March 12, 1968 K. PÖSCHL ET AL 3,373,309

ELECTRON BEAM TUBE FOR FREQUENCY MULTIPLICATION

Filed Sept. 30, 1963 2 Sheets-Sheet 1

Fig.1

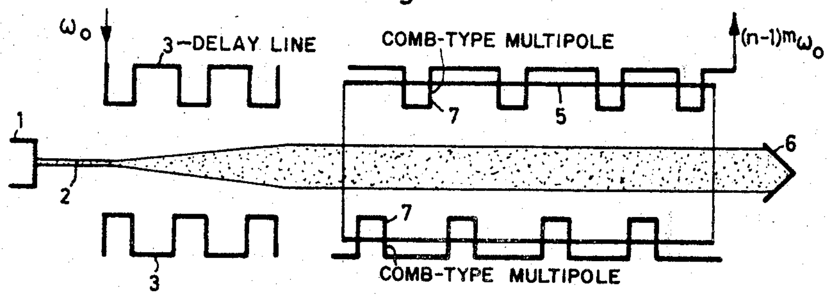


Fig.2

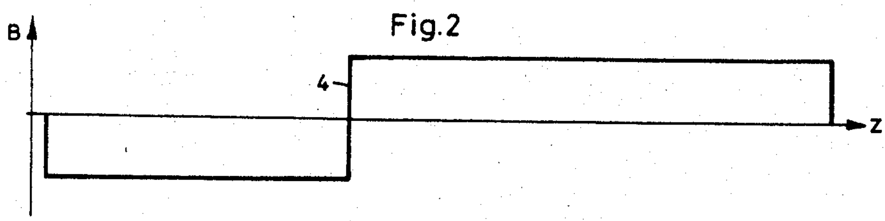


Fig.3

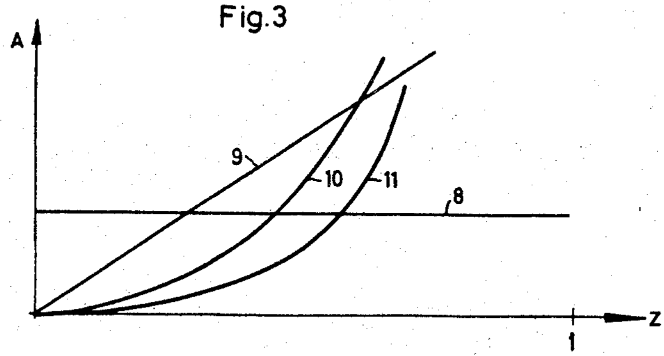


Fig.4

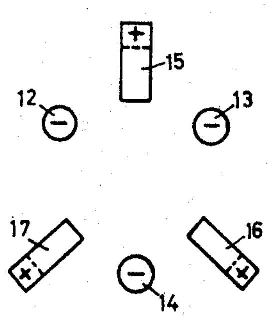
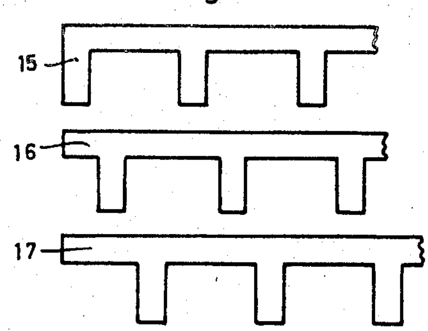


