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ELECTRON GUN STRUCTURE FOR PRODUCING AN ELECTRON BEAM FREE OF RADIAL VELOCITY COMPONENTS WHEREIN THE LENGTH OF THE FIRST NON-MAGNETIC CYLINDER IS APPROXIMATELY EQUAL TO AN INTEGRAL NUMBER OF WAVE LENGTHS OF THE SCALLOP FREQUENCY

Filed May 22, 1961

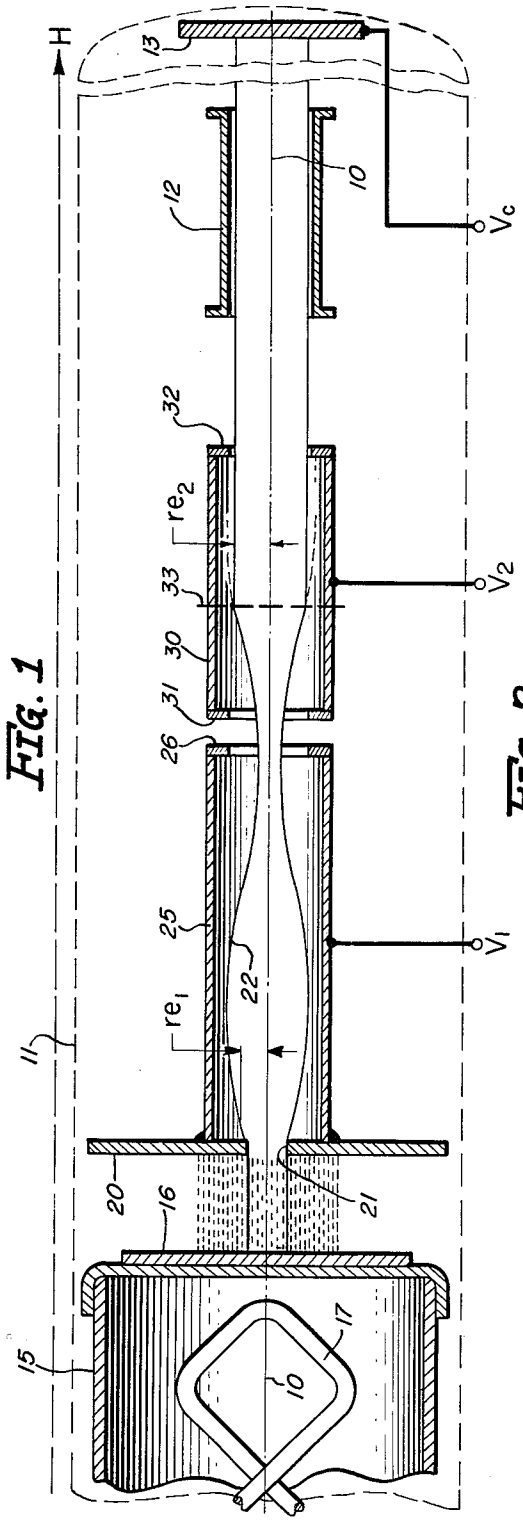


FIG. 1

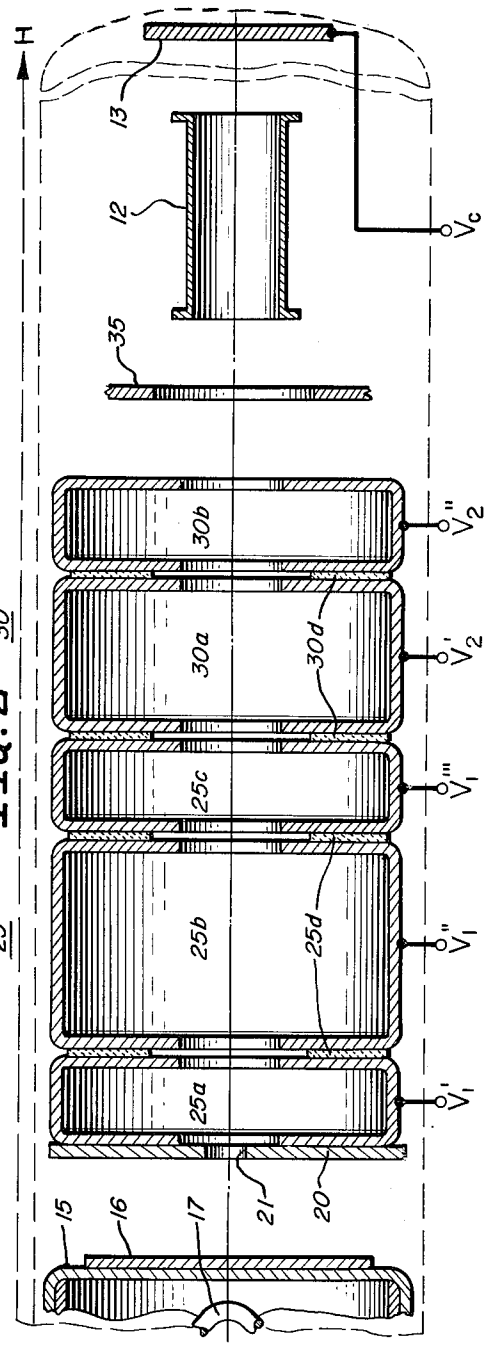


FIG. 2

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The present invention is directed to an electron gun arrangement of particular value for low voltage electron discharge devices such as the electron beam transverse-mode parametric amplifier.

The gun structure is an improvement over that described and claimed in copending application Serial No. 822,267, filed June 23, 1959, in the name of George W. Hrbek, and assigned to the same assignee as the present invention, now Patent 2,983,842, issued May 9, 1961.

An electron gun of the type under consideration is utilized to produce and project, along a path which extends coaxially of a homogeneous unidirectional magnetic field, an electron beam having the optimum condition of substantially no radial component of motion. That is to say, the gun is an arrangement for achieving in a practical manner a beam in the form of a solid cylindrical rod projected coaxially of a homogeneous magnetic focusing field while concurrently rotating about its longitudinal axis. This optimum beam condition is usually referred to as a condition of balance attained between the space charge and centrifugal forces acting on the electrons on the one hand and the focusing force of the magnetic field on the other.

If achieved, it permits the transverse-mode parametric amplifier which is inherently a low noise device to exhibit an optimum noise figure because it represents a condition of minimum beam noise. The practical significance is apparent when it is recognized that a slight mismatch may occur in the input coupler of the amplifier through which signal energy is transferred to the beam for amplification and any such mismatch reflects noise back into the electron stream to adversely affect the noise figure.

