

July 19, 1960

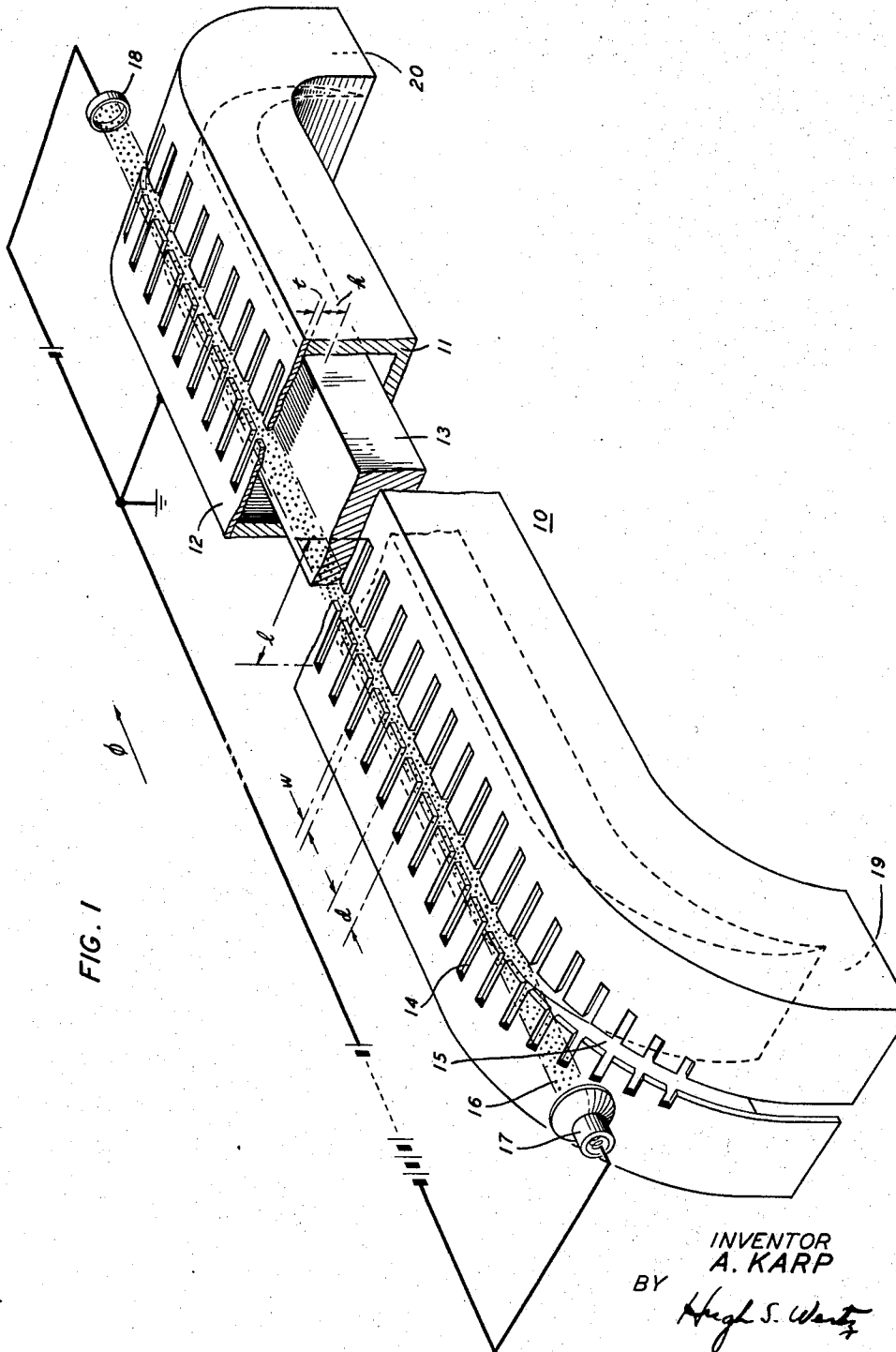
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2,945,979

