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BEAM COLLECTOR WITH AUXILIARY COLLECTOR FOR REPELLED
OR SECONDARILY-EMITTED ELECTRONS
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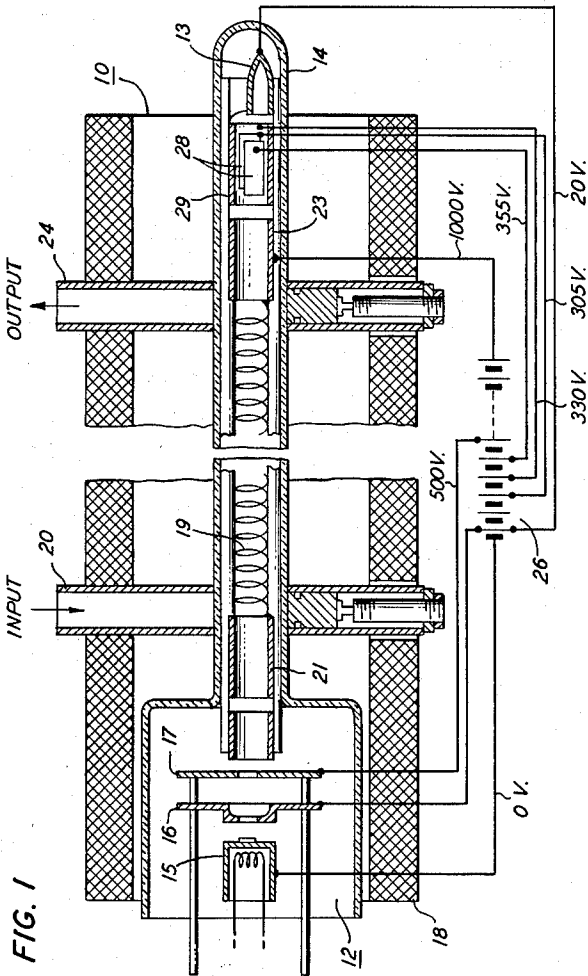


FIG. 1

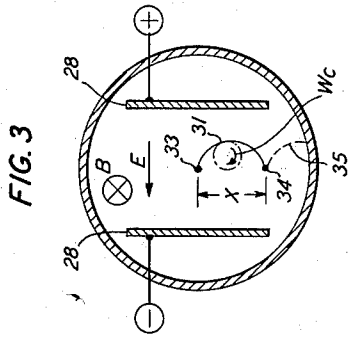


FIG. 3

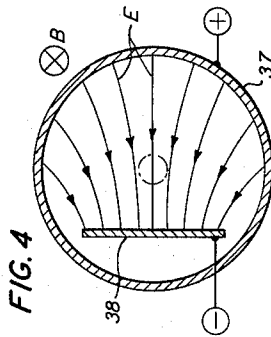


FIG. 4

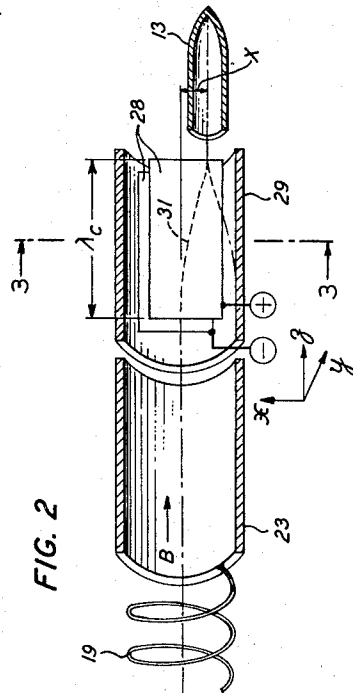


FIG. 2

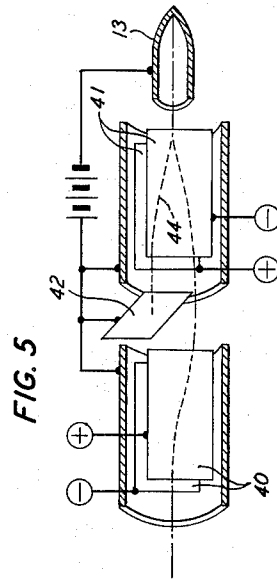


FIG. 5

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BEAM COLLECTOR WITH AUXILIARY COLLECTOR FOR REPELLED OR SECONDARILY-EMITTED ELECTRONS

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5 Claims. (Cl. 315—3.5)

This invention relates to velocity modulation electron beam devices, and more particularly to electron beam collectors.

