ELECTRON-BEAM TUBE FOR FREQUENCY MULTIPLICATION

Fig.1

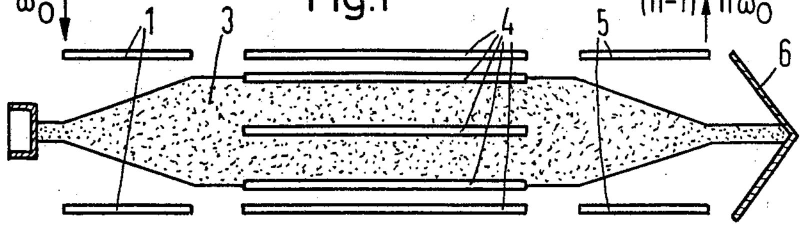

Fig.2

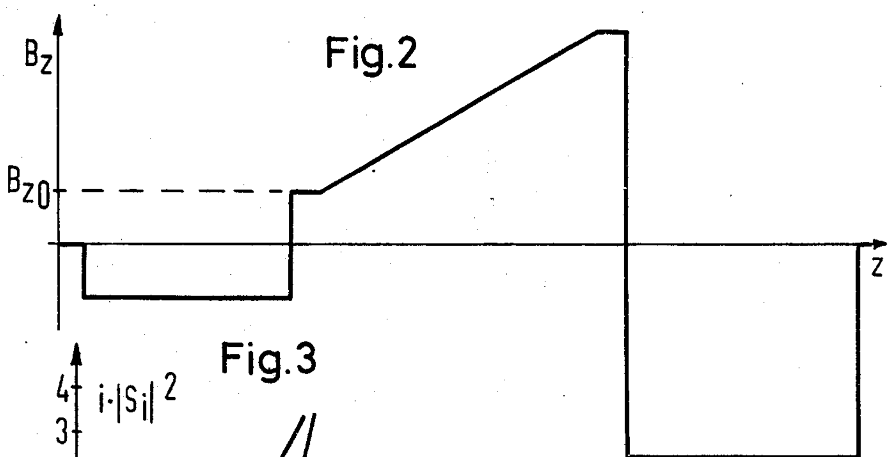

Fig.3

