Feb. 18, 1947. M. D. FISKE 2,416,168

ULTRA HIGH FREQUENCY CONTROL SYSTEM

Filed Sept. 17, 1942

Fig.2.

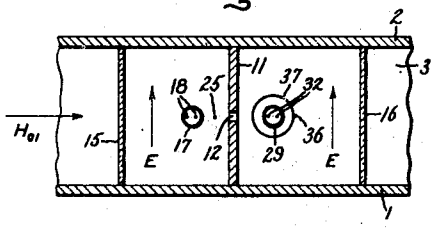


Fig.4.

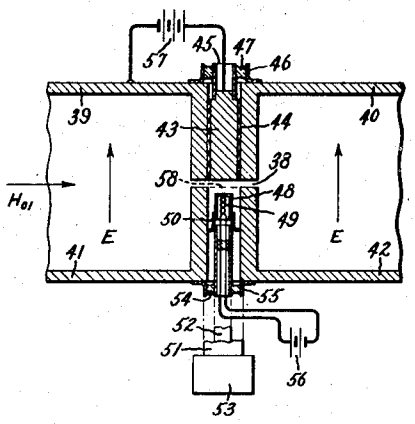


Fig.3.

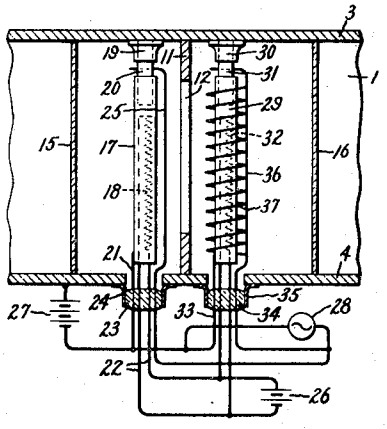


Fig.5.

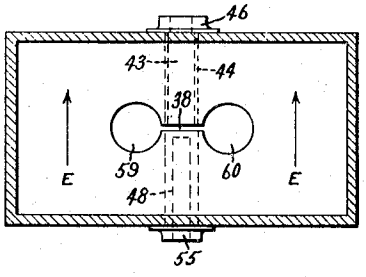
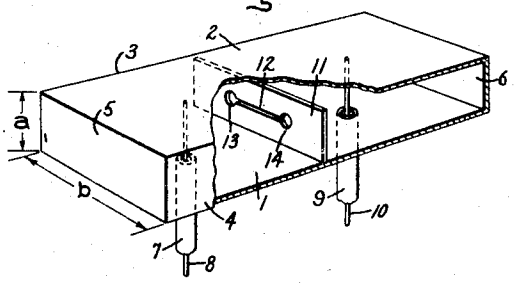


Fig.1.



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2,416,168

ULTRA HIGH FREQUENCY CONTROL SYSTEM

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Application September 17, 1942, Serial No. 458,671

7 Claims. (Cl. 179—171.5)

1

My invention relates to ultra high frequency systems and more particularly to control means and apparatus for controlling the transmission of ultra high frequency electromagnetic waves through dielectric wave guides of the hollow-pipe type.

It is now somewhat generally known that ultra high frequency electromagnetic waves may be transmitted dielectrically through wave guides of the hollow-pipe type which may be constructed of a highly conductive material, such as copper or brass. In order to effect the propagation of electromagnetic waves dielectrically, it is necessary that the frequency of the exciting electromagnetic waves be greater than a critical or minimum frequency which is determined largely by the character of the waves being transmitted, the dielectric constant of the medium within the guide, and the transverse dimensions of the guide.

The types of waves which may be transmitted dielectrically through guides of this nature are manifold and have heretofore been classified generally into the E and H types. In the E type waves, the electromagnetic waves have both longitudinal and transverse components of electric field but only a transverse component of magnetic field. By use of the word "transverse" is meant transverse to the direction of wave propagation through the guide. In the H type waves, the electromagnetic waves have both longitudinal and transverse components of magnetic field but only a transverse component of electric field. The waves which may be transmitted through guides of this nature have been identified by the use of the subscripts as indicated, $E_{n,m}$ and $H_{n,m}$. The subscript n indicates the order of the wave and the subscript m indicates the mode of propagation. The order of the wave is determined by the manner in which the field intensity varies circumferentially around the axis of the guide, whereas the mode is determined by the manner of its variation with distance from the axis of the guide. Although hereinafter in the discussion of my invention an H_{01} type of wave is referred to, it is to be appreciated that my invention is applicable with equal facility to other H type waves as well as to E type waves.

