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ELECTRON BEAM PARAMETRIC AMPLIFIER WITH
POSITIVE ION ELIMINATION
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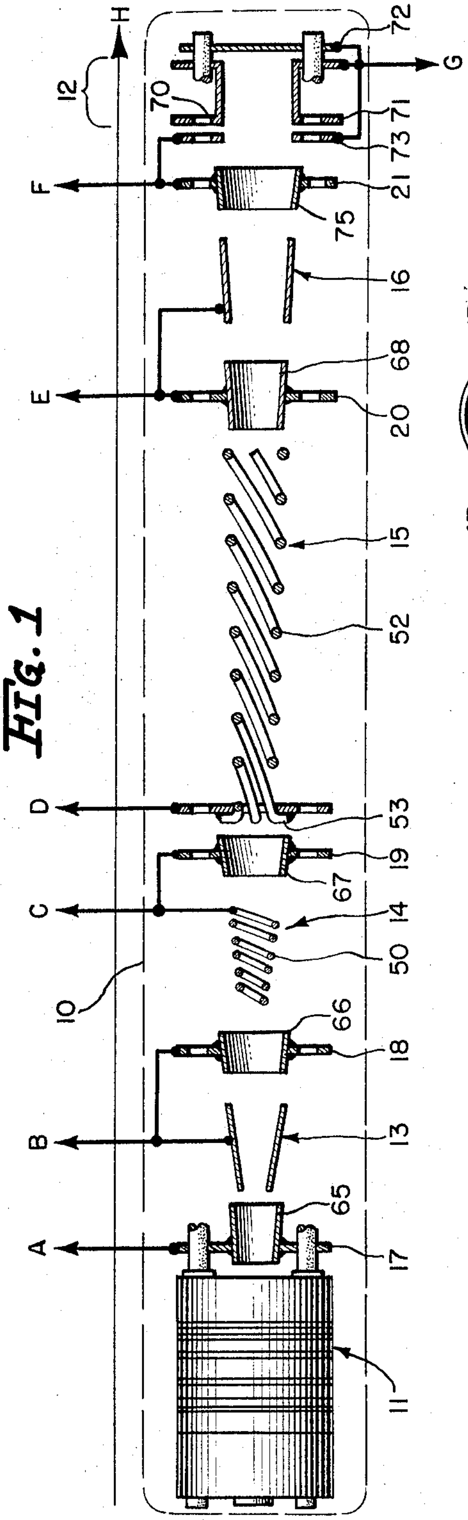

FIG. 1

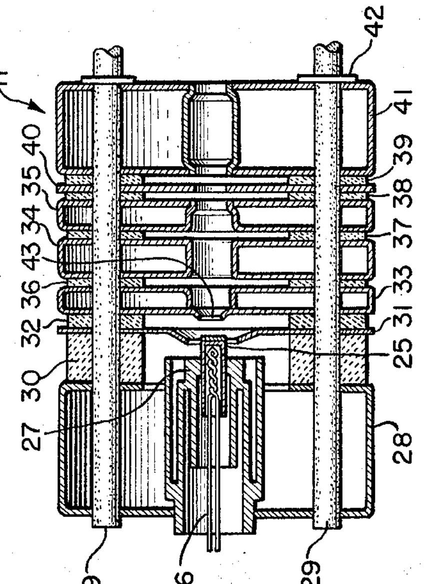

FIG. 2

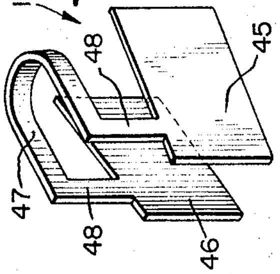

FIG. 3

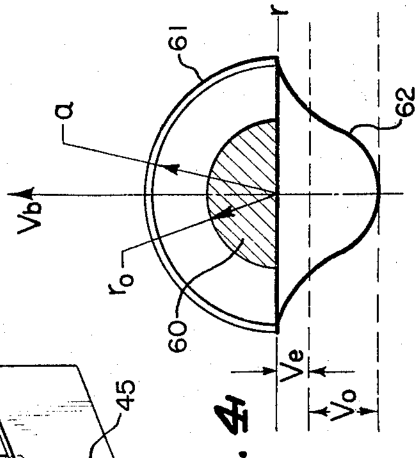

FIG. 4

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ELECTRON BEAM PARAMETRIC AMPLIFIER WITH POSITIVE ION ELIMINATION

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10 Claims. (Cl. 330—4.7)

The present invention pertains to electron beam devices. More particularly, it has to do with transverse-mode electron beam parametric amplifiers.

Great success has been had with the electron beam parametric amplifier in certain applications. Such success, however, has not been without the need to overcome many obstacles both of a theoretical and of a practical nature. A demand has existed for amplifiers capable of operating at high power levels but yet having the good noise figures, stability, and phase shift characteristics of predecessor lower-power apparatus of this kind. It has been found that acceptable performance of these devices under conditions involving electron beams of high potential and current levels poses certain severe difficulties not previously encountered with the low-power devices.

One particular difficulty arises in such devices whenever the electron velocity becomes sufficiently high to ionize any residual gas present within the tube envelope. One serious result is a variability in phase shift of the signal translated through the device. Of course, this problem suggests an effort to achieve better evacuation of the devices in order to lower the internal gas pressure and thus reduce the quantity of residual gas molecules. Hereinafter disclosed are processing techniques which result in significant improvement in the final performance characteristics of the device.

