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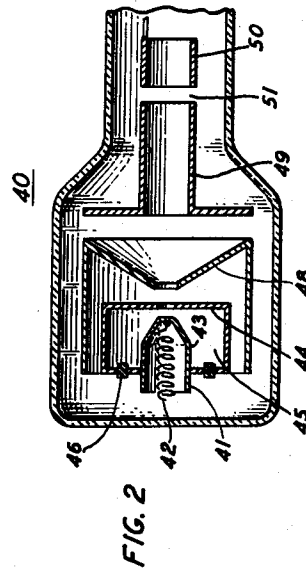
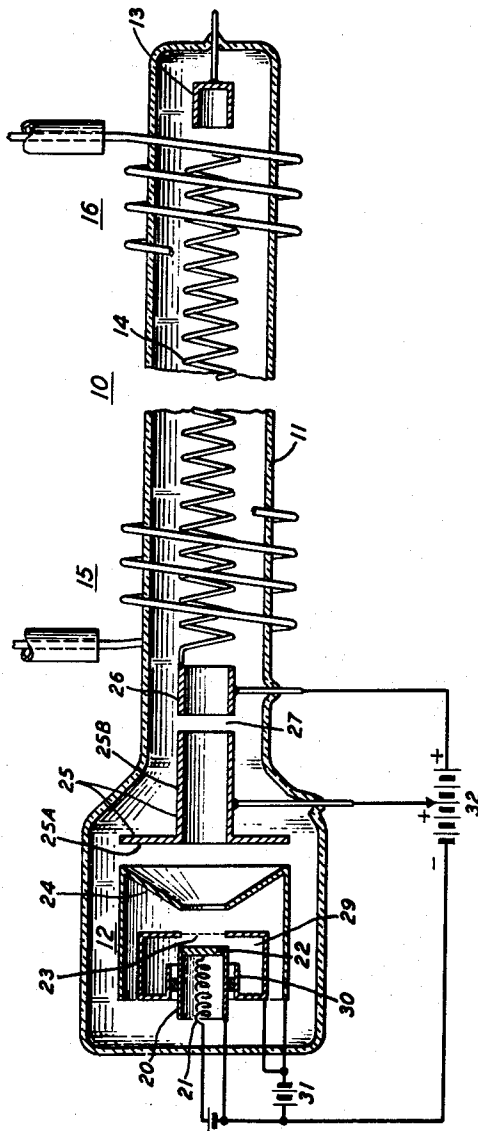
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LOW NOISE VELOCITY MODULATION APPARATUS

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FIG. 1



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## LOW NOISE VELOCITY MODULATION APPARATUS

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This invention relates to velocity modulation apparatus for amplifying radio frequency signals.

An object of the present invention is to improve the signal-to-noise ratio (or, noise figure) in velocity modulation-type amplifiers, for example, of the klystron and traveling wave tube type.

A more specific object is in such amplifiers to minimize the effect on the signal circuits associated with the electron beam of "shot" noise in the current emitted from a thermionic cathode.

It is characteristic in velocity modulation-type amplifiers that an electron beam which has been space-charge-limited is projected past an input arrangement which impresses signal modulations on the beam and such modulations are thereafter used in setting up an amplified electromagnetic wave in an output arrangement. In a klystron, the input and output arrangements each comprise a cavity resonant at the operating frequency. In a traveling wave tube, the input and output arrangements comprise opposite ends of a slow wave interaction circuit.

One of the most important problems still faced in such velocity modulation apparatus is the relatively high noise level characteristic thereof which makes difficult operation at low input signal levels. The most important source of such noise is the random rate of emission of and the Maxwellian distribution of velocities among the electrons emitted from the thermionic cathode characteristic of such apparatus. Such inhomogeneities in the beam are usually described as shot noise, or modified shot noise, and velocity fluctuations. The invention is related in a broad sense at the reduction of the effects of the shot noise component, or convection current component, of the noise.

