Feb. 8, 1944. J. L. HATHAWAY 2,341,040

FREQUENGY MODULATOR

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Fig. 1

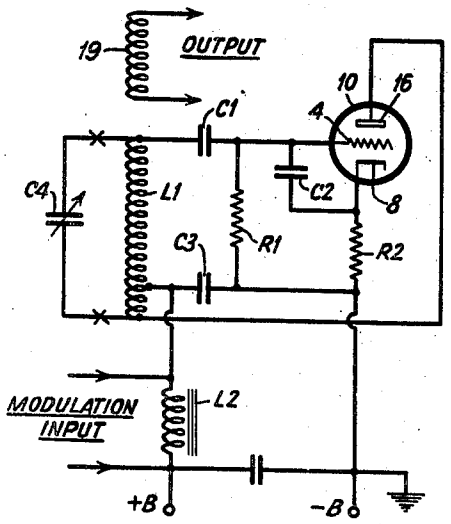


Fig. 2

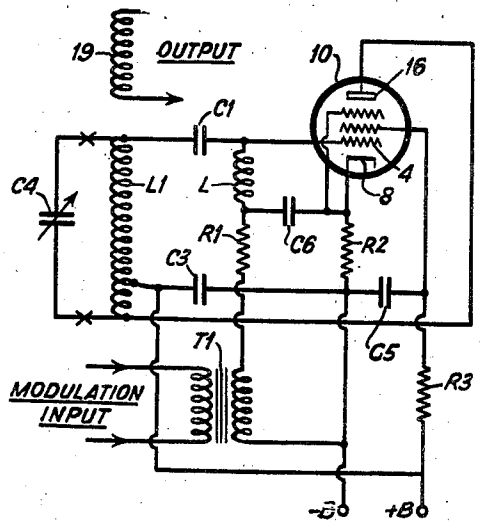
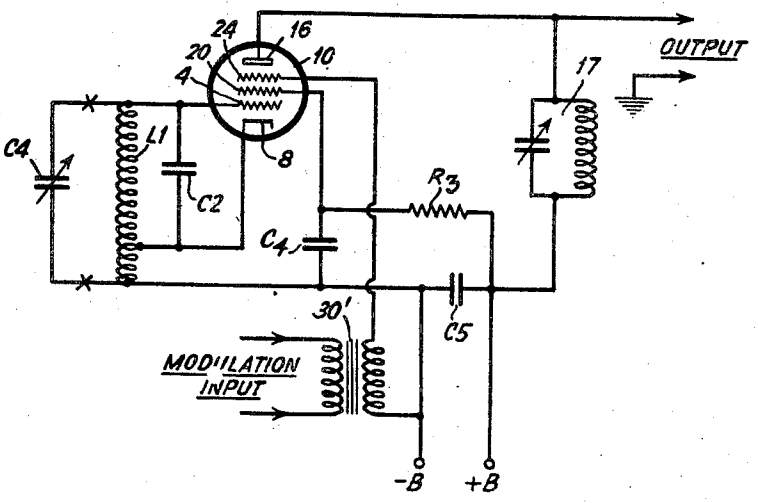