The gun structure of the Hrbek application has proved to be an acceptable and satisfactory approach to the problem of producing the desired electron flow for the beam of a transverse-mode parametric amplifier. It has been discovered, however, that the noise figure of such an electron gun has an undesirable dependence upon the potentials of its several electrodes. The electron gun of the present invention is an improvement over the Hrbek structure in that it materially reduces the dependence of noise figure upon gun potentials which facilitates adjustment of the amplifier. It also reduces to a minimum the number of electrodes required to accomplish optimum conditions of flow of the electron beam.

In principle, the desired objective is accomplished by a gun structure comprising a cathode immersed in a magnetic field and an adjacent anode having an aperture which determines the initial beam diameter. As the beam emerges from the anode aperture it must diverge due to the lens effect of the anode and to existing excessive space charge forces and this perturbation of the beam gives rise to a sinusoidal component of radial motion. The

perturbed beam is permitted to drift for awhile and at the right time the perturbation is stopped so that the beam exhibits substantially no component of radial motion.

It is therefore a principal object of the invention to provide a new and improved electrode system for producing a confined flow electron beam which has no substantial component of radial motion.

Another principal object of the invention is to provide an electron gun for a beam type parametric amplifier in which the noise figure is less dependent on operating potentials of the electrodes and in which the gun elements are reduced in number to simplify both the gun structure and its power supply.

It is another particular object of the invention to provide a novel electron gun system for a parametric amplifier which permits the amplifier to exhibit improved noise properties.

