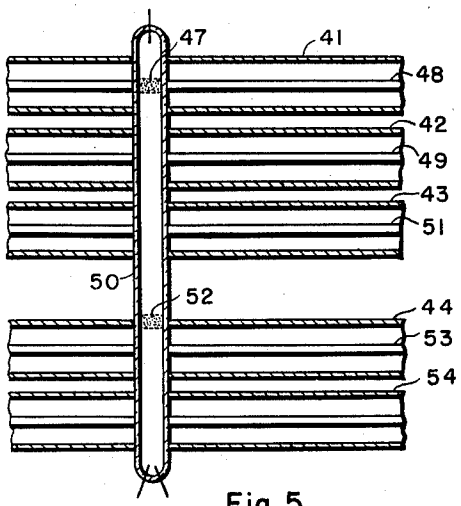


Fig. 5

WITNESSES

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CYCLIC MICROWAVE SWITCHING TUBE

Filed Dec. 31, 1953 2 Sheets-Sheet 2

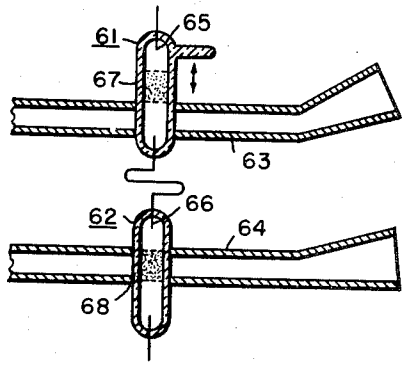


Fig. 6

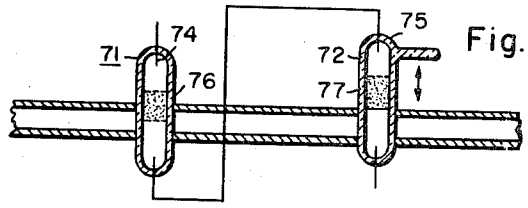


Fig. 7

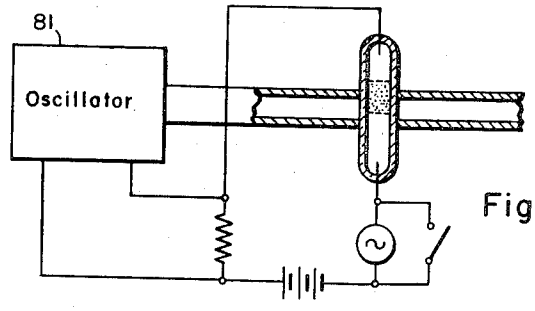


Fig. 8

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CYCLIC MICROWAVE SWITCHING TUBE

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12 Claims. (Cl. 333—1)

My invention relates to electrical switching means and in particular relates to switching means adapted to periodically acquire and lose electrical conductivity at a relatively rapid rate. A particularly valuable field of use of my switching means is for periodically cutting off and passing the propagation of electromagnetic waves of high frequency through wave guides, which may be of either the hollow or the coaxial type.

A particular instance of the utility of my invention appears in connection with radar systems in which it is desired to sweep surrounding space with moving beams of electromagnetic radiation of such wave length that it is transmitted to the radiation emitter through wave guides. In many such devices the emitter directing the beam has been moved mechanically, but the rapidity with which a given space-volume may be searched is held to a low value by the rates of mechanical movement which it is practicable to apply to objects of the size of the radiating horns or antennas required in directing the beam and the mechanism required is costly and complicated. Such mechanical movement of the radiator may be avoided by providing an array of horns or antennas which can be switched in and out of circuit in proper sequence to move the radiated beam, and a much more rapid traverse of the search space is thus made possible. The switching of wave guides supplying such horns or antennas is one use to which my invention is particularly well adapted, although it is by no means limited to that use.

While attempts have been made to utilize the initiation of discharges between electrodes in gaseous atmospheres by suddenly applied voltage pulses to open and close electric circuits with high rapidity, these are found to suffer from the limitation that the control circuits for causing periodic operation of the discharge paths are complicated and costly.

While discharges in tubes between unheated electrodes in gaseous atmospheres of low pressures appear to the unaided eye to be continuous, they often actually comprise alternate luminous (conductive) regions and non-luminous (non-conductive) regions which move between the electrodes at a speed too great for the eye to distinguish. These striae and their speed are very regular, and may be controlled with considerable precision by the parameters of the tube and the discharge. In accordance with my invention I employ these alternate moving masses of conducting and non-conducting gas for periodic switching of wave guides.

