

July 6, 1943.

A. L. NELSON

2,323,672

FREQUENCY MULTIPLIER

Filed Jan. 18, 1940

2 Sheets-Sheet 1

FIG. 1

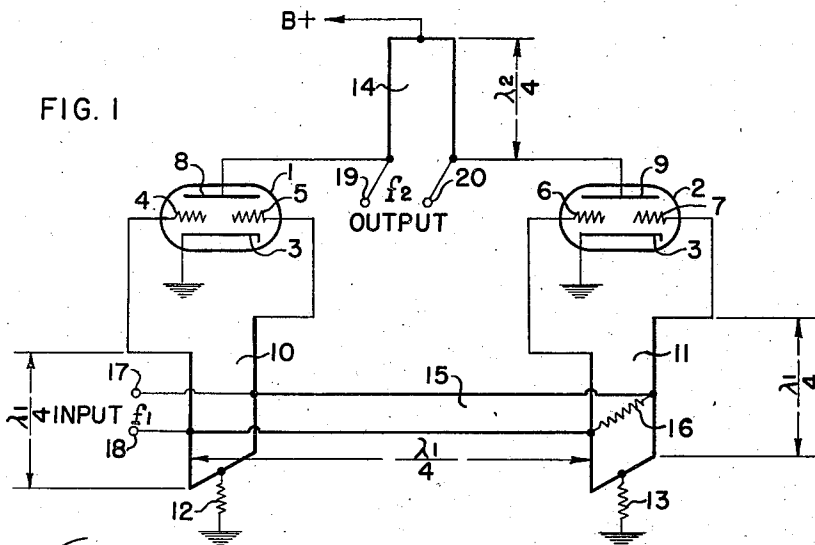
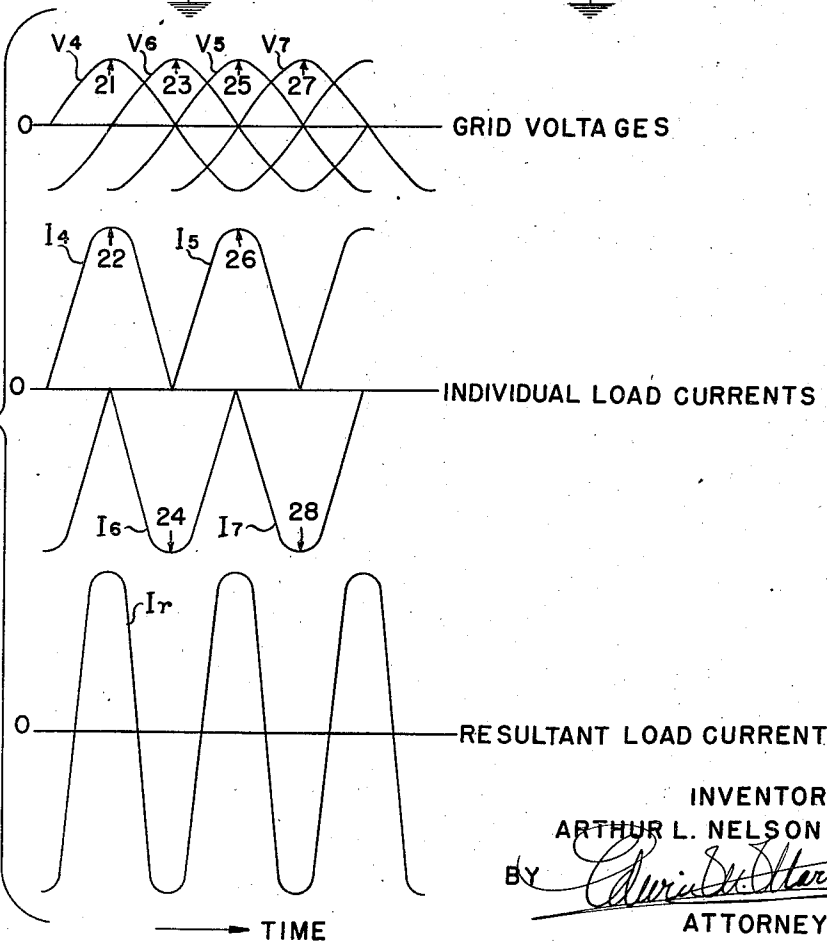