It is an object of my invention to provide new and improved ultra high frequency control apparatus.

It is another object of my invention to provide new and improved structures for controlling the propagation or attenuation of electromagnetic waves through dielectric wave guides.

2

It is a further object of my invention to provide new and improved apparatus including electronic control devices associated with a resonant aperture positioned within a dielectric wave guide for controlling the wave propagation characteristics of the guide.

Briefly stated, in the illustrated embodiments of my invention I provide new and improved arrangements for controlling the propagation of electromagnetic waves through dielectric wave guides, and which are improvements of the type of systems disclosed and broadly claimed in my copending joint patent application Serial No. 458,670, filed September 17, 1942, and which is assigned to the assignee of the present application.

In accordance with the teachings of my invention described hereinafter, I provide new and improved electric discharge means to be used in conjunction with a tuned or resonant aperture which is positioned within or associated with the guide. The resonant aperture is provided in a transverse metallic wall which lies in a plane substantially transverse to the direction of propagation of the electromagnetic waves through the guide, and is tuned to the frequency of the exciting means to effect a concentration or accentuation of the potential of the field incident to the propagation of the electromagnetic waves through the guide.

The electric discharge path which controls the propagation of the electromagnetic waves through the guide or which effects modulation of the waves may comprise a cathode structure and associated grid control means, such as a single wire grid or a spiral or helically wound grid. In another modification of my invention, the anode and cathode of the electric discharge path may be arranged to produce a stream of electrons having a direction of movement substantially transverse or perpendicular to the direction of wave propagation, and may be positioned within the body of the transverse wall having the tuned or resonant aperture.

In accordance with a further object of my invention, I provide structure peculiarly adaptable for use in the ultra high frequency field where it is desired to modulate the electromagnetic waves at ultra high frequency.

Other objects of my invention will appear from the following description of my invention and the novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself, however, both as to its organi-

zation and method of operation together with further objects and advantages thereof may best be understood by reference to the following description taken in connection with the accompanying drawing in which Fig. 1 is a perspective view, partly in section, of one type of system to which my invention may be applied; Figs. 2 and 3 are, respectively, cross-sectional side and plan views of one modification of my invention; and Figs. 4 and 5 are, respectively, vertical cross-sectional and end views of a further modification of my invention.

There is a critical minimum frequency or cut-off frequency for each dielectric guide, the value of which is determined by the dielectric constant of the medium within the guide through which the electromagnetic waves are propagated and the transverse dimensions of the guide. Below this value of critical frequency, the electromagnetic waves are rapidly attenuated and the energy thereof is not transmitted an appreciable distance along the axis of the guide. Above the critical frequency, the electromagnetic waves are propagated with an attenuation and velocity determined by the propagation constant of the guide. This propagation constant P may be expressed as follows:

$$P=\alpha+i\beta \tag{1}$$

where α is the attenuation constant, and β is the phase constant and both are real quantities whose magnitudes depend upon frequency.

If the frequency is great enough, α is very small compared to β and waves are propagated without appreciable attenuation at a phase velocity

$$\frac{\omega}{\beta}$$

which varies with the transverse dimensions of the guide. When the excitation frequency is below the critical frequency, the Expression 1 may still be used but now α and β both become imaginary with the result that β determines the attenuation and α determines the extent of wave action. Since below the critical frequency β is again much larger than α, the attenuation is very pronounced and the wave action is very small. Physically, this means that transmission of waves through the guide is virtually non-existent at frequencies below the cut-off frequency.

Although my invention may be applied with equal facility to dielectric wave guides of various configurations, in the following discussion in order to present some fundamental considerations relative to the description of my invention, the fundamental aspects will be described with particular reference to dielectric wave guides having a rectangular cross section and wherein the height of the guide is a and the base is b.

