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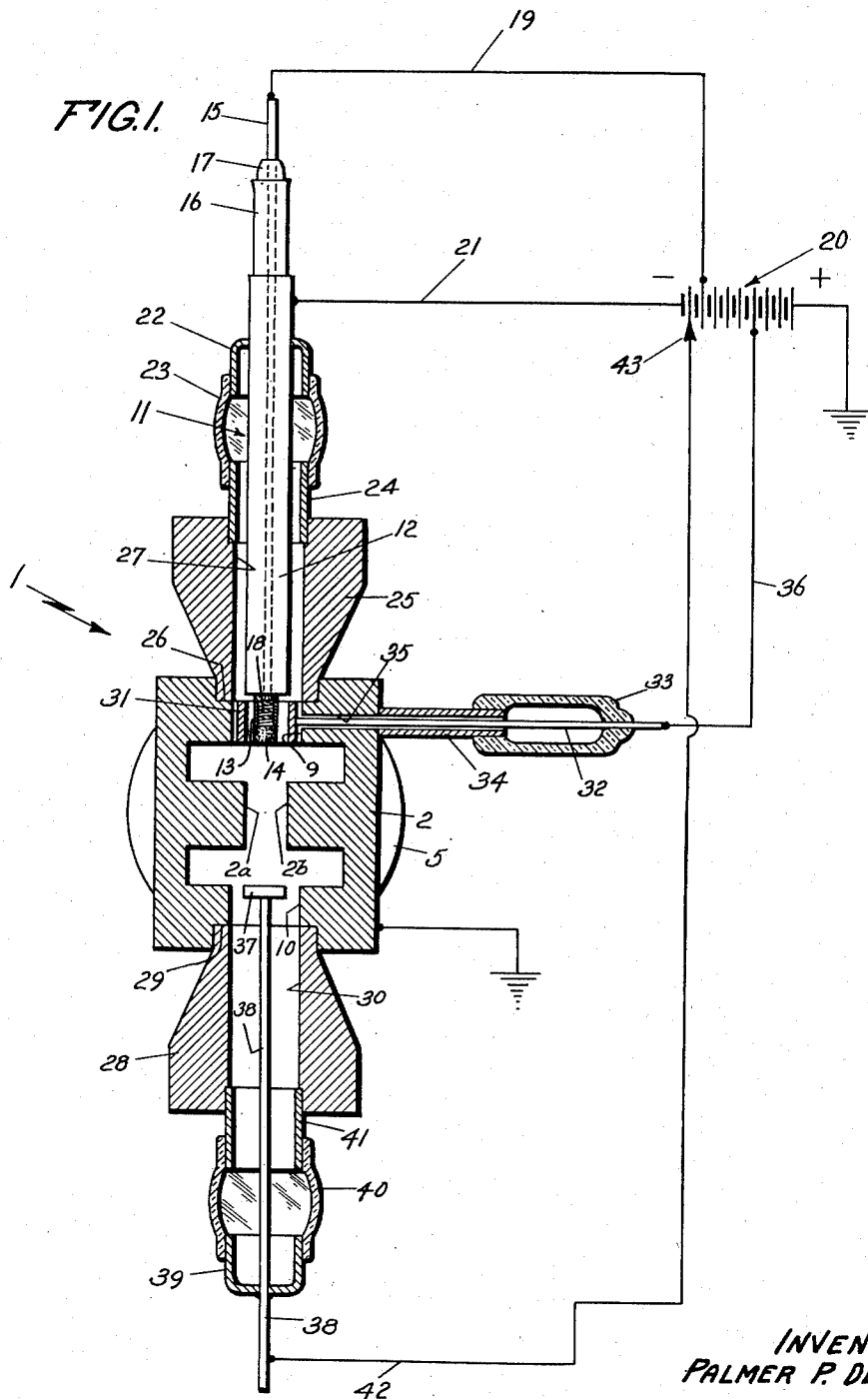
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ELECTRON DISCHARGE DEVICE FOR MICROWAVE AMPLIFICATION

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2 SHEETS—SHEET 1



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ELECTRON-DISCHARGE DEVICE FOR
MICROWAVE AMPLIFICATION

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This invention relates to an electron-discharge device in which electrons are caused to react with an electromagnetic wave in a waveguide so as to give up energy to said wave, thereby producing amplification of said wave.

