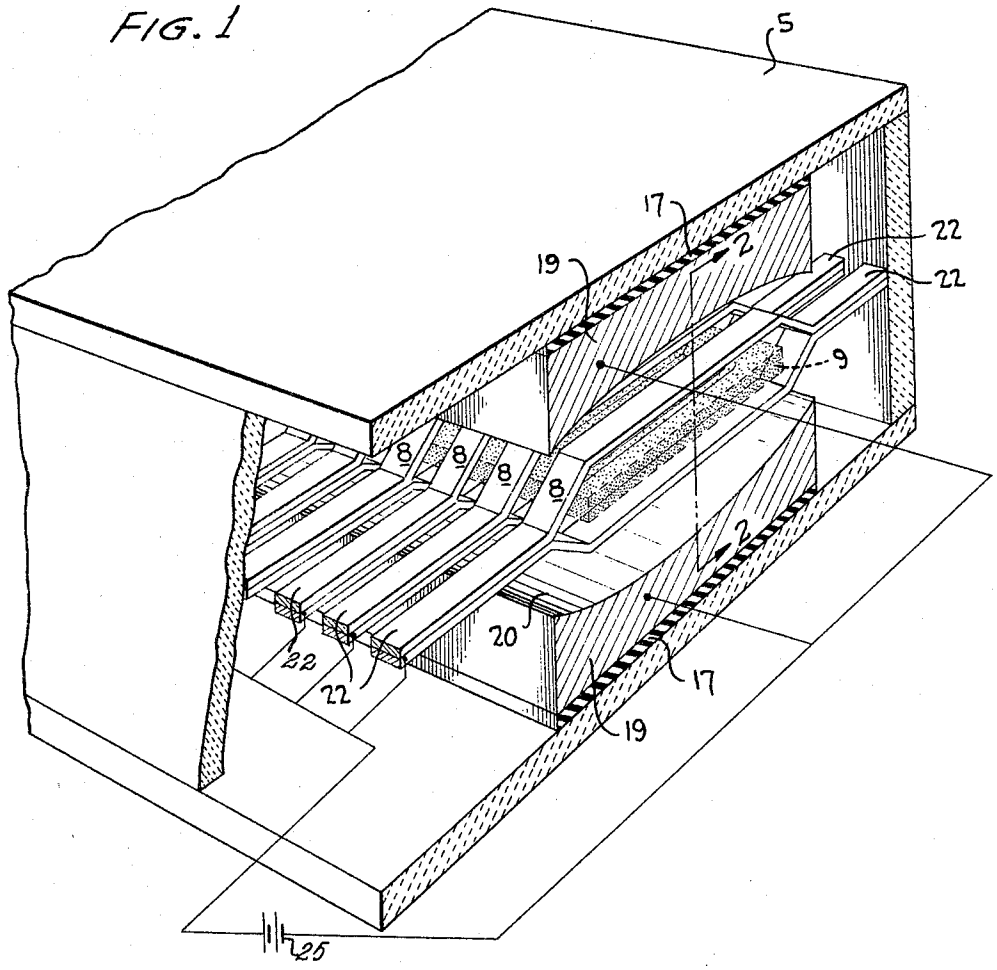
Aug. 2, 1966 B. J. UDELSON 3,264,514

ELECTROSTATIC PLANER ELECTRON BEAM FOCUSING

Filed July 2, 1962 2 Sheets-Sheet 1

FIG. 1



INVENTOR
BURTON J. UDELSON
BY S. J. Rotondi, a. I. Dupont
+ J. P. Edgerton

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FIG. 2

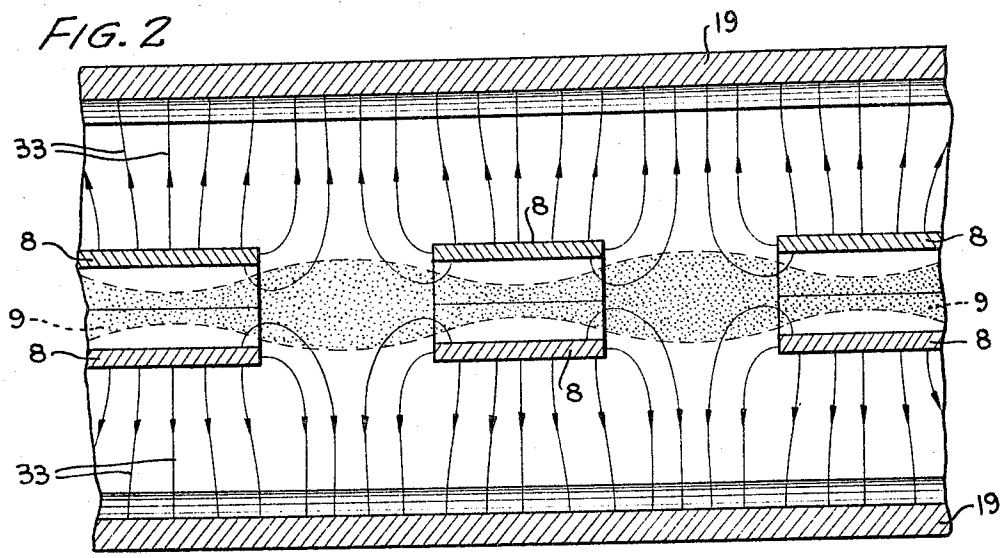
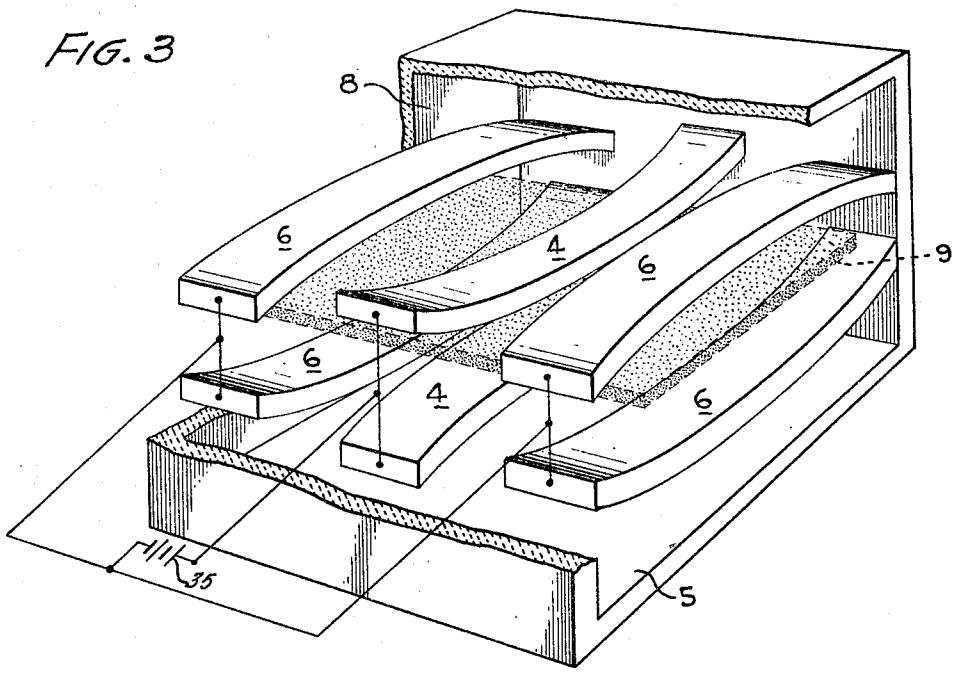


FIG. 3



INVENTOR
BURTON J. UDELSON

BY S. J. Rotondi, A. J. Dupont
& J. D. Edgerton

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ELECTROSTATIC PLANAR ELECTRON BEAM FOCUSING

Burton J. Udelson, Rockville, Md., assignor to the United States of America as represented by the Secretary of the Army

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11 Claims. (Cl. 315—5.29)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment to me of any royalty thereon.

This invention relates to the field of electron beam focusing, and more particularly to a method and systems for focusing a planar electron beam.