An electrode system or electron gun, embodying the present invention, produces and projects an electron beam along a path which extends coaxially of a homogeneous unidirectional magnetic field. The gun comprises a cathode and an aperture anode. Usually, the anode aperture is small in area compared with the cathode and it is centered on the desired beam path. Means are provided for operating the anode at a positive potential with respect to the cathode to draw electrons therefrom into a beam having an initial radius determined by the anode aperture. Such a beam, as it emerges from the anode aperture, expands radially outwardly and this perturbation gives rise to a sinusoidal component of radial motion of a predetermined scallop frequency. The gun has other means, including a cylinder of non-magnetic conductive material positioned coaxially of the beam path, for establishing about that path a substantially electric field-free drift space for the perturbed beam. The cylinder is dimensioned so that the length of the drift space is approximately equal to an integral number of wavelengths at the scallop frequency. Finally, there are means for terminating the drift space in a convergent lens which has a principal plane located at the intercept of the perturbed beam with an equilibrium radius larger than the initial beam radius and which subjects the perturbed beam to a radially inward force to cancel its component of radial motion.

The features of the present invention which are believed to be novel are set forth with particularity in the appended claims. The organization and manner of operation of the invention, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings, in the several figures of which like reference numerals identify like elements, and in which:

FIGURE 1 is an enlarged and schematic representation of an electron gun system constructed in accordance with the invention; and

FIGURE 2 represents a modification of the structure of FIGURE 1.

Referring now more particularly to FIGURE 1, the dash-dot construction line **10—10** designates a path along which an electron beam is to be projected. In most cases this path is the central axis of the tube which, as represented in the drawing, has an envelope **11** enclosing the electron gun and the other structures constituting a transverse-mode type of parametic amplifier. Since the invention concerns most particularly the elec-

tron gun as distinguished from the other components of the amplifier, the illustration and the text are confined largely to the gun and reference is made to the above-identified Hrbek application for a representation of the remaining structural components of such an amplifier. In addition to the electron gun, such an amplifier normally includes, in the recited order, an input coupler, a modulation expander, an output coupled and a collector electrode. Of these elements, only input coupler **12** and collector electrode **13** have been illustrated and the break shown in the representation of envelope **11** as well as the beam path are intended to indicate the omission.

The parametic amplifier also has a homogeneous unidirectional magnetic field represented in FIGURE 1 by arrow H. This is a focusing field which is usually established by means of a solenoid arranged coaxially of the beam path and coupled to a direct current source of adjustable magnitude to facilitate the development of a focusing field of a desired value. Again, the structure of this solenoid has been omitted in order to simplify the drawing.

The overall operation of such an amplifier is well understood and need not be developed in detail. Suffice it to say that a signal to be amplified is applied to input coupler **12** to deflection-modulate the electron beam after which the beam enters the modulation expander where the modulation, represented by transverse electron motion, is expanded. Thereafter, the beam with its expanded modulation traverses an output coupler where the amplified signal energy is taken off and applied to a load. The remainder of this description will be confined to the development of the electron beam which, as presented to the field of input coupler **12**, has no substantial radial component of motion.

The electron gun is of the immersed type, comprising a cylindrical cathode **15** immersed in magnetic field H and having an end cap **16** coated with electron emissive material. As is usually the case, the cathode is indirectly heated by a filament enclosed within cylinder **15** as indicated by the fragmentary section **17**. A thin planar anode **20** is disposed across beam path **10** and spaced axially a short distance from emitting surface **16** of the cathode. The anode is provided with a centrally located aperture **21** which is small in area compared with emitting surface **16** of the cathode and is centered on the beam path.

The application of a positive potential to anode **20**, through means presently to be described, causes current flow between the cathode and the anode as shown by the broken-construction lines extending therebetween. This current will be spaced charged limited and the electrons drawn through anode aperture **21** constitute the useful electron beam which has an initial radius determined by and corresponding essentially to the anode aperture. As the beam emerges from the anode aperture, its expands radially outwardly and this perturbation gives rise to a sinusoidal component of radial motion of a predetermined scallop frequency, as indicated by the sinusoidal beam envelope **22**. The scallop frequency, if space charge effects are ignored, is equal to the cyclotron frequency of the amplifier which may be adjusted by adjustment of focusing field H. When space charge effects are taken into consideration, however, the wavelength corresponding to the scallop frequency is slightly larger, perhaps 10% larger, than the cyclotron wave length. It may be shown that the scallop wavelength is determined by the beam current, the size of anode aperture **21** and the beam velocity, assuming a fixed value for the axial magnetic field. The sinusoidal perturbation of the beam is a manifestation of a radial component of motion which is undesired and which the structure under consideration effectively suppresses. The construction line r_{e_1} is the equilibrium radius of the beam and is the radius at which the opposing radially directed forces acting upon the electrons are equal.

