June 4, 1968 O. HEIL 3,387,171

DEVICE FOR MODULATING BEAMS OF CHARGED PARTICLES UTILIZING A LONG INTERACTION GAP

Original Filed June 10, 1960 2 Sheets-Sheet 1

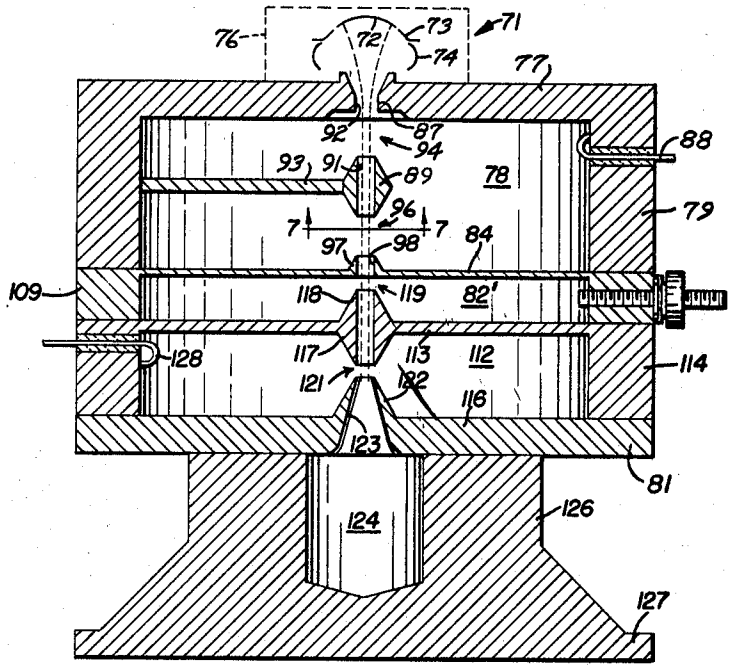


Fig. 2

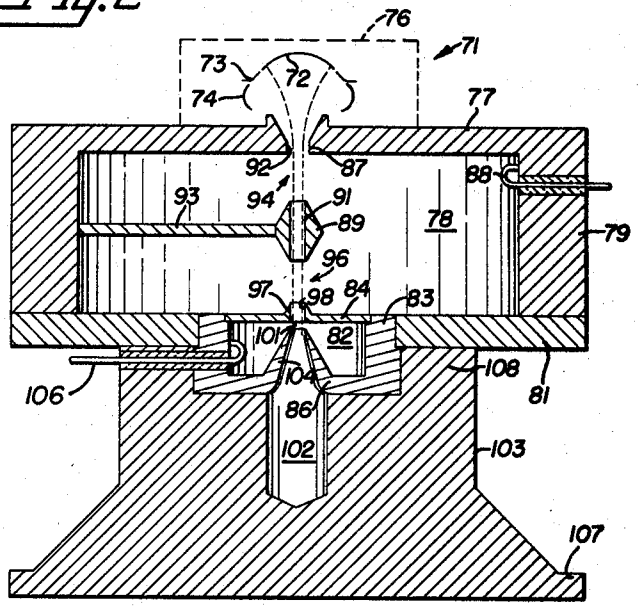


Fig. 1

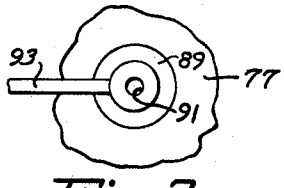


Fig. 3

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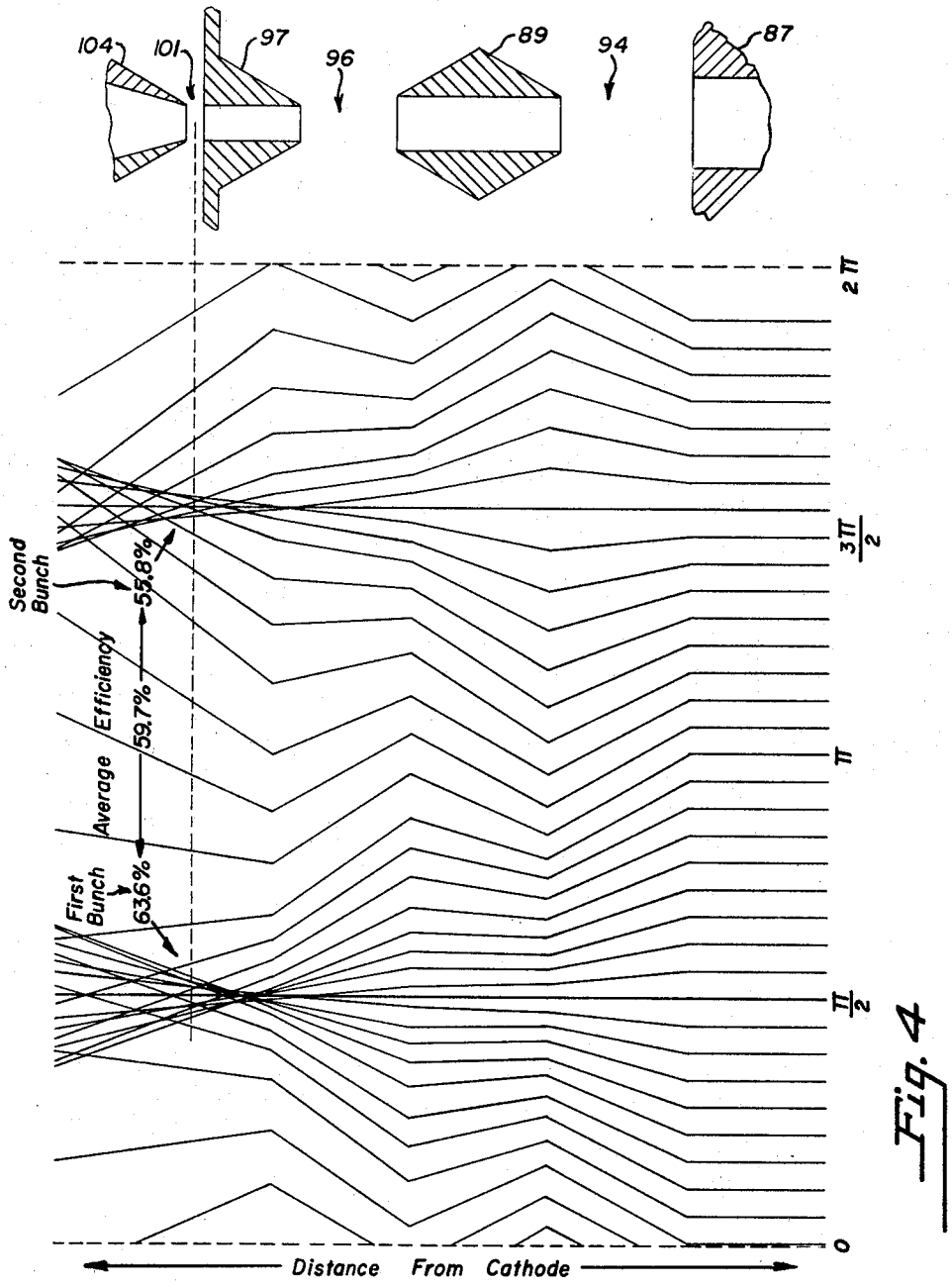


Fig. 4

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3,387,171

DEVICE FOR MODULATING BEAMS OF CHARGED PARTICLES UTILIZING A LONG INTERACTION GAP

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Original application June 10, 1960, Ser. No. 35,258, now Patent No. 3,234,426, dated Feb. 8, 1966. Divided and this application Oct. 22, 1965, Ser. No. 510,436

5 Claims. (Cl. 315—5.51)

ABSTRACT OF THE DISCLOSURE

A device for density modulating beams of charged particles is described which utilizes an interaction gap having a length substantially equal to the distance a charged particle traveling the beam velocity will travel during one full cycle of the input frequency. The efficiency of the device is discussed. Embodiments of the device capable of frequency doubling and of operation at the input frequency are described.

This application is a division of my pending application Ser. No. 35,258, filed June 10, 1960, now U.S. Patent No. 3,234,426 issued Feb. 8, 1966.