The chief power drain in a velocity modulation device such as the traveling wave tube or the klystron, is the electron collector, which usually dissipates a large quantity of beam kinetic energy through heat radiation and secondary emission. One way of reducing these losses is to depress the potential of the collector below that of the beam, so that the beam velocity is reduced prior to impingement. The electron beam of most klystrons and traveling wave tubes, however, is velocity modulated in an interacting region, this modulation creating a longitudinal velocity spread among the electrons of the beam. If the collector potential is reduced too much, many of the slower electrons will be repelled from the collector. These repelled electrons, together with secondary electrons that may be emitted from the collector, will then travel back to the interaction region with deleterious results.

Various types of devices have been proposed for efficiently collecting a velocity modulated electron beam, but for many applications these devices have proved to be impractical. For example, lens systems have been used to convert velocity modulations into charge density modulations. Because of inherent non-linearities in the beam, this device is not always as effective as would be desired, and, further, the lens system is mechanically complicated and not easily fabricated.

It is an object of this invention to minimize energy dissipation accompanying electron beam collection in a velocity modulation electron beam device.

It is another object of this invention to prevent electrons that are repelled and emitted from the collector of a velocity modulation device from traveling back to the interaction region of the device.

These and other objects of the invention are attained in an illustrative embodiment thereof, comprising an electron gun for forming and projecting an electron beam along a path. The beam is constrained to flow along the path by a longitudinal magnetic field that threads through the beam. A slow wave structure, such as a helix, extends along a portion of the path for transmitting signal wave energy in interacting relationship with the beam in accordance with well-known traveling wave tube principles. The signal wave energy produces longitudinal velocity variations among various electrons of the beam, but the beam is maintained at a relatively high beam velocity by virtue of a high D.-C. potential on the slow wave structure and other associated elements. The beam is collected by a collector electrode which is at a much lower potential than the slow wave structure. The low potential on the collector reduces the velocity at impact of the beam and minimizes energy losses due to heat dissipation and secondary emission.

According to one aspect of this invention, any electrons that are reflected or emitted from the low potential collector are diverted along a separate path toward an auxiliary collector having a slightly higher potential than the primary collector. By this method, the majority of electrons are collected efficiently at a very low potential and

the only electrons that are collected by the auxiliary collector are those that would otherwise be reflected back into the interaction region. The auxiliary collector only collects electrons when the beam has been modulated, because in the absence of velocity modulation, substantially all of the electrons travel at a sufficiently high velocity to be collected by the primary collector.

It is a feature of one embodiment of this invention that a pair of deflecting plates surrounded by a cylindrical auxiliary collector be included between the interaction region and the primary low potential collector for deflecting the beam away from the tube's central axis. The primary collector is therefore offset from the central axis so that the beam is collected efficiently. Any electrons that are reflected by the primary collector are again deflected by the deflecting plates in the same direction as the initial deflection and therefore impinge upon the auxiliary collector cylinder surrounding the plates.

It is another feature of this embodiment that the deflection plates be substantially one cyclotron wavelength long, the cyclotron wavelength being a function of the magnetic field and mean beam velocity. Under this condition, as will be explained hereafter, the electrons leaving the deflection region will have no transverse velocity component, but will travel in a longitudinal direction toward the lower potential collector. This particular length also insures that any electrons that are reflected from the collector will be deflected sufficiently to impinge on the auxiliary collector cylinder.