The phase constant β may be expressed:

$$\beta=\left[\omega^2\mu_1\epsilon_1-\left(\frac{n\pi}{a}\right)^2-\left(\frac{m\pi}{b}\right)^2\right]^{\frac{1}{2}} \tag{2}$$

where ω is the angular velocity of the wave propagated through the medium ($\omega=2\pi f$, where f is the frequency of the wave), μ_1 is the permeability of the medium, and ϵ_1 is the dielectric constant of the medium. The quantities n and m are, of course, the order and mode of the particular wave being transmitted through the guide.

The critical frequency f_0 may be defined as follows:

$$f_0=\frac{1}{2\sqrt{\mu_1\epsilon_1}}\left[\left(\frac{n}{a}\right)^2+\left(\frac{m}{b}\right)^2\right]^{\frac{1}{2}} \tag{3}$$

The wave length λ_g of the electromagnetic waves propagated through the guide may be defined as:

$$\lambda_g=\frac{2\pi}{\beta} \tag{4}$$

An inspection of the above equations, particularly Equation 3 indicates that the critical frequency is smallest for the lowest order wave and increases as either n or m is increased, that is as the order of the wave becomes larger. Furthermore, it will be noted that as either dimension a or b of the wave guide is decreased, the critical frequency increases. In addition, it should be noted that the critical frequency may also be decreased by increasing the value of the dielectric constant or by employing a material having a larger dielectric constant.

In order to simplify still further the presentation of the subject matter of my invention, it will be assumed that the dielectric is air and the system is arranged for the transmission of an H_{01} type wave where the electric component of the field is perpendicular to b, in which case the phase constant and critical frequency expressed by Equations 2 and 3 become:

$$\beta=\left[\left(\frac{\omega}{c}\right)^2-\left(\frac{\pi}{b}\right)^2\right]^{\frac{1}{2}} \tag{5}$$

$$f_0=\frac{c}{2b} \tag{6}$$

where c is the velocity of light in air.

The electromagnetic waves are propagated through the guide; that is, the expression for the progressive wave may be expressed as a function of the propagation constant and time. The electric intensity E and the magnetic H field may be expressed as follows:

$$E=(\text{real})\,E\epsilon^{-i\beta x+i\omega t} \tag{7}$$

$$H=(\text{real})\,H\epsilon^{-i\beta x+i\omega t} \tag{8}$$

An inspection of the Equations 7 and 8 indicates that for given values of x, which is the distance along the axis of the guide for excitation above the critical frequency, the magnitude of the wave varies sinusoidally with time; and furthermore at a given instant the wave has a sinusoidal distribution along the axis.

Referring now to Fig. 1 of the accompanying drawing, I have there diagrammatically illustrated one type of system to which my invention may be applied. The system comprises a dielectric wave guide of the hollow-pipe type having a rectangular cross section and provided with a base member 1 of transverse dimension b and a top plate member 2.

These members, which comprise a confining and directional chamber for the electromagnetic waves, are preferably constructed of a highly conductive material, such as brass or copper. The sides may be provided by plate members 3 and 4 having a height dimension a and are also constructed of a highly conductive metal. One end of the guide may comprise a metallic plate 5 which is conductively connected to the top, bottom and side members.

The wave guide may be completely enclosed by utilizing another end member 6 of conductive material, or may be open to the atmosphere and terminated in a suitable radiator. Electromagnetic waves are established within the guide by suitable input electrode means which may take the form of a concentric or coaxial transmission line comprising a tubular conductor 7 and a concentric

conductor 8, the former of which is conductively connected to base member 1 and the latter of which may be conductively connected to the top plate 2. It is to be appreciated that other forms of input electrode means, such as probes and the like, may be employed in place of the concentric transmission line, and the character of the input electrode means is determined by the type of electromagnetic waves which it is desired to establish within the guide.

The energy of the electromagnetic waves may be extracted from the guide by output electrode means which may also take the form of a concentric transmission line having an outer tubular conductor 9 and a concentric conductor 10. Conductor 9 may be conductively connected to the base 1, and conductor 10 may be connected to the top plate member 2.