An object of this invention is to devise an electron-discharge device capable of amplifying electromagnetic waves of very high frequency, for example waves in the microwave range.

Another object is to provide an amplifying device of the above character which has a rather broad frequency-response band.

A further object is to devise a travelling wave amplifier which is of simple construction, yet is highly efficient in operation.

The foregoing and other objects of the invention will be best understood from the following description of an exemplification thereof, reference being had to the accompanying drawings, wherein:

Fig. 1 is a central vertical cross-section of a microwave amplifier embodying this invention;

Fig. 2 is a vertical cross-section taken at right angles to that of Fig. 1; and

Fig. 3 is a partial sectional view taken along line $x-x$ of Fig. 2, looking in the direction of the arrows.

It has been found that, if an electron in a waveguide is caused to travel along a non-linear path with respect to said waveguide at such a rate that the motion thereof is in phase synchronism with the electromagnetic wave being propagated through said guide, an interchange of energy can and will occur between said electron and said wave. The direction of this interchange (that is, whether the electron imparts energy to, or abstracts energy from, the wave) will depend upon the relative phase relation existing between the wave and the electron when the latter is injected into the waveguide.

Generally, according to this invention, an electromagnetic wave of the transverse electric (TE or H) type, the electric field lines of which extend transversely substantially at right angles to the waveguide walls, is propagated through a waveguide having a portion of constricted cross-section, the reason for such shape appearing hereinafter; a plurality of electrons is injected into the waveguide and caused to move transversely thereacross through said constricted portion, the electrons being caused to move along substantially helical paths with respect to said waveguide at such angular velocities and such linear velocities that the electrons move in synchronism with an angular phase velocity of the

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wave. Therefore, the electrons react with the wave to interchange energy therewith, the structure of the device being so arranged that the electrons of such phase relative to the wave as to be capable of abstracting or absorbing energy therefrom are effectively removed from the waveguide, leaving effective only those which are of such relative phase as to impart energy to the wave; therefore, a net energy increase or amplification of the wave results. In the device of this invention, means are also provided for reversing the original transverse direction of movement of the electrons to cause them to return toward the injection side of the waveguide, thus enabling those of proper phase for wave amplification to impart a maximum proportion of their available energy to the wave.

It is desired to be explained at this point what is meant herein by the expression, "the angular phase velocity of a wave in a waveguide." The angular phase velocity is the velocity at which the phase of an electromagnetic wave in a waveguide propagates along a non-linear path with respect to said waveguide, said non-linear path being so related to the longitudinal axis of said waveguide as to provide a substantially periodic angular component of motion with respect to said axis for a point moving along said non-linear path at a uniform rate.

It is known that angular velocities of a fixed and predetermined value may be imparted to electrons by magnetic fields. An expression has been developed in the copending application of Elmer J. Gorn, Serial No. 744,143, filed April 26, 1947, for the value of magnetic field necessary to produce a helical motion of an electron in synchronism with an angular phase velocity of the wave, this expression defining the magnetic field strength in terms of the angular velocity of the wave, the mass of the electron, the electronic charge, the linear velocity of the electron, and the linear phase velocity of the wave in the waveguide. Reference is hereby made to the said Gorn application for a full discussion of the entire subject.

In a waveguide amplifier excited with a TE mode wave according to this invention, energy is abstracted, by the wave, from the orbital motion of the electrons of favorable phase, causing them to travel in helices of decreasing radius but of constant pitch. Energy is imparted, by the wave, to the orbital motion of the electrons of unfavorable phase, causing them to travel in helices of increasing radius. This increase in radius of the orbits of these electrons is utilized to effectively

remove such electrons of unfavorable phase from the waveguide, as will be more fully explained hereinafter.