There are two different ways in which these discharges may be used for switching purposes. In one, the tube containing the discharge passes through the wave guide transversely at a point of its length, and acts as a short circuit at the wave frequencies between the walls of the guide, blocking energy flow in the guide at that point when an ionized stria occupies the guide and allowing wave energy to pass freely when no stria is within the guide walls. This action is, of course, most effective when the cloud or stria is substantially congruent with the cross-section of the guide. In the other method, a

portion of the discharge tube occupies a gap in the wave guide wall about equal in length to one stria. When an ionized stria occupies this gap, the wave guide passes wave energy readily, but when the gap is occupied by a non-conductive interval between striae, the guide is substantially blocked to energy flow. This form of my invention is particularly well adapted to use in wave guides of the concentric type where the above-mentioned gap is located in a tubular central core of the guide.

One object of my invention is to provide a novel arrangement for periodically interrupting the flow of energy in wave guides.

Another object is to provide a new and improved arrangement for switching energy flow between a plurality of wave guides.

Another object is to provide a new and improved arrangement for periodically shifting the direction of an output beam from a radio antenna system.

Another object is to provide a new and improved arrangement for causing a beam of radiation to shift about in accordance with a predetermined pattern.

Another object is to provide a novel type of search arrangement for radar systems.

Other objects of my invention will become apparent upon reading the following description taken in connection with the drawings in which:

Figure 1 is a schematic representation of radiation transmission system capable of periodically shifting the direction of a beam of radiant energy and employing the principles of my invention in one form;

Fig. 2 is a schematic representation of a wave guide of the concentric form employing one form of my invention;

Fig. 3 is a similar representation of a concentric type wave guide using another form of my invention;

Fig. 4 is a similar representation of a wave guide of rectangular type using a still different modification of my invention;

Fig. 5 is a modification of my invention which is particularly suitable where it is desired to have only one of a set of parallel wave guides conduct at any one time; for instance where the guides respectively supplied energy to a set of horns which should emit energy in succession;

Fig. 6 is a schematic representation of a radiation transmission system capable of periodically shifting the direction of a beam of radiant energy in accordance with another embodiment of my invention;

Fig. 7 is a schematic representation of a radiation transmission system in accordance with another embodiment of my invention; and

Fig. 8 is a schematic representation of a radiation transmission system in accordance with another embodiment of my invention.

Referring to Fig. 1 in detail, separate wave guides 1, 2, 3 and 4, which may be any well known type and of rectangular cross-section may be supplied with electro-magnetic waves or spaced pulses from a common source (not shown). The wave length of the radiation may have any value suited to efficient transmission through the guides 1 to 4. The guides 1 to 4 may be provided with tapered outlets or horns for efficiently emitting the radiation to free space in a beam, and the horns are variously tilted to send out beams of different direction. This arrangement of wave guides and horns may be employed to emit a shifting beam by blocking all guides but one, at any one time, and switching the blocking to the various guides periodically and in predetermined succession.

An evacuated discharge tube 5 passes transversely through the wave guides 1 to 4. Tube 5 may have a glass container enclosing a gas such, for example, as argon (or any inert gas) at a pressure of 2 mm. of

mercury and a positive electrode 6 comprising a single wire which may end in a disc and a negative electrode 7 comprising a filament containing electron-emissive material supported on a pair of wires sealed through the wall of tube 5. However, a number of other forms of electrodes 6 and 8 are well known in the discharge tube art and may be used. When a direct current of the order of 0.1 ampere is applied from a suitable source (not shown) an electric discharge, which can be shown to comprise striations of luminous, and highly ionized, regions 8 to 12 separated by intervals of non-luminous and substantially unionized gas moving rapidly along the tube 5 from positive electrode 6 to negative electrode 7. The velocity of movement of the striations 8 through 12, and their size and electrical conductivity depend upon the voltage and current flow between electrodes 6 and 7 which can be adjusted at will by means well known in the art.

