

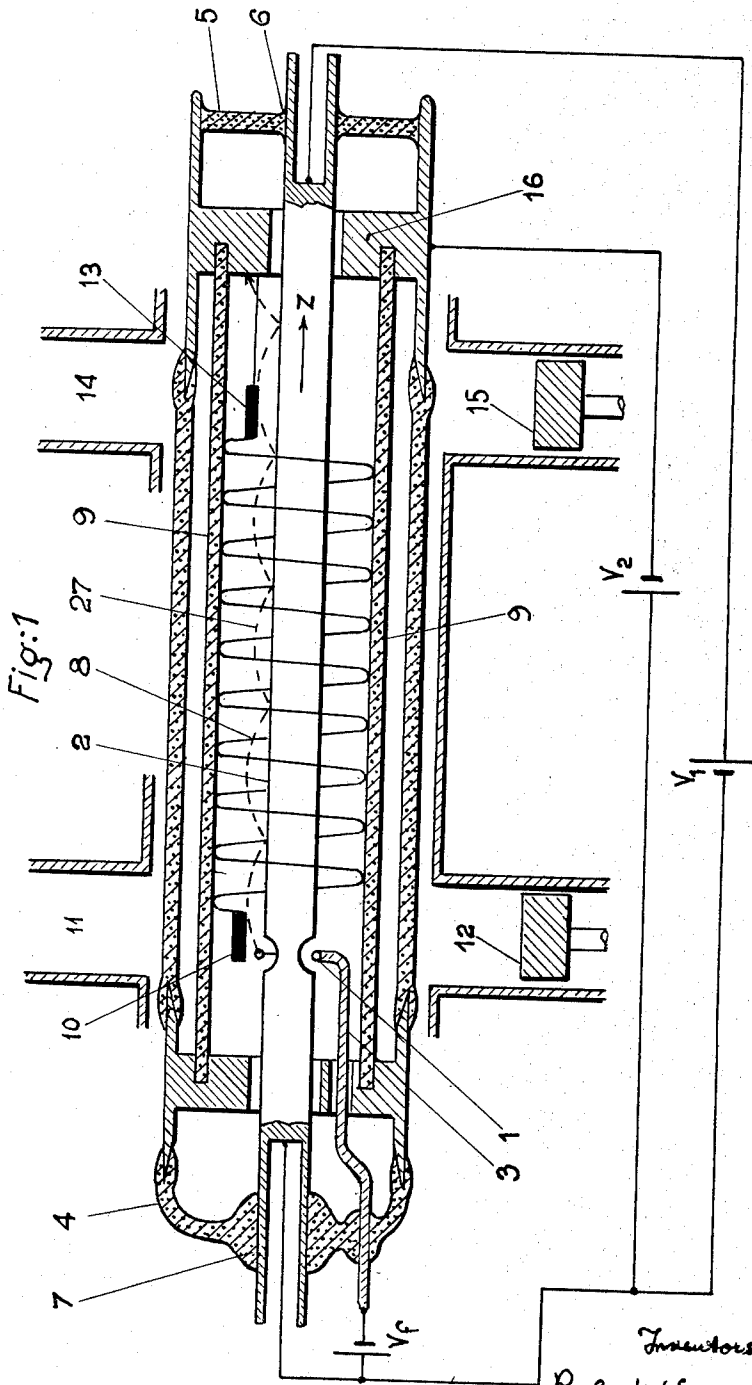
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TRAVELLING-WAVE AMPLIFYING TUBE