Now referring to the drawings, numeral 1 generally designates an electron-discharge device according to this invention. A central block 2, of copper or other highly-conductive material and of generally rectangular prismoidal outer configuration, has hermetically sealed thereto, at opposite sides thereof, two similar hollow rectangular waveguide sections 3 and 4, also of copper or similar material (see Fig. 2). Block 2 has a centrally-located H-shaped aperture extending longitudinally therethrough, so that said block can act as a waveguide of H-shaped cross-section; the said aperture in said block communicates, at its opposite ends, with the openings in the corresponding waveguide sections 3 and 4. Although, in Fig. 1, the aperture in block 2 appears to be in the shape of the letter I, this is merely for convenience in illustration; when Fig. 1 is turned on its side, this aperture will assume the shape of the letter H. Waveguides of this configuration are generally referred to as H-shaped waveguides by those skilled in the art to which this invention relates, so the term H-shaped will be used herein. The cross-bar or constricted portion of the H-shaped waveguide 2 extends vertically in Fig. 1, and said portion has a width or waveguide internal dimension defined or delimited by the two oppositely-disposed walls 2a and 2b.

The larger internal dimension of rectangular waveguide sections 3 and 4 extends vertically in Fig. 2, and this dimension is substantially larger than the total height of the H-shaped aperture in block 2, as shown.

In order to seal off from the atmosphere the interiors of waveguides 2, 3, and 4, a substantially cup-shaped metallic element 5 entirely surrounds waveguide 3 and is brazed thereto and to block 2 at its inner end. The base of said cup extends across the outer end of waveguide 3, and has a circular central hole therein in which is sealed a circular window 6 of glass or other suitable material which is transparent to microwave energy. A similar cup-shaped element 7 similarly surrounds waveguide 4 and is sealed thereto and to block 2 at its inner end; element 7 has sealed therein a similar circular window 8 which is transparent to microwave energy. The outer diameter of cup-shaped elements 5 and 7 is preferably substantially equal to the overall or external height of block 2, which height is the largest dimension of said block.

Upper and lower coaxial circular apertures 9 and 10, respectively, are drilled through the respective upper and lower walls of block 2, said apertures 9 and 10 communicating with the H-shaped aperture in block 2, being of approximately the same diameter as each other, and the axis of apertures 9 and 10 extending transversely of guide 2 or vertically in Figs. 1 and 2; the longitudinal axis of waveguides 2, 3, and 4 extends horizontally in Fig. 2. The diameter of apertures 9 and 10 is somewhat greater than the distance (measured horizontally in Fig. 1) between faces 2a and 2b.

A cathode structure 11 is mounted in aperture 9 axially thereof. Said structure preferably comprises an elongated sleeve 12, conventionally made of nickel, or the like, and having a reduced portion 13, the lower end of which terminates in substantially the same horizontal plane as the lower end of aperture 9 (or the upper edge of the

H-shaped aperture in block 2), said portion being provided with a highly electron-emissive coating 14, for example, of the well-known alkaline-earth metal-oxide type.

In order to support a lead-in conductor 15 centrally with respect to sleeve 12, said sleeve has, at its upper end, a ferrule 16 closed by a glass bead seal 17 through which said conductor passes. The inner (lower) end of said conductor 15 is connected to the upper end of a heating filament 18, which is substantially coextensive with the cathode coating 14 and the opposite (lower) end of which is electrically connected to the cathode sleeve 12.

Current may be conveyed to the filament 18 by connecting the upper end of the lead-in conductor 15, through a conductor 19, to a positive tap on a suitable source 20 of electromotive force, the negative terminal of said source being connected, through a conductor 21, to the sleeve 12.

The positive terminal of the source 20 may be grounded, as shown, as may be the block 2, whereby a potential difference is established between the cathode structure 11 and the block or waveguide 2.

In order to insulate and support the cathode structure 11 from the block 2, I provide the sleeve 12 with a cup-like bushing 22 which is fused into the upper end of a glass insulating member 23, the lower end of said insulating member having a tubular bushing 24 fused therein which, in turn, is secured in a recess formed in the upper end of a pole piece 25.

The pole piece 25 is hermetically sealed, as at 26, into a suitable recess provided in the upper wall of block 2, and is provided with a bore 27, of substantially the same diameter as aperture 9 and coaxial therewith, through which the cathode structure 11 may enter the device.

A cooperating pole piece 28 is hermetically sealed, as at 29, into a suitable recess provided in the lower wall of block 2, and is provided with a bore 30, of substantially the same diameter as aperture 10 and coaxial therewith. Pole piece 28 and pole piece 25 are fixed, for example, at the ends of a suitable source of magnetomotive force (not shown), so that a magnetic field is established, between said pole pieces, in a direction transversely of waveguide 2, substantially parallel to the cross-bar portion of the H, or substantially vertically in Figs. 1 and 2. The inner ends of pole pieces 25 and 28 have a reduced cross-section, as shown, in order to increase the flux density of said magnetic field.