It is a feature of another embodiment of this invention that two pairs of deflection plates, separated by an auxiliary collector, be included between the interaction region and the primary low potential collector. Each pair of deflecting plates is one cyclotron wavelength long and produces an electric field in a direction opposite that produced by the other pair. If the first pair that the beam encounters deflects the beam downwardly, the second pair will deflect it upwardly to an equal degree so that the majority of the electrons are collected on the central axis of the device. Any reflected electrons will, however, be again deflected upwardly and will follow a separate path back toward the interaction region. The auxiliary collector located between the two pairs of deflecting plates thereby conveniently collects the reflected electrons without interfering with the deflected electron beam.

These and other objects and features of my invention will be more clearly understood with reference to the following detailed explanation taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a sectional view of a traveling wave tube which includes electron collection apparatus embodying the principles of this invention;

FIG. 2 is a perspective view of the electron beam collection apparatus of FIG. 1;

FIG. 3 is a view taken along lines 3—3 of FIG. 2;

FIG. 4 is a sectional view of another embodiment of this invention; and

FIG. 5 is a perspective view of still another embodiment of this invention.

Referring now to FIG. 1, there is shown a traveling wave tube 10 having an electron gun 12 for forming and projecting a beam of electrons toward a primary low potential collector 13. These elements are maintained in a substantial vacuum by an envelope 14 which is of glass or some other suitable material. The electron gun 12 is shown, for illustrative purposes, as comprising a cathode 15, a beam forming electrode 16, and an accelerating anode 17. Extending between the electron gun and the collector is a helix 19.

Surrounding traveling wave tube 10 is a focusing mag-

net 18, only a portion of which is shown for purposes of clarity. Magnet 18 produces a magnetic field within the tube which is substantially parallel with the tube axis to constrain the beam to follow the axis and to prohibit undesired electron impingement on helix 19.

Electromagnetic waves are introduced into tube 10 by means of an input wave guide 20 and are caused to propagate along helix 19 by an input coupler 21. As the electromagnetic waves propagate along the helix, the fields associated therewith produce velocity modulations on the electron beam that propagate as space-charge waves. As is well known, the fields of the space-charge waves interact with the fields of the wave on the helix to produce a net amplification of the electromagnetic waves. The amplified electromagnetic waves are thereafter removed via an output coupler 23 and an output waveguide 24, and transmitted to an appropriate load.

In order for interaction to take place with resulting amplification, the velocity of the electron beam must be in approximate synchronism with the longitudinal velocity of the wave on helix 19. As is known, the velocity of the electron beam is dependent upon its electrical potential. For this reason, helix 19 is held at an appropriately high D.-C. voltage to meet synchronism requirements. The D.-C. voltages on the various tube elements are maintained by a battery 26. The typical potentials shown are indicated for illustrative purposes only.

Once the beam leaves the interaction region defined by helix 19, it is unnecessary to maintain the beam at a high velocity. If the beam is collected at a high velocity, considerable beam kinetic energy will be lost through heat radiation and secondary emission. The primary collector 13 is therefore biased at a low potential to minimize such losses. As is known, if no energy were added or extracted from the beam after leaving the cathode, the beam could be collected by a collector at a potential very near the cathode potential. Some energy, however, is removed from the beam during the amplification processes and so the collector should be at a slightly higher potential to receive the majority of electrons.

Because of residual velocity modulations, some of the electrons approaching the collector travel faster, and some travel slower, than the mean beam velocity. As the beam leaves output coupler 23, the velocity spread of the various electrons traveling toward the collector is rather slight and can be treated as a second order effect. As the beam potential is reduced, however, the ratio of the velocity spread to the mean beam velocity increases, and hence, many electrons travel at a relatively low velocity with respect to the mean beam velocity as they enter the primary collector. If collector 13 were to collect all of the electrons of the beam, it would therefore have to be biased at a relatively high potential to compensate for the wide velocity spread and to prevent low velocity electrons from being reflected back into the interaction region. This, of course, would result in high collector losses as explained previously.

