Aug. 31, 1954 R. WARNECKE ET AL 2,687,777

THERMIONIC TUBES FOR ULTRASHORT WAVES

Filed July 2, 1949 5 Sheets-Sheet 1

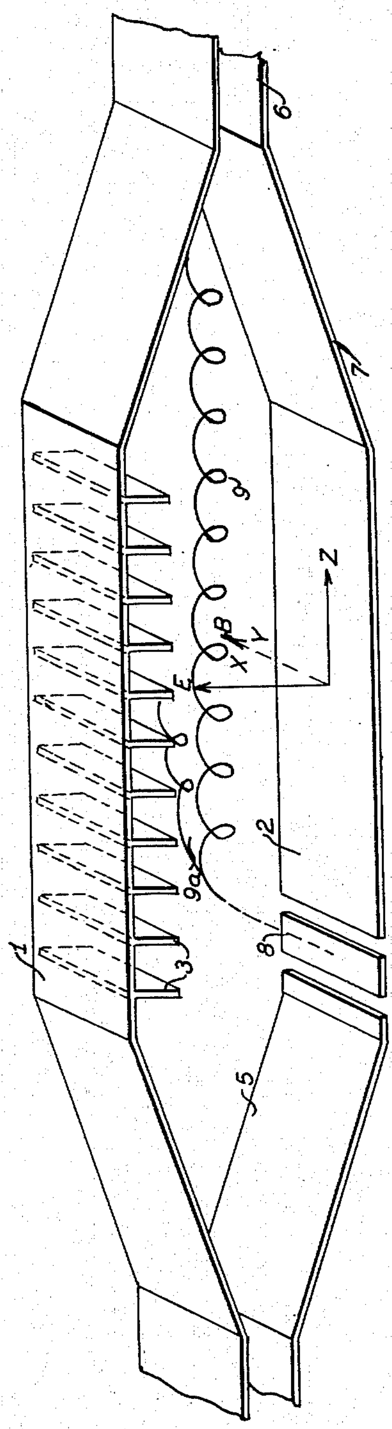

Fig-1

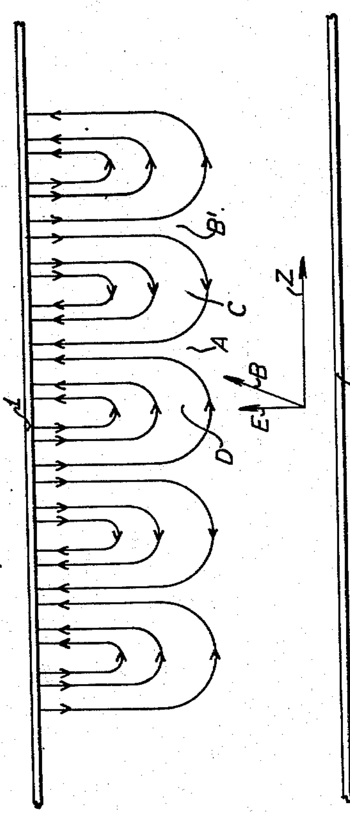

Fig-2

Aug. 31, 1954 R. WARNECKE ET AL 2,687,777

THERMIONIC TUBES FOR ULTRASHORT WAVES

Filed July 2, 1949 5 Sheets-Sheet 2

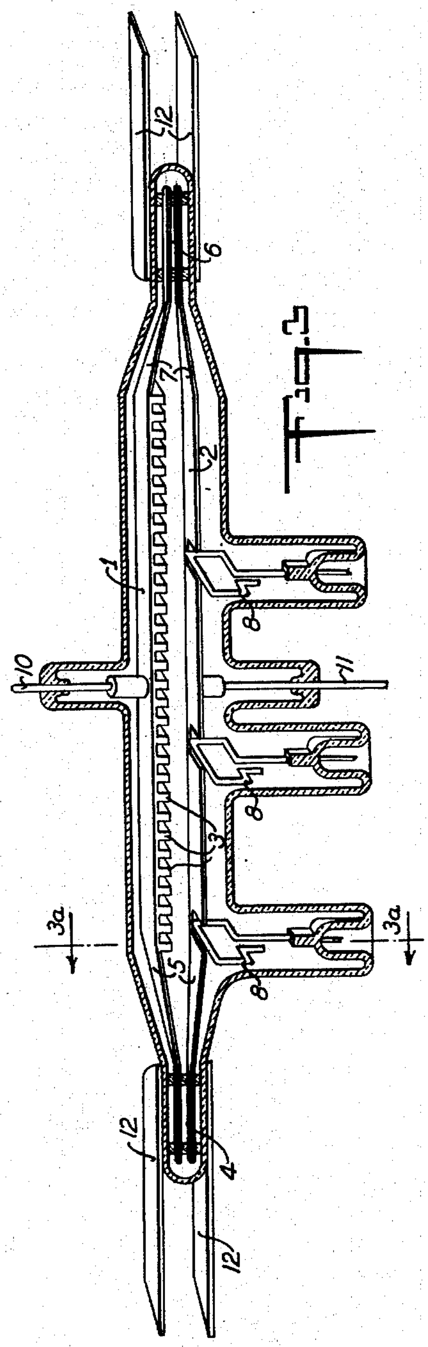

Fig. 3

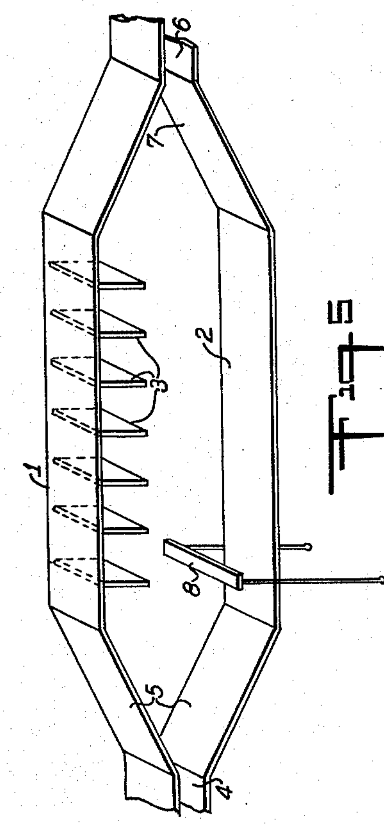

Fig. 5