A hollow open-ended cylindrical electrode element 31 is mounted axially in aperture 9, said element surrounding cathode 13 and being concentric therewith and with said aperture. Element 31 preferably has an axial (vertical) length equal to the distance between the lower edge of pole piece 25 and the upper edge of the H-shaped aperture in block 2, so that the lower face of said element lies in a common horizontal plane with the lower face of cathode 13 and the upper edge of the H-shaped aperture.

The inner diameter of electrode element 31 is made equal to the internal dimension of waveguide 2 between faces 2a and 2b (measured horizontally in Fig. 1), or, in other words, is made equal to the width of the cross-bar portion of the H.

Electrode 31 is secured to a stiff support wire 32 which enters the device through a glass seal 33, the latter being fused to a pipe 34 which is

hermetically sealed to block 2, a horizontal bore 35 being provided in the upper wall of block 2 for the passage of said wire 32 to aperture 9 and electrode 31. The electrode 31 is connected, by wire 32 and a conductor 36, to an intermediate tap on the source 20, this connection raising electrode 31 to a potential which is positive with respect to cathode 13 but negative with respect to ground or the potential of block 2.

A disk-shaped repeller electrode 37 is positioned axially of aperture 10, and has its upper surface lying in the same horizontal plane with the lower edge of the H-shaped aperture; this electrode may have a diameter substantially equal to the horizontal distance between faces 2a and 2b, or said diameter may be somewhat larger than said distance. In order to insulate and support electrode 37 from the block 2, and also to allow electrical connection to be made to said electrode, I attach a stiff support wire 38 to said electrode, said wire 38 passing axially downwardly through bore 30. Wire 38 is provided with a cup-like bushing 39 which is fused into the lower end of a glass insulating member 40, the upper end of said insulating member having a tubular bushing 41 fused, therein which, in turn, is secured in a recess formed in the lower end of pole piece 28.

Electrode 37 is connected, by wire 38 and a conductor 42, to an adjustable tap 43 on the source 20, by means of which connection a potential is applied to said electrode 37, this potential being on the order of that applied to cathode 13 but being capable of variation therefrom for proper operation of the device, as described below.

The electron-discharge device of this invention is designed to amplify microwaves propagating in a waveguide system, and is adapted to be coupled directly into such a system by means of windows 6 and 8, with the input to the device coupling through window 6 and the amplified output therefrom coupling through window 8, or vice versa. In either event, it is intended that the microwave energy propagate axially through waveguides 2, 3, and 4, which means from right to left or from left to right in Fig. 2.

The microwave amplifier of this invention is intended to be used with $TE_{0,1}$ waves, the electric field lines of which extend transversely to the waveguide walls, specifically in a horizontal direction in Fig. 1 or in a direction perpendicular to the paper in Fig. 2. In the constricted portion of the H-shaped waveguide 2, that is, in the portion thereof defined or delimited by faces 2a and 2b, the electric field lines of such a wave extend horizontally, transversely between faces 2a and 2b, perpendicularly to both faces. In the rectangular waveguide sections 3 and 4, the electric field lines of the wave extend perpendicularly to the paper in Fig. 2, or in a direction perpendicular to the longer cross-sectional dimension of said waveguide sections.

When heater 18 is energized by source 20, a copious supply of electrons is thermionically emitted from the cathode coating 14, these electrons originally proceeding radially outwardly toward electrode 31 because of the positive potential thereon with respect to the cathode. As described above, pole pieces 25 and 28 produce a magnetic field transversely of waveguide 2 (and also transversely to this original radial motion), in a substantially vertical direction. Due to the transverse motion of each electron across this magnetic field, each electron is caused to move in an orbital substantially circular path, at an

angular velocity determined by the strength of the magnetic field, around the axis of aperture 9. The radius of the electron orbit will tend to increase as long as the electrons remain in the field between cathode 13 and electrode 31. Since a plurality of electrons are emitted by the cathode, in all directions and from all points on said cathode, there will be a hollow (because of the finite diameter of cathode 13) substantially cylindrical cloud of electrons present between cathode 13 and electrode 31. The outer or maximum diameter of this cloud will be substantially equal to the inner diameter of electrode 31 (and therefore also substantially equal to the horizontal distance between faces 2a and 2b), since if the diameter of the cloud tended to increase beyond this value, the outer fringe of electrons would strike, and be captured by, electrode 31.

