Jan. 21, 1947. C. J. MADSEN 2,414,541

ELECTRONIC FREQUENCY MULTIPLIER

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Fig.1.

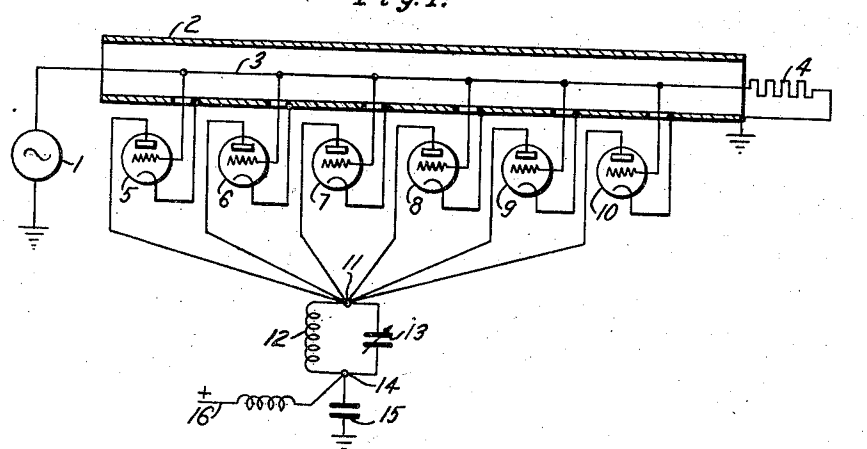



Fig.2.

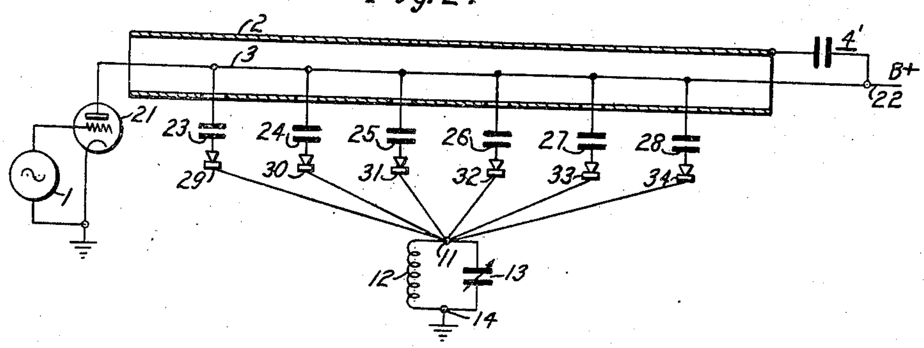
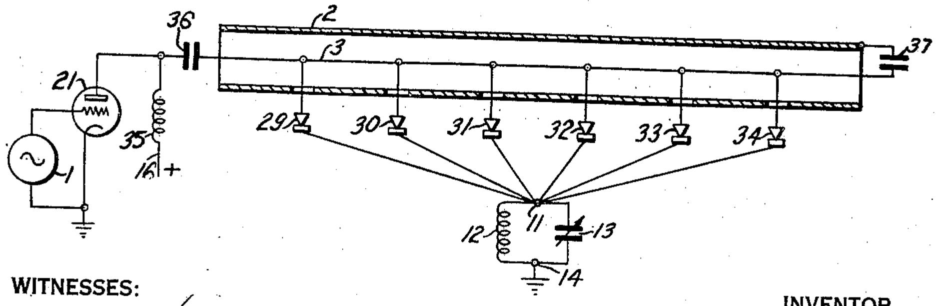



Fig.3.

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## ELECTRONIC FREQUENCY MULTIPLIER

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8 Claims. (Cl. 250—36)

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My invention relates to electronic frequency multipliers, and in particular to such frequency multipliers operating at very high frequencies.

Frequency multipliers employing electronic tubes are well known in the radio art, such devices employing grid controlled tubes in which a voltage of the fundamental frequency is employed on the control electrode of a tube which is operated under such conditions that it introduces considerable distortion of the wave shape being transmitted through it. The distorted wave contains substantial harmonics of the fundamental frequency. A resonant circuit connected to the tuned output may be tuned to one of these harmonics thereby furnishing for any desired use a current of the harmonic frequency to which it is resonant. However, it is, in practice found to be difficult to secure substantial amounts of power output when it is attempted to obtain higher harmonics than the second or third.

For many purposes it is desirable to obtain frequency multiplications of substantially higher order than those just mentioned. Furthermore, in operating with frequencies of extremely high ranges such, for example, as those commonly termed ultra short-wave, it is difficult to obtain resonant circuits having sufficiently high frequency if constructed with conventional elements of lumped inductance and capacity.

One object of my invention is, accordingly, to provide a new type of frequency multiplier adapted to produce with substantial amounts of power frequencies which are high harmonics of a fundamental wave.