Fig. 3a



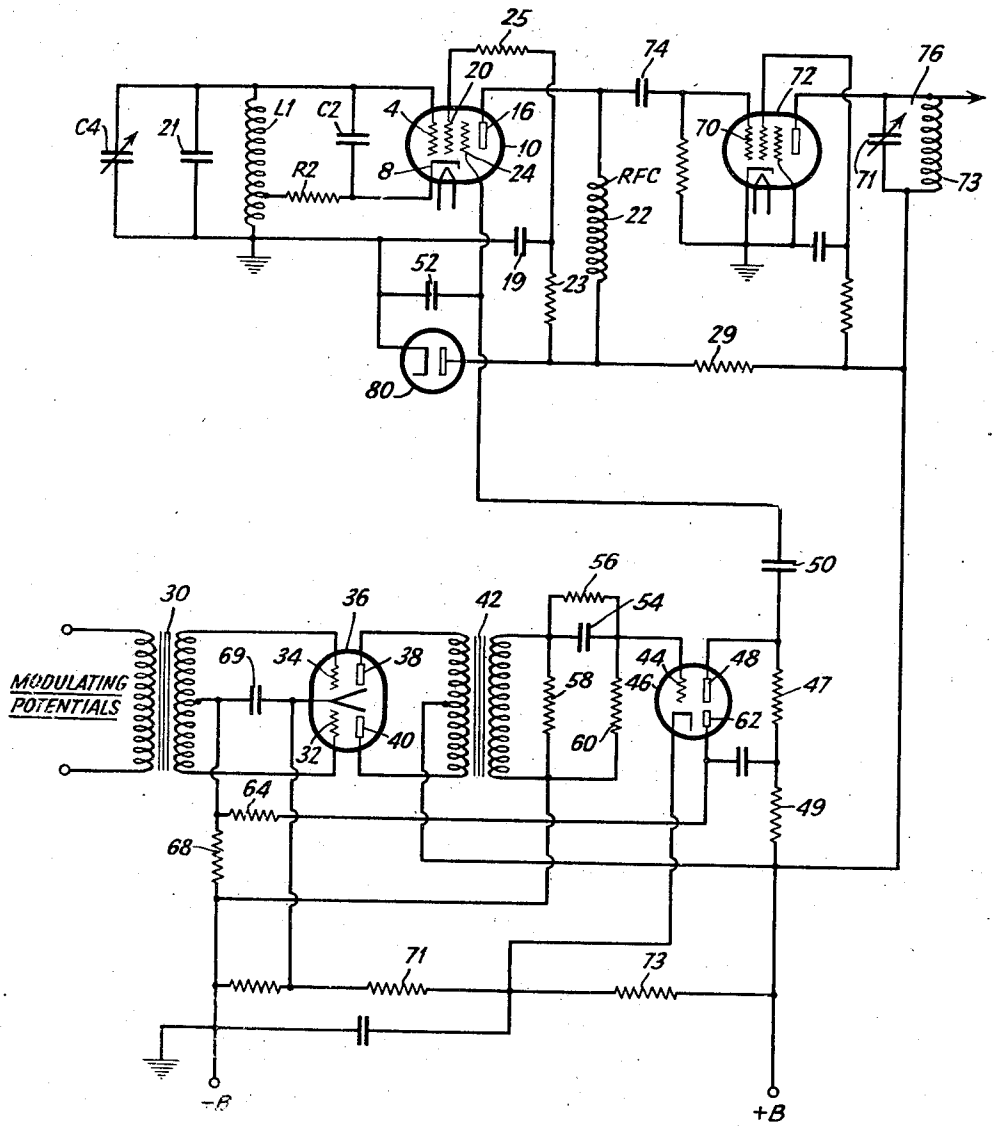
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Feb. 8, 1944. J. L. HATHAWAY 2,341,040

