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ELECTRON VELOCITY MODULATION TUBES

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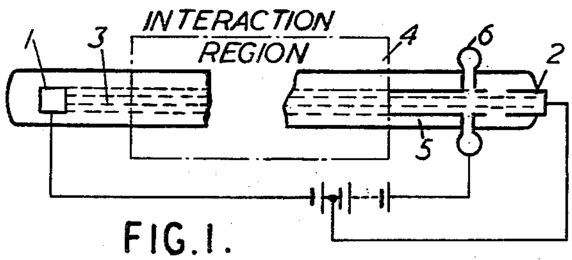


FIG. 1.

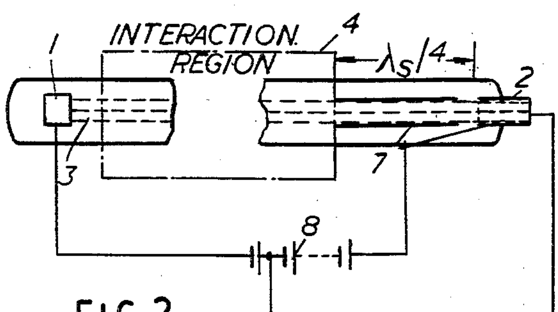


FIG. 2.

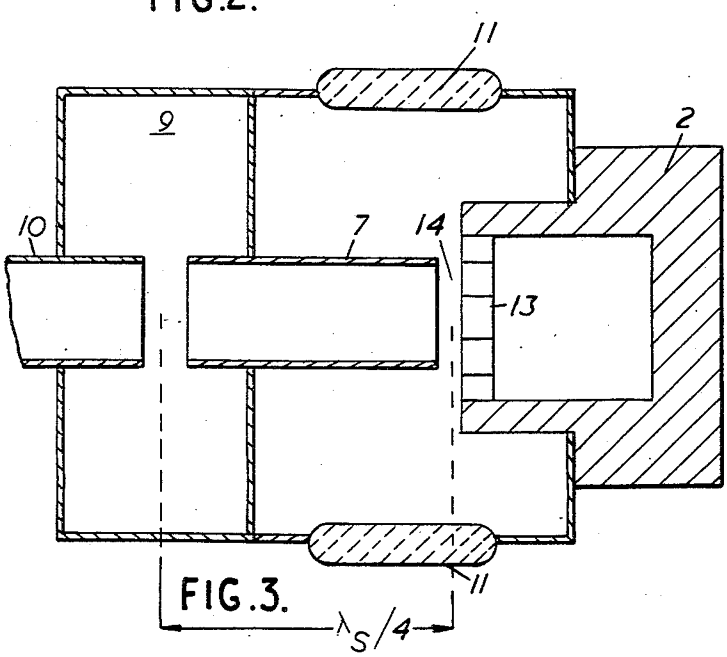


FIG. 3.

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# ELECTRON VELOCITY MODULATION TUBES

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2 Claims. (Cl. 315—3)

The present invention relates to high power electron velocity modulation tubes and is particularly concerned with electron collector arrangements therefor.

It is well known that the overall efficiency of a velocity modulation tube could be improved if the voltage of the electron collector electrode could be reduced below that of the cavity resonators, in the case of a klystron, or that of the slow wave structure, in the case of a travelling wave tube or backward wave oscillator or amplifier. It is nevertheless found that the collection efficiency drops sharply when the collector voltages falls below some minimum value which is typically 50 to 70% of the voltage of the resonator or slow wave structure, as the case may be. To take the case of the klystron, though what follows applies equally to other types of velocity modulation tube, the drop in efficiency follows because the electron beam at exit from the output resonator is very strongly velocity modulated and, when confronted with a low D.C. collector voltage, many of the electrons have insufficient energy to overcome the retarding field of the collector region.

It is an object of the present invention to provide means for overcoming the above mentioned drop in collection efficiency and hence to allow the electron collector electrode to be operated at low voltage, thereby providing an electron velocity modulation tube of increased overall efficiency.

The invention is based upon the realisation that if the velocity distribution among the electrons about the mean, or D.C., beam potential can be made small, then the collector voltage can be reduced nearly to cathode potential and still collect all the beam electrons. This is achieved, according to the invention, by effectively suppressing the electron velocity modulation of the beam at the collector electrode; it may be carried out either by subjecting the beam to strong V.P. energy absorbtion after leaving the output resonator or slow wave structure by the expedient of passing the beam through a separate resonant electrode means which may comprise a highly damped additional resonator, or the placing of an electron collector at the end of a drift tube maintained at high D.C. potential and of such length that the electron plasma waves on the beam are at a point of minimum A.C. velocity immediately in front of the collector. The electron collector electrode in this second case surrounds, as in conventional practice, a hollow space, but the entrance to this hollow space is gridded so as to provide a flat collecting field and help in the suppression of secondary emission.