Electrostatically focused planar electron sheet, or "ribbon," beams find application in a number of microwave devices such as traveling-wave amplifiers, backward-wave oscillators, and parametric amplifiers. The space charge forces that act to increase beam thickness may be counteracted by electrostatic focusing techniques wherein a series of focusing plates are spaced periodically along the path of travel in such a manner as to create a series of focusing fields which tend to maintain the beam at the center of its line of travel. These focusing mechanisms have not been capable, however, of preventing the beam electrons from spreading in the direction of the beam width. Various techniques have been used to prevent such spreading, such as negatively charged metallic strips or pins placed on each side of the beam sheet. Both of these mechanisms, while preventing the beam from spreading in the lateral direction, have one shortcoming in that the space charge forces which tend to cause this beam spread are opposed unequally across the beam width. Thus, these space charge forces may be completely counteracted at the edges of the beam but not at the portions of the beam near its center. This results in a tendency for the beam density to be greater at its lateral edges than at the beam center. This nonuniform distribution may result in a loss of beam transmission or, because of space charge effects, a depression of potential over various portions of the beam may result, causing variations in beam velocity. Such variations may affect the efficiency of interaction between the electron beam and the R.-F. circuit when the system is used in microwave devices.

It is therefore an object of this invention to provide electron sheet beams having uniform beam density across their width.

It is a further object of this invention to exactly counteract the lateral space charge forces at all points within the beam.

It is still another object of this invention to simplify the construction of means to maintain the proper width of an electron sheet beam.

According to the present invention, the foregoing and other objects are obtained by providing within an electron sheet beam tube an electrostatic focusing element having a cross-section in a plane perpendicular to the direction of travel of the beam which is of such a shape as to accurately counteract the space charge forces, at every point across the beam.

Alternatively, the principle of this invention may be embodied in an electron sheet beam tube having a plurality of focusing segments spaced along the path of travel of the beam. In such a tube each of the focusing elements could be individually shaped so as to achieve the desired result.

The specific nature of the invention, as well as other objects, uses and advantages thereof, will clearly appear

from the following description and from the accompanying drawing, in which:

FIG. 1 is a partial perspective view illustrating one embodiment of the present invention.

FIG. 2 is a cross-sectional view of the portion of FIG. 1 taken along line 2—2.

FIG. 3 is a partial perspective view illustrating a second embodiment of this invention.

Referring now to the drawing wherein like reference numerals designate identical or corresponding parts throughout the several views, and more particularly to FIG. 1, there is shown a ladder line electrostatic focusing system contained within a ceramic casing 5. The two focusing electrodes 19, known as ridge plates, are connected to their respective insulators 17, and these insulators are mounted on a first pair of opposite internal walls of casing 5. A second group of focusing electrodes 8, known as ladder lines, are arranged between ridge plates 19. These focusing electrodes 8 form a top series of linear focusing electrodes separated from each other and spaced along the direction of travel of the beam 9 and a bottom series of linear focusing electrodes separated from each other and also spaced in the direction of travel of the beam 9. The ends of ladder lines 8 are connected to the second pair of opposite internal walls of casing 5 by means of supporting members 22. Electrodes 8 and 19 are arranged so as to provide symmetrical focusing fields both above and below electron sheet beam 9. The ridge plates 19 extend along substantially the entire distance of ladder lines 8 and are biased negatively, by means of a battery 25, with respect to ladder lines 8.

Skilled persons will readily understand that, as sheet beam 9 travels through the described structure, it passes alternately through defocusing regions that cause the beam to increase in thickness and through focusing regions that cause the beam to decrease in thickness, as illustrated in FIGURE 2. FIGURE 2 is a sectional view of the focusing elements and the electron beam with the variations of beam thickness greatly exaggerated. The figure also illustrates the lines of electric field 33 that constitute the various focusing and defocusing regions. The defocusing regions are those regions through which the beam passes in which the lines of electric field, as shown in FIGURE 2, have a component that is directed inward toward the center plane of the beam and that thus applies a transverse converging force to the electrons constituting the beam. The focusing regions are those regions through which the beam passes in which the lines of electric field have a component that is directed outward away from the center plane of the beam and that thus applies a transverse diverging force to the electrons constituting the beam.

