

May 3, 1955

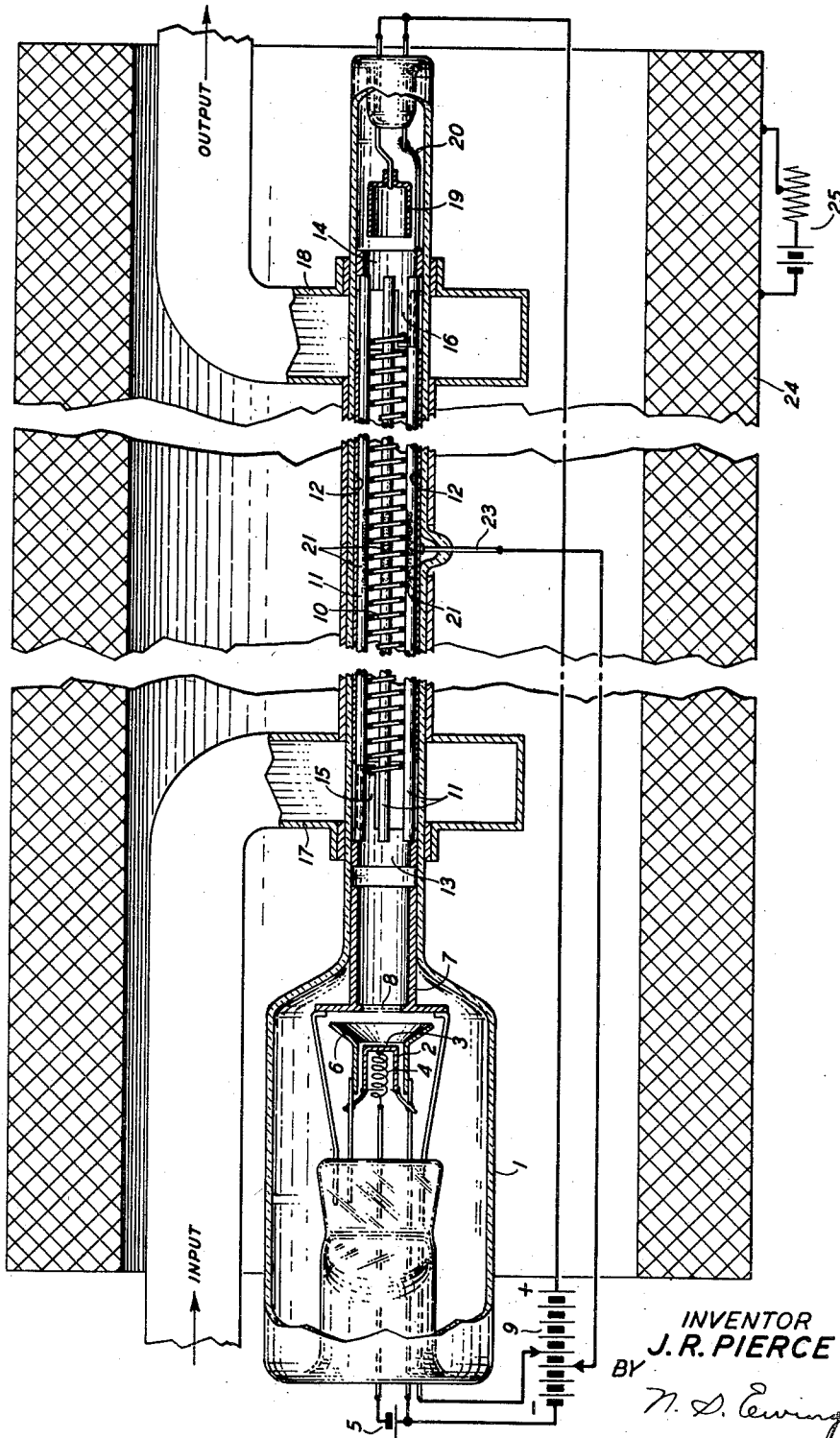
J. R. PIERCE
ELECTRONIC AMPLIFIER

2,707,759

Filed Dec. 10, 1948

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FIG. 1



