

July 22, 1958

C. F. QUATE
TRAVELING WAVE TUBE

2,844,753

Filed April 3, 1953

2 Sheets-Sheet 1

FIG. 1

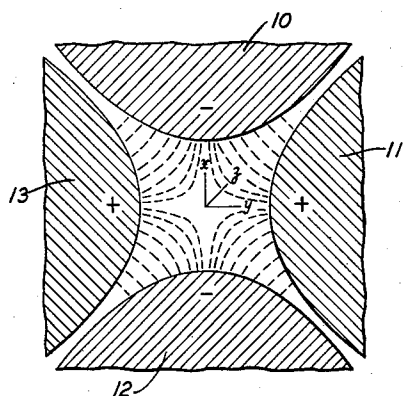


FIG. 2

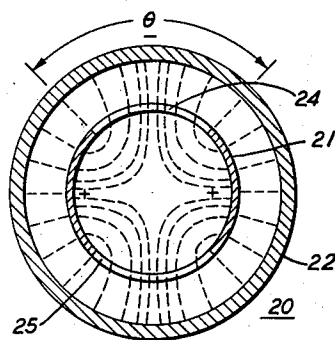


FIG. 3

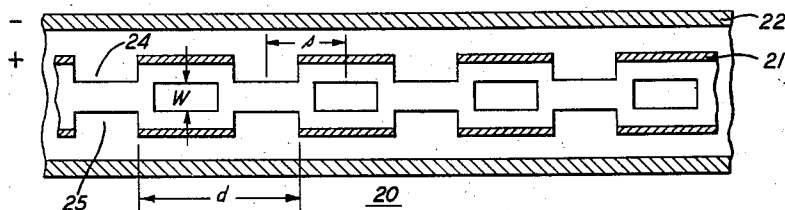


FIG. 4A

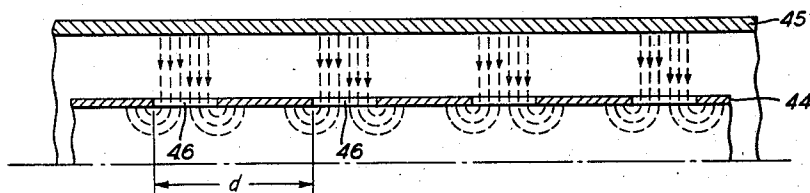
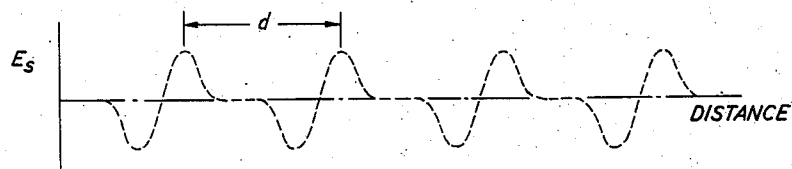


