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CYCLOTRON WAVE HARMONIC GENERATOR

Filed Aug. 21, 1961

Fig. 1.

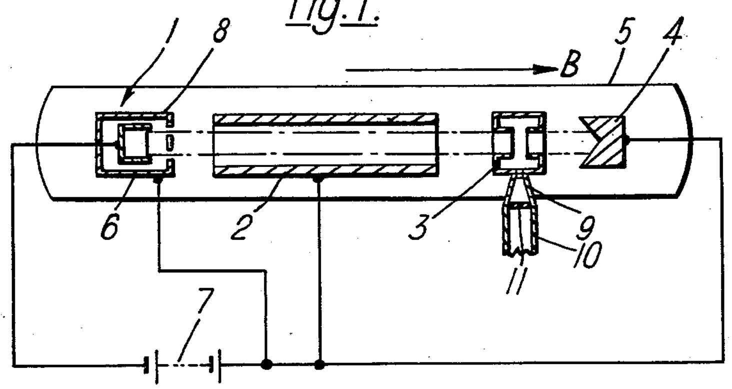
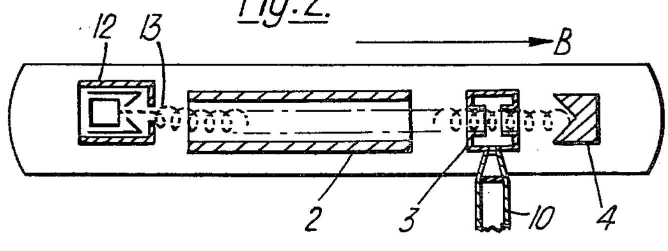


Fig. 2.



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CYCLOTRON WAVE HARMONIC GENERATOR

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The present invention relates to electron beam tubes and more particularly to an electron beam harmonic wave generator.

It is known that in any electron beam oscillator in which, before being collected, the beam issues from its region of interaction with electromagnetic fields, the issuing beam will contain radio frequency current components which are harmonics of the fundamental frequency. This is inevitable, as the amplitude of the oscillations must be limited by some non-linear effect.

There have been attempts to produce harmonic waves using klystron frequency multipliers, but in these it is necessary to provide resonant cavities tuned both to the fundamental frequency and to the harmonic frequency. Other arrangements eliminating the need for mechanical tuning at the fundamental frequency have been proposed using backward wave oscillations at the fundamental frequency; here however some form of slow wave structure has hitherto been needed. At the shorter, e.g. millimetric, wavelengths it becomes increasingly difficult to make slow wave structures. More recently, it has been shown that an electron beam which itself has a spatially periodic structure—e.g. the beam follows a helical path about a given axis—can interact with electromagnetic fields in a hollow waveguide which supports only waves having a phase velocity greater than the velocity of light and which is unloaded by a slow wave structure. An oscillation generator utilizing what is called cyclotron resonance in a hollow waveguide has been described by R. Pantell in a letter entitled "Backward wave oscillations in an unloaded waveguide," published in The Proceedings of the I.R.E., vol. 47, No. 6, June 1959, page 1146. The cyclotron resonance phnomena are dependent on the strength of an axial magnetic field in which the electrons and the beam rotate; this means that a straightforward frequency-multiplier using cyclotron resonance at the harmonic frequency would entail the use of a magnetic field n times the strength of the magnetic field associated with the fundamental oscillations, where n is the order of the harmonic.

An object of the present invention is to provide an improved electron beam harmonic wave generator.

In the present invention, oscillations at a fundamental frequency are generated by the use of cyclotron resonance in an unloaded waveguide. After issuing from the waveguide the electron beam is passed through a cavity resonator tuned to the desired harmonic frequency and supporting a mode having the same azimuthal field distribution as the current in the electron beam and arranged for excitation by longitudinal current components of the beam. This resonator is, essentially, a klystron resonator provided with an interaction gap as in a klystron.

The invention will be further described with reference to the accompanying drawings, in which:

FIG. 1 shows schematically a harmonic generator according to the invention using an annular electron beam; and,

FIG. 2 illustrates a modification of the arrangement of FIG. 1 for use with a solid electron beam.

In the arrangement of FIG. 1, an annular beam electron gun 1 is provided for projecting a beam of electrons through a length of hollow waveguide 2 and a klystron type cavity resonator 3 to an electron collector electrode 4. The cavity resonator 3 is situated downstream of the waveguide 2, i.e. between the waveguide and the electron collector electrode. The components mentioned are represented in FIG. 1 as enclosed in a hermetically sealed and evacuated envelope 5, although, in practice, the envelope would in most cases be provided by the components themselves, formed, for example, from a block of copper providing an integral mechanical structure for the waveguide and cavity resonator.