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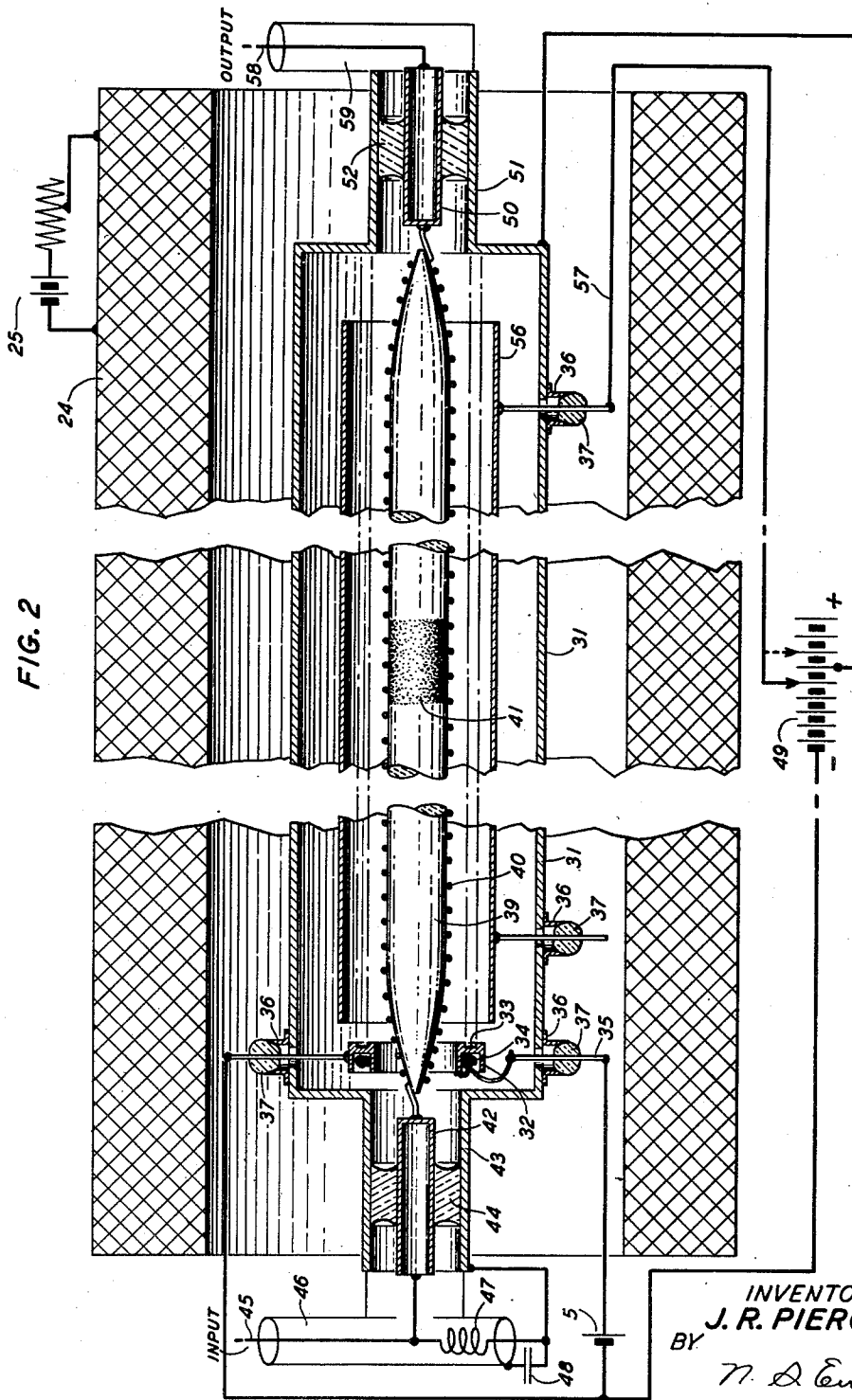
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FIG. 2