FIG. 4B



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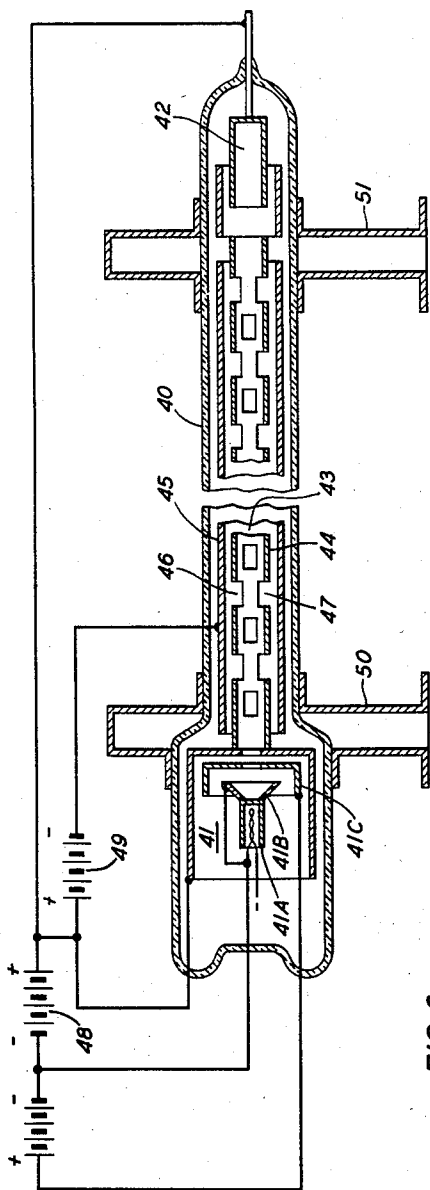
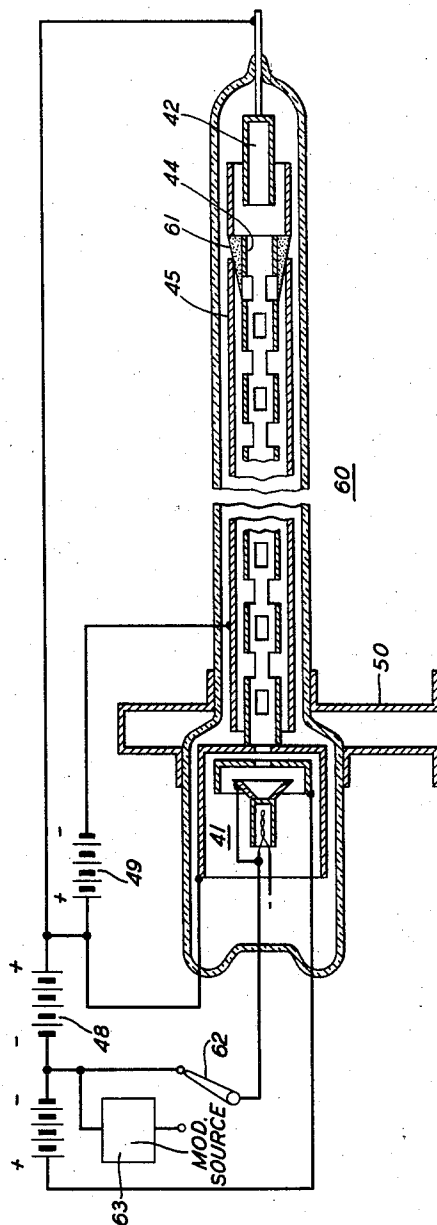


FIG. 5

FIG. 6



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TRAVELING WAVE TUBE

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17 Claims. (Cl. 315—3.5)

This invention relates to traveling wave tubes which utilize the interaction between an electron stream and a traveling electromagnetic wave over a plurality of operating wavelengths to secure gain to the traveling wave.

In traveling wave tubes, an electromagnetic wave propagates along an interaction circuit past which is projected an electron stream in field coupling relationship. Because of the relatively long length of the electron path and because of the space charge forces acting in an electron stream when the electron density is high, as is here desirable, it is generally advantageous to provide focusing to keep the electron flow cylindrical during its travel past the interaction circuit. In the past, such focusing generally has been provided by establishing a longitudinal magnetic field along the beam path. However, in practice the high fluxes required for good magnetic focusing have necessitated the use either of large permanent magnets or solenoids which have added much bulk and weight to traveling wave tube systems.

An object of this invention is to eliminate the necessity for a longitudinal magnetic field and thereby to effect a saving in the size and weight of the auxiliary equipment necessary for the operation of traveling wave tubes.

There has recently been developed a technique for focusing a beam of charged particles which has been described as "strong focusing," which utilizes a transverse magnetic field which interacts with the longitudinal velocity of the charged particles to provide an inward force acting on the charged particles. However, in the free space occupied by a beam it is impossible to have transverse magnetic fields which cause all particles to be acted on by an inward force. If the beam is focused in one plane, there exists another plane perpendicular thereto where it is defocused. Strong focusing systems overcome this problem by providing a succession of magnetic field regions along the beam path and orienting the field in successive regions so that the beam is focused alternately in two mutually perpendicular planes. The strength and periodicity of the magnet sections are adjusted so that the excursions of the edge particles are small. In particular, it has been found advantageous to employ quadrupole types of magnets for establishing the successive magnetic field regions, successive magnets being rotated 90°. Moreover, there have been developed electrostatic analogues which function in accordance with these same general principles, utilizing a series of quadrupole transverse electric field regions, the field directions being appropriately shifted along successive regions.