TRAVELING WAVE TUBE STRUCTURE

Filed Dec. 30, 1952

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

FIG. 2

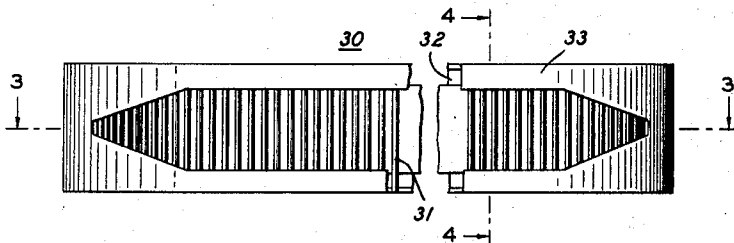


FIG. 3

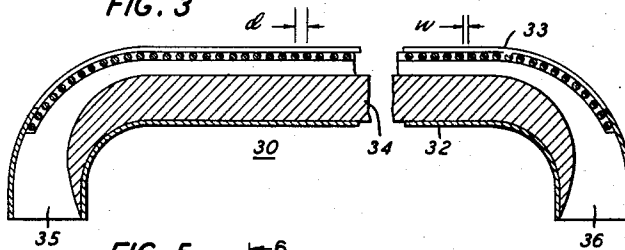


FIG. 4

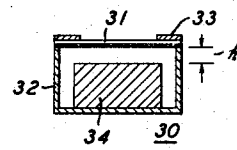


FIG. 5

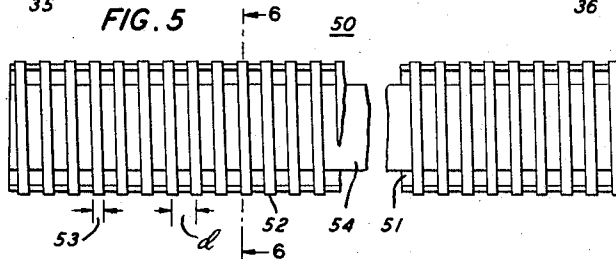


FIG. 6

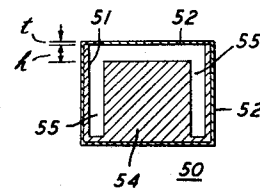
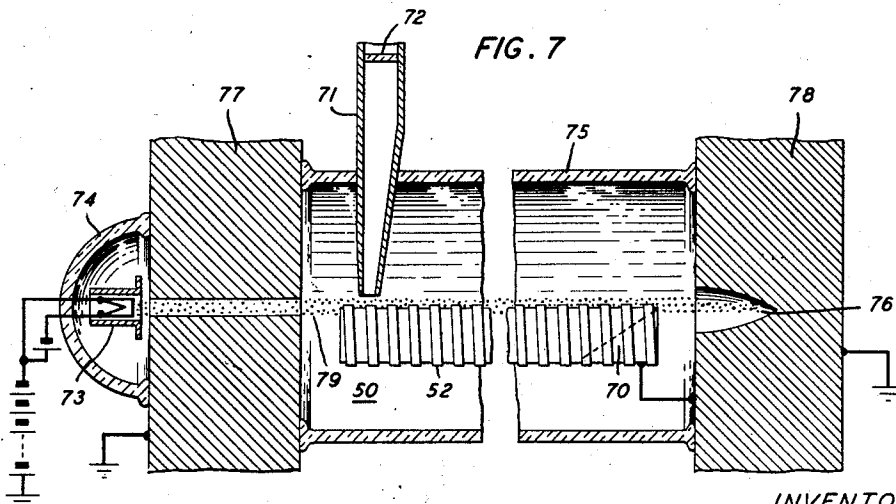


FIG. 7



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TRAVELING WAVE TUBE STRUCTURE

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10 Claims. (Cl. 315—3.5)

This invention relates to high frequency electronic devices and more particularly to those devices of the so-called traveling wave type.

The principal object of this invention is to simplify the structure of traveling wave tubes operating at extremely short wavelengths.

Another object is to achieve broad band operation in traveling wave tubes without sacrificing gain and ease of construction.

Heretofore, traveling wave tubes, to secure gain, have commonly utilized the interaction of an electron stream with an electromagnetic wave traveling at approximately the same velocity as the electrons, the wave being slowed down to the velocity of the electrons by passing it along a specialized wave guiding circuit such as a helix of proper pitch. Such an arrangement is well suited for amplification of waves longer than, for instance, several centimeters wavelength and it would be a possible structure for amplifying even shorter wavelengths if it were not for the difficulty of physically realizing tube structures small enough. A helix of optimum size for operation at one-half centimeter wavelength, for example, has a diameter of the order of that of the shaft of a common pin and its individual turns are almost impossible to discern by the normal unaided human eye. As a consequence, not only is the power dissipation capacity of such a structure very limited, but its construction is tedious and difficult, if not impossible. Several ways of overcoming this limitation as to size have been proposed, but it is believed that no one solution has been ideal, principally because of practical considerations such as difficulties in manufacture and cost.