My invention claimed herein relates to novel electron tube structures, and more particularly to electron beam tubes of the klystron type specially modified to accomplish bunching in accordance with an aspect of the teaching of my above identified pending application combined with an aspect of the teaching of my U.S. Patent 3,012,170.

The technological advances of the last decade, particularly in the electronics industry, have resulted in electronic systems and components being utilized in wholly new applications which impose new concepts of reliability, life expectancy, efficiency of operation, weight, vibration, acceleration, impact shock and adaptability to extreme fluctuations in temperature and pressure.

As these new applications render such systems and components less accessible, the more critical these qualities become, and the more limited become the sources of supply for components possessing these desirable qualities. For instance, in the electronics industry, the power demanded of high-frequency tubes becomes greater every year, particularly as regards tubes of the beam type such as klystrons and traveling wave tubes. The demands for increased power sometimes becomes so pressing that other desirable qualities, such as efficiency and light weight, are sacrificed to meet the demand for power. It is therefore one of the objects of the invention to provide a more efficient method of securing well-defined bunching of the charged particles forming the beam in a beam tube, particularly an electron beam tube.

At least two kinds of forces move electrons in electron tubes: first, the well known force which causes an electron to be attracted by a positive charge, and second, a more complicated force which causes an electron to be repelled from a region of electromagnetic turbulence such as is caused by an electromagnetic field which is inhomogeneous in space and varies with time. These conditions may be referred to as space inhomogeneity and time inhomogeneity. The nature of this second force can perhaps be best described in terms of its effect on an electron, which effect is to translate the oscillating motion which an electron experiences in a region of electromagnetic turbulence into a motion of propagation which the electron has when it is repelled from the turbulent region. Accordingly, this second force will be hereinafter referred to as a rectifying force. In the case of the first, or electrostatic force, the space potential to which an electron moves is more positive than the space potential from which it was moved, while in the case of the second, or rectifying force, there is no change in the average space potential.

In the past, longitudinal focusing of electron beams to cause bunching has been accomplished by use of the first type of force. It is one of the objects of this invention to accomplish longitudinal focusing of electron beams by use of the second type or rectifying force.

Increasing the degree of longitudinal focusing of an electron beam leads to higher efficiencies; however, in conventional klystrons and traveling wave tubes, this higher degree of longitudinal focusing results in a greater amount of radial defocusing, which has heretofore had to be controlled by an electromagnetic radial-focusing circuit. This object is obtained by use of the rectifying type of force to obtain radial focusing, as well as longitudinal focusing. When the rectifying type of force is used in accordance with the invention to accomplish both longitudinal and radial focusing, these two types of focusing become compatible and can be obtained simultaneously; whereas, when the first type of force is used to achieve longitudinal focusing in conventional beam tubes, radial defocusing is an inherent by-product which results in the need for separate radial-focusing circuitry.

It is known that positively charged particles are amenable to the same type of control as negatively charged particles or electrons, and it is also known that there are a variety of ways of creating alternate regions of relative turbulence and relative quiet with respect to charged particles. Accordingly, it is another object of the invention to provide a device in which a beam of charged particles is caused to interact with regions of relative turbulence and relative quiet.

A still further object of the invention is to provide a frequency multiplier device in which the physical parameters are cooperatively arranged to provide simultaneous radial and longitudinal focusing of the electron beam without the need of external focusing means.

Still another object of the invention is the provision of a multi-cavity klystron structure with which the method of focusing herein described is particularly useful.

The invention possesses other objects and features of advantage, some of which, with the foregoing, will be set forth in the following description of the invention. It is to be understood that the invention is not limited to the embodiments disclosed, as I may adopt variant embodiments within the scope of the appended claims.

Referring to the drawings:

FIGURE 1 is a vertical half-sectional view illustrating a frequency doubler designed to utilize simultaneous radial and phase focusing.

FIGURE 2 is a vertical half-sectional view illustrating a three-cavity kylstron designed to utilize simultaneous radial and phase focusing to obviate the need for external magnetic means preventing dispersal of the electrons in the beam.

FIGURE 3 is a fragmentary view illustrating the floating drift tube and support means therefor used in FIGURE 2.