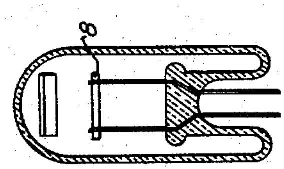

Fig. 3A

THERMIONIC TUBES FOR ULTRASHORT WAVES

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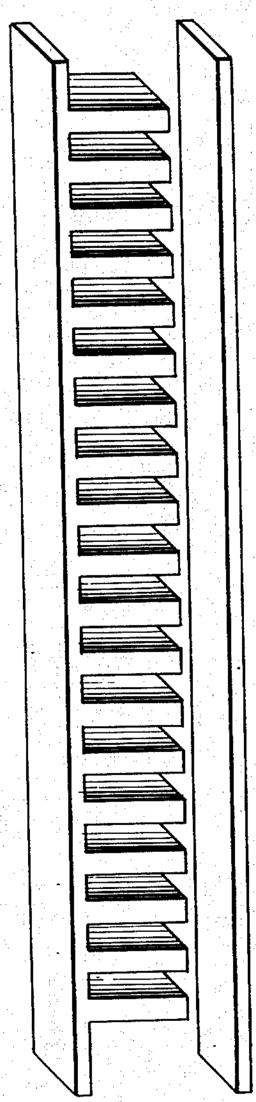

Fig. 4a

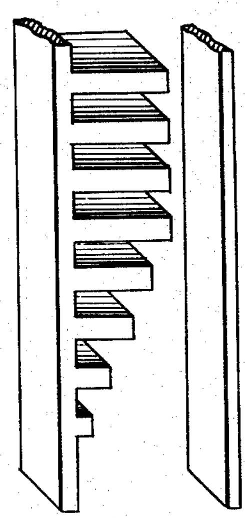

Fig. 4b

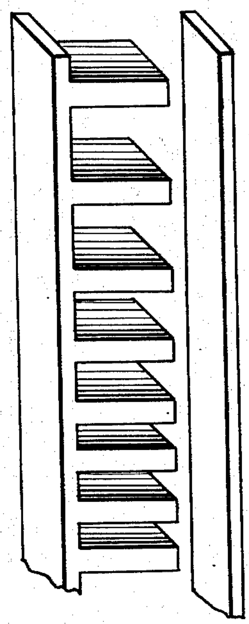

Fig. 4c

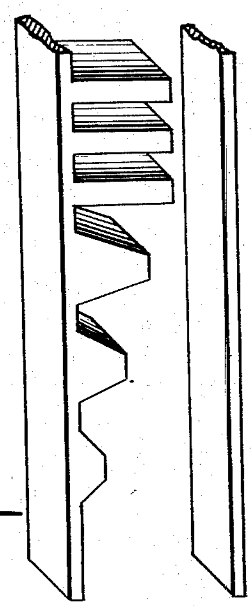

Fig. 4d

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THERMIONIC TUBES FOR ULTRASHORT WAVES