In one important aspect, the present invention relates to a novel wave guiding structure which is rugged, easy to build and which provides good gain-bandwidth characteristics at these very short wavelengths.

Wave guiding structures of the so-called spatial harmonic wave type are known and such a wave guiding structure is described for use in a traveling wave tube in an article, entitled "A Spatial Harmonic Traveling-Wave Amplifier for Six Millimeters Wavelength," by S. Millman, appearing in the Proceedings of the Institute of Radio Engineers, volume 39, page 1035, September 1951. However, because the present invention utilizes the spatial harmonic wave principle in its operation, it will be advantageous to present here a brief description of this principle in order to supply a background for the appreciation of the novel features incorporated therein. In a traveling wave tube which relies upon the transfer of kinetic energy from an electron stream to an electromagnetic wave, it is necessary for the electron flow to receive a net slowing down in its passage from the electron source to the collector electrode, and for this to happen the electromagnetic wave must be so phased along its propagation path that the electron stream interacting with it receives an average deceleration. A conventional helix traveling wave guiding structure achieves this phasing by causing the electromagnetic wave to travel along a helix of such a pitch that the component of wave phase

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velocity along the electron path is approximately equal to the electron velocity, which may for example be one-tenth the speed of light. A spatial harmonic traveling wave guiding structure achieves this necessary phasing between the electric field and the electrons by propagating a relatively faster electromagnetic wave which, for instance, may have a phase velocity only a little less than the speed of light along a wave circuit having sharp discontinuities therein. These discontinuities are chosen so that there exists near each of them a component of electric field parallel to the direction of electron flow and so that no such component exists elsewhere. By adjusting the velocity of the electron stream, a given electron can be made to reach each discontinuity at a time when the phase of the electric field intensity at that discontinuity is the same as it was at the preceding discontinuity when this electron arrived there. Thus, the electrons can be synchronized with any wave propagating along these discontinuities with a phase velocity equal to the velocity of the electrons plus a velocity such that the electric vector rotates any multiple of plus or minus 360 degrees between successive interaction intervals.

Traveling wave structures which embody the spatial harmonic principle have advantages not otherwise obtainable through the use of conventional traveling wave structures of the helix type at millimeter wavelengths since they are more rugged and have larger dimensions than the latter, but up to now their construction has nevertheless been tedious and difficult partly because of the exacting tolerances required and the complexity of structure. One purpose of this invention therefore is to alleviate this drawback and to reduce the expense of manufacture.

In accordance with the present invention, an electron stream is beamed in coupling relation to the electric field existing in the vicinity of a series of regularly spaced discontinuities of basically simple construction positioned in one wall of a conductively bounded wave guiding path. These discontinuities in one specific embodiment are formed by slot-like openings through one wall of a rectangular wave guide. In a second embodiment, they are formed by parallel wires laid transversely across an opening in one wall of a rectangular wave guide; while in a third embodiment they are formed by the turns of a wire wrapped with a pitch around a rectangular wave guide having a section of one wall thereof removed. A more complete understanding, however, of the nature and objects of this invention may be gained from the following description given in connection with the accompanying drawings of several illustrative embodiments thereof, in which:

Fig. 1 is a perspective view of one embodiment of a wave guiding circuit wherein the recurrent discontinuities are formed by slot openings cut through a wave guide wall;

Fig. 2 shows in plan view a second embodiment of a wave guiding circuit wherein the discontinuities are formed by transverse parallel wires;

Fig. 3 is a side section view of Fig. 2;

Fig. 4 is a cross section of the arrangement of Fig. 2 taken in a plane through line 4—4;

Fig. 5 shows in plan view a third embodiment wherein the discontinuities are formed by a wire tape tightly wound upon a grooved form;

Fig. 6 is a cross section view of Fig. 5 taken in a plane through line 6—6; and

Fig. 7 illustrates the structure of Fig. 5 used in a backward traveling wave tube oscillator.

Referring now more particularly to the drawings, Fig. 1 shows, for purposes of illustration of the invention, a spatial harmonic wave guiding circuit 10 in which a series of recurrent discontinuities, recurring along the direction

of wave propagation, is formed by transverse slot-like openings 14 through wall 12 of a conductively bounded wave guiding enclosure 11. The inside dimensions of the rectangular guide 11 with its ridge 13 are chosen so that a transverse electric wave can propagate there-through with its electric field perpendicular to wall 12. Ridge 13, which is centered along the wall opposite to wall 12, and which is separated from it by a distance h serves primarily to broaden the useful operating frequency bandwidth of the circuit, but it is not essential otherwise. This ridge may be formed separately from the guide but is preferably an integral part thereof and may be hollow or not as desired. Both ridge and guide are made of a non-magnetic conductor such as copper or gold plated molybdenum. Transverse slots 14, which together with the metal separating them form slot-resonators, perforate wall 12, and are regularly spaced along this wall parallel to each other in a series extending parallel to the direction of flow of the electron stream and the flow of wave power. Length l of these slots is a little less than one-half of a free space wavelength at the upper cut-off frequency of the circuit and this length is the principal factor in determining this frequency.