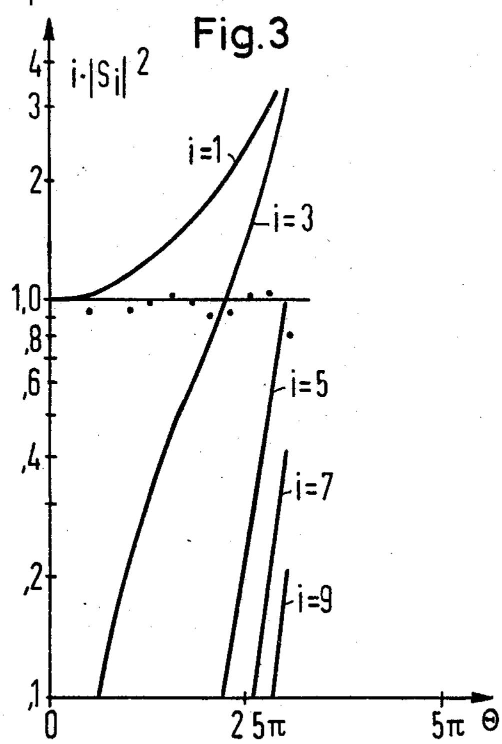

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Fig. 5

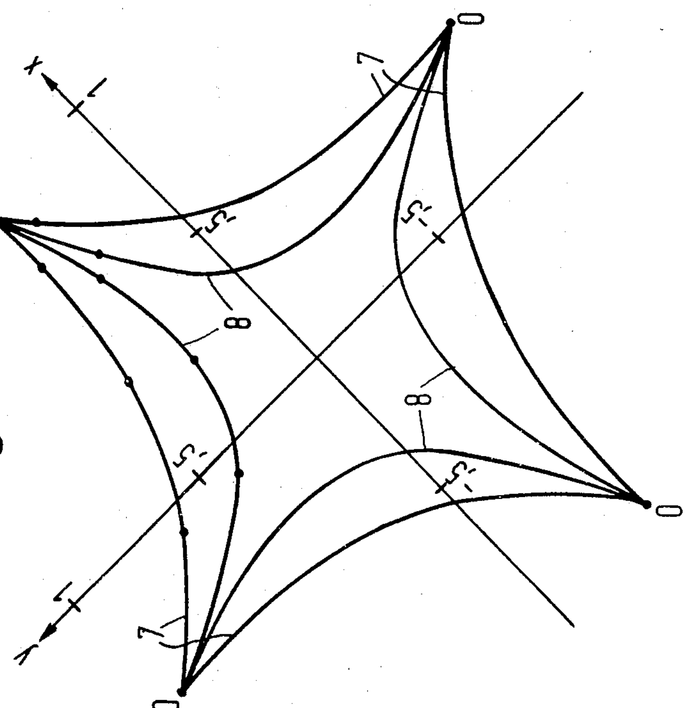
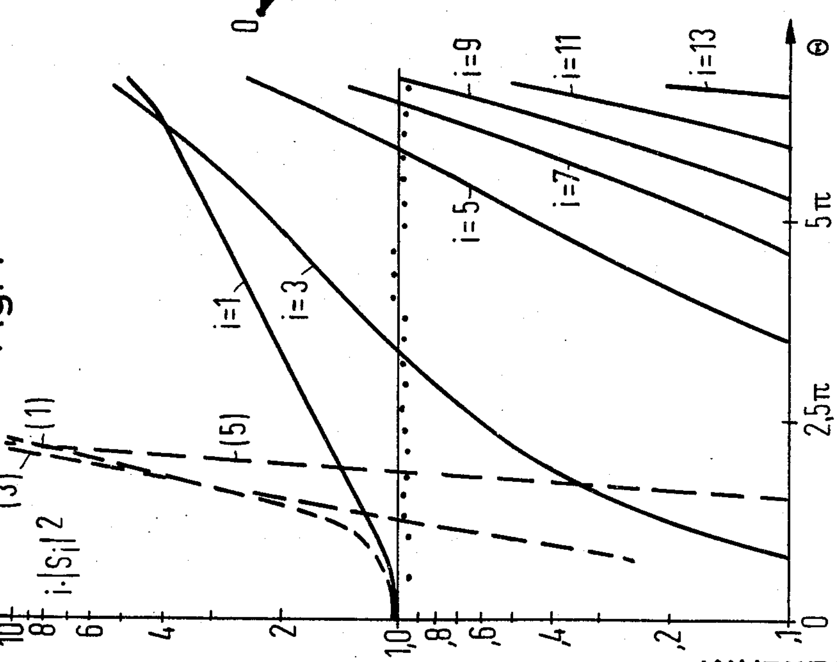