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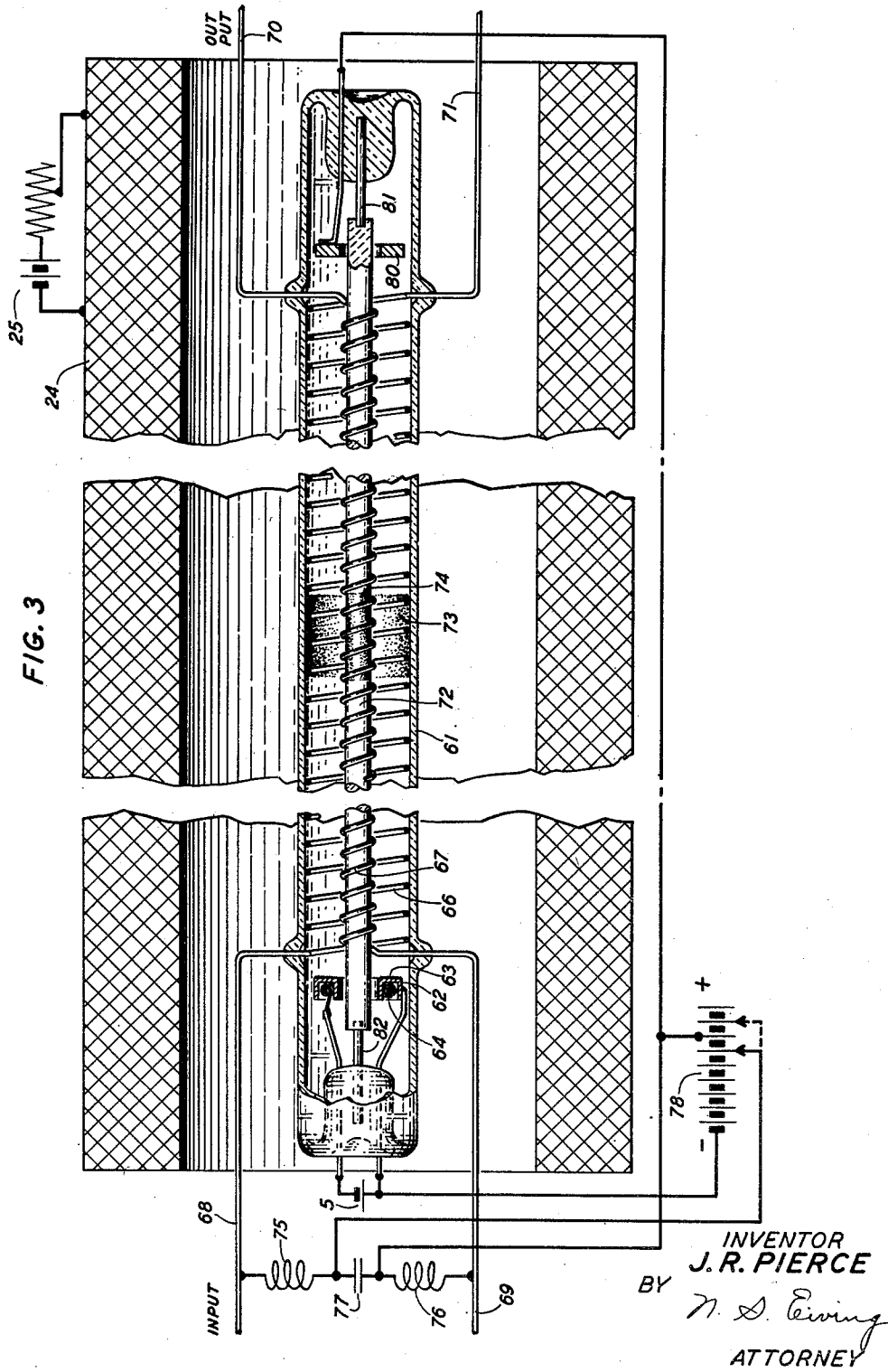
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ELECTRONIC AMPLIFIER

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3 Claims. (Cl. 315—3.6)

This invention relates to high frequency electronic amplifiers, particularly those of the traveling wave type in which a relatively long electron beam is projected along an electrical wave transmission circuit in such proximity as to be coupled thereto.

This application is a parent of my applications Serial No. 197,412, filed November 24, 1950 and Serial No. 345,503, filed March 30, 1953.

The general objective of the invention is to provide improved electron beam type traveling wave amplifiers.

A collateral objective is to provide improved focussing of the electron beam in such traveling wave amplifiers.

Another objective is to reduce the undesirable noise components in the output signal of such devices.

Another object is to provide amplifiers having high current electron beams with the noise reducing feature.

Another object is to provide for simple coupling means between amplifier tube elements and the external high frequency transmission circuit.