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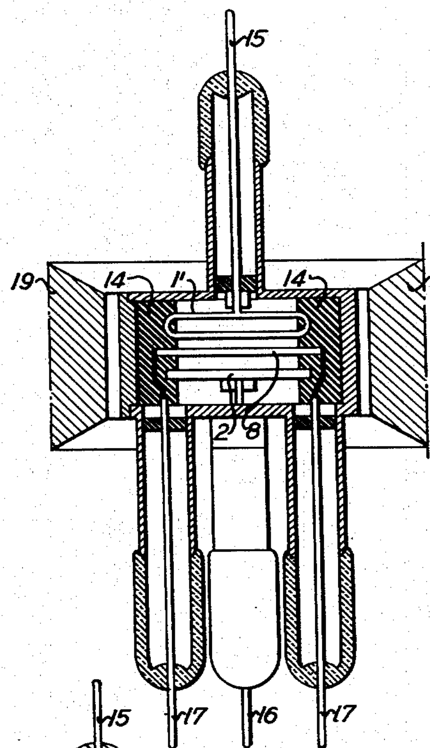

Fig. 6

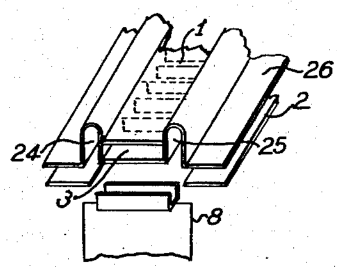

Fig. 11

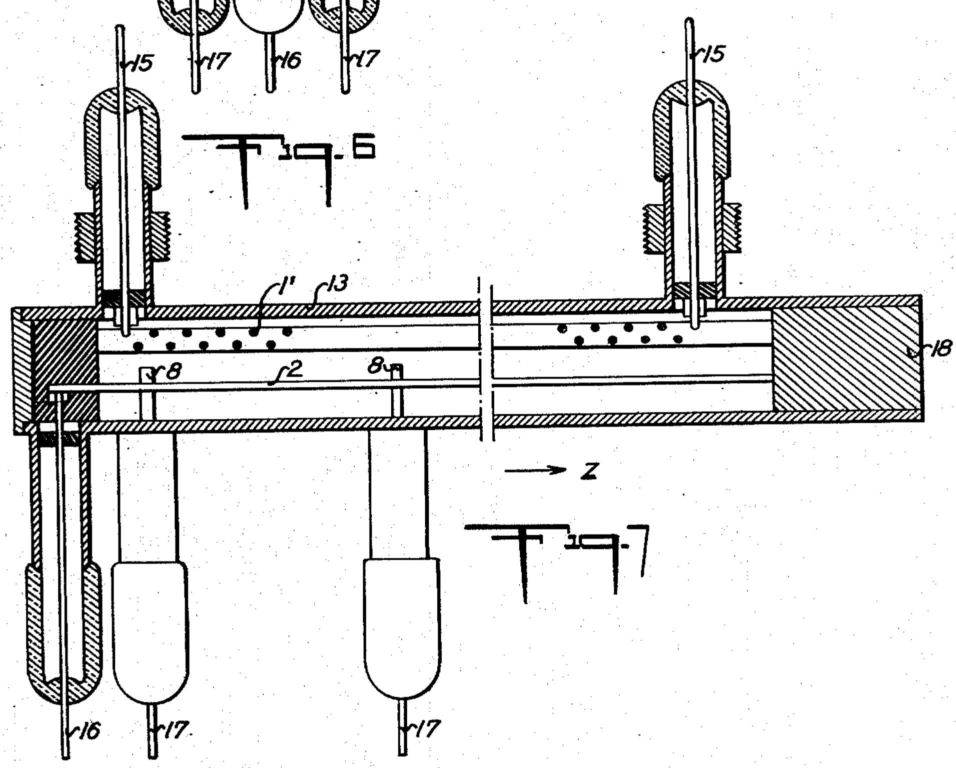

Fig. 7

THERMIONIC TUBES FOR ULTRASHORT WAVES

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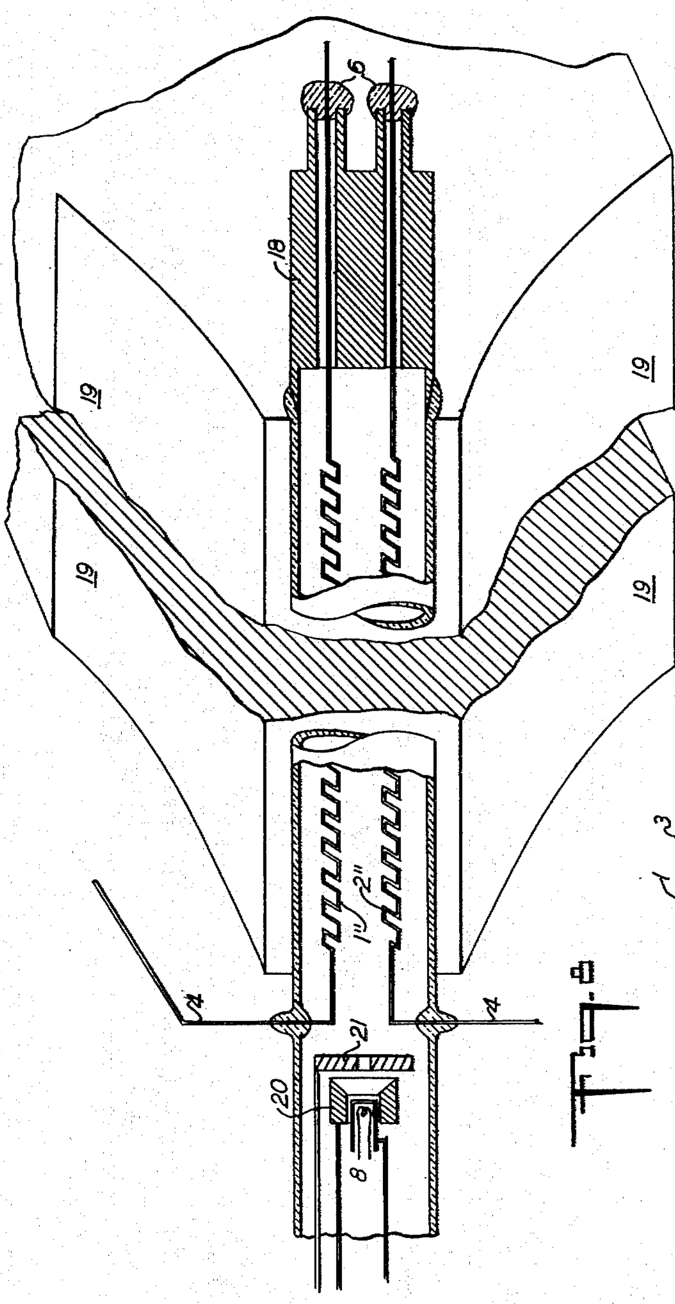

Fig. 8

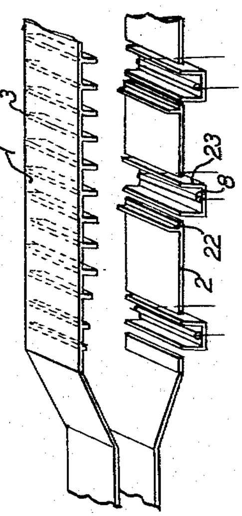

Fig. 9

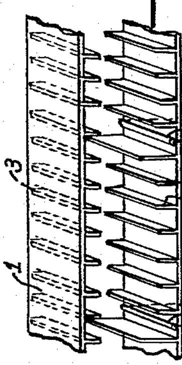

Fig. 10

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UNITED STATES PATENT OFFICE

2,687,777

THERMIONIC TUBE FOR ULTRASHORT WAVES

Robert Warnecke, Jean Bernier, Pierre Guénard, and Werner Kleen, Paris, France, assignors to Compagnie Generale de Telegraphie Sans Fil, a corporation of France

Application July 2, 1949, Serial No. 102,896

Claims priority, application France July 20, 1948

8 Claims. (Cl. 315—3)

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Our invention relates to a thermionic tube intended for the amplification of electromagnetic waves, in particular of very high frequency electromagnetic waves. The amplification is obtained by interaction between an electron beam and a traveling wave guided by a retardation line. This interaction between the electromagnetic wave and the electron beam takes place inside a time-constant transverse electric field having its lines of force at right angles to the direction of propagation of the beam and of the wave, and a time-constant magnetic field also having its lines of force at right angles to the direction of the beam and also to those of said time-constant electric field. The existence both of the electric field and the magnetic field, both fields being substantially time-constant, is the essential feature of the tube according to the invention as compared to the normal travelling-wave tube which, for example, is described in the publications of J. R. Pierce, Proc. Inst. Radio Eng., February 1947, or of J. Bernier, Annales de Radioéléctricité, January 1947. But these differences are the basis of a number of particular advantages of the tube according to the invention, inter alia a much higher efficiency and an essentially greater useful power, which are the most important.

The principle of the invention is connected with the application of Dohler, Kleen and Huber, Serial No. 794,164, filed December 27, 1947, and now Patent No. 2,511,407, but with respect to that patent the features of the present invention which are set forth hereinafter have been found in practice to have a number of advantages.

