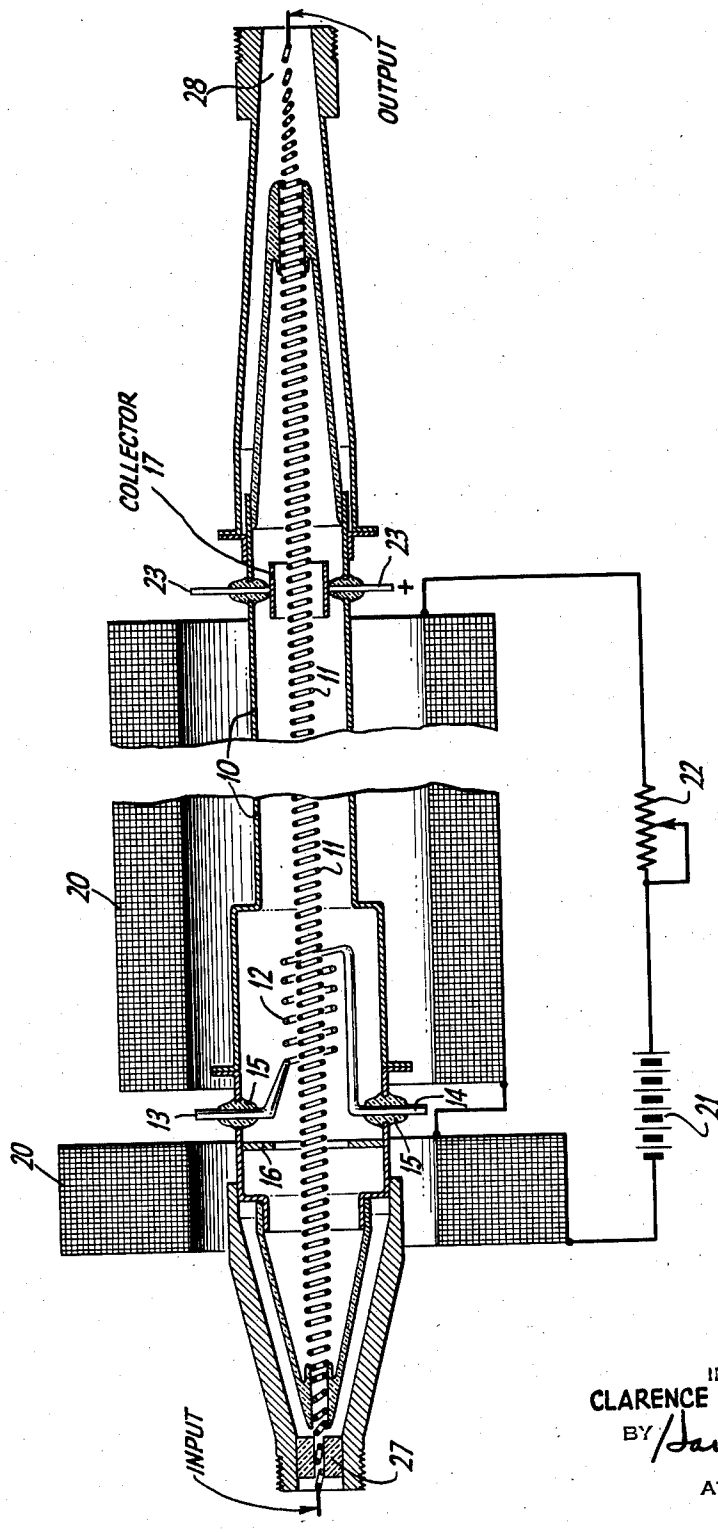
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HIGH-FREQUENCY ELECTRON DISCHARGE TUBE OF THE TRAVELING WAVE TYPE

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HIGH-FREQUENCY ELECTRON DISCHARGE TUBE OF THE TRAVELING WAVE TYPE

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This invention relates to improvements in electron discharge devices and circuits therefor, especially adapted for use at frequencies ranging from 500 megacycles into thousands of megacycles.

The present invention provides an electron discharge device amplifier of the growing-wave (sometimes called a traveling-wave) type tube capable of amplifying a wide band of high frequencies and which does not depend upon resonance phenomena in the input and output circuits.