In my copending applications, Serial No. 640,597, filed January 11, 1946, now issued as Patent 2,636,948, April 28, 1953, and Serial No. 704,858, filed October 22, 1946, now issued as Patent 2,602,148, July 1, 1952, several forms of high frequency amplifier tubes of the traveling wave type employing extended electron beams and wave circuits coupled to each other are shown. Such devices, by their nature, impose rather severe mechanical and electrical requirements. The length of the beam and the wave circuit and the necessity for maintaining suitable coupling between them require accurate alignment of the tube elements and due to the proximity of the beam and the circuit it is important that the beam be kept well focussed. Further, in order to obtain amplification efficiently through transfer of energy from the electron beam to the electrical wave, it is desirable to have a large current electron beam coupled as completely as possible to the electrical wave circuit. Also, it has been found that in long beam tubes, particularly, troublesome electrical noise may occur in the output circuit, apparently due to the trapping of positive ions along the electron beam where a potential depression is formed by the electron space charge. This makes it desirable to remove these ions from the electron stream and so prevent their accumulation to a troublesome degree.

The above requirements are met and the associated problems overcome according to this invention by providing electrodes producing transverse direct-current electric fields in the vicinity of the electron beam to focus the beam and to sweep out the positive ions, by utilizing tubular electron beams concentric with the helices to obtain high beam current with close coupling to the helices and by providing for direct connection between tube helices and an external coaxial or balanced transmission line to secure simple coupling means.

The invention, its objects and advantages, are explained more fully in the following description and the accompanying drawings, in which:

Fig. 1 is a diagram of a traveling wave amplifier tube

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and circuit somewhat similar to embodiments shown in my previously mentioned copending applications in that a solid electron beam is projected along the axis of a single helix and in that wave-guide type external circuits are used. A novel feature is a metallic sleeve forming an electrical shield which surrounds the helix and is maintained at a potential negative with respect to the helix;

Fig. 2 shows an embodiment of the invention employing a single tapered helix along the external surface of which is projected a tubular electron beam. An electrical shield surrounds the electron beam and the helix is directly connected to coaxial external circuits; and

Fig. 3 illustrates an embodiment in which two concentric helices directly connected to balanced external circuits are employed and a tubular electron beam is projected concentric with and between the two helices which are maintained at different direct-current potentials.

Referring now to the drawings in more detail, all of them show the tubes and circuits broken in the central portions in a conventional manner so that the elements may be shown in sufficiently large scale without the longitudinal dimensions exceeding the available drawing space. To show the entire length of typical tubes at the scale employed would require about twice the length of the drawing space.

In Fig. 1 the evacuated envelope of the amplifier tube which may be of glass or other suitable material is indicated by the designation 1. Within this envelope are tube and circuit elements. The cathode 2 has an emissive coating on the surface 3 which is heated by means of heater 4. The electron beam-forming electrode 6 is shaped and positioned with respect to the cathode to direct the electrons in parallel paths toward the electron collector 19. 7 is an electron accelerating electrode with an associated grid 8. The helix 10 of conducting material provides the high frequency wave transmission path through the tube and is designed so that the phase velocity of the wave along the axis of the helix is substantially the same as the velocity of the electron beam projected along the axis. Ceramic rods 11 support and position accurately the helix 10 and at the ends are fitted into notches in the metallic collars 13 and 14. The metallic sleeve or shield 12 surrounding the helix 10 between the envelope 1 and the rods 11 is maintained at a potential negative with respect to the potential of the helix to provide a field penetrating into the helix which will tend to focus the electron beam and at the same time pull positive ions out between the turns of the helix to the shield where they will be collected and neutralized. The collar 13 terminates the input end of the helix 10 and by-passes the electric wave from the input end of the helix to the input wave guide 17. The collar 14 terminates the output end of the helix 10 and by-passes the electric wave from the output end of the helix to the output wave guide 18. The connector 15 between the input end of the helix 10 and the collar 13 couples the input end of the helix to the input wave guide 17. The connector 16 between the output end of the helix 10 and the collar 14 couples the output end of the helix to the output wave guide 18. 19 is an electron collector which terminates the electron beam path. Potential source 5 serves to energize the cathode heater 4 while source 9 provides potential differences between the cathode and electron accelerator 7, the shield 12, the collector 19 and the helix 10 by means of the leads shown, lead 20 furnishing the connection to the helix 10 through collar 14 and connector 16. 21 designates dissipative material capable of absorbing high frequency energy. This material is deposited on the ceramic rods 11 on the inwardly facing surfaces only and not on the surfaces in contact with the sleeve 12 so that the helix 10 is not short-circuited to the sleeve by the conduction through the dissipative material. This loss

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material 21 provides a certain amount of attenuation to the high frequency wave in the wave transmission circuit along which the electron beam amplifies the wave energy which is important in a wave amplifier of this type. The solenoid 24 which may be energized from any direct-current source such as battery 25, serves to provide an axial magnetic focussing field throughout the length of the electron beam. It should be noted in this connection that all of the conducting material employed in the tube structure must be non-magnetic.