Fig.5



ELECTRON BEAM TUBE FOR FREQUENCY MULTIPLICATION

Filed Sept. 30, 1963 2 Sheets-Sheet 2

Fig.6

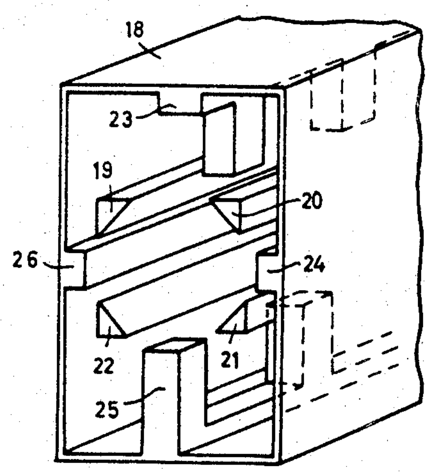
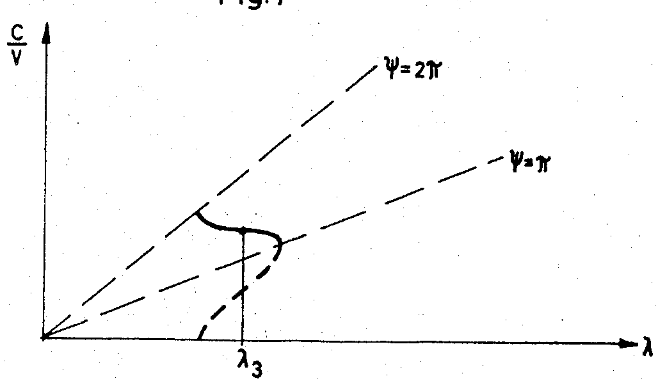


Fig.7



United States Patent Office

3,373,309
Patented Mar. 12, 1968

3,373,309

ELECTRON BEAM TUBE FOR FREQUENCY MULTIPLICATION

Klaus Pöschl and Werner Veith, Munich, Germany, assignors to Siemens Aktiengesellschaft, a corporation of Germany

Filed Sept. 30, 1963, Ser. No. 313,412
Claims priority, application Germany, Oct. 3, 1962, S 81,874
11 Claims. (Cl. 315—3)

ABSTRACT OF THE DISCLOSURE

An electron beam tube for frequency multiplication comprising an electron beam generating system, a coupling system for synchronous waves, an electrostatic multiple field of even pole number having at least six poles, a decoupling system and a collector, in which system electron beam extends in a longitudinal magnetic field.

The present invention relates to an electron beam tube for frequency multiplication, wherein the electron beam extends in a longitudinal magnetic field, comprising an electron beam generating system, a coupling system in which the electrons of the electron beam are deflected out of the axis of the unmodulated electron beam, an even numbered multipole, the electrodes of which are arranged with axial symmetry about the axis of the electron beam and are in peripheral direction of the multipole acted on alternately by direct current potentials of the same absolute value, but opposite polarity, a decoupling system in which the electron beam produces by induction a very high frequency signal, and a collector for the electron beam.

Electron beam tubes of this type are already known for the amplification of very high frequencies. As coupling part, there is used a coupler for cyclotron waves, for instance, a so-called Cuccia coupler. As amplifier part there is used a quadrupole which comprises four electrodes arranged symmetrically around the axis of the tube. In one known arrangement, the electrodes of the quadrupole are twisted in the longitudinal direction of the tube and opposing electrodes are acted upon with an electric direct current potential of the same absolute value but of opposite polarity. It has also been proposed, in the case of such an amplifier tube, to omit the twisting of the electrodes of the quadrupole. However, this electron beam tube is unsuitable for frequency multiplication.

The object of the present invention is to provide a simple electron beam tube which is adapted for frequency multiplication with simultaneous amplification of the multiplied frequency. In order to realize this object, there is proposed an electron beam tube of the type mentioned above, in which the coupling system is in accordance with the invention constructed as a synchronous wave coupler and in which the multipole comprises at least six electrodes which extend linearly parallel to the electron beam axis.

