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L. E. NORTON
FREQUENCY MULTIPLIER

2,253,575

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FIG. 1.

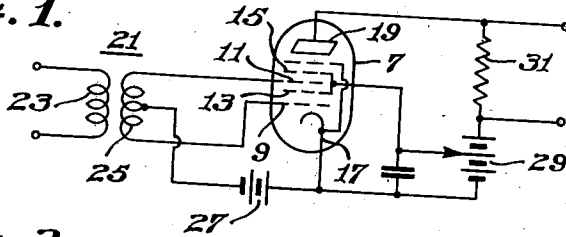


FIG. 2.

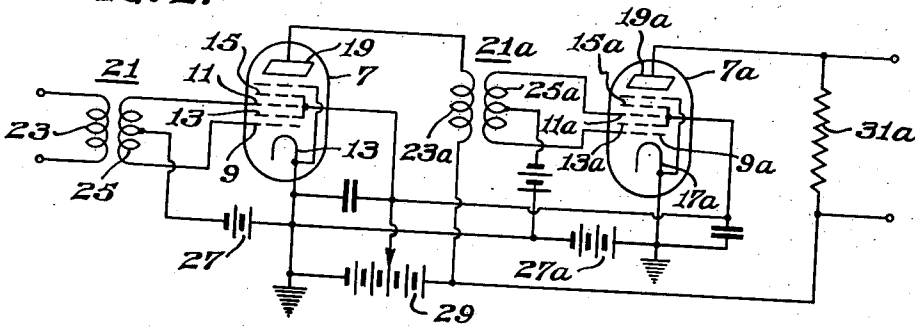


FIG. 3.

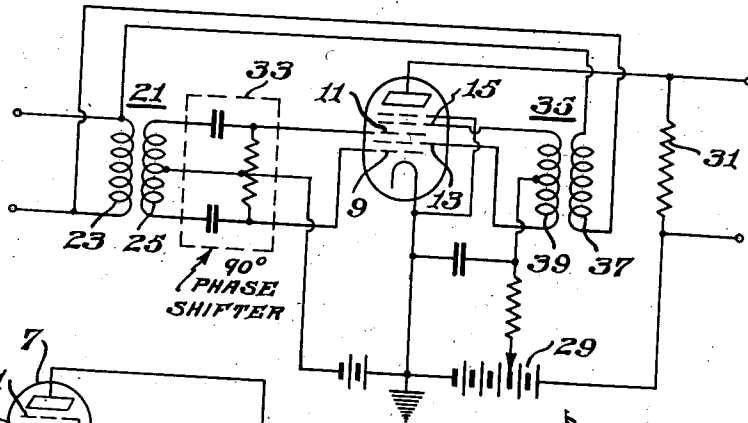


FIG. 4.

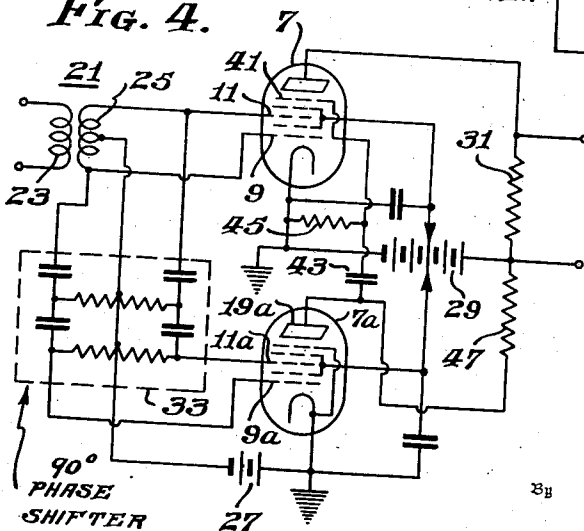
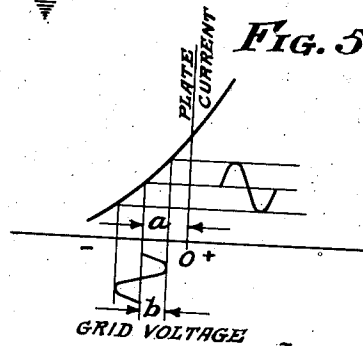


FIG. 5.



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FREQUENCY MULTIPLIER

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6 Claims. (Cl. 250—36)

This invention relates to frequency multipliers, and has for its principal object the provision of an improved and simplified device for translating currents or potentials of one frequency into currents or potentials of a higher frequency which is a multiple of the original frequency. Additional objects include the provisions of a frequency multiplier which operates without readjustment over a wide range of frequencies; the provision of a device which generates only a predetermined multiple frequency without at the same time generating a large number of unwanted frequencies; the provision of a frequency multiplier which does not rely on the frequency characteristic of a resonant circuit to select a desired harmonic from a series of undesired harmonics; the provision of a frequency multiplier which utilizes a minimum number of parts; and the provision of a frequency multiplier of improved efficiency.

I am aware of systems of multiplication in which distortion is intentionally introduced into a signal in order to produce a series of high order harmonics. In such a system, a tuned circuit is used to select the desired harmonic and to reject the undesired harmonics. In such a system, however, a great deal of the available energy is wasted in the production of the undesired harmonics, with the result that but a feeble output is obtained at the desired frequency. I am also aware of the use of balanced modulators for the production of frequencies equal to the sum, difference and harmonics of the applied voltages. Such systems, however, also contain many different output frequencies, and require a resonant or other selective circuit to remove those which are unwanted. Like the first use mentioned, the energy of the balanced modulator is not confined to any particular desired frequency.

In brief, this invention makes possible frequency doubling by applying an input voltage in phase opposition between two grids, respectively, and a cathode of a multi-grid tube, and if care is taken to insure linear operation, the pure double frequency is available in the anode circuit, without the need of frequency selective circuits. Additional frequency multiplication may be achieved by cascaded stages, or in an alternative arrangement, the input may be divided into two balanced circuits each including a pair of grids. The voltages applied to the two grids, in pairs, are made to be in quadrature phase by means of a phase shifter. The resultant voltages are applied either to a single four-grid tube or two

double-grid tubes, as will be explained in detail hereinafter.

This invention will be better understood from the following description when considered in connection with the accompanying drawing. Similar reference numerals will be applied to similar elements in the drawing. Its scope is indicated by the appended claims.

Referring to the drawing, Figure 1 is a circuit diagram of a simple frequency doubler; Figure 2 is a schematic diagram of a cascaded frequency doubler; Figure 3 is a circuit diagram of a frequency multiplier utilizing a four-grid tube; Figure 4 is a circuit of a frequency multiplier utilizing a pair of two-grid tubes; and Figure 5 is a graph used in describing the invention.

Referring to Fig. 1, a thermionic tube 7 includes two input grid electrodes 9 and 11, a screen grid comprising two sections 13 and 15, a cathode 17 and anode 19. The input voltage is applied in phase opposition between the two grids 9 and 11, respectively, and the cathode 17 by means of a transformer 21 having a primary 23 and a secondary 25, the point intermediate the ends being connected to the cathode 17 through a bias battery 27. Screen and anode potentials are supplied by a battery 29. A non-resonant impedance, such as resistor 31, is the anode load resistor.

The voltages developed across the two sections of the secondary 25 of the input transformer 21 which are applied, respectively, to the first pair of grids 9 and 11 take the form:

$$(1) \quad a + b \sin \omega t$$

and

$$(2) \quad c - d \sin \omega t$$

where a and c are constant bias voltages which are adjusted to provide operation on the linear portion of the tube characteristic. The two bias voltages are equal in the case under consideration, and the amplitudes of the alternating voltages may be adjusted as desired. The factors b and d indicate the amplitude of the sine wave voltage. This relation is illustrated in Fig. 5, which shows the voltage on one grid. The ratio of the peak amplitude b to the bias voltage a is called the modulation factor, and is designated m_1 . Similarly, the modulation factor m_2 for the second voltage is

$$\frac{d}{c}$$

The output voltage E developed across the an-

ode load resistor 31 is equal to the product of the two applied voltages, since they successively operate on the anode-cathode electron stream; that is

$$(3) \quad E = k(1 + m_1 \sin \omega t)(1 - m_2 \sin \omega t)$$

$$(4) \quad = k(1 + m_1 \sin \omega t - m_2 \sin \omega t - m_1 m_2 \sin^2 \omega t)$$

$$(5) \quad = k(1 + (m_1 - m_2) \sin \omega t - m_1 m_2 [\frac{1}{2} - \frac{1}{2} \cos 2\omega t])$$

and when $m_1 = m_2$

$$(6) \quad E = k \left(1 - \frac{m_1 m_2}{2} + \frac{m_1 m_2}{2} \cos 2\omega t \right)$$

where k is a proportionality factor which depends on the tube characteristics and circuit constants.

The first two terms are direct current, while the last term is an alternating current of twice the frequency of the input voltage. When m_1 and m_2 approach unity, the amplitude of the output voltage approaches one-half the input amplitude. Substantial energy at the doubled frequency is therefore realized. It is to be noted that when $m_1 = m_2$ the fundamental frequency component vanishes, so that it is not necessary to use a frequency selective network to obtain the new frequency. The system, therefore, will operate over a wide frequency range without requiring the readjustment of a tuned circuit.

Fig. 2 illustrates an arrangement for multiplying a given frequency by a factor of four. This system comprises two systems of the type described in Fig. 1 connected in series, so that the output voltage of doubled frequency of the first tube 7 becomes the input voltage for the second tube 7a, in which tube the frequency is again doubled in exactly the same manner. Additional stages may be employed to produce higher even harmonics. Since the circuit of Fig. 2 is similar to that of Fig. 1, it is not necessary to describe it in detail again. Similar reference numerals have been applied to similar parts, and the letter "a" is added to the reference characters which indicate the second doubler tube and associated apparatus.

Fig. 3 illustrates a circuit for producing frequency quadrupling in a single tube, the output voltage being entirely free from all other frequencies, as before. While there is no tube commercially available at the present of the type illustrated, I have found that a tube of the 6L7 type can be modified by bringing connecting separate leads to two screen grid sections 13 and 15. Otherwise, the tube is the same as the tubes illustrated in Figs. 1 and 2.

As before, an input transformer 21 is utilized to provide two voltages which are mutually out of phase. A phase shifting network 33 is connected between the transformer and the two control grids 9 and 11, the object of which is to shift the input voltage by 90°. A second input transformer 35 is provided, the primary 37 of which is connected in parallel with the primary 23 of the first input transformer 21. The secondary 39 of the second input transformer is provided with a tap, and the outer secondary terminals are connected to the two sections 13 and 15 of the screen grid. If desired, a single transformer having two tapped primaries may be provided. Also, the phase shifting network 33 may be connected between the secondary of the second input transformer and grids 13 and 15, or in the lead connecting the primaries of the two input transformers. The only requirement is that the

voltages applied to the respective grids be in phase quadrature.

The screen grid sections 13 and 15 may be maintained at their normal positive potential by means of a suitable tap on anode supply battery 29. Grid bias for the control grids is supplied by battery 27, as before, and the output is developed across the non-resonant plate load impedance 31.

The operation of the modification described above is similar to the first described system. The four grids act on the electron stream and the resultant may be expressed as a product of the applied voltages. Bearing in mind the stated phase relations, the output voltage E is equal to:

$$(7) \quad E = k [(1 + m_1 \sin \omega t)(1 - m_2 \sin \omega t)(1 + m_3 \cos \omega t)(1 - m_4 \cos \omega t)]$$

The first two terms are the voltages applied to the screen grid sections, while the cosine terms are the voltages of shifted phase which are applied to the control grids. The terms m_1 , m_2 , m_3 , and m_4 are, as before, the modulation factors. It is to be noted that since the usual fixed positive potential is applied to the screen sections, the amplitudes of the applied voltages must be increased accordingly so that the modulation factors m_3 and m_4 are equal to m_1 and m_2 . The impedance looking into the screen grid sections will be somewhat lower than the impedance looking into the negatively bias control grids, but a suitable transformer design will provide for linear operation notwithstanding the lower impedance.

When the modulation factors m_1 , m_2 , m_3 and m_4 are all equal to m , the fundamental frequency terms which appear in the expanded form of Equation 7 drop out as before, leaving only direct current terms and one alternating current term:

$$(8) \quad E = d.c. + \frac{m^4}{8} \cos 4\omega t$$

The frequency of the alternating current term is four times the original frequency. Since this is the only alternating term present, selective networks are not necessary.

By suitable choice of the relative phases and amplitudes of the voltages applied to the two control grids and the two screen grid sections, the circuit may also be operated as a frequency tripler, although because of the complexity of the necessary adjustments, it is preferably operated to obtain even order harmonic frequencies.

The tube illustrated in Fig. 3 would be improved by the addition of shielding electrodes between the active grids to prevent electrostatic feedback from one grid to another. In the absence of such a tube, the amplitudes of the input voltages should be kept to reasonably small values so as to make m_1 , m_2 , m_3 and m_4 considerably less than unity. An alternative solution is to use two tubes in a circuit illustrated in Fig. 4, to which reference is now made.

Two tubes 7 and 7a of the 6L7 type are employed, the control grids of which are energized by voltages which are derived from the secondary of the input transformer 21, and which are mutually in phase opposition. The voltages applied to the second tube 7a are in phase quadrature with the respective voltages applied to the first tube 7. This quadrature phase relation is accomplished by means of a phase shifting network 33 connected in series with the grid input circuits of one of the tubes.

It will be seen that tube 7a and the inner part

of tube 7 up to grid 41 are connected in a manner similar to the circuit of Fig. 1, and it will operate as a frequency doubler under the same conditions. The output voltage of twice the original frequency which is developed across the anode load resistor 47 of the second tube is coupled to the suppressor grid 41 of the first tube 7 by means of a capacitor 43. A resistor 45 provides a ground return for the suppressor grid. The suppressor grid of the second tube 7a is connected to its cathode in the usual manner.

In effect, then, the control grids 11 and 9 of the first tube 7 modulate the electron stream to produce frequency doubling, and the electron stream is then modulated at the suppressor grid by a second doubled frequency voltage in phase quadrature with the first, so that the resultant modulation produces a voltage across the anode load resistor 31 which contains only direct current components and one alternating component, the frequency of which is four times the frequency of the input voltage. This operation is similar to that of the system illustrated in Fig. 3, except that one step of frequency doubling is accomplished in a separate tube.

The advantage of the modification illustrated in Fig. 4 over that of Fig. 3 is that the input voltages are applied to the control grid electrodes having high impedances. This eliminates the necessity of using two input transformers, and decreases the power consumption of the input circuits. Since substantially no power is taken by the negatively biased grids, distortion due to poor regulation of the source is avoided.

I have thus described several embodiments of a system for multiplying the frequency of a given alternating voltage, the system being characterized by the absence of resonant circuits tuned to the desired frequency, by the absence of intentional distortion which is frequently used to increase the harmonic content of an alternating voltage, and by the fact that the system generates only the desired harmonic voltage.

I claim as my invention:

1. A frequency multiplier comprising a thermionic tube having at least two pairs of grid electrodes, cathode and anode electrodes, a source of alternating voltage, phase shifting means, means for applying said alternating voltage in phase opposition between the grids of one of said pairs, respectively, and said cathode, means including said phase shifting means for applying said alternating voltage in phase opposition between the grids of the other of said pairs, respectively, and said cathode, and means for deriving an alternating output voltage the frequency of which is a multiple of the frequency of said alternating voltage.

2. A frequency multiplier comprising a thermionic tube having at least two pairs of grid electrodes, cathode and anode electrodes, a source of alternating voltage, phase shifting means, means for applying said alternating voltage in phase opposition between the grids of one of said pairs, respectively, and said cathode, means including said phase shifting means for

applying said alternating voltage in phase opposition between the grids of the other of said pairs, respectively, and said cathode, and a resistor connected in circuit with said anode for deriving and alternating output voltage the frequency of which is a multiple of the frequency of said alternating voltage.

3. A device of the character described in claim 1 in which said phase shifting means produces a 90° phase shift.

4. A frequency multiplier comprising a thermionic tube having at least two pairs of grid electrodes, cathode and anode electrodes, a source of alternating voltage, means for applying said alternating voltage in phase opposition between the grids of one of said pairs, respectively, and said cathode, means for biasing said grids for operation on the linear portion of the grid voltage-plate current characteristic of said tube, phase shifting means, means including said phase shifting means for applying said alternating voltage in phase opposition between the grids of another of said pairs, respectively, and said cathode, and a nonresonant impedance connected in circuit with said anode for deriving an alternating output voltage the frequency of which is a multiple of the frequency of said alternating voltage.

5. A frequency multiplier comprising a pair of thermionic tubes, each having at least two grids, a cathode and an anode, a source of alternating voltage, means coupled to said source for applying said alternating voltage in phase opposition between the grids, respectively, and the cathode of the first of said tubes, means coupled to said source for applying said alternating voltage in phase opposition between the grids, respectively, and the cathode of the second of said tubes and in phase quadrature with the voltages applied to the grids of said first tube, means for coupling the output of one of said tubes to a control circuit of the other of said tubes and impedance means connected in the anode circuit of said other tube for deriving an output voltage the frequency of which is a multiple of the frequency of said alternating voltage.

6. A frequency multiplier comprising thermionic tube means including at least two pairs of grid electrodes, a source of alternating voltage, means for applying said alternating voltage in phase opposition between the grid electrodes of one of said pairs of grid electrodes respectively and a point of reference potential, 90° phase-shifting means, means including said phase-shifting means for applying said alternating voltage in phase opposition between the grid electrodes of the other of said pairs of grid electrodes, respectively, and said point of reference potential and in phase quadrature with the respective voltages applied to said one of said pairs of grid electrodes, and means for deriving an alternating output voltage from said thermionic tube means the frequency of which is a multiple of the frequency of said alternating voltage.

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