The system to which my invention is particularly applicable also includes within the guide or associated therewith a wall 11 lying in a plane substantially transverse to the direction of wave propagation through the guide, and which is constructed of a highly conductive material such as brass or copper, the wall being in physical contact with the top, bottom and sides of the guide.

A resonant aperture or slot 12 is provided in the wall 11 and has an appreciable dimension transverse to the electric component E of the electromagnetic field due to the waves transmitted through the guide. The resonant aperture may be of the type which comprises a central or elongated slit terminated at each end in circular openings 13 and 14. The resonant aperture is tuned to the frequency of the electromagnetic waves, that is the frequency of the input electrode means, for effecting a concentration of the potential due to the field of the waves within the guide. This concentration of potential is due to the resonant characteristics of the aperture.

The dimensions of the resonant aperture 12, that is the effective height and length thereof, are determined by the excitation frequency of the guide and the transverse dimensions thereof.

Figs. 2 and 3 diagrammatically illustrate one embodiment of my invention which may be employed in connection with a resonant aperture used in connection with or associated with a dielectric wave guide. More particularly, I provide means for establishing within the region of the tuned aperture or slot a controllable space charge which controls the effective dielectric constant of the medium surrounding the aperture and the effective dielectric constant of the medium within the guide through which the waves pass. A reference to Equations 2 and 3 above indicates that the phase constant β and the critical frequency f_0 or functions of the dielectric constant of the medium through which the waves are propagated. Furthermore, it will be noted that the critical frequency increases as the effective dielectric constant of this medium decreases.

In Figs. 2 and 3 I disclose arrangements whereby the space charge is controllable and whereby the wave propagating characteristics of the dielectric wave guide are controllable. Fig. 3 is a cross sectional plan view of one modification of my invention, and Fig. 2 is a cross sectional side view, the top, bottom and wall members being assigned reference numerals corresponding to those employed in connection with Fig. 1.

In order to provide an isolated or sealed region within which the electric discharge path is housed, I provide suitable sealing means such as a pair of glass or vitreous insulating walls 15 and 16. The evacuation of the region defined thereby may be obtained by employing a suitable tubulation which may be sealed off after evacuation.

Referring now to Fig. 3, I provide a cathode, such as a thermionic cathode, comprising a metallic cylinder 17 in spaced relation with the wall 11 and more particularly with respect to the tuned aperture 12. The cylinder 17 is preferably of a length equal to or greater than the length of the resonant aperture 12 and may be constructed of a metal coated with an alkaline earth metal or oxide thereof in order to provide a cathode surface of desired emissivity. A heating element 18 is provided for the cathode and may be embedded within suitable material placed within the interior of the cylinder 17.

Cathode 17 may be supported from the side walls 3 and 4 by means of a metallic circular collar 19 and a concentric vitreous insulator 20, the latter of which may extend an appreciable distance into the end of cylinder 17. The other end of the cathode cylinder 17 may be supported by a rigid conductor 21 which serves the additional purpose of impressing a control potential on cathode 17. The cathode heating leads 22 may be made externally accessible by extending through a glass bead insulator 23 which with a flanged metallic cylinder 24 constitutes a seal.

I provide a single wire grid 25 which is preferably parallel to the principal dimension of the resonant slot 11 and which is maintained in spaced relation with the cathode 17 and the resonant aperture. This element is preferably of a length equal to or greater than the principal dimension of the resonant aperture, and one end thereof may be embedded or anchored in the glass insulator 24. The other end of the single wire grid 25 is also sealed in the glass bead 23 and made externally accessible for control purposes.

A suitable source of current, such as a battery 26, may be employed for supplying heating current to element 18 and the voltage for the electric discharge path, constituted by the plate 11 and the cathode cylinder 17, may be furnished by a suitable source such as a battery 27 which is connected to impress a relatively positive potential on the structure including the wall 11.