FIG. 2



INVENTOR
ARTHUR L. NELSON
BY *Arthur L. Nelson*
ATTORNEY

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FIG. 3

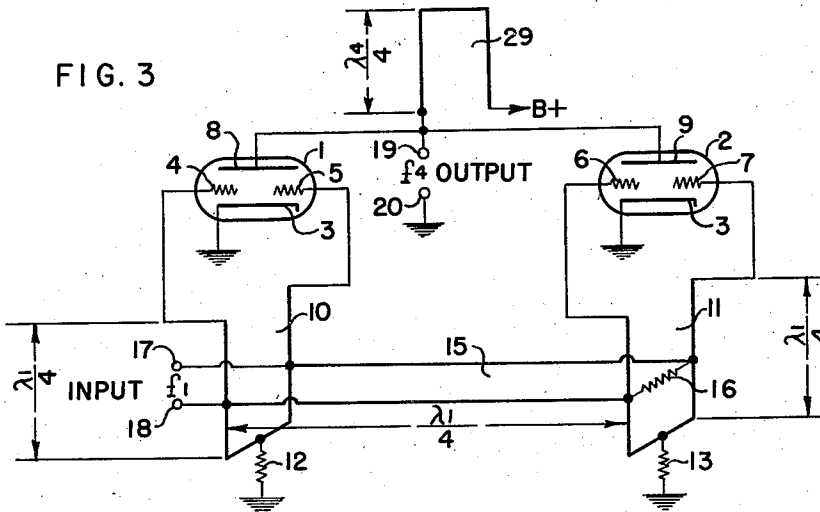
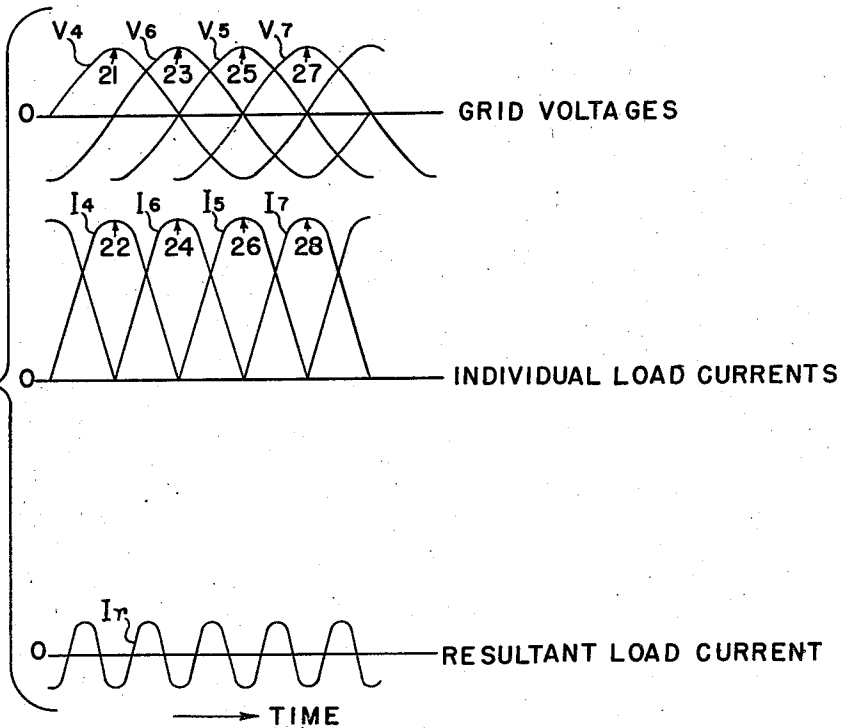


FIG. 4



INVENTOR
ARTHUR L. NELSON
BY *Arthur L. Nelson*
ATTORNEY

UNITED STATES PATENT OFFICE

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FREQUENCY MULTIPLIER

Arthur L. Nelson, Fort Wayne, Ind., assignor to
Farnsworth Television and Radio Corporation,
a corporation of Delaware

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11 Claims. (Cl. 250—36)

This invention relates to frequency multipliers, and particularly to means for multiplying high and ultra-high frequencies.