Another object of my invention is to provide a means for producing output voltages which are of extremely high frequency.

Another object of my invention is to provide a method of multiplying the frequency of voltages lying within the ultra high frequency range.

Other objects of my invention will become apparent upon reading the following description taken in connection with the drawing, in which:

Figure 1 illustrates an apparatus capable of carrying out the principles of my invention;

Fig. 2 shows another type of apparatus capable of carrying out the principles of my invention; and

Fig. 3 shows a modified form of the apparatus shown in Fig. 2.

In accordance with my invention I employ a travelling wave along a transmission line to obtain a series of triggering voltage-impulses which produce a series of exciting impulses in a resonant circuit, the time intervals between successive impulses being equal to the periodic time of the high harmonic frequency which it is desired to produce.

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The mode of embodying this general principle in practical circuits will become apparent from the following detailed description of the drawing.

Referring specifically to Fig. 1, a source 1 which is preferably of the impulse type generating a voltage pulse of comparatively short duration and steep wave front has one terminal connected to ground and its other terminal connected to one side of a transmission line embodying distributed capacity and inductance; for example, a concentric line comprising a cylindrical conductor or sheath 2 having in its axis a central conductor or core 3 which is insulatingly supported. The side of the above mentioned transmission line other than that already mentioned as connected to the alternator 1 is connected to ground. When the distributed capacity between the central core 3 and the outside cylinder or sheath 2 and the distributed inductance inherent in the core 3 and sheath 2 provide a system in which the alternator 1 causes voltage waves of steep wave-front to travel from the end adjacent the alternator 1 to the more distant end. These waves travel with a definite velocity which is a function of such distributed inductance and capacity and which in practical cases is not far below the velocity of light. Preferably I interconnect the conductors 2 and 3 at the end remote from the alternator 1 with a resistance which equals the surge impedance of the line; that is to say, which is equal to

$$\sqrt{\frac{L}{C}}$$

where L is the inductance per unit length and C the capacitance per unit length of the line. The resistor 4 prevents any reflection of the travelling waves from the remote end of the line.

At points spaced apart by a distance such that the travelling wave impressed moves from one to its neighbor in a time equal to the periodic time of the current of high frequency which it is desired to produced, I connect leads to one side of the transmission line which are maintained insulated from the other side of the transmission line and connected to control electrodes of a plurality of electronic tubes 5, 6, 7, 8, 9 and 10. The length of such leads from the point of connection to the transmission line to the control electrode is made as nearly as possible the same for each tube. In the drawing I have shown for purposes of illustration six such tubes but any number may be employed.

One of the principal electrodes, for example, the cathode of each of the tubes 5 to 10 is connected to the other side of the transmission line 2, 3 from that to which the control electrodes are connected. Preferably these cathode connections are made by leads as nearly as possible equal in length to each other and are made to points as nearly as possible opposite in position to the points at which the control electrode connections are made.

The remaining principal electrode, for example, the anode of each of the tubes 5 to 10, is connected by leads as nearly the same in electrical length as possible to a common point 11 on a resonant circuit comprising an inductance 12 and a capacitance 13. Where extremely high frequency currents are to be derived, it may be desirable that the resonant circuit 12, 13 shall be of the transmission line type, for example, a quarter wave concentric line of the frequency of the current being produced. A point 14 on the resonant circuit 11, 12, 13, preferably symmetrically positioned on such circuit relative to the point 11, is connected through a capacitor 15 to ground, and is also connected to the positive terminal 16 of a direct current voltage source having its negative terminal grounded. The resonant period of the circuit 11, 12, 13, 14 should be made equal to the time required by the above mentioned travelling pulse to traverse the distance between successive lead tap-points on the line-side 3.

It is believed to be evident to those skilled in the art that the travelling wave along the transmission line 2, 3 will, in passing each of the connection points of the grid electrodes, produce a sudden voltage pulse on the control electrode of the corresponding tubes 5 to 10. Such a voltage pulse will in general be of short duration and will be amplified by the electronic tube to produce an exciting pulse on the resonant circuit 11, 12, 13, 14. While each one of the electronic tubes produces but a single exciting pulse, the combined effect of the exciting pulses thus produced in the resonant circuit will cause the latter to be maintained in oscillation at its resonant frequency. Preferably the time between generation of successive pulses by the generator 1 should be $n$ times the period of the tuned circuit 11, 12, 13, 14, where $n$ is the number of tubes connected to the transmission line.

It is desirable that the electronic tubes 5 to 10 shall be of a type drawing only small grid currents and power; in short, they should be voltage-operating devices. Where the power of the source 1 is small, these tubes should be of a type such as tetrodes or pentodes of small size which require relatively low input power. The control-grid bias-potential should be sufficiently high so that rectified grid current would be negligible. The screen grid and suppressor grid potentials should be high enough to keep the tube impedance low, thereby permitting a high degree of amplification.