The end groups of slots are gradually tapered down in length over a distance until l is at least halved and ridge 13 is tapered to zero height over the same or greater distance. The amount and distance of both tapers, however, may be varied according to the quality of impedance match desired between the slotted and un-slotted sections of the guide. Slit 15, which perpendicularly bisects slots 14, may provide among other things, a mechanically free space for an electron stream such as stream 16, but this slit has negligible electrical effect on the wave guiding properties of the circuit. Electron gun 17 and collector electrode 18 are aligned so that the electron stream flowing between them is oriented along the axis of slit 15 in the plane of wall 12 as shown in the drawing. Wave energy for interaction with electron stream 16 is supplied to wave guiding circuit 10 by connecting to end 19 thereof, which is bent down out of the line of electron flow, a guide of the same dimensions in which a transverse electric electromagnetic wave is propagating with its electric field perpendicular to the wider walls of the guide. Output energy is then obtained at end 20 which is similarly bent downward. A single line of magnetic flux ϕ , parallel to the electron stream 16, is shown in Fig. 1 to indicate the orientation of the magnetic field with respect to the other structural elements. This field may be formed by parallel magnets such as 77 and 78 in Fig. 7 or by any other appropriate means. It is to be understood that the structure shown in Fig. 1 when interacting with electron stream 16 must be enclosed in an evacuated envelope, such as for example, the enclosure including envelope 75 in Fig. 7, which may either be glass or a non-magnetic metal.

Thickness t of wall 12 partly determines the ratio of the series capacitance in the circuit to the shunt capacitance therein and hence the impedance and band width for the circuit illustrated and this thickness is therefore important. A practical ratio of this thickness t to distance h is 0.1. Slots 14 in wall 12 may be formed by any suitable method, but it has been found convenient to form them by photoengraving a metal sheet of proper thickness, two of which sheets may then be joined to the guide in the position shown.

The operation of wave circuit 10, shown in Fig. 1, will best be understood by consideration of the following mathematical analysis adapted specifically to the operation of this structure but applicable in general to spatial harmonic phenomenon.

If z is the direction of wave velocity in a wave guide, then in the vicinity of recurrent discontinuities in the guide the z component of a traveling wave may be written

$$E_z = F(z) e^{j\omega t} \quad (1)$$

in which ω is the radian frequency and

$$F(z) = \sum_{n=-\infty}^{n=\infty} A_n \exp \left[-j(2\pi n + \theta) \frac{z}{d} \right] \quad (2)$$

where d is the mean distance between successive slots, n is an integer and θ is the phase delay in radians from one discontinuity to the next and is given by

$$\theta = \frac{2\pi d}{\lambda_g} \quad (3)$$

where λ_g is the guide wavelength of the fundamental wave in this guide loaded with iterated reactive discontinuities. Assuming the amplitude of E_z to be constant at the edge of the slots, and denoting it by E_0 , A_n may be written

$$A_n = \frac{E_0}{d} \int_{-\frac{w}{2}}^{+\frac{w}{2}} \left[\exp \left(j(2\pi n + \theta) \frac{z}{d} \right) dz \right] = \frac{2E_0}{2\pi n + \theta} \sin \left((2\pi n + \theta) \frac{w}{2d} \right) \quad (4)$$

where w is the width of a slot 14. Combining Equations 1, 2, and 4, we obtain:

$$E_z = E_0 \sum_{n=-\infty}^{n=\infty} \frac{2 \sin \left((2\pi n + \theta) \frac{w}{2d} \right)}{2\pi n + \theta} \exp \left[j\omega t - (2\pi n + \theta) \frac{z}{d} \right] \quad (5)$$