Next along the beam path, following anode **20**, are means for establishing about the path a substantially electric-field-free drift space for the perturbed beam. This means in the modification of FIGURE 1 comprises a first cylindrical electrode **25** of non-magnetic conductive material supported coaxially of the beam path. The cylinder has a diameter only slightly larger than the beam diameter and may have a centrally apertured end plate at the end thereof closer to cathode **15** which may conveniently be employed as anode **20**. The other end **26** of the cylinder may have an inwardly directed flange, as shown, to serve as an element of a lens to be considered presently.

Positioned next adjacent cylindrical electrode **25** in the direction of collector **13** is a second cylindrical electrode **30** which constitutes means for terminating the drift space provided for the perturbed beam in a convergent lens. This electrode is quite similar to electrode **25**, being constructed of non-magnetic conductive material and positioned coaxially of the beam path. Its end portions **31** and **32** having inwardly directed flanges and its terminal portion **31** serves as a lens element, cooperating with end portion **26** of cylinder **25**, to constitute a convergent lens. Additionally, cylinder **30** establishes a second drift space for the beam which leads directly to input coupler **12**.

It is not necessary to use flanged terminations at end portions **26**, **31** and **32** of cylinders **25** and **30** if the diameters of these cylinders have their preferred dimensions which is only slightly larger than the maximum beam diameter.

The principal plane of the convergent lens provided by electrode sections **26** and **31** is represented by broken construction line **33** and the effective electrical length of the drift space established by cylindrical electrode **25** is chosen to be approximately equal to an integral number of wavelengths at the scallop frequency. For many gun structures the length of this drift space falls between n and $(n+\frac{1}{4})$ wavelengths at the scallop frequency, where n is any integer including one. The dimensioning of the drift space is such that the lens plane **33** is located at the intercept of the perturbed beam with an equilibrium radius r_{e_2} within cylinder **30**. This equilibrium radius is always greater than the initial beam radius determined by anode aperture **21** and is greater than equilibrium radius r_{e_1} within cylinder **25** for any gun structure in which the operating potential of cylinder **30** is less than that of cylinder **25**. Since equilibrium radius r_{e_2} exceeds the initial beam radius, its intercept with the perturbed beam occurs at a distance from anode aperture **21** which is greater than a scallop wavelength.

In addition to locating the lens plane appropriately as described, it is necessary that the strength of the lens be adjusted by selection of the relative potentials of lens elements **26** and **31** to subject the perturbed beam to a radially inward force which cancels the component of radial motion developed by the beam through its expansion as it emerges from anode aperture **21**. Accordingly, cylinders **25** and **30** have connections designated V_1 and V_2, respectively, leading to a power supply (not shown) from which operating potentials are applied to the cylindrical electrodes. Cylinder **25** is positive with respect to the cathode and electrode **30** is usually less positive than electrode **25** in an amount to establish the desired strength of convergent lens **26**, **31**. As a consequence of the compensating effect of the convergent lens, the perturbation of the beam is wiped out and the beam traverses the drift space of cylinder **30** and enters input coupler **12** with no substantial component of radial motion.

In selecting operating potentials V_1 and V_2, it is especially beneficial to have potential V_2 approximately equal to the direct current operating potential of input coupler **12**. This avoids undesired lens effects that may otherwise arise if cylinder **30** and input coupler **12** are at substantially different potential levels.

The modification of FIGURE 2 features sectionalizing of cylindrical electrodes **25** and **30**. More particularly, electrode **25** is here formed of three mutually insulated cylindrical sections **25***a*, **25***b* and **25***c*, the insulation therebetween being designated **25***d*. This modification also indicates that anode **20** may be a separate, thin plate conductively affixed with the adjacent end of cylindrical section **25***a* to increase heat dissipation at the anode. Of course, as is clear from the discussion of FIGURE 1, it is not essential that a separate anode electrode be employed. Providing the individual cylindrical electrode sections **25***a–c* with terminals V_1' to V_1''', respectively, increases the flexibility of the system by permitting the cylindrical sections to operate at approximately the same potentials but to obtain optimum performance through fine adjustment.