Frequency multiplier arrangements of the prior art have generally operated by utilizing the non-linear relation which exists between the grid voltage and plate current, or the non-linear relation between the grid voltage and grid current, of a vacuum tube to produce harmonics of the impressed signal. The output currents in such arrangements include components of the desired frequency or frequencies which are selected by suitable means, such as sharply tuned filters. Such methods of frequency multiplication are inherently inefficient, complicated and expensive, and moreover are incapable of providing output signals of substantially the same wave form as that of the impressed signal.

It will be understood that where, in this specification and the appended claims, the word "signal" is used, reference is made to any useful series of electrical variations regardless of wave form or periodicity; and that "wave length" is used to mean the wave length of the fundamental frequency if harmonics are also present.

The present invention is directed to the solution of the problem of providing frequency multiplication without the disadvantages of arrangements for this purpose heretofore provided.

The primary object of the present invention, therefore, is to provide an improved method of and means for effecting frequency multiplication characterized by simplicity and high efficiency.

A further object of the invention is to provide a frequency multiplier, the efficiency of which becomes increasingly relatively greater than that of prior-art devices as the frequency of the impressed signal is raised.

In accordance with the present invention, there is provided a frequency multiplier which comprises signal repeating means adapted to repeat portions of a signal impressed on them and having an input circuit. Means are provided for so connecting the input circuit with the repeating means as to effect a plurality of applications of a signal, which is impressed upon the input circuit, to the repeating means, each with a predetermined different relative phase. An output circuit for the repeating means is also provided for combining the repeated signal portions.

In one approved embodiment of the invention, the frequency multiplier comprises a pair of similar multielement vacuum tubes. An individual input circuit is provided for each of these tubes, consisting preferably of a single transmission line,

A phase-shifting means, preferably comprising a transmission line, connects the individual input circuits, and the main input circuit for the multiplier device is connected thereto. The output circuit preferably includes a single transmission line. In such a multiplier, employing a single pair of vacuum tubes, frequency doubling or frequency quadrupling is readily obtained at the option of the user without any changes in the input circuits, and with only a small change in the output circuit arrangement and constants. Higher orders of multiplication than four times are also readily possible, in accordance with the invention, by simply employing additional tubes and making minor adjustments in the circuit constants.

It will be understood that, at the lower frequencies, ordinary resonant circuits employing lumped reactances may be substituted for the transmission lines between the grids of each tube, and that the phase-shifting means connecting the tube input circuits may be other than a transmission line, without departing from the scope of the present invention.

For a better understanding of the invention, together with other and further objects thereof, reference is made to the following description, taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

In the accompanying drawings:

Fig. 1 is a schematic circuit diagram of a frequency multiplier, in accordance with the present invention, arranged for frequency doubling;

Fig. 2 is a graph representing certain operating characteristics of the multiplier of Fig. 1;

Fig. 3 is a schematic circuit diagram of a modified form of the multiplier of Fig. 1, arranged for frequency quadrupling; and

Fig. 4 is a graph representing certain operating characteristics of the device of Fig. 3.

It will be understood that the dimensions shown in Figs. 1 and 3 of the drawings are electrical dimensions and do not necessarily indicate the physical size of the components employed.

