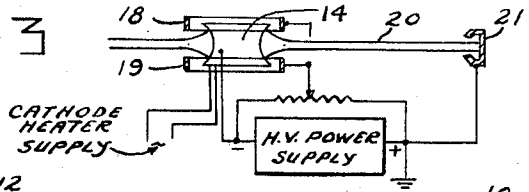
Feb. 21, 1967 W. FRIZ 3,305,752

FAST WAVE CROSSED FIELD TRAVELING-WAVE TUBE

Filed Dec. 6, 1963

Fig-3



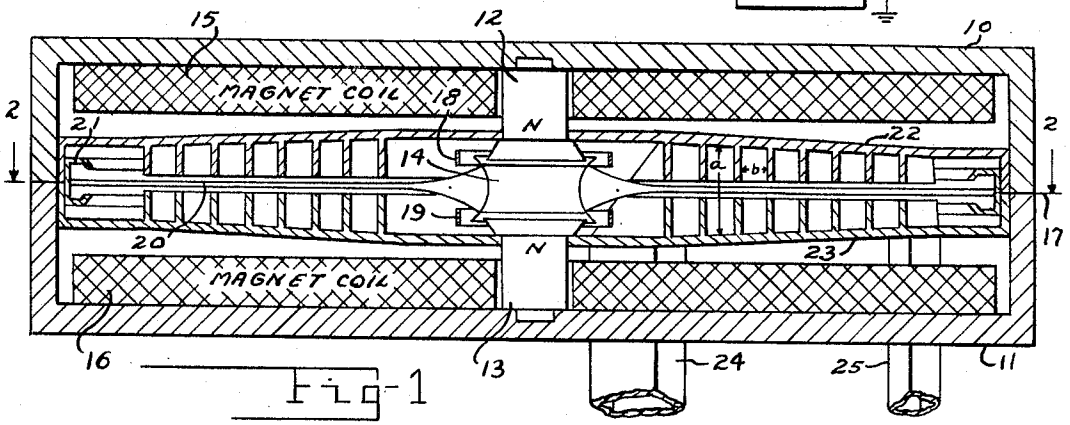


Fig-1

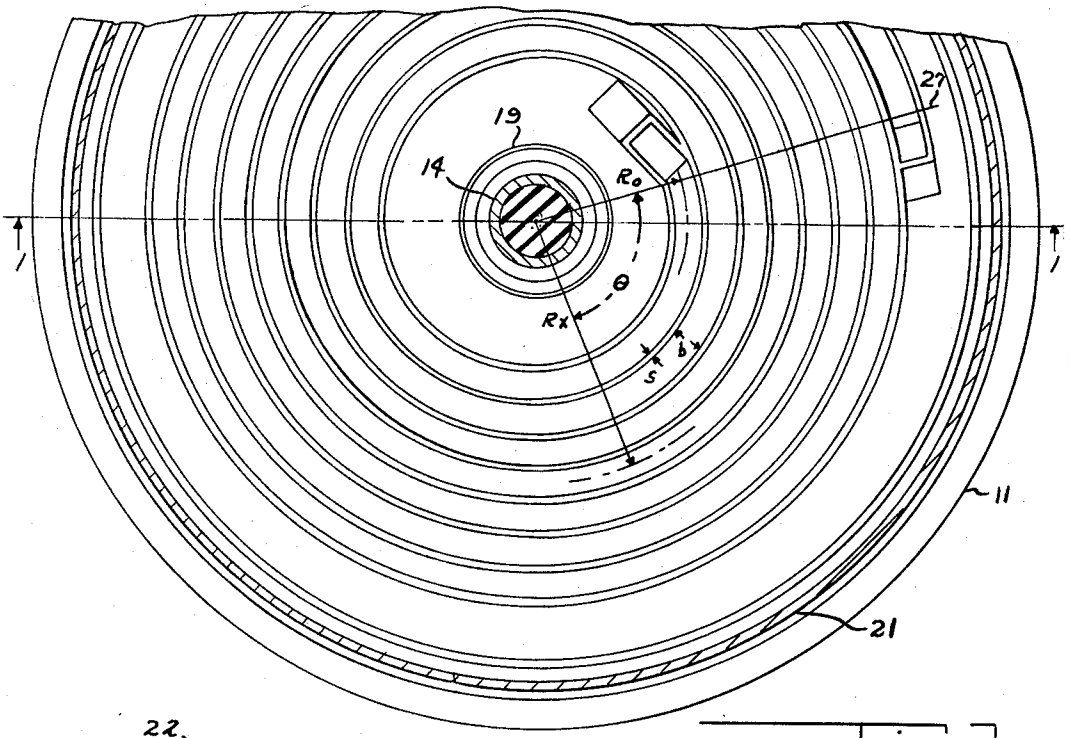


Fig-2

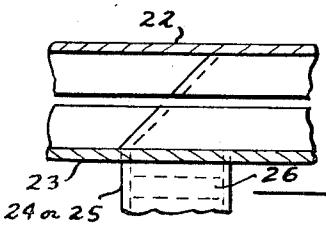


Fig-4

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FAST WAVE CROSSED FIELD TRAVELING-WAVE TUBE

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1 Claim. (Cl. 315—39)

The invention described herein may be manufactured and used by or for the United States Government for governmental purposes without payment to me of any royalty thereon.