The above mentioned patent describes a tube comprising a delay line between the preferably concentric conductors of which there exists a time-constant electric field. An electron beam is adapted to move inside said line in the direction of the periphery, this movement of the electrons being produced by a time-constant magnetic field having its lines of force in the direction of the axis of the system. A signal applied to the input of the tube produces a travelling wave which is propagated along the line and, owing to the interaction between said line and the electron beam, an amplified signal can be collected at the output end. But as experience has shown, this shape of tube creates a difficulty for decoupling the output and the input ends owing to the mutual proximity of the output and input elements. Consequently, there is danger of reaction occurring which causes self-oscillation of the tube and which, as is obvious, makes it difficult to use the tube as an amplifier. This effect, which

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is difficult to avoid in a cylindrical tube having concentric conductors, is eliminated in the various shapes of tubes described hereinafter.

According to an essential feature of our invention, interaction between the input and the output ends of the tube of the type described is eliminated by the linear shape which is given to the delay line.

According to another feature of the invention, the delay is produced by means of fins provided either on one of the conductors of the line or, according to a further feature, on both conductors.

According to a still further feature, a plurality of electron beams are made to interact successively with the same delay line, one of said beams beginning to act when the amplification of the wave produced by the previous beam ceases to increase sufficiently.

Matching means are provided for preventing the amplified wave from being reflected at each discontinuity of the circuit caused by the means for introducing the various beams.

Other features will become apparent on reading the explanation which is given hereinafter and which describes a number of non-limitative embodiments of tubes according to the invention which are illustrated in the accompanying drawings.

In said drawings:

Fig. 1 is a diagrammatic perspective view illustrating the operating principle of the invention;

Fig. 2 is an explanatory diagram illustrating the forces at work in the tubes according to the invention;

Fig. 3 shows a longitudinal section of a tube in a glass container and wherein, as a modification, a plurality of cathodes are provided instead of one cathode, Fig. 3*a* being a cross-section on line 3*a*—3*a*;

Figs. 4*a* to 4*d* show diagrammatically the shape which may be given to one of the conductors of the delay line of the tube, those illustrated in Figs. 4*b* to 4*d* being intended to provide a matching of the delay line at the input and output ends of the tube;

Fig. 5 shows the principle of a tube in which the cathode is not located in the plane of one of the conductors of the delay line but in the space between the two conductors, a construction which has a number of advantages which are described hereinafter;

Figs. 6 and 7 show a tube, respectively in transverse section and in longitudinal section, in which the delay line does not contain a conductor provided with fins, but wherein the wave is delayed by means of a wire bent into a sinuous shape which constrains the wave to follow a roundabout path and therefore decreases the axial component of the velocity of the wave;

Fig. 8 shows diagrammatically a tube in which the cathode is not located inside the delay line and the electron beam is injected from outside into the amplifying system;

Fig. 9 shows a modification of the tube shown in Fig. 3, which illustrates in particular the construction of reflection correctors;

Fig. 10 shows an embodiment in which the delay line comprises two symmetrical portions; and

Fig. 11 shows an embodiment of a delay line with an adjustable phase velocity of the guided wave.

The principle of a tube according to the invention is shown in Fig. 1. In said figure, there are shown the conductors **1** and **2** of a line which enables a wave to be delayed and in which the electric vector of the guided wave has both a longitudinal component in the direction Z and a transverse component in the direction X. The line is linear and in the interaction duct between its two conductors there is a substantially time-constant transverse electric field E produced by applying different potentials to the conductors **1** and **2**, the potential of conductor **1** being positive with respect to that of conductor **2**. An induced magnetic field B is applied to the tube with its lines of force in the direction y, i. e. at right angles to the lines of force of the electric field E and to the direction Z of the propagation of the electron beam. Inside the line, the wave may be delayed by various means; in Fig. 1, for example, it is delayed by means of a number of fins **3**; other means will be mentioned hereinafter. The signal is applied to the input **4** of the tube. The matching is obtained by means of members which, by way of example, are shown in Fig. 1 in the shape of a widening **5** of the portion of the two conductors between the line at the input and the line inside the tube. Other matching means will be referred to hereinafter. At the output **6** of the tube, the matching is obtained by means of a narrowing **7** of the portion of the conductors between the line in the tube and the line at the output. The cathode **8** is located near the conductor **1** or in a slot provided therein, the electron stream leaving the cathode owing to the presence of the D. C. electric field. If suitable values are chosen for E and B, electron paths are obtained which, when there is no wave to be amplified, are of the shape **9** shown diagrammatically in Fig. 1.

Stress must be laid on the fact that not only does the application of a magnetic field to a progressive or travelling-wave tube act to curve the trajectories into circles, but that said magnetic field is of very great importance for the operation of the tube, even of a linear tube corresponding to Fig. 1. The presence of this magnetic field produces a very high efficiency in such a tube. This fact may be explained in the following manner by examining the mechanism of the interaction between the longitudinal and transverse electric vectors of a wave guided by the delay line and the electron beam, in particular the influence of said wave on the trajectories and velocities of the electrons.