Convection current noise of this kind ordinarily is wide band in its frequency components, and accordingly such components which are within the operating band subsequently induce noise wave energy of corresponding frequencies into the signal circuit which is amplified in the manner of input signals and gives rise to appreciable noise wave energy at the output. It is in accordance with the invention to reduce in the electron beam the noise components characterized by frequencies in the operating band whereby the noise wave energy at the output is reduced to an insignificant value.

It has been shown hitherto that both the noise convection current and the noise velocity fluctuations cause noise standing wave patterns on the electron stream, and these patterns exhibit maxima and minima along the path of electron flow between the cathode and the point where signal modulations are impressed on the beam. It is further characteristic that a point of noise convection current maximum is a point of noise velocity minimum, and vice versa, at regions of the beam significantly removed from the cathode surface.

Noise reduction in a traveling wave tube has been achieved hitherto both by passing the electron stream through a nonresonant gap which sharply accelerates the

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electrons at a point of noise convection minimum along the path of flow between the cathode and the start of the slow wave circuit and by locating the start of the slow wave interaction circuit at an optimum point with respect to a noise convection minimum. The general principles applicable are set forth in an article by D. A. Watkins, entitled "Traveling Wave Tube Noise Figure," Proceedings of the I.R.E., volume 40, pages 65 through 70 (1952). In essence, this technique acts to reduce the noise due to velocity fluctuations near the cathode but tends to increase the noise due to convection currents in the electron beam. Accordingly, although such a technique does afford some improvement, there is a limit, determined by the noise convection current near the cathode, beyond which it is impossible to reduce noise further by this technique alone.

The present invention relates still more particularly to an arrangement which reduces specifically the effect of noise convection current near the cathode. Accordingly, the invention has primary application in combination with arrangements which reduce the effect of noise velocity fluctuations on the signal, although it does have separate utility. In velocity modulation devices, electrons ordinarily are accelerated through a long space-charge-limited region through which the noise convection current is transmitted to downstream portions of the beam. It is important if the noise convection current is to be kept low, that the electrons be appreciably accelerated only in a region beyond that where the current is so limited. A space-charge-limited beam is one which obeys Child's law, i.e., only a fraction of the electrons emitted is drawn off to form the beam, the remainder returning to the cathode through the agency of a potential minimum in a region adjacent to the front of the cathode, so that for further increases in cathode emission in the absence of changes in the accelerating potential only a small change in the beam current results. A space-charge-limited region is one where the space charge forces in the direction of flow are so strong that they limit the flow and so the net current in the beam is appreciably affected by changes in the accelerating field. This limiting effect has a tendency to reduce fluctuations in convection current, but this tendency becomes ineffective for components corresponding to high frequencies where the transit times are long in comparison to the period of such high frequency components.

A more specific object of the invention is to effect the reduction of convection current noise corresponding to high frequencies. To this end, a feature of the invention is an electron permeable control member or electrode positioned close to the cathode and biased with respect thereto for acting to confine the region affecting the return of electrons to the cathode to the short interspace formed between it and the cathode. By this expedient the effect of controlling the fraction of the emitted current which forms the beam is confined to a short region of relatively short transit time. Moreover, as a related feature of the invention the cathode and the control electrode are made to form opposite surfaces of a cavity substantially resonant at the operating frequency to provide a high radio frequency impedance across the space-charge-limited region. By this expedient, there is further reduced in the beam passing beyond the control electrode noise convection components characteristic of the frequencies in the operating band.

It is important that this smoothing cavity be as close to the electron source as possible since there the noise velocity fluctuations and noise convection current are still substantially uncorrelated and it is possible to reduce the one without affecting the other. At points removed along the path of flow from the cathode surface, correlation

between the two types of noise develops and it becomes difficult to affect one independently of the other.

In an illustrative traveling wave tube embodiment of the invention, a control grid is positioned in front of the cathode and maintained at a suitable D.-C. potential with respect thereto for defining the space-charge-limited portion of the path of flow of the electrons, and the cathode and the control grid are designed to form opposite surfaces of a cavity resonant at the operating frequency. This arrangement serves to keep small the noise convection current which ordinarily sets up noise waves of frequencies in the operating band. Beyond the control grid an electrode system focuses the electrons penetrating there past into a beam and thereafter accelerates the beam to a velocity suitable for permitting interaction with the slow wave on the interaction circuit. Advantageously, this electrode system also provides a velocity jump in the electron beam at a point of noise velocity maximum to attenuate the noise velocity fluctuations on the beam. The wave interaction circuit is located beyond the electrode system at a point which preferably is chosen experimentally for lowest noise.

