Aug. 18, 1959

D. A. WATKINS

2,900,558

BEAM-TYPE TUBE

Filed July 18, 1957

2 Sheets-Sheet 1

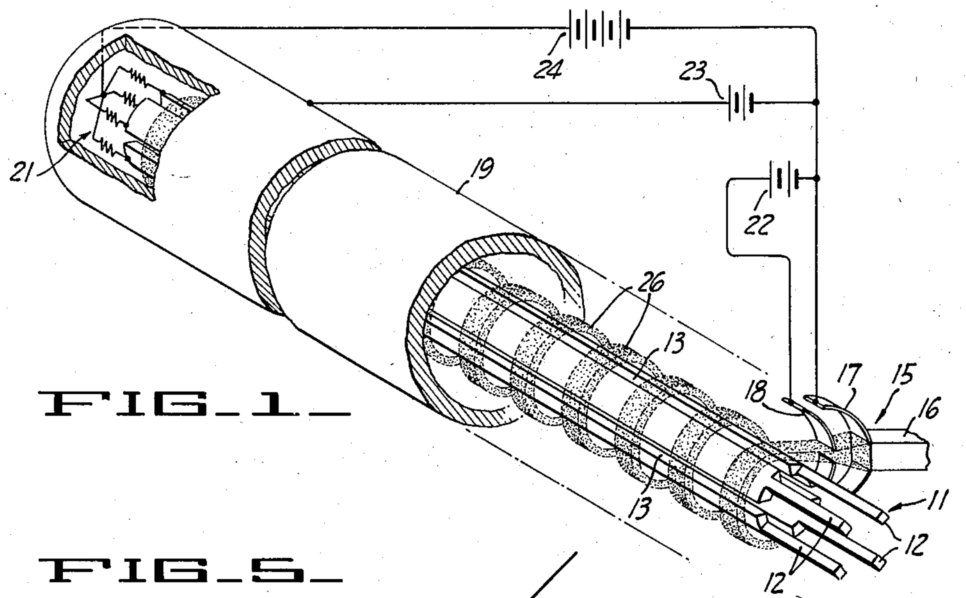
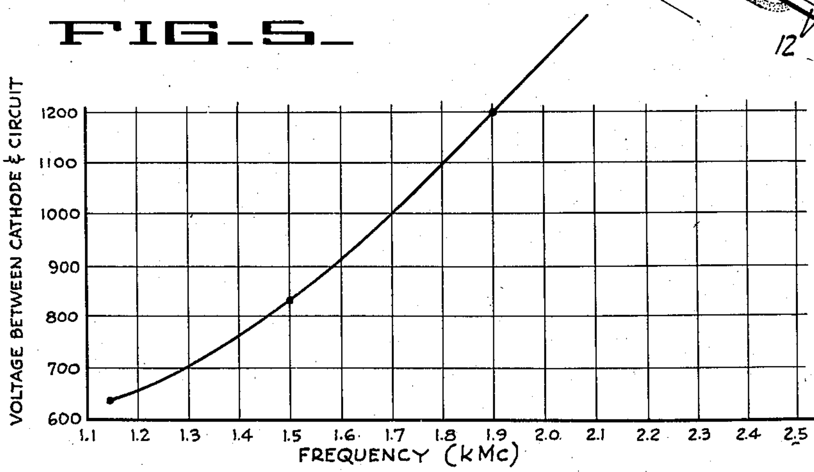