Briefly stated, the tube of the present invention comprises an evacuated envelope containing therein a coiled transmission line positioned on the longitudinal axis of the tube with means for projecting a hollow cylindrically shaped electron beam down the length of the tube and surrounding the coiled line. Both ends of the coiled line are tapered in diameter and preferably in pitch for enabling the line to be substantially matched from an impedance standpoint to input and output radio frequency current carrying lines. The tapering and change in pitch at the ends of the coiled line provide low impedance terminations for minimizing wave reflections at the junctions with the input and output lines.

The invention is more completely described in conjunction with a drawing whose single figure illustrates one embodiment of the invention.

Referring to the drawing, there is shown in cross-section a wide-band growing-wave vacuum-tube amplifier in which an elongated non-magnetic metallic envelope 10 surrounds a coiled line 11 lying on the axis of the tube. The coiled line 11 is a plurality of wavelengths long at the mean operating frequency and may range in length from 20 to 100 wavelengths. Both ends of the coiled line are tapered in diameter and pitch as shown in order to give low impedance terminations for the coiled line. The central portion of the coiled line has a relatively-high characteristic impedance. It should be noted that the diameter of the coiled line is decreased and its pitch or spacing between turns increased gradually as the ends are approached, until the ends of the coiled line come out as straight wires. This, in combination, if desired, with a smoothly tapering outer shield makes it possible to reduce the characteristic impedance of the coiled line gradually and smoothly to a value which approximates the relatively low characteristic impedance of a concentric line, and as a result, waves of a broad range of frequencies may be passed in either direction between the two

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types of line without substantial wave reflections taking place in the junction. At one end of the tube there is provided a cathode in the form of a coiled filament 12 within an enlarged space in the envelope 10. Heating current for the filament is supplied by leads 13 and 14 which extend into the interior of the evacuated envelope 10 through glass seals 15. The coiled filament may be thoriated or oxide coated. An electron repeller shield or electrode 16 serves to concentrate the electrons emanating from the cathode and aids in directing them to pass toward the electron collector electrode 17 at the other end of the tube.

Surrounding the tube envelope there are provided magnetic field coils 20 which are supplied with unidirectional current from a battery 21 arranged in series with a variable resistor 22. The field coil produces lines of flux which extend parallel to the longitudinal axis of the tube and focus the beam or stream of electrons which surround the coiled line 11 and are projected from the cathode end of the tube to the other end of the tube.

The collector electrode 17 is in the form of a ring and is maintained at a positive potential relative to the cathode or filament 12. Leads 23 extend from the collector electrode 17 out through the envelope of the tube. The collector 17 is positive whereas the cathode 12 and the envelope 10 are kept negative with respect to coiled line 11. The electron stream expands radially where it reaches the more positive collector electrode 17 and the electrons therefore are easily collected.

Input and output coaxial line couplings 27 and 28 respectively, have their inner conductors connected to the tapered ends of the coiled line 11 through glass seals. These coaxial lines have a relatively low characteristic impedance (of the order of 50 to 75 ohms) compared to the higher characteristic impedance of the central portion of the coiled line which may be several hundred ohms. A direct current connection is made to the inner conductor of the input or output transmission line at any convenient place, through a suitable filter circuit to isolate the D. C. supply system from the high frequency circuits.

In the operation of the tube of the invention, electrons are released from the coiled filament or cathode from regions lying approximately on an imaginary cylinder. These electrons are drawn radially inward by an electric field between the cathode and the inner coiled line 11,

which serves as an accelerating electrode, but due to the presence of an axial magnetic field the electrons are unable to travel to the coaxial line 11 and are forced to follow spiral paths which cause them to travel more or less circumferentially around the coiled line and also axially toward the collector electrode 17. The magnetic field focusses the whirling electron stream in a hollow path parallel to but spaced from the coiled line 11 and, by suitable adjustment of electrode potentials the electrons are made to increase in axial velocity as they move from the region of the cathode 12 to the region of the collector electrode 17.