The invention will be described in more detail in conjunction with the accompanying drawings in which:

Fig. 1 shows in longitudinal cross section a traveling wave amplifier constructed in accordance with the invention for improved signal-to-noise ratio; and

Fig. 2 shows in longitudinal cross section an electron gun which can be incorporated in the tube of Fig. 1 in place of the electron gun shown therein.

In the traveling wave tube 10 shown in Fig. 1, the various tube elements are housed in an evacuated envelope 11, for example, of glass or quartz. At one end of the envelope, an electron gun 12 serves as the source of electrons which are formed into a beam for projection axially through the envelope to a target electrode 13 housed at the opposite end. Along the major portion of the path of flow a slow wave circuit 14, shown, for example, as a helical conductor, propagates an electromagnetic wave in field coupling relation with the beam for interaction therewith over a plurality of operating wavelengths. An input connection 15 to the upstream (i.e. adjacent the source) end of the wave circuit is used to apply to the circuit for amplification a signal wave supplied from a signal source and an output connection 16 to the downstream (i.e. adjacent the target) end of the circuit is used to abstract the amplified wave which is thereafter supplied to a load. The input and output connections are shown, for example, as coupled helices. The principles of such coupling are set forth in United States Patent 2,811,673, issued October 29, 1957, of R. Kompfner. Various other coupling arrangements are known to workers in the art.

In the various respects described briefly above, the tube is of familiar form. In accordance with the invention, the tube is modified by the inclusion of a novel form of electron gun. The electron gun 12 comprises a conductive heater compartment 20 which houses the heater filament 21 and one surface 22 of which is coated to be electron emissive when heated to serve as the thermionic cathode of the gun. Spaced close to the cathode is an electron permeable control electrode member 23, shown, for example, as a very fine grid, which is maintained at a potential slightly negative with respect to the cathode so that electron current interception thereby is minimized. In accordance with one feature of the invention the member 23 is positioned sufficiently close to the cathode so that its presence rather than that of the potential minimum effectively controls the current at the frequency of operation. Either it should be so close to the cathode that there is no potential minimum between it and the cathode, or it should be very close to the potential minimum. This means that beyond the member 23 the space charge forces in the direction of

flow do not serve to limit the flow. As a consequence, changes in potential in this region have little effect on the amount of current flow passing the grid 23. Beyond the grid 23 beam forming electrode 24 advantageously serves to form the electrons which penetrate beyond the control electrode 23 into a solid electron beam, one preferably circular in cross section. The beam forming electrode 24, too, is advantageously maintained at a slightly negative potential with respect to the cathode. In some applications, it may be convenient to incorporate the roles of the control electrode 23 and the beam forming electrode 24 in a single electrode which will serve both to confine the space-charge-limited region of flow to only a short initial portion of the path of flow as discussed above and to form the electrons into a beam for flow beyond this initial portion. Beyond the beam forming electrode 24 is the first accelerating anode 25 which is operated at an intermediate positive potential with respect to the cathode 22 and serves to accelerate the electrons in the beam. The accelerating electrode 25 comprises a circular flange like portion 25A and an elongated tubular portion 25B surrounding the path of flow and forming a first drift region. Beyond the first accelerating anode 25 there is positioned a second accelerating anode 26 which is an elongated tube surrounding the path of flow and forms a second drift region along the path of flow. The second accelerating anode 26 is maintained at a high positive potential for accelerating the electron beam to a velocity substantially equal to the axial phase velocity of the wave propagating along the slow wave circuit 14. In the manner characteristic of the technique described in the above identified Watkins article for reducing noise velocity fluctuations on the electron beam, the gap 27 between the first and second accelerating anodes is made nonresonant and located experimentally at a point along the path of flow which corresponds to a noise velocity maximum.