FIGURE 4 is a view illustrating how the inhomogeneity of the fringing field at the entrance and exit of the drift tube of the frequency doubler shown in FIGURE 1 results in longitudinal focusing of the electrons into two slightly asymmetrical bunches per cycle of the fundamental frequency.

In FIGURE 1, I have illustrated the structure of a practical frequency doubler utilizing the principle of simultaneous longitudinal and radial focusing. In the drawing the gun structure is indicated generally by the numeral 71, it being understood that the gun structure

comprises an electron emitting cathode 72 operatively associated with electron beam forming electrodes 73 and 74. The electron gun structure is preferably enclosed within an evacuated envelope portion 76 which in integrally and hermetically united to the main body of the electron tube. Operatively associated with the electron gun structure is one wall 77 of a hollow cylindrical resonant cavity 78. A cylindrical wall 79 joined integrally and hermetically at one end to the peripheral portion of the wall 77 enclosed the cavity 78, while a third wall 81 integral with the other end of the cylinder 79 constitutes a partition between the cavity 78 and a second cavity 82. The second cavity 82 includes a cylindrical cup shaped portion 83 closed at one end by an extension of the wall 81, the extension being designated by the numeral 84 while the other end of the cavity is closed by a wall 86. As shown in FIGURE 1, the beam of electrons generated by the cathode 72 is projected to a drift tube 87 formed as an integral part of the wall 77 of the first cavity. The cavity is excited at the desired frequency by the input loop 88 extending through the wall 79 of the cavity and connected at its outer end to a source of high alternating current frequency. Floating between the wall 77 and the wall 84 of the first cavity 78 is a floating drift tube 89. The drift tube 89 is provided with a bore 91 of somewhat smaller diameter than the bore 92 of the drift tube 87. A slender supporting rod 93 supports the drift tube 89 intermediate the walls 77 and 84. The support rod 93 is preferably located in the cavity in a neutral position so that it does not constitute a conductor between the wall of the cavity and the drift tube, thus rendering the drift tube a true floating type.

The drift tube 89 is preferably positioned in the cavity so that gap 94 betwen the drift tube 87 and 89 is one full cycle of the exciting frequency. It will thus be seen that the long 360° control gap between the drift tube 87 and 89 provides a homogeneous AC field intermediate these two drift tubes, with the field inhomogeneity existing only in the fringing field at the entrance to the drift tube 89 and at the exit of the drift tube 87. It is thus apparent that the major portion of the gap 94, taken with the drift tube 89, provide two regions of homogeneity through which the electrons are projected. I have found that in order to obtain velocity modulation of electrons, you must have time variation of the electric field, and space variation of the electric field. If one is missing, no velocity modulation will occur. Thus, in the structure of FIGURE 1, the space variation or space inhomogeneity exists in the fringing field immediately adjacent the exit and entrance of the drift tubes. Because a drift tube is generally a field free region, a region of space inhomogeneity exists at the exit of the drift tube 87. The length of the fringing field at this point is roughly equal to the diameter of the dritf tube bore. Such region of inhomogeneity defines the acceleration or deceleration or focusing region of the device. Between this region and a similar region immediately adjacent the inlet or input end of the drift tube 89, there lies a region or field in which the AC field is homogeneous. This homogeneous AC field is equivalent to a drift tube, and by analogy forms a region in which the beam may be longitudinally focused. It will therefore be apparent that if the AC field strength in the region of the homogeneous field is fixed, the amount of phase focusing of electrons entering this field can be varied or controlled by the extension of the inhomogeneous region.