The second cylinder is likewise divided into sections shown as **30***a* and **30***b*, insulated from one another by insulation **30***d*. These sections also have separate terminals V_2' and V_2'', respectively, to permit fine adjustment of the nominally equal values of operating potential. Between cylinder **30** and input coupler **12** is an end wall **35** of a cylindrical shield housing which may enclose the coupler.

Obviously, if electrode sections **25***a–c* operate at the same potential, segmented cylindrical electrode **25** of FIGURE 2 is electrically the same as the corresponding electrode **25** of FIGURE 1. Similarly, operating sections **30***a* and **30***b* of cylinder **30** at a common potential causes the embodiment of FIGURE 2 to be electrically identical to that of FIGURE 1 but, the provision of separate terminals permits more flexibility of adjustment than is possible with the first described arrangement.

For example, variation of the potential applied to terminal V_1'' permits adjustment of the effective electrical length of cylinder **25** properly to locate the principal plane of the convergent lens defined by electrodes **25***c* and **30***a* to cancel out the perturbation developed on the beam at anode aperture **21**. Adjustment of the potential applied to terminal V_1', on the other hand, controls beam current while variation of the potential applied to terminal V_2' adjusts the strength of the convergent lens. Finally adjustment of the potential applied to terminal V_2'' prevents lens action of the corrected beam in its traverse to input coupler **12**. So long as the operating potentials of contiguous sections within cylindrical electrodes **25** and **30** are nearly alike, no appreciable lens action occurs at their boundaries and, therefore, it is feasible to vary the operating potentials, within limits, to accomplish the several adjustments described.

The specific dimensions and significant voltages applied to the electron gun in one embodiment, operated satisfactorily for an input signal at 900 megacycles, were as follows:

Spacing of cathode to anode **20**	inches	.0232
Spacing of anode to principal plane of convergent lens	inches	.1675
Length of electrode **25**	do	.1385
Minimum diameter of cylindrical electrodes	inches	.016
Diameter of anode aperture **21**	do	.010
Potentials applied to terminals V_1', V_1'', V_1'''	volts	30
Potentials applied to terminals V_2' and V_2''	volts	10
Beam current	microamperes	66
Cathode current density	ma./cm.^{2}	110
Electrode thickness	inches	.005
Insulation thickness	do	.003

It is not necessary that electrodes **25** and **30** or their several sections be circumferentially closed cylinders. Where thin, planar elements constituting the end plates of the cylinders or their several sections have a diameter that is large relative to the spacing of each plate from its neighbor, a substantially field-free space may be established if transverse plates constituting a given cylindrical electrode are strapped so that the necessary pairs of plates are maintained at the same operating potential. In other words, section **25***a* in the embodiment of FIGURE 2, for example, may be formed of a pair of parallel planar electrodes, centrally apertured and bridged at spaced points around their peripheries so that they are maintained at a common potential through the connection extending from terminal V_1'.

In arriving at the described structures, efforts were first directed to establishing a convergent lens immediately following anode **20** but it was found that the spacing of the lens in an axial direction to accomplish compensation was so small that it could not be realized in a physical structure. The spacing required for the compensating lens from anode **20** was calculated to be less than the diameter of the anode aperture but, since an electron lens has an axial length at least equal to the diameter of the electrode apertures, such space requirements could not be satisfied.

This difficulty is overcome in the described structures where the compensating lens is spaced sufficiently from anode **20** that the lens effects are isolated from one another. A further advantage is realized from this separation in that the perturbation experienced at the anode would be stronger if the decelerating field of the compensating lens were a factor in determining the divergence angle of the beam at anode aperture **21**. Since the perturbation developed on the beam at anode aperture **21** is minimized in the described gun structures, the gun is less critical to adjustment of operating potentials. There is the further obvious advantage of a reduction in the number of electrodes with an attendant simplification in the power supply. Parametric amplifiers to which the described electron guns have been adapted show a marked improvement in noise factor which is not, in any sense, critically dependent on operating potentials.