From this last equation it can be seen that near the slot discontinuities in the wave guide there appear to be an infinite number of spatial harmonic components of the fundamental wave, each traveling at a different phase velocity given by

$$\frac{\omega d}{(2\pi n + \theta)}$$

in which n is an integer between $-\infty$ and $+\infty$. Setting $n=0$ we see that the fundamental wave travels in the positive z direction with a phase velocity of

$$\frac{\omega d}{\theta}$$

For $n=1$ a wave appears to travel in the positive z direction with a velocity of

$$\frac{\omega d}{(2\pi + \theta)}$$

which is less than the velocity for the fundamental wave. A similar reasoning applies for other positive values of n . For $n=-1$, there appears to be a wave traveling in the positive z direction with a phase velocity

$$\frac{\omega d}{(-2\pi + \theta)}$$

which is negative since fundamental phase displacement θ between successive slots is less than 2π . Thus for each negative integer n there is a corresponding wave having negative phase velocity, or, in other words, a backward traveling wave. The group velocity of all spatial harmonic waves, it should be remembered, is always in the direction of power propagation and is the same for all, including those which have negative phase velocity.

In the vicinity of the guide wall between slots, that is, the metal region between slots 14, the electrons see substantially no z component of electric field, while when passing over a slot opening they see a strong z direction electric field. This alternate passage from drift space to interaction-space is analogous to a stroboscopic light flashing on a patterned wheel, the duration of each flash corresponding to the time the electrons are in the reaction space over the slot opening, the interval between flashes corresponding to the time it takes an electron to

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go from one slot center to the next and the angular velocity of the wheel corresponding to the phase velocity of the fundamental spatial harmonic of the traveling wave. For a given wheel velocity there will be several discrete stroboscopic frequencies at which the wheel appears stationary and each of these apparent non-rotations of the wheel corresponds to synchronism between the phase of a spatial harmonic of the wave and that of the electrons. In this synchronous condition a single electron "sees" the same field vector as it passes each slot opening and therefore the requirement for electromagnetic-wave electron-stream interaction is met by, in effect, "fooling the electrons."

By assuming that the group velocity of the wave propagating down the guide is opposite to the velocity of electron flow, it can be seen, following the above analogy, that the electrons can be synchronized with a spatial harmonic of the wave having a negative phase velocity relative to the group velocity. When such conditions actually exist in a spatial harmonic tube, electromagnetic power flows from the collector end to the gun end of the tube. This mode of operation, useful for amplification up to a critical value of beam current, is likewise useful for obtaining oscillations beyond this critical value since the necessary feedback path for sustaining the oscillations is then automatically provided by the electron stream.

From an inspection of Fig. 1, it is apparent that, for a given slot spacing d , somewhere between the condition where the slot width w is almost equal to d , in which case the amount of spatial harmonic field is negligible and there is substantially no interaction between the electromagnetic wave and the electron stream, and the condition where width w of the slot opening is almost zero, in which case the impedance approaches zero and the interaction is likewise negligible, there must be some ratio of slot width to slot spacing which gives optimum interaction if there is to be any net gain. Now, it can be shown that the electron velocity V_e required for synchronization is given by

$$V_e = \frac{\omega d}{(2\pi n + \theta)} \quad (6)$$

where ω is the radian frequency, d the center to center slot spacing, n an integer, and θ the fundamental phase displacement between slots, usually

$$\frac{\pi}{3} \text{ to } \frac{\pi}{2}$$

It can further be shown that the amplification of the electromagnetic wave interacting with the electrons is proportional to

$$\text{Gain} = K \frac{\sin^2 \frac{[(2\pi n + \theta)w]}{2d}}{(2\pi n + \theta)w} \quad (7)$$

where K is a proportionality constant and w is the width of a slot opening. By differentiating this last equation with respect to

$$\frac{w}{d}$$

and setting the result equal to zero, the gain is seen to be maximum when

$$\frac{w}{d} = \frac{2.33}{(2\pi n + \theta)} \quad (8)$$

As mentioned previously, practical values of θ may be roughly between

$$\frac{\pi}{3} < \theta < \frac{\pi}{2}$$

and so, from Equations 6 and 8, w can be determined for a given electron velocity V_e , a given value of n and

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a given frequency of operation. A detailed study of Equation 7 shows that, for small values of n , as

$$\frac{w}{d}$$

is varied about the optimum, the gain does not fall off very rapidly. Hence, there is little loss in gain if

$$\frac{w}{d}$$

is not exactly its optimum value.