It may be explained that the electrons from the cathode are accelerated toward the coiled line by giving the coiled line a relatively large positive potential with respect to the cathode. However, because of the magnetic field, the electrons cannot reach the coiled line but follow paths tending to bend back toward the cathode. The result is that a dense space charge cloud is set up in the space between the cathode and coiled line. As a result of the density, and the mutual forces of repulsion between electrons, a hollow stream of the electrons is forced out of the end of the cathode 12 toward the collector electrode 17, assuming that envelope 10 is at a potential not too different from the cathode potential. The repeller electrode 16 prevents the electrons from traveling in the opposite direction.

Such an arrangement makes it possible to obtain a space charge limited electron beam of relatively great electron density and current values. In fact, the beam current density may be much greater than the density of electron emission at the cathode surface.

The velocity of electrons in an axial direction (axial component of velocity) is made somewhat less than the axial velocity of the waves traveling along the coil 11 at the input end only of the coil. It will thus be seen that the input waves applied by the input line coupling 27 to the coil 11 will deliver radio frequency power to the electron stream along a portion of the length of the coil. Along the major portion of the length of the coil 11, however, the axial velocity of the electrons is greater than the axial velocity of the waves traveling along the coil. Thus along the major portion of the length of the coil the electrons deliver energy to the coil 11. The purpose of this velocity relationship is to make it possible to deliver the maximum fraction of the input radio frequency power to the electron stream in order to produce initial bunching of the electrons in the stream. This is because it is desired to produce maximum bunching of the electrons in response to the input waves as compared to random bunching of the electrons due to thermal agitation, which produces noise. Once the greatest practical amount of signal-to-noise ratio is obtained in the electron bunching near the input end of the tube, the velocity relationship of waves on the coil 11 and the surrounding electron stream is reversed in order for the electron stream to increase the power of the waves and to deliver this increased power to the coiled line. This is achieved (1) by the space charge and potential relationships in the electron stream, and (2) if necessary, by the variation in the pitch of the coiled line throughout its length. There is a tendency for the electrons to be accelerated axially to increasing velocities as they move from the region of the cathode to the region of the collector electrode. The variation in pitch of the coiled line throughout its length is arrived at in practice empirically.

The feature of using an internal coil which is surrounded by an electron stream has the advantage of enabling the coil to be supported more easily than an external coil can be. This internal coil if desired can be wound on and sealed to glass rod or tubing. Where the means operating frequency of the tube is of the order of many thousands of megacycles, the coiled line may be quite long, perhaps of the order of 20 to 100 wavelengths.

One method of constructing the coiled line is to take wire which has the same thermal coefficient of expansion as the glass rod and to wind the wire on the glass rod in a fixture for controlling the diameter, while sufficient electrical current is passed through the wire as it is wound to heat the glass to the softening point. Such coils are preferably made of an alloy known by the trade-names of "Kovar" and "Fernico" wound on and sealed to a rod of Corning 7052 glass. This alloy is made of 29% nickel, 17% cobalt, 0.3% manganese and the rest iron. It has considerable magnetic permeability and high resistivity. These coils when wound of plain Kovar (Fernico) had too much high frequency attenuation so that in order to overcome this a thin layer of copper was applied over the Kovar and then a thin protective coating of oxidized chromium, before winding the coil, thus resulting in a low loss line which could be easily sealed to the glass rod. The specific steps in the manufacture of this coiled line included electroplating copper on top of the alloy (Kovar or Fernico). The wire was then heated sufficiently to liberate the gasses in the electroplated copper coating, and at the same time to melt the copper sufficiently to produce a smooth uniform dense coating of copper on the Kovar wire. Inasmuch as a copper-coated Kovar line cannot readily be sealed to glass without spoiling the copper coating, the copper-coated line was then coated with a layer of chromium plating. The resulting product was then heated in wet hydrogen, as a result of which the chromium layer (but not the copper) oxidizes. There is no very sharp dividing surface between the highly conducting copper and the highly insulating chromium oxide, as a result of which there is an absence of a high loss layer. The resulting wire could then be sealed to glass without creating a high loss layer between the copper and the glass. The chromium oxide is, in effect, a dense protective coating which prevents oxygen from reacting on the copper where it would form a high loss layer.