While particular embodiments of the invention have been shown and described, modifications may be made, and it is intended in the appended claims to cover all such modifications as may fall within the true spirit and scope of the invention.

I claim:

1. An electrode system for producing and projecting along a path, extending coaxially of a homogeneous unidirectional magnetic field, an electron beam having no substantial radial component of motion comprising: a cathode; an anode having an aperture centered on said path; means for operating said anode at a positive potential with respect to said cathode to draw electrons therefrom into a beam having an initial radius determined by said aperture, said beam, as it emerges from said aperture, expands radially outwardly and this perturbation gives rise to a sinusoidal component of radial motion of a predetermined scallop frequency; means, including a cylinder of nonmagnetic conductive material positioned coaxially of said path, for establishing about said path a substantially electric-field-free drift space for said perturbed beam having a length approximately equal to an integral number of wave lengths at said scallop frequency; and means for terminating said drift space in a convergent lens which has a principal plane located at the intercept of said perturbed beam with an equilibrium radius larger than said initial radius and which subjects said perturbed beam to a radially inward force to cancel said component of radial motion.

2. An electrode system for producing and projecting along a path, extending coaxially of a homogeneous unidirectional magnetic field, an electron beam having no substantial radial component of motion comprising: a cathode; an anode having an aperture small in area compared with said cathode and centered on said path; means for operating said anode at a positive potential with respect to said cathode to draw electrons therefrom into a

beam having an initial radius determined by said aperture, said beam, as it emerges from said aperture, expands radially outwardly and this perturbation gives rise to a sinusoidal component of radial motion of a predetermined scallop frequency; means, including a cylinder of non-magnetic conductive material positioned coaxially of said path, for establishing about said path a substantially electric-field-free drift space for said perturbed beam having a length approximately equal to an integral number of wave lengths at said scallop frequency; and means for terminating said drift space in a convergent lens which has a principal plane located at the intercept of said perturbed beam with an equilibrium radius larger than said initial radius and which subjects said perturbed beam to a radially inward force to cancel said component of radial motion.

3. An electrode system for producing and projecting along a path, extending coaxially of a homogeneous unidirectional magnetic field, an electron beam having no substantial radial component of motion comprising: a cathode; an anode having an aperture small in area compared with said cathode and centered on said path; means for operating said anode at a positive potential with respect to said cathode to draw electrons therefrom into a beam having an initial radius determined by said aperture, said beam, as it emerges from said aperture, expands radially outwardly and this perturbation gives rise to a sinusoidal component of radial motion of a predetermined scallop frequency; means, including a cylinder of non-magnetic conductive material positioned coaxially of said path, for establishing about said path a substantially electric-field-free drift space for said perturbed beam having a length approximately equal to an integral number of wave lengths at said scallop frequency; and means for terminating said drift space in a convergent lens which has a principal plane located at the intercept of said perturbed beam with an equilibrium radius larger than said initial radius and which subjects said perturbed beam to a radially inward force to cancel said component of radial motion, said last-named means including a second cylinder of non-magnetic conductive material positioned coaxially of said path adjacent said first-mentioned cylinder and providing a second substantially electric-field-free drift space for said beam.

4. An electrode system for producing and projecting along a path, extending coaxially of a homogeneous unidirectional magnetic field, an electron beam having no substantial radial component of motion comprising: a cathode; an anode having an aperture small in area compared with said cathode and centered on said path; means for operating said anode at a positive potential with respect to said cathode to draw electrons therefrom into a beam having an initial radius determined by said aperture, said beam, as it emerges from said aperture, expands radially outwardly and this perturbation gives rise to a sinusoidal component of radial motion of a predetermined scallop frequency; a first cylindrical electrode of non-magnetic conductive material positioned coaxially of said path, for establishing about said path a substantially electric-field-free drift space for said perturbed beam having a length approximately equal to an integral number of wave lengths at said scallop frequency, said electrode having a centrally apertured end plate at the end thereof closer to said cathode serving as said anode; and a second cylindrical electrode of non-magnetic conductive material positioned coaxially of said path adjacent said first electrode at the end thereof remote from said cathode for establishing about said path a second drift space for said beam, the contiguous end portions of said first and second cylindrical electrodes constituting a convergent lens which has a principal plane located at the intercept of said perturbed beam with an equilibrium radius larger than said initial radius and which subjects said perturbed beam to a radially inward force to cancel said component of radial motion.