Slot spacing in Fig. 1 may be designed according to Equations 3 and 6 for synchronization of the electrons with forward or backward traveling spatial harmonic waves. The number of slots cut in the guide wall 12 that are to couple to the beam is dependent upon the gain desired from a beam of given length and intensity. By way of example, 70 is a typical number. For the purpose of illustration however, the spacing shown has been designed for operation with the first forward ($n=+1$) wave. In a circuit such as is shown in Fig. 1 which has been built and tested, it has been found that the following dimensions are suitable for this mode of operation with an electron velocity corresponding to approximately 1300 volts: distance $h=0.087\lambda_0$ (λ_0 is the free space wavelength at the center frequency of operation); thickness $t=0.0087\lambda_0$; distance $d=.086\lambda_0$; slot width $w=0.025\lambda_0$; slot length $l=0.420\lambda_0$; the width of slit 15= $0.065\lambda_0$; the width of ridge 13= $0.437\lambda_0$; the inside width of guide 11= $0.655\lambda_0$; and the inside height of guide 11= $0.31\lambda_0$. It should be understood, however, that a circuit having these dimensions is not restricted to use with the specified electron velocity and frequency of operation but may be used to cause interaction between an electron stream having greatly different velocities and waves having slightly greater or smaller frequencies.

Fig. 2 illustrates a second embodiment of the invention wherein a series of discontinuities along wave guiding circuit 30 is formed by parallel spaced wires 31 laid transversely across wave guide 32 and secured to it by frame 33. The opening in frame 33, of width such that wires 31 are half-wave resonant at the upper cut-off frequency of the circuit, is tapered at each end thereof in order to facilitate impedance matching to the input and output wave guides.

Fig. 3, which is a side-section of the structure in Fig. 2, shows the end tapering of ridge 34 as well as the diameter of wires 31 which are spaced a distance d apart. The diameter of these wires corresponds to both thickness t of the perforated wall shown in Fig. 1, and the interslot metal breadth ($d-w$). The ends of wave guide circuit 30 are bent down out of the line of electron flow so that the electrons may be beamed to pass close to wires 31. Wave energy for interaction with the electron stream may be supplied at guide end 35 and extracted at end 36 by means similar to those suggested for use with the embodiment of Fig. 1. Similarly the electron gun, collector electrode, air-tight envelope and magnetic field, all of which have been omitted here for simplicity, may be as described previously.

Fig. 4 shows a cross section of the wave guiding circuit of Fig. 2. Ridge 34, which is not necessarily solid as shown, is seen to be equally spaced from the shorter walls of guide 32 and spaced distance h from wires 31. It is preferably, through not necessarily, formed as an integral part of the lower channel of guide 32 while frame 33 is best formed separately and then brazed or soldered in place. All of these elements should be of conducting non-magnetic metal such as copper, or gold-plated molybdenum or tungsten.

The parallel wire structure in the embodiment shown in Figs. 2, 3, and 4 is particularly, although not solely, suitable for backward wave spatial harmonic operation since the ratio of space w between the wires to wire spacing d can easily be made to satisfy Equations 6 and 8 for negative integers.

The operation of wave guiding circuit 30 is substantially the same as that of the circuit of Fig. 1, except that since the former has been designed to produce optimum interaction between an electron stream having a velocity equivalent roughly to 1000 volts and the first backward spatial harmonic wave, wave energy should be fed into the collector end of the circuit and extracted at the gun end thereof. In the event that this circuit is operated as a backward wave oscillator the collector end should be terminated with a wave reflection minimizing impedance and the gun end thereof should be connected to an output wave guiding means for extracting the oscillating energy. The details of an illustrative backward wave oscillator arrangement are given more completely later in connection with Fig. 7.

Fig. 5 illustrates a third method of forming along a wave guiding circuit the discontinuities necessary for spatial harmonic operation. In this embodiment, shown in plan view, wave guiding circuit 50 includes wire tape 52 of width 53 which is wrapped with pitch d around guide 51 to form a succession of parallel wire turns which are half-wave resonant at the upper cut-off frequency of the circuit. These turns lie substantially transversely across the guide and together with the openings between them, are equivalent to the slot-resonators in the previous embodiments. Ridge 54 is positioned within guide 51 and extends the length thereof, centered between the two side walls. Neither this ridge nor the parallel wire turns over it are shown tapered at the ends of the guide as was done in the previous embodiments, since impedance matching here is accomplished as will be described below in connection with Fig. 7.

Fig. 6 shows, in a cross section view of the structure in Fig. 5, that wire tape 52, having a thickness t , is wrapped completely around guide 51. Ridge 54, which is preferably formed as an integral part of guide 51, is separated by distance h from the turns of wire 52 and is separated by spaces 55 from the vertical or side walls of guide 51. The ratio of thickness t to distance h should be roughly the same as the corresponding ratio in the embodiment of Fig. 1.

