June 15, 1965 J. DAIN ET AL 3,189,750

PARAMETRIC FREQUENCY CONVERTING ELECTRON DISCHARGE TUBES

Filed Nov. 30, 1959 2 Sheets-Sheet 1

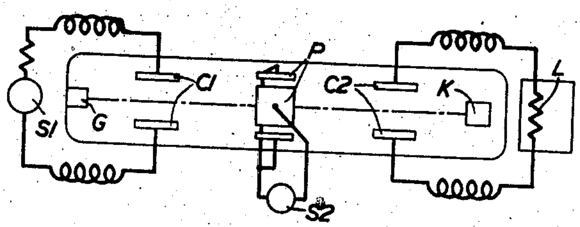

FIG. 1.

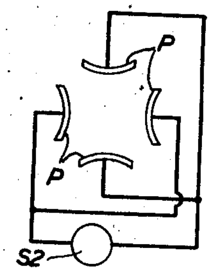

FIG. 2.

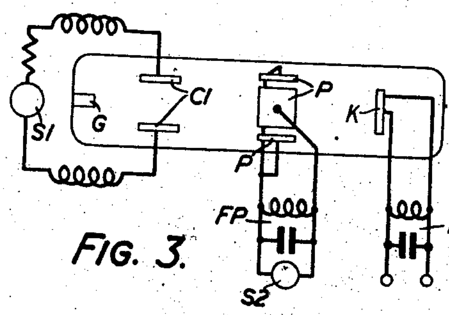

FIG. 3.

FIG. 4.

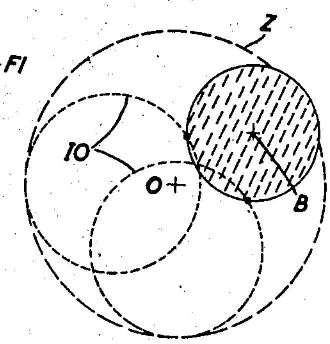

FIG. 5.

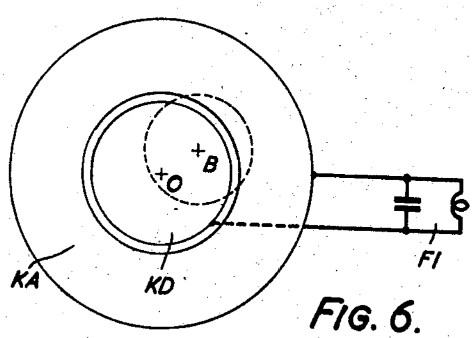

FIG. 6.

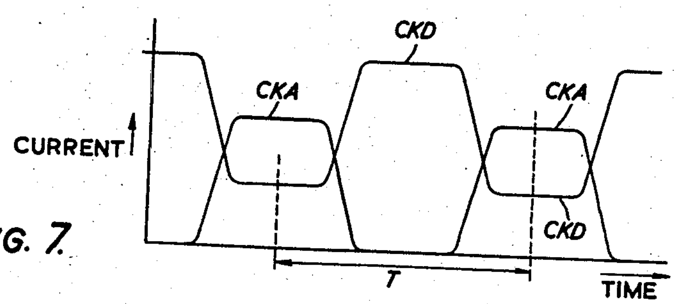

FIG. 7.

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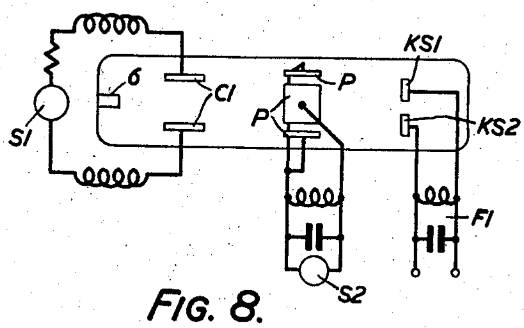

FIG. 8.

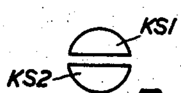

FIG. 9.

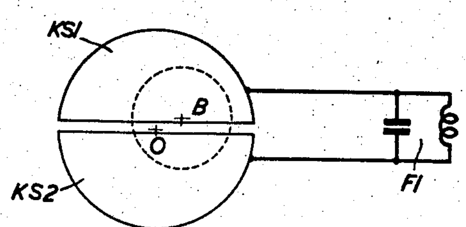

FIG. 10.