Nevertheless, a problem can still exist with respect to a small quantity of residual gas in devices operating at high beam voltages which result in electron velocities of comparatively large magnitude. Somewhat similar overall considerations previously have been encountered in velocity-modulated or longitudinal-mode traveling wave devices. For example, it has been recognized that positive ions may be trapped in a lower potential region along the electron beam of a longitudinal-mode device, known as a velocity-jump amplifier, in which the beam is projected through sections having different potentials. Such trapped ions may degrade the noise figure of the signal carried by the space-charge waves. A solution proposed for this problem involves a different amplification mechanism in which the size of physical elements surrounding the beam is periodically made larger and smaller to vary in turn the plasma-frequency reduction factor in a periodic manner. This approach is said to enable the electron beam to be completely enclosed within a continuous conductive shield from input to output so that, in a direction parallel to the electron beam, there are no lower-potential areas in which the ions might be trapped.

However, the aforesaid technique is not applicable to the transverse-mode electron beam parametric amplifier which has geometrically separate sections along separate portions of the electron beam path and between which there should not be any abrupt changes of field. The differently sized sections of the aforementioned prior amplifier cause abrupt changes of voltage gradient in a direction transverse to the electron beam. Since this is the significant direction in all transverse-mode devices, such changes would cause unwanted and unstable electron motion components. Further, a collection of positive ions in any low-potential portion of the beam eventually cancels to some degree the effect of the negative space charge inside the beam, as a result of which in certain cases the ions may move outwardly and strike the adjacent electrode surfaces, thereby developing additional undesired transverse-mode noise energy.

In certain other previously known longitudinal-mode electron beam devices, electrode potentials along the beam path are purposefully arranged to create a lower potential region in which the positive ions are collected within the beam. This is done in recognition of the fact that the mutually-repelling space-charge forces inside the beam tend to cause the beam to expand in diameter. The objective of such prior devices, therefore, is to cause positive ions to be collected in the beam in an attempt to neutralize the space-charge forces. In effect, these structures achieved that which it has now been discovered should be avoided in electron beam parametric amplifiers, and especially in those of the transverse-mode electron wave type.

Accordingly, it is a general object of the present invention to provide a transverse-mode electron beam parametric amplifier which may be operated with high beam voltages while yet achieving low noise figures and good phase stability characteristics.

Another object of the present invention is to provide an electron beam device of the transverse-mode type in which different potentials may exist along the electron beam path while yet avoiding the development of undesired ion concentrations within the beam.

A further object of the present invention is to provide an electron beam parametric amplifier having its various sections spaced along the beam path but in which ion concentrations are avoided.

An electron beam device constructed in accordance with the present invention includes a substantially evacuated envelope through which an electron stream may be projected at a velocity sufficient to ionize residual gas molecules. The stream exhibits a potential distribution across its width having a positive potential minimum at its axis tending to attract any positive ions of the gas toward that axis. Throughout the path the stream is subjected to a magnetic field which has flux lines parallel to the path to establish a condition of transverse electron resonance. Included within the envelope is an amplifying assembly having an input coupler for imparting motion to the electrons to establish transverse-mode electron waves on the stream, a pump section downstream from the input coupler for developing a periodic inhomogeneous field having a periodicity phased with the electron motion to increase the magnitude of the waves, and an output coupler downstream from the pump section for extracting signal energy from the waves. A plurality of conductive structures included in the assembly are spaced along a path and also are individually spaced thereabout to define a drift region. The conductive structures taper apart in a given direction along the path and are biased to establish, together with the taper of the structures, a negative potential gradient along the portion of the path from one of the couplers to the other. Also included within the envelope are means spaced along the stream in the aforesaid given direction from the couplers and biased at a potential substantially negative relative to the potentials within the gradient region for collecting the positive ions; the gradient is sufficiently negative to draw the ions in the aforesaid direction. Finally, the envelope includes means at the downstream path end for collecting the electrons.

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

FIGURE 1 is a diagrammatic longitudinal cross-sectional view of one embodiment of the present invention;

FIGURE 2 is a fragmentary enlarged cross-sectional view of an electron gun utilized in the device shown in FIGURE 1;

FIGURE 3 is a perspective view of one section of the device shown in FIGURE 1; and

FIGURE 4 is a graphical diagram useful in explaining the electrical characteristics of the device illustrated in FIGURE 1.

As shown in FIGURE 1 for the purpose of illustrating the invention, an electron beam parametric amplifier is composed of a substantially evacuated envelope **10** within which a plurality of sections are disposed along an electron beam path between an electron gun **11** and a collector **12**. The principal sections of the device, stated in order of succession from gun **11** to collector **12**, are a signal input coupler **13**, an idler signal coupler **14**, a twisted quadrupole pump **15**, and an output coupler **16**. Disposed individually between each of the successive sections are a plurality of shield electrodes **17–21**, respectively. Biasing of all of the different electrodes with the required potentials is achieved by leads which feed through the envelope wall, preferably through conventional pins in a press forming one or both ends of the envelope. In use, envelope **10** is supported and positioned within an enclosing solenoid, the field of which is depicted by arrow H, for developing a magnetic field along the beam path with its flux lines parallel thereto.