2,761,088

Filed Feb. 16, 1950

4 Sheets-Sheet 1



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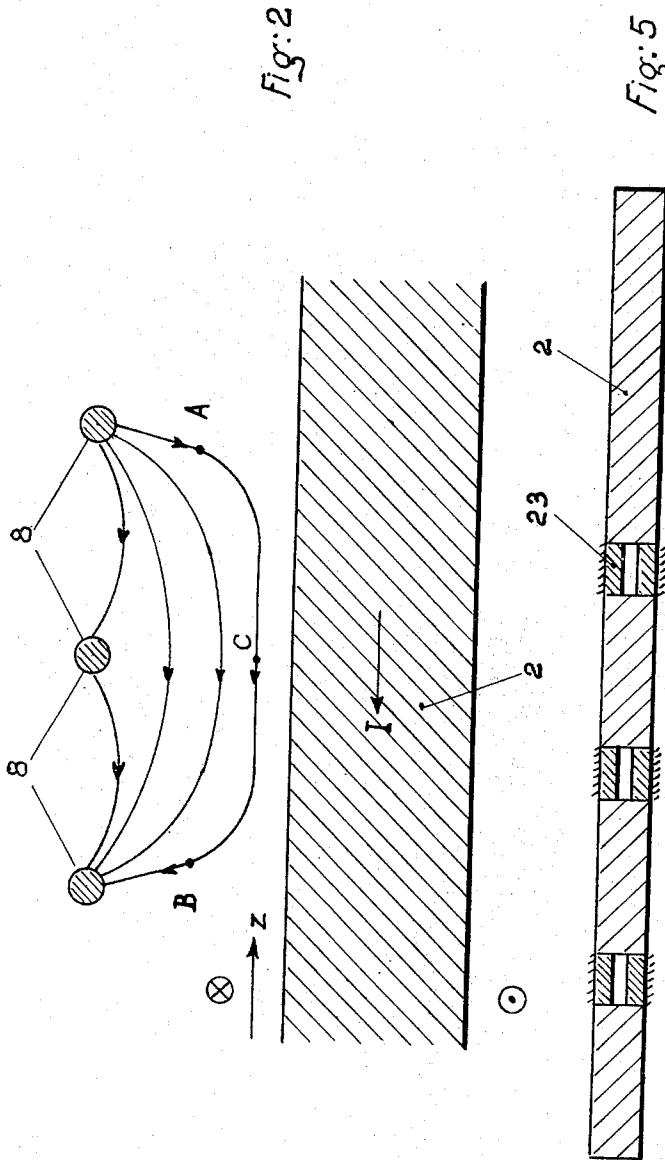


Fig:2

Fig:5

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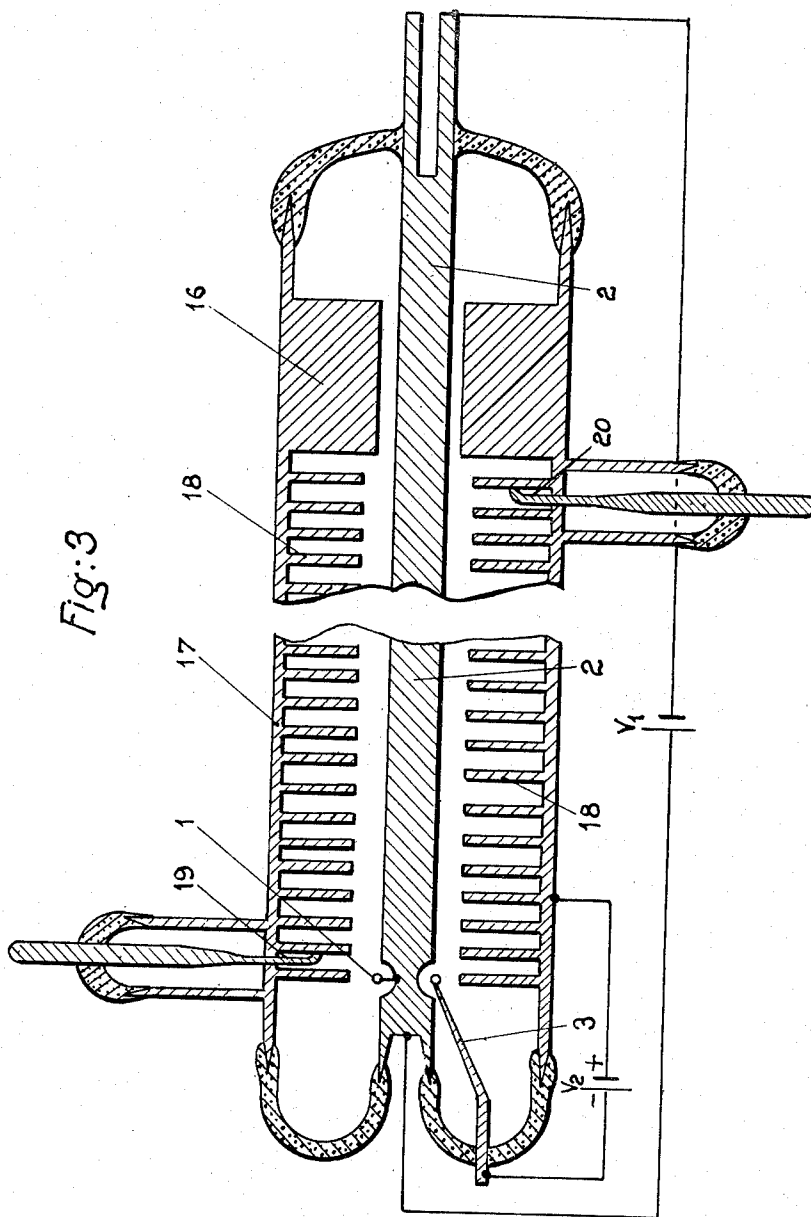