The invention proceeds from recognition of the fact that synchronous waves are amplified in an electron beam when the electron beam moves along the axis of an electrostatic quadrupole field containing a longitudinal magnetic field. (By synchronous waves, there is understood, as is known, an electron beam which is so modulated by a transverse electric alternating field in a longitudinal

magnetic field, that the train of electrons rotates in synchronism with a selected frequency about the axis of the unmodulated electron beam while the electrons individually extend linearly parallel to the axis of the electron beam.) Thorough investigations and mathematical analyses have now shown that in a linear multipole, the number of poles of which is greater than four, for instance, in a hexapole or octapole, the synchronous wave present in the electron beam of the selected frequency is not amplified but rather a frequency multiplication takes place. The potential distribution of an electrostatic multipole is expressed in polar coordinates by

$$V=Ar^n \cos n\varphi$$

in which A is a constant and n is half the number of poles. Mathematical calculation shows that upon the feeding of a synchronous wave into such an electrostatic multipole field in which is present a longitudinal magnetic field, there is produced a synchronous wave of opposite polarity (energy) of the frequency $(n-1)\omega_0$, ω_0 being the frequency of the synchronous wave fed. Accordingly, upon using a hexapole, there is produced a synchronous wave of twice the frequency of the synchronous wave fed, and upon using an octapole, there is produced a synchronous wave of three times the frequency of the synchronous wave fed. Moreover, calculation shows that the amplitude of this new synchronous wave increases linearly with the length of the multipole field through which the electron beam passes. The value of the amplitude can in this connection be as high as desired, and, therefor, in particular also greater than the amplitude of the synchronous wave fed. There is thus obtained a frequency multiplication with simultaneous amplification of the multiplied frequency.

It may be pointed out that in an electron beam tube in accordance with the present invention, the synchronous wave formed with a frequency $(n-1)\omega_0$ in turn causes again a frequency multiplication. From the synchronous wave of the frequency $(n-1)\omega_0$, there is then produced a synchronous wave of opposite polarity (energy) of the frequency $(n-1)^2\omega_0$ the amplitude of which is greater the longer the multipole path traversed by the electron beam. If, for instance, in the case of a hexapole, a synchronous wave of positive energy having the frequency ω_0 is fed into the multipole field, there is produced from this synchronous wave one of negative energy of the frequency $2\omega_0$, and from the latter, during the further course of the multipole path, a synchronous wave of positive energy of the frequency $4\omega_0$. The operation described leads to frequencies which are as high as desired. For a given desired multiplication factor, it is, however, advisable to suppress the production of synchronous waves of still higher frequency.

It is therefore, in accordance with a further feature of the invention, proposed to include the decoupling system in the multipole. If the decoupling system included in the multipole is tuned to a frequency range which corresponds to the product $(n-1)^2\omega_0$, the component of synchronous waves of positive energy of this frequency is immediately decoupled at each place of the multipole where this component occurs, thus removing the basis for the production of synchronous waves of higher frequency. One practical possibility of achieving this resides in constructing the electrodes of the multipole which are acted on by positive potential (that is, each second electrode in the circumferential direction of the multipole) as a comb, the teeth of which extend radially of the multipole in the direction of the axis of the electron beam. The individual combs are thereby so staggered with respect to each other, in the longitudinal direction of the multipole, that the free ends of the teeth lie in the circumferential direction of the multipole, along a spiral curve.

Aside from the measure of suppressing the production of synchronous waves of higher frequency than that desired, it is very generally of advantage for electron beam tubes according to the present invention, to include the decoupling system in the multipole. Thus, when using an octapole, two oppositely disposed electrodes can be constructed as combs which are staggered with respect to each other in the longitudinal direction of the multipole. On the delay line, which is formed in this manner, both, the synchronous waves of positive energy and the synchronous waves of negative energy undoubtedly excite a high frequency wave when the line is dimensioned for the corresponding frequency. If the synchronous wave which couples with the line is of negative energy, the production of synchronous waves of still higher frequency will in such case not be prevented since, as is known, a wave of negative energy cannot be decoupled from an electron beam. (There is no contradiction in the fact that the synchronous wave with negative energy cannot be decoupled from the electron beam while this wave nevertheless produces by induction, in a corresponding decoupling system, a signal of the frequency of the synchronous wave. There may be recalled, in this connection, the known mechanism of a traveling wave tube in which the slow space charge wave, that is, the space charge wave of negative energy, induces an electromagnetic wave in the delay line of the traveling wave tube, without the slow space charge wave being decoupled from the electron beam. The electron beam is rather modulated more and more strongly with the slow space charge wave. In similar manner, in an electron beam tube in accordance with the present invention, upon the excitation of a very high frequency wave by a synchronous wave of negative energy, the electron beam is modulated stronger and stronger with such synchronous wave.)