Any of a variety of electron guns may be utilized to project a pencil-like beam through the device. Preferably, the properties of Brillouin flow are at least approximated. As is known, in such a beam the entire stream of electrons moves as a unit, like a solid pencil which rotates around the beam axis; the centripetal force applied by the flux lines of the magnetic field and tending to confine the beam diameter is made equal to the sum of the centrifugal forces resulting from the mutual electrostatic repulsion of the electrons and from their rotation with the beam as a whole. With theoretical perfection, and if thermal motions are disregarded, there is no radial component of the electrons in the stream as they enter input coupler **13**.

The particular electron gun shown in FIGURE 2 and embodied in the complete device of FIGURE 1 is designed in accordance with the invention described and claimed in the copending and commonly assigned application of Asher Blum, Serial No. 111,831, filed May 22, 1961, and now abandoned. Gun **11** includes an impregnated cathode **25** having an internally disposed heater coil **26** with the cathode sleeve being secured within a re-entrant double-walled cylinder **27** in turn formed inside an outer hollow cylindrical shell **28** through which pass longitudinally disposed ceramic support rods **29**. A longitudinally depending skirt inside cylinder **27** serves as additional heat shielding for heater **26**, the entire cathode mounting structure affording substantial heat dissipation area consistent with the high operating temperature of the dispenser-type cathode.

The overall gun construction is such that the electron beam path within it is shielded. It includes a plurality of stacked double-walled cylindrical shells, the inner walls of which define the beam-forming space. Beginning in order away from cathode shell **28** is a ceramic spacer annulus **30**, a conductive annulus **31**, another spacer annulus **32**, path-defining shells **33**, **34** and **35** individually separated by respective spacers **36** and **37**, and followed by spacers **38** and **39** sandwiched about a conductive annulus **40**. Finally, there is another double-walled shell **41** followed by a retaining annulus **42**. The aforementioned shells and annular conductive elements are metallic, while the spacers and retainers are of ceramic material.

Element **31** is apertured at its center and depressed frusto-conically toward and around the end of cathode **25**. Electrode **40** has an aperture on its axis which serves as part of the beam forming structure completed by the internal walls of the successively disposed shells.

In operation, electrode **31** serves as a Pierce electrode to initially confine the beam. A smaller-diameter aperture **43** at the entrance to shell **33** serves to initially confine the beam diameter and this electrode also functions as an anode to draw electrons from the cathode. The beam issuing through aperture **43** expands radially outward, resulting in a sinusoidal component of radial motion having a scalloped envelope at a certain frequency of periodicity. Succeeding shells **34** and **35** serve to define a drift space for the perturbed beam, and the length of the drift space is approximately equal to an integral number of wave lengths at the scallop frequency. Beyond the drift space, apertured electrode **40** and shell **41** define a convergent lens having a principal plane located at a point where the perturbed beam intercepts the equilibrium radius of the beam within the final beam space. The strength of the lens is adjusted to apply to the beam a radial inward force which cancels the component of radial motion developed by the beam as an incident of its expansion in emerging from anode aperture **43**. In a typical functioning device constructed in accordance with FIGURES 1 and 2, the potentials applied to the different gun electrodes to achieve correct operation were as follows:

Electrode number:	Voltage
25	0
31	—3 to —15
33	440–470
34	440–470
35	500–600
40	80–130
41	100–130

Within a given assembly and environment, some adjustment of these potentials will usually be necessary to remove the scallop accurately and achieve Brillouin-type flow.

Input coupler **13** (FIGURE 3) has as its principal elements a pair of deflector plates **45** and **46** disposed respectively on opposite sides of the beam path. An inductive loop **47** disposed near the internal wall of envelope **10** is connected at its ends by straps **48** to plates **45** and **46**. By means of a similar inductive loop placed on the outside of envelope **10** opposite loop **47**, signal energy from an input source is delivered to coupler **13** to develop a signal potential across plates **45** and **46**. Such inductive coupling arrangements, for the couplers as well as the quadrupole section, are described in more detail and claimed in the copending and commonly assigned application of Robert Adler and Robert Cohoon, Serial No. 74,084 filed December 6, 1960, now Patent No. 3,179,895. In operation, input coupler **13** responds to the input signal energy and imparts motion to the electrons as a result of which transverse-mode electron waves are established on the stream.

In the present instance, idler coupler **14** is of a different form. In construction, the active element in coupler **14** is a bi-filar helix **50**. In operation, coupler **14** performs as if it were simply a longitudinally twisted version of coupler **13**, the twist changing the actual interaction frequency with the electron beam inasmuch as the electrons appear to see a field varying at a frequency different from that of the signal energy at the output from the coupler. In a manner analogous to inductive loop **47** connected to coupler **13**, an inductive loop (not shown) is coupled across the two windings of bi-filar helix **50**. An expanded description and claims to the bi-filar helix type coupler are contained in the copending and commonly assigned application of Robert Adler, Serial No. 119,931, filed June 27, 1961.

For a cyclotron wave device, as is herein embodied, bi-filar helix **50** is wound to have a pitch such that:

$$n=n_r\left(1-\frac{\omega}{\omega_r}\right) \qquad (1)$$

where n is the number of helix turns per unit length, n_r is the number of electron resonance periods per unit length, ω_r is the electron resonance frequency, and ω is the interaction signal frequency. The interaction frequency in this instance is that of the idler inherently produced as a result of the parametric process and the general purpose of coupler **14** is to strip noise energy from the beam at the idler frequency which otherwise would appear in the output.

