

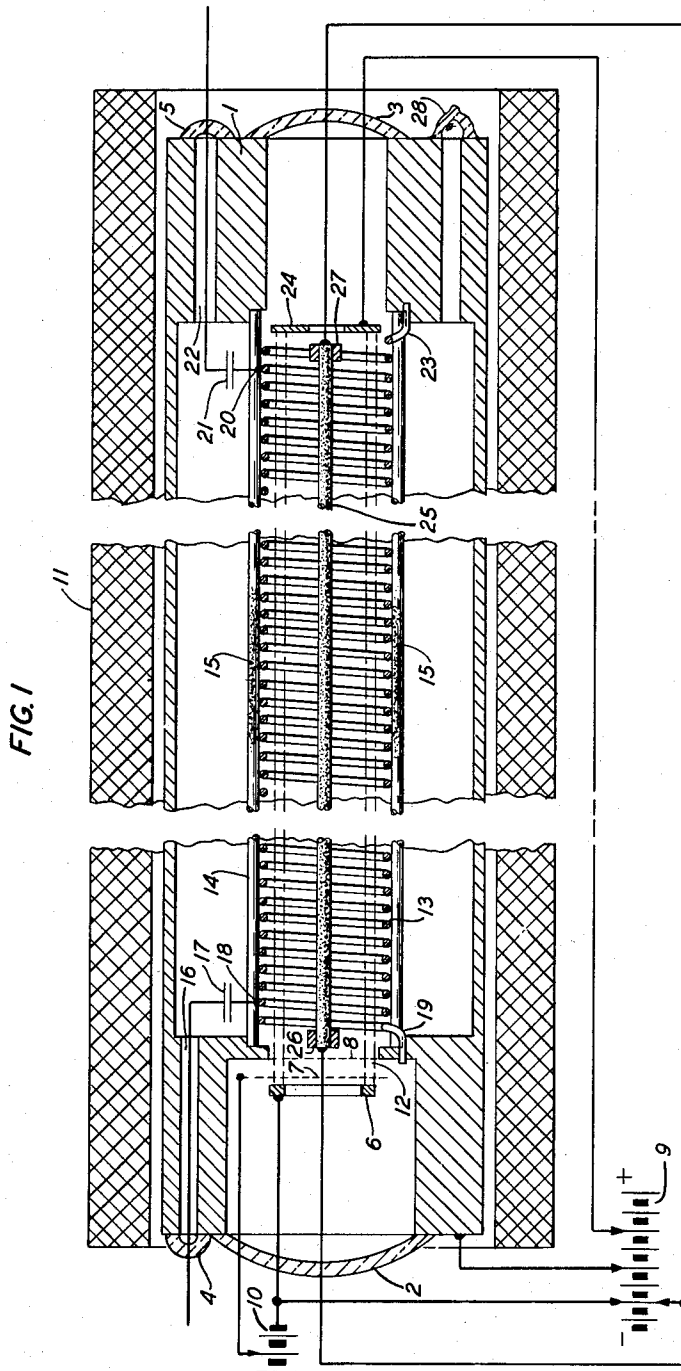
April 17, 1956

A. V. HOLLENBERG
ELECTRONIC AMPLIFIER

2,742,588

Filed Jan. 7, 1950

3 Sheets-Sheet 1



INVENTOR