Fig. 4



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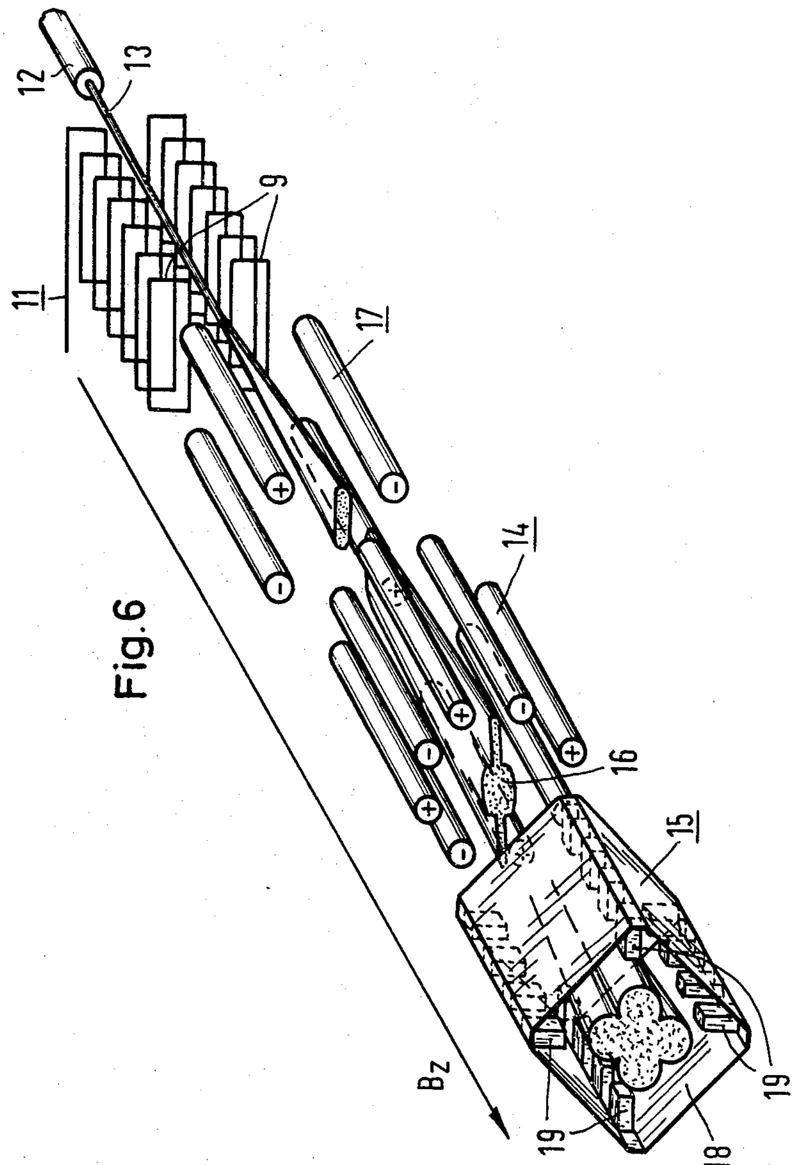

Fig. 6

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3,500,108

ELECTRON-BEAM TUBE FOR FREQUENCY MULTIPLICATION

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Int. Cl. H01j *23/16, 29/96*
U.S. Cl. 315—3 9 Claims

ABSTRACT OF THE DISCLOSURE

An electron-beam tube for frequency multiplication with a longitudinal magnetic field, wherein an electron beam emanating from a beam-generating system successively passes through a coupling system, a multiplier system, and a decoupling system, in which the coupling system is designed as a synchronous wave coupler and the multiplier system is a multipole comprising at least six rectilinear electrodes extending parallel to the axis of the magnetic field, which are symmetrically arranged around the axis of the magnetic field and alternately loaded in circumferential direction of the multipole, according to the arrangement, with equal electrical potentials of opposite polarity, in which the longitudinal magnetic field increases progressively and constantly along the length of the multipole from a magnitude existing at the end of the multipole facing the beam-generating system, and in an embodiment of which the coupling system may comprise two delay lines facing each other and extending parallel to the axis of the magnetic field which, cooperably, and synchronously with the speed of the electron beam, carry an electrical alternating field diagonally directed with respect to the axis of the magnetic field, so that the electron beam undergoes a modulation with the rapid as well as with the slow synchronous wave.

The invention relates to an electron-beam tube for frequency multiplication with a longitudinal magnetic field, wherein an electron beam emanating from beam-generating system passes successively through a coupling system, a multiplying system, and a coupling system, in which the coupling system is designed as a synchronous wave coupler and the multiplying system is a multipole comprising at least six rectilinear electrodes extending parallel to the axis of the magnetic field, which are symmetrically arranged around the magnetic field axis in circumferential direction of the multipole and alternately loaded, according to the specific arrangement, with equal electrical potentials of opposite polarity.

From the periodical "Records of Electrical Transmission," vol. 17 (1963), No. 7, pages 345 to 350, it is known that in a multipole comprising at least six rectilinear electrodes disposed parallel to the longitudinal axis of the multipole field, there occur multiples of the fundamental frequency of a synchronous wave in an electron beam, namely with the frequencies $(mn\pm1)\ \omega_0$, wherein ω_0 is the fundamental frequency, n half the number of poles of the multipole, and m any positive whole number. The amplitudes of all synchronous waves of the occurring frequencies thereby increase in each case, with the length

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of the multipole. At specific distances in the multipole, the power of the harmonic waves exceeds that of the fundamental as determined by the product of the frequency and the square of the amplitude of the specific synchronous wave. For example, in an eight-pole, the power of the harmonic wave with quintupled frequency at a cyclotron transit angle of 2π already amounts to 2.5 times the power which the fundamental wave had upon entering the eight-pole.