In Fig. 2, are shown the lines of electric force, or more exactly the portion of these lines of force that extends beyond the fins of a wave propagated along the delay line in the direction Z. It will be assumed that the average velocity of the electrons in the same direction, and which is given by:

$$V_0=\frac{E}{B} \qquad (1)$$

is equal to the velocity of propagation of the wave. Consider an electron which is located at the point A, i. e. in an accelerating field towards the anode. This corresponds to a greater (static + U. H. F.) total electric field E; consequently according to Equation 1 a higher velocity is obtained and the electron moves (together with the wave) towards the point C where there is a delaying field. An electron located at the point B′ is in a total transverse electric field which is smaller than the mean value. According to Equation 1, V_0 becomes smaller, the electron is delayed and also moves towards the point C in the delaying field. The magnetic field, the effect of which is combined with that of the transverse electric component of the wave, therefore produces a focusing of the electrons in a delaying field, which is necessary for the transfer of energy from the electron beam. Thus, as hereinbefore mentioned, the magnetic field is of great importance for the mechanism of the tube, since it enables the electrons to be focused and grouped in a field of favorable phase for the amplication.

But the presence of the magnetic field produces yet another important effect. The electrons which are focused at the point C are subjected to two forces: that of the electric field eE directed towards the conductor **1** and that of the magnetic field (Lorentz force) evB directed towards the conductor **2**, v being the velocity of the electron in the direction Z. If, owing to the braking action exerted by the delaying field, v is decreased, the force evB decreases and the electron moves closer to the anode along the path **9***a* in Fig. 1, whereas an electron located at the point D in an accelerating field moves towards the cathode. Consequently, the electrons which enter an accelerating field which is unfavorable for the transfer of energy to the wave are moved away from the conductor **1** (anode) and enter a weaker field adjacent the collector **2**. The electrons of unfavorable phase have no important effect on the mechanism of the transfer of energy and are even absorbed by the conductor **2**. The electrons of favorable phase move towards the anode and transfer energy to the wave and are absorbed by the anode when they have only a very small amount of energy, the greater part of the energy being converted into electromagnetic energy of the wave.

The magnetic field combined with the transverse electric field of the wave therefore causes the electrons of unfavorable phase to move away from the A. C. field, whereas the electrons of favorable phase reach the anode at a very low velocity despite the high positive potential of said anode. It is obvious that such a fact means a high efficiency of the tube.

This explanation of the mechanism of the tube according to the invention is only qualitative and rather rough. It neglects a number of additional effects, for example the effect of the centrifugal force of the electrons. But this effect as well as others, does not very greatly alter the electronic mechanism of the tube, particularly if the dimensions of the tube are adapted to the necessary requirements for preventing harmful effects.

Figs. 1 and 2 together with the foregoing description of the electronic behaviour serve as an explanation of the principle of the invention. Hereinafter, practical embodiments of tubes will be described, together with advantageous details for their operation.

In Fig. 3, the system of the tube is located inside a glass container. The conductors 1 and 2 of the delay line are again those between which the transverse electric field is applied. Conductor 1 is raised to a positive potential with respect to that of conductor 2, the voltages being applied to the leads-in 10 and 11. The conductor 1 is provided with a number of fins 3 that produce the delay of the wave. At both its ends, the delay line has constricted portions 5 and 7 for the purpose of matching the generator and the load. The tube contains one or more cathodes 8, the provision of a plurality of cathodes having the advantage of increasing the useful power. The cathodes may advantageously be spaced apart at decreasing distances from the input to the output since the high frequency field increases in an approximately exponential manner, and the electrons therefore reach the anode quicker and quicker. It is also possible to replace the discontinuous system of cathodes by a single cathode extending along the delay line. Fig. 3*a* shows a section through the plane 3*a*—3*a* of one of the cathodes 8 and of its leading-in wires which, by way of example, are embedded in a flat pinch. The cathodes may be raised to the potential of the conductor 2, or the potential of said conductor may even be negative with respect to the cathode which, as shown by tests, may have an advantage which will be discussed hereinafter. The coupling of the tube both to the generator and to the load is obtained by means of the capacitances between the ends 4 and 6 of the inner line and the conductors 12 of two Lecher lines. The invention is obviously not restricted to such a form of coupling, it would also be possible to make the inner line pass across the container and thereby obtain any desired couplings both at the input and at the output of the tube.

For the behaviour of the tube as an amplifier, the problem of matching both at the input and at the output plays an important part. A suitable matching is not only necessary for transferring all the useful power produced in the tube to the utilization load, but it must exist so as to prevent self-oscillation of the tube. A bad matching produces standing waves inside the tube and consequently oscillation. The constrictions at the ends of the delay line already provide an improvement in the matching. But it is preferable to vary the contours and the heights of the fins at the end of the line.