The structure and operation described thus far are well known. The alternate focusing and defocusing to which the beam is subjected as it moves down the tube has the effect of maintaining the average beam thickness substantially constant. However, if it were not for an important and novel feature of FIGURE 1 that will be described shortly, the beam would tend to spread laterally and to develop lower electron density near the center.

In an effort to control this undesirable lateral spreading, various schemes have been proposed or used involving various types of electron-repelling structures adjacent to the lateral edges of the beam. Unfortunately, such known systems, besides requiring additional structural elements, counteract the lateral space-charge forces at the beam edges only.

My invention involves modifying the electrodes already present in known electron sheet beam tubes in such a manner as to counteract the lateral space-charge forces at every point within the beam and not merely at the edges of the beam. I accomplish this in the embodiment

of FIGURE 1 by providing ridge plates **19** with concave surfaces **20**. By making the surfaces **20** concave I am able to introduce into the focusing and defocusing regions a lateral component of electric field that applies to each electron within a beam having uniform electron distribution an inward lateral force that is equal and opposite to the outward lateral force due to space charge. It will be understood that these lateral forces—both the force due to space charge and the compensating force due to my invention—are substantially zero at the center of the beam and increase continuously with lateral distance to the edge of the beam.

If the variation of space charge forces as a function of lateral displacement from the beam center were known, it would be possible to so shape the surface **20** of ridge plate **19** as to provide exact compensation for these forces. Such a relation was derived by Houtermans and Riewe in 35 Archiv. für Electrotechnik 686 (Germany 1941) (Equation 7). When this equation is integrated it yields an expression for the variation in space-charge force across the beam width. Also, the variation of average D.-C. potential between the two ladder lines in the absence of space charge must be known as a function of the separation between the ladder line and the ridge plate. This variation may be determined by applying conducting paint to resistance paper in a pattern which simulates the cross section of the ladder line and ridge plate structure. A series of measurements may then be made of the variation of D.-C. potential as a function of the separation between the ladder line and ridge plate. The ridge plate may then be shaped so that the lateral variation of D.-C. potential (due to the variation of ladder line to ridge plate separation) exactly compensates the lateral potential variation due to the presence of space charge. The lateral electric fields would then be balanced at each point. It has been determined that a ridge plate having a concave surface which is in the form of the arc of a circle closely approximates that obtained from the above noted theoretical consideration and provides satisfactory results.

Exact compensation of the lateral space charge force will be obtained only for the proper combination of ladder potential, ridge plate potential, and beam space charge density. It has been determined theoretically that for an application such as the backward-wave oscillator in which the average beam potential must be varied, this exact compensation will be maintained if the ridge plate is operated at cathode potential and the current is kept proportional to the three-halves power of the ladder line potential. This proportionality may be achieved by operating the anode of a Pierce type electron gun, such as that described in Pierce, Theory and Design of Electron Beams, chapter 10 (1954), at a potential proportional to the ladder line potential.

A second type of sheet beam focusing structure which may be modified in accordance with the invention is the planar plate electrostatic focusing structure. A modification of this structure is illustrated in FIG. 3 wherein is shown focusing electrodes **4** and **6** forming two series of electrodes on top of the sheet electron beam **9** and two series of electrodes on the bottom of the sheet electron beam **9** which are maintained at D.-C. potentials by means of, for example, a battery **35**, with the potential on plates **6** being more negative than the potential on plates **4**. The potential variation between adjacent plates creates electrostatic forces which form a series of focusing lenses which maintain the beam at the proper thickness. By forming the more negative plate **6** so as to have a concave shape on the side nearest the electron beam, and the less negative plates **4** so as to have a convex shape on the side nearest the beam, the exact compensation of lateral space charge forces at every point in the beam may be obtained. The precise shapes which these electrodes should have may be determined in a manner similar to that discussed in connection with the structure of FIG. 1.