The utilization of a frequency multiplication according to the principle known in the prior art is limited, because the increase in amplitudes of the harmonic waves is accompanied with a strong deflection of the electrons from the axis of the electron beam. The deflection of the electrons increases so rapidly that it becomes difficult to even evaluate the frequency multiplication. It is, therefore, the initial problem of the present invention, to so design an electron-beam tube for frequency multiplication that a practical controllable frequency multiplication can be achieved. In order to solve this problem, it is proposed in an electron-beam tube of the type referred to, that the longitudinal magnetic field, initially increase progressively and constantly from a magnitude existing at the end of the multipole disposed at the beam-generating side along the length of the multipole.

The frequency multiplication achieved in an electron-beam tube according to the invention is based on the creation of synchronous waves of positive and negative energy. Since these synchronous waves are independent of the cyclotron frequency and, therefore, of the longitudinal field, the increase in the magnetic field strength within the field of the multipole proposed in the invention does not interfere with the described frequency multiplication function. The deflection of the electrons in the multipole can be controlled by an increase in the magnetic field, which can preferably be linear. In particular, the point of discontinuity, occurring when the harmonic waves increase in a tube according to the known principle, can be excluded, based upon the fact that the electrons reaching the space between the individual multipole electrodes are exposed to very strong electrical fields, which can tear the electron beam apart in an uncontrollable manner.

Thus, with a tube according to the invention, harmonic waves also are obtained which increase in power. The tube, however, can readily be operated in a stable manner, because the deflection of the electrons increases more slowly than in a tube without an increase in the magnetic field within the multipole. More electrons thereby travel along the length of the multipole toward the beam axis, as well as inwardly, than in a constant magnetic field. Accordingly, the core of the trajectory cross section increasingly contracts in the rising magnetic field, resulting at least partially, in an increase of both the fundamental wave and the harmonic waves.

The rise in the magnetic field of a frequency-multiplying tube according to the invention can be so produced that the extreme deflection of the electrons in the multipole remains constant. This occurs, with a linear rise of the magnetic field, when the magnetic field along a cyclotron wave length, relative to the initial value of the magnetic field, increases by about 1.26 times the initial value.

In a frequency multiplication according to the known principle, it is generally assumed that the electron beam entering the multipole is modulated with a single synchronous wave, namely with a synchronous wave of positive energy. The electron beam, however, in a further development of the invention can simultaneously carry a synchronous wave of negative energy as well as the synchronous wave of positive energy. (In this case, the electrons are not circularly distributed, but deflected in a plane from the beam axis.) The concept of feeding both synchronous waves, instead of one single synchronous wave, into the multipole requires, in particular, the adaptation of a frequency-multiplying tube to practical necessities. The modulation of an electron beam with two synchronous waves fundamentally can be realized with simpler means than the generation of a single synchronous wave and, in addition, has the advantage that it is achieved without a power loss. In order to generate both synchronous waves, the coupling system preferably can be a coupler in the form of two helical or meandering lines facing one another and disposed parallel to the axis of the magnetic field, for example, as is known from U.S. Patent 3,218,503.

The power output of an electron-beam tube according to the invention depends on the modulation strength of the electron beam upon entering the multipole. This means that, in the case of a single synchronous wave, it must be coupled with as much power as possible, while in a linear deflection of the beam electrons (coupling of both synchronous waves) the electron beam, to be sure, does not carry high-frequency energy, but the electrons, nevertheless, are supposed to be strongly deflected. For this purpose, it is proposed in a further development to arrange a conventional linear quadrupole between the coupler for both synchronous waves and the multipole which amplifies the amplitudes of the rapid and the slow synchronous wave in a manner known in the prior art.