After drifting through the drift tube 89 the electrons are again acted upon by the region of inhomogeneity at the exit of the drift tube 89 after which they enter the region of a homogeneous AC field in gap 96. After traversing the gap 96, the electrons again enter a region of inhomogeneity at the entrance to drift tube 97, formed in the wall 84 interposed between the cavity 78 and 82. The bore 98 of the drift tube 97 is preferably dimensioned to provide a diameter equal to the bore 91 of drift tube 89. It will also be noted that the diameter of the drift tube 87 is increased in size over the diameter of drift tube 89 in order to provide a different interaction between the drift tube and the beam passing therethrough. The reason for this geometry is that it is essential that the amount of modulation effected by the first fringing field by only half the value of successive ones. In the structure shown in FIGURE 1, this is effected by increasing the diameter of the drift tube 87. The effect of the inhomogeneity surrounding the gap 87 is thus at half value of the effect of the region of inhomogeneity at the entrance of the drift tube 89. The desired symmetry of bunching is thus achieved. Thus in the structure of FIGURE 1, with the help of electrolytic tank measurements, the diameter of the first drift tube is determined to provide a modulation which is only half the modulation in succeeding gaps or regions of inhomogeneity. Additionally, the average transit time of each gap and of the drift tube 89 is one cycle each, resulting in four counteracting focusing actions. As previously explained, the phase focusing actions take place in the regions of inhomogeneity at the entrance and exit fringing fields of the various drift tubes. With the structure shown, two bunches of electrons are obtained for each cycle of the driving frequency. The first bunch provided an efficiency of 63.6%, whereas the second bunch provides an efficiency of 55.8%, resulting in an average efficiency of 59.7%, a rather high value for such a simple frequency doubler. It will thus be seen that in this device the frequency of the bunches equals the frequency generated, whereas in the conventional klystron doubler the bunch frequency is only half of the generated frequency.

As indicated in the drawing, the output cavity 82 provides a gap 101 across which the bunches of electrons pass before they enter into the hollow interior 102 of collector 103. The collector is comprised of a rather thick body of copper which increases the efficiency of the device through its ability to dissipate heat. A portion of the hollow interior of the collector is preferably formed by a projection 104 integral with the wall 86 of the cavity 82, and projecting into the cavity 82 to a point adjacent the drift tube 97, therewith forming the gap 101. As shown by the drawing, the size of the cavity 78 is proportioned to the size of the cavity 82 to provide a doubling of the frequency. Power is extracted from the output cavity 82 through a loop 106 which passes through the wall of the cavity to the exterior thereof. For rigidity of construction and efficiency in dissipating heat away from the tube the collector 103 at its lower end is preferably provided with a radially extending flange 107 which may be utilized to secure the tube to a supporting structure in thermally conductive fashion. At its other end the collector is integrally united by means of the peripheral flange 108 to the outer surface portion of the cavity 82 and the annular plate 81. It will thus be apparent that an extremely rigid and efficient construction has been provided.

For a better understanding of the foregoing frequency doubler structure, the structure may be correlated with the showing of FIGURE 4 in the drawings, in which the phase relationship of the electrons is indicated for each of the gaps shown. This figure indicates very clearly the asymmetric nature of the two bunches obtained in the frequency doubler.

In FIGURE 2 is illustrated a multi-cavity klystron adapted to utilize the principle of simultaneous longitudinal and radial focusing of electron beams herein described. In the structure shown in FIGURE 2, instead of the second harmonic cavity 82 utilized in the frequency doubler of FIGURE 1, a fundamental high Q resonant cavity 82′ is used. This second cavity 82′ of the structure shown in FIGURE 2 will be excited in its fundamental mode due to the asymmetry of the bunches formed, and will retard the stronger and accelerate the weaker bunch, making them join into one bunch per cycle which can be utilized in the third cavity 112 of the device. With this design the second cavity 82′ should be tuned directly to

the true frequency and not higher as in conventional klystrons. An efficiency of 83% for the fundamental frequency has been computed for the tube shown in FIGURE 2. Structurally, the tube is very similar to the tube shown in FIGURE 1, the difference lying in the arrangement of the second 82' and third 112 cavity. Like numbers of reference have therefore been assigned to corresponding elements of this device, and the discussion above relating to FIGURE 1 and these corresponding elements applies as well to the structure of FIGURE 2. With respect to the cavity 82, it will be seen that in FIGURE 2 the cavity 82' has been increased in size to be excited in the fundamental mode by moving peripheral wall 109 outwardly to coincide with the wall 79 of the first cavity 78. A third cavity 112 of this device is formed by a wall 113 common to the cavity 82' and to the cavity 112 and comprising an annular membrane extending between or across the cylindrical wall section 114 forming the outer peripheral wall of the cavity.