A. V. HOLLENBERG
BY *N. D. Ewing*
ATTORNEY

April 17, 1956

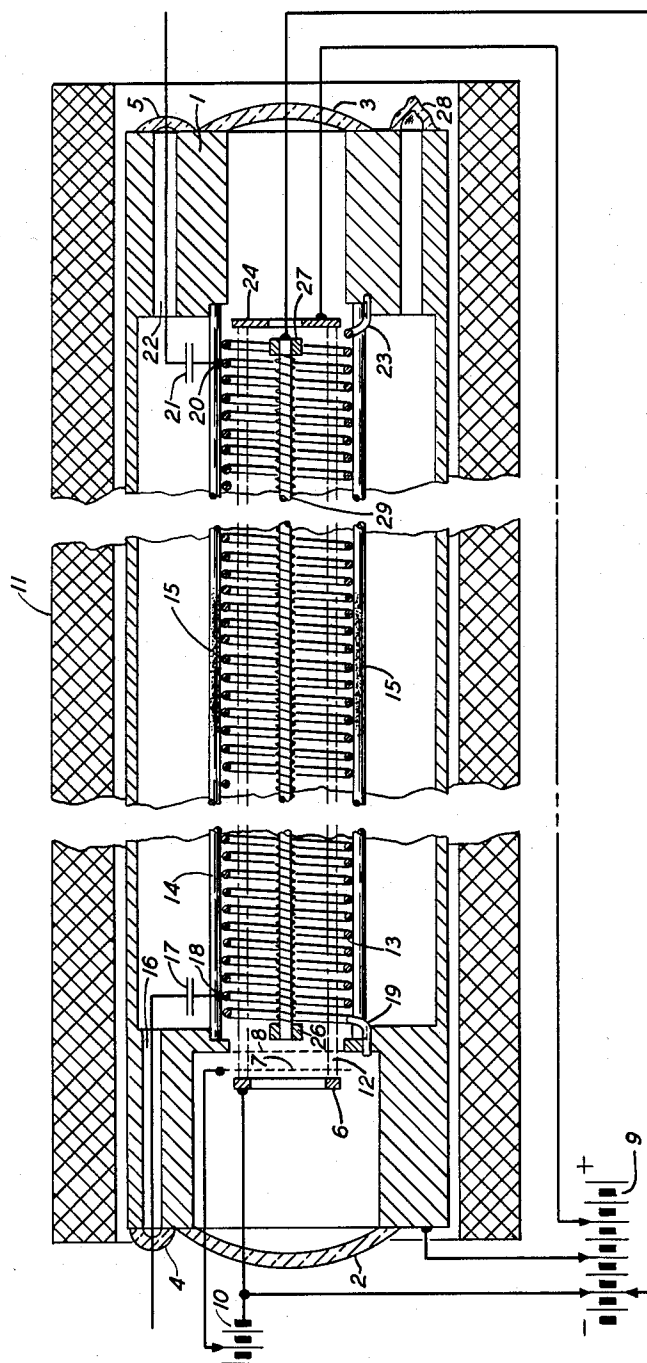
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3 Sheets-Sheet 2