FIG_1_

FIG_5_



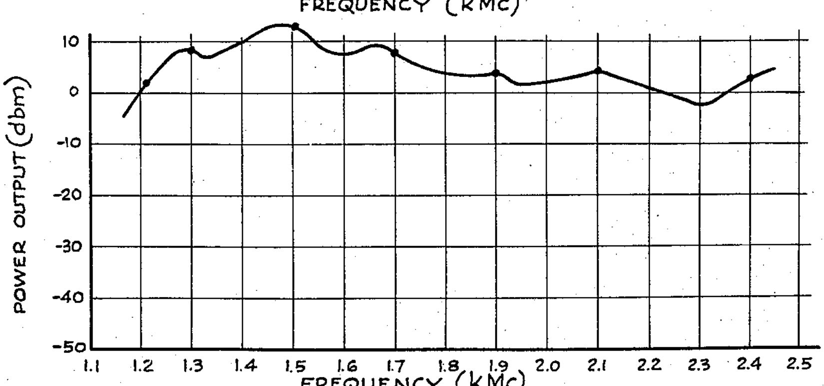


FIG_6_

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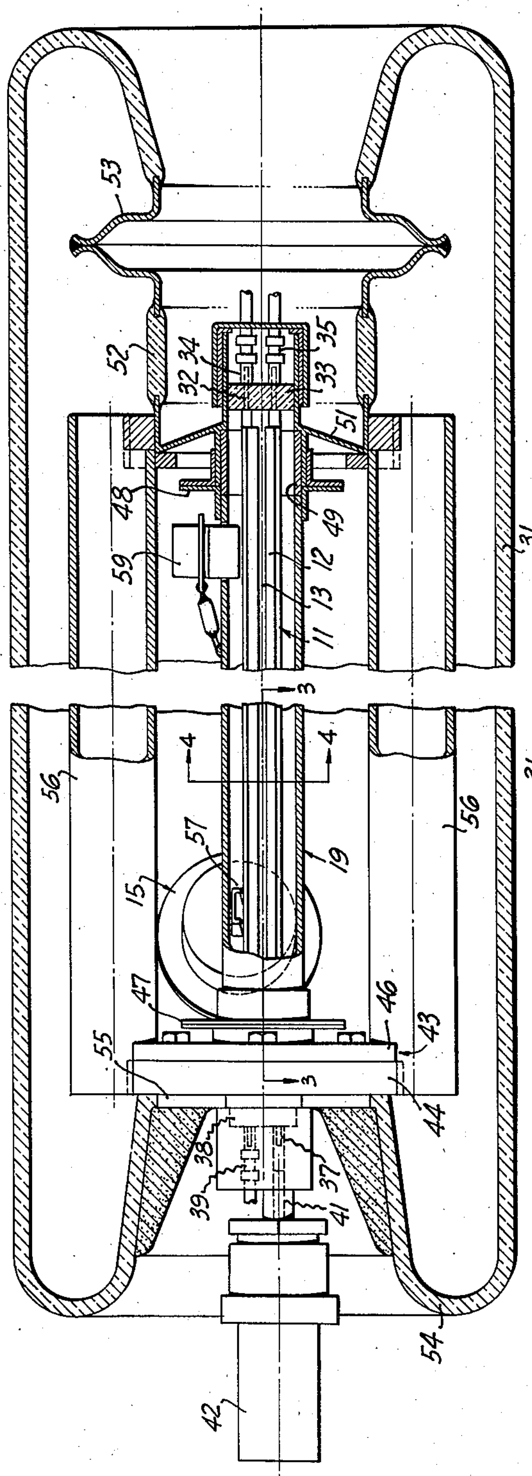

FIG_2_

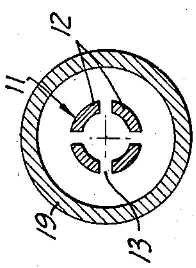

FIG_4_

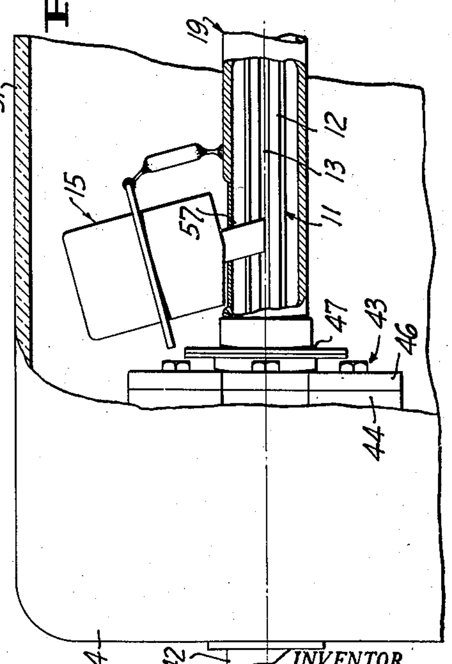

FIG_3_

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BEAM-TYPE TUBE

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Application July 18, 1957, Serial No. 672,736

4 Claims. (Cl. 315—3.5)

This invention relates generally to beam-type tubes.