FREQUENCY MODULATOR

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Fig. 3



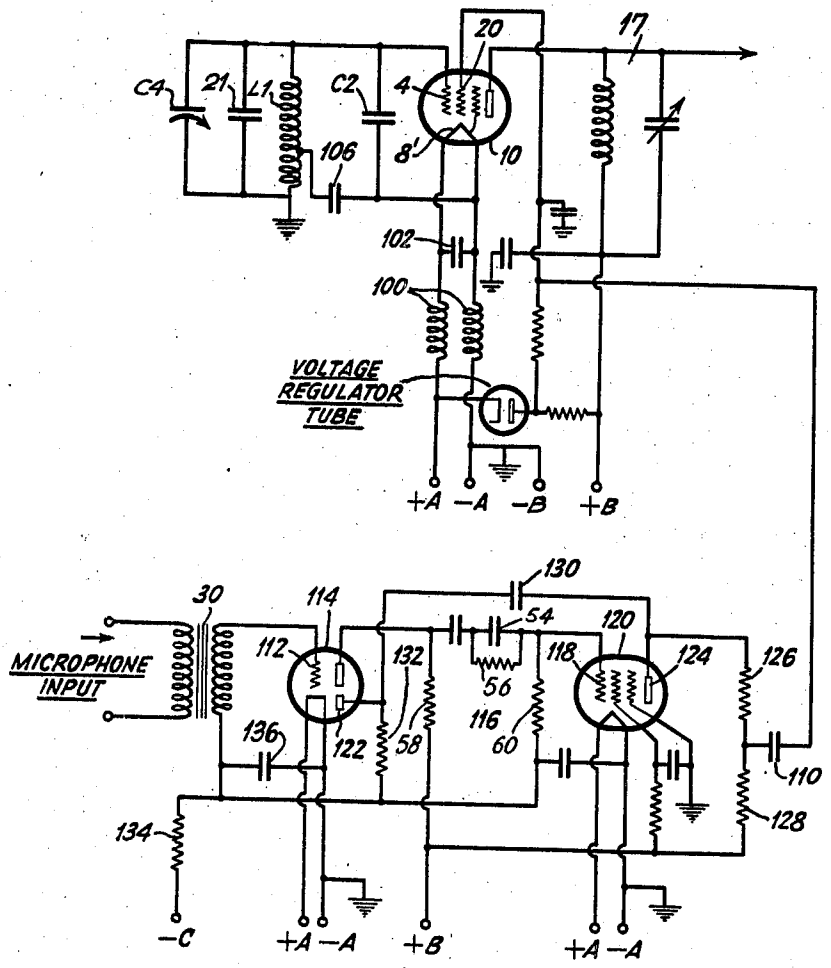
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FREQUENCY MODULATOR

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Fig. 4



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UNITED STATES PATENT OFFICE

2,341,040

FREQUENCY MODULATOR

Jarrett Lewis Hathaway, Manhasset, N. Y., assignor to Radio Corporation of America, a corporation of Delaware

Application November 22, 1940, Serial No. 366,546

14 Claims. (Cl. 179—171.5)

This application concerns a new and improved method of and means for modulating the frequency of oscillatory energy in accordance with control potentials. In the method and means of the application an oscillator has its frequency of operation controlled in accordance with changes in the modulating voltage. The oscillator may be of the electron-coupled type or other types of oscillators may be used.

In my system, oscillation generation, modulation, and, if desired, frequency multiplication, is accomplished in a single tube.

The principle involved here is the same as that involved in Townsend's United States application #346,309, filed July 19, 1940, now U. S. Patent No. 2,288,375, dated June 30, 1942. In the said Townsend application, the controlled reactance comprised a separate tube coupled to the generator tube to control the reactance in the generator circuits. In the system of my present application, a single tube is arranged for the production of oscillations and the provision of a controllable reactance, inductive or capacitive, to modulate the frequency of the oscillations generated.

This frequency modulated oscillator operates on the principle of capacity or inductance controlled by tube transconductance. That is, the grid-to-cathode impedance with externally connected impedances, is effectively raised by degeneration from the cathode circuit. The same tube which acts to degenerate the input impedance also acts regeneratively to produce self oscillations. Thus, an oscillating tube may be controlled in frequency by shifting the potential of any or all of its elements to produce a shift of transconductance.

Although, as will be seen, my system is simple in nature and circuit arrangement, it has proved very stable in operation. Although I make no use of special apparatus such as automatic frequency control means, compensating reactances, etc., my system has been found to operate over a period of six or eight hours with a total maximum deviation of considerably less than 1500 cycles when operating at a frequency of 39.64 megacycles. This is well within the requirements of the F. C. C.

In describing my invention, reference will be made to the attached drawings wherein:

Figs. 1 to 4, inclusive, each shows a frequency modulation system arranged in accordance with my invention. In Fig. 1, a triode is arranged for the production of oscillations and a capacity, the value of which is controlled, is connected across the grid-to-cathode impedance and the voltage thereacross controlled by a resistance in the cathode return degeneratively connected.

In Fig. 2, a pentode tube is used and the variable reactance is inductive with modulation on the control grid whereas in Fig. 1 modulation is on the anode.

Figs. 3 and 4 include with the generator and modulator the audio-frequency source and amplifier. In Fig. 3, a pentode is used with suppressor grid modulation and the output is electronically coupled to the generator. Fig. 4 is similar to Fig. 3 but modulation is applied to the screen grid. Fig. 3*a* is a modification of the arrangement of Fig. 3. In Fig. 3*a*, a modulation potential amplifier is omitted.