FIG. 2



INVENTOR
A. V. HOLLENBERG

BY

N. A. Ewing
ATTORNEY

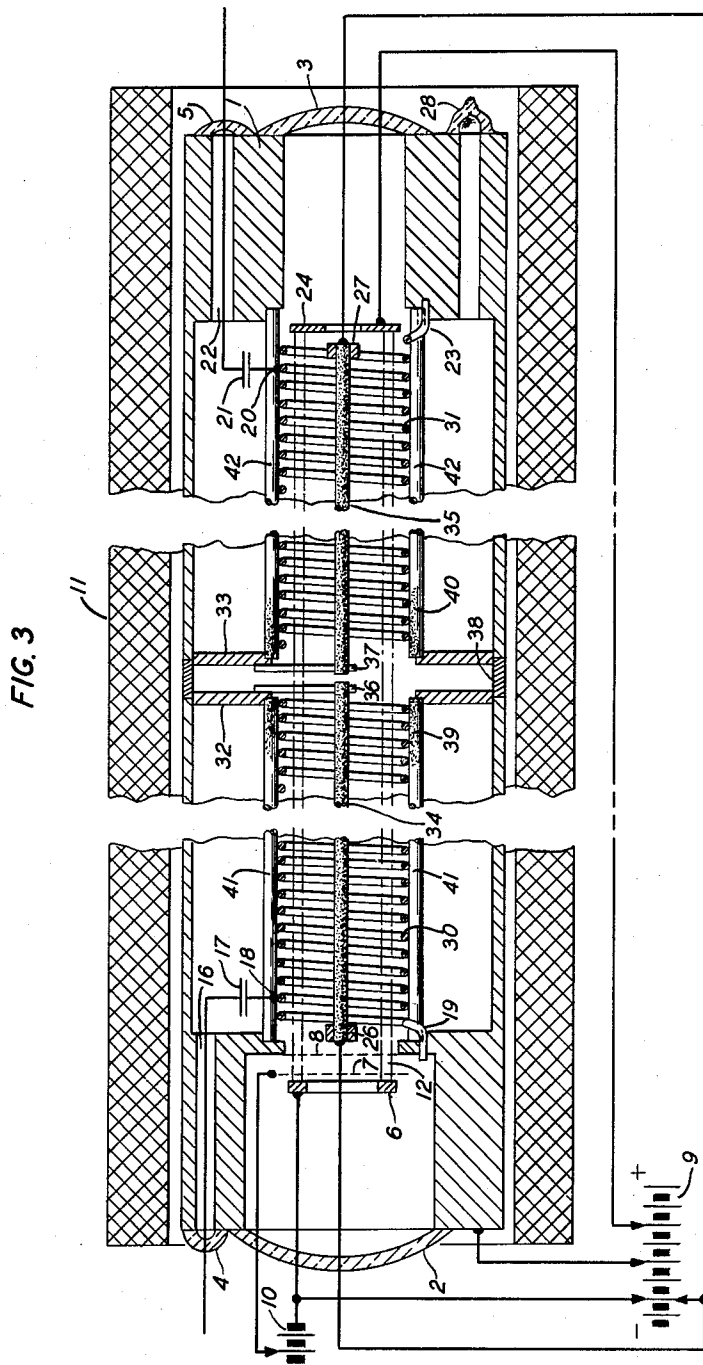
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INVENTOR
A. V. HOLLENBERG
BY *N. A. Ewing*
ATTORNEY

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ELECTRONIC AMPLIFIER

Arthur V. Hollenberg, Morris Plains, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

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This invention relates to electronic devices utilizing extended hollow electron beams and particularly to high frequency amplifiers of the traveling-wave type in which a defined beam of electrons travels for some distance near a metallic circuit such as a helix in which an electromagnetic wave travels at a speed suitably related to that of the electrons in the beam and in which the wave is amplified in its travel by virtue of interaction with the electron beam.

An objective of the invention is to provide improved operation of traveling-wave amplifiers of the type employing a tubular electron beam.

Another objective is to reduce the amplitude of unwanted noise signal components generated within such amplifiers.

Another objective is to provide a means generally useful for reducing the accumulation of positive ions in long hollow electron beams.

In the operation of traveling-wave amplifiers in which an electron beam travels for a considerable distance, it has been found that unwanted signal components, which appear as noise in the output circuit, are generated within the device which are apparently due to a concentration of positive ions in the region of the electron beam where there is a space charge depression of potential. The ions may be produced from collisions between electrons in the beam and molecules of residual gas within the device.

According to this invention this difficulty with noise signal components in the output of the amplifier is overcome by the use of a cylindrical or helical conductor placed within and coaxial with the hollow beam and the helix or other circuit which conveys the electrical wave signal. This cylindrical or helical central conductor is maintained at a potential different from that of the wave circuit so that a transverse electrical field is produced across the space between the circuit and the central conductor, and if the circuit is a helix the field will extend between the turns of the helix. The electron beam is tubular and is coaxial with the circuit and the central conductor and, in a preferred design, passes longitudinally in the space between them. The beam is, therefore, in the transverse electric field between the central conductor and the circuit. The intensity and direction of the transverse field depends upon the relative potentials of the central conductor and the wave circuit conductor. Forces are exerted on the positive ions by the transverse field, tending to remove them from the region of the electron beam and draw them to the central conductor when it is at a lower potential than the wave circuit and to the circuit itself when the central conductor is at a higher potential. When the transverse electric field is sufficiently intense the positive ions are drawn out of the region of depressed potential in the electron beam, thus reducing the amplitude of the unwanted electrical noise signals due to the concentration of the ions in the region of the beam.