Beam-type tubes have been employed as amplifiers and oscillators. In this type tube a beam of electrons is directed adjacent to a slow wave structure which supports the R.-F. signal. The R.-F. electromagnetic fields extend away from the structure and are coupled to the beam. Energy from the beam is transferred to the R.-F. fields to amplify the signal. In general, these tubes may be divided into three classes depending upon the way in which the electrons give up energy to the R.-F. electromagnetic field. In one class, the electron beam gives up energy to the R.-F. field through the loss of kinetic energy. The conventional traveling wave tube presents an example of this mechanism at work.

A second class of beam-type tubes is one in which the electrons give up potential energy to the R.-F. fields. An example of this type of tube is the linear magnetron amplifier. The electron beam is introduced with appropriate velocity into a region of cross electric and magnetic fields. The electrons have kinetic energy by virtue of their velocity and potential energy by virtue of their position in the crossed electric field. The closer they are to the positive side of the circuit, the less potential energy they have. In order to keep the electrons on course, a transverse magnetic field is applied to counteract the force of the crossed electric fields on the electrons. This type of tube has a higher efficiency than the first type described.

The third class is also one in which potential energy is given up to the R.-F. fields. However, the electrons are made to travel a circular path in a radial electric field. The inward force due to the electric field is balanced in the static case by the centrifugal force experienced by the electrons in their circular path. Thus, the electrons give up a portion of the energy by moving to a circular path of smaller radius but maintaining the same angular velocity. This type is similar to the second type described above but does not include a magnetic field. This type of beam is referred to herein as an "E" type tube.

A general object of the present invention is to provide an improved "E" type tube.

Another object of the present invention is to provide a beam-type tube in which the electron beam which is coupled to the R.-F. field follows a spiral path.

It is another object of the present invention to provide a beam-type tube in which the electron beam travels in a spiral path in a radial electric field and gives up potential energy to the R.-F. fields.

It is a further object of the present invention to provide a backward wave tube which operates at a relatively high efficiency and which does not include a magnetic structure.

It is a further object to provide an "E" type tube in which the R.-F. fields and electron beam are coupled over a large number of cycles.

These and other objects of the invention will become more clearly apparent from the following description when read in conjunction with the accompanying drawing.

Referring to the drawing:

Figure 1 is a pictorial diagram of a tube constructed in accordance with the invention;

Figure 2 is an elevational view, partly in section, showing an electron tube in accordance with the invention;

Figure 3 is an enlarged view of the electron gun employed with the tube of the invention;

Figure 4 is a sectional view taken along the line 4—4 of Figure 2;

Figure 5 is a tuning curve for a tube constructed in accordance with the invention; and

Figure 6 is a curve of power output for the tube represented in Figure 4.

Referring to Figure 1, the tube comprises a slow wave circuit **11** which, as illustrated, includes four conductors **12**. In section, the conductors have the configuration of segments of a circle. They are arranged to form a cylindrical circuit with four gaps **13** therebetwen. It is to be understood, of course, that this is merely illustrative and that the circuit may have any desired even number of conductors forming an even number of gaps. For example, the tube may include a pair of conductors arranged to form two gaps. The impedance of the slow wave circuit is determined by the number of conductors and spacing and dimensions of the same.

As is well known, R.-F. fields carried by the slow wave circuit **11** extend across the gaps and outwardly therefrom. They are coupled to the electron stream, as will be presently described, and extract energy therefrom when the fields and beam are in proper synchronization.

An electron gun **15** which includes a cathode **16** with focus electrode **17** and anode **18** projects an electron beam tangentially with respect to the circuit **11**. Preferably, the beam is substantially rectangular in cross section, as illustrated. A conducting cylinder or sole **19** is coaxial with and surrounds the slow wave circuit. The sole **19** has a greater inner diameter than the outer diameter of the circuit **11** whereby an annular space exists between the sole and circuit. The complete tube, as described, is enclosed in an evacuated envelope.