The electron-beam tube according to the invention can serve to generate a signal of very high frequency, wherein the high-frequency power can normally fall between a milliwatt and a watt. Besides this utilization, an electron beam tube according to the invention can advantageously be employed as a high-power tube to replace magnetrons, wherein great importance is attached to high frequency stability. The frequency precision of modern magnetron tubes varies between 10^{-4} to 10^{-5}. For various fields of application, however, e.g. for Doppler radar, a higher frequency stability is required. This requirement can be met by an electron-beam tube according to the present invention by feeding the coupling system from a suitable oscillator of very high frequency stability, e.g. from a quartz oscillator. In this application, according to the invention both the current and the voltage of the multipole can be pulsed. A frequency variation need not be feared, in contrast to magnetrons, as the multiplied frequency is determined only by the geometry of the multipole.

The invention is explained in connection with the drawings, in which:

FIG. 1 is a diagrammatic representation of the structure of an electron-beam tube according to the invention;

FIG. 2, oriented with FIG. 1, illustrates the pattern of the field strength of a longitudinal magnetic field B_z;

FIG. 3 is a chart illustrating the power of respective synchronous waves with respect to that of the fundamental wave;

FIG. 4 is a chart similar to FIG. 3;

FIG. 5 is a chart illustrating electron positions in the diagonal planes of the cyclotron transit angles $\theta=\pi$, $\theta=8\pi$ in the eight-pole; and

FIG. 6 is a diagrammatic perspective view of another embodiment of the invention.

Referring to FIGS. 1 and 2, the coupling system of the tube is designated by the reference numeral **1**, into which a high-frequency signal ω_0 is fed. The coupling system **1** forms a coupler for the rapid cyclotron wave so that the electron beam **3** emanating from the beam-generating system **2** is, after leaving the coupling system **1**, modulated with a cyclotron wave of positive energy. The cyclotron wave in the electron beam is subsequently converted in known manner into a synchronous wave by a reversal of the longitudinal magnetic field B_z. The electron beam thus modulated with a synchronous wave of the frequency ω_0 then passes through a multipole **4** comprising of an even number of at least six rectilinear electrodes disposed parallel to the axis of the magnetic field which are symmetrically arranged around the axis of the magnetic field in circumferential direction of the multipole and alternately loaded, according to the specific arrangement, with electrical potentials of equal magnitude and opposite polarity. Along the length of this multipole **4**, the longitudinal magnetic field B_z is to increase progressively from an initial value B_{zo} (FIG. 2), particularly in linear relation. In the direction of the electron beam, following the multipole **4**, a reversion of the magnetic field B_z reoccurs, so that the electron beam again carries a cyclotron-wave modulation upon entering the decoupling system **5**, which coupling system is thereby synchronized with one of the frequencies $(n-1)\omega_0$, $(2n-1)\omega_0$, $(n+1)\omega_0$, etc. with n being equal to half the number of poles of the multipole **4**. Thus, a cyclotron wave of the desired frequency can be decoupled from the electron beam before the electron beam **2** strikes the electron catcher **6**.

Briefly reviewing the known processes of the frequency multiplication taking place in the multipole **4**, from a synchronous wave of positive energy of the frequency ω_0 fed into the multipole, there is created through the effect of the electrostatic field of the multipole in interrelation with the longitudinal magnetic field B_z a synchronous wave of negative energy of the frequency $(n-1)\omega_0$, and from this a synchronous wave of positive energy of the frequency $(n+1)\omega_0$ leads to a synchronous wave of negative energy with the frequency $(2n-1)\omega_0$, from which a positive synchronous wave of the frequency $(2n+1)\omega_0$ can be further developed. This process theoretically can be continued up to infinitely high frequencies $(mn\pm1)\omega_0$. The amplitudes of both the fundamental wave and the harmonic waves are thereby increased. The total power carried by the electron beam, however, remains constant, as the sum of the individual powers of the synchronous waves occuring in each case is always equal to the injected power, taking into consideration their sign (plus or minus). The path of the chronological succession of electrons describes, in planes at right angles to the axis of the multipole **4**, a star with n-tips or points. To being with, the electrons which are deflected the farthest points of the star proceed close to each second of the center planes of the zero potential disposed between the positive and negative electrodes. While in a magnetic field which is constant along the length of the multipole **4**, the electrons located at the points of the star-wave rapidly forward and are difficult to control, which deflection is restricted by a rise in the magnetic field, as illustrated in FIG. 2. In this case also, the succession of beam electrons again forms stars with n points in diagonal planes, wherein, however, the distance of the star points from the beam axis increases only slowly, which indicates that a stable operation of the frequency multiplier is achieved.