The present invention is directed to the application of electrostatic strong focusing techniques to traveling wave tubes. In particular, the invention permits the substitution of transverse electrostatic fields for longitudinal magnetic fields in focusing the electron beam and thereby effects a saving in size and weight of the auxiliary equipment necessary for operation of traveling wave tubes.

An important feature of the present invention is a novel form of interaction circuit which is especially well adapted for use with electrostatic strong focusing techniques. To

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this end, in one specific embodiment, the interaction circuit comprises a coaxial type transmission line of which the inner conductor is tubular and is provided with a succession of pairs of slots, the two slots of each pair being substantially diametrically opposite with respect to the axis of the line, and successive pairs of slots along the line being rotated approximately 90° around the axis with respect to the preceding pair. By impressing a D.-C. voltage across the inner and outer conductors of the line, there is provided along the interior of the inner tubular conductor a succession of regions corresponding to slots in the inner conductor each characterized by an electrostatic field of a quadrupole type configuration, successive quadrupole field patterns being rotated 90° in a fashion corresponding to the rotation of successive pairs of slots. In operation, the electron beam is projected through this inner tubular conductor past the successive electrostatic field regions which serve to focus it.

An interaction circuit of the kind described is particularly well suited for spatial harmonic operation in which mode of operation the interaction circuit gives rise to spatial harmonic components which propagate therealong with phase velocities slow compared to the phase velocity of the fundamental component of a wave propagating therealong and thereafter the velocity of the electron stream is adjusted to be substantially equal to the phase velocity of a suitable one of such components for interaction therewith. Moreover, spatial harmonic operation of this kind permits interaction either with a forward or backward traveling wave. The invention will be described with reference both to forward and backward wave operation.

The invention will be better understood from the following more detailed description taken in conjunction with the accompanying drawings of which:

Fig. 1 shows a conventional electrode system for achieving a quadrupole electrostatic pattern similar to that developed by the interaction circuit which is a feature of the invention;

Figs. 2 and 3 show transverse and longitudinal sectional views, respectively, of a wave guiding structure in accordance with the invention;

Fig. 4A shows the pattern of radio frequency electric fields associated with alternately disposed apertures along the structure shown in Figs. 2 and 3, and Fig. 4B is a plot of the amplitude of the radio frequency electric field seen by an electron moving along this same structure; and

Figs. 5 and 6 show the interaction circuit which is a feature of the invention embodied in a traveling wave amplifier and a backward wave oscillator, respectively.

Typically for electrostatic focusing in accordance with the spirit of the invention, there is desired a field configuration, transverse to the path of flow, of the kind shown in Fig. 1 where the desired field pattern is achieved by a quadrupole arrangement of electrodes 10, 11, 12 and 13 where the opposite electrodes 10 and 12 are maintained at a suitable negative D.-C. potential with respect to electrodes 11 and 13. The faces of the electrodes are preferably hyperbolic, so that the electric field E is zero at the center and

$$\frac{dE_x}{dy}$$

65 and

$$\frac{dE_y}{dx}$$

are equal and uniform. The electron beam in passing transversely through such a field configuration (moving longitudinally perpendicular to the plane of the paper in the z direction) tends to be focused in the XZ plane and

defocused in the YZ plane. Alternatively, this action can be described as a compression into the XZ plane and an expansion in the YZ plane. To overcome this asymmetry, the field patterns are shifted 90° periodically along the longitudinal path of flow so that the focusing is alternately in the YZ and XZ planes. The strength and periodicity of the successive regions of transverse electrostatic fields can be adjusted so that the excursions of the edge electrons are always small.

The interaction circuit which is the principal feature of the present invention makes possible the realization of quadrupole electrostatic field patterns of the kind shown in Fig. 1 by a wave guiding structure which is at the same time suitable for the propagation of electromagnetic waves for interaction with the electron beam focused by the quadrupole field patterns. By the incorporation of such an interaction circuit in a traveling wave tube and the utilization of electrostatic focusing in conjunction therewith, there is obviated the need for the longitudinal magnetic field required in previously developed traveling wave tubes.