At the instant pictured in Fig. 1 the stria 8 is centered in the wave guide 1 and its conductivity acts as a short circuit between opposite sides of the guide shutting off substantially all energy flow through the guide 1 from the energy source to the horn. In wave guide 2 the conductive stria 9 likewise interposes such large masses of conductive gas that nearly all the wave energy is reflected back toward its source and little or none of it emerges from the outlet horn. On the other hand, the nonconductive interval between striations 10 and 11 occupies the wave guide 3 and permits virtually all the wave energy to pass through the latter and emerge from its horn. The wave guide 4 is partially blocked off by striation 12.

As the striations move downward striation 10 will move to partly block guide 3 but striation 12 will uncover guide 4 so that the energy radiation from the horn of guide 3 ceases and the beam shifts to the horn of guide 4; because the nonconductive interval between striations 11 and 12 permits energy passage freely through guide 4. This shifting of the energy outflow from guide to guide and horn to horn continues cyclically as long as the striations move down the tube 5. The rapidity of beam shift obviously may be determined by adjusting the velocity of movement of the striations by altering the discharge path parameters.

Fig. 2 shows an arrangement particularly adapted to switching in a wave guide of the concentric type. The core conductor 14 is hollow and encloses a gaseous discharge tube 15, except for a gap positioned about half way between the positive terminal 16 and the negative terminals 17 of the tube 15. The tube 15 is traversed by conductive regions or striae 18 and 19 each at least as long as the gap in core conductor 14, and separated by an interval of substantially unionized gas of about the same length. When a conductive stria covers the gap in core conductor 14, the wave guide permits wave energy to pass through it; but when a nonconductive interval occupies a substantial part of the gap energy flow through the wave guide is blocked. Flow of radiant energy is thus alternately turned on and cut off periodically by the discharge in tube 15.

Fig. 3 shows an alternative form in which my invention may be applied to switching off and on energy flow in a wave guide of the concentric type. A gaseous discharge tube 21 of the type previously described passes diametrically through the wave guide substantially at right angles to its axis. Tube 21 is preferably so adjusted that the nonconductive intervals between striations are about equal in length to the diameter of its core 22, and the conductive bright regions 23 have a length about equal to the radial dimension between the core 22 and sheath 24. When the conductive bright regions 23 span the space between the sheath and core they act as short circuits between the core and sheath, and substantially cut off flow of wave energy along the guide. When a striation is centered on core 22 and so nonconductive intervals line up with the space between core and sheath wave energy flows freely along the guide.

Fig. 4 shows still another form in which my invention may be applied. The wave guide 31, here shown as of rectangular type, is provided with a side branch 32, closed at its outer end and having a length equal to half the wave length, which flows through guide 31. A gaseous discharge tube 33, similar to those already described, passes transversely through the branch 32 at its mid-point. When a conductive striation 34 is centered in the branch 32 flow of wave energy along the guide 31 is blocked. When a nonconductive interval is centered in branch 32, the main guide passees wave energy freely.

As an alternative form the distance of the tube 33 in Fig. 4 from the wall of the wave guide 31 may be made equal to one half the wave length, the length of branch 32 being increased accordingly. The presence of a conductive region at the mid-point of tube 33 would then make the stub a half-wave tuner causing the guide 31 to conduct waves freely, while the presence of a nonconductive region at that mid-point would permit waves to pass down branch 32 to any load connected to it beyond tube 33.

For certain purposes it may be desirable to insure that only a single wave guide is conductive to wave energy at any one time; for example the set of wave guides and horns in Fig. 1 for a radar search-antenna may be one such case. In such instances the assembly of concentric wave guides 41, 42, 43 and 44 in Fig. 5 may require that only a single guide shall be conductive at any one time. A gas discharge tube 46 may pass transverse to the cores of the respective guides and have the tube parameters so adjusted that the conductive striations have length about equal to the diameter of the central cores of the wave guides, and are widely spaced apart by intervals of nonconductive gas so that only a single conductive striation 47 can be aligned with any of the three upper wave guides 41, 42, and 43 at any one time. Thus when the striation 47 is aligned with the core 48 of the upper wave guide 41, that wave guide will freely conduct wave energy to its horn, but the wave guides 42 and 43 will be blocked to wave energy flow because of the gaps in their core conductors 49 and 51. As the striation 47 moves downward away from the core 48 the wave guide 41 will be blocked, and no wave guide will conduct wave energy until the striation 47 aligns with the core 49 of the wave guide 42. Thereupon the latter guide will become freely conductive as long as the striation 47 lines up with its core 49, but all three guides will then be nonconductive until the striation 47 aligns with the core 51 of the wave guide 43. It is thus insured that none of the three wave guides 41, 42 or 43 will transmit wave energy while any other guide of the group is conductive.