Pump **15** is a twisted quadrifilar quadrupole as fully disclosed and claimed in the copending and commonly assigned application of Glen Wade, Serial No. 289,792 filed June 20, 1963, which is a continuation of application Serial No. 747,764 filed July 10, 1958. Briefly, a signal from an external pump source is coupled across alternate windings of quadrifilar helix **52** by an inductive coupling arrangement analogous to loop **47** of input coupler **13**. The quadrifilar helix creates a field to which the electrons are subjected and which has a quadrupole pattern skewed around the beam path. Because of this skew, the electrons encounter field reversals at a rate which is different from the actual frequency of the pump source. The pitch of the quadrifilar helix together with the pump source frequency are selected so that the apparent pumping field frequency is twice the cyclotron frequency of the orbiting electrons. The resulting periodic inhomogeneous field consequently has a periodicity which is phased with the electron motion in a manner which increases the magnitude of the input signal electron waves on the stream.

Output coupler **16** operates identically in principle to input coupler **13**. It is composed of a pair of deflector plates disposed individually on opposite sides of the beam and coupled to an inductive loop from which signal energy is transferred through the envelope wall to an external load. The action upon the moving electrons is the reverse of that in the input coupler.

For a more complete description and analysis of the quadrupole amplifier, as such, reference may be made to an article entitled, "The Quadrupole Amplifier, a Low-Noise Parametric Device," which appeared on pages 1713–1723 of the October 1959 issue of the "Proceedings of the I.R.E." Many different variations and improvements, including a full explanation of the operation of a twisted quadrupole pump, will be found in commonly assigned British patent specification 929,015 published June 19, 1963.

With reference now to FIGURE 4, the potential distribution across the beam path is of particular interest. The ordinate represents voltage and the abscissa distance from the center or axis of the electron beam; a cross-section of half the beam is depicted by the shaded area **60**. Surrounding but spaced from the electron beam is a coaxial cylindrical conductive electrode **61** which as a result of space charge in the beam carries a positive potential with respect to that of the electron beam. Curve **62** illustrates the potential distribution laterally across the beam path from a point on the inner wall of electrode **61** through the axis of the beam to a point on the opposite wall of the electrode. Between the electrode wall and the the outer edge of the beam, the potential V_e decreases in accordance with the relationship:

$$V_e=2V_0 \ln \frac{a}{r_0} \qquad (2)$$

where V_0 represents the potential depression within the beam itself, a is the radial distance from the beam axis and r_0 is the radius of the electron beam. The potential drop V_0 within the electron beam may be calculated from the expression:

$$V_0=\frac{1}{2}\left[\frac{\omega_q^2 r_0^2}{2\eta}\right] \qquad (3)$$

where ω_q is the plasma frequency of the electrons within the beam and η is their charge to mass ratio. Further, it can be shown that the plasma frequency is expressed by the relationship:

$$\omega_q=1.83\times 10^8\left[\frac{J^{1/2}}{V_b^{1/4}}\right] \qquad (4)$$

where J is the current density and V_b is the potential on electrode **61**. Another useful relationship is the expression:

$$\frac{V_0}{\overline{V}_0}=2\pi^2\left[\frac{r_0}{\lambda_q}\right]^2 \qquad (5)$$

where $\overline{V}_0$ is the average beam voltage and λ_q is the plasma wavelength.

An examination of Equation 2 will reveal that the difference of potential between the beam surface and the inner wall of the electrode becomes larger as the radius of the cylinder is increased relative to the radius of the electron beam. Equations 3 and 4 reveal that the plasma frequency increases with increased current density which in turn increases the potential depression V_0 within the beam. Equations 2–5 therefore define the characteristics of curve **62** and reveal that the electron stream exhibits a potential distribution across its width which has a positive potential minimum or depression at its axis.

When the electron beam velocity in the longitudinal direction is sufficient to ionize residual gas molecules within envelope **10**, positive ions are created which drift toward the potential minimum at the beam axis. These ions have velocities very small in comparison to the electrons and which correspond to room temperature motion. When the ions are permitted to collect in a given portion of the beam path, the ion density will build up to a constant value with an upper limit at the point where the space charge would be neutralized as a result of which the beam potential no longer would be depressed. The ions then could escape radially. When such escaping ions would strike a coupler plate, for example, noise would be induced on the electron beam which in turn would be picked up by output coupler **16**.

Even though the ions do not reach a density sufficient that they are permitted to escape radially, their presence within the electron beam tends to destroy phase stability of the amplifier. The ions tend to accumulate in low potential regions and their effect on the beam is as if the magnetic field strength were increased; thus, the cyclotron frequency is increased. This increases the number of electron orbits through the device, resulting in a change of phase shift in the signal being amplified. Moreover, this phase shift is subject to instability of magnitude, being dependent upon many variables including envelope, temperature, gas pressure, magnetic field strength, and biasing potentials. Further, any radial motion of the ions is detectable in the output coupler since the latter is a transverse-motion responsive device.

In accordance with the invention, the amplifying assembly of device **10**, which includes the input and output couplers and the pump section, includes a plurality of conductive structures spaced along the path and individually spaced about the path to define a drift region, with the structures tapering apart in a given direction along the path. As illustrated, the active electrodes of couplers **14** and **16** and of pump **15** are themselves conductive and all are tapered in the same direction. Still further, within the central apertures of each of shields **17, 18, 19** and **20**, between the successive principal sections of the device, generally cylindrical drift tubes **65–68**, respectively, are individually disposed. Each of these drift tubes likewise is conductive and is of frustro-conical shape so as to taper apart in the same direction as the electrodes within the couplers and the pump.