The interaction circuit shown in Figs. 2 and 3 comprises a coaxial line 20 having inner and outer cylindrical conductive members, 21 and 22, respectively. The inner member 21 is tubular and is perforated along its length in a succession of pairs of discrete slots 24, 25 the two slots of each pair 24 and 25 being diametrically opposite with reference to the axis of the coaxial line. By impressing a D.-C. potential difference between the two members of the line there is achieved transverse to the line axis an electrostatic field pattern of the kind shown in Fig. 2. As can be seen there, the field lines are radial in the interspace between the two members corresponding to unslotted portions of the inner member 21. However, in the regions corresponding to slots 24 and 25 in the inner member, the field lines passing through become bent in terminating on the adjacent inner surfaces of inner member 21, and there results a quadrupole electrostatic field in the region enclosed by the inner member 21 which can be used for electrostatic focusing in accordance with the principles described. Moreover, by shifting successive pairs of slots along the inner member substantially 90° around the axis, there results along the space enclosed by the inner member 21 a succession of regions of transverse quadrupole electrostatic fields, the patterns of successive regions being rotated 90°. Accordingly, an electron beam projected longitudinally through this inner member can be focused by the successive regions of quadrupole electrostatic fields.

It is evident that the angle θ which is an angular measure of the size of the slots largely determine the nature of the field patterns within the inner member. In practice, it has usually been found advantageous to utilize a value of θ corresponding approximately to $\pi/2$ radians.

In the traveling wave tube amplifier shown in Fig. 5 the various tube elements are enclosed in an evacuated glass envelope 40. In the interest of simplicity, such details as supports and spacers whose need will be obvious to a worker in the tube art, have been omitted. At one end of the tube, an electron gun 41 serves as the source of an electron stream which flows longitudinally through the envelope to a target electrode 42, in collecting relation to the electron stream, at the other end of the envelope. The electron gun is of conventional design and includes an electron emissive cathode 41A, a beam shaping electrode 41B, and an accelerating anode 41C. Co-axially disposed about the path of electron flow is an interaction circuit 43 of the kind described with reference to Figs. 2 and 3. The interaction circuit comprises the coaxial line having the center or inner conductive member 44 through which flows axially the electron stream and the outer or surrounding conductive member 45. The inner member 44 is provided along its length, which is many operating wavelengths long, with a regularly spaced succession of identical pairs of discrete slots 46, 47, the

two slots of each pair being rectangular and circumferentially disposed to be diametrically opposite. An indicated above, successive pairs of slots are shifted 90° around the path of electron flow. For accelerating the electron flow, the inner member 44 is maintained at a positive D.-C. potential with respect to the electron emissive cathode 41A by means of lead-in connections from a voltage supply source 48. Additionally, for achieving the desired electrostatic field patterns in the region of electron flow, the inner member is also maintained at a positive D.-C. potential with respect to the outer member 45 by lead-in connections from a voltage supply source 49.

The interaction circuit described gives rise to spatial harmonic components of a wave propagating therealong. It is now well known that amplification of a traveling wave can be achieved by interaction of an electron beam and a spatial harmonic of the wave. For interaction with a spatial harmonic of a traveling wave, the velocity of the electron flow is adjusted to be substantially equal to the phase velocity of the spatial harmonic. Since spatial harmonic circuits have spatial harmonics with phase velocities both positive and negative, they are adaptable for amplification either of forward or backward traveling waves. Before continuing with the description of this amplifier, it will be helpful to examine more closely the nature of the radio frequency potentials acting on the electron stream.

Fig. 4A shows the radio frequency potentials acting on an electron traveling along within the interior hollow space of the tubular center conductor 44 at a point displaced from the axis. It is assumed that the spacing of successive pairs of slots 46, 47 along the line is short compared to the length of the wave traveling along the circuit. Fig. 4B is a plot of the amplitude of the radio frequency field E_s acting on the electron in its travel along its path of flow. It can be seen that the amplitude of the field is generally low in the regions surrounded by the unslotted portions of the center conductor because of the shielding effect thereof, and varies as substantially a full cycle of a sine wave with a wavelength d corresponding to the mean distance between adjacent discrete slots 46. It is this cyclical nature of the radio frequency potentials in the regions of stream and wave interaction that gives rise to spatial harmonics and makes this circuit conducive to spatial harmonic operation.