Referring now more particularly to Fig. 1 of the drawings, there is shown schematically a frequency multiplier embodying the present invention in a preferred form. In general, the frequency multiplier includes two vacuum tubes 1 and 2 which are substantially identical. Each of tubes 1 and 2 has a cathode 3 which may be of either the filament or indirect heater type. Conventional means may be employed for heating cathodes 3, these means not being shown in

the drawings to avoid unnecessary complication thereof. Tubes 1 and 2 also respectively include grids 4, 5 and 6, 7 which are substantially identical but which are designated by different reference numerals for convenience in describing the operation of the system. Anodes 8 and 9 are provided for the tubes 1 and 2, respectively, and are also substantially identical but are designated by different reference numerals for convenience.

Cathodes 3 may be grounded and grids 4 and 5 of tube 1 may be connected by means of transmission line 10, and grids 6 and 7 of tube 2 may be connected by means of a similar transmission line 11, as shown. These lines 10 and 11 preferably have effective lengths equal to one-quarter the wave length of the input signal to be applied, thereby providing a high-impedance input circuit for each tube whereby a maximum input-signal voltage may be impressed upon the grids of the tubes. The center points of transmission lines 10 and 11 may be grounded through resistors 12 and 13, as shown. Anodes 8 and 9, respectively, of tubes 1 and 2 are connected by means of transmission line 14 or other suitable load impedance. The effective length of line 14 is preferably equal to one-quarter the wave length of the output signal and its mid-point may be connected to a source of positive operating potential as indicated at B+, as shown.

Transmission lines 10 and 11, respectively, forming the individual input circuits of tubes 1 and 2, are preferably connected together by means of a transmission line 15, the effective length of which is preferably equal to one-quarter the wave length of the input signal to be applied. Transmission line 15 is connected at its opposite ends, preferably near the low-impedance ends of transmission lines 10 and 11, respectively, in order to minimize the effect of resistor 16 which terminates line 15 and the effect of the excitation source, not shown, upon the input circuits of tubes 1 and 2. It will be understood, however, that line 15 may be connected at higher impedance points on lines 10 and 11, or directly to grids 4, 5 and 6, 7 if desired, without departing from the scope of the invention. It will also be understood that line 15 may have a different effective length in order to provide a phase shift other than 90 degrees.

The signal to be multiplied is applied to input terminals 17 and 18, and its frequency is designated in the drawing as f_1 . The output signal appears across output terminals 19 and 20, its frequency being designated in the drawing by f_2 .

The operation of the device of Fig. 1 may be readily understood by reference to the curves of Fig. 2. These curves are all plotted to the same time base, with the time increasing to the right, as indicated. Curve V_4 indicates the alternating voltage applied to grid 4 of tube 1, corresponding in both frequency and wave form to the input voltage applied to the terminals 17 and 18. Curve V_6 indicates the alternating voltage applied to grid 6 of tube 2. It will be observed that curve V_6 lags curve V_4 by 90 degrees, due to the quarter-wave transmission line 15 between the input circuits of tubes 1 and 2. Curves V_5 and V_7 indicate the voltages on the grids 5 and 7, respectively, which are 180 degrees out of phase with the voltages on grids 4 and 6. Curves I_4 and I_6 indicate the alternating load current of tube 1 resulting from the voltages on grids 4 and 5, respectively; and curves I_6 and I_7 represent the alternating load current of tube 2 resulting from the voltages on grids 6 and 7, respectively. Curve

I_r represents the resultant alternating load current of both tubes 1 and 2 and hence corresponds with the output signal of the multiplier.

In operation, a voltage of frequency f_1 is applied to terminals 17 and 18 from any suitable source of excitation. Let it be assumed that, at a given instant, grid 4 is at the peak of its positive half-cycle, as indicated by the point 21 of curve V_4 . A resulting current flows in the anode circuit of tube 1, its peak value being indicated by the point 22 of curve I_4 . Because of the 90-degree phase shift due to quarter-wave transmission line 15, 90 degrees later the voltage on grid 6 reaches the peak of its positive half-cycle, as indicated by the point 23 of curve V_6 . This in turn produces a corresponding current in the anode circuit of tube 2 which, with respect to the circulating current in line 14, is opposite in direction to that flowing in the anode circuit of tube 1, due to the fact that the anodes of the tubes 1 and 2 are connected in series with the load or output circuit 14. Hence, the maximum negative value of this current is indicated by the point 24 of curve I_6 .