The magnitude of the space charge is controlled by controlling the potential difference between the cathode cylinder 17 and the wire 25, and this potential difference may be effected by any suitable control signal which, for the purposes of illustration, is represented as a source of alternating current 28. It is to be understood that this source may be of any desired nature, either intermittent or periodic, and may be of low, high or intermittent frequency.

In operation, control of the potential of grid wire 25 determines the magnitude of the space charge, and by a suitable choice of the range of signal potential the electron flow may be completely interrupted. The wave propagation characteristics of the guide, as explained above, are determined in a measure by the density of the space charge. Within the purview of my invention, the system may be operated by establishing a space charge which changes the guide from a propagator to an attenuator, or the space charge may be varied throughout limits which lie above that value of space charge which completely attenuates the waves within the guide.

While in the specific description of my invention I have chosen to describe the electric discharge means which produces the region of charged particles as being one which produces a

stream or beam of electrons, it will be appreciated that I contemplate the provision of electric discharge means for establishing within the vicinity of the resonant slot or aperture a region of charged electric particles. For example, I may also employ within the purview of my invention electric discharge means comprising a gas or vapor which is capable of ionization and which may be controlled by suitable means such as electrostatic control means for initiating the establishment of the ionized condition of the medium. For example, the isolated or sealed region may contain proportions of inert gases such as neon, argon or zenon, or may include an ionizable vapor such as a mercury vapor. Furthermore, combinations of ionizable gases and vapors may be employed.

Generally speaking, it may be said that the effective dielectric constant of the medium is a function of the difference of the dielectric constant of the medium with no electron beam present and a quantity which is directly proportional to the number of charged particles per unit volume, the square of the unit charge of each particle and inversely proportional to the mass of each charge and some function of the field.

It will be apparent that my invention may be applied to numerous types of dielectric wave guides or modifications of apparatus using dielectric wave guides. For example, my invention may be applied to systems wherein it is desired to amplify or phase modulate the electromagnetic waves through the guide.

It will be apparent that apparatus built in accordance with my invention may also be employed as a controllable filter for guided waves. The aperture reflects waves of all frequencies other than those in the region about the resonant frequency of the aperture.

Fig. 3 also shows an alternative arrangement of a grid structure which may be employed as the control means for the electric discharge path. A cylindrical cathode **29** may be supported in spaced relation with respect to wall **11** and aperture **12** in a manner similar to that explained above in connection with cathode cylinder **17**, that is, may be supported by a metallic collar member **30** which is welded or soldered to the side wall **3** and an insulating cylinder or rod **31** which extends into and is supported at one end by collar **30** which itself extends into one end of the cylinder **29**. The cathode in this instance may also be of the thermionic type and may be heated by a heating element **32**. The other end of cylinder **29** may be supported by a rigid lead-in conductor **33** which is conductively connected to cathode **29** and is made externally accessible by extending through a sealing structure comprising a vitreous glass insulator **34** and a flanged cylinder **35**, the latter of which may be welded or soldered to wall **4**.

A single wire or conductor **36** is positioned to lie substantially parallel with cylinder **29** and one end thereof may be embedded in the insulating rod **31**, the other end of which may extend through and be sealed in the glass insulator **34**. I provide an improved grid structure comprising a spiral or helically wound grid **37** which is about cylinder **29** and conductively connected at spaced points to the wire **36**. It is, of course, apparent that the grid **37** does not engage, and is not in physical contact with cylinder **29**, but is in spaced relation thereto as illustrated in side view of Fig. 2.

In operation, the electric discharge path com-

prising the wall **11**, which operates as an anode, the cathode cylinder **29** and the grid **37** function as a controlled discharge path, the potential difference between grid **37** and the cathode cylinder **27** determining the magnitude or density of the space charge. This potential difference may also be derived, as illustrated in the drawing, from a signal source such as the source **28** to vary the potential cyclically and, if desired, grid **37** and grid wire **25** may be varied simultaneously in potential.

A further modification of my invention is illustrated in Figs. 4 and 5, Fig. 4 being a vertical cross sectional view and Fig. 5 being an end view. The arrangement of my invention illustrated in Fig. 4 may also be applied to a system such as that shown in Fig. 1. More particularly, the controlled electric discharge path for the resonant aperture in this modification of my invention is illustrated as producing a stream of electrons the direction of motion of which is transverse or perpendicular to the direction of wave propagation through the guide.