For interaction to occur with a backward traveling wave (i. e. a wave traveling from the collector end of the interaction circuit to the electron source end) the wave must travel a distance equal to the difference $(\lambda_g - d)$ at a velocity v in the time that an electron travels the distance d at an average velocity u , where λ_g is the wavelength of the traveling wave along the interaction circuit and d is the mean distance between alternate pairs of slots along the path of charged particle flow, as shown in Fig. 3. If this requirement is satisfied this electron will see the proper phase of the backward traveling wave at each slot in the center conductor. This requirement may be written in equation form as

$$\frac{d}{u} = \frac{\lambda_g - d}{v} \quad (1)$$

Now since

$$\lambda_g = \lambda_0 \frac{v}{c} \quad (2)$$

where λ_0 is the corresponding wavelength in free space of the wave, and c is the velocity in free space of light, Equation 1 may be rewritten as

$$\frac{d}{\lambda_0} = \frac{1}{\frac{c}{u} + \frac{c}{v}} \quad (3)$$

Now the ratio

$$\frac{v}{c}$$

is determined by the properties of the coaxial line and typically may be of the order of .7. Thus, for operation at a given wavelength λ_0 and with a convenient beam velocity u , the slot separation d can be calculated from Equation 3. The length of each slot preferably is slightly less than the separation between adjacent pairs of slots for maximum interaction. The optimum ratio of the outer to inner conductor diameter is dependent on a number of factors relating to the radio frequency impedance of the coaxial line desired and the voltage difference between the inner and outer conductors most suitable for focusing. Generally, however, it is most convenient to fix this optimum voltage difference experimentally for a given coaxial structure and electron beam.

As indicated above, the interaction circuit which is a feature of the invention can similarly be used for spatial harmonic amplification of a forward traveling wave. By an analysis similar to that set forth above for the amplification of a backward traveling wave, it can be shown that the condition for forward wave amplification can be written as

$$\frac{d}{\lambda_0} = \frac{1}{\frac{c}{u} - \frac{c}{v}} \quad (4)$$

Returning now to the description of the amplifier shown in Fig. 5, for amplification of a forward traveling wave the input wave is applied to the upstream or electron source end of the interaction circuit for propagation therealong in the same direction as the electron flow. A variety of arrangements are possible for introducing the input wave into the interaction circuit. Usually, the traveling wave tube is inserted as an element in a hollow wave guide system being bridged across input and output wave guide sections of the system for forming a wave path continuation therebetween. Such an arrangement is here shown schematically. The section of wave guide 50 which in the forward mode of amplification will be the input section is apertured into two of its opposite side walls through which extends the glass envelope, the electron source end of the interaction circuit being positioned in the wave guiding path. Then any of the usual expedients (not shown here) for enhancing an energy transfer between the hollow wave guide and the coaxial line can be employed additionally. The amplified wave can be abstracted from the collector end of the interaction circuit in an analogous fashion for continued travel along the section 51 of the wave guide system.

For amplification of a backward traveling wave, the roles of sections 50 and 51 of the wave guide system are interchanged, section 51 being used to introduce the wave to be amplified into the collector end of the interaction circuit for travel therealong in a direction opposite to that of electron flow, and section 50 is used for abstracting the output wave.

The velocity of electron flow in each case would be adjusted to meet the condition for interaction described by corresponding Equations 3 or 4.

Additionally, when operation is in the backward wave mode, it is important to keep the beam current sufficiently low that oscillations in the backward wave mode are not initiated. This is discussed more fully below. When operation is in the forward wave mode, it is generally desirable to insert loss along the interaction circuit to minimize the tendency to oscillate. This can be done by depositing a coating of lossy material, such as aquadag, on either of the two conductors forming the interaction circuit.

The backward wave oscillator shown in Fig. 6 is in most respects similar to the amplifier shown in Fig. 5. However, in the manner characteristic of backward wave oscillators while the output oscillatory energy is abstracted at the upstream or electron source end of the interaction circuit in the manner characteristic of a backward wave amplifier, the downstream end or collector end is terminated internally to be substantially reflectionless over the

broad band of frequencies in which spurious amplification may be secured. Because of the basic similarities, it will be convenient to use the same reference numerals in the backward wave oscillator as were used in designating corresponding elements of the amplifier shown in Fig. 5.