In operation of the Fig. 1 embodiment just described, the wave to be amplified enters through wave-guide portion 17, is transferred to the input end of the helix 10 through the coupling connector 15 which is in the field of the wave guide, is transmitted along the helix to the coupling connector 16 at the output end of the helix by which it is transferred to the output wave guide 18. The electron beam originating at the cathode surface 3 is projected along the axis of the helix to the collector 19. The helix provides a wave transmission path several wavelengths long (in a typical case as many as forty wavelengths). The velocity of the high frequency wave along the axis of the helix is less than its velocity along the wire of the helix depending upon the radius of the helix and the pitch of the winding, the axial velocity being approximately the velocity along the wire divided by the circumference of the helix in inches and the number of turns per inch. Thus, the helix may be designed so that the velocity of the wave along the axis of the helix is reduced to be near the velocity of the electron beam projected therealong, such a velocity being necessary to allow amplification of the wave. Final adjustment of the electron beam velocity may be made by adjustment of the electron accelerating voltage.

With the tube adjusted and in operation there is interaction between the high frequency field of the helix and the electron beam so that the input high frequency wave applied to the helix 10 induces a similar wave in the electron beam which increases along the beam and transfers high frequency energy from the beam to the electric wave traveling along the helix to the output wave guide 18. Thus the electric wave is amplified in its passage between the input guide 17 and the output guide 18. In order to obtain efficiently the required interaction between the high frequency field of the helix and the electron beam it is desirable that the beam focus be well maintained so that the beam may be projected close to the helix without an excessive number of electrons striking it. To aid in maintaining the beam focus the sleeve 12, previously mentioned, is provided. This sleeve is inside the tube envelope. It surrounds and is coaxial with the helix 10 and the path of the electron beam therein. The helix is separated from the sleeve by the insulating supporting rods 11 which fit snugly inside the sleeve and outside the helix and position the helix in the tube and with respect to the electron beam. The sleeve 12 is connected to potential source 9 through lead 23 to maintain its potential below that of the helix 10 which is shown connected to a more positive potential point on source 9 through lead 20, collar 14 and connector 16. By virtue of the potential difference between sleeve 12 and helix 10 a configuration of electric field is produced in the vicinity of the helix conductor, between the turns and in the interior of the helix which tends to focus the electron beam and so prevent spreading of the beam and excessive collection of electrons by the helix conductor.

The sleeve 12 maintained at a lower potential than the helix 10 in addition to providing a focussing effect on the electron beam performs also another important function. The electric field configuration produced, having radially directed components transverse to the direction of the electron beam, tends to move positive ions out of the beam and between the turns of the helix to the sleeve where they are collected. This tends to prevent the accumulation of ions in the beam to a degree

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where noise oscillations may occur. In this manner noise current at the output of the tube originating in the electron beam is reduced.

Fig. 2 illustrates an embodiment of the invention differing from Fig. 1 principally in that the electron beam is tubular and is projected along the exterior of the helix rather than along the axis of the helix as in Fig. 1. There are, however, other differences in the structure and circuit of Fig. 2.