The known coupling systems for synchronous waves are relatively complicated. In order to avoid this disadvantage in the case of an electron beam tube according to the present invention, it is proposed to use, for the production of a synchronous wave in the electron beam, a coupler for cyclotron waves, and to convert the cyclotron wave of positive energy produced in the electron beam, by a discontinuity in the field intensity of the longitudinal magnetic field, into a synchronous wave of positive energy. The discontinuity in the magnetic field consists in this connection advantageously of a reversal of the magnetic field. A known coupler for cyclotron waves is the Cuccia coupler. The Cuccia coupler is, however, limited to a relatively narrow frequency band. The multipole of an electron beam tube in accordance with the present invention is on the other hand wide-band by its nature. Accordingly, for an electron beam tube in accordance with the present invention, there is better suited, as coupler for cyclotron waves, a delay line which conducts a wave having a transverse electric alternating field.

Further details and features of the invention will appear from the appended claims and from the description which is rendered below with reference to the accompanying drawings.

FIG. 1 shows schematically the construction of an electron-beam tube according to the invention, in which the decoupling system is included in a multipole;

FIG. 2 indicates the distribution of the field strength of the longitudinal magnetic field of a tube in accordance with FIG. 1;

FIG. 3 represents the mechanism of the frequency multiplication in a multipole included in FIG. 1;

FIGS. 4 and 5 illustrate an example of a practical embodiment of a hexapole multipole;

FIG. 6 shows a possible construction of the multipole indicated in FIG. 1, as an octapole; and

FIG. 7 presents in the form of a customary

$$\frac{c}{v}-\lambda$$

diagram, the dispersion course of the delay line according to the invention.

The coupling system indicated in connection with FIGS. 1 and 2 comprises a delay line **3**, which is to conduct a wave having a transverse electric alternating field of the frequency ω_0. With appropriate dimensioning of the intensity of the longitudinal magnetic field B, the electron beam **2**, extending from the beam generating system **1**, will then be modulated with a cyclotron wave of positive energy. Beyond the delay line **3**, the electron beam **2** passes through the magnetic field discontinuity **4**, which is so dimensioned that it compensates for the rotational movement of the electrons, counteracting their rotational movement. The cyclotron wave in the electron beam is therefore converted into a synchronous wave. (A cyclotron wave, as is known, is described by a simultaneous motion of rotation and translation of the electrons of the electron beam, while in the case of a synchronous wave, the individual electrons have merely a translatory movement.) The electron beam which is modulated in this manner with the synchronous wave of positive energy of the frequency ω_0 passes through the multipole **5** and then impinges on the collector **6**. By the multipole **5**, there is to be understood an arrangement which consists of an even number of at least six electrodes which are arranged with axial symmetry around the axis of the electron beam and are acted on in circumferential direction alternately by electric direct current potential of the same absolute value but of opposite polarity. The electrodes are to extend linearly parallel to the axis of the electron beam. The combs **7** indicate that at least two electrodes of the multipole **5** which are arranged symmetrically to the axis of the electron beam are formed as combs, staggered with respect to each other in the longitudinal direction of the multipole, and thus form a delay line over which the high frequency signal which is multiplied in frequency in the multipole **5** by the factor $(n-1)^m$ can be decoupled $(m=1, 2, 3, \ldots)$.