Fig. 3

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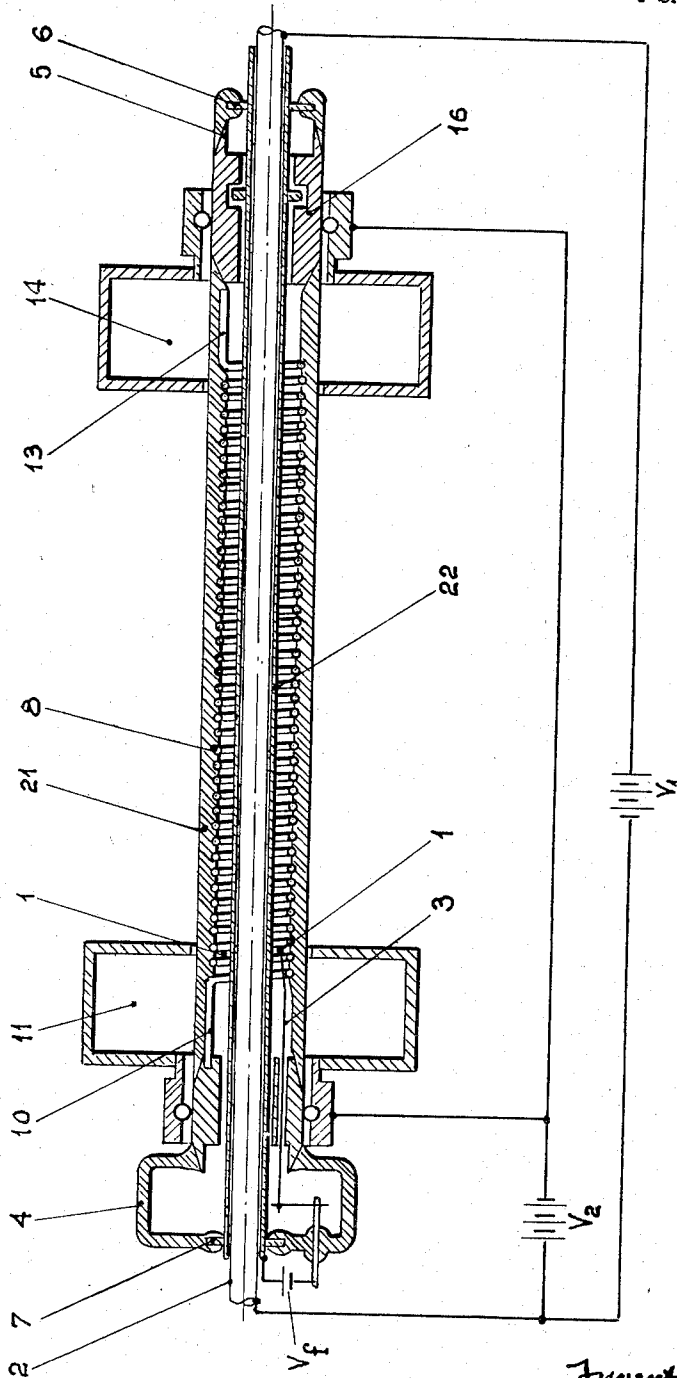


Fig:4

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2,761,088

## TRAVELLING-WAVE AMPLIFYING TUBE

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Claims priority, application France February 22, 1949

10 Claims. (Cl. 315-3.5)

Our invention relates to an electronic tube which is particularly intended for power amplification in the very short wave field, for example decimetric, centimetric or millimetric waves. The electronic mechanism in this tube corresponds to a certain extent with that of travelling-wave tubes with a transverse magnetic field, but as compared to those electronic tubes, the tube according to our invention has certain advantages which are obtained by means of a modification of the principle of operation. As in the tubes hereinbefore mentioned, the operation of the novel tube is based on the interaction between a wave and an electron beam inside a time-constant electric field and a time-constant magnetic field, the two fields being at right angles to the direction of propagation of the wave and of the electron beam. But whereas in the known tubes a homogeneous magnetic field is applied, which is produced by a permanent or an electromagnet located outside the tube, in the novel tube the magnetic field is produced by a strong current flowing through an axial conductor. This produces a magnetic field of cylindrical symmetry, which varies with the distance from the axis. This affects the shape of the electron trajectories and the operation of the tube described hereinafter.