Turning now to Fig. 2 which shows another modification of my invention, a voltage source 1 which is preferably of a type producing a pulse of short duration has one terminal grounded and its other terminal connected to the control electrode of a tube 21 of the electron type. One of the principal electrodes of the tube 21, for example, the cathode is connected to ground and its other principal electrode is connected to one side 3 of a transmission line having distributed capacity and inductance; for example, to the core of a transmission line of the concentric type. The other side 2 of the transmission line is connected to ground and is likewise connected through a capacitor 4′ to the above-mentioned side 3.

The generator 1 acting through the tube 21 will cause a voltage pulse of steep wave front to traverse the transmission line 2, 3 at each pulse of the source 1 similarly to the action which has been described in connection with Fig. 1. The line-side 3 may be connected to the positive terminal 22 of a voltage source of which the negative terminal is grounded and which is adapted to supply current to the anode of the tube 21.

At points spaced apart by such a distance that the above mentioned travelling wave will successively pass them at intervals equal to the periodic time of the high frequency current which it desired to produce by the apparatus are connected leads of substantially equal electrical length running to the upper plates of a series of capacitors 23 to 28. The other plates of the capacitors 23 to 28 are connected to homologous terminals of a series of rectifiers 29 to 34. The other terminals of the rectifiers 29 to 34 are connected to a common terminal 11 of a resonant circuit similar to the resonant circuit 11, 12, 13, 14 already described in Fig. 1. The point 14 on the resonant circuit 11, 12, 13, 14 is connected to ground. The electrical length, i. e., the traverse-time for electric pulses is preferably made the same for each of the paths from the line-side 3 through the capacitors and rectifiers above mentioned to the common terminal 11. The resonant circuit 11, 12, 13, 14 is tuned to the frequency which the apparatus is desired to produce. For purposes of illustration I have shown six capacitor-rectifier paths between the line-side 3 and the point 11 and in such a case it is preferable that the period between successive pulses of the source 1 shall be six times the period of the resonant circuit 11, 12, 13, 14. However, I have shown six such paths merely for purposes of illustration and the general statement may be made that if $n$ such paths are provided the period between successive pulses of the generator 1 should be $n$ times the period of the resonant circuit 11, 12, 13, 14. The wave front of the pulse produced by the generator 1 should be sufficiently steeped so that it is short compared with a half cycle of the resonant circuit 11, 12, 13, 14.

The rectifiers 29 to 34 are preferably so arranged that $1/n$ of the energy of the pulse is dissipated in each of the capacitor-rectifier paths between the line-sides 3 and the common terminal 11. The power absorption in the above-mentioned paths may, for example, be adjusted if the respective rectifiers 29 to 34 are of hot cathode high vacuum type by adjusting the temperature of their cathodes.

It is believed that the operation of the circuit above described in maintaining continuous oscillations in the resonant circuit 11, 12, 13, 14 will be evident to those skilled in the art without further explanation in view of that given for Fig. 1.

Fig. 3 shows a modification of the arrangement in Fig. 2 by which the capacitors 23 to 28 in Fig. 2 may be dispensed with. In Fig. 3 a source of pulsing voltage 1 similar to that used in other figures is connected to the control electrode of an electron tube 21 of which the cathode is connected to ground and to one terminal of the source 1. The anode of the tube 21 is connected through a choke coil 35 to the positive terminal 16 of a direct current source having its negative terminal grounded. A capacitor 36 is connected between the anode of the tube 21 and one side 3 of a transmission line having distributed inductance and capacity such, for example, as the concentric line already described in connection with Figs. 1 and 2. The other side 2 of the transmission line is connected through a capacitor 37 of large value to the line-side 3 at a point remote from the capacitor 36. The line-side 2 is grounded also at such remote point.

At a succession of points equally spaced by a distance equal to that traversed in a time equal to one period of the frequency which it is desired to derive, there are connected to the line-side 3 a series of leads which are, in turn, connected through energy absorbers such, for example, as rectifiers 29 to 34, to a common terminal 11 on the resonant circuit 11, 12, 13, 14 of the type already described in connection with Figs. 1 and 2. The point 14 is grounded.

As in the case of Figs. 1 and 2, I have shown six current-paths between the line-side 3 and the common terminal 11, and in such case the period intervening between the period of the pulses should be equal to six times the resonant currents of the circuit 11, 12, 13, 14. However, my invention is not limited to the use of six such paths but it may be said, in general, that if $n$ such paths are used the period between pulses of the source 1 should be $n$ times the resonant current of the circuit 11, 12, 13, 14.