Because grids 4 and 5 are connected to the opposite terminals of transmission line 10, they are of opposite polarity at any given instant and are, respectively, in phase quadrature relative to grids 6 and 7 due to the 90-degree phase shift of transmission line 15. Since the voltage on grid 5 is 180 degrees out of phase with the voltage on grid 4, grid 5 reaches its maximum positive potential at the end of the next 90-degree time period, as indicated by the point 25 of curve V_5 , and a corresponding current flows in the anode circuit of tube 1, the maximum amplitude of which is indicated by the point 26 of curve I_5 . Again, quarter-wave transmission line 15 causes grid 7 to reach its maximum positive potential 90 degrees later than grid 5, as indicated by point 27 of curve V_7 , which in turn produces a current in the anode circuit of tube 2, the maximum negative amplitude of which is indicated by point 28 of curve I_7 .

By taking an algebraic sum of the instantaneous currents represented by curves I_4 , I_5 , I_6 and I_7 , a resultant current is obtained such as is represented by curve I_r . Curve I_r , as stated above, represents the output current of the multiplier, that is, the resultant load current due to tubes 1 and 2. This current, as will be apparent, has twice the frequency of, but is substantially of the same wave form as, the voltage represented by curve V_4 , which corresponds in both frequency and wave form to the input signal. Hence, the output signal of the multiplier of Fig. 1 has double the frequency of the input signal and is of substantially the identical wave form.

Referring now to Fig. 3, in which like components are designated by the same reference numerals as were used in Fig. 1, it will be seen that the vacuum tubes, their individual input circuits, and the means for connecting these input circuits, are the same in Fig. 3 as in Fig. 1. Fig. 3 differs from Fig. 1 chiefly in the arrangement of the output circuit. In Fig. 3, anodes 8 and 9 of tubes 1 and 2, respectively, are connected together and are connected to a source of positive operating potential designated by B+, by means of a transmission line 29. The line has an effective length equal to one-fourth the wave length of the output signal. One output terminal 19 of this arrangement is connected to anodes 8 and 9, and the other output terminal 20 is effectively grounded, as shown. As indicated in the

drawing by f_4 , the frequency of the output signal of this arrangement is four times that of the input signal.

In Fig. 4, which graphically shows the operating characteristics of the device of Fig. 3, curves V_4 , V_6 , I_1 and I_5 are identical with the correspondingly designated curves of Fig. 2, and indicate, respectively, the alternating voltage applied to grid 4, the alternating voltage applied to grid 6, the alternating anode current of tube 1 due to the voltage applied to grid 4, and the alternating load current of tube 1 due to the voltage applied to grid 5. The alternating load current of tube 2 due to the voltage applied to grid 6 is indicated by curve I_6 , and the alternating load current of tube 2 due to the voltage applied to grid 7 is indicated by curve I_7 . Since the anodes 8 and 9 of tubes 1 and 2 in Fig. 3 are connected in parallel, the anode currents of these tubes flow in the same direction in the load, and the curves I_6 and I_7 lie on the same side of the base line as the curves I_4 and I_5 .

The operation of the device of Fig. 3, so far as the time relations of the grid voltages and of the individual plate currents are concerned, is identical with that of the device of Fig. 1.

The resultant load current of the device of Fig. 3 has the form indicated by curve I_r of Fig. 4. This curve is obtained by taking the algebraic sum of the instantaneous currents represented by curves I_4 , I_5 , I_6 and I_7 of Fig. 4. It will be seen that curve I_r , which represents the output current of the multiplier, has substantially the same wave form as curve V_4 , which corresponds in both frequency and wave form to the input signal, but that the frequency of the output current is four times as great.