Skilled persons will understand that, just as in the ladder-line embodiment of FIGURES 1 and 2 only the negatively-charged electrodes **19** were curved, the planar plate embodiment of FIGURE 3 could be modified to provide a planar plate embodiment in which only the more positive plates **4**, or only the more negative plates **6**, but not both, would be curved. It will be understood that, to provide the required lateral variation of D.-C. potential in the focusing and defocusing regions, curvature on the side of the electrode facing the beam must be concave when applied to negative plates but convex when applied to positive plates.

It will be apparent that the embodiments shown are only exemplary and that various modifications can be made in construction and arrangement within the scope of the invention as defined in the appended claims. In the claims, "longitudinal" means the direction of beam motion, "transverse" means the direction of beam thickness, and "lateral" means the direction of beam width, and "transverse center plane" means a transverse plane that includes the longitudinal axis of the beam.

I claim as my invention:

1. In an electron space-discharge device of the type having a cathode adapted to issue a sheet electron beam toward a longitudinally-spaced collector, a focusing system comprising a first pair of electrodes and a second pair of electrodes, wherein:

(a) the electrodes of said first pair are electrically connected to each other and to a first circuit point and the electrodes of said second pair are electrically connected to each other and to a second circuit point, means being provided to maintain the potential at said first circuit point positive with respect to said second circuit point,

(b) the first electrode of each pair is positioned opposite the second electrode of each pair, the beam passing between the first electrode and the second electrode,

(c) the electrodes of said first pair are longitudinally spaced from the electrodes of said second pair,

(d) each electrode is at least approximately as wide as said beam,

(e) the surface of each electrode is symmetrical with respect to the transverse center plane of the beam,

(f) all longitudinal elements of the surface of each electrode are straight lines parallel to the longitudinal axis of the beam, and

(g) the surface of at least one of said electrodes is curved in the lateral direction, the curvature being convex in the case of electrodes of said first pair and concave in the case of electrodes of said second pair, so that the beam in passing through the region of said first and second pairs passes through regions of transverse defocusing and focusing fields upon which is superimposed a lateral field component that subjects electrons in said beam to a space-charge-compensating force directed laterally toward the transverse center plane of said beam, the amplitude of said force being substantialy zero at said center plane and increasing continuously and symmetrically on both sides of the center out to the lateral edges of the beam.

2. The invention according to claim **1**, wherein both electrodes of said first pair are identical to each other and are identically spaced from said beam and wherein both electrodes of said second pair are identical to each other and are identically spaced from said beam.

3. The invention according to claim **2** wherein the electrodes of said first pair are curved.

4. The invention according to claim **2** wherein the electrodes of said second pair are curved.

5. The invention according to claim **2** wherein the electrodes of both pairs are curved.

6. The invention according to claim 5 wherein the curvatures of the convex electrodes are substatially identical to the curvatures of the concave electrodes.

7. The invention according to claim 6 wherein the spacings of all electrodes from said beam are substantialy identical.

8. The invention according to claim 4 wherein the electrodes of said second pair are spaced substantially farther from said beam than the electrodes of said first pair.

9. The invention according to claim 7 comprising additionally at least third through seventh odd-numbered pairs of electrodes and at least fourth through eighth even-numbered pairs of electrodes, all pairs being longitudinally spaced with even-numbered pairs alternating with odd-numbered pairs, said first through seventh odd-numbered pairs being identically constructed, positioned, and connected and said second through eight even-numbered pairs being identically constructed, positioned, and connected.

10. The invention according to claim 8 comprising additionaly at least third through seventh odd-numbered pairs of electrodes and at least fourth through eighth even-

numbered pairs of electrodes, all pairs being longitudinally spaced with even-numbered pairs alternating with odd-numbered pairs, said first through seventh odd-numbered pairs being identically constructed, positioned, and connected and said second through eighth even-numbered pairs being identically constructed, positioned, and connected.

11. The invention according to claim 10 wherein the electrodes of said even-numbered pairs are segments of a single upper ridge plate and a single lower ridge plate.

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JAMES W. LAWRENCE, *Primary Examiner.*

GEORGE WESTBY, *Examiner.*

V. LAFRANCHI, S. D. SCHLOSSER,
Assistant Examiners.