The operation of circuit 50 is substantially the same as that of circuit 30 described previously, and it is only necessary to note briefly the several uncritical structural differences between the two. Most noticeable of these differences is that the openings between turns of wire 52 in Fig. 5 extend the whole width of guide 51 and the lengths are not tapered at the ends of the guide. For a resonator length equal to that of the resonators in Fig. 2 the bandwidth of circuit 50 is somewhat less than that of circuit 30 but this may be in part compensated for by making the height of the shorter walls 52 of guide 51 greater than the height of wall 32. Impedance matching to the input or output circuits other than by end tapering slot length and ridge height can be accomplished by any appropriate means but for purposes of illustration one specific way may be as that described in connection with the combination shown in Fig. 7.

The dimensions of wire 52 and the pitch d with which it is wrapped are capable of wide variation and accordingly circuit 50 may easily be designed for the amplification or for the generation of forward or of backward traveling wave energy. An example of a backward wave oscillator of which circuit 50 is a component part may be as shown in Fig. 7, but it should be understood that such a combination is not limited to the use of circuit 50 nor is circuit 50 limited to use in such a combination.

Fig. 7 is a side view of an actual arrangement devised for using the wave guiding structure of Figs. 5 and 6 as a backward traveling wave oscillator. Circuit 50 is positioned so that electron stream 79 may pass over and through the free space between ridge 54 and the turns of wire 52. Non-magnetic envelopes 74 and 75 and wave transparent window 72, together with magnet poles 77 and 78 form an air-tight enclosure surrounding electron gun

73 and its associated electron stream 79 which flows parallel to the magnetic field. Opening 76 serves as an electron trap to prevent the emission of secondary electrons from pole piece 78 which serves additionally as a collector electrode. Wedge shaped resistance material 70 is positioned in spaces 55 (the spaces 55 without this material are shown in Fig. 6) at the collector end of circuit 50 in order to prevent wave reflections to the gun end thereof. Wave guide 71, sealed to envelope 75, is of somewhat greater width than circuit 50 and is tapered approximately as shown. This output wave guide is positioned above wires 52 near the second turn from the gun end so that oscillating wave energy flowing from the collector end to the gun end of circuit 50 may be coupled into it and thereby extracted from the circuit.

When the tube shown in Fig. 7 is operating, the electron stream interacts with wave energy originating at the collector end of circuit 50 and flowing toward the gun end thereof. At the gun end, most of the wave energy is extracted from the circuit by impedance matching wave guide 71 and any remainder is reflected back to the collector end, without undergoing any interaction along the way, where it is absorbed by lossy material 70 positioned there for this purpose. As wave energy flows toward the gun end of the circuit, spatial harmonic interaction with the electron stream causes an increase of this energy. At the same time this interaction causes a bunching of the electron stream which in turn carries energy towards the other end and thus the feedback necessary to sustain oscillations is automatically provided by the electron stream. It is necessary, however, in order to maintain oscillations that the beam current exceed a certain minimum value. Since the frequency of oscillation is determined principally by the electron velocity for a given structure and since this velocity is easily varied electrically over a wide range, the frequency may be continuously varied over a broad band.

The fact should be evident from the foregoing description of the several illustrative embodiments of this invention which are shown in the accompanying drawings, that this invention is not limited solely to these embodiments. It is likewise not limited to spatial harmonic circuits of rectangular cross section but may include circuits of other cross sections as well. It should further be evident that the input and output connections described above in connections with the drawings may be replaced without altering the nature of this invention. Lastly, it will be apparent to those skilled in the art that the dimensions of the wave guiding circuits shown herein may be selected within a wide range of values without departing from the spirit or scope of the invention as set forth. It is intended that the foregoing description and the drawings of the several embodiments shown be interpreted as in illustration and not in limitation of this invention.

What is claimed is:

1. An electronic device comprising a wave guide for propagating an electric wave, a section of one wall of said wave guide including a plurality of discrete transverse slot-like openings extending therethrough and spaced apart in a series parallel to the direction of wave propagation to form a succession of discrete slot-resonators, each of said slot resonators extending across said wall substantially in the plane thereof, means for forming and projecting an electron stream parallel to the direction of wave propagation and in coupling relation to said succession of resonators for achieving electron stream electromagnetic wave interaction, and a conductive member extending along a major portion of said series in capacitive coupling with said slot-like openings.

2. In a traveling wave tube, means including an electron gun and a collector electrode for forming and projecting an electron stream, and wave guiding means for propagating therethrough an electric wave in coupling relation

and in a direction parallel to said electron stream, said wave guiding means including a length of wave guide of rectangular cross section surrounding a raised rectangular ridge, a section of one wall of said wave guide being formed by a thin conducting sheet through which there are a plurality of slot-like openings lying substantially transverse to the direction of wave propagation and regularly spaced in a series along the direction of the electron stream, the transverse ends of each of said openings being conductively closed.