Each of the aforesaid conductive structures is biased so that, together with the taper of the conductive structures, a potential gradient is established along the beam which is negative in a direction along the path from one coupler through the other; preferably, the potential decreases monotonically throughout the path portion over which the gradient extends. The different bias potentials are adjusted so that the gradient is sufficiently negative to draw the positive ions in the direction in which the conductive structures taper apart. As is discernable from Equation 2, the taper increases the radial distance *a* which in turn increases the potential difference between each adjacent electrode and the beam. As seen by the beam, this has the effect of a negative gradient along the electrode.

In the present embodiment, all of the conductive structures taper apart in the direction toward collector **12**, as a result of which the ions are drawn downstream in the same direction as the electron flow. Consequently, a positive ion collector **70** is disposed within the overall collector assembly on one side of the beam path; in this instance, collector **70** is simply a U-shaped conductive element having the bottom of the U facing the beam. On the opposite side of the beam path, a similar U-shaped conductive element **71** serves as the electron collector. A transverse conductive plate **72** extends entirely across the electron beam path at its downstream end and functions together with element **71** to collect the electrons. For the purpose of defining a collection chamber in which both the electrons and the ions tend to be retained, an apertured electrode **73** is disposed across the electron path immediately upstream from collector elements **70** and **71**. Further cooperating in the ion collecting process is a frustro-conical cylinder **75**, tapering toward positive ion collector **70**. Cylinder **75** is disposed within the central aperture in shield **21** between the output coupler and collector assembly **12**. In use, shield **21** and ion collector **70** are biased to a potential which is substantially negative relative to that within the region from input coupler **13** to output coupler **16**.

It may be noted that, in principle, the potential gradient and the taper of the conductive structures could be reversed, as a result of which the positive ions would be drawn toward the cathode. While a suitable ion collector could then be disposed in the immediate vicinity of the cathode, it is preferred to avoid any chance of ion penetration into the electron gun by causing the ions to travel, as shown, toward the electron collector end of device **10**. Although not shown, it is also contemplated to taper the different electrodes within electron gun **11**, since ions can have an effect upon the focusing of the beam within the gun structure. These effects are particularly noticeable under pulsed operational conditions. However, for ordinary steady-state operation, the design and adjustment of the electron gun elements for proper beam formation are considerably simplified by aligning the different gun electrodes parallel to the desired beam path.

In operation, the biasing and tapering of the conductive structures create a potential gradient along the beam which varies the beam potential depression. This increases the speed at which the ions are swept from a region where they otherwise would tend to collect. Consequently, the ion density in that region decreases. Once an ion is caused by the potential gradient to move axially across a voltage step even as small as one or two volts, the ion attains sufficient velocity to travel very rapidly through the remainder of the tube to ion collector **70**. Consequently, ions coming from, for example, the region of input coupler **13** travel through the remaining sections so rapidly that their effect upon the ion density in those sections is insignificant.

As mentioned, the tapering of the electrodes serves to depress the space-charge potential along the beam in a manner which is the equivalent of an actual potential gradient along each electrode. Further, drift tubes **66–68** tend to bridge the electrode gaps which otherwise would exist between each of the principal sections. It has been found necessary to maintain a sufficient spacing between the different sections in order adequately to minimize inductive coupling therebetween. Absent the drift tubes in the shield electrodes, the radius *a* (Equation 2) of the effective cylinder surrounding the electron beam would become quite large, creating a potential difference which would tend to cause an ion trap to exist along the beam. Experiments have shown that gaps as small as ten to twenty thousandths of an inch with drift tube diameters of fifty to sixty thousandths of an inch are sufficient to avoid any appreciable axial trapping of the ions, at least in combination with a stepping of the electrode potentials on the successive electrodes. In a successfully operated tube according to the invention as depicted in FIGURE 1, the following biasing potentials were applied to the different conductive structures, by the connections indicated in FIGURE 1 by the letters A through G:

Electrode:	Voltage
65	100–130
13, 66	110–120
50, 67	100–105
52	70–80
68, 16	60–75
70, 75	0
71–73	400

The ranges are somewhat variable and subject to adjustment for optimum operation, with minimum beam interception by the various electrodes and with optimum phase performance. While the ranges given above the potentials applied to pump **15** and coupler **16** overlap, output coupler **16** will be adjusted to a potential to have a bias lower than that on the pump.

As will be noted from an examination of FIGURE 1, certain of the conductive structures are connected in common to a single potential source. Thus, elements **13, 66**; **50, 67**; and **16, 68** are commonly connected to single potential sources. This reduction in the total number of separate bias sources and the number of connecting leads which must extend through envelope **10** is another advantage stemming from the tapered structure of the different conductive elements. Where two successive electrodes have a common potential supply, the potential taper, as seen by the beam, is maintained by dimensioning the upstream electrode to have a lesser exit diameter than the entrance diameter of the downstream one of the two.

As a further aid in preventing abrupt potential discontinuities, but in this case of radio-frequency potentials which may undesirably affect the electron flow, the input or upstream end of all four windings of quadrifilar helix **52** are connected together by a strap **53**. The inductance of quadrifilar helix **52** is sufficient that strap **53** has little effect on the amplitude of the pumping field developed throughout the length of the pump section, but the pump field intensity is reduced near and at the upstream end of helix **52**. Consequently, the pump field intensity begins at a very low value and gradually increases in the downstream direction. Because of the taper of helix **52** along the stream, the pump field intensity actually then begins to decrease toward its downstream end. This change of pump field potential gradient is not harmful to the pumping action, simply causing more gain in one portion of the pump section than in another.