The outer peripheral wall coincides in diameter with the walls 79 and 109 of the cavities 78 and 82' respectively, and is closed on its end opposite the wall 113 by another wall 116. A drift tube 117 is provided integrally mounted in the wall 113 axially aligned with the drift tube section 97, and extends into the cavity 82' on one side of the partition 113, and into the cavity 112 on the other side of partition to provide in the cavity 82' a gap 119 and in the cavity 112 an output gap 121. A centrally disposed section 122 of the wall 116 extends into the cavity 112 to provide the other extremity of the gap 121. As indicated in the drawing the outer surfaces of the portions of each drift tube which extend into the cavities are preferably tapered toward the supporting structure in order to decrease multipactoring. Additionally, the interior of the section 122 is preferably tapered outwardly toward the hollow interior 124 of the collector 126. As with the collector 103 of the device shown in FIGURE 1, the collector shown in FIGURE 2 is provided with a peripheral flange 127 adapted to be useful in securing the tube to a supporting structure. Electromagnetic energy may be extracted from the output cavity 112 through an appropriate output loop 128 extending through the peripheral wall 114 of the cavity.

It is well known in the electronics industry that a large proportion of the cost of electronic components results from the high labor costs required to assemble delicate electronic elements. From the structures shown in FIGURES 1 and 2, it will be apparent that I have devised structures which may be accurately machined and assembled by mass production methods. The devices have additionally been designed to provide maximum rigidity of construction for long life. While I have shown only two different devices capable of utilizing my method of simultaneous longitudinal and radial focusing, it will be apparent that other devices are feasible. It should be noted that in the design illustrated, the necessity for external magnetic circuitry to control the beam has been eliminated. The saving thus effected in terms of dollars spent for labor and materials, and in weight saved, will be obvious to those skilled in the art.

I claim:

1. A device for density modulating a beam of charged particles comprising means for generating a beam of such particles, at least one cavity resonant at a given frequency and through which said beam passes at a given beam velocity, means driving said cavity at said resonant frequency to establish an oscillating electric field therein, means within the cavity forming regions of homogeneity and inhomogeneity in said electric field through which regions said beam passes to effect density modulation of the beam, output means for extracting electromagnetic energy from the density modulated beam, means to collect the beam after it passes through said output means, and said means within the cavity forming regions of homogeneity and inhomogeneity including drift tube means forming an interaction gap having a length substantially equal to the distance one of said charged particles traveling at said given beam velocity will travel during one full cycle of the driving frequency.

2. A device as claimed in claim 1 wherein said drift tube means includes a drift tube section having a length substantially equal to the distance one of said charged particles traveling at said given beam velocity will travel during one full cycle of said driving frequency and each end of said drift tube section is spaced from a drift tube section mounted on the end wall of the cavity adjacent thereto an amount substantially equal to the distance one of said charged particles traveling at said beam velocity will travel during one full cycle of the driving frequency.

3. A device for density modulating a beam of charged particles comprising means for generating a beam of such particles, at least one cavity resonant at a given frequency and having aligned entrance and exit apertures for passage of said beam therethrough at a given beam velocity, and a drift tube in said cavity coaxially aligned with said entrance and exit apertures, the length of said drift tube and the spacing of said drift tube from said entrance aperture and said exit aperture, respectively, being substantially equal to each other and to the distance one of said charged particles traveling at said given beam velocity will travel during one full cycle of said resonant frequency, said drift tube and said exit aperture having substantially the same transverse dimensions and said entrance aperture having enlarged transverse dimensions whereby the velocity modulation imposed on said charged particles at said entrance aperture is substantially one half the velocity modulation imposed on said charged particles adjacent the ends of said drift tube.

4. A device as claimed in claim 3 including an output cavity resonant at the first harmonic frequency of said given frequency and having entrance and exit apertures coaxially aligned with said entrance and exit apertures of said one cavity and spaced from each other to form a conventional output interaction gap through which said beam of charged particles passes after it is velocity modulated in said one cavity.

5. A device as claimed in claim 3 including an intermediate cavity and an output cavity resonant at said given frequency and each having entrance and exit apertures coaxially aligned with each other and with said entrance and exit apertures of said one cavity and spaced from each other to form conventional interaction gaps through which said beam of charged particles passes consecutively after being velocity modulated in said one cavity.

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