In the diagram shown in FIG. 3, which indicates the mechanism of the frequency multiplication in the multipole **5**, there is plotted as abscissa the length l of the multipole field and as ordinate the amplitude A of the synchronous waves in the electron beam. The horizontal line **8** indicates the synchronous wave of positive energy of frequency ω_0 fed in the multipole. This synchronous wave, by the action of the electrostatic multipole field and of the longitudinal magnetic field B produces in the electron beam a synchronous wave of negative energy of the frequency $(n-1)\omega_0$. The amplitude of this synchronous wave increases linearly with the multipole path passed through. The curve **9** therefore indicates the course of the amplitude of the synchronous wave of the frequency $(n-1)\omega_0$. It can readily be seen that over the length of the multipole, the synchronous wave of the curve **9** again produces a synchronous wave of correspondingly multiplied frequency, which is then again of positive energy. In the event that the mutipole is an octapole, the synchronous wave then has, in accordance with curve **10**, the frequency $9\omega_0$. The increase of the amplitude of this synchronous wave can no longer take place linearly, since the amplitude of the synchronous wave increases an such in accordance with curve **9** (in the indicated example of the octapole, a synchronous wave of negative energy of the frequency $3\omega_0$). The process of the frequency multiplication continues as desired. For example, the curve **11** indicates that the synchronous wave of positive energy in accordance with curve **10**, produces a synchronous wave of negative energy of the frequency $(n-1)^3\omega_0$ (in the case of an octapole, this means of the frequency $27\omega_0$). Which of the multiplied frequencies is decoupled depends solely on the geometry of the decoupling system, and particularly on the geometry of the combs **7** of an electron beam tube in accordance with FIG. 1.

It is apparent from FIG. 3 that the synchronous wave of the frequency $(n-1)^2\omega_0$ is of positive energy. This synchronous wave can therefore be decoupled from the electron beam, thus preventing the formation of synchronous waves of higher frequency. In order to achieve this, it is merely necessary that the decoupling system be included in the multipole and tuned to a frequency range which corresponds to the frequency $(n-1)^2\omega_0$. With reference to FIGS. 4 and 5, there shall now be explained a practical embodiment of the multipole suitable for this purpose, the multipole being a hexapole. FIG. 4 shows the hexapole from the front. The six electrodes arranged symmetrically about an axis are to extend linearly in the longitudinal direction of the hexapole. The electrodes **12, 13** and **14** which are acted on in each case with the same electric potential of negative polarity are simple, elongated bars. The electrodes **15, 16** and **17** located opposite these electrodes and acted on by a potential of equal absolute value but positive polarity are, on the other hand, developed as combs, the teeth of which extend in radial direction to the axis of the hexapole. The individual combs are so staggered with respect to each other, in the longitudinal direction of the hexapole, that the free ends of the teeth lie, in the peripheral direction of the multipole, on a spiral curve. This is indicated in FIG. 5, in which the electrodes **15, 16** and **17** are shown in developed view.

Another possible embodiment of the multipole **5** of FIG. 1 as octapole is shown in perspective in FIG. 6. The electrodes of the octapole are in this connection arranged in a wave-guide **18**. The electrodes which are to be acted on with negative potential are bars **19, 20, 21** and **22** of triangular cross-section which are insulated from the wave-guide **18**. Outside the wave-guide, they are to be electrically connected with each other. The other four electrodes **23, 24, 25** and **26**, which are to be acted on with positive potential, extend from the center of the respective sidewalls of the wave-guide **18** into the inside of the wave-guide. The electrodes **23** and **25** extending from the narrow sides of the wave-guide **18** are constructed as combs, the teeth of which are with respect to each other staggered in the longitudinal direction of the wave-guide. There is in this manner, produced a delay line on which a high-frequency wave can be excited by synchronous waves of both positive and negative energy.

The variation of the dispersion of such a line is shown in FIG. 7 in an ordinary

$$\frac{c}{v}-\lambda$$

diagram. It will be seen that the delay line as rearward-wave structure has a substantially horizontal course of the dispersion of the first forward passing partial wave, so that the delay line has a very broad-band upon operation with this partial wave. The dimensions of the delay line are so selected that the average wavelength $\lambda 3$ of the pass range is a third of the synchronous wave-length λ_0 originally fed into the octapole. The synchronous wave produced in the octapole of the multiplied frequency $3\omega_0$ then excites on the line a high-frequency wave of the frequency $3\omega_0$. By changing the geometry of the delay line, the latter can, however, also be tuned to some other desired frequency which has been multiplied in the octapole, for instance to the frequency of $9\omega_0$ or $27\omega_0$.