Summarizing as to the ion-collecting arrangement, by reason of the potential gradient established from the input coupler through the output coupler, by means of both a stepping of biases on successive electrodes or electrode groups and through the inclusion of physically tapered electrode elements, regions of potential depression in an axial direction and of a magnitude sufficient to trap positive ions are precluded. The ions are caused to travel at a comparatively high velocity along the beam path through an effective barrier established by reduced-potential drift tube **75**, following which they may drift around somewhat in the collector region until finally accepted by collector **70**. Further, the employment of tapered drift tubes between the different principal sections avoids the creation of potential gaps in localized regions which otherwise might cause the build-up of positive-ion concentrations. The transverse-mode electron waves, therefore, are unaffected by the generation of ions within the device.

Tubes constructed in accordance with the invention have been found to exhibit substantial gains at high power levels. Yet, they may be operated to exhibit very low noise figures and stable phase shift characteristics, parameters comparable to those of more conventional low-power electron beam parametric amplifiers. The beam is effectively supported along its entire length to avoid the creation of potential wells which in turn establish ion traps within the beam, and the positive ions are caused to travel along the electron stream to a point at which they are collected without entering into the electron-wave amplification process.

While a particular embodiment of the present invention has been shown and described, it is apparent that changes and modifications may be made therein without departing from the invention in its broader aspects. The aim of the appended claims, therefore, is to cover all such changes and modifications as fall within the true spirit and scope of the invention.

We claim:

1. An electron beam device comprising:

a substantially evacuated envelope;

means for projecting an electron stream along a path at a velocity sufficient to ionize residual gas molecules, said stream exhibiting a potential distribution across its width having a positive potential minimum at its axis tending to attract any positive ions of said gas toward said axis;

means for subjecting said stream to a magnetic field having flux lines parallel to said path for establishing a condition of transverse electron resonance;

an amplifying assembly having an input coupler responsive to input signal energy for imparting motion to said electrons establishing transverse-mode electron waves on said stream, a pump section downstream from said input coupler responsive to applied energy for developing a periodic inhomogeneous field having a periodicity phased with said motion to increase the magnitude of said waves, and an output coupler downstream from said pump section for extracting signal energy from said waves;

a plurality of conductive structures included in said assembly, spaced along said path, and individually spaced about said path to define a drift region and tapering apart in a given direction along said path;

bias means connected to said conductive structures for establishing, together with the taper of said structures, a negative potential gradient along the portion of said path from one of said couplers through the other, said gradient being sufficiently negative to draw said ions in said direction;

means, spaced along said stream in said direction from said couplers and biased at a potential negative relative to that along said portion, for collecting said positive ions;

and means at the downstream end of said path for collecting said electrons.

2. An electron beam device comprising:

a substantially evacuated envelope;

means for projecting an electron stream along a path at a velocity sufficient to ionize residual gas molecules, said stream exhibiting a potential distribution across its width having a positive potential minimum at its axis tending to attract any positive ions of said gas toward said axis;

means for subjecting said stream to a magnetic field having flux lines parallel to said path for establishing a condition of transverse electron resonance;

an amplifying assembly having an input coupler responsive to input signal energy for imparting motion to said electrons establishing transverse-mode electron waves on said stream, a pump section downstream from said input coupler responsive to applied energy for developing a periodic inhomogeneous field having a periodicity phased with said motion to increase the magnitude of said waves with said pump section including a quadrifilar helix coaxial with said path together with a conductive short connecting all four windings of said helix together at the upstream end thereof, and an output coupler, downstream from said pump section for extracting signal energy from said waves;

a plurality of conductive structures included in said assembly, spaced along said path, and individually spaced about said path to define a drift region and tapering apart in a given direction along said path;

bias means connected to said conductive structures for establishing, together with the taper of said structures, a negative potential gradient along the portion of said path from one of said couplers to the other, said gradient being sufficiently negative to draw said ions in said direction;

means, spaced along said stream in said direction from said couplers and biased at a potential negative relative to that along said portion, for collecting said positive ions;

and means at the downstream end of said path for collecting said electrons.

3. An electron beam device comprising:

a substantially evacuated envelope;

means for projecting an electron stream along a path at a velocity sufficient to ionize residual gas molecules, said stream exhibiting a potential distribution across its width having a positive potential minimum at its axis tending to attract any positive ions of said gas toward said axis;

means for subjecting said stream to a magnetic field having flux lines parallel to said path for establishing a condition of transverse electron resonance;

an input coupler, including conductive structure spaced about said path to define a drift region and tapering apart in a given direction along said stream, responsive to input signal energy for imparting motion to said electrons establishing transverse-mode electron waves on said stream;

a pump section downstream from said input coupler, including conductive structure spaced about said path to define a drift region and tapering apart in said direction, responsive to applied energy for developing a periodic inhomogeneous field having a periodicity phased with said motion to increase the magnitude of said waves;

an output coupler downstream from said pump section, including conductive structure spaced about said path to define a drift region and tapering apart in said direction, for extracting signal energy from said waves;

bias means connected to different ones of said conductive structures for establishing, together with the taper of said structures, a negative potential gradient along the portion of said path from one of said couplers through the other, said gradient being sufficiently negative to draw said ions in said direction;

means, spaced along said stream in said direction from said couplers and biased at a potential negative relative to that along said portion, for collecting said positive ions;

and means at the downstream end of said path for collecting said electrons.