In accordance with another feature of the invention, the cathode 22 and the control electrode 23 form opposite surfaces of a cylindrical cavity 29 which is resonant at the midfrequency of the operating band to be amplified. The cavity 29 is constricted in its center to define there a short gap between its two opposite surfaces including the cathode and control grid. This gap is advantageously short since it represents the space-charge-limited portion of the path of flow which should be short for low noise convection current. In order to isolate the cathode and the control grid for direct currents so that a D.-C. potential may be set up therebetween and yet to maintain continuity for radio frequency currents flowing in the cavity, the cavity includes a tubular portion 30 which surrounds the heater compartment 20 spaced therefrom by insulating spacers. The geometry of the gap formed between the heater compartment and the tubular portion 30 is adjusted so that the gap acts as a quarter wavelength choke at the operating frequency. This arrangement minimizes leakage from the cavity and yet makes feasible D.-C. isolation of the cathode and control portions of the cavity. By suitable lead-in connections from the D.-C. voltage source 31, there is established a D.-C. potential between the cathode 22 and control grid 23. By other lead-in connections from the D.-C. voltage source 32, operating potentials are applied to the other elements of the electron gun.

It is characteristic of an electron gun of the kind described that the fraction of the electron current forming the beam is influenced by the beam current only over a short region which is close to the cathode. The electrons are little accelerated in this region of high space charge, but instead are accelerated in a subsequent region in which the space charge forces in the beam are relatively low. In addition, in this region of acceleration, a high impedance at the operating frequency is presented to the beam essentially at the point of potential minimum associated with the space-charge-limited flow. This serves to

attenuate the noise convection current at the operating frequency. The net effect of these expedients is to provide a beam in which the noise convection current which can affect the signal has been made low. Moreover, the noise due to velocity fluctuations is reduced in turn by the velocity jump provided at the gap 27 between the two drift sections of different potentials of the beam path. Accordingly, the two arrangements complement one another in providing for use by the slow wave circuit a beam in which both the noise convection current and noise velocity fluctuations are small.

The slow wave circuit 14 is advantageously operated at the same D.-C. potential as the second accelerating anode 26 in order to avoid further velocity discontinuities in the beam. Accordingly, one end of the helical conductor 14 is connected to the second accelerating anode 26. For minimum noise, there is an optimum location along the beam path for the start of the slow wave circuit, but such location is best found experimentally for a given set of operating parameters.

In a klystron, the buncher cavity would be similarly located experimentally at a point of minimum noise and operated at the same D.-C. potential as the last accelerating anode.

Because of radial space charge forces which tend to make electrons in the beam diverge therefrom, it is usually desirable in a traveling wave tube to apply focusing forces to keep the beam cylindrical in its flow past the wave circuit. Such focusing forces can be provided by a longitudinal magnetic field. In the interest of simplicity, there is omitted the auxiliary equipment for providing the longitudinal magnetic field. As is known to workers in the art, if magnetic focusing of the kind described as Brillouin focusing is employed, it is important to shield the cathode from the magnetic field. In such a case, the flange like portion 25A of the first accelerating anode 25 can advantageously be made of magnetic material and used as a magnetic shield.

It will also be necessary to adopt measures for avoiding oscillations as the result of mismatches at the coupling connection. Various techniques are now known for this purpose including the insertion of resistive lossy material in the circuit or the use of ferrite elements to introduce loss selectively in the undesired direction of propagation of the circuit.