This invention relates to traveling-wave tubes and particularly to the type of tube in which the traveling-wave structure is a rectangular waveguide wound in a linear spiral and having a slit along its plane of symmetry for the passage of a disc-shaped electron beam for interacting with the wave propagated in the guide. The purpose of this invention is to provide a traveling-wave tube of the above type so constructed that the phase relation between the propagated wave and the electron beam modulation along any radius of the beam is such that a transfer of energy occurs from the beam to the wave. In accordance with the invention, this is accomplished by decreasing the larger dimension of the waveguide as the radius of the spiral increases in order to increase the phase velocity of the propagated wave as required to maintain the proper phase relation between the wave and the beam modulation.

The invention will be described in more detail with reference to the specific embodiment thereof shown in the accompanying drawings in which

FIGS. 1 and 2 are cross sectional views of a traveling-wave tube incorporating the invention,

FIG. 3 shows the electrical connections to the electrodes of the tube in FIGS. 1 and 2, and

FIG. 4 illustrates a method of coupling to the spiral waveguide.

Referring to FIGS. 1 and 2, the traveling wave tube is contained in an annular housing of magnetic material having an upper half **10** and a lower half **11**. Centrally located in these halves are magnetic pole pieces **12** and **13** which extend toward each other, leaving space between their flared ends for an annular concave cathode **14**. Series connected magnet coils **15** and **16** surround the pole pieces **12** and are supplied with direct current from a suitable source (not shown). The coil winding directions are such that the ploe pieces from similar magnetic poles, north poles for instance, so that the magnetic flux passes radially outward from the cathode of the tube parallel to the plane of symmetry **17** of the tube to the outer rims of the upper and lower halves **10** and **11** of the housing, and thence equally through the upper and lower halves back to the pole pieces. The concave cathode **14** together with the accelerating electrodes **18** and **19** act as an annular electron gun causing the electrons emitted by the cathode to converge into a thin disc-shaped beam **20** centered on the plane of symmetry **17** and extending to collector electrode **21**, the electrons being constrained to follow paths generally radial and parallel to the plane of symmetry by the above described magnetic field. The electron beam system power supply circuit is shown schematically in FIG. 3. The cathode may be insulated and supported between the pole pieces **12** and **13** in any suitable manner.

The traveling-wave structure of the tube consists of a rectangular waveguide, having a greater dimension a and a lesser dimension b, wound in a linear spiral defined by the equation

$$R_x=R_0+K\theta \tag{1}$$

where R_0 is the starting radius, θ is measured in radians and

$$K=\frac{b+s}{2\pi}$$

as shown in FIG. 2.

This structure may be formed in two halves **22** and **23** joined at plane **17** to form a structure symmetrical with respect to this plane. The waveguide walls in each half of the structure are made of such length as, when the structure is assembled, to leave a slit at the plane of symmetry **17** for passage of electron beam **20**. The two halves **22** and **23** are joined to each other and to collector electrode **21** at their circumferences and to pole pieces **12** and **13** at their centers by soldering, brazing, welding or other suitable method providing gas-tight joints so that the traveling wave structure may be evacuated.

The spiral waveguide may be coupled to external circuits by waveguides **24** and **25** which may be joined to the spiral waveguide in the manner illustrated in FIG. 4. In each case, a gas-tight window **26** is provided to seal the interior of the traveling-wave structure.

The rectangular waveguide is operated in its dominant mode, the $TE_{1,0}$ mode. In this mode the electric field is transverse to the direction of propagation and its lines are normal to the larger dimension of the waveguide with maximum intensity at the center. The electric field lines are therefore parallel to the electron beam and densest on either side of the beam. The lines of the magnetic field form closed loops parallel to the wider surface of the waveguide.

In order for the electron beam and the propagated wave in a traveling-wave tube to interact in such a way that the wave energy is increased, it is necessary that the phase velocity of the electromagnetic wave be approximately equal to the average velocity of the electrons. Applying this requirement to a tube of the type shown in FIG. 2, in order for this condition to obtain along any radial filament of the beam, such as the filament along line **27** in FIG. 2, it is necessary that the beam see substantially the same phase of the electromagnetic wave in each successive transit of the waveguide along line **27**. With a constant phase velocity in the guide this would be impossible except along certain radial filaments of the beam because of the increasing lengths of the spiral turns. In accordance with the invention, the phase velocity is increased by a continuous reduction of the dimension a of the guide as required to provide the proper phase relation along all radii of the disc beam. The required value of a at any point in the spiral may be determined as follows:

In order that the phase relation between the electromagnetic wave and the beam density modulation wave, which results from the velocity modulation of the beam electrons by the electric field in the waveguide, shall remain substantially the same, the phase shift encountered by the wave in one spiral turn should differ from the phase shift encountered by the beam modulation wave in traversing the radial distance between turns only by the angle $n\pi$ where n is an even integer of either sign. This is expressed by the equation

$$2\pi r\beta_g=h\beta_e=n\pi \tag{2}$$

where r is the average radius of a spiral turn, β_g is the phase constant of the waveguide, β_e is the phase constant of the beam modulation wave and h is the increment in the spiral radius in one turn, these terms being further defined as follows:

$$r=R_0+\frac{h\theta}{2\pi}-\frac{h}{2}$$

where R_0 is the starting radius of the spiral and θ is the spiral angle, measured from line **27** (FIG. 2), at the end of the turn for which the average radius r is desired

$h=b+s$ (FIG. 2)

$\beta_g=\omega/v_g$, where v_g is the phase velocity of the electromagnetic wave in the guide

$\beta_e=\omega/v_b$, where v_b is the average velocity of the beam electrons

Substituting the above value of r in (2) and rearranging

(3) $$\beta_g=\frac{\beta_e+\frac{n\pi}{h}}{\theta+\left(\frac{2R_0}{2}-1\right)\pi}$$

The phase constant of a rectangular waveguide in terms of its greater dimension a is

(4) $$\beta_g=\sqrt{\left(\frac{2\pi}{\lambda}\right)^2-\left(\frac{\pi}{a}\right)^2}$$

where λ is the free space wavelength of the electromagnetic wave. Using the relationships

$$\beta=\frac{2\pi}{\lambda}$$

and

$$\lambda=\frac{c}{f}=\frac{2\pi c}{\omega}$$

when β is the free space phase constant of the wave and c is the velocity of light, Equation 4 becomes

(5) $$\beta_g=\beta\sqrt{1-\left(\frac{\pi c}{\omega a}\right)^2}$$

Equating (3) and (5)

(6) $$\frac{\beta_e+\frac{n\pi}{h}}{\theta+\left(\frac{2R_0}{h}-1\right)\pi}=\beta\sqrt{1-\left(\frac{\pi c}{\omega a}\right)^2}$$

Solving (5) for a gives

(7) $$a=\pi\sqrt{\frac{1}{\beta^2-\left[\frac{\beta_e+\frac{n\pi}{h}}{\theta+\left(\frac{2R^0}{h}-1\right)\pi}\right]}}$$

Since, as indicated above, the value of r in Equation 2 is the average radius of the spiral turn ending at the spiral angle θ, the value of "a" given by Equation 7 is that value of "a" required to give the proper phase shift in one complete turn of a rectangular waveguide of constant cross section formed in a circle of radius r. However, in order to obtain the proper phase relations along all radii of the disc beam, the cross section of the spiral waveguide in FIGS. 1–2 cannot remain constant in any given turn of the spiral but must continuously decrease throughout the spiral as θ increases. Therefore, the value of "a" computed from Equation 7 is an effective value of "a" for the spiral turn ending at θ, with the actual value of "a" being greater than the effective value in the earlier part of the turn and less in the latter part. Assuming the actual and effective values to become substantially equal midway of the turn, the actual value of "a" at any point θ' in the spiral, measured from line 27 in FIG. 2, may be determined by substituting $\theta=\theta'+\pi$ in Equation 7. Thus, to determine the values of a at the points where line 27 intersects the spiral waveguide ($\theta'=0$, 2π, 4π, 6π, . . . etc.) the values of θ to be substituted in equation 7 are π, 3π, 5π, 7π . . . etc. By drawing a smooth curve through these values of "a" plotted against θ', the value of "a" at any point θ' in the spiral may be determined. From this information a spiral rectangular waveguide having the proper taper of its longer dimension may be constructed.

It will be obvious to those skilled in the art that the positions of cathode **14** and collector **21** may be interchanged. This would not require any change in the construction of the waveguide.

I claim:

A traveling-wave tube comprising: means including an annular cathode and an annular collector electrode for producing a thin disc-shaped beam of electrons between said cathode and collector; a rectangular waveguide wound in a linear spiral and situated between said cathode and said collector, said spiral waveguide being concentric with said disc-shaped beam and symmetrically positioned with respect to the central plane of said beam, the larger dimension of said waveguide being normal to said central plane and said waveguide being slit at the center of its larger dimension to permit passage of said beam; means for introducing an electromagnetic wave at one end of said spiral waveguide and for removing said electromagnetic wave from the other end of said spiral waveguide after propagation therethrough, said propagated wave interacting with said beam to produce a velocity modulation of its electrons and a resulting density modulation of the beam; and said spiral waveguide further having its larger dimension vary continuously as an inverse function of the spiral angle such that the difference between the phase shift incurred by said electromagnetic wave in traveling around any complete turn of said spiral waveguide and the phase shift incurred by the density modulation of said beam in traveling the radial distance between turns of said spiral waveguide is substantially equal to $n\pi$ radians where n is an even integer.

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