The structure which produces the resonant aperture **38** may comprise right-angle flanges of top members **39**, **40** and bottom members **41**, **42** of two sections of a metallic wave guide. Alternatively, the metallic structure or transverse wall which includes the resonant aperture may be constructed of solid pieces of metal welded to the two sections of the guide. If desired, of course the entire structure may be positioned or enclosed within a sealing chamber so that the surrounding atmosphere may be reduced to the desired pressure.

I provide an anode structure for the electric discharge path which may comprise an anode **43** of solid material, preferably of circular cross-sectional area, which is arranged to lie within the body of the wall constituting the transverse dimension of the structure. The anode **43** is preferably insulated by an insulating cylinder **44** and the entire anode structure may be supported by a metallic cylinder **45** which is welded to the anode **43**. The whole anode structure may be supported from the top of the wave guide by means of a flanged cylindrical collar **46** and an insulating vitreous spacer and seal **47**. The cathode structure may also be positioned within the body of the transverse wall and may comprise a thermionic cathode **48** of inverted cup shape within which a cathode heating element **49** is provided. The cathode **48** is maintained in insulated spaced relation with respect to the body of the transverse wall by means of insulator **50**.

The magnitude of the space charge and hence the modulation of the electromagnetic waves through the guide may be controlled at ultra high frequency by controlling the effective potential difference between the anode **43** and cathode **48**. Consequently, I provide a concentric or coaxial transmission line comprising an outer conductor **51** and an inner conductor **52**, the latter of which extends to the vicinity of, but does not engage, the cathode **48**. It will be appreciated that inasmuch as the spacing between the inverted cup **48** and the tubular conductor **52** is very small, these members are effectively connected together so far as the high frequency circuit is concerned. The modulating potential may be impressed between conductors **51** and **52** by any suitable agency and this agency is represented diagrammatically as element **53** in the drawing.

The cathode structure is also sealed so that

the region within which the electric discharge takes place may be maintained at the desired low pressure, and this may be accomplished by employing a glass annular insulator 54 which is sealed to conductor 52 and the bottom plates 41 and 42 by means of a metallic collar 55. The conductors for the cathode heating element 49 may extend through a part of the length, or the entire length, of the inner conductor 52 of the coaxial transmission line. A source of cathode heating current, such as a battery 56, may be employed.

A source of unidirectional voltage, such as a battery 57, may be employed for impressing a relatively positive potential on the anode 43. Of course, it is not necessary for the utilization of my invention to employ a unidirectional voltage for anode energization.

A grid 58 may be placed within the electric discharge path provided by anode 43 and cathode 48. Grid 58 may be welded or soldered to the transverse wall and extend substantially the entire length of the intermittent slot portion of the resonant aperture shown in Fig. 5. This grid may be coextensive with the anode transverse area and may be employed as a potential equalizing means for the electron stream. In addition, this grid will also serve to maintain the desired resonant characteristics of the resonant aperture assembly.

It will be noted by referring to Fig. 4 that the cathode 48 is spaced some distance from the grid 58. This particular configuration of the elements and spacing thereof also assists in assuring that the resonant aperture maintains its desired qualities during operation with or without an electron beam or stream.

In Fig. 5, which is an end view, the resonant aperture is shown somewhat in detail and may be arranged to have enlarged openings such as circular openings 59 and 60 at each end of the elongated central slit. Other elements have been assigned reference numerals corresponding to the elements shown in Fig. 4.

In operation, the embodiment of my invention illustrated in Figs. 4 and 5 functions in substantially the same way as that explained above in connection with Figs. 2 and 3. The density of the space charge controls the propagation characteristics of the wave guide, the effective dielectric constant of the medium surrounding the guide being decreased as the electron stream density increases. In this way, the electromagnetic waves are modulated.