The invention will be more clearly understood by considering Figs. 1, 3 and 4 which show a few non-limitative embodiments thereof in axial section. Fig. 2 is a field distribution diagram, and Fig. 5 shows a modification of construction of the cathode.

The principle of the novel tube is shown in Fig. 1. In this figure, 1 represents the cathode in the shape of a broken ring, one end of which is connected to the axial conductor 2, and the other end to the current lead-in wire 3. The heating voltage for the annular cathode is applied across the lead-in wire 3 and the inner conductor 2 by means of the source  $V_t$ . The cathode is located inside a groove in the axial conductor 2, which is insulated from the other electrodes and is sealed in the glass walls 4 and 5 of the tube at the two ends 6 and 7 thereof; the conductor is of such a cross-section that a current of about 100 amperes or even more can flow along said conductor without heating the same to too high a temperature, i. e. without its temperature exceeding a value of a few hundred degrees Centigrade. The conductor is surrounded by a helix 8 which acts as a retardation line adapted to guide a wave in the direction of the axis at a substantially lower velocity than that of light. The helix is supported by a plurality of insulating rods 9. The wave to be amplified is introduced by means of a dipole 10 connected to one of the ends of the helix. The dipole 10 at the input end is coupled to a waveguide 11 which is located outside the tube and supplies the control power. The piston 12 serves for matching the dipole 10 with the waveguide 11. The collection of the useful power at the output end is effected in the same manner by means of the dipole 13 and the waveguide 14 which is matched by means of the piston 15. Beyond the out-

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put end is located a collector 16 adapted to collect the electrons which have been emitted by the annular cathode 1 and have passed through the electron and wave interaction space between the helix and the axial conductor.

In order to produce a magnetic field, a voltage  $V_1$  is applied between the ends of the axial conductor 2, said voltage causing a current of from a few tens to a few hundreds of amperes to flow through said conductor. The helix 8, which is connected to the collector 16, is raised to a positive potential  $V_2$  of a few hundred volts or a few kv., with respect to the axial conductor 2 and to the cathode 1.

Starting from this illustration of the principle of the construction of the tube according to the invention, the principle of its operation will now be examined.

The application of the voltage  $V_2$  produces a radial electric field  $E_r$  between the axial conductor and the helix. The axial current produces a magnetic field, the magnetic lines of force being circles about the axis, the magnetic induction  $B$  at a point  $P(r, z)$  being independent of the axial co-ordinate and being of the value

$$B = \mu_0 \frac{J}{2\pi r}$$

$r$  being the distance between the point  $P$  and the axis,  $J$  being the axial current,  $\mu_0$  being the permeability of the vacuum. Since the electric force is in the radial direction and the magnetic field is circular, the electrons emitted by the cathode are subjected to a force in the direction  $z$ , and if  $B$  is sufficiently high they do not reach the helix but move in the direction of  $z$  by following the trajectory 27 shown in Fig. 1. This movement takes place in the same plane, i. e. there is no rotation of the electrons about the axis of the tube. The velocity  $v_z$  of the electrons in the direction  $z$  can be readily calculated and the following equation is obtained for a point located a distance  $r$  from the axis:

$$v_z = \frac{e J}{m 2\pi} \mu_0 \log_e \frac{r}{r_0}$$

$r_0$  being the radius of the inner conductor. It can be seen that  $v_z$  is dependent on  $r$ , that is to say that the velocity is not constant along the trajectory. In order to obtain an interaction between the electrons and the wave inside the electric field of said wave, it is necessary for the mean value of  $v_z$  to be equal to the velocity of propagation of the wave with reference to the direction  $z$ . Take a numerical example:  $r_0 = 0.5$  cm., radius of the helix  $r_h = 2$  cm. and  $v_z = 1.5 \times 10^9$  cm./s. that corresponds to a twentieth of the velocity of light for  $r = 1.25$  cm., that is to say to the middle of the space between the inner conductor and the helix. With

$$\frac{e}{m} = 1.76 \times 10^{18} \text{ and } \mu_0 = 1.26 \times 10^{-8} \frac{V_s}{A \text{ cm.}}$$

it is found that the necessary current  $J$  is about 500 amperes. This value is rather high but it is possible to construct the inner conductor of a material of very good conductivity, of copper for example, in such a manner that the power applied to said conductor still remains fairly low, about a few tens of watts for example.