While the introduction of a central conductor makes possible the application of the transverse field for ion removal, it may without proper precautions introduce dif-

ficulties of a different sort. The presence of a conductor in the high frequency field of the signal wave in the electromagnetic circuit may modify the field in an undesired manner which may cause propagation of signal in both directions at velocities and with field distributions which are undesirable. The method of avoiding this difficulty is to impede the flow of high frequency current in the central conductor associated with the signal wave either by making the resistance of the central conductor high as may be done by making it of a ceramic or other insulating material upon which a very thin layer of conducting material such as graphite has been deposited or by making the impedance of the central conductor high to currents at the signal frequencies while keeping the direct-current resistance moderately low as by making it in the form of a core of ceramic or other insulating material on which a helix of fine wire has been wound. The use of the high resistance or high impedance central conductor for removing positive ions from a tubular electron beam and thereby reducing the amplitude of unwanted electrical noise signals without adversely affecting the operation of the traveling-wave amplifier is a particular feature of this invention.

The invention and its application in specific embodiments will be understood from the following description and the accompanying drawings, of which:

Fig. 1 shows a traveling-wave amplifier incorporating the invention through utilization of a central conductor for ion removal in the form of a high resistance rod;

Fig. 2 shows an amplifier similar to that of Fig. 1 but employing a central conductor for ion removal in the form of a helix; and

Fig. 3 illustrates an embodiment of the invention in a traveling-wave amplifier which is divided in the center and assembled in sections. It shows two sections of central conductor for ion removal and as an example the high resistance rod type of conductor is shown.

In Fig. 1 the vacuum-tight envelope 1 is of non-magnetic metal and contains the elements of the traveling-wave amplifier. Other embodiments of the invention may employ a non-metallic envelope, such as glass, in which case means for supporting and connecting to the helix other than those to be described may be employed. Elements of the tube are connected outside of the envelope by leads passing through glass or ceramic seals 2, 3, 4, and 5. The ring-shaped indirectly heated cathode 6, the heater for which is not shown, emits a tubular beam of electrons 12, the flow of which is controlled by grid 7 which is variably biased with respect to the cathode by battery 10. The electron beam is accelerated by grid 8 connected to the metal envelope 1 and thereby to the accelerating potential source, battery 9. Transverse motion of the electrons is restricted by a longitudinal magnetic field produced by current flowing in the solenoid 11 and the beam of electrons is, therefore, tubular in shape throughout the length of the tube. The direct current for the solenoid 11 may be supplied from any suitable source (not shown). The electron beam travels within the helix 13 in the region close to the wires of the helix where the amplitude of the high frequency field of the signal is large. The helix is supported by ceramic rods 14 which may be supported directly by the metal envelope as shown or indirectly by two metal collars attached to the rods and supported by the envelope. The turns of the helix are maintained in proper spacing by a series of notches ground into the supporting rods 14 into which the helix wires are bound by glazing material. High frequency loss is introduced into the central portion of the helix by means of a thin coating of conducting material such as graphite on the supporting rods in the central region as indicated at 15. The thickness of the coating is gradually increased from each end toward the center in order to prevent reflection

of the signal wave. The graphite coating attenuates all signal waves passing this region except those carried in the electron beam. Input signals on the coaxial line 16 are applied to the helix 13 through capacitor 17 and a connection at point 18 on the helix. The location of point 18 and the capacitance of capacitor 17 are chosen to apply the signal wave to the helix at the operating frequency without reflection. The input end of the helix wire is connected, at point 19, to the metal envelope which also forms the outer conductor of the coaxial line 16. At the output end of the helix, identical arrangements are made for extracting the signal wave at point 20 through capacitor 21 into output coaxial line 22, with connection of the end of the helix wire to the metal envelope and outer conductor of the coaxial line at point 23. The electron beam 12 is collected by collector 24 which is maintained at an appropriate potential by battery 9. The ion removing central conductor 25 is supported on the axis of the helix 13 by suitable means, not shown, which may be insulators which support collars 26 and 27 from grid 8 and collector 24, respectively, or other appropriate insulating supports. Connections may be brought out from one or both ends of the central conductor. Connections from both ends are shown in Fig. 1 and these are brought to a common point on battery 9 which maintains the central conductor above or below the potential of the helix depending upon the position of the connection to the battery. With the connection shown in Fig. 1 the central conductor is at a lower potential than the helix which is the preferred method of operation. However, the conductor may be operated at a potential higher than the helix.