It will be understood that vacuum tubes 1 and 2, shown in Figs. 1 and 3 of the drawings, may each be replaced by a pair of ordinary triodes without departing from the scope of the present invention. In this case, the cathodes and anodes of each pair of triodes would be connected together, and the grids connected as shown in the drawings. In practicing the invention, the only requirement as to the vacuum tubes to be employed, other than the usual conditions imposed by the frequency range in which the device is to operate, is that two separate grids be provided which exercise equal control over a single anode circuit. In one successful embodiment, Elmac type Twin-30 tubes were used, the only modification of the standard construction being to connect the plates together internally.

The frequency ranges in which the devices of the present invention may be used are limited principally by the interelectrode capacitances of the vacuum tubes employed. No neutralization means are necessary for the stable operation of the device of the present invention. This permits the use of twice as many tubes with the same effective input capacitance as similar tubes when used in a conventional neutralized circuit. Experiments prove that the new device is practical and admirably suited for multiplying input frequencies up to the order of 100 megacycles, and it is noted that the advantage of the new device over prior-art devices becomes greater as the frequency is increased toward and into the ultra-high region. This is due to the fact that frequency multipliers of the prior art become increasingly inefficient as the frequency is raised because of the inherent output circuit capacitance, whereas in multipliers in accordance with the present invention the detrimental

effects of this output capacitance are greatly minimized.

The efficiency of the frequency multiplier of the present invention is higher than that previously realized, and by proper design may be made to equal and even surpass that of an ordinary class C amplifier. It will be understood by those skilled in the art that, in practice, the wave form of the signal applied to the grids, and hence the wave form of the output signal, may be considerably modified from the forms shown in Figs. 2 and 4 with resultant substantial improvement in efficiency. Such modification, for example, may be realized by so biasing the vacuum tubes that plate current flows only during a portion of the positive grid swings, in accordance with the customary Class C mode of operation.

While there has been described what is at present considered the preferred embodiment of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What I claim is:

1. A frequency multiplier comprising a signal input circuit, a plurality vacuum-tube signal repeating means, each having an anode and a plurality of control electrodes and being adapted to repeat portions of a signal impressed thereon, a plurality of separate input circuits individually connected to said control electrodes for applying a signal to the control electrodes of each of said repeating means in opposite polarity, phase-shifting means connecting said separate input circuits to said multiplier signal input circuit for successively applying a signal to said repeating means in phase quadrature, and means connected to the anodes of said repeating means for combining signal portions repeated by said repeating means.

2. A frequency multiplier comprising a pair of vacuum tubes each having two grids and one anode, an input circuit, means connecting said input circuit to the grids of said tubes for applying a signal to the grids of each of said tubes in opposite polarity and to the corresponding grids of the different tubes in phase quadrature, and means connected to said anodes for combining signal portions repeated by said vacuum tubes.

3. A frequency multiplier for multiplying the frequency of an input signal, comprising a pair of vacuum tubes each having two grids and one anode, an input circuit, a transmission line having an effective length equal to one-quarter the wave length of said input signal connected to said input circuit, means connecting the grids of one of said tubes to opposite sides of said transmission line at one end thereof, means connecting the grids of the other of said tubes to opposite sides of said transmission line at the other end thereof, and a common output circuit connected to said anodes.

4. A frequency multiplier for multiplying the frequency of an input signal, comprising a pair of vacuum tubes each having two grids and one anode, an input circuit, a first transmission line having an effective length equal to one-quarter the wave length of said input signal, second and third transmission lines respectively for each of said tubes having an effective length equal to one-quarter the wave length of said input signal connecting the grids of said tubes to the op-

posite ends respectively of said first transmission line at opposite sides thereof, and a common output circuit connected to said anodes.