In Fig. 2 the evacuated envelope of the tube, designated 31, is of non-magnetic conducting material such as copper, bronze, aluminum or molybdenum, for example. It is vacuum-tight and the necessary leads enter the envelope through glass or ceramic insulating seals such as 37, 44 and 52. The seals 37 are attached to metal eyelets 36. 32 is a ring-shaped cathode within a groove of which is an emissive coating 33 which is heated by heater 34. The heater 34 is energized from battery source 5. The cathode 32 with its emissive coating 33 forms a tubular electron beam between the helix 40 and the shield 56 as indicated by the broken lines extending to the right of the cathode. The electrons in the beam are collected by the conducting envelope 31 at the output end of the tube though alternatively a separate collecting electrode may be used if desired. The helix 40 is wound on a supporting member 39 which may be of ceramic or a similar insulating material. The helix is wound over most of its length to give an axial wave velocity approximately equal to the velocity of the electron beam as was explained in connection with Fig. 1; however, the ends may be tapered in diameter as shown, and also in pitch of the winding if desired, to provide impedance match to the input and output coaxial lines. As an alternative it may be understood that input and output wave guides coupled as shown in Fig. 1, may be employed in place of the coaxial lines and tapered helix of Fig. 2. Near the center of the helix loss material 41 is deposited on the insulating support member 39. This provides high frequency attenuation in the wave transmission circuit to prevent backward transmission and feedback and to facilitate matching the input and output impedances. 42, 43 and 44 designate respectively the inner conductor, the outer conductor, and the ceramic or glass insulating seal of the coaxial vacuum-tight input lead to the helix. 45 and 46 designate the coaxial signal input line. 47 is a high frequency choke coil to provide a high impedance connection between the helix and the battery 49. 48 is a by-pass condenser. 50, 51 and 52 designate respectively the inner conductor, the outer conductor, and the ceramic or glass insulating seal of the coaxial vacuum-tight output lead from the helix. 58 and 59 designate the coaxial signal output line. Electron beam accelerating voltage is provided by battery 49 which is connected to the conducting envelope 31 of the tube and from thence through choke 47 to the helix 40 as previously mentioned. The battery 49 also provides potential, which may be either below or above that of the helix, to the shield 56 through lead 57. The solenoid 24 which may be energized from any suitable direct-current source, such as battery 25, serves to provide an axial magnetic focussing field throughout the length of the electron beam. The tubular shield 56 of non-magnetic conducting material surrounds the electron beam and is maintained at a potential different from that of the helix which is surrounded by the beam. Thus, an electric field is produced between the helix and the shield which is transverse to the direction of the electron beam and acts to move positive ions from the beam. If the shield 56 is positive with respect to the helix 40 the ions from the beam are collected on the helix, while if the shield 56 is negative with respect to the helix 40 the ions are collected on the shield. In this manner the accumulation of ions in the beam is prevented and the noise current at the output of the device reduced as in the case of the Fig. 1 embodiment.

The Fig. 2 embodiment serves to amplify the electric wave as it travels along the helix in the same manner as the Fig. 1 embodiment.

The Fig. 3 embodiment like that of Fig. 2, utilizes a hollow electron beam. However, the beam is projected between two coaxial helices which together form the electrical wave transmission circuit rather than between a helix and a shield as shown in Fig. 2.

In Fig. 3 a vacuum-tight evacuated glass envelope is designated 61. The ring cathode 62 with an emissive coating 63 is utilized to produce a tubular beam extending between the two coaxial helices 66 and 67 to the collector 80. The cathode is heated by heater 64 energized from the battery 5. The outer helix 66 rests against and is supported by the inner surface of the envelope 61. The inner helix 67 is wound upon the ceramic support 72 which is supported at the ends by the pins 81 and 82. The balanced signal input line 68, 69 is connected directly to the input ends of the two helices 66 and 67 and the balanced output line 70, 71 is connected directly to the output ends of the two helices. Loss material 73 is deposited on the inside surface of the envelope 61 near the center of the helix 66 and loss material 74 is deposited on the ceramic support 73 near the center of the helix 67. This loss material provides the desirable high frequency attenuation in the wave transmission circuit. Electron beam accelerating voltage is derived from the battery 78 which is connected to the helices 66 and 67 through the high impedance choke coils 75 and 76, respectively, and to the electron collector 80. 77 is a by-pass condenser. The two helices are maintained at different direct-current potentials and either one may be the higher as indicated by the tap connections to the battery 78. With the helices at different potentials a radial electric field, transverse to the direction of the electron beam, is produced in the region of the electron beam between the two helices. This field tends to move any positive ions in the beam toward the lower potential one of the helices where they are collected and thereby prevented from accumulating in the beam to a degree where noise oscillations are produced. 77 is a high frequency by-pass condenser. The solenoid 24 energized from a direct-current source such as the battery 25 provides an axial magnetic focussing field along the path of the electron beam.

The helices are wound to have about the same phase velocities separately and, as explained in connection with Fig. 1, to have phase velocities approximately the same as the velocity of the electron beam. For this reason since the diameters of the helices are different the turn spacings may be quite different though for convenience they are shown nearly the same in Fig. 3. Under this condition, as in the Fig. 1 and Fig. 2 embodiments, the high frequency wave receives energy from the electron beam and is amplified as it travels along the helices.