While I have shown and described my invention as applied to particular systems embodying various devices diagrammatically shown, it will be obvious to those skilled in the art that changes and modifications may be made without departing from my invention, and I, therefore, aim in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In combination, a dielectric wave guide of the hollow-pipe type comprising two metallic sections, exciting means for establishing electromagnetic waves within one of said sections, an electric discharge means for producing a region of charged particles to control the wave propagation characteristics of said guide and including an anode and a cathode, a metallic wall structure lying in a plane substantially transverse to the direction of wave propagation of electromagnetic waves through said guide and formed to provide a resonant aperture tuned substantially to the frequency of said exciting means and housing said anode and said cathode, and means for controlling said electric discharge means.

2. In combination, a dielectric wave guide of the hollow-pipe type comprising a pair of metallic sections, means for establishing electromagnetic waves within one section of said guide, an electric discharge device comprising an anode and a cathode for producing a region of charged particles for controlling the wave propagation characteristics of said guide, a metallic wall structure lying in a plane substantially transverse to the direction of wave propagation of electromagnetic waves through said guide and provided with a resonant aperture tuned substantially to the frequency of said exciting means, said wall structure substantially enclosing said anode and said cathode, and means for controlling the density of said charged particles.

3. In combination, a dielectric wave guide of the hollow-pipe type, exciting means for establishing electromagnetic waves within said guide, a metallic wall structure lying in a plane substantially transverse to the direction of propagation of electromagnetic waves through said guide and having therein a resonant aperture tuned to the frequency of the exciting means, electric discharge means within the body of said wall for producing a region of charged particles across said aperture and comprising an anode structure electrically insulated from said wall and a cathode structure also within the body of said wall and electrically insulated therefrom, and means for controlling the potential difference between said anode and said cathode to vary the density of said charged particles for modulating the electromagnetic waves.

4. In combination, a dielectric wave guide of the hollow-pipe type, exciting means for establishing electromagnetic waves within said guide, a metallic wall within said guide and lying in a plane substantially transverse to the direction of wave propagation therethrough and having therein a resonant aperture tuned substantially to the frequency of said exciting means, electric discharge means lying within the body of said wall and comprising anode and cathode structures lying within the body of said wall and spaced on opposite sides of the principal dimension of said aperture, and means for controlling the difference in potential between said anode and said cathode to vary the density of said charged particles for modulating the electromagnetic waves.

5. In combination, a dielectric wave guide of the hollow-pipe type, exciting means for establishing electromagnetic waves within said guide, a metallic wall within said guide and lying in a plane substantially transverse to the direction of wave propagation therethrough and comprising a resonant aperture tuned substantially to the frequency of the exciting means, electric discharge means for producing a region of charged electric particles substantially transverse to the direction of wave propagation and including an insulated anode structure on one side of the principal dimension of said aperture and lying within the body of said wall and cathode structure on the opposite side of said aperture and also lying within the body of said wall and insulated therefrom, and means for controlling the difference of potential between said anode structure and said cathode structure for controlling the propagation of waves through said guide.

6. In combination, a dielectric wave guide of the hollow-pipe type, exciting means for establishing electromagnetic waves within said guide, a metallic wall within said guide lying in a plane substantially transverse to the direction of wave propagation therethrough and comprising a resonant aperture tuned substantially to the frequency of said exciting means, an electric discharge device lying within the body of said wall and comprising an anode and a cathode electrically insulated from said wall, a source of potential connected between said anode and said guide, and a high frequency concentric transmission line one conductor of which is connected to said guide and the other conductor of which is connected to said cathode for modulating the electromagnetic waves transmitted through said guide.

7. In combination, a dielectric wave guide of the hollow-pipe type, exciting means for establishing electromagnetic waves within said guide, a metallic wall within said guide lying in a plane substantially transverse to the direction of wave propagation therethrough and comprising a resonant aperture tuned substantially to the frequency of said exciting means, electric discharge means for establishing a region of charged electric particles within the vicinity of said aperture and comprising an anode structure lying within the body of said wall on one side of said aperture and a cathode structure lying within the body of said wall on the opposite side of said aperture, and externally accessible high frequency conductor means connected to said cathode and lying within the body of said wall.

MILAN D. FISKE.

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