The conditions for different values of linear rise in the magnetic field will be examined more closely in an eight-pole. FIG. 3 illustrates the power of the respective synchronous waves with the i-fold fundamental frequency relative to that of the injected fundamental wave in an eight-pole response to the transit angle θ, when the magnetic field along a cyclotron wave length

$$\lambda_{co}(\lambda_{co}=2\pi mc./eB_{zo})$$

relative to the initial value B_{zo} in each case increases by 0.64 times the initial value B_{zo}. It is thereby assumed that the value K_4^2 indicated in Equation 15 in initially mentioned article in "Records of Electrical Transmission," 1963, pp. 345–350, is 0.1. The product of i and the square of the amplitude S_i of the synchronous wave is representative of the relative power. It is apparent that both the power of the fundamental wave ($i=1$) and the harmonic wave with threefold frequency ($i=3$) increase moderately. In addition, the increasing powers of the harmonic waves $i=5, 7, 9$ are represented. The sum of the powers of all the synchronous waves always corresponds to the injected value, considering their specific plus or minus signs ($i=l$ is positive, $i=3$ is negative, $i=5$ is again positive, etc.), as is indicated by the points distributed on opposite sides of the straight line $i|S_i|^2=1$.

In the coordinate diagram of FIG. 4, wherein corresponding to FIG. 3 the ordinate indicates the power $i|S_i|^2$ of the synchonous waves of the i-fold fundamental frequency relative to the value 1.0, and the abscissa the transist angle, the increase in the fundamental wave, as well as the harmonic waves, is illustrated when the magnetic field per cyclotron wave length λ_{co} increases linearly relative to the initial value B_{zo}. In comparison therewith, the conditions for a constant magnetic field appear in dotted lines with the corresponding values of i indicated in brackets. Thus, it can very clearly be seen that by use of the invention a stable frequency multiplication is possible despite conversion gain. Furthermore, it is also here established, by adding the powers according to their signs (plus or minus) that the frequency multiplication occurs without power loss (compare the points distributed around the straight line representing the value 1.).

It has already been explained that in a tube according to the invention, the succession of electrons within the multipole forms stars with n-points in planes diagonal to the axis of the multipole. Thus, in an eight-pole 4-pointed stars are formed. In a specific dimensioning of the magnetic field increase according to the invention, it can be achieved that the points of the star-like beam cross section remain on the same radius along the length of the multipole. This is of importance if it is desired that the electron beam be conducted very closely past the electrodes of the multiple. Retention of the points of the star formed by the chronological succession of electrons is not achieved until the magnetic field per cyclotron wave length λ_{co} is increased by 1.25 times the initial value B_{zo}. FIG. 5 illustrates the positions of the electrons, obtained through calculation, in the diagonal plances of the cyclotron transit angle $\theta=\pi$ and $\theta=8\pi$ in the eight-pole, wherein again K^2_4 is assumed to be equal to 0.1. Reference numeral **7** designates the star formed by the beam electrons when $\theta=\pi$, while the star **8** having the same radius is valid for $\theta=8\pi$. The effect of the eight-pole is there reflected only by the contraction of the cross section of the beam.

FIG. 6 illustrates a particularly advantageous practical embodiment of an electron-beam tube according to the invention. For purposes of simplification, the change in induction of the magnetic field B_z increasing within the multipole **14**, having at least 6 poles, is not represented. The coupling system **11** of the tube here comprises two parallel delay lines facing each other comprising, for example, two helical lines **9** of rectangular cross section. Between the helical lines **9**, an electrical alternating field directed at right angles to the axis of the magnetic field is to expand in delayed fashion. Thus, the electron beam **13** is modulated simultaneously with the rapid as well as with the slow synchronous wave of the frequency of the alternating field. This is tantamount to saying that the electrons of the electron beam **13** are linearly deflected from the beam axis, i.e. in a single plane. To achieve a maximum deflection of the beam electrons upon entering the eight-pole, there is arranged in the present example, a conventional rectilinear quadrupole **17** between the coupling system **11** comprising the helical lines **9** and the eight-pole **14**. Such a quadrupole amplifies in known manner (again without power loss) both synchronous waves of positive and negative energy, which amounts to an increase in the linear deflection of the beam electrons. A frequency multiplication thus occurs in the eight-pole **14**