In the arrangement just described there is of course an interval of time while the striation 47 has left alignment with core 48 and has not yet reached alignment with core 49 during which energy transmission takes place through none of the wave guides. If it is desired to shorten this interval the tube parameters may be made such that another striation 52 is so spaced from the striation 47 that it aligns with the core 53 of the wave guide 44 while the striation 47 is midway between the cores 48 and 49 of wave guides 41 and 42. The gap in emission of wave energy from the group 41, 42, 43 of wave guides is thus filled by emission through the wave guide 44. A similar wave guide 54 with a core 55 may be arranged just below wave guide 44 at such a distance that the striation 52 aligns with the core 55 when the striation 47 is half way between the cores 49 and 51, so that the wave guide 53 will emit energy during the time interval intervening between flow of energy in wave guide 42 and wave guide 43. The Fig. 5 arrangement permits

spacing of the wave guides 41, 42, 43 very close together, it will be noted.

Where it is desired to have the wave guides spaced rather far apart, on the other hand, a grouping made up like Fig. 5 with the guides 42 and 43 omitted may be resorted to. It will be noted that notwithstanding the wide spacing between wave guide 41 and wave guide 44 the time interval between conductions in these guides with the striations spaced like striation 47 and 52, is less than that intervening between the conductive periods in the closely spaced wave lengths 41 and 42 in a system in which the wave guide 44 was omitted.

It may be noted that while I have shown in Figs. 1 and 5 arrangements in which a single gas discharge tube passes through a plurality of guides similar results may be achieved with a wave guide system in which separate discharge tubes are provided for the respective wave guides, provided the discharges in the different guides are made to occur in proper time succession. As shown in Fig. 6, one means by which this can be accomplished would be to run the tubes 61, 62, in series with each other, but making the tubes 61, 62, long enough so that their anodes 65, 66, may be pushed nearer to or drawn back further away from the wave guide wall. Thus if conductive striations 67, 68, start from the respective anodes 65, 66, of several series-connected discharge tubes 61, 62, at the same instant, the conductive striation 68 will occupy the wave guide 64 in which the anode 66 is positioned close to the wave guide wall first, and the conductive striation 67 will occupy the wave guide 63 where the anode 65 is more distant from the wave guide wall, a short time later. The two guides 63, 64, will thus be rendered conductive successively, and not simultaneously. Thus by adjusting the positions of the different discharge tubes 61, 62, the conduction time of various wave guides 63, 64, may be adjusted at will.

It will be evident that where, in a wave guide system, two different groups of wave guides are desired to be made conductive, and nonconductive simultaneously, this could be readily done by adjusting the positions of the serially connected tubes in the respective groups. Likewise when it is desired to render one group of guides conductive at the instant another group becomes nonconductive, this could be done by properly adjusting the positions in each of their discharge tubes provided such discharge tubes all are connected in series.

As shown in Fig. 7, two or more discharge tubes 71, 72, connected in series with each other could be positioned across the wave guide 73 at separate points of its length. The guide 73 would, if it were the hollow type, then be conductive only during an interval of time when a conductive striation in neither discharge tube was positioned within the guide, a conductive striation in either tube which was positioned within the guide would shut off wave energy flow regardless of whether the conductive striation in the other discharge tube occupied the wave guide or not. Thus by pushing the anode 75 of one discharge tube 72 to a position such that its conductive striation 77 began to occupy the wave guide 73 only a short interval after the conductive striation 76 of the other discharge tube 71 passed out of the wave guide 73 energy pulses of extremely short duration could be caused to flow through the wave guide 73. Thus the length of energy pulses flowing through the wave guide 73 could be altered at will from a very sharp pulse to a much longer pulse by adjusting the position of the anode of one discharge tube from the wave guide wall.

When the tubes 5, 15, 21, 33 and 50 are energized from a pulsed radio-frequency source, as is usual in radar, the voltage oscillations at the tube terminals due to arrival of striae may be caused in ways evident to those skilled in the art to synchronize or trigger the oscillator pulses.