In Fig. 1, an electron discharge tube 10 has its control grid 4 and its anode 16 with its cathode 8 connected in an oscillation generating circuit comprising a grid leak resistance R1, grid condenser C1, blocking and coupling condenser C3, inductance L1, tuning condenser C4, and controlled condenser C2. When the tube electrodes are energized, self-oscillations are sustained by virtue of the inductive coupling in the two sections of L1 on opposite sides of the cathode tap thereto. This operation being well known in the art needs no further description here.

The condenser C2 is connected between the grid 4 and cathode 8 of tube 10 and this connection is extended to ground and minus B through the resistance R2. A positive direct-current potential is supplied to the anode 16 by way of inductor L2 and a part of inductance L1. Modulating potentials are supplied by way of this same circuit between the anode and cathode of the tube 10 across condenser C3.

The object of the circuit illustrated in Fig. 1 is to provide a method and means by which the frequency of the oscillations developed in the tube 10 and the circuit comprising elements L1 and C2 can be varied in accordance with changes in a voltage supplied at the terminals marked "Modulation input."

This frequency variation is, in part at least, the result of changes in the effective capacity of the condenser C2, which is included in the oscillation generating circuits and the changes in the capacity of condenser C2 are caused in the following manner.

The charge which condenser C2 assumes is a function of, among other things, the voltage appearing across it. The voltage appearing across condenser C2 is a function of the transconductance of tube 10. Through the action of tube

10 when connected as shown, a voltage is generated across resistance R2 which is a fraction of, and in phase with, the voltage appearing across C2 and R2 in series due to the oscillations generated in 10. The effective voltage applied to condenser C2 is this oscillator voltage minus that portion of the voltage (degenerative) appearing across R2 which is due to current flowing in the output of tube 10.

More in detail, radio-frequency current produced in the oscillator flows through the circuit including C2 and R2 in series. This current flows all of the time (when the oscillator is operating) irrespective of the operating potential on tube 10. Also, flowing through R2 is the radio frequency flowing through the plate-to-cathode path of tube 10 which includes R2. When tube 10 conducts, a voltage is produced across R2 which is due to the plate-to-cathode current in tube 10, which current is in phase with the potential difference between grid and cathode. This grid to cathode voltage will lag the generated voltage at the grid of tube 10 by an amount determined by the relative impedances of C2 and R2. If the impedance of R2 is kept small in proportion to that of C2, a relatively large part of the voltage across R2 due to the action of tube 10 will be in phase with the voltage at the grid of tube 10. Since this voltage across R2 is applied to the terminal of C2 opposite to that at which the voltage at the grid of tube 10 is applied, the effective drop across C2 is reduced by the action of tube 10. As a consequence, the value of C2 depends on this voltage difference and the latter is modulated to frequency modulate the oscillations.

The voltage drop in R2 is variable and is varied as a function of the modulating voltage by varying the conductance of 10. Since the magnitude of this voltage across R2 is a function of the mutual conductance of 10, the effective capacity of C2 and hence the frequency of the combination of L1 and C2 are also functions of the mutual conductance of tube 10. In the diagram, control of the mutual conductance of tube 10 is obtained by voltages applied to the anode direct-current circuit.

When the tube 10's mutual conductance is raised by the modulating potentials, the effective capacity of C2 is lower (because the radio-frequency voltage across R2 increases and that across C2 goes down) and the effective capacity in the oscillator circuit is lower. This causes the oscillator frequency to increase when the transconductance of tube 10 is increased.

Obviously, since the frequency of operation of tube 10 is determined in part by its reactance circuits, the frequency of operation thereof can be controlled and if the control potential is characteristic of voice or television signals, the frequency modulation of the oscillations will correspond to said signals.

A feature of my method and system is that the upper capacity limit is determined by condenser C2 and occurs when the tube 10 is nonconductive. When a comparatively narrow frequency swing or modulation is required, a capacity C4 is connected across L1 as shown. If a wide swing is desired, C4 is removed by breaking the connections at X. Increasing the size of C2 increases the obtainable deviation and the condenser C2 can be rightly called the swing control condenser. The lower capacity range is limited in my system only by the extent to which the conductivity of the tube can be raised, assuming cathode and grid potential to be in phase. In practice, deviation of the oscillations over a wide range with a comparatively stable mean frequency can be attained.