Figs. 4*a* to 4*d* show diagrammatically such constructions of the delay line by means of which an essential improvement in the matching is obtained. Fig. 4*a* repeats the regular arrangement of fins 3 of Fig. 3, Figs. 4*b*, 4*c*, 4*d* enable a better understanding of the novel arrangement according to the invention, in particular the variable height in Fig. 4*b*, the variable distance in Fig. 4*c* and the variable contour in Fig. 4*d*. The invention is not restricted to the shapes illustrated and as a general provision, the height, the distance and the contours of the fins may be varied at both ends of the delay line in order to provide a better matching.

In Figs. 1 and 2, the cathode or cathodes are placed in the plane of one of the conductors of the delay line. The principle of a modification is shown in Fig. 5. In this figure, the cathode 8 is located inside the space between the conductors of the delay line. It may, for example, be of the shape of a flat strip. This construction has the following advantage:

Both tests and theory have shown that it is is advantageous to raise the electrode 2 in Figs. 1, 3, 4 and 5 to a negative potential with respect to that of the cathode. This is comprehensible owing to the fact that by means of such a negative potential, the paths of the electrons are brought closer to the anode, i. e. into a region in which the A. C. electric field of the wave is stronger. This produces a more intense interaction between the electron beam and the wave that results in an increase in the gain. If, in the constructions of Fig. 1 or Fig. 3 for example, the potential of the electrode 2 is rendered negative, this negative voltage has a very great effect on the electron stream leaving the cathodes. The electrode 2 acts as a control electrode on said stream which is decreased or even eliminated by a negative voltage on said electrode. This unfavorable effect is much smaller if the cathode 8 is located inside the two conductors of the delay line and a variation of the voltage of the conductor only has a slight effect on the cathode stream. This principle is not restricted to a single cathode: if the tube is provided with a plurality of cathodes, they may all be located inside the delay line.

Fig. 6 shows a transverse section and Fig. 7 a longitudinal section of a tube in which this principle is embodied. In these figures, 1′ and 2 are the conductors of the delay line. Contrary to the shapes given to this line in the previous figures, the delay is not obtained by means of a conductor 1 provided with multiple fins, but by means of a helically wound conducting wire 1′ as shown in Fig. 6. The wave is propagated along the helical wire 1′ at substantially the velocity of light and it has transverse and longitudinal electric vectors which are propagated in the direction Z with a velocity component which is essentially lower than that of light. The whole system is enclosed in a metal case 13 which, for example, is made of copper and is vacuum-tight. The helix 1′ is fixed by means of two ceramic members 14, preferably of aluminum or beryllium oxide owing to the high temperature of the helix. At its two ends the helix is connected to two leading-in wires 15 which, as the inner conductors of small coaxial lines, serve for coupling the generator and the load respectively. The conductor 2 is also fixed in the ceramic members and is connected to a leading-in wire 16 which enables the D. C. voltage to be applied which, as stated, should preferably be negative with respect to that of the cathodes 8. 17 are the leading-in wires of the cathodes. This construction is in particular suitable for an amplifier of very high useful power. After the electrons have passed through the delay line, they are collected by a collector 18 formed of a block of copper which, if necessary, may be cooled with water or compressed air. 19 are the pole-pieces of a permanent magnet or of an electro-magnet that serves for producing the magnetic field inside the tube.

It is also possible to inject the electron beam from outside into the system in which the interaction between the wave and said beam takes place. Such a construction is shown diagrammatically in Fig. 8. In this tube, the electron beam is produced by means of an electron gun which comprises the cathode 8, a focusing (Wehnelt) electrode or buncher 20 and an anode 21. The tube again shows the modification in which the delay line has two conductors 1'' and 2'' provided with elements that act to delay the wave. The conductors 1'' and 2'' consist of two wires bent into a sinuous shape. Owing to this shape of the conductors, the line has the necessary longitudinal inductance for delaying the wave and the guided wave has longitudinal and transverse electric vectors. 19 is one pole of a permanent magnet or an electro-magnet, the other pole being located outside the plane of the drawing. At the end of the tube is located the catcher 18 for collecting the electrons of the electron beam after it has passed through the delay line. Between the conductors 1'' and 2'' a D. C. voltage is applied either across the input terminals 4 or across the output terminals 6. The signal is applied at 4, the amplified power is transferred at 6, i. e. between the ends of the conductors 1'', 2'' which pass through passages in the collector 18. The principle of injecting the electron beam from outside into the delay line is not restricted to the construction of the tube according to Fig. 8. It is also possible to use delay lines of the shapes shown in the other figures, or one in which a single conductor contains elements that serve for decreasing the speed of propagation of the wave.