The ion removing central conductor 25 shown in Fig. 1 is of the high resistance type utilizing in its construction a rod of ceramic material having a small diameter. A rod of .058-inch diameter has been used. For the metallic collars 26 and 27 molybdenum has been used. These collars closely fitting the ceramic rod are attached near the two ends of the rod and are held in position by a glazing paste which is applied to the assembly, the assembly then being heated in a reducing atmosphere until the paste melts. On cooling, the melted glazing paste becomes a firm glass bond holding the collars in place. Electrical connections are made to one or both of the metal collars. The region between the collars 26 and 27 is covered uniformly with a thin layer of conducting material, for example graphite which in suspension form may be applied to this region by spraying, the spray overlapping the metal collars. The amount of material deposited may be measured if the deposit is uniform, by measuring the electrical resistance between the metal collars, and this measures the property of the conductor which must be properly chosen to permit the conductor to serve its purpose of drawing out positive ions without materially disturbing otherwise the operation of the traveling-wave amplifier. The resistance per unit length of the coating should be high enough that the electric field of the signal wave is not distorted or unduly attenuated. It must be low enough to allow the positive ions collected by the central conductor, when it is negative with respect to the circuit, to flow out without accumulation and resulting large change of potential of the conductor. Ion currents which have been observed under circumstances similar to those of a traveling-wave tube roughly 25 centimeters long are a few microamperes in magnitude. A total resistance in the central conductor of one megohm (which amounts to 40,000 ohms per centimeter) will under such a condition lead to potential differences between the ends of the central conductor or between the ends and the center of at most a few volts which is not believed injurious. On the other hand, the power absorbed in the central conductor from the high frequency field of the signal wave in the helix must be considered. It is desired that the resistance in the central conductor be sufficiently high that the total attenuation in the length of the tube

is not large compared with the total gain otherwise to be expected from the device. Estimates of typical cases show that a total resistance of the order of one megohm for the central conductor 25 is also satisfactory on this basis. A total resistance, uniformly distributed, of about one megohm for the central conductor may, therefore, satisfy both requirements. Circumstances may, of course, dictate a different value of resistance for the central conductor. Therefore it is not intended to limit the value of resistance other than is required to avoid excessive direct-current potential gradient along the conductor or excessive attenuation of the high frequency wave.

The enclosure within the envelope 1 of Fig. 1 is evacuated in the usual manner and sealed off at the tubulation 28. Impedances and by-pass condensers or other means according to common practice may be associated with the external leads to the electrodes of the amplifier tube in order to prevent high frequency feedback along the connections to the battery or other undesired effects of the presence of high frequency voltage on the leads.

Fig. 2 shows the use of a central ion removing conductor in helical form. The conductor may be made in this form by winding a fine wire, for example tungsten or molybdenum wire, on an insulating rod of ceramic or other suitable material. In Fig. 2, all of the elements 1 to 24 and 26 to 28 are the same as in Fig. 1. The central conductor 29 is in helical form wound on a ceramic rod of small diameter to the ends of which metallic collars 26 and 27 are attached as in the showing of Fig. 1 and which may be supported as suggested for Fig. 1. The ends of the wire of the helical central conductor are connected to these collars 26 and 27. The wire may be of 0.001-inch diameter and wound 500 turns per inch. It is desirable to make the diameter of the helix of the central conductor small, for example 0.060-inch diameter. With the dimensions given, the velocity of propagation of a signal wave along the axis of the helical central conductor will be roughly $\frac{1}{100}$ of the speed of light. Equality of velocities of propagation in the outer signal wave carrying helix and in the helical central conductor probably leads to coupling between the helices and therefore absorption of power in the helical central conductor and should be avoided. The velocity resulting from the above given dimensions is smaller than that usually found useful in traveling-wave tubes. The direct-current resistance of the wire of the helical central conductor of the dimensions given is only a few thousand ohms for wire material such as tungsten and molybdenum. Large currents than mentioned in connection with Fig. 1, of the order of one milliampere, for example those which result from partial interception of the electron stream by the conductor or its supports could therefore, be withdrawn by the central conductor, if necessary, without excessive voltage drop. Where only small currents, of the order of microamperes, from the positive ions are expected, there is negligible voltage difference between the ends of the central conductor even if connection is made only to one end as in Fig. 2. Connections may, of course, be made to both ends as in Fig. 1 if desired.