The above discussion has neglected the effect of the potential applied to waveguide 2. However, due to the presence of this structure which is biased positively with respect to cathode 13, each electron of the cloud is caused to move or drift downwardly, transversely of waveguide 2, in a direction along the cross-bar portion of the H, to, into, and through said cross-bar or constricted portion of said waveguide 2; the linear velocity of the electrons, or the velocity of this drift, being determined by the potential of waveguide 2. Each electron of the cloud, as a result of its circular orbital motion combined with its drift or motion along the cross-bar portion of the H, follows a substantially helical path with respect to waveguide 2; all of the electrons taken together can be pictured as a hollow substantially cylindrical cloud which is rotating at a predetermined angular velocity and is moving downwardly along the cross-bar portion of the guide at a predetermined linear velocity.

The strength of the magnetic field in the device of this invention has such a value, and the potential on waveguide 2 has such a value, that the electron angular velocity (determined by the strength of the magnetic field) and the electron linear velocity (determined by the potential on waveguide 2) are made such that the electrons of the cloud move in synchronism with an angular phase velocity of the wave. As a direct result of this synchronism, the electrons of the cloud react with the electromagnetic wave propagating axially through waveguide 2, to interchange energy therewith.

As described above, in a waveguide amplifier excited with a TE mode wave, through which electrons are moving transversely along a non-linear path in phase synchronism with the wave, energy is abstracted from, or imparted to, the orbital motion of the electrons, by the wave, in the first case decreasing the orbital radii of the electrons, and in the second case increasing the orbital radii of the electrons. Due to the fact that the cloud of electrons is solid or is a complete circle (the electrons are emitted from the cathode at all times, and not only at instants when the electrons if emitted would have a desired phase relative to the wave), there would be substantially as many electrons abstracting energy from the wave at any instant on one side of the circle as there would be imparting energy thereto on the other. Therefore, in order to increase the net energy level of the wave, it is necessary to effectively remove from the waveguide the electrons of such phase relative to the wave as to be capable of abstracting or absorbing energy therefrom, leaving effective only those

which are of such phase relative to the wave as to be capable of imparting energy to said wave. This is done in the following way:

It will be recalled that the electrons which absorb energy from the wave have their orbital radii increased, and that the outer diameter of the electron cloud is substantially equal to the horizontal distance between waveguide walls 2a and 2b. As the cloud of electrons proceeds downwardly between waveguide walls 2a and 2b in a synchronous fashion, those electrons of the cloud which absorb energy from the wave have the radii of their orbits increased and, since the distance between walls 2a and 2b is such that any increase in the radius of the cloud causes the outer electrons to strike said walls, the wave-energy-absorbing electrons strike the said walls 2a and 2b and are retained thereby, because of the positive potential on said walls, thereby effectively removing these electrons of unfavorable phase from the interior of the waveguide 2, or removing them from energy-absorbing relation to the wave.

The energy-imparting electrons give up energy to the wave, resulting in a net increase in the energy level of, or amplification of, the wave; this giving up of energy by the electrons causes their orbital radii to decrease.

As the cloud of electrons proceeds downwardly below the lower end of the cross-bar portion of the H, it approaches the zone of the repeller electrode 37, which is at the opposite side of the waveguide 2 from the electron injecting means 13, 31, etc. Electrode 37 is at a potential on the order of that of the cathode, and acts as a negative electrode to reverse the direction of movement of the electron cloud, thereby causing the same to move upwardly toward the cathode 13. By proper adjustment of the potential on electrode 37, the electrons can be made to move upwardly transversely of waveguide 2 in phase synchronism with the wave, and with the proper phase relative to the wave as to impart energy thereto. Thus, by causing each electron to traverse at least two energy-imparting paths through the device, a larger proportion of its total available energy is abstracted by the wave from each electron, thus making the device as a whole more efficient.

Due to the fact that the device has no resonant cavities or other tuned elements, it has a rather broad frequency-response band.