of the injected syinchronous waves with simultaneous conversion gain. The increase in the magnetic field assumed along the length of the eight-pole **14** prevents an uncontrollable expansion of the beam cross section which takes the shape of the cross section designated by the reference numeral **16** under the effect of the increasing magnetic field strength and of the eight-pole field strength. The decoupling system **15**, in accordance with FIG. 1, again is preferably a cyclotron wave coupler, since synchronous waves of positive and negative energy cannot readily be decoupled. Therefore, in order to convert synchronous waves into cyclotron waves, the magnetic field in this case also reverses its direction between the eight-pole **14** and the recoupling system **15**. The decoupling system **15** advantageously can be a coupling element for a rapid cyclotron wave of positive dispersion. In the illustrative embodiment such a coupling element is constructed as a hollow conductor **18**, having four rows of teeth **19** which are staggered with respect to one another by 90°, and whose free ends are positioned on a helical coaxially enclosing the axis of the electron beam **13**.

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. An electron-beam tube for frequency multiplication with a longitudinal magnetic field, wherein an electron beam emanating from a beam-generating system passes successively through a coupling system, a multiplier system, and a decoupling system, wherein the coupling system comprises a synchronous wave coupler and the multiplier system is a multipole comprising at least six rectilinear electrodes extending parallel to the axis of the magnetic field, which electrodes are symmetrically arranged around the axis of the magnetic field and alternately loaded in circumferential direction of the multipole, according to the arrangement, with equal electrical potentials of opposite polarity, the longitudinal magnetic field being so arranged that it increases progressively and constantly along the length of the multipole from a magnitude existing at the end of the multipole facing the beam-generating system.

2. An electron-beam tube according to claim **1**, wherein said multipole has eight poles and the magnetic field is so arranged that it increases linearly with respect to the initial value of the magnetic field in the multipole along a cyclotron wave length by 0.6 to 1.3 of such initial value.

3. An electron-beam tube according to claim **2**, wherein the linear rise of the magnetic field per cyclotron wave, relative to the magnetic initial value, is approximately equal to 1.26 the initial value.

4. An electron-beam tube according to claim **1**, wherein the coupling system comprises two delay lines facing each other and extending parallel to the axis of the magnetic field which, cooperably and synchronously with the speed of the electron beam, carry an alternating electrical field diagonally directed relative to the axis of the magnetic field, whereby the electron beam undergoes a modulation with the rapid as well as with the slow synchronous wave.

5. An electron-beam tube according to claim **4**, wherein each delay line comprises a conductor extending in meander-like fashion.

6. An electron-beam tube according to claim **5**, wherein said delay line has a helical configuration.

7. An electron-beam tube according to claim **4**, wherein a quadrupole, having rectilinearly extending electrodes is disposed between the coupling system and the multiplying system for amplifying the amplitudes of the rapid and the slow synchronous wave.

8. An electron-beam tube according to claim **4**, wherein the decoupling system comprises a coupling element for cyclotron wave and the longitudinal magnetic field is so arranged that it reverses its direction between the multiplying system and the decoupling system.

9. An electron-beam tube according to claim **1**, for use as a frequency-stable power tube for pulse operation or continuous-dash operation, wherein the signal fed into the coupling system is derived from an oscillator of very high frequency stability.

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U.S. Cl. X.R.

315—3.5; 330—4.7

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,500,108 Dated March 10, 1970

Inventor(s) Klaus Pöschl et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 4, line 34, "$(n + 1)\omega_0$" should read as --$(n + 1)\omega_0$. The synchronous wave of the frequency $(n + 1)\omega_0$--

Col. 4, line 66, "eight-pole response" should be --eight-pole in response--

Col. 4, line 73, "Equation" should be --equation--

Col. 5, line 15, "transist" should be --transit--

Col. 6, line 14, "recoupling" should be --decoupling--

SIGNED AND SEALED

SEP 22 1970

(SEAL)
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