The principal difference in the structural details of the amplifier 40 shown in Fig. 5 and the oscillator 60 shown in Fig. 6 is the substitution in the oscillator, for the collector end section 51 of wave guide of the amplifier, an internal reflectionless termination of the interaction circuit. The use of an internal termination instead of an external termination facilitates the problem of making the downstream end of the interaction circuit reflectionless over the broad band of frequencies in which some spurious gain can be achieved. To provide such a termination an annular wedge 61 of dielectric material which is coated with lossy resistive material is inserted in the interspace between the inner and outer conductors 44 and 45. The wedge 61 is tapered to increase in cross section with distance in the direction of electron flow and to have a length sufficient to make a good termination over the broad band of frequencies at which amplification can be realized.

By such an expedient, the downstream end of the interaction circuit can be made substantially reflectionless.

For abstracting oscillatory energy, the upstream end of the interaction circuit is coupled to a suitable wave guiding path for transmission to the point of utilization. As shown, the output wave is abstracted, in a manner similar to that described before in connection with the amplifier shown in Fig. 5, into a wave guide section 50 which is a continuation of a wave guide system.

Since the interaction in an oscillator of this kind is with a backward traveling wave, the condition for interaction is that given by Equation 3. However, for operation as an oscillator, it is important that the beam current be in excess of the starting current necessary to initiate and sustain oscillation. Since it can be shown that in backward wave operation, the intensity of the beam current is a parameter determining the gain, for a given interaction circuit, there is a minimum current whose value can best be determined experimentally below which the backward wave gain is insufficient to sustain oscillations. Moreover, as indicated above, for amplifier operation in the backward wave mode, it is important to operate with values of beam currents below this starting current value.

It is characteristic of backward wave oscillators of the kind described that the frequency of oscillations can be controlled by the velocity of the electron beam, and, accordingly, by the accelerating potential acting on the beam. As a result, by modulating the beam accelerating potential in accordance with signal intelligence, there can be modulated correspondingly the frequency of the oscillations. For operation as a frequency modulator in this way there can be inserted in series in the D.-C. path between the electron source and the inner member of the coaxial line a source of modulating signals controlled by the signal intelligence. In the oscillator 60 shown, provision is made for such modulator operation by the inclusion of switch 62 which permits the insertion of such a source 63 of modulating voltage.

It is to be understood that the two specific embodiments described are merely illustrative of the general principles of the invention. Various other arrangements may be devised by one skilled in the art without departing from the spirit and scope of the invention. In particular, various modifications may be desirable for special applications in the shapes of the two members forming the coaxial line. Alternatively, it may be desirable to vary the shape of the slots made in the inner member or even to increase the number and position of the slots circumferentially disposed around the member to achieve sextipole or octopole electrostatic field configurations along

the path of flow. Additionally, resort may be had to expedients for modifying the retardation effect of the line which comprises corrugations on the interspace surfaces of the two members.

What is claimed is:

1. In a device which utilizes the interaction between a traveling wave and an electron stream, an electron source and target defining therebetween a path of electron flow, a two conductor coaxial transmission line disposed along the path of flow having a hollow inner member of a first diameter disposed around the path of flow and a hollow outer member of a larger diameter disposed around the inner member, and characterized in that the hollow inner member includes a plurality of discrete slots axially and symmetrically disposed at periodic intervals along its length for the penetration therethrough of electric fields of an electromagnetic wave propagating along the two conductor transmission line for interaction with the electron flow, the axially disposed slots at adjacent intervals being shifted circumferentially with respect to each other.

2. In a device which utilizes the interaction between a traveling wave and a stream of charged particles, an interaction circuit for the traveling wave comprising first and second hollow conductive members, and means for projecting said stream of charged particles through the region enclosed by said first member, the first member being coaxially disposed within the second member and characterized by a succession of pairs of slots spaced along said first member in a longitudinal direction, the two slots of each pair being substantially diametrically opposite and successive pairs being shifted substantially 90°.