It should be brought out why it is preferable to use an H-shaped waveguide for the energy-interchanging waveguide section 2. As is known, the cutoff wavelength for a $TE_{0,1}$ mode wave in a rectangular waveguide is twice the larger internal dimension of the guide, where the electric field lines of the wave are perpendicular to the longer side of said guide. The cutoff wavelength for the same type of wave in an H-shaped guide, on the other hand, is only very indirectly dependent on the height of such a guide, so that, for the same cutoff wavelength, an H-shaped waveguide can have a substantially smaller internal total height than a rectangular guide. "Height," here, refers to the vertical dimension in Figs. 1 and 2. Since the height of waveguide section 2 determines the length of the air gap between pole pieces 25 and 28, this means a shorter air gap is possible with an H-shaped guide than with a rectangular guide having the same cutoff wavelength. It is desirable to decrease the length of the air gap in the magnetic circuit as much as possible, in order to decrease

the total reluctance of the magnetic circuit, thus making it easier to achieve the required magnetic field strength.

Another reason for using an H-shaped waveguide is in order to easily obtain the required small horizontal internal dimension of the waveguide, so as to effectively eliminate from the waveguide those electrons whose phase is unfavorable for wave amplification. This required small dimension can be obtained readily by providing a constricted portion in an H-shaped waveguide; at the same time, this constriction actually causes an increase in the cutoff wavelength of the guide, which is to be desired.

Of course, it is to be understood that this invention is not limited to the particular details as described above, as many equivalents will suggest themselves to those skilled in the art. It is accordingly desired that the appended claims be given a broad interpretation commensurate with the scope of this invention within the art.

What is claimed is:

1. In combination, a waveguide through which an electromagnetic wave may be propagated, said waveguide having a portion of constricted cross-section, means adjacent said waveguide for injecting a substantially uniformly cylindrical cloud of electrons into said constricted portion, the outer diameter of said cloud being substantially equal to the internal dimension of said waveguide at said constricted portion, and means adjacent said waveguide for applying a force to move the electrons of said cloud in a direction having a component tangent to the circumference of a cross-section of said cylindrical cloud.

2. In combination, a waveguide through which an electromagnetic wave may be axially propagated, said waveguide having a portion of constricted cross-section, means adjacent said waveguide for injecting a substantially cylindrical cloud of electrons transversely of said guide into said constricted portion, the outer diameter of said cloud being substantially equal to the internal dimension of said waveguide at said constricted portion, and means adjacent said waveguide for applying a force to move the electrons of said cloud in a direction having a component tangent to the circumference of a cross-section of said cylindrical cloud.

3. In combination, a waveguide through which an electromagnetic wave may be axially propagated, said waveguide having a portion of constricted cross-section, the electric field lines of the wave extending transversely to the waveguide walls defining said constricted portion, means adjacent said waveguide for injecting a substantially cylindrical cloud of electrons transversely of said guide into said constricted portion, the outer diameter of said cloud being substantially equal to the internal dimension of said waveguide at said constricted portion, and means adjacent said waveguide for applying a force to move the electrons of said cloud in a direction having a component tangent to the circumference of a cross-section of said cylindrical cloud.

4. In combination, a waveguide through which an electromagnetic wave may be propagated, said waveguide having an H-shaped cross-section, means adjacent said waveguide for injecting a substantially cylindrical cloud of electrons into said waveguide along the cross-bar portion thereof, the outer diameter of said cloud being substantially equal to the width of the cross-bar portion of said guide, and means adjacent said waveguide for applying a force to move the elec-

trons of said cloud in a direction having a component tangent to the circumference of a cross-section of said cylindrical cloud.

5. In combination, a waveguide through which an electromagnetic wave may be propagated, means at one side of said waveguide for injecting an electron thereinto and for moving it in a first direction transversely thereacross toward the opposite side of said guide, means adjacent said waveguide for applying a force to move said electron in a second direction perpendicular to said first direction, means adjacent said waveguide for applying a force to move said electron in a third direction having a component perpendicular to both said first and second directions, and means at the opposite side of said waveguide for reversing said first direction of movement of said electron to cause it to move toward said one side.