The invention will be further described with reference to the accompanying drawings in which:

Fig. 1 shows, purely diagrammatically, a velocity modulation tube having an extra beam-demodulating cavity resonator according to the invention;

Fig. 2 shows, similarly, a velocity modulation tube according to the invention having a final drift tube in front of the electron collector electrode to position the latter where the A.C. velocities are a minimum; and

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Fig. 3 is a fragmentary drawing of the output end of a klystron tube according to the invention.

In the drawings of Figs. 1 and 2, an electron gun cathode, from which the electron beam emanates, is indicated by the rectangle **1** and the electron collector electrode is shown at **2**. The path of the electron beam is indicated by the dotted lines **3**. Between the electron gun and the electron collector electrode the beam passes through a region of its path in which it is coupled, by electrode means not shown, to electromagnetic fields with which it interchanges energy. This region is indicated by the chain-lined rectangle **4**. In the case of a klystron the region **4** comprises two or more resonant cavities separated by drift tubes, while in the case of a travelling wave tube the region comprises a helix or other form of slow wave structure linked with the electron beam path together with input and output waveguide or coaxial line feeders and the necessary impedance matching arrangements well known in the art. (The waveguides and, usually, the coaxial line feeders just mentioned, are not part of the tube itself, but are coupled to the slow wave structure within the tube envelope by the said matching arrangements, part of which will, normally, be within the envelope enclosure.) Whatever be the type of tube, the electron beam within the interaction region, at least at the output cavity or the end of the slow wave structure, will be subject to high D.C. potentials and the electrons will have a corresponding high mean velocity along their path.

In the case of a klystron, when the beam crosses the gap in the output resonator the electron bunches excite the electromagnetic waves to which the resonator is tuned. The high frequency energy in the output resonator is obtained from the beam at the expense of the kinetic energy of the beam electrons; the electrons in the "bunch" are slowed down and the electrons reaching the gap in unfavourable phase are accelerated, so that energy is obtained by debunching of the beam. But, for optimum power extraction, this debunching is far from complete, and, in fact, on leaving the output gap many of the electrons will have velocities very far from the mean value, so that quite a large proportion would be reflected back along their path by the field of a low potential collector electrode placed, as is normally the case, immediately following the output resonator. As mentioned previously, it is normally found that the collector voltage cannot be reduced below some 50% to 70% of the output resonator voltage. The reflected electrons are either collected on the cavity walls at the full H.T. potential or penetrate through the interaction space. In the first case they prevent the overall efficiency from being increased, while in the second they contribute to undesired instabilities and self-oscillation. Both effects must be eliminated. Similar considerations apply in the case of tubes where there is a continuous instead of a localised interchange of energy between beam and field. Thus, in the case of the backward wave oscillator, in which the field energy is extracted near the electron gun end of the tube, although on the average the electrons will deliver up more energy to the field along the slow wave structure than they receive, they will leave the interaction region of their path with an appreciable velocity modulation.

In the arrangement of Fig. 1, after leaving the interaction region the beam passes along a further length of drift tube **5** and through a cavity resonator **6** all at high D.C. potential. In carrying out the invention the resonator **6** is caused to be very heavily loaded. If the parallel load resistance of the resonator **6** is made much lower than the load for optimum power extraction, the ratio frequency voltage developed is very low and the beam at exit is of practically uniform velocity. At the same time the Q of the resonator is very low while the energy absorbing gap in the resonator can be made long and the capacity across the lips of the gaps correspondingly low, giving flat tuning; thus the resonator does not have to be tunable. The radio frequency power in the resonator 6 can be dissipitated either in a built-in load or may be added to the useful output from the output resonator proper. After passing the resonator 6, the electrons are collected by electrode 2 which may be of conventional type and be located at any convenient distance beyond the output gap, but may now be operated at or but little above the cathode potential. It follows from what has been said above about the characteristics of the resonator 6 that the drift tube 5 may be made any convenient length.

In the preferred arrangement of Fig. 2 a drift tube is used to reduce the velocity modulation of the electrons. This arrangement is based on the space charge wave theory of velocity modulation processes. From this theory it appears that the effect of velocity modulation of the beam electrons is to set up on the beam electron plasma waves which form along a drift tube, stationary waves of A.C. current and A.C. velocity, the current and velocity waves being in phase quadrature. In the case of a klystron the output gap is positioned at an A.C. current antinode, which, since current and velocity are in quadrature, is an A.C. velocity node of the plasma waves. If the output gap could extract all the power from the beam, the A.C. current of the plasma waves would be reduced to zero and the beam would be left with no velocity modulation at all; the electron collector electrode could then be placed at any subsequent position and be maintained at cathode potential without repelling any electrons. In practice, however, the output gap not only does not demodulate the beam completely, but the high R.F. voltage developed across the lips of the gap remodulates the electron beam, and, from the point of view we are considering, must be regarded as a source of velocity modulation for the beam. An analogous argument can be developed for other types of tube such as the travelling wave tube or backward wave tube. Here the end of the slow wave structure is to be regarded as a source of fresh electron velocity modulation.