The foregoing considerations only relate to the static behaviour of the tube and are intended to show in particular the existence of a velocity component of the electrons in the direction  $z$  of the axis. The following explanations will make it possible to understand the dynamic behaviour of the tube as an amplifier of a wave guided by a retardation line along the direction of the axis of the tube at a velocity of propagation which is equal to the mean velocity of the electrons in the same direction.

In the space between the inner conductor and the helix, the electric vector of the guided wave has radial and

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longitudinal components. The action of the radial vector (Fig. 2) will first be examined, taking into account the fact that if an electron inside a magnetic field is subjected to the force of an electric field, the electron obtains an acceleration in a direction at right angles to the directions of the electric field and the magnetic field. In Fig. 2, 2 is the inner conductor, 8 the sections of the convolutions of the helix, the lines shown representing the lines of force of the electric field of the wave. An electron which is moving in the direction  $z$  and which is located at the point A in an electric field that retards the movement directed towards the helix, is slowed down if the magnetic field at right angles to the plane of the drawing is directed from the observer towards the paper (the current flowing through the axial conductor is in that case directed from right to left of the figure). An electron which is located at the point B is accelerated. There is therefore a grouping of the electrons adjacent the point C in an electric field which, without a magnetic field, would have retarded the electrons. Now, in a magnetic field, the retardation is replaced by a lateral movement; the electrons retain their velocity but move towards the helix and, after a certain travel, reach the helix with a substantially smaller energy than that which corresponds to the potential of the helix. The difference of energy is converted into electromagnetic energy, in other words, it has been used for the amplification of the wave along the path  $z$  of same and of the electrons. Since the power of the wave is higher at the output end than at the input end, the tube can be used as a power amplifier.

The tube according to Fig. 1 only serves as a non-limitative example for describing the principle of the invention. Figs. 3, 4 and 5 show several modifications of construction of the tube according to the invention.

In Fig. 3, another shape for the retardation line has been shown. The line also has an inner conductor 2 through which flows a current that produces a magnetic field. But instead of a helix, use is made as an outer conductor of a metal cylinder 17 which is provided with numerous annular diaphragms 18, the inner conductor passing through the holes in said diaphragms. It is easily possible to choose the dimensions of the cylinder and of the diaphragms in such a manner that a very substantial retardation of the wave is obtained with respect to the velocity of light. The other reference numerals of Fig. 3 have the same meaning as those of Fig. 1.

The coupling of the input generator and the collecting of the amplified power are effected by means of coupling loops 19, 20 respectively. As compared with the helical-shaped retardation line, this shape of the line has the disadvantage that, with the dimensions given, the tube can only be used in a restricted range of frequencies; on the other hand, it has the advantage that the dissipated power and the useful power which it can supply are substantially higher than in the case of the helix.

In Fig. 4, a modification is shown which is characterized by the fact that the conductor that produces the magnetic field is located outside the vacuum chamber of the tube. As in the construction of Fig. 1, the retardation of the wave is obtained by means of a helix 8 which is supported by the wall of a glass tube 21 and which, by way of example, may be partly embedded in the inner wall of said tube. Instead of being provided with a solid axial conductor, a hollow tube 22 passes axially through the container, the walls of said tube being vacuum-tight so that the inside thereof is outside the vacuum. This tube 22 may be constructed, as shown in the figure, of conducting material and in this case the heating source  $V_r$  is connected between said tube 22 and the cathode lead-in wire 3. But the tube 22 may also be made of insulating material, and in this case it is necessary to provide a second cathode lead-in wire and to connect the heating source across the two lead-in wires. The solid conductor 2 is inserted into said tube 22, and through said conductor 2 is made to flow the current which pro-

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duces the magnetic field necessary for the operation of the tube. It is obvious that this construction, as compared with the constructions of Figs. 1 and 3, has the advantage of avoiding the necessity of providing glass-to-metal seals through which a current of fairly high value has to pass, since such seals, in the technique of electronic tubes, always involve certain difficulties. The other reference numerals have the same meaning as in the other figures.