Fig. 3 illustrates a modification of the structures shown in Figs. 1 and 2 which performs the same functions and may employ either the high resistance central conductor of Fig. 1 or the helical type of Fig. 2. For a convenient example the high resistance type is shown in Fig. 3. The structure of Fig. 3 may, under some circumstances, possess advantages of mechanical convenience in fabrication and assembly in that the lengths of the helix and central conductor which are required to be fabricated in single units are half that required with the structures of Figs. 1 and 2. It possesses also the feature of attenuating more completely the signals crossing the central portion of the tube except those carried in the electron stream.

In Fig. 3, the elements bearing the same designations as those in Fig. 1 are identical, except that the envelope

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1 is assembled in sections in Fig. 3, and perform the same functions as in Fig. 1. The helix which conducts the electrical signal is in two sections 30 and 31. The ends of these sections in the central portion of the tube are supported so as to be in alignment by members 32 and 33 attached to the respective halves of the envelope. The central conductor, of either high resistance, as shown, or helical form is in two portions 34 and 35. The ends in the central portion of the tube are supported by members 36 and 37, which are thin to avoid interception of more than a small portion of the beam current, and are attached to members 32 and 33. As in Figs. 1 and 2 thin coatings of conducting material are deposited on the support rods 41 and 42 of the signal wave carrying helices 30 and 31 in the regions 39 and 40 with thickness gradually increasing toward the center of the tube in order to terminate the two helix sections without reflection. The two halves of the tube are completely assembled independently and finally joined together by ring 38 so that the complete envelope is vacuum tight.

As has been stated above, the central ion removing conductor or electrode may be maintained either above or below the potential of the conductor of the electrical signal wave circuit, though it is believed preferable to maintain the central conductor at the lower potential.

Also, it is not without the scope of the invention to use the central ion removing conductor with a helical signal wave circuit which is within the hollow electron beam rather than external to the beam as shown in the three figures. In that case the withdrawal of positive ions from the electron beam would depend upon the lines of force of the transverse field between the central conductor and the helix of the signal wave circuit which extend through between the turns of that helix as far as the outside electron beam. The arrangement with the electron beam between the central conductor and the circuit helix as shown in all three figures is believed preferable.

It is not intended that the scope of the invention be limited to the field of traveling-wave amplifiers as obviously the central ion removing conductor may be employed in other devices employing hollow electron beams from which it is desired to remove positive ions.

What is claimed is:

1. An electronic device comprising an evacuated envelope containing an electron emitter and an electron collector spaced apart, beam focusing means for forming a tubular-shaped beam of electrons in which the electron paths are substantially parallel to the axis between said emitter and said collector, electric potential means connected to said emitter, collector and beam focusing means for moving the electrons along said paths, an electrical wave transmission circuit whereby an applied wave is amplified as it travel therealong comprising a helical coil coaxial with and extending along external to said path of the tubular electron beam, an electrical conductor in the form of a helix and having a high impedance at the operating frequency of the wave transmission circuit substantially coaxial with and extending along within said path of the tubular electron beam, and electric potential means connected to said conductor for maintaining it at a direct-current potential substantially different from that of said helical coil of the wave transmission circuit.