Moreover by energizing the electrodes of a tube 83 placed in a wave guide 82, as shown in Fig. 8, from a direct-current source 84 having an alternating voltage from a source 85 superposed on it the timing of the striae is possible; and in particular this alternating voltage may be used to trigger the pulses of a radio frequency oscillator 81 sending out radar pulses or the like as shown in Fig. 8.

I claim as my invention:

1. In combination with a wave guide for the transmission of electromagnetic energy, a cold electrode gaseous electrical discharge tube having an envelope, a central portion and two end portions, said central portion being positioned within said wave guide so that said central portion is exposed to said electromagnetic radiation, said central portion including a central envelope portion which is transmissive to said electromagnetic energy, an electrode positioned in each of said end portions, means for operating said tube to form alternate conductive and nonconductive moving striations between said electrodes to periodically prevent and allow the passage of said electromagnetic energy through said wave guide, said conductive moving striations having a length equal to a substantial portion of said exposed central tube portion.

2. In combination with a wave guide which is operable to transmit electromagnetic energy, a cold electrode gaseous electrical discharge tube having an envelope, a central portion and two end portions, said central portion passing transversely through said wave guide, an electrode positioned in each of said end portions, the portion of said envelope which is within said wave guide being transmissive to said electromagnetic energy, means for operating said tube to form alternate conductive and nonconductive moving striations between said two electrodes to periodically prevent and allow the passage of said electromagnetic energy through said wave guide, said conductive moving striations having a length equal to a substantial portion of the length of said part of said tube which passes through said wave guide.

3. In combination with a plurality of wave guides which are operable to transmit electromagnetic energy, a plurality of cold electrode gaseous electrical discharge tubes, each of said discharge tubes having an envelope, a central portion and two end portions, each said central portion passing transversely through one of said wave guides, the portions of said envelopes which are within said wave guide being transmissive to said electromagnetic energy, an electrode positioned in each of said end portions, means for operating said discharge tubes to form alternate conductive and nonconductive moving striations between said electrodes to periodically prevent and allow the passage of said electromagnetic energy through said wave guides, said conductive moving striations having a length equal to a substantial portion of the length of said portions of said tubes which are within each said wave guide, and means for operating said electrical discharge tubes in series.

4. In combination with a plurality of wave guides which are operable to transmit electromagnetic energy, a plurality of cold electrode gaseous electrical discharge tubes, each of said discharge tubes having an envelope, a central portion and two end portions, each said central portion passing transversely through one of said wave guides, the portions of said envelopes which are within said wave guide being transmissive to said electromagnetic energy, an electrode positioned in each of said end portions, means for operating said discharge tubes to form alternate conductive and non-conductive moving striations between said electrodes to periodically prevent and allow the passage of said electromagnetic energy through said wave guides, said conductive moving striations having a length equal to a substantial portion of the length of said portions of said tubes which are within each said wave guide, means for operating said electrical discharge tubes in series, said electrical discharge tubes being longer than the distance between the walls of said wave guides at the point through which said tubes

pass, and means for longitudinally displacing at least one of said discharge tubes.

5. In combination with a concentric wave guide for the transmission of electromagnetic energy, said wave guide having a central core member and a sheath member surrounding and spaced from said core member, said central core member including a hollow portion having an axially extending gap, a cold electrode gaseous electrical discharge tube having an envelope, a central portion, two end portions and an electrode positioned in each of said end portions, said electrical discharge tube being coaxially positioned within said hollow portion so that said central portion is positioned within said gap, the portion of said envelope which is within said gap being transmissive to said electromagnetic energy, means for operating said tube to form alternate conductive and nonconductive moving striations between said electrodes to periodically prevent and allow the passage of said electromagnetic energy through said wave guide, said conductive moving striations having a length equal to a substantial portion of said gap.

6. In combination with a concentric wave guide for the transmission of electromagnetic energy, said wave guide having a central core member and a sheath member surrounding and spaced from said core member, a cold electrode gaseous electrical discharge tube having an envelope, a central portion and two end portions and an electrode positioned in each of said end portions, said central portion passing transversely through said sheath member and said central core member of said wave guide, the portion of said envelope which is within said sheath member being transmissive to said electromagnetic energy, means for operating said tube to form alternate conductive and nonconductive moving striations between said electrodes to periodically prevent and allow the passage of said electromagnetic energy through said wave guide, said conductive moving striations having a length equal to a substantial portion of the diameter of said central core member.