In Figs. 1 and 3, the cathode is located adjacent the axial conductor which is placed inside the vacuum chamber. In Fig. 5, a modification is shown in which the emitting surface of the cathode directly forms a portion of the inner conductor. Only this conductor 2 is shown, it being understood that the construction applies to Figs. 1 and 3 without making any other modification in same. The portions of this conductor where the surface is not covered with an emitting layer are made of a metal of good conductivity, normally copper. At the places where it is desired to have an emitting surface on the cylindrical axial conductor, the resistance of the conductor is increased. This is effected by replacing the good conducting metal by another metal, nickel for example, and by making the conductor hollow. In Fig. 5 this method has been shown diagrammatically; at the locations 23 a portion of the conductor 2 has been replaced by a nickel annulus, the outer surface of which is covered with a layer of barium oxide in order to obtain a heavy electron current. Contrary to the previously described embodiments, the single cathode has been replaced by a plurality of cathodes spaced along the axis of the tube, this modification having been found to favor the operation of the tube.

The construction according to Fig. 5 has the advantage that it is possible to use the current required for obtaining the magnetic field also as the heating current for the cathodes. On the other hand, its disadvantage consists in the fact that it is only possible to vary the magnetic field very slightly by varying the axial current, owing to the variation of the temperature of the cathode which is only permissible within narrow limits.

The invention is not restricted to the examples shown in Figs. 1, 3, 4 and 5 which are only intended to show the principle. It is possible for example to alter the manner of coupling the generator and the load to the retardation line by using couplings of any nature, either inductive, capacitative or mixed, as is at present well known in high-frequency technique. The annular cathode may be replaced by a cathode of any other shape. The invention generally consists in a tube in which an electron beam moves inside a transverse electric field and a magnetic field of cylindrical symmetry, said magnetic field being produced by a current flowing through an axial conductor.

What we claim is:

1. An electron discharge tube comprising a vacuum-tight envelope, an electron-emissive source, means for concentrating the electrons emitted by the source into a beam, a delay line of hollow cylindrical structure having input and output extremities and defining an electron and wave interaction space, means for causing the beam to pass axially through the interaction space, wave input means coupled to the input extremity of the delay line, the delay characteristic of the line determining the phase propagation velocity of the wave in the line, terminal connections for applying a potential to the delay line thereby to produce a transverse time-constant electric field in the interaction space, and means for producing in the interaction space a time-constant magnetic field of cylindrical symmetry with circular lines of force about the axis of the delay line, the strength of the magnetic field being predetermined thereby substantially to obtain equality between the average axial velocity of the beam in the interaction space and the wave phase propagation velocity.

2. Tube according to claim 1, wherein said means for producing a time-constant magnetic field comprises a

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straight conductor extending along the axis of the delay line, and means for passing a direct current through the conductor thereby to produce the magnetic field of cylindrical symmetry.

3. Tube according to claim 2, wherein the straight conductor is located inside the envelope and extends through insulating elements at the ends thereof, the conductor having extremities extending outside of the envelope, and terminals for connecting a direct current source between said extremities.

4. Tube according to claim 3, wherein the electron-emissive source comprises at least one cathode located on the straight conductor near the input extremity of the delay line.

5. Tube according to claim 4, wherein means are provided in the straight conductor structure for increasing the resistance thereof at spaced points.

6. Tube according to claim 5, wherein said means in the straight conductor structure comprise cylinders of a material of higher resistance than the remainder of the conductor and located in the body thereof at said spaced points.

7. Tube according to claim 5, wherein said means in the straight conductor structure comprise cylinders whose cross-sectional area is decreased by providing an axial passage therein and which are located in the body of the straight conductor at said spaced points.

8. Tube according to claim 2, wherein the envelope includes a hollow tube extending along the inside of the cylinder of the delay line, the straight conductor extending through the tube and being located outside the envelope.

9. Tube according to claim 2, wherein the electron-emissive source comprises an annulus connected to the straight axial conductor.

10. An electron discharge tube comprising a vacuum-

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tight enclosure, an electron-emissive source, means for concentrating the electrons emitted by the source into a hollow annular beam, a delay line of hollow cylindrical structure having input and output extremities and defining an electron and wave interaction space, means for causing the beam to pass through the interaction space, wave input means coupled to the input extremity of the delay line, the delay characteristic of the line determining the phase propagation velocity of the wave in the line, terminal connections for applying a potential to the delay line thereby to produce a transverse time-constant electric field in the interaction space, a straight conductor extending along the axis of the delay line inside the annular space occupied by the beam, and means for passing a direct current through the conductor thereby to produce about the axis of the delay line a time-constant magnetic field with circular lines of force of desired intensity to predetermine substantial equality between the average axial velocity of the beam and the wave phase propagation velocity.

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