In order to permit primary low potential collector 13 to collect the majority of electrons of the beam, and still prevent reflected electrons from drifting back to the interaction region, there is included, in accordance with my invention, a pair of deflecting plates 28 surrounded by a conductive cylinder 29, between helix 19 and collector 13, as is best seen in FIGS. 2 and 3. It will be shown that conductive cylinder 29 acts as an auxiliary collector to intercept any electrons that are reflected from the primary collector 13. Referring to FIG. 3, the deflecting plates produce an electric field E that is transverse to the magnetic focusing field B. The effect of these "crossed-fields" on the electron beam is much the same as that produced in a magnetron. The beam is initially attracted toward the positive plate and thereby acquires a transverse velocity component. The transverse velocity acts with the magnetic field according to the "left-hand rule" to force the beam in a downward direction. The combi-

nation of transverse forces produced by the electric and magnetic fields thereby causes the beam to follow a cycloidal trajectory 31. The frequency of rotation of the imaginary circle describing cycloidal trajectory 31 is known as the cyclotron frequency ω_c and given by:

$$\omega_c = B\eta \quad (1)$$

where B is the flux density of the magnetic field and η is the charge-to-mass ratio of an electron. The vertical distance x that the beam travels during one cycle of cyclotron rotation is given by:

$$x = \frac{2\pi E}{B^2\eta} \quad (2)$$

The longitudinal distance z that the beam travels during the time taken to complete one cyclotron cycle is defined as the cyclotron wavelength λ_c , which is given by:

$$\lambda_c = \frac{2\pi u_0}{B\eta} \quad (3)$$

where u_0 is the mean longitudinal velocity of the beam.

According to my invention, the length of deflection plates 28, as shown in FIG. 2, is equal to one cyclotron wavelength, λ_c . Referring to FIG. 3 it can be seen that during one cyclotron cycle, or cyclotron wavelength, the electrons of the beam move from a point 33 on the tube axis to a point 34 that is displaced from the axis a distance x is given by Equation 2. It is easily proved that the instantaneous velocity of any particle following a cycloidal trajectory is zero at the completion of one cycloidal cycle. Hence, at point 34 the beam has no transverse velocity component and it leaves the deflection region in a direction parallel with the tube axis as shown in FIG. 2. Low potential collector 13 is therefore displaced a distance x from the tube axis for efficient beam collection.

Any low velocity electrons that are repelled or reflected from collector 13 will travel back into the deflection region defined by plates 28. These electrons will again be deflected in the same manner as described above and will follow a new cycloidal trajectory 35. The distance between conductive cylinder 29 and point 34, however, is less than the deflection distance x so that the electrons will impinge on the cylinder 29 before traversing the deflection region. Cylinder 29 is biased at a higher positive potential than collector 13 or the potential of any of the returning electrons so that it acts as an auxiliary collector electrode, rather than a repeller.

An alternative deflection system and high potential collector is shown in FIG. 4. The deflection field E of FIG. 4 is produced between an outer cylinder 37 and a conductive plate 38. The outer cylinder serves a dual function in that it collects reflected electrons in the manner described previously, in addition to producing the deflecting field E.

Still another embodiment of my invention is shown in FIG. 5. Two pairs of deflection plates 40 and 41, each one cyclotron wavelength long, are included between the interaction region and the primary collector 13. An auxiliary collector 42 for collecting reflected electrons is located between deflection plates 40 and 41.

As the beam traverses the deflection region defined by plates 40, it is deflected downwardly and leaves the deflection region with no transverse velocity component, in the same manner as described previously. The electric field produced by plates 41, however, has a direction opposite that produced by plates 40 and therefore deflects the beam upwardly. The field produced by plates 41 is equal in magnitude to that produced by plates 40 so that the beam leaves the second deflection region on a path coincident with the tube axis.

Any electrons that are repelled by primary collector 13 are again deflected upwardly by plates 41 and are directed along a separate cycloidal trajectory 44. Auxiliary collector 42 intercepts trajectory 44 to collect any reflected electrons, but it does not interfere with the electron beam traveling toward collector 13.