While I have specifically mentioned rectifiers as the energy absorbing devices 29 to 34, any other form of energy absorber which may be regulated to absorb substantially $1/n$ times the energy of the pulse produced by the tube 21 for each such path may be substituted for such rectifiers. It is believed that the mode of operation of the arrangement just described in Fig. 3 to produce resonant currents in the circuit 11, 12, 13, 14 needs no further description in view of that already given in Figs. 1 and 2.

While I have described the specific embodiment of my invention, the principles thereof are of a broader application which in many ways will be evident to those skilled in the art.

I claim as my invention:

1. In combination, a transmission line having distributed inductance and capacity, means for causing a voltage pulse to traverse said line from one end to the other, a resonant circuit, means for connecting to a common point on said circuit a plurality of points on said transmission line spaced apart by a distance equal to the travel of a wave along said transmission line in one period of said resonant circuit.

2. In combination, a transmission line having distributed inductance and capacity, means for causing a voltage pulse to traverse said line from one end to the other, a resonant circuit, means for connecting to a common point on said circuit through paths of substantially equal electrical length a plurality of points on said transmission line spaced apart by a distance equal to the travel of a wave along said transmission line in one period of said resonant circuit.

3. In combination, a transmission line having distributed inductance and capacity, means for causing a voltage pulse to traverse said line from one end to the other, a resonant circuit, means for connecting to a common point on said circuit a plurality of points on said transmission line spaced apart by a distance equal to the travel of a wave along said transmission line in one period of said resonant circuit, said voltage pulse having a wave front which is abrupt compared with one-half cycle of said resonant circuit.

4. In combination, a transmission line having distributed inductance and capacity, a resistor equal in value to the surge impedance of said line interconnecting the sides thereof at one end, means for causing a voltage pulse to traverse said line from the end opposite to said resistor, a series of current-paths connected to one side of said line at equally spaced points, and terminating at a common point on a resonant circuit, a symmetrically disposed point on said resonant circuit being connected to the other terminal of said means through a path of low impedance, each said current path embodying a pair of principal electrodes associated with a control electrode connected to one of said spaced points, the electrical length of said current paths being substantially equal, the period between successive pulses of said source being substantially equal to the product of the periodic time of said resonant circuit by the number of said current paths.

5. In combination, a transmission line having distributed inductance and capacity, means for short circuiting one end of said line for the frequency of current applied thereto, a source of voltage pulses of steep wave front, a tube having principal electrodes and a control electrode, said control electrode being connected to one terminal of said source and one of its principal electrodes being connected to the other terminal of said source, means for supplying energizing voltage to the other principal electrode of said tube, means for connecting said other principal electrode to one side of said line through a path of low impedance, a resonant circuit having one point connected to the first mentioned terminal of said source, and a plurality of current paths connecting a second point on said resonant circuit to equally spaced points along one side of said transmission line, the period between pulses of said source being $n$ times the period of said resonant circuit where $n$ is the number of said current paths.

6. In combination, a transmission line having distributed inductance and capacity, means for short circuiting one end of said line for the frequency of current applied thereto, a source of voltage pulses of steep wave front, a tube having principal electrodes and a control electrode, said control electrode being connected to one terminal of said source and one of its principal electrodes being connected to the other terminal of said source, means for supplying energizing voltage to the other principal electrode of said tube, means for connecting said other principal electrode to one side of said line through a path of low impedance, a resonant circuit having one point connected to the first mentioned terminal of said source, and a plurality of current paths connecting a second point on said resonant circuit to equally spaced points along one side of said transmission line, the period between pulses of said source being $n$ times the period of said resonant circuit where $n$ is the number of said current paths, each said current path containing a rectifier.

7. In combination, a transmission line having distributed inductance and capacity, means for short circuiting one end of said line for the frequency of current applied thereto, a source of

voltage pulses of steep wave front, a tube having principal electrodes and a control electrode, said control electrode being connected to one terminal of said source and one of its prinsipal electrodes being connected to the other terminal of said source, means for supplying energizing voltage to the other principal electrode of said tube, means for connecting said other principal electrode to one side of said line through a path of low impedance, a resonant circuit having one point connected to the first mentioned terminal of said source, and a plurality of current paths connecting a second point on said resonant circuit to equally spaced points along one side of said transmission line, the period between pulses of said source being $n$ times the period of said resonant circuit where $n$ is the



number of said current paths, each said current path containing a rectifier in series with a capacitor.

8. In combination, a transmission line having distributed inductance and capacity, means for causing a voltage pulse to traverse said line from one end to the other, a resonant circuit, means for connecting to a common point on said circuit a plurality of points on said transmission line spaced apart by a distance equal to the travel of a wave along said transmission line in one period of said resonant circuit, only a single said voltage pulse being present at any one time between the first and last of said plurality of points.

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