6. In combination, a waveguide through which an electromagnetic wave may be propagated, said waveguide having a portion of constricted cross-section, means at one side of said waveguide for injecting a substantially cylindrical cloud of electrons thereinto and for moving the entire cloud transversely thereacross in a first direction through said constricted portion toward the opposite side of said guide, the outer diameter of said cloud being originally substantially equal to the internal dimension of said waveguide at said constricted portion, means adjacent said waveguide for applying a force to move the electrons of said cloud in a direction having a component tangent to the circumference of a cross-section of said cylindrical cloud, and means at the opposite side of said waveguide for reversing said first direction of movement of said cloud to cause it to move toward said one side.

7. In combination, a waveguide through which an electromagnetic wave may be propagated, said waveguide having an H-shaped cross-section, means at one side of said waveguide for injecting a substantially cylindrical cloud of electrons thereinto in a first direction along the cross-bar portion of said waveguide and for moving the entire cloud across said guide toward the opposite side thereof, the outer diameter of said cloud being originally substantially equal to the width of the cross-bar portion of said guide, means adjacent said waveguide for applying a force to move the electrons of said cloud in a direction having a component tangent to the circumference of a cross-section of said cylindrical cloud, and means at the opposite side of said waveguide for reversing said first direction of movement of said cloud to cause it to move toward said one side.

8. In combination, a waveguide through which an electromagnetic wave may be propagated, said waveguide having a portion of constricted cross-section, means adjacent said waveguide for injecting a substantially cylindrical cloud of electrons into said constricted portion, the outer diameter of said cloud being substantially equal to the internal dimension of said waveguide at said constricted portion, and means for applying force to move the electrons of said cloud along substantially helical paths with respect to said waveguide at angular and linear velocities at which the electrons move in synchronism with a chosen angular phase velocity of the wave.

9. In combination, a waveguide through which an electromagnetic wave may be axially propagated, said waveguide having a portion of constricted cross-section, the electric field lines of the wave extending transversely to the waveguide walls defining said constricted portion,

means adjacent said waveguide for injecting a substantially cylindrical cloud of electrons transversely of said guide into said constricted portion, the outer diameter of said cloud being substantially equal to the internal dimension of said waveguide at said constricted portion, and means for applying force to move the electrons of said cloud along substantially helical paths with respect to said waveguide at angular and linear velocities at which the electrons move in synchronism with an angular phase velocity of the wave.

10. In combination, a waveguide through which an electromagnetic wave may be propagated, said waveguide having an H-shaped cross-section, means adjacent said waveguide for injecting a substantially cylindrical cloud of electrons into said waveguide along the cross-bar portion thereof, the outer diameter of said cloud being substantially equal to the width of the cross-bar portion of said guide, and means for applying force to move the electrons of said cloud along substantially helical paths with respect to said waveguide at angular and linear velocities at which the electrons move in synchronism with a chosen angular phase velocity of the wave.

11. In combination, a waveguide through which an electromagnetic wave may be propagated, means at one side of said waveguide for injecting an electron thereinto and for moving it transversely thereacross toward the opposite side of said guide, means for rotating said electron in addition to its said transverse motion so that it moves in a substantially helical path with respect to said waveguide at angular and linear velocities at which said electron moves in synchronism with a chosen angular phase velocity of the wave, and means at the opposite side of said waveguide for reversing the transverse direction of movement of said electron to cause it to move toward said one side.

12. In combination, a waveguide through which an electromagnetic wave may be propagated, said waveguide having a portion of constricted cross-section, means at one side of said waveguide for injecting a substantially cylindrical cloud of electrons thereinto and for moving it transversely thereacross through said constricted portion toward the opposite side of said guide, the outer diameter of said cloud being originally substantially equal to the internal dimension of said waveguide at said constricted portion, means for rotating the electrons of said cloud in addition to the said transverse motion thereof so that said electrons move in substantially helical paths with respect to said waveguide at angular and linear velocities at which the electrons move in synchronism with a chosen angular phase velocity of the wave, and means at the opposite side of said waveguide for reversing the direction of movement of said cloud to cause it to move toward said one side.