7. In combination with a concentric wave guide for the transmission of electromagnetic energy, said wave guide having a central core member and a sheath member surrounding and spaced from said core member, a cold electrode gaseous electrical discharge tube having an envelope, a central portion and two end portions and an electrode positioned in each of said end portions, said central portion passing transversely through said sheath member and said central core member of said wave guide, the portion of said envelope which is within said sheath member being transmissive to said electromagnetic energy, means for operating said tube to form alternate conductive and nonconductive moving striations between said electrodes to periodically prevent and allow the passage of said electromagnetic energy through said wave guide, said conductive moving striations having a length equal to a substantial portion of the radial distance between said central core member and said sheath member.

8. In combination with a wave guide for the transmission of electromagnetic energy, a stub-guide extending outward from the walls of said wave guide, a cold electrode gaseous electrical discharge tube having an envelope, a central portion and two end portions, said central portion passing transversely through said stub-guide, an electrode positioned in each of said end portions, the portion of said envelope which is within said stub-guide being transmissive to said electromagnetic energy, means for operating said tube to form alternate conductive and nonconductive moving striations between said two electrodes to periodically prevent and allow the passage of said electromagnetic energy through said wave guide, said conductive moving striations having a length equal to a substantial portion of the length of said part of said tube which passes through said stub-guide.

9. In combination with a wave guide for the transmission of electromagnetic energy, a stub-guide extending outward from the walls of said wave guide, a cold electrode gaseous electrical discharge tube having an envelope, a central portion and two end portions, said central portion passing transversely through said stub-guide, an electrode positioned in each of said end portions, the portion of said envelope which is within said stub-guide being transmissive to said electromagnetic energy, means for operating said tube to form alternate conductive and nonconductive moving striations between said two electrodes to periodically prevent and allow the passage of said electromagnetic energy through said wave guide, said conductive moving striations having a length equal to a substantial portion of the length of said part of said tube which passes through said stub-guide, said stub-guide having a closed end distant from its junction with the wall of said wave guide by one-half the wavelength of the electromagnetic energy of one transmission mode for said wave guide, said electrical discharge tube passing through said stub-guide at a point substantially midway between its closed end and its junction with the wall of said wave guide.

10. In combination with a plurality of wave guides which are operable to transmit electromagnetic energy, said wave guides lying in substantially the same plane, a cold electrode gaseous electrical discharge tube, an envelope, a central portion and two end portions, said central portion passing transversely through each of said wave guides, the portions of said envelope which are within said wave guides being transmissive to said electromagnetic energy, an electrode positioned in each of said end portions, and means for operating said discharge tubes to form alternate conductive and nonconductive moving striations between said electrodes to periodically prevent and allow the passage of said electromagnetic energy through said wave guides, said conductive moving striations having a length equal to a substantial portion of the length of said portions of said tubes which are within each said wave guide.

11. In combination with a wave guide for the transmission of electromagnetic energy, a plurality of cold electrode gaseous electrical discharge tubes each having an envelope, a central portion and two end portions, each of said electrical discharge tubes passing transversely through said wave guide at spaced intervals so that said central portion passes transversely through said wave guide, an electrode positioned in each of said end portions, electrical connections for operating said electrical discharge tubes in series, means for operating each said electrical discharge tube to form alternate conductive and nonconductive moving striations between said two electrodes to periodically prevent and allow the passage of said electromagnetic energy through said wave guide, said conductive moving striations having a length equal to a substantial portion of the length of said part of said tube which passes through said wave guide.

12. In combination with a wave guide for the transmission of electromagnetic energy, a plurality of cold electrode gaseous electrical discharge tubes each having an envelope, a central portion and two end portions, each of said electrical discharge tubes passing transversely through said wave guide at spaced intervals so that said central portion passes transversely through said wave guide, an electrode positioned in each of said end portions, electrical connections for operating said electrical discharge tubes in series, means for operating each said electrical discharge tube to form alternate conductive and nonconductive moving striations betwen said two electrodes to periodically prevent and allow the passage of said electromagnetic energy through said wave guide, said conductive moving striations having a length equal to a substantial portion of the length of said part of said tube which passes through said wave guide, at least one of said electrical discharge tubes having a length substantially greater than said length of said part of said

tube which passes through said wave guide, and means for displacing the last said electrical discharge tube in directions parallel to its axis.

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