In accordance with the invention this fresh or reimposed velocity modulation is suppressed at the electron collector electrode by inserting a drift tube 7, Fig. 2, following the interaction region 4. In accordance with the simple space charge wave theory this drift tube 7 should be made of length $\lambda_s/4$ long, where $\lambda_s$ is the electron plasma wavelength, modified to take account of the drift tube geometry, and the electron collector electrode should be placed at the end of drift tube 7; the electron collector electrode is now positioned at an A.C. velocity null of the space charge waves induced at the end of the interaction region. The electrons may thus be collected at low potential, as indicated in Fig. 2 where a D.C. source 8 is represented as connected between the cathode and drift tube 7 and collector 2 is connected near the cathode end of source 8. The gap between collector 2 and drift tube 7 may be made as short as allowed by the sparking distance between them. The collector, as in conventional practice, is made hollow, but its mouth is grided to present a flat equipotential surface to the beam at the end of the drift tube 7. If a conventional, ungrided, collector electrode were used, the penetration of the high voltage field into the interior of the collector would tend to accelerate secondary electrons out of the collector hollow space. Thus the grid assists in the suppression of secondary emission.

A practical example of the invention of Fig. 2 as applied to a klystron is shown in Fig. 3, which illustrates the basic construction of the output end of the tube. The output resonator is indicated at 9, the main drift tube at 10, and the additional drift tube and the collector electrode are identified by the same reference numerals as before. The collector electrode 2 is joined to resonator 9 through insulators 11, and the drift tube 7 is fixed in the wall of resonator 9. The mouth of the collector electrode is closed by an electron permeable grid 13, which is separated by a short insulating gap 14 from the end of drift tube 7. The distance between the output gap in resonator 9 and gap 14 is made $\lambda_s/4$.

The embodiment of Figs. 2 and 3 as so far described is based upon the simple single space charge wave theory. In this the basic wave parameters are determined, inter alia, by the fact that at the conducting surface of a drift tube the tangential components of electric force must vanish. Thus, if $E_z$ be the component of electric force acting on the beam in the axial direction, and the beam fills the tunnel formed by the drift tube, $E_z$ must vanish at the beam boundary. But the consequent radial variation of $E_z$ across the beam is far from what must obtain in an ungrided klystron gap, or indeed, in the helix field of a travelling wave tube. The situation is somewhat analogous to the excitation in the fundamental mode of a hollow waveguide by a probe; higher order modes must come into play. But in the hollow waveguide the higher order modes are rapidly attenuated, and can be ignored for most purposes; the electron beam, on the other hand, can and does transmit the higher order plasma waves, which should, therefore, be taken into account throughout the length of the velocity modulated beam. Thus, in order to obtain a closer approximation to practice, instead of considering only a single space charge wave, the higher order space charge wave theory considers a Fourier-Bessel series of space charge waves which gives rise to a non-uniform distribution of $_z$-directed A.C. velocities in the beam and explains, inter alia, the experimental fact that in a solid beam there is a reversal in sign of A.C. velocities across the beam section.

When the higher order space charge wave theory is taken into account, the length of the drift tube 7 should be made greater than $\lambda_s/4$ for the best compromise of velocity modulation suppression at the collector electrode; the collector electrode would also have to be somewhat above cathode potential. From this theory it would appear that the best position for the electron collector electrode is where the A.C. velocities corresponding to the first and second order modes are equal and opposite. In a practical construction the exact collector position for maximum collection efficiency can be determined empirically.

While the principles of the invention have been described above in connection with specific embodiments, and particular modifications thereof, it is to be clearly understood that this description is made only by way of example and not as a limitation on the scope of the invention.

What is claimed is:

1. An electron velocity modulation tube comprising electrode means for projecting an electron beam from a cathode along a given path in energy interacting relationship with electromagnetic waves in a given region of the path, means providing a high direct potential operating on said beam at the end of the said given region, a drift tube maintained at the said high potential following the beam exit from the said region and of length exceeding one quarter electron plasma wavelength of the first mode of plasma waves by an amount such that the alternating current velocities of the first and second modes of plasma waves on the said beam are equal and opposite, an electron collector electrode at a potential near that of the said cathode, located at the exit from the said drift tube, the said collector electrode providing a hollow space for the collection of the electrons and an electron permeable grid covering the end of the said hollow space to provide a substantially flat equipotential surface, at collector potential.

2. An electron velocity modulation tube comprising electrode means for projecting an electron beam from a cathode along a given path in energy interacting relation-

ship with electromagnetic waves in a given region of the path, means providing a high direct potential operating on said beam at the end of said given region, a drift tube maintained at said high potential region following the beam exit from said region and of a length substantially equal to a one-quarter electron plasma wavelength of the first mode of plasma waves, an electron collector electrode at a potential near that of said cathode located at the exit from said drift tube, said collector electrode present-



ing a spaced substantially unipotential surface immediately adjacent the end of said drift tube.


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