2. An electronic device comprising an evacuated envelope containing an electron emitter and an electron collector spaced apart, beam focusing means for forming a tubular-shaped beam of electrons in which the electron paths are substantially parallel to the axis between said emitter and said collector, electric potential means connected to said emitter, collector and beam focusing means for moving the electrons along said paths, an electrical wave transmission circuit whereby an applied wave is amplified as it travels therealong comprising a

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helical coil coaxial with and extending along said path of the tubular electron beam, an electrical conductor in the form of a helix and having a high impedance at the operating frequency of the wave transmission circuit substantially coaxial with and extending along within said path of the tubular electron beam, and electric potential means connected to said conductor for maintaining it at a direct-current potential substantially different from that of said helical coil of the wave transmission circuit.

3. An electronic amplifier comprising an evacuated envelope containing an electron emitter and an electron collector spaced apart, beam focusing means for forming a tubular-shaped beam of electrons in which the electron paths are substantially parallel to the axis between said emitter and said collector, electric potential means connected to said emitter, collector and beam focusing means for moving the electrons along said paths, an electrical wave transmission circuit whereby an applied wave is amplified as it travels therealong comprising an electrical conductor extending along said path of the tubular electron beam in proximity thereto, an electrical conductor in the form of a helix and having a high impedance at the operating frequency of the wave transmission circuit extending along within said path of the tubular electron beam substantially along the axis thereof and electric potential means connected to said conductors for maintaining a substantial direct-current difference of potential between them.

4. An electronic device comprising an evacuated envelope containing an electron emitter and an electron collector spaced apart, beam focusing means for forming a tubular-shaped beam of electrons in which the electron paths are substantially parallel to the axis between said emitter and said collector, electrical potential means connected to said emitter, collector and beam focusing means for moving the electrons along said paths, two sections of electrical wave transmission circuit whereby a wave is amplified as its travels therealong each comprising a helical coil, the two coils being coaxial with and extending along different portions of said path of the tubular electron beam, two sections of electrical conductor each in the form of a helix and having a high impedance at the operating frequency of the wave transmission circuit and being located substantially coaxial with and extending along within said path of the tubular electron beam, one of said sections of conductor being within each of said sections of wave transmission circuit, and potential means connected to said conductor sections for maintaining each at a direct-current potential substantially different from that of the coil of the wave transmission circuit within which it is located.

5. A device according to claim 1 in which the high impedance electrical conductor comprises a helical conductor having a wave propagation velocity substantially less than the wave propagation velocity of the said helical coil of the wave transmission circuit.

6. A device according to claim 4 in which a said section of high impedance electrical conductor comprises a helical conductor having a wave propagation velocity substantially less than the wave propagation velocity of the coil of the wave transmission circuit within which it is located.

7. A device according to claim 3 in which the axial electrical conductor comprises a helical conductor having a wave propagation velocity substantially less than the wave propagation velocity of the said wave transmission circuit.

8. An electronic device comprising an evacuated envelope containing an electron emitter and an electron collector spaced apart, beam focusing means for forming a tubular-shaped beam of electrons in which the electron paths are substantially parallel to the axis between said emitter and said collector, electric potential means connected to said emitter, collector and beam

focusing means for moving the electrons along said paths, an electrical wave transmission circuit whereby an applied wave is amplified as it travels therealong comprising a helical coil coaxial with and extending along external to said path of the tubular electron beam, an electrical impedance means capable of conducting direct current, in the form of a helix and having substantial impedance at the operating frequency of the wave transmission circuit substantially coaxial with and extending along within said path of the tubular electron beam, and electric potential means connected to said impedance means for maintaining it at a direct-current potential substantially different from that of said helical coil of the wave transmission circuit.

9. An electronic device comprising an evacuated envelope containing an electron emitter and an electron collector spaced apart, beam focusing means for forming a tubular-shaped beam of electrons in which the electron paths are substantially parallel to the axis between said emitter and said collector; electric potential means connected to said emitter, collector and beam focusing means for moving the electrons along said paths, an electrical wave transmission circuit whereby an applied wave is amplified as it travels therealong comprising a helical coil coaxial with and extending along external to said path of the tubular electron beam, and electrical impedance means capable of conducting direct current, in the form of a helix, substantially coaxial with and extending along within said path of the tubular electron beam, and electric potential means connected to said impedance means for maintaining it at a direct-current potential substantially different from that of said helical coil of the wave transmission circuit.