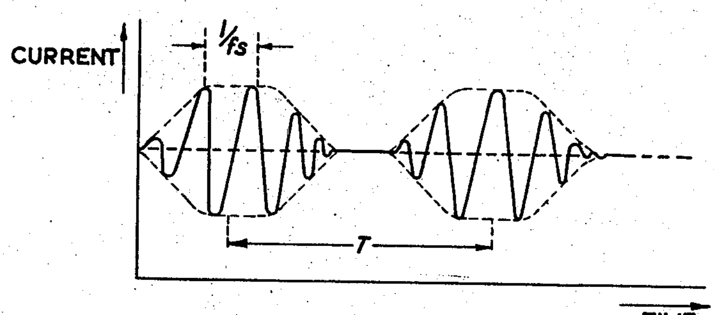

FIG. 11.

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PARAMETRIC FREQUENCY CONVERTING ELECTRON DISCHARGE TUBES

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Claims priority, application Great Britain, Apr. 27, 1959, 14,270/59
1 Claim. (Cl. 307—88.3)

This invention relates to frequency converting electron discharge tubes and has for its object to provide improved frequency converting electron discharge tubes of low noise and which will convert an input of one frequency into an output of another frequency which may even be zero frequency, i.e. direct current.

Tubes in accordance with this invention utilise certain principles which are also utilised in electron beam parametric amplifier tubes. In order that the invention may be better understood the general nature of the electron beam parametric amplifier will first be described with the aid of FIGS. 1 and 2 of the accompanying drawings. For further information with regard to these amplifiers reference may be made to the Proceedings of the Institute of Radio Engineers, vol. 46, pages 1300, 1301 (R. Adler) and pages 1756–1757 (R. Adler, G. Hrbek and G. Wade).

FIGURE 1 is a schematic view of a parametric amplifier tube;

FIGURE 2 is a schematic view of a quadrupole pump structure included in the arrangement shown in FIGURE 1;

FIGURE 3 is a diagrammatic representation of one frequency converter embodiment in accordance with the invention;

FIGURE 4 is a face view of the collector system employed in FIGURE 3;

FIGURES 5, 6 and 7 are explanatory figures related to the embodiment of FIGURE 3;

FIGURE 8 is a diagrammatic representation of a further embodiment of the invention;

FIGURE 9 is a face view of the collector electrode system used in the embodiment of FIGURE 8; and

FIGURES 10 and 11 are explanatory diagrams related to the embodiment of FIGURE 8.

In the parametric amplifier tube of FIGS. 1 and 2 an electron beam from an electron gun G is constrained by an axial magnetic field generated by a coil (not shown) and with its lines of force running parallel to the axis (represented by the chain line), the magnitude of the magnetic field being such that the so-called cyclotron frequency is approximately equal to the frequency of an input signal to be amplified and which is applied from a source S1 to an input coupler C1 coupled to the beam. The beam passes to an electron beam collector K through an output coupler C2 from which amplified output is taken to a receiver or load L. In its path from the input coupler to the output coupler the beam passes through a so-called "pump" system P which may be, and is shown as, a quadrupole structure as described by Adler, Hrbek and Wade (supra). FIGURE 2 is a schematic view, at right angles to FIGURE 1, showing the quadrupole pump structure.

With this arrangement, as is described in the above mentioned Proc. I.R.E. references, the input coupler extracts the fast wave component of the beam noise and simultaneously creates a new fast wave in accordance with the input signal from source S1 which signal will normally be of a frequency of the order of 500 mc./s. In its passage through the input coupler each electron has imparted to it, by the input signal, a deflection such that its path becomes helical—more strictly spire-helical since the diameter of the helix increases with progress of the electron in the axial direction. When the electron leaves the input coupler, it is following a helical path of maximum diameter. When it enters the pump section the electron is subjected to an inhomogeneous electric field excited by a source S2 of radio frequency which is connected to the four poles of the pump system as best shown in FIGURE 2. This causes the radius of the circular component of electron movement to be increased or decreased in accordance with the relation between the azimuthal position (i.e. position round the circle) of any particular electron when it enters the pump system and the phase of the pumping field. As the beam leaves the pump system it will trace out a momentarily annular area obtained by rotating its cross section, assumed to be circular, about the axis. The diameter of the annulus varies since the distance between the centre of the beam cross section and the axis depends on the input signal strength, the strength of the radio frequency pump field and the relation between the azimuthal position of the beam as it enters the pump system and the phase of the radio frequency pump field at that point. The angular velocity of rotation of the beam about the axis as it leaves the pump section is equal to the angular frequency of the input signal from source S1 and the radial distance between the centre of the beam, as it leaves the pump section, and the axis will vary periodically with a period related to the input signal frequency and the pump frequency. If the pump field has a dependence on the azimuthal co-ordinate of position of the form cos 2θ then the period T will be given by