It is unnecessary that a grid be employed as the control element. In Fig. 2 there is shown a modified gun 40 which can be used in the tube of Fig. 2 in place of electron gun 12. In this gun, the heater compartment 41 which houses the heater filament 42 has a constricted end portion 43 which is coated to be electron emissive for serving as the cathode. The electron permeable control electrode is formed by a conductive surface 44 which is positioned close to the cathode and apertured for passage of the electrons therepast. The various factors involved in its positioning are the same as were discussed above. The conductive surface 44 together with the heater compartment 41 form opposite surfaces of a cavity 45 resonant at the middle of the operating frequency band. In order to permit the establishing of a D.-C. potential between the cathode 43 and the control element 44, the cavity includes a dielectric ring 46 which has no effect on radio frequency currents but does isolate for D.-C. the cathode and control element portions of the resonant cavity 45. Suitable lead-in connections from a D.-C. voltage source (not shown) maintain the control element at a small negative D.-C. potential with respect to the cathode. Therebeyond, a beam forming electrode 48 forms the electrons passing through the aperture in the control surface 44 into a solid cylindrical beam. Accelerating anodes 49 and 50, corresponding to the accelerating anodes 25 and 26 of electron gun 12 shown in Fig. 1, provide a velocity jump at the nonresonant gap 51 for reducing noise velocity fluctuations in the beam. With a gun of this kind, it is preferable to immerse the whole gun in a longitudinal

magnetic field for suppressing the diverging effects of radial space charge forces.

The various embodiments described are illustrative merely of the general principles of the invention. Various modifications will appear to a worker skilled in the art which do not depart from the spirit and scope of the invention. In particular, as indicated briefly above an electron beam formed in the manner described to have small noise convection current and noise velocity fluctuations may be modulated by a buncher cavity supplied with an input signal and used to induce an output signal in a catcher cavity in the manner characteristic of klystron operation. Moreover, various modifications may be made in the electron gun proper consistent with the principles of the invention. The cathode may be of the hollow cathode type of the kind described in United States Patents 2,810,088, 2,810,089 and 2,810,090, all issued October 10, 1957, of D. MacNair, and the hollow cathode may itself be constructed to act as a cavity resonant at the operating frequency. Additionally, for some applications a sufficient improvement in noise figure may be had merely by reducing the noise convection current in the manner described to obviate the necessity of also reducing the noise velocity fluctuations in the beam so that a velocity jump may be omitted. Moreover, noise due to velocity fluctuations may be reduced by any of the techniques described United States Patent 2,828,439, issued March 25, 1958, of R. C. Fletcher.

What is claimed is:

1. In velocity modulation apparatus, an electron emissive cathode surface, a control element located between the cathode surface and means for modulation of electron flow therefrom and spaced close to said surface for space-charge-limiting the flow therefrom, means for providing a high R-F impedance across said space-charge-limiting region, said means including the cathode and control element forming opposite surfaces of a cavity which is resonant at the midfrequency of the operating band of the apparatus, and means positioned along the path of flow beyond said control element for imparting a velocity jump to the electrons at a point of noise velocity maximum.
2. In a traveling wave tube, an electron emissive cathode for serving as a source of an electron beam, a control element located between the cathode and means for modulation of said beam and spaced close to said cathode for space-charge-limiting the flow therefrom, means for providing a high R-F impedance across the space-charge-limiting region, said means including the cathode and control element forming opposite surfaces of a cavity which is resonant at the midfrequency of the amplifying band of the tube, first and second accelerating anodes positioned along the path of flow beyond said control element and maintained at successively higher D.-C. accelerating potentials, the region of separation between said first and second anodes corresponding to a point of noise velocity maximum along the path of flow, and a traveling wave circuit positioned along the path of flow beyond said first and second accelerating anodes and maintained at the higher accelerating potential of said second anode for propagating a signal wave for interaction with the beam.
3. In velocity modulation apparatus which utilizes an electron beam, means for reducing the noise convection current in the beam characteristic of frequencies in the operating band of said apparatus, said means including a cathode emissive surface which is the source of the electron beam and a control element for space-charge-limiting the flow of the electrons from said cathode emissive surface, said control element being located between the cathode and means for modulating said beam and spaced from said emissive surface a distance the transit time of which for the electrons in the beam is short relative to the period of frequencies in the operating band of the apparatus, and means for providing a high R-F impedance across said space-charge-limiting region, said

means including the cathode and control element forming opposite surfaces of a cavity resonator which is substantially closed and free of coupling providing excitation from an external source and which is resonant at the mid-frequency of the operating band of the apparatus. 5

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