All slow electromagnetic waves have both longitudinal and transverse electric field components. Sometimes either the longitudinal or the transverse field may go to zero along a line or plane parallel to the direction of propagation. For instance, for the slow mode of propagation there is no transverse field on the axis of a helically-conducting sheet. Still, over any plane normal to the direction of propagation there are bound to be both longitudinal and transverse field components.

If a very strong longitudinal magnetic field is used in connection with a traveling wave tube, the transverse motions of electrons may be so restricted as to be of little importance. With weak focussing fields, however, the transverse motion of electrons may be important in producing gain. The transverse fields can force the electrons sidewise, and thus change the longitudinal fields acting on them in such a way as to abstract energy from the electron stream. This is closely analogous to the action of the longitudinal fields in displacing electrons for-

ward or backward into regions of greater or lesser longitudinal field.

The double helix structure shown in Fig. 3 will support both a longitudinal wave in which the electric field mid-way between the helices is substantially longitudinal, and a transverse wave in which the electric field mid-way between the helices is substantially transverse. The two waves will have slightly different phase velocities. Either wave may be used in producing amplification. If, for example, the transverse wave is to be used the electron velocity should be made substantially equal to the phase velocity of the transverse wave, and the coupling at the ends of the helix should be made such as to couple efficiently to the transverse wave. This adjustment can be made by varying the pitch of one helix near the end so as to add or subtract wire. For instance, if the coupling is initially good for exciting a longitudinal wave, adding or subtracting approximately a half free-space wavelength of wire at the end of either helix will make the coupling good for the transverse wave.

It is desirable that the differences in velocity between the longitudinal and the transverse wave be made as great as possible, so that the desired wave can be clearly chosen by adjusting electron speed. For a given separation of helices, the separation in wave velocity will be greater if the helices are wound in opposite senses than if they are wound in the same sense, and hence they should be wound in opposite senses.

What is claimed is:

1. An electronic device comprising an evacuated envelope containing a cathode and an electron collector spaced apart, means for producing a beam of electrons along an extended linear path between said cathode and said collector, a first member of electrically conducting material in helical form surrounding said path and extending therealong in proximity thereto, a second member of electrically conducting material extending along said path in proximity thereto, surrounding said first member and spaced laterally therefrom, and direct current potential means connected to said two members for maintaining a substantial direct current potential difference between them with said first member at the higher potential.

2. An electronic device having input terminal means for coupling to an external input circuit and output terminal means for coupling to an external output circuit, said device comprising an evacuated envelope containing a cathode and an electron collector spaced apart, means for producing a beam of electrons along an extended linear path between said cathode and said collector, a high frequency electrical wave propagating circuit surrounding and disposed along said path in proximity thereto and having an output end coupled to said output terminal means, a member of electrically conducting material extending along said path in proximity thereto surrounding said wave propagating circuit and spaced laterally therefrom, and direct current potential means connected to said propagating circuit and said member for maintaining a substantial potential difference between them with the propagating circuit at the higher potential.

3. An electronic device having input terminal means for coupling to an external input circuit and output terminal means for coupling to an external output circuit, said device comprising an evacuated envelope containing a cathode and an electron collector spaced apart, means for producing a beam of electrons along an extended linear path between said cathode and said collector, a high frequency electrical wave propagating circuit surrounding and disposed along said path in proximity thereto, one end of said propagating circuit being coupled to said output terminal means and the other end of said wave propagating circuit being coupled to said input terminal means, a member of electrically conducting material extending along said path in proximity thereto surrounding said wave propagating circuit and spaced laterally therefrom, and direct current potential means connected to said propa-

gating circuit and said member for maintaining a substantial direct current potential difference between them with the propagating circuit at the higher potential.

References Cited in the file of this patent

UNITED STATES PATENTS

2,064,469 Haeff ----- Dec. 15, 1936

2,233,126

2,300,052

2,511,407

2,578,434

5 2,600,509

Haef ----- Feb. 25, 1941
Lindenblad ----- Oct. 27, 1942
Kleen et al. ----- June 13, 1950
Lindenblad ----- Dec. 11, 1951
Lerbs ----- June 17, 1952