The circuit shown has one end terminated as illustrated at **21**. The output from the tube is obtained from the other end of the slow wave circuit. It is, of course, understood that rather than being terminated as shown, the end **21** may serve as the input terminal whereby a signal applied at **21** is amplified and the amplified signal is available at the other end of the circuit **11**. Further, the role of input and output may be reversed whereby the electron stream is coupled to the forward wave components of the R.-F. field rather than the backward wave component as illustrated.

A suitable accelerating voltage **22** is applied between the anode and cathode and serves to project the electron beam. The sole is maintained at a positive potential with respect to the cathode as indicated by the voltage source **23**. A radial electric field is applied between the circuit and the sole as indicated by the voltage source **24**.

The electron beam which is projected tangentially with respect to the circuit **11** is acted upon by the radial field whereby it spirals about the circuit **11** as indicated by the spiral beam **26**. The electrons are kept in a spiral path (focused) by the joint action of the radial electric field and the centrifugal force of the electron. The radial electric field pushes the electrons radially inward while the centrifugal force due to the spiral action tends to push them outwardly. When the forces are balanced, the beam travels at a constant radial distance from the circuit **11**.

As the electrons travel in their spiral path, they can give up energy to the R.-F. field by moving inwardly toward the circuit **11** (toward the region of higher D.-C. potential). By controlling the velocity of the electron beam, the frequency with which any given electron crosses the gaps 13 may be controlled thereby controlling the output frequency. The velocity of the electron stream is controlled by controlling the cathode to anode voltage. It is to be noted that the electron stream and the R.-F. fields are coupled over a considerable number of cycles whereby a maximum amount of energy is extracted from the beam before it is collected.

In one particular construction to be presently described in detail, the electron beam velocity was so chosen that it interacted with the backward wave components of the R.-F. fields of the circuit. The device operated as an oscillator with the frequency of oscillation being controlled by varying the accelerating voltage provided by battery 24. The frequency of operation is given by

$$f=\frac{\exp\frac{1+\tan^2 4'}{2}\sqrt{\frac{e/m}{\log\,(s/c)}}}{\pi S}\sqrt{V_c-V_s}\left(\frac{C}{S}\right)^{\left(\frac{V_s}{V_c-V_s}\right)}$$

where

f=frequency
S=sole radius
C=circuit radius
e/m=ratio of charge to mass of an electron
V_c=cathode to circuit voltage
V_s=cathode to sole voltage
exp=natural logarithm base
$4'$=beam pitch angle

Referring now more particularly to Figures 2–4, a tube constructed in accordance with the foregoing is illustrated. The operating parts of the tube are enclosed in an evacuated envelope 31. The circuit 11 is held coaxial within the sole 19 by supporting the conductive elements 12 at the two ends of the same. For example, the ends may be provided with pins 32 which extend through the envelope and are engaged externally by suitable connecting means. Referring to the right-hand side of the figure, the pins 32 extend through a glass seal 33. The ends of the pins are engaged by the conductors 34 which carry the terminating resistors 35. The other end of the circuit 11 also includes pins 37 which extend through a glass seal 38 and are adapted to connect to external connecting means. For example, one conductor is shown connected to the resistor 39 while another conductor is connected to the central conductor 41 of a coaxial transmission line which is provided with a coaxial connection 42.

The sole 19 is supported at one end by the assembly designated generally by the reference numeral 43. The assembly includes an alignment ring 44 and a ring 46 which carries the sleeve assembly 47 to which the sole is secured. The other end of the sole is received by the collar 48 and is in abutment with the ring 49 which is also carried within the collar. A seal 51 has an axial portion which extends between the collar 48 and the ring 49, an axial portion which engages the glass seal 33 and a radial portion which engages the glass cylinder 52. The other end of the cylinder is suitably sealed to a bellows 53. The bellows has its other end sealed to the glass envelope 31. The metallic parts 48, 49, 51 and 53 are preferably made of Kovar whereby a competent glass to metal seal may be made between the glass and metallic portions. The other end of the glass envelope 54 is suitably secured to a Kovar member 55. A pair of supporting members 56 is secured to the adjusting ring 44 and the sealing ring 51 and serves to provide rigidity to the structure.