The invention is not inherently limited to the embodiments shown. In particular, it is not necessary for the decoupling system to be a part of the multipole. Furthermore, the multipole can have ten or more electrodes. It is also possible to pulsate the potentials of the positive and negative electrodes and thereby use the tube in pulse operation. This results in the advantage that even with poor pulse shape, the frequency is strictly maintained, since the frequency depends solely on the geometry of the multipole. Such a tube is particularly suitable for very high power pulse operation when high frequency stability is desired.

The electron beam tube in accordance with the invention has a number of advantages. The frequency multiplication is very precise, since it is dependent only on the geometry of the multipole, but not on the current and voltage conditions. The multiplication factor can be made very large. The multiplication, finally, proceeds with a simultaneous gain in power.

Changes may be made within the scope and spirit of the appended claims which define what is believed to be new and desired to have protected by Letters Patent.

We claim:

1. In an electron beam tube for frequency multiplication, in which the electron beam extends in a longitudinal magnetic field, the combination of an electron beam generating system, a coupling system comprising means for modulating the beam with a synchronous wave, in which the electrons of the electron beam are deflected away from the axis of the electron beam, an even-numbered multipole having at least six electrodes which extend linearly in parallel to the axis of the electron beam, said electrodes being arranged with axial symmetry about the axis of the electron beam following said coupling system and being acted on in circumferential direction of the multipole alternately by electric direct current potentials of the same absolute value but opposite polarity, a decoupling system also following said coupling system and disposed to act upon the electron beam and in which such beam effects a very high frequency signal by induction, and a collector disposed to receive the electron beam following the passage thereof through the decoupling system.

2. An electron beam tube according to claim **1**, wherein the voltage with which the electrodes of the multipole are acted on has a pulse shape.

3. An electron beam tube according to claim **1**, wherein said coupling system includes a coupler for cyclotron waves, there being formed a discontinuity in the field strength of the longitudinal magnetic field, such that the cyclotron wave is converted in the electron beam into a synchronous wave.

4. An electron beam tube according to claim **3**, wherein the magnetic-field discontinuity consists in a reversal of the direction of the magnetic field.

5. An electron beam tube according to claim **4**, wherein the coupler for cyclotron waves is a delay line, which conducts a wave having a transverse electric alternating field.

6. An electron beam tube according to claim **1**, wherein the decoupling system is a part of the multipole.

7. An electron beam tube according to claim **6**, wherein the multipole is an octapole, the electrodes of which are arranged in a wave guide of rectangular cross-section, the electrodes which are acted on by positive potential being electrically connected with the sidewalls of the wave guide, and the electrodes connected on the two narrow sides of the wave guide being constructed as combs, the teeth of which are staggered with respect to each other in the longitudinal direction of the wave guide.

8. An electron beam tube according to claim **6**, wherein the decoupling system is tuned to a frequency range which corresponds to the product of the coupled frequency and the square of the difference of half the number of poles of the multipole minus 1.

9. An electron beam tube according to claim **8**, wherein each second electrode of the multipole is constructed as a comb, the teeth of which extends radially in the direction of the axis of the electron beam.

10. An electron beam tube according to claim 9, wherein the teeth of the individual combs are so staggered with respect to each other in the longitudinal direction of the multipole that the free ends of the teeth lie in the circumferential direction of the multipole along a spiral curve.

11. An electron beam tube according to claim 10, wherein the multipole is a hexapole.

References Cited

UNITED STATES PATENTS

3,094,643	6/1963	Wade	315—3
3,122,710	2/1964	Miller	330—4.7
3,176,234	3/1965	Kluver	330—4.7

HERMAN KARL SAALBACH, *Primary Examiner.*

P. L. GENSLER, *Assistant Examiner.*