4. An electron beam device comprising:

a substantially evacuated envelope;

means for projecting an electron stream along a path at a velocity sufficient to ionize residual gas molecules, said stream exhibiting a potential distribution across its width having a positive potential minimum at its axis tending to attract any positive ions of said gas toward said axis;

means for subjecting said stream to a magnetic field having flux lines parallel to said path for establishing a condition of transverse electron resonance;

an input coupler, including conductive structure spaced about said path to define a drift region and tapering apart in a given direction along said stream responsive to input signal energy for imparting motion to said electrons establishing transverse-mode electron waves on said stream;

a pump section downstream from said input coupler, including conductive structure spaced about said path to define a drift region and tapering apart in said direction, responsive to applied energy for developing a periodic inhomogeneous field having a periodicity phased with said motion to increase the magnitude of said waves;

an output coupler downstream from said pump section, including conductive structure spaced about said path to define a drift region and tapering apart in said direction, for extracting signal energy from said waves;

bias means connected to different ones of said conductive structures for establishing, together with the taper of said structures, a negative potential gradient along the portion of said path from one of said couplers through the other, said gradient being sufficiently negative to draw said ions in said direction;

means, spaced along said stream in said direction from said couplers and biased at a potential negative relative to that along said portion, for collecting said positive ions;

a conductive element, interposed individually between and substantially encompassing the space between said couplers and said ion-collecting-means, defining a drift region and tapering apart in said direction;

means for biasing said element at a potential negative relative to that along said path portion;

and means at the downstream end of said path for collecting said electrons.

5. An electron beam device comprising:

a substantially evacuated envelope;

means for projecting an electron stream along a path at a velocity sufficient to ionize residual gas molecules, said stream exhibiting a potential distribution across its width having a positive potential minimum at its axis tending to attract any positive ions of said gas toward said axis;

means for subjecting said stream to a magnetic field having flux lines parallel to said path for establishing a condition of transverse electron resonance;

an input coupler, including conductive structure spaced about said path to define a drift region and tapering apart in the downstream direction, responsive to input signal energy for imparting motion to said electrons establishing transverse-mode electron waves on said stream;

a pump section downstream from said input coupler, including conductive structure spaced about said path to define a drift region and tapering apart in the downstream direction, responsive to applied energy for developing a periodic inhomogeneous field having a periodicity phased with said motion to increase the magnitude of said wave;

an output coupler downstream from said pump section, including conductive structure spaced about said path to define a drift region and tapering apart in the downstream direction, for extracting signal energy from said waves;

bias means connected to different ones of said conductive structures for establishing, together with the taper of said structures, a negative potential gradient along the portion of said path from said input coupler through said output coupler, said gradient being sufficiently negative to draw said ions downstream;

means, disposed downstream from said output coupler and biased at a potential negative relative to that along said portion, for collecting said positive ions;

and means at the downstream end of said path for collecting said electrons.

6. An electron beam device comprising:

a substantially evacuated envelope;

means for projecting an electron stream along a path at a velocity sufficient to ionize residual gas molecules, said stream exhibiting a potential distribution across its width having a positive potential minimum at its axis tending to attract any positive ions of said gas toward said axis;

means for subjecting said stream to a magnetic field having flux lines parallel to said path for establishing a condition of transverse electron resonance;

an input coupler, including conductive structure spaced about said path to define a drift region and tapering apart in the downstream direction, responsive to input signal energy for imparting motion to said electrons establishing transverse-mode electron waves on said stream;

a pump section downstream from said input coupler, including conductive structure spaced about said path to define a drift region and tapering apart in the downstream direction, responsive to applied energy for developing a periodic inhomogeneous field having a periodicity phased with said motion to increase the magnitude of said waves;

an output coupler downstream from said pump section, including conductive structure spaced about said path to define a drift region and tapering apart in the downstream direction, for extracting signal energy from said waves;

bias means connected to different ones of said conductive structures for establishing, together with the taper of said structures, a negative potential gradient along the portion of said path from said input coupler through said output coupler, said gradient being sufficiently negative to draw said ions downstream;

means, spaced along one side of said stream downstream from said output coupler and biased at a potential negative relative to that along said portion, for collecting said positive ions;

a conductive element, interposed individually between and substantially encompassing the space between said output coupler and said ion-collecting-means, defining a drift region and tapering apart in the downstream direction;

means for biasing said element at a potential negative relative to that along said portion;

and means, disposed along said path and opposite said ion-collecting-means, biased to a positive potential for collecting said electrons.