The cathode, represented at 6, is shown connected to the negative terminal of a D.C. potential source indicated by the battery symbol 7, the electron gun anode 8 and the other components shown on the drawing being connected to the positive terminal. At least the waveguide cavity resonator portions of the device of FIG. 1 are immersed in an axial magnetic field indicated by the arrow B. On leaving the electron gun, the electrons rotate about the axis of the device under the influence of the magnetic field with an angular velocity ω_c, the cyclotron frequency, which frequency is given by the well known expression

$$\omega_c = \eta B$$

where η is the numerical ratio of charge to mass of an electron and B is the flux density of the magnetic field. Since the beam is hollow and each electron path is a helix about the axis of the device, the electron paths are of a spatially periodic form in which interaction with the TE_{11} mode in a cylindrical guide can occur. As shown by Pantell, backward wave oscillations are then set up inside the waveguide 2. When it emerges from the waveguide 2, the electron beam will contain a series of harmonic currents having an azimuthal variation corresponding to that of the waveguide mode used, and these currents have axial components which are much larger than the azimuthal components—i.e. the beam will be bunched longitudinally. The resonator 3 is provided with an interaction gap in the same manner as for employment with klystron tubes, and is shown in FIG. 1 coupled through a tapered matching section of waveguide 9 to an output waveguide feeder 10, a hermetically sealing wave guide window being indicated at 11. The longitudinal components of the radio frequency waves carried on the electron beam will excite the resonator 3 in a mode having a similar azimuthal variation of the electric vector therein as the azimuthal variation of current on the electron beam, the beam and wave interaction being essentially same as in a klystron resonator. This interaction is independent of the magnetic field, but the latter is allowed to extend over the resonator towards the electron collector electrode so as not to upset the electron optics of the system.

The arrangement of FIG. 2 is essentially similar to that of FIG. 1 except that, here, a solid beam electron gun 12 is used offset from the axis of waveguide 2 and having its cathode shielded from the magnetic field. The beam issuing from the electron gun will then assume a helical path as indicated at 13.

The rotating beam sets up backward wave oscillations in the waveguide and longitudinal harmonic current components of the waves of the beam will be present in the issuing beam as in FIG. 1, and are utilized in the cavity resonator 3 in the same manner.

In the above described embodiments a circular waveguide is used and is excited at the fundamental frequency in the TE_{11} mode. It is possible to excite the circular guide in the TE_{21} mode at one half the cyclotron frequency and, in this case, a square waveguide for excitation in the essentially similar TE_{11} mode of a rectangular guide can be used instead of a circular guide.

It is to be understood that the foregoing description of specific examples of this invention is not to be considered as a limitation on its scope.

What we claim is:

1. An electron beam harmonic generator comprising a

hollow waveguide, means for projecting an electron beam in said hollow waveguide, means for exciting fast mode backward wave oscillations at the cyclotron frequency of said electrons in said hollow waveguide along the axis of which the electron beam is projected, and a cavity resonator tuned to a harmonic of the cyclotron frequency and supporting a mode having the same azimuthal field distribution as the radio frequency current in the electron beam, said resonator being arranged downstream of the waveguide for excitation by longitudinal components of said current imposed on the beam by the said oscillations.

2. An electron beam harmonic generator including a length of hollow cylindrical waveguide, means for providing an axial static magnetic field along the waveguide, electrode means at one end of said waveguide for projecting an electron beam along the waveguide along a helical path in such manner that backward wave oscillation of the cyclotron frequency of the electrons are set up in the waveguide and on the beam, and a cavity resonator surrounding the path of the beam at the other end of said waveguide, said cavity being tuned to a harmonic of the cyclotron frequency and supporting a mode having the same azimuthal field distribution as the radio frequency current in the electron beam, said resonator being arranged for excitation by longitudinal current components of the electron beam.

3. An electron beam harmonic generator tube including a length of hollow waveguide, electrode means for projecting an electron beam along the waveguide in a helical path to excite backward mode cyclotron oscillations in the waveguide, a cavity resonator positioned at and spaced from the end of said waveguide opposite said electrode means for excitation by longitudinal current components of the beam, said cavity resonator being tuned to a harmonic of the cyclotron frequency and supporting a mode having the same azimuthal field distribution as the radio frequency current in the electron beam.

4. An electron beam harmonic generator tube according to claim 3, in which the length of the hollow waveguide is of square section, the arrangement being such as to excite the waveguide TE_{11} mode at one half the cyclotron frequency.

5. An electron beam harmonic generator according to claim 1 wherein said beam projecting means is offset from said axis and provides a solid electron beam and includes magnetic shielding means.

6. An electron beam harmonic generator according to claim 1 including a collector electrode positioned adjacent said cavity resonator and output coupling means connected to said resonator.

References Cited in the file of this patent

FOREIGN PATENTS

1,003,492 France ________________ Nov. 21, 1951

OTHER REFERENCES

Backward Wave Oscillations in an Unloaded Waveguide; Article by R. H. Pantell, page 1146, Proc. of I.R.E., for June 1959.