In order to improve the matching at the ends of the conductors, it is proposed to vary the pitch of the wires near the input and the output of the tube in such a manner that the speed of propagation of the wave is increased outwards.

The successive introduction of a plurality of beams by means of a plurality of cathodes (see Fig. 6) forms obstacles on which the slowly propagated electromagnetic wave may be partly reflected and thereby cause a faulty operation of the tube. It is recommended, according to another object of the invention, as shown diagrammatically in Fig. 9, to arrange along the delay line 1, 2, obstacles which are preferably formed by flat fins 22, the sizes and position of which are suitable for correcting the reflections produced by the beams and the other obstacles formed by the assemblies comprising the cathode 8 and the focusing electrode 23 which may be used if desired.

Hereinbefore, only those circuits have been considered that had a single series of transverse fins in the upper part thereof, but it is also possible to contemplate tubes as shown in Fig. 5, the delay line of which comprises two portions 1 and 2, each of which is provided with elements 3 adapted to delay the electromagnetic wave and which are arranged in a substantially symmetrical manner. In Fig. 10, in which these elements are flat fins, some of said fins have been shown of different sizes from the others so as to enable the wave reflections that might be produced by the cathodes (8*a*), (8*b*) to be compensated. Said cathodes have been shown in the shape of a cylinder of small diameter and the fins on either side of each of said cathodes form a focusing electrode.

It is often convenient to be able to adjust the phase velocity of the electromagnetic wave to the mean velocity of the electrons without thereby altering the trajectory of said electrons. For this purpose, it is possible to act by mechanical deformation on the shape of the reduced phase-velocity wave-guide by means of a device such as that shown diagrammatically in Fig. 11. The upper part 1 of the delay line is formed by a metal sheet which is so bent that the medial portion thereof supports the transverse fins 3, while the spaces between these various fins 3 are coupled to one another by the capacitors 24 and 25 formed by the ends of the fins and a fold of the metal sheet. By varying the thickness of this capacitative portion by compression, the phase velocity of the wave can be varied. Another fold 26 of said metal sheet forms with the lower part 2 of the delay line, a capacitor which acts as a short-circuit for the high-frequency field but which enables conductors 1 and 2 to be raised to different electrostatic potentials.

What we claim is:

1. An electronic amplifier comprising means for establishing a substantially time-constant magnetic field, a delay line including two spaced parallel conductors of linear shape having their surfaces parallel to the lines of force of the magnetic field and defining therebetween an electron and wave interaction duct located within said field and extending in a plane substantially perpendicular to the lines of force thereof, a plurality of distinct emissive cathodes spaced apart from each other along a conductor of the delay line and having their surfaces substantially parallel to the lines of force of the magnetic field and position to emit a flow of electrons into said duct and within said field, fins on said conductor adjacent said cathodes and extending into said duct to prevent wave reflections in said line due to the presence of said cathodes, terminal connections for applying a potential to said conductors giving rise to a substantially time-constant electrical field therebetween in a direction substantially perpendicular to the lines of force of said magnetic field and to the plane of said duct, at least one of said conductors including delaying elements having the characteristics of longitudinal inductances inserted in a Lecher line and being so dimensioned that the phase velocity of wave propagation along said delay line is less than in space and substantially equal to the velocity of electron flow in said duct, said velocity of electron flow being determined by the ratio of the intensities of the electrical and magnetic fields, and said conductors having radio-frequency input and output extremities separated from each other.

2. An amplifier according to claim 1 wherein said cathodes are of flat strip form.

3. An amplifier according to claim 1 wherein the distance between said conductors varies at the portions thereof adjacent said extremities to provide correct matching of said input extremity to a wave source and of said output extermity to a load.

4. An amplifier according to claim 1 wherein said elements comprise fins arranged as baffles, at least one of the height, distance and contour of said fins varying at the portions of said line adjacent said extremities to provide correct matching of said input extremity to a wave source and of said output extremity to a load.

5. An amplifier according to claim 1 wherein at least one of said emissive cathodes is located in the space between said conductors, said one cathode being adapted to be at an intermediate potential between the potentials of said two conductors.

6. An amplifier according to claim 1 wherein at least one of said conductors comprises fins arranged as baffles and a metal sheet having a central strip supporting said fins and a fold along each longitudinal edge, means being provided for varying the shape of said folds to vary the phase velocity of wave propagation in said line.

7. An amplifier according to claim 1 wherein the spaces between said cathodes decrease substantially exponentially in the direction of electron flow.

8. An amplifier according to claim 1 wherein said delay line has a single continuous conducting structure defining an uninterrupted wave path between two extremities thereof, said cathodes being positioned between said extremities.

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