10. An electronic device comprising an evacuated envelope containing an electron emitter and an electron collector spaced apart; beam focusing means for forming a tubular-shaped beam of electrons in which the electron paths are substantially parallel to the axis between said emitter and said collector; electric potential means connected to said emitter, collector and beam focusing means for moving the electrons along said paths, an electrical wave transmission circuit whereby an applied wave is amplified as it travels therealong comprising a helical coil coaxial with and extending along said path of the tubular electron beam, an electrical impedance means capable of conducting direct current, in the form of a helix and having substantial impedance at the operating frequency of the transmission circuit substantially coaxial with and extending along within said path of the tubular electron beam, and electric potential means connected to said impedance means for maintaining it at a direct-current potential substantially different from that of said helical coil of the wave transmission circuit.

11. An electronic device comprising an evacuated envelope containing an electron emitter and an electron collector spaced apart; beam focusing means for forming a tubular-shaped beam of electrons in which the electron paths are substantially parallel to the axis between said emitter and said collector; electric potential means connected to said emitter, collector and beam focusing means for moving the electrons along said paths, an electrical wave transmission circuit whereby an applied wave is amplified as it travels therealong comprising a helical coil coaxial with and extending along said path of the tubular electron beam, an electrical impedance means capable of conducting direct current, in the form of a helix, substantially coaxial with and extending along within said path of the tubular electron beam, and electric potential means connected to said impedance means for maintaining it at a direct-current

potential substantially different from that of said helical coil of the wave transmission circuit.

12. An electronic amplifier comprising an evacuated envelope containing an electron emitter and an electron collector spaced apart, beam focusing means for forming a tubular-shaped beam of electrons in which the electron paths are substantially parallel to the axis between said emitter and said collector; electric potential means connected to said emitter, collector and beam focusing means for moving the electrons along said paths, an electrical wave transmission circuit whereby an applied wave is amplified as it travels therealong comprising an electrical conductor extending along said path of the tubular electron beam in proximity thereto, a second electrical conductor extending along within said path of the tubular electron beam substantially along the axis thereof, said second electrical conductor being in the form of a wave transmission line having a wave propagation velocity therealong substantially less than the wave propagation velocity of said wave transmission circuit, and electric potential means connected to said conductors for maintaining a substantial direct-current difference of potential between them.

13. An electronic device comprising an evacuated envelope containing an electron emitter and an electron collector spaced apart, beam focusing means for forming a tubular-shaped beam of electrons in which the electron paths are substantially parallel to the axis between said emitter and said collector; electric potential means connected to said emitter, collector and beam focusing means for moving the electrons along said paths, two sections of electrical wave transmission circuit whereby a wave is amplified as it travels therealong each comprising a helical coil, the two coils being coaxial with and extending along different portions of said path of the tubular electron beam, two sections of electrical conductor located substantially coaxial with and extending along within said path of the tubular electron beam, one of said sections of conductor being within each of said sections of wave transmission circuit, each said section of conductor being in the form of a helix and having an impedance at the operating frequency of the wave transmission circuit which for a given length along the wave transmission circuit is higher than the similar impedance of the wave transmission circuit, and potential means connected to said conductor sections for maintaining each at a direct-current potential substantially different from that of the coil of the wave transmission circuit within which it is located.

14. A traveling wave vacuum tube comprising means for generating a hollow tubular electron beam for flow along a given path, a wave propagating circuit in the form of a helically wound conductor extending along and coaxial with said beam path, an electrode in the form of a helically wound conductor extending along inside of and coaxial with said beam path and having a wave propagation velocity therealong substantially less than the wave propagation velocity along said wave propagating circuit, and means electrically connected to said circuit and said electrode to apply thereto a difference of direct current potential.

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