5. A frequency multiplier comprising a pair of vacuum tubes each having two grids and one anode, an individual input circuit for each of said tubes connected to the grids thereof, phase-shifting means connected between relatively low-impedance points of said individual input circuits, a common input circuit connected to said phase-shifting means whereby a signal may be applied to the grids of each tube in opposite polarity and to corresponding grids of the different tubes in phase quadrature, and means connected to said anodes for combining signals repeated by said vacuum tubes.

6. A frequency multiplier for multiplying the frequency of an input signal, comprising a pair of vacuum tubes each having two grids and one anode, an individual input circuit for each of said tubes connected to the grids thereof, phase-shifting means connected between relatively low-impedance points of said individual input circuits, said phase-shifting means comprising a transmission line having an effective length equal to one-quarter the wave length of said input signal, a common input circuit connected to said phase-shifting means whereby a signal may be applied to the grids of each tube in opposite polarity and to corresponding grids of the different tubes in phase quadrature, and a common output circuit connected to said anodes.

7. A frequency doubler for providing an output signal, having twice the frequency of an input signal comprising a pair of vacuum tubes each having two grids and one anode, an individual input circuit for each of said tubes connected to the grids thereof, phase-shifting means linking said individual input circuits, said phase-shifting means comprising a transmission line having an effective length equal to one-quarter the wave length of said input signal, a common input circuit connected to said phase-shifting means whereby an input signal may be applied to the grids of each tube in opposite polarity and to corresponding grids of the different tubes in phase quadrature, and a common output circuit connected to said anodes, said output circuit comprising a transmission line having an effective length equal to one-quarter the wave length of said output signal.

8. A frequency quadrupler for providing an output signal having a frequency four times the frequency of an input signal, comprising a pair of vacuum tubes each having two grids and one anode, an individual input circuit for each of said tubes connected to the grids thereof, phase-shifting means linking said individual input circuits, said phase-shifting means comprising a transmission line having an effective length equal to one-quarter the wave length of said input signal, a common input circuit connected to said phase-shifting means whereby an input signal may be applied to the grids of each tube in opposite polarity and to corresponding grids of the different tubes in phase quadrature, and a com-

mon output circuit connected to said anodes, said output circuit including a transmission line having an effective length equal to one-quarter the wave length of said output signal.

9. A frequency multiplier comprising a signal repeater including a plurality of repeating means each having a plurality of control elements and unipotential anode means and being adapted to repeat portions of a signal impressed on said control elements, an input circuit for said multiplier, means so connecting said input circuit with said control elements as to effect applications of a signal impressed on said input circuit to the control elements of one of said repeating means with different phases and to the corresponding control elements of a different repeating means with different phases, the phases of the signals applied to corresponding control elements of said first-named and said second-named repeating means being different by the same predetermined amount, and means connected to the anode circuits of said repeating means for combining repeated signal portions.

10. A frequency multiplier comprising a signal repeater including a plurality of repeating means each having a plurality of control elements and unipotential anode means and being adapted to repeat portions of a signal impressed on said control elements, an input circuit for said multiplier, means including phase-shifting means so connecting said input circuit with said control elements as to effect applications of a signal impressed on said input circuit to the control elements of one of said repeating means with different phases and to the corresponding control elements of a different repeating means with different phases, the phases of the signals applied to corresponding control elements of said first-named and said second-named repeating means being different by the same predetermined amount, and means connected to the anode means in said repeating means for combining repeated signal portions.

11. A frequency multiplier comprising a signal repeater including a plurality of repeating means each having a plurality of control elements and unipotential anode means and being adapted to repeat portions of a signal impressed on said control elements, an input circuit for said multiplier, means including a transmission line so connecting said input circuit with said control elements as to effect applications of a signal impressed on said input circuit to the control elements of one of said repeating means with different phases and to the corresponding control elements of a different repeating means with different phases, the phases of the signals applied to corresponding control elements of said first-named and said second-named repeating means being different by the same predetermined amount, and a common output circuit for said repeating means for combining repeated signal portions.

ARTHUR L. NELSON.