Since, in practice, it may be found very difficult to match the impedance of the coiled line well enough over a large enough frequency band to prevent oscillation it should be recognized that the attenuation can be made too low. Therefore the copper coating may be adjusted in thickness to obtain a desired range of attenuation, or a portion of the line, between the ends may have the copper coating removed. Generally, the high loss part of the line should be in the region where the electron velocities increase through a value equal to the line velocity.

In general, it will be convenient to ground the outer metallic envelope 10 of the amplifier tube of the invention for direct currents, although this is not essential. Moreover the metal tube 10 can be somewhat magnetic without too objectionable effects, though this is not preferred. If desired, the metal tube 10 may be replaced by

a glass envelope provided the inside surface of the glass envelope is coated with metal to give it sufficient electrical conductivity to maintain the coated surface at a more or less uniform potential.

A copending application of Nils E. Lindenblad, Serial No. 724,330, filed January 25, 1947, and assigned to the same assignee as the instant application, discloses and claims a traveling wave tube wherein a coiled line is connected at one end to a coaxial line of which the inner conductor is a helix of uniform diameter with the turns more closely spaced near the coiled line than farther away therefrom. The coaxial line is displaced laterally from the axis of the coiled line to permit the projection of an electron beam through the inside of the coiled line.

What is claimed is:

1. An electron discharge device comprising an evacuated envelope containing therein a coiled line along the longitudinal axis thereof, said coiled line having an end portion which tapers both in diameter and pitch, said end portion extending axially outside said envelope, means including a cathode within said envelope and surrounding said coiled line for projecting a hollow stream of electrons along the length of and around said coiled line, and means adjacent to said envelope for producing a magnetic field having flux lines running parallel to said axis.

2. An electron discharge device comprising an evacuated envelope containing therein a coiled line along the longitudinal axis thereof, both ends of said coiled line being tapered downward in diameter in a direction away from the central portion of the line, an input circuit coupled to one tapered end of said line, an output circuit coupled to the other tapered end of said line, means within said envelope for projecting a hollow stream of electrons along the length of and around said coiled line, and means adjacent to said envelope for producing a magnetic field having flux lines running parallel to said axis.

3. An electron discharge device comprising a metallic tube, a coiled line along the axis of said tube and extending over the major portion of the length of said tube, said coiled line having a central portion of substantially constant diameter and oppositely disposed end portions which taper both in diameter and pitch, and means including a cathode within said device and surrounding said line intermediate the ends of said line for projecting a stream of electrons which travels circumferentially around said coiled line from said cathode toward one end of said line.

4. An electron discharge device comprising a metallic tube, a coiled line arranged along the axis of said tube, said line having an intermediate portion of substantially constant diameter and end portions which taper in pitch and downward in diameter, a source of input waves connected to one end of said line, an output circuit connected to the other end of said line, and means including a cathode within said device surrounding said line intermediate the ends thereof for projecting a stream of electrons which travel circumferentially around said coiled line from cathode toward one end of said line.

5. An electron discharge device comprising a metallic tube, a coiled line arranged along the axis of said tube and having ends which taper toward smaller diameters as the ends are approached, a source of input waves connected to one end of said line, an output circuit connected to the other end of said line, a cathode surrounding a portion of said line nearer said source of input waves than to said output circuit, a collector electrode within said tube located at a point on said line between said cathode and said output circuit, and means adjacent to said tube for causing the electrons emanating from said cathode to be projected toward said collector electrode as a whirling hollow stream which surrounds but is spaced from said coiled line.

6. An electron discharge device comprising an evacuated envelope containing therein a coiled conductor along the longitudinal axis thereof and having a central portion of substantially constant diameter, both ends of said coiled conductor being tapered in diameter and pitch, means for supplying high frequency waves to one end of said coiled conductor and means for abstracting high frequency waves from the other end of said coiled conductor, a source of electrons and an electron collector electrode spaced from each other along the length of and located between the ends of said coiled conductor, and means adjacent to said envelope for producing a magnetic field having flux lines extending parallel to the length of said coiled conductor for causing the electrons emanating from said source to travel circumferentially around said conductor as a whirling stream toward said collector electrode in a path parallel to but spaced from said coiled conductor.