3. A traveling wave tube including an evacuated envelope, means for forming and projecting an electron stream, means for focusing said stream along an axis, and wave guiding means in said envelope for propagating therethrough an electric wave in coupling relation and in a direction parallel to said electron stream, said wave guiding means comprised of a length of wave guide whose ends are bent downward and whose center section surrounds a raised ridge tapered for a distance at the ends thereof, one surface in said center section being formed by a plurality of discrete transverse slot-resonators regularly spaced in the direction of wave propagation, said resonators formed by said surface in conjunction with a plurality of discrete openings extending in depth completely through said surface.

4. In an amplifying device, means for forming and projecting an electron stream for interaction with an electromagnetic wave, and conductively bounded rectangular wave guiding means adapted to propagate therethrough an electric wave and having along one wall thereof a raised conducting ridge which is tapered in height at the ends thereof, said wave guiding means having a plurality of openings lying substantially transverse to the direction of wave propagation and extending through a bounding surface thereof, said openings being regularly spaced in a series along the direction of the electron stream, the end groups of said openings being tapered in length for a distance at both ends of the series and each of said openings being conductively closed at both of its transverse ends.

5. In a device which utilizes the interaction between an electron stream and an electromagnetic wave for amplifying the wave, means having a high-frequency cut-off for propagating an electromagnetic wave at frequencies proximate said high-frequency cut-off, said means including a planar conductive member forming a bounding surface thereof, means for establishing a longitudinally extending array of regions of longitudinal, high intensity electric fields separated by regions of substantially no longitudinal field comprising a plurality of transversely extending spaced apertures in said planar member forming slot resonators wherein the longitudinal electric field is concentrated, both transverse ends of each of said apertures being conductively closed by said planar member, and a conductive member extending along a major portion of the length of said array in capacitive coupling relation with said apertures; and means for forming and projecting an electron stream in coupling relation to said apertures and parallel to the direction of wave propagation for interaction with said wave.

6. In an electron discharge device, means for forming and projecting an electron stream for interaction with an electromagnetic wave, and conductively bounded rectangular wave guiding means adapted to propagate therethrough an electric wave and having along one wall thereof a raised conducting ridge, means for forming a longitudinally extending array of regions of longitudinal high intensity electric field separated by regions of substantially no longitudinal electric field comprising a plurality of transversely extending, spaced metallic elements forming a portion of a bounding surface of said guide opposite said ridge, the spaces between said members forming slot resonators extending through said bounding surface wherein the longitudinal electric field is concentrated for interaction with said electron stream.

7. In an electron discharge device, the combination as claimed in claim 6 wherein said metallic elements comprise a plurality of turns of wire lying transverse to the direction of wave propagation and regularly spaced therealong.

8. In an electron discharge device, conductive wave guide means for propagating an electromagnetic wave for interaction with an electron beam, means for establishing a longitudinally extending array of regions of longitudinally high intensity electric field separated by regions of substantially no longitudinal field, said means comprising a plurality of transversely extending spaced slots in one wall of said wave guide forming slot resonators extending therethrough wherein the longitudinal electric field is concentrated, means for forming and projecting an electron beam parallel to the direction of wave propagation in coupling relationship to said slot resonators for interaction between said beam and the fields within the slots, and a conductive member extending along at least a portion of said array in capacitive coupling with said slots.

9. In an electron discharge device, the combination as claimed in claim 8 wherein said one wall has a longitudinally extending slot, said slot perpendicularly bisecting said plurality of transverse slots, said beam being projected through said slot.

10. An electronic device comprising a wave guide for propagating an electric wave, a section of one wall of said wave guide including a plurality of discrete transverse slot-like openings extending therethrough and spaced apart in a series parallel to the direction of wave propagation to form a succession of discrete slot resonators, each of said slot resonators extending across said wall substantially in the plane thereof, means for forming and projecting an electron stream parallel to the direction of wave propagation and in coupling relation to said succession of resonators for achieving electron stream electromagnetic wave interaction, said electron stream having a velocity V_e given by the equation

$$V_e = \frac{\omega d}{(2\pi n + \theta)}$$

where ω is the radian frequency of operation, d is the center to center spacing between openings, n is an integer and θ is fixed by the wave guide dimensions and the frequency, and a conductive member extending along a major portion of said series in capacitive coupling with said slot-like openings.

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