In summary, it should be pointed out that my invention is particularly advantageous for collecting electron beams that are modulated intermittently, as, for example, in traveling wave tubes that amplify pulsed waves. All of the embodiments employ two collectors—a primary low potential collector for collecting medium and high velocity electrons, and an auxiliary collector for collecting reflected and secondarily emitted electrons. If the beam is modulated only intermittently, the primary collector will collect the entire beam during its quiescent state with maximum efficiency. Secondary electrons are not emitted from the collector in this state because the beam is not of a sufficiently high velocity; on the other hand, the beam velocity is high enough to insure impingement of all of the electrons. Hence, the auxiliary collector is effectively a “standby” collector for intercepting only those electrons, produced as a result of velocity modulation, that would otherwise drift back into the interaction region. It is an important feature of this invention that the deflection regions of each of the embodiments be one cyclotron wavelength long, or an integral number of cyclotron wavelengths long, because only under this condition will the majority of electrons leave the deflection region in a longitudinal direction.

The embodiments that have been shown are intended to be merely illustrative of my inventive concept. The embodiment of FIG. 5 may be desired if it is advantageous to locate the low potential collector 13 on the tube axis, while the embodiments of FIGS. 2 and 4 may be employed if a minimum number of structural elements is desired. Auxiliary collector 42 of FIG. 5 may be located anywhere along trajectory 44 if desired. Although the deflection plates are described as being one cyclotron wavelength long, they may be made any integral number of wavelengths long if more deflection is considered to be advantageous. Various other arrangements may be devised by those skilled in the art without departing from the spirit and scope of this invention.

What is claimed is:

1. An electron discharge device having a central axis and comprising: means for forming and projecting an electron beam along said axis; means for producing a magnetic field that is parallel with said axis, said field establishing a cyclotron frequency of electron rotation in said beam; a source of signal wave energy; a slow wave structure coupled to said source and extending along a portion of said axis; first means for deflecting said beam away from said axis; second means adjacent said first means for deflecting the beam back to the axis; a primary collector adjacent said second means; and an auxiliary collector between said first and second means, the auxiliary collector being at a higher positive potential than the primary collector.

2. The electron discharge device of claim 1 wherein the length of each of said deflecting means along the axis is substantially equal to $n\lambda_c$, wherein n is an integral number and λ_c is the mean cyclotron wave length.

3. Apparatus for efficiently collecting a velocity modulated electron beam that travels at a mean velocity in a longitudinal direction and is focused by a longitudinal magnetic field comprising: first means for producing along a portion of the beam a first electric field that is transverse to said magnetic field; second means for producing

along another portion of the beam a second electric field that is transverse to said magnetic field; the directions of said first and second electric fields being substantially diametrically opposite; a first collector adjacent said second means; and a second collector interposed between said first and second means; the second collector being at a higher positive potential than the first collector.

4. The apparatus of claim 3 wherein the distance that each of said electric fields extends along a longitudinal portion of the beam is substantially equal to

$$\frac{n2\pi u_0}{B\eta}$$

where n is any integral number, u_0 is the mean beam velocity, B is the magnetic flux density in the beam, and η is the charge-to-mass ratio of an electron.

5. An electron discharge device having a central axis and comprising:

means for forming and projecting an electron beam along a first path substantially coincident with said axis;

transmitting means extending parallel with, and proximate to, said first path;

and means for producing an axial magnetic field throughout said beam;

a first electron collector;

deflecting electrodes between said transmitting means and said first electron collector for producing a transverse D.-C. electric field along a portion of said beam;

said deflecting electrodes comprising means for causing said beam to follow a second path that is substantially parallel with said first path and spaced from the first path a transverse distance x substantially equal to

$$x = n \frac{2\pi E}{B^2 \eta}$$

where n is an integral number, E is the intensity of the D.-C. transverse electric field, B is the flux density of the magnetic field, and η is the charge-to-mass ratio of an electron;

second deflecting means located between said deflecting electrodes and said first collector;

said second deflecting means comprising means for causing the beam to flow along the central axis;

said first collector defining a terminus of said central axis;

and a second collector being located between said deflecting electrodes and said second deflecting means; said second collector being at a higher positive potential than the first collector.

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