7. An electron discharge device comprising a metallic tube, a coiled line arranged along the axis of said tube and having ends which taper in pitch and downward in diameter, in a direction away from the central portion of said coiled line, an input coaxial line having an inner conductor connected to one end of said line, an output coaxial line having an inner conductor connected to the other end of said line, connections of low impedance to energy of the operating frequency between said metallic tube and the outer conductors of said coaxial lines, and means at a location near the input end of said coiled line for projecting a stream of electrons which travels circumferentially around said coiled line toward the other end of said line.

8. An electron discharge device comprising an envelope, an elongated coiled line within and extending through the ends of said envelope, said coiled line being made of an alloy of nickel, cobalt, manganese and iron and having coatings of copper and chromium oxide, and means for supporting said coiled line for the major portion of its length within said envelope comprising an elongated glass rod having substantially the same thermal coefficient of expansion as said coiled line extending within and sealed along its length to said coiled line.

9. A coiled line, for use at high frequencies, made up of an alloy of nickel, cobalt, manganese and iron and having coatings of copper and chromium oxide, said coiled line being wound on and sealed to a supporting glass rod having substantially the same thermal coefficient of expansion as said line.

10. In an electron discharge device, an evacuated envelope containing therein a coiled line having an intermediate portion of substantially constant diameter and end portions which taper gradually in diameter from said intermediate portion toward the ends of said line.

11. An electron discharge device comprising an evacuated envelope containing therein a coiled line having end portions which taper both in

diameter and pitch and an intermediate portion of substantially constant diameter, and a cathode and a collector electrode spaced from each other along the length of and located between the ends of said coiled line.

12. An electron discharge device comprising an evacuated envelope containing therein a coiled line extending over the length of said envelope, said coiled line having a central portion of substantially constant diameter within said envelope and end portions of tapering diameter and pitch extending axially through said envelope, and a cathode and a collector electrode located within said envelope but spaced from each other along the length of said central portion.

13. An electron discharge device comprising an evacuated envelope containing therein a coiled line having end portions which taper both in diameter and pitch and an intermediate portion of substantially constant diameter, said envelope having a metallic surface surrounding said coiled line over the entire length of said intermediate portion, a cathode and an electron collector electrode within said envelope and spaced from each other along the length of said coiled line and between the ends thereof, and means external of said envelope for producing a magnetic field having components of flux lines extending parallel to said coiled line.

14. Means for coupling together two spaced radio frequency transmission lines comprising a coiled conductor having a central portion of substantially constant diameter and end portions tapering gradually in diameter from said central portion toward the ends of said conductor, one of said end portions being adapted to couple to one of said transmission lines while the other end conductor is adapted to couple to the other transmission line.

15. Means for coupling together two spaced radio frequency transmission lines of relatively low characteristic inpedance comprising a coiled conductor having a central portion of substantially constant diameter and relatively high characteristic impedance and end portions tapering gradually both in pitch and diameter, the diameter decreasing and the pitch increasing from said central portion toward the ends of the conductor, one of said end portions being adapted to couple to one of said transmission lines while the other end conductor is adapted to couple to the other transmission line.

16. An electron discharge device comprising an elongated coiled line, a hollow cathode coaxially surrounding said line, means adjacent said line and cathode for providing an axial magnetic field in the space therebetween, and a repeller electrode adjacent to but axially spaced from said cathode at one side thereof to prevent emergence of electrons from said cathode on said side.

17. An electron discharge device comprising an evacuated envelope containing an elongated coiled line extending axially through the ends of said envelope, and means including a cathode surrounding said line in spaced relation therewith at a point spaced from one end thereof for projecting a hollow stream of electrons longitudinally along the outside of said line.

18. An electron discharge device according to claim 17, including a collector electrode spaced from said cathode and surrounding said line at a point intermediate said cathode and the other end of said line.

19. An electron discharge device according to claim 18, including means adjacent said envelope for producing a magnetic field having flux lines running parallel to the axis of said line.

20. An electron discharge device according to claim 19, including a repeller electrode surrounding said line and located adjacent said cathode on the side thereof opposite from said collector electrode.

21. An electron discharge device according to claim 17, including hollow conducting means coaxially surrounding said line in spaced relation therewith along the entire length thereof, the ends of said conducting means and the ends of said line forming coaxial line input and output couplings for said device.

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