The arrangement in Fig. 2 uses the principle involved in Fig. 1 but differs from Fig. 1 in the following important respects. In Fig. 2, a pentode tube 10 is used in place of the triode of Fig. 1. The swing condenser C2 is replaced by an inductance L which serves the same purpose in the circuits as C2. The variable reactive effect in this modification is inductive so that, as will be seen later, the frequency swing is down when the transconductance of tube 10 is increased, this being opposite to the operation of the arrangement of Fig. 1. C6 acts merely as a blocking condenser. Modulation is applied to the control grid 4.

The operation of the arrangement of Fig. 2, in general, is similar to operation of the modification shown in Fig. 1. However, in Fig. 2, the inductance L and the resistor R2 are in the oscillator radio-frequency current path and the voltage across L is leading the current whereas in Fig. 1 the voltage across C is lagging the current. Now, the ability of inductance L to take this lagging current is a function in part at least of the voltage across L. Consequently, when the tube 10's conductance is low, the drop across R2 is small, the voltage across L is high, and its effective inductance is low and as the tube becomes more conductive, the voltage across L becomes lower and its effective inductance increases. The frequency of the oscillations generated in this modification consequently decreases with increase in tube transconductance.

The frequency modulated output may be taken from the system of Figs. 1 and 2 by coupling the tank circuit inductance L1 to an output circuit 19. Any approved coupling and output circuit may be used here and the output may be amplified, multiplied, limited, etc., before transmission.

In the arrangement of Fig. 3, I use a tube of the pentode type with the screen grid 20, control grid 4, and cathode 8 connected in an oscillation generating circuit with the screen grid acting as the anode of the oscillator. The anode 16 is connected with an output circuit including choke inductance 22 and is coupled to the generating circuits substantially by the electron stream only of the tube.

If additional capacitive reactance is desired, a condenser 21 may be connected in parallel to the condenser C4. As pointed out above, however, if wide band modulation is desired, it is preferable to keep these condensers small and increase the size of swing condenser C2. However, it is usually necessary to keep C2 much smaller than the total of C4 and C21 in order to secure stable oscillation. C2 is the swing condenser and in this respect the system is similar to that shown in Fig. 1. Modulation is accomplished by varying the potential on the suppressor grid 24 by means described more in detail later to vary the tube transconductance. The radio voltage at the grid 4 and cathode 8 are sufficiently in phase to provide the desired amount of degeneration and the voltage across C2 is varied as the drop in R2 varies with variations in the transconductance of tube 10. Simultaneously, oscillation occurs due to regeneration between grid and plate circuits in the conventional manner.

If less frequency shift is desired, R2 may be omitted. The voltage difference across the portion of the inductance L1 in the cathode return

circuit allows some degree of control to be had through cathode degeneration. In Fig. 3a is shown this latter arrangement.

Returning to Fig. 3, modulating potentials are supplied from any source such as a mike or a television scanner to the primary winding of a transformer 30, the secondary winding of which is connected in push-pull relation to the grids 32 and 34 of an amplifier tube 36. The anodes 38 and 40 of tube 36 are coupled in push-pull relation to the primary winding of a transformer 42, the secondary winding of which is connected to the input electrodes of a triode portion of a triode-diode type tube 46. The output of the amplifier system is supplied from the anode 48 of tube 46 by way of a coupling condenser 50 to the suppressor grid 24 of tube 10 to control its transconductance for the purpose specified in detail above. This circuit is bypassed at a point close to tube 10 by a radio-frequency bypass condenser 52.