The electron gun is supported from the sole 19 and directed whereby it projects an electron beam through the port 57 which is formed in the sole 19. The electron gun is more clearly shown in Figure 3. The electron gun may be of any well known type which is suitable for projecting an electron beam.

A collector 59 serves to collect the electron beam. The collector is formed by providing an opening in the sole and then inserting a collector portion which is insulated from the sole. No voltage is applied between this member and the circuit. Thus, when the electron beam reaches the region of no radial electric field, the centrifugal force urges the electrons outwardly where they strike the collector 59.

An electron tube was constructed in accordance with the foregoing in which the circuit had an inner radius of .056 inch and an outer radius of .070 inch and consisted of four adjacent conductors in which the gaps each spanned an angle of 22.5°. The conductors were arranged in a circle as illustrated.

The sole inner radius was .158 inch and the electron gun had a perveance of .46. The complete tube was assembled and operated. The tuning and power output curves are shown in Figures 5 and 6.

The "0" mode has no interacting fields. For synchronization, the beam must see the same field distribution as it passes any gap. Synchronization can occur at ω_0, and at $3\omega_0$. The turning curve for ω_0 is shown.

Thus, it is seen that an improved beam-type tube is provided. The R.-F. field extracts potential energy from the electron beam. The beam is focused by the combined action of a radial field and centrifugal force thereby eliminating the necessity of a magnetic circuit. The R.-F. fields on the slow wave structure are coupled to the electron beam over a considerable number of cycles due to the spiral path of the beam.

I claim:

1. A beam-type tube comprising a travelling wave circuit, said circuit comprising at least a pair of rectilinear conductors arranged to form a pair of longitudinal gaps therebetween, a conductor surrounding said circuit and spaced therefrom, means for applying an electric field between said circuit and said conductor, means for projecting an electron beam into said electric field adjacent to the circuit, said beam following a spiral path about said circuit and coupling with the electromagnetic wave carried by the same.

2. A beam-type tube comprising a travelling wave circuit serving to support electromagnetic waves, said circuit comprising at least two rectilinear conductors arranged to form longitudinal gaps between the same, said conductors serving to define a cylindrical surface, a cylindrical conductor surrounding said circuit and spaced therefrom, means forming a radial electric field between said circuit and said conductor, means for projecting an electron beam tangentially of said circuit with an axial component of velocity, said beam traversing a helical path between said circuit and conductor under the influence of the radial electric field and the centrifugal force of electrons.

3. A beam-type tube comprising a travelling wave circuit serving to support electromagnetic waves, said circuit comprising at least two rectilinear conductors arranged to form longitudinal gaps between the same, said conductors being so formed that their outer surfaces define a cylinder, a cylindrical conductor surrounding said circuit and spaced therefrom, means for applying an electric field between said circuit and said conductor whereby a radial electric field is set up between the same, a collector insulated from said conductor, an electron gun serving to project an electron beam into the electric field, said beam following a spiral path about said circuit and coupling with the electromagnetic waves carried by the same, said electron beam traveling outward at the collector to be collected thereby.

4. A beam-type tube comprising a travelling wave circuit serving to support electromagnetic waves, said circuit including at least two rectilinear conductors arranged to form longitudinal gaps between the same, said conductors serving to define a cylindrical surface, a cylin-

drical conductor surrounding said circuit and spaced therefrom, means forming a radial electric field between said circuit and said conductor, means disposed at one end of said circuit for projecting an electron beam tangentially of said circuit with an axial component of velocity, said beam traversing a helical path between said circuit and conductor under the influence of the radial electric field and centrifugal force of the electrons, a collector disposed at the other end of said circuit, said collector being insulated from said conductor and having no electric field applied between it and the circuit whereby the electrons in reaching the region of no electric field are urged outwardly by the centrifugal force to be collected by the collector.

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