7. An electron beam device comprising:

a substantially evacuated envelope;

means for projecting an electron stream along a path at a velocity sufficient to ionize residual gas molecules, said stream exhibiting a potential distribution across its width having a positive potential minimum at its axis tending to attract any positive ions of said gas toward said center;

means for subjecting said stream to a magnetic field having flux lines parallel to said path for establishing a condition of transverse electron resonance;

an input coupler responsive to input signal energy for imparting motion to said electrons establishing transverse-mode electron waves on said stream;

a pump section downstream from said input coupler responsive to applied energy for developing a periodic inhomogeneous field having a periodicity phased with said motion to increase the magnitude of said waves;

an output coupler downstream from said pump section for extracting signal energy from said waves;

means interposed individually between and substantially encompassing the space between each of said couplers and said pump section, including conductive structures spaced about said path to define a drift region and tapering apart in a given direction along said stream;

bias means connected to different ones of said conductive structures, couplers and pump section for establishing, together with the taper of said structures, a negative potential gradient along the portion of said path from one of said couplers through the other, said gradient being sufficiently negative to draw said ions in said direction;

means, spaced along said stream in said direction from said couplers and biased at a potential negative relative to that along said portion, for collecting said positive ions;

and means at the downstream end of said path for collecting said electrons.

8. An electron beam device comprising:

a substantially evacuated envelope;

means for projecting an electron stream along a path at a velocity sufficient to ionize residual gas molecules, said stream exhibiting a potential distribution across its width having a positive potential minimum at its axis tending to attract any positive ions of said gas toward said axis;

means for subjecting said stream to a magnetic field having flux lines parallel to said path for establishing a condition of transverse electron resonance;

an input coupler responsive to input signal energy for imparting motion to said electrons establishing transverse-mode electron waves on said stream;

a pump section downstream from said input coupler responsive to applied energy for developing a periodic inhomogeneous field having a periodicity phased with said motion to increase the magnitude of said waves;

an output coupler downstream from said pump section for extracting signal energy from said waves;

means interposed individually between and substantially encompassing the space between each of said couplers and said pump section, including conductive structure spaced about said path to define a drift region and tapering apart in the downstream direction;

bias means connected to different ones of said conductive structures, couplers and pump section for establishing, together with the taper of said structures, a negative potential gradient along the portion of said path from said input coupler through said output coupler, said gradient being sufficiently negative to draw said ions downstream;

means, disposed downstream from said output coupler and biased at a potential negative relative to that along said portion, for collecting said positive ions;

and means at the downstream end of said path for collecting said electrons.

9. An electron beam device comprising:

a substantially evacuated envelope;

means for projecting an electron stream along a path at a velocity sufficient to ionize residual gas molecules, said stream exhibiting a potential distribution across its width having a positive potential minimum at its axis tending to attract any positive ions of said gas toward said axis;

means for subjecting said stream to a magnetic field having flux lines parallel to said path for establishing a condition of transverse electron resonance;

an input coupler, including conductive structure spaced about said path to define a drift region and tapering apart in a given direction along said stream responsive to input signal energy for imparting motion to said electrons establishing transverse-mode electron waves on said stream;

a pump section downstream from said input coupler, including conductive strcture spaced about said path to define a drift region and tapering apart in said direction, responsive to applied energy for developing a periodic inhomogeneous field having a periodicity phased with said motion to increase the magnitude of said waves;

an output coupler downstream from said pump section, including conductive structure spaced about said path to define a drift region and tapering apart in said direction, for extracting signal energy from said waves;

means interposed individually between and substantially encompassing the space between each of said couplers and said pump section, including conductive structure spaced about said path to define a drift region and tapering apart in said direction;

bias means connected to different ones of said conductive structures for establishing, together with the taper of said structures, a negative potential gradient along the portion of said path from one of said couplers through the other, said gradient being sufficiently negative to draw said ions in said direction;

means, spaced along said stream in said direction from said couplers and biased at a potential substantially negative relative to that along said portion, for collecting said positive ions;

a conductive element, interposed individually between and substantially encompassing the space between said couplers and said ion-collecting-means, defining a drift region and tapering apart in said direction;

means for biasing said element at a potential substantially negative relative to that along said portion;

and means at the downstream end of said path for collecting said electrons.

10. An electron beam device comprising:

a substantially evacuated envelope;

means for projecting an electron stream along a path at a velocity sufficient to ionize residual gas molecules, said stream exhibiting a potential distribution across its width having a positive potential minimum at its axis tending to attract any positive ions of said gas toward said axis;

means for subjecting said stream to a magnetic field having flux lines parallel to said path for establishing a condition of transverse electron resonance;

an input coupler, including conductive structure spaced about said path to define a drift region and tapering apart in the downstream direction, responsive to input signal energy for imparting motion to said electrons establishing transverse-mode electron waves on said stream;

a pump section downstream from said input coupler, including conductive structure spaced about said path to define a drift region and tapering apart in the downstream direction, responsive to applied energy for developing a periodic inhomogeneous field having a periodicity phased with said motion to increase the magnitude of said waves;

an output coupler downstream from said pump section, including conductive structure spaced about said path to define a drift region and tapering apart in the downstream direction, for extracting signal energy from said waves;

means interposed individually between and substantially encompassing the space between each of said couplers and said pump section, including conductive structure spaced about said path to define a drift region and tapering apart in the downstream direction;

bias means connected to different ones of said conductive structures for establishing, together with the taper of said structures, a negative potential gradient along the portion of said path from said input coupler through said output coupler, said gradient being sufficiently negative to draw said ions downstream;

means, disposed downstream from said output coupler and biased at a potential substantially negative relative to that along said portion, for collecting said positive ions;

a conductive element, interposed individually between and substantially encompassing the space between said output coupler and said ion-collecting-means, defining a drift region and tapering apart in the downstream direction;

means for biasing said element at a potential substantially negative relative to that along said portion;

and means at the downstream end of said path for collecting said electrons.

No references cited.

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