$$T=\frac{1}{|2f_s-f_p|}$$

where f_s is the input signal frequency and f_p is the pump frequency. Also, if $f_p=2f_s$ the radial distance between the centre of the beam leaving the pump system and the axis will be constant for constant values of signal and pump powers.

After leaving the pump section the beam passes into the output coupler C2 which is similar to the input coupler and which absorbs the energy associated with the rotation component of movement of the electrons so that the helical electron paths (more strictly spire-helical paths) decrease in diameter as the electrons proceed towards the collector until finally the path becomes substantially axial again when the electrons leave the output coupler for the collector.

The known tube as above described operates as an amplifier producing from the output coupler an amplified output signal of the same frequency as that applied to the input coupler. One of the great advantages of the principle used in this tube—what may be termed the "parametric" principle—lies in the high degree of "noiselessness" obtained.

The present invention provides a tube using the parametric principle but which will operate as a frequency converter, converting input signals of one frequency into an output of another, different frequency. In a special case the converted, output frequency may be zero frequency, i.e. direct current and the expression "frequency conversion" and like expressions are used in this specification to include (where the context allows) this special case of zero output frequency.

According to this invention an electron beam discharge tube adapted to utilise the parametric principle for frequency conversion comprises an electron gun, and, in the order stated starting with the gun, an input coupler adapted to be fed with input signals, a so-called pump electrode system adapted to be fed with pump signals at a predetermined frequency, a collector electrode system consisting of a plurality of separate electrodes so positioned as differently to intercept the rotating beam leaving the pump system in dependence upon the momentary diameter of the path of beam rotation, and output means connected between separate electrodes of the collector electrode system.

According to a feature of this invention a frequency converter comprises an electron beam discharge tube having an electron gun, and, in the order stated starting with the gun, an input coupler, a so-called pump electrode system and a collector system consisting of a plurality of separate electrodes so positioned as differently to intercept a rotating beam leaving the pump system in dependence upon the momentary diameter of the path of beam rotation; means for applying input high frequency signals of predetermined frequency to the input coupler; means for subjecting the electron beam of the tube to a magnetic field with lines of force parallel to the axial direction of the tube and of such magnitude that the so-called cyclotron frequency of the electrons in said field is approximately equal to the input high frequency; means for applying a pump signal frequency of predetermined value to the pump system; and at least one output circuit connected between separate electrodes of the collector electrode system.

In the preferred forms of construction in accordance with this invention the pump electrode system is a quadrupole system and the collector electrode system consists of two electrodes with the output circuit connected between them. In one form of tube in accordance with the invention the two electrodes of the collector electrode system comprise a disc electrode at right angles to the tube axis and with its centre on said axis and an annular electrode spaced a short distance from and concentrically surrounding the disc electrode. In another form of tube in accordance with the invention the two electrodes of the collector electrode system are identical segmental electrodes each a little smaller than a semicircle, mounted co-planar with their chord edges parallel and spaced a short distance from one another so that the two electrodes, together with the space between their chord edges, occupy a circular area centred on the tube axis and at right angles thereto.

In a tube in accordance with this invention and having a quadrupole pump system the diameter of the circular path of rotation of the electron beam leaving the pump system will be constant if the pump frequency is twice the input signal frequency. In one form of frequency converter embodying the invention and employing a tube with a quadrupole pump system and a concentric ring and annulus collector system as above described, the pump frequency (f_p) is chosen at a value a little different from twice the value of the input signal frequency (f_s) and a resonant output circuit resonant to a frequency (f_1) given by the expression

$$f_1=|2f_s-f_p|$$

is connected between the two electrodes of the collector system. Thus the output frequency f_1 will be much lower in value than either f_s or f_p. If f_p is chosen exactly equal to $2f_s$, $f_1=|2f_s-f_p|=0$ and the output will be direct current so that the output circuit may be resistive or of some other aperiodic form.

In another form of frequency converter embodying the invention and employing a tube with a quadrupole pump electrode system and a collector electrode system of two segmental electrodes arranged as above described, the pump frequency is chosen equal or approximately equal to twice the input signal frequency and a resonant output circuit resonant either to the frequency $|f_s+f_p|$ or to the frequency $|f_s-f_p|$ (as may be desired) is connected between the electrodes of the collector system.

The invention is illustrated in and further explained in connection with FIGS. 3 to 11 inclusive of the accompanying drawings.

Referring to FIG. 3, it will be seen that the tube employed in this embodiment differs from the tube shown in FIG. 1 by the omission of the output coupler C2 and the provision in place of the simple collector K of FIG. 1 of a collector system consisting of two concentric electrodes of which the inner one is a disc KD at right angles to and on the axis of the tube, and the outer one is an annulus KA co-planar with the disc KD and concentric therewith and spaced a little distance therefrom. A parallel tuned circuit FP tuned to the pump frequency f_p is shown connected across the pump source S2 and a parallel tuned circuit F1 tuned to the output frequency f_1 is connected between the electrodes KA and KD of the collector electrode system.

FIG. 5 is a diagrammatic representation taken at right angles to the view of FIG. 3 showing the behaviour of the electron beam (presumed to be of circular section) as it leaves the pump system P. At this point the electron beam, whose centre is marked by the cross B and which is represented by the shaded circle, will be rotating about the tube axis represented by the cross O, with an angular velocity $2\pi f_s$. The dimension OB will vary due to the pump input with a period

$$T=\frac{1}{|2f_s-f_p|}$$

Typical individual electron orbits are indicated by the broken line circles IO. The outer circle Z represents the boundary of the area traced out by the beam when the distance OB is constant.

In FIGURE 6 the collector electrode system is represented to a rather larger scale and one position of the beam incident on that system is represented by the broken line circle with its centre at B, the cross O again representing the axis. As will be at once apparent from FIGURE 6, the current will divide between the two electrodes KA and KD and the ratio of the currents will depend on the magnitude of OB so that the currents will very periodically with a period T as indicated in FIGURE 7 where the wave of current to the disc is represented by the line CKD and the wave current to the annulus is represented by the line CKA. Accordingly a circuit F1 tuned to the frequency $f_1=|2f_s-f_p|$ connected between the electrodes of the collector system will respond to the current fluctuations.

The arrangement shown in FIGURES 8 and 9 differs from that of FIGURES 3 and 4 in the use of a collector electrode system of different form. Here the collector electrodes are alike, each being in the form of a circular segment a little smaller than a semi-circle. The segments are co-planar with their chord edges spaced apart by a short distance and parallel to one another with the said segments having a common centre on the axis of the tube. FIGURE 9, which shows the collector system in face view, indicates the arrangement quite clearly, the identical segments being marked KS1 and KS2.

These segments appear again in FIGURE 10 on which is also shown, by means of a broken line circle with its centre at B, one position of the rotating electron beam incident on the collector electrode system. With this arrangement the current to the two electrodes will vary as shown in FIGURE 11, the current waveform being in effect that of an amplitude modulated waveform with a carrier f_s and a modulation period T. Thus a circuit marked F1 in FIGURES 8 and 10 connected between the two segmental electrodes and tuned either to the sum or to the difference of the frequencies f_s and f_p will respond to the current fluctuations.

We claim:

A frequency converter comprising an electron beam discharge tube having an electron gun, and, in the order stated starting with the gun, an input coupler, a quadrupole pump electrode system and a collector electrode system consisting of two separate electrodes, said two electrodes comprising a disc electrode at right angles to the tube axis and having its center on said axis and an annular electrode spaced a short distance from and concentrically surrounding the disc electrode so as differently to intercept a rotating beam leaving the pump system according to the momentary diameter of the path of beam rotation; means for applyig an input signal of frequency f_s to the input coupler of the tube, means for applying a pump frequency f_p to the quadrupole pump system of the tube, f_p being different in value from $2f_s$; means for subjecting the electron beam of the tube to a magnetic field with lines of force parallel to the axial direction of the tube and of such magnitude that the so-called cyclotron frequency of the electrons in said field is approximately equal to the input high frequency; and a resonant output circuit connected between the two electrodes of the collector electrode system of the tube, said output circuit being resonant at a frequency f_1 where $f_1=2f_s-f_p$.

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