5. An electrode system for producing and projecting along a path, extending coaxially of a homogeneous unidirectional magnetic field, an electron beam having no substantial radial component of motion comprising: a cathode; an anode having an aperture small in area compared with said cathode and centered on said path; means for operating said anode at a positive potential with respect to said cathode to draw electrons therefrom into a beam having an initial radius determined by said aperture, said beam, as it emerges from said aperture, expands radially outwardly and this perturbation gives rise to a sinusoidal component of radial motion of a predetermined scallop frequency; a first cylindrical electrode of non-magnetic conductive material positioned coaxially of said path, for establishing about said path a substantially electric-field-free drift space for said perturbed beam having a length approximately equal to an integral number of wave lengths at said scallop frequency, said electrode having a centrally apertured end plate at the end thereof closer to said cathode serving as said anode; a second cylindrical electrode of non-magnetic conductive material positioned coaxially of said path adjacent said first electrode at the end thereof remote from said cathode for establishing about said path a second drift space for said beam, the contiguous end portions of said first and second cylindrical electrodes constituting a convergent lens which has a principal plane located at the intercept of said perturbed beam with an equilibrium radius larger than said initial radius and which subjects said perturbed beam to a radially inward force to cancel said component of radial motion; and an input coupler for transferring signal energy relative to said beam, positioned adjacent the end of said second electrode remote from said cathode, and maintained at a direct-current potential substantially equal to that of said second electrode.

6. An electrode system for producing and projecting along a path, extending coaxially of a homogeneous unidirectional magnetic field, an electron beam having no substantial radial component of motion comprising: a cathode; an anode having an aperture centered on said path; means for operating said anode at a positive potential with respect to said cathode to draw electrons therefrom into a beam having an initial radius determined by said aperture, said beam, as it emerges from said aperture, expands radially outwardly and this perturbation gives rise to a sinusoidal component of radial motion of a predetermined scallop frequency; means, including a cylinder of non-magnetic conductive material positioned coaxially of said path, for establishing about said path a substantially electric-field-free drift space for said perturbed beam having a length approximately equal to an integral number of wave lengths at said scallop frequency; and means including a second cylinder of non-magnetic conductive material positioned coaxially of said path adjacent said first-mentioned cylinder, for terminating said drift space in a convergent lens which has a principal plane located at the intercept of said perturbed beam with an equilibrium radius larger than said initial radius and which subjects said perturbed beam to a radially inward force to cancel said component of radial motion, said second cylinder comprising a plurality of mutually insulated sections and terminal connections for applying desired operating potentials thereto.

7. An electrode system for producing and projecting along a path, extending coaxially of a homogeneous unidirectional magnetic field, an electron beam having no substantial radial component of motion comprising: a cathode; an anode having an aperture small in area compared with said cathode and centered on said path; means for operating said anode at a positive potential with respect to said cathode to draw electrons therefrom into a beam having an initial radius determined by said aperture, said beam, as it emerges from said aperture, expands radially outwardly and this perturbation gives rise to a sinusoidal component of radial motion of a predetermined

scallop frequency; a first cylindrical electrode of non-magnetic conductive material positioned coaxially of said path for establishing about said path a substantial electric-field-free drift space for said perturbed beam having a length approximately equal to an integral number of wave lengths at said scallop frequency, said electrode having a centrally apertured end plate at the end thereof closer to said cathode serving as said anode; and a second cylindrical electrode of non-magnetic conductive material positioned coaxially of said path adjacent said first electrode at the end thereof remote from said cathode for establishing about said path a second drift space for said beam, the contiguous end portions of said first and second cylindrical electrodes constituting a convergent lens which has a principal plane located at the intercept of said perturbed beam with an equilibrium radius larger than said initial radius and which subjects said perturbed beam to a radially inward force to cancel said component of radial motion, both of said cylindrical electrodes comprising a plurality of mutually insulated sections and terminal connections for applying desired operating potentials thereto.

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