3. In a device which utilizes the interaction between a traveling wave and an electron stream, an interaction circuit for the traveling wave comprising a coaxial transmission line having hollow inner and outer members, and means for projecting said electron stream through the region enclosed by the inner member, said inner member being grooved in a succession of longitudinally spaced pairs of slots, the two slots of each pair being diametrically disposed around the axis and successive pairs of slots being shifted circumferentially about the axis substantially 90°.

4. An electron beam system comprising a source of electrons and a target for defining therebetween a path of electron flow, first and second conductive members, the first member being longitudinally disposed around the path, the second member being longitudinally disposed around the first member, the first member having spaced intermittently along its length a succession of pairs of slots, the two slots of each pair being in diametrically opposite sides of the path of electron flow, successive pairs of slots being shifted circumferentially with respect to the path of electron flow, and means for applying a D.-C. potential difference between the first and second members.

5. In a device which utilizes the interaction between a traveling wave and an electron stream, an interaction circuit for the traveling wave comprising a coaxial transmission line having hollow inner and outer members, and means for projecting said electron stream through the region within the hollow interior of the inner member, said inner member being grooved to provide a succession of longitudinally spaced pairs of slots, each slot having a length slightly less than mean separation between adjacent slots, the two slots of each pair being diametrically disposed around the axis, and successive pairs of slots being shifted circumferentially about the axis.

6. In a device which utilizes the interaction between a traveling wave and an electron stream, an interaction circuit for the traveling wave comprising a coaxial transmission line having hollow inner and outer members and characteristic in that the inner member is grooved to provide a succession of longitudinally spaced pairs of slots for the penetration of the electric field of the wave into

the region enclosed by the inner member, the two slots of each pair being diametrically disposed around the axis and successive pairs of slots being shifted circumferentially about the axis substantially 90°, means for applying an input wave to be amplified to one end of said interaction circuit, means for abstracting the output wave at the opposite end of said interaction circuit, and means for projecting the electron stream through the region enclosed by said inner member for interaction with the penetrating electric field of the traveling wave.

7. In an oscillator which utilizes the interaction between a traveling wave and an electron stream, an interaction circuit for the traveling wave comprising a coaxial transmission line having hollow inner and outer members and characterized in that the inner member is grooved to provide a succession of longitudinally spaced pairs of slots, the two slots of each pair being diametrically disposed around the axis and successive pairs of slots being shifted circumferentially about the axis substantially 90°, an electron source for projecting the electron stream through the region enclosed by said inner member, means for abstracting oscillatory energy from the electron source end of the interaction circuit, and means for terminating the opposite end of the interaction circuit to be substantially reflectionless.

8. An oscillator according to claim 7 in which the means for terminating the opposite end of the interaction circuit comprises an annular lossy wedge disposed between the inner and outer members of the coaxial transmission line.

9. In an oscillator which utilizes the interaction between a traveling wave and an electron stream, an interaction circuit for the traveling wave comprising a coaxial transmission line having hollow inner and outer members, and means for projecting said electron stream through a region within the hollow interior of the inner member, said inner member being grooved to provide a succession of longitudinally spaced pairs of slots, the two slots of each pair being diametrically disposed around the axis and successive pairs of slots being shifted circumferentially about the axis substantially 90°, means for abstracting oscillatory energy from the end of the line adjacent the electron source and means for terminating the end of the line adjacent the target in its characteristic impedance.

10. In a device which utilizes the interaction between a traveling wave and an electron stream, a source of electrons and a target for defining therebetween a path of electron flow, wave guiding means comprising first and second conductive members, the first member being longitudinally disposed around the path, the second member being longitudinally disposed around the first member, the first member having along its length a succession of pairs of rectangular slots, the two slots of each pair being on diametrically opposite sides of the path of electron flow, and successive pairs of slots being shifted circumferentially with respect to the path of electron flow, means for applying an input wave to one end of said wave guiding means, and means for abstracting output waves from the opposite end of said wave guiding member.