A modulating potential wave modifying means is included between the secondary winding of the transformer 42 and the grid 44 of tube 46. This means comprises an attenuator resistor 56, which allows the low and medium frequency to pass to a limited degree shunted by condenser 54, which allows high frequencies to pass unattenuated by virtue of its reactance characteristic. Resistances 58 and 60 are connected from the opposite ends of condenser 54 to the low potential end of the secondary winding for impedance matching purposes. In this circuit the high frequency modulating potentials are exalted; that is, are relatively increased in amplitude with respect to the lower frequency modulating potentials. Another manner of stating this is to say that the low frequency modulating potentials are attenuated to an extent greater than that to which the higher modulating potentials are attenuated.

The direct-current supply circuits for the tubes 36 and 46 are shown and will be understood by those skilled in the art, it is believed. However, it will be noted that the bias for the control electrodes 32 and 34 of tube 36 is supplied in part by a diode 62, in tube 46, connected by way of a resistor 64 to the grid end of resistor 68. A predetermined negative bias is supplied to the control grid 44 of tube 48 so that during desired operation rectification will not take place in the circuit including diode 62. However, in the presence of unduly high modulating potentials in the input of tube 46, a negative potential is supplied by way of resistor 64 to the grids 32 and 34 to compress the range. Time constants of condenser 69 with resistors 64 and 68 are of such size as to give a rapid rate of gain reduction and slow gain recovery.

In Fig. 3a, the modulating circuit is shown simply as a transformer 30' coupled to any source of modulation potentials on the one hand and on the other hand to the suppressor grid electrode 24 of tube 10.

The frequency modulated output of the arrangement of Fig. 3 is supplied to the grid 70 of tube 72 by way of a coupling condenser 74 amplified therein and repeated in the tuned tank circuit 76.

In the simplified diagram of Fig. 3a, the output electrode 16 of the electron-coupled generator and modulator is connected to a tuned tank circuit 17 and supplied from said circuit to the desired frequency multipliers, amplifiers, etc.

The oscillator 10 may operate at any desired frequency. In the arrangement used, the oscillator of tube 10 operates at a frequency

$$\frac{f}{6}$$

where f is the final mean frequency to be radiated. The tank circuit 76 can then be tuned to frequency

$$f, \frac{f}{2} \text{ or } \frac{f}{3}$$

When this circuit is tuned to a fraction of the final frequency, multiplication takes place in the later stages to bring the frequency up to the frequency f.

In Fig. 3a, the oscillator circuit may operate at a frequency

$$\frac{f}{N}$$

in which case the circuit 17 may operate at a frequency

$$\frac{nf}{N}$$

where N and n represent constants which result in a final desired output frequency f.

As stated above, oscillations of extremely stable mean frequency were obtained by an arrangement as illustrated in Figs. 3 and 3a without the use of automatic frequency control, compensating reactances, etc. Careful construction, including the following precautions, were followed to obtain the stability. A well regulated power source for the oscillator tube 10 is assured by the use of a voltage regulator tube 80, the operation and purpose of which needs no explanation. The winding L1 is of Nilvar heavily coated with copper. Nilvar has a low thermal coefficient of expansion but is also of low Q. The Q was raised by the copper coating.

In the apparatus (Figs. 3 and 3a) tested, certain of the components thereof have the values listed below.

f is 39.64 megacycles
C4 is 0.25 mmf.
21 is 370 mmf.
C2 is 40 mmf.
19 is 25 mmf.
74 is 25 mmf.
52 is 25 mmf.
R2 is 100 ohms
25 is 400 ohms
23 is 20,000 ohms
29 is 20,000 ohms
RFC is 2 m. h.
71 is 0.35 mmf.
73 is 2.5 m. h.

Fig. 4 illustrates a light portable frequency modulated transmitter utilizing the principles of my invention. In Fig. 4, the modulator operates substantially the same as the modulator of Fig. 1, etc. The tube 10 in this modification, however, is of the direct heated filament type and in this circuit I have included choking inductances 100 in the filament leads to prevent the radio frequencies flowing in the circuits of tube 10 from reaching the supply sources and modulation source. The inductances 100 are preferably bi-filar wound with their terminals adjacent the filament 8' shunted by by-pass condenser 102. In this arrangement, as in certain of the prior modifications, the condenser C2 is the variable reactance or swing reactance and the size of this condenser determines the extent of the frequency deviation obtainable. In this modification, however, the re-

sistance R2 has been omitted and the condