May 9, 1933. A. HUND 1,908,249

FREQUENCY MULTIPLICATION SYSTEM

Filed Oct. 6, 1926

FIG. 1

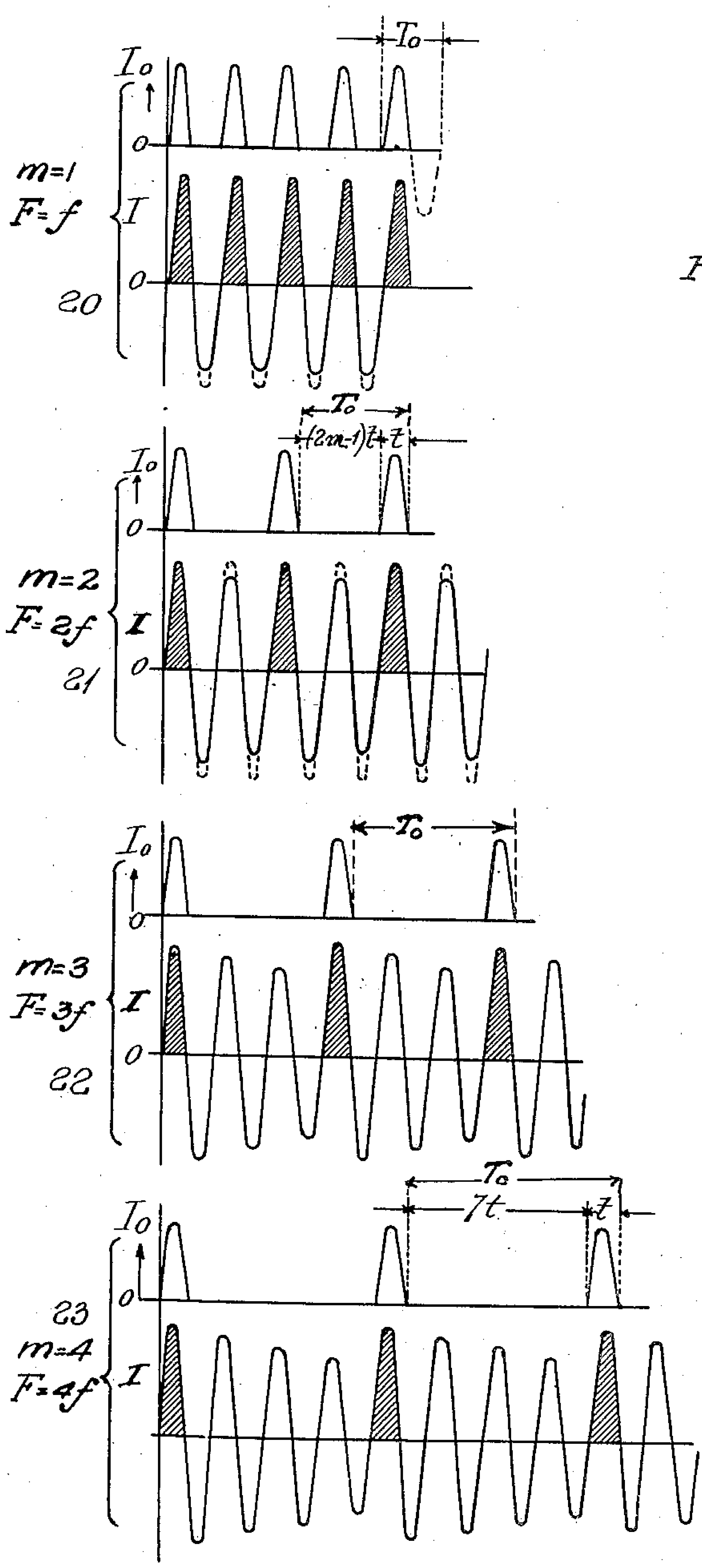


FIG. 2

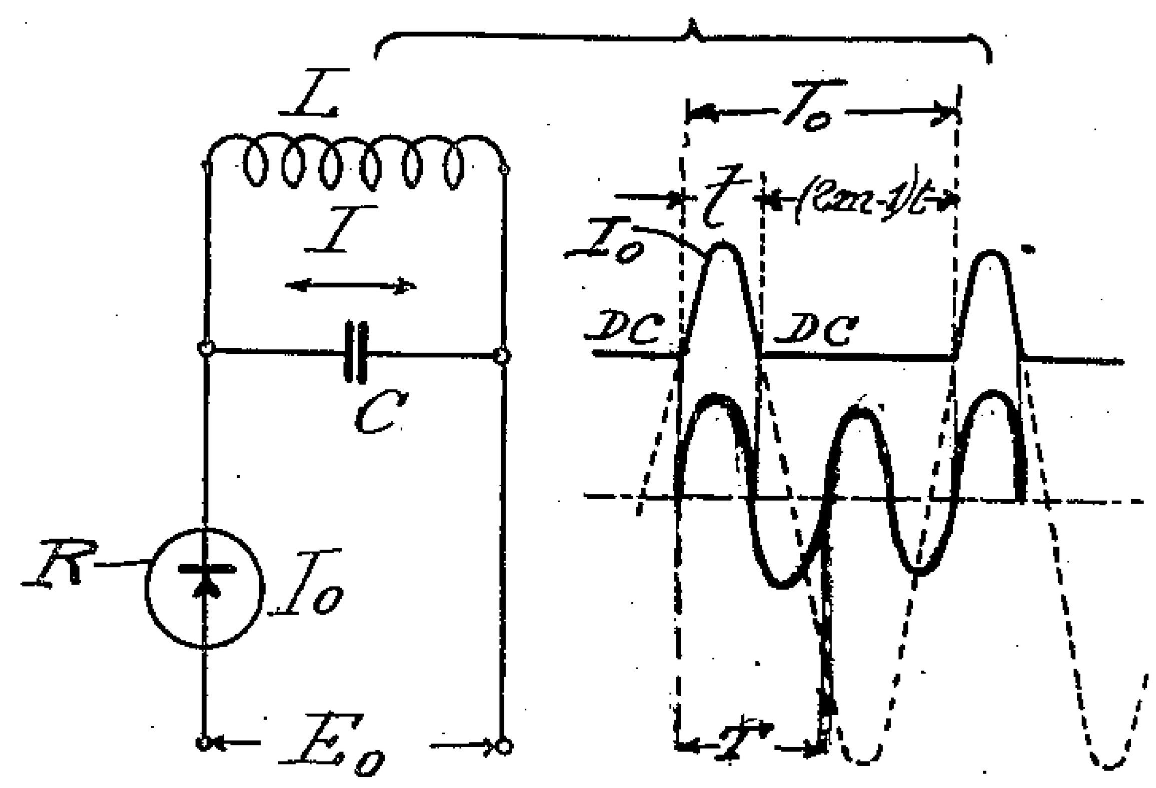


FIG. 3

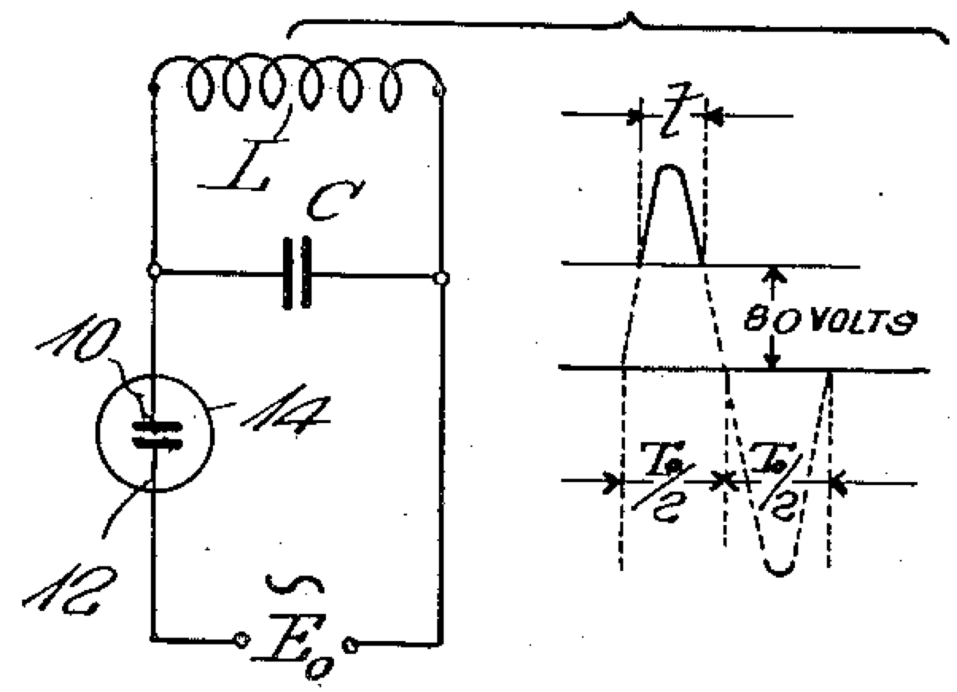
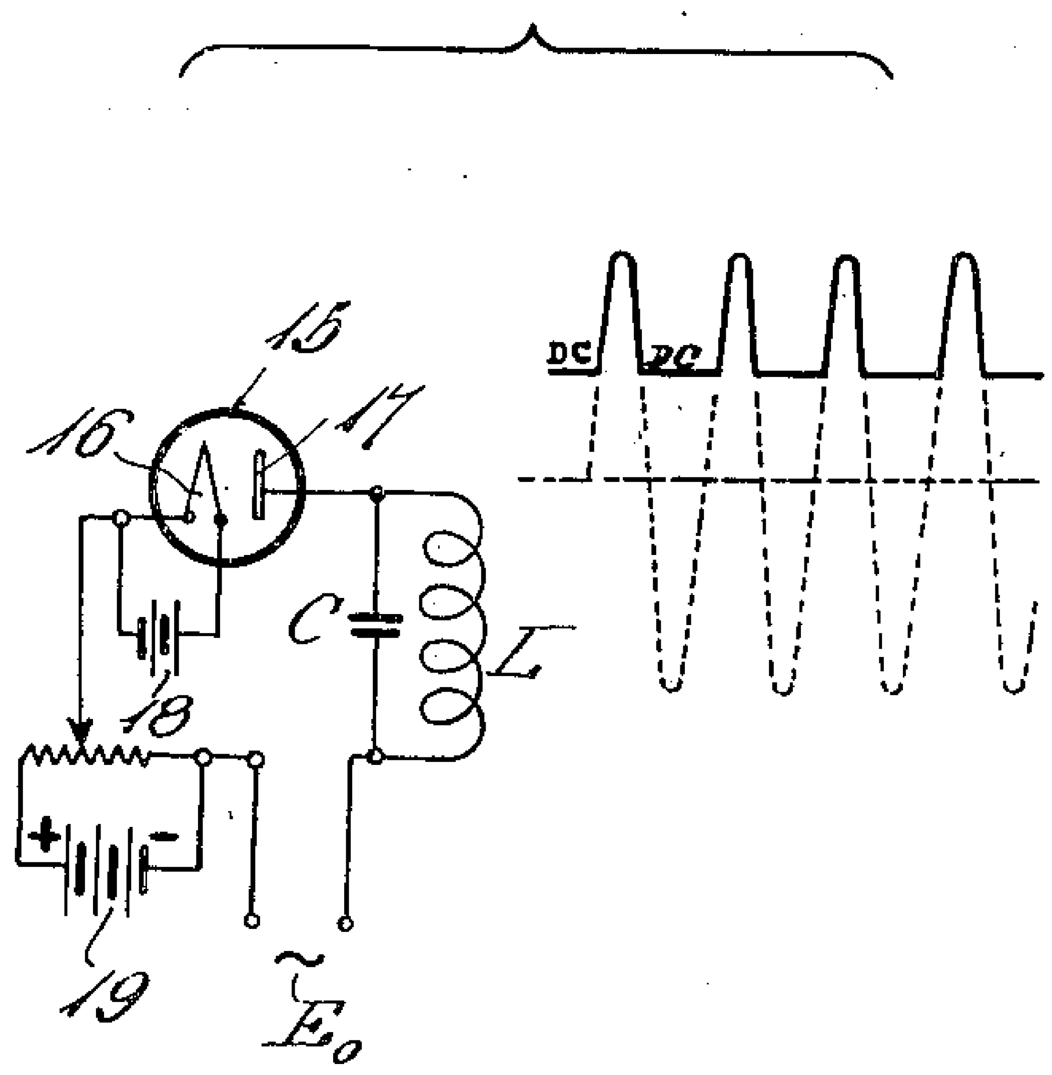


FIG. 4



INVENTOR.

August Hund,

BY John B. Brady

ATTORNEY.

Patented May 9, 1933 **1,908,249**

UNITED STATES PATENT OFFICE

AUGUST HUND, OF BETHESDA, MARYLAND, ASSIGNOR, BY MESNE ASSIGNMENTS, TO WIRED RADIO, INC., OF NEW YORK, N. Y., A CORPORATION OF DELAWARE

FREQUENCY MULTIPLICATION SYSTEM

Application filed October 6, 1926. Serial No. 139,946.

My invention relates broadly to systems for generating oscillations and more particularly to frequency multiplication circuits.

One of the objects of my invention is to provide a frequency multiplication system and method by which a relatively low frequency impressed voltage may be increased in frequency a plurality of times.

Another object of my invention is to provide a system and method for generating relatively high frequency electrical oscillations by the impression of unidirectional current impulses upon an oscillation circuit and controlling the frequency thereof by the timed relation of the current impulses.

A further object of my invention is to provide an oscillation generator circuit in which the frequency may be controlled by successively impressing unidirectional charges upon the oscillation circuit, the charges being derived from an initial source of low frequency current subsequent to its impression upon a rectification circuit.

Still another object of my invention is to provide a circuit system for the production of high frequency oscillations from an initial source of low frequency alternating current where a form of rectifier is interposed between the initial source and the high frequency oscillation circuit and adjusted to allow the periodic impression of charging current upon said oscillation circuit during selected time intervals separated by non-current intervals, whereby oscillations of a frequency dependent upon the rate of impression of the charging current upon said oscillation circuit may be produced.

My invention will be more clearly understood from the following specification by reference to the accompanying drawing in which:

Figure 1 represents graphically the characteristics of the circuits of the frequency changing system of my invention; Fig. 2 shows a circuit diagram embodying the principles of my invention with characteristic curves of the current which is supplied to the oscillatory circuit and the current in the oscillating circuit; Fig. 3 shows a further circuit arrangement embodying the principles of my invention with an explanatory curve showing the characteristic of the current supplied to the circuit; Fig. 4 shows a modified arrangement of rectifier and frequency multiplication circuit illustrating the characteristic of the current supplied to the frequency multiplication circuit.

My invention finds particular application in association with piezo electric crystal control circuits for increasing the frequency of oscillations derived from the piezo electric crystal element of relatively large thickness. In controlling high frequency oscillations by piezo electric crystal elements the piezo electric element is normally very thin and fragile. The grinding of a crystal to the extreme thinness required in high frequency operation is relatively tedious and difficult and the possibility of breakage and the labor necessary for grinding of the crystal involve relatively large expense. Besides, it is more difficult to make thin crystals oscillate. By my invention I provide a circuit arrangement which may be associated with a piezo electric crystal oscillator of relatively low frequency for multiplying the frequency thereof within limits to any required frequency. My invention finds application in other circuit arrangements where it is necessary to increase the frequency of a relatively low frequency alternating current to a higher frequency.

Referring to the drawing in detail, Fig. 2 shows circuits arranged for operation in accordance with my invention and curves indicating the current in said circuits. A source of alternating potential E_o is shown having one side connected to a rectifier R and the other side to an oscillatory circuit comprising inductance L and capacity C.

The rectifier R is connected intermediate the source of alternating potential E_o and the oscillatory circuit LC. The natural frequency of oscillation of the circuit LC is determined by the values of the inductance L and the capacity C, and is substantially equal to

$$F=\frac{1}{2\pi\sqrt{LC}}$$

It is well known that if the capacity C is charged and the source of charge is then removed, capacity C will discharge and recharge repeatedly through the inductance L at the natural frequency of oscillation of circuit LC. The current so set up in LC is indicated by reference character I. The current I will have a lower value for each succeeding cycle and will die out after a period of time depending on the losses in the circuit.

In order to maintain oscillations in the circuit LC and in accordance with my invention, I provide a rectifier R in series with the source of alternating potential E_o and select values for L, C, and the frequency and voltage of the supply source E_o so that the frequency of the current I is substantially a multiple of the frequency of source E_o. I arrange the rectifier R so that it will offer practically infinite impedance to a current I_o until a predetermined value of voltage is impressed across the rectifier. When the voltage of E_o exceeds this predetermined value the resistance of the rectifier changes and a current I_o flows from the source E_o to the circuit LC. When the voltage across the rectifier R falls below the said predetermined value the rectifier again offers practically infinite impedance to current I_o and also when the voltage of E_o is of opposite polarity. It is readily seen, therefore, that current flows into the circuit LC from the source E_o only when the voltage of E_o exceeds a predetermined value in one direction. This results in the circuit LC receiving a series of current impulses I_o of predetermined duration at the frequency of the source E_o. During the intervals when no impulses are being received by the circuit LC said circuit is free to oscillate at its natural frequency. I arrange the circuit LC so that each impulse I_o will be substantially in phase with the current I in the circuit LC.

In order to show the relations between the various factors as illustrated in the drawing I have chosen the following additional symbols:

f=frequency of the alternating potential source E_o.

F=frequency of oscillation of circuit LC

m=multiplication factor

T_o=cyclic period of source E_o

T=cyclic period of current I

t=duration of an impulse of current I_o.

The multiplication factor m represents the relation between the frequency of source E_o and the frequency of oscillation of circuit LC from which it follows that—

$$(1)\quad F=mf$$

The cyclic period is the reciprocal of the frequency so therefore

$$(2)\quad F=\frac{1}{T}$$

and

$$(3)\quad f=\frac{1}{T_o}$$

I control the duration t of the impulses of current I_o so that t is equal to one-half cycle of current I, hence

$$(4)\quad T=2t$$

By substituting Equations (2) and (3) in Equation (1) I obtain

$$(5)\quad \frac{1}{T}=m\times\frac{1}{T_o}$$

and substituting t for T as in Equation 4, I obtain

$$(6)\quad \frac{1}{2t}=\frac{m}{T_o}$$

or

$$(7)\quad T_o=2mt$$

that is, the cyclic period of the source E_o is equal to twice the multiplication factor times the duration of an impulse of I_o. As there is one impulse for time t for each cyclic period T_o, it follows that the interval between the impulses equals

$$(8)\quad T_o-t=(2m-1)t$$

Now referring to Fig. 1 of the drawing, I have schematically illustrated the relations between the currents I_o and I for four conditions of operation of the circuits of my invention.

The curves in bracket 20 show the relation between I_o and I when the multiplication factor m equals 1. In this case the frequencies of the source E_o and of the circuit LC are equal.

In bracket 21 I have illustrated the current relations when m equals 2. Under this condition of operation the frequency of the circuit LC is twice the frequency of source E_o and the interval between impulses I_o is $3t$, which is obtained by substituting the value of 2 for m in Equation (8). Similarly in bracket 22 illustrating the current relations when m equals 3, F equals $3f$ and the interval between impulses is $5t$; and similarly in bracket 23 I have illustrated the current relations when m equals 4; then F equals $4f$ and the interval between impulses is $7t$.

It is evident, therefore, from the foregoing description and equations that if the circuit LC is so proportioned as to have a natural frequency which is substantially a multiple of the frequency of the source E_o, the frequency of said source will control the frequency of the circuit LC by means of the recurring impulses I_o which are impressed on the circuit LC, that is, if the natural frequency of the circuit LC is very nearly but not exactly a multiple of the frequency of the source E_o, the recurring impulses I_o, which supply the energy to maintain oscillations in the circuit LC, will maintain the frequency of LC at an exact multiple of the frequency of the source E_o.

Such properly timed current impulses I_o can be readily obtained from a source of alternating potential, as previously described, by using a selected portion of each cycle of said alternating potential. This result can be accomplished by the use of many types of rectifiers such as glow discharge, thermionic, mercury arc, dry contact rectifiers, etc.

When the rectifier R is a glow discharge tube as illustrated at 14 in Fig. 3, the frequency multiplication is accomplished in a very simple manner because the voltage across the glow discharge tube must reach a certain value before the tube will pass current. For instance, in Fig. 3 I have illustrated a glow discharge tube 14 containing a suitable gas and the electrodes 10 and 12. Suppose the ignition voltage of such a rectifier is 80 volts as indicated in Fig. 3, then no current can flow for voltages less than 80 volts and the current passing through the tube 14 is limited to the current produced by voltages in excess of 80 volts. By selecting the proper voltage for the alternating potential E_o, the duration t of the impulses I_o may be controlled.

In Fig. 4 of the drawing, I have illustrated a rectifier comprising an ordinary thermionic two element tube 15 having a hot cathode or filament 16 and an anode or plate 17. The source of potential 18 supplies the energy to heat the filament 16. The source of potential 19 opposes the voltage from the source E_o and until the voltage of E_o becomes greater than the voltage of source 19 no current flows into the circuit LC. I use the source of potential 19 in connection with rectifiers which do not have a definite ignition voltage such as the glow discharge tube illustrated in Fig. 3.

It is believed that the principles of my invention will be clear, and while I have described my invention in its preferred embodiments, I desire that it be understood that modifications may be made and that no limitations upon my invention are intended other than are imposed by the scope of the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States is as follows:

1. In a frequency multiplication system a source of alternating current, a circuit adapted to oscillate at a frequency which is a multiple of the frequency of said source, a gaseous discharge tube interposed between said source and said circuit, means for fixing a critical point of potential above which unidirectional current impulses may be transferred from said source to said circuit through said gaseous discharge tube and below which critical point of potential transfer of energy is prevented, and means for limiting the duration of energy transfer to time intervals in which the current from the alternating source and the current of the multiple frequency are in phase with one another.

2. In a frequency multiplication system a resonant circuit adapted to oscillate at a desired frequency, a source of energy, a glow discharge tube connected between said source of energy and said circuit and controlling said energy to produce impulses for recurrently energizing said circuit at a frequency which is an aliquot part of the frequency of said resonant circuit, said glow discharge tube being adapted to pass said energy by ionization at predetermined potentials only.

3. In a frequency multiplication system a source of energy suitable for periodic shock excitation, a circuit adapted to oscillate at a desired frequency, said frequency being a harmonic of the periodicity of said shock excitation, a gaseous discharge tube interposed between said source and said circuit, means for fixing a critical point of potential above which unidirectional current impulses may be transferred from said source to said circuit through said gaseous discharge tube and below which critical point of potential transfer of energy is prevented, and means for limiting the duration of energy transfer to time intervals in any one of which not more than a half cycle of oscillations of said circuit is comprehended.

In testimony whereof I affix my signature.

AUGUST HUND.