11. In an oscillator which utilizes the interaction between a traveling wave and an electron stream, a two conductor coaxial transmission line having a hollow inner member of a first diameter and a hollow outer member of a larger diameter disposed around the inner member, the hollow inner member being apertured in discrete slots for the penetration of the electric field of waves traveling along the transmission line into the hollow region enclosed by said inner member, said slots being axially and symmetrically disposed at periodic intervals along the length of the inner member and the slots at adjacent intervals being shifted circumferentially with respect to each other, means for maintaining a D.-C. potential difference between said inner and outer members for creating a transverse electrostatic field within the hollow region defined by said inner member, means for project-

ing said electron stream through the hollow region defined by said inner member, resistive means for terminating the downstream end of said two conductor line, and means for abstracting oscillatory energy from the upstream end of said two conductor line.

12. In a device which utilizes the interaction between a traveling wave and a stream of charged particles, an interaction circuit for the traveling wave comprising a coaxial transmission line having hollow inner and outer members, and means for projecting said stream of charged particles through the region enclosed by the inner member, said inner member being perforated to provide a succession of longitudinally spaced pairs of slots, the two slots of each pair being symmetrically disposed around the periphery of said inner member and each of said slots subtending an angle of 90° , and successive pairs of slots being shifted circumferentially around the axis substantially 90° .

13. A wave retardation circuit comprising a two conductor coaxial transmission line having a hollow inner member of a first diameter surrounded by a hollow outer member of a larger diameter for propagating an electromagnetic wave, said inner member being longitudinally disposed within the outer member and including a plurality of pairs of discrete slots along its length, the two slots of each pair being substantially diametrically opposite one another and adjacent pairs being substantially in quadrature.

14. A device which utilizes the interaction between a traveling wave and a stream of charged particle, comprising a hollow outer member and a hollow member longitudinally disposed within said outer member forming an interaction circuit for propagating an electromagnetic wave, at least one of said members being characterized by a plurality of longitudinally spaced pairs of slots, the two slots of a given pair being substantially diametrically opposite and each pair of slots displaced circumferentially with respect to the preceding pair, and means for projecting a stream of charged particles in coupling proximity to the slotted member.

15. In a device which utilizes the interaction between a traveling wave and an electron stream for amplifying the wave, waveguiding means for propagating an electromagnetic wave comprising a hollow inner member having predetermined transverse dimensions and a hollow outer member of larger transverse dimensions disposed around said inner member, characterized in that the hollow inner member includes a plurality of discrete slots axially and symmetrically disposed at periodic intervals along its length, means for maintaining a D.-C. potential difference between said inner and outer members for creating a transverse electrostatic field for penetration through the slots into the hollow region enclosed by said

inner member, said slots at adjacent intervals being shifted circumferentially with respect to each other thereby shifting the orientation of the transverse electrostatic field, and means for projecting an electron stream through the region enclosed by said hollow inner member for interaction with the propagating electromagnetic wave.

16. In a device which utilizes the interaction between a traveling wave and an electron stream, an electron source and target for defining therebetween a path of electron flow, a two conductor coaxial transmission line disposed along the path of flow having a hollow inner member of predetermined transverse dimensions disposed around the path of flow and a hollow outer member of larger transverse dimensions disposed around the hollow inner member and characterized in that the hollow inner member includes a succession of pairs of slots disposed at periodic intervals along its length for the penetration therethrough of the electric fields of an electromagnetic wave propagating along the coaxial conductor line, the two slots of each pair being substantially diametrically opposite each other, means for applying an input wave to be amplified to one end of said coaxial transmission line and means for abstracting an output wave from the opposite end of said coaxial transmission line.

17. In an oscillator which utilizes the interaction between the traveling wave and an electron stream, a two conductor coaxial transmission line having a hollow inner member of a first diameter and a hollow outer member of a larger diameter disposed around the inner member, the hollow inner member characterized by a succession of pairs of slots disposed at periodic intervals along its length, the two slots of each pair being substantially diametrically opposite each other and successive pairs of slots being shifted circumferentially with respect to each other, means for maintaining a D.-C. potential difference between said inner and outer members for creating within the region enclosed by said hollow inner member a succession of regions of transverse electrostatic field, the successive circumferentially shifted pairs of slots shifting the orientation of the transverse electric field along successive regions, means for projecting an electron stream through the region enclosed by said hollow inner member, resistive means for making the downstream end of said two conductor line substantially reflectionless, and means for abstracting oscillatory energy from the upstream end of said two conductor line.

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