13. In combination, a waveguide through which an electromagnetic wave may be propagated, said waveguide having an H-shaped cross-section, means at one side of said waveguide for injecting a substantially cylindrical cloud of electrons thereinto in a direction along the cross-bar portion of said waveguide and for moving it transversely across said guide toward the opposite side thereof, the outer diameter of said cloud being originally substantially equal to the width of the cross-bar portion of said guide, means for rotating the electrons of said cloud in addition to the said transverse motion thereof so that said elec-

trons move in substantially helical paths with respect to said waveguide at angular and linear velocities at which the electrons move in synchronism with a chosen angular phase velocity of the wave, and means at the opposite side of said waveguide for reversing the direction of movement of said cloud to cause it to move toward said one side.

14. A microwave amplifier, comprising a waveguide through which an electromagnetic wave may be propagated, said waveguide having a portion of constricted cross-section, means adjacent said waveguide for injecting a substantially cylindrical cloud of electrons into said constricted portion, the outer diameter of said cloud being originally substantially equal to the internal dimension of said waveguide at said constricted portion, and means for moving the electrons of said cloud along substantially helical orbital paths with respect to said waveguide at angular and linear velocities at which the electrons move in synchronism with a chosen angular phase velocity of the wave, the electrons thereby reacting with the wave to interchange energy therewith, the electrons of such phase relative to the wave as to be capable of absorbing energy therefrom by such reaction having the radii of their orbits increased so that they strike the waveguide walls defining said constricted portion and means connected to said waveguide to remove electrons which strike said walls from said cloud and hence from energy-absorbing relation to the wave.

15. A microwave amplifier, comprising a waveguide through which an electromagnetic wave may be propagated, said waveguide having an H-shaped cross-section, means adjacent said waveguide for injecting a substantially cylindrical cloud of electrons into said waveguide along the cross-bar portion thereof, the outer diameter of said cloud being originally substantially equal to the width of the cross-bar portion of said guide, and means for moving the electrons of said cloud along substantially helical orbital paths with respect to said waveguide at angular and linear velocities at which the electrons move in synchronism with a chosen angular phase velocity of the wave, the electrons thereby reacting with the wave to interchange energy therewith, the electrons of such phase relative to the wave as to be capable for absorbing energy therefrom by such reaction having the radii of their orbits increased so that they strike the waveguide walls at the cross-bar portion of said guide and means connected to said waveguide to remove electrons which strike said walls from said cloud and hence from energy-absorbing relation to the wave.

16. A microwave amplifier, comprising a waveguide through which an electromagnetic wave may be propagated, said waveguide having a portion of constricted cross-section, means at one side of said waveguide for injecting a substantially cylindrical cloud of electrons thereinto and for moving it transversely thereacross through said constricted portion toward the opposite side of said guide, the outer diameter of said cloud

being originally substantially equal to the internal dimension of said waveguide at said constricted portion, means for rotating the electrons of said cloud in addition to the said transverse motion thereof so that said electrons move in substantially helical orbital paths with respect to said waveguide at angular and linear velocities at which the electrons move in synchronism with a chosen angular phase velocity of the wave, the electrons thereby reacting with the wave to interchange energy therewith, the electrons of such phase relative to the wave as to be capable of absorbing energy therefrom by such reaction having the radii of their orbits increased so that they strike the waveguide walls defining said constricted portion and are thereby removed from energy-absorbing relation to the wave, and means at the opposite side of said waveguide for reversing the direction of movement of said cloud to cause it to move toward said one side.

17. A microwave amplifier, comprising a waveguide through which an electromagnetic wave may be propagated, said waveguide having an H-shaped cross-section, means at one side of said waveguide for injecting a substantially cylindrical cloud of electrons thereinto in a direction along the cross-bar portion of said waveguide and for moving it transversely across said guide toward the opposite side thereof, the outer diameter of said cloud being originally substantially equal to the width of the cross-bar portion of said guide, means for rotating the electrons of said cloud in addition to the said transverse motion thereof so that said electrons move in substantially helical orbital paths with respect to said waveguide at angular and linear velocities at which the electrons move in synchronism with a chosen angular phase velocity of the wave, the electrons thereby reacting with the wave to interchange energy therewith, the electrons of such phase relative to the wave as to be capable of absorbing energy therefrom by such reaction having the radii of their orbits increased so that they strike the waveguide walls at the cross-bar portion of said guide and are thereby removed from energy-absorbing relation to the wave, and means at the opposite side of said waveguide for reversing the direction of movement of said cloud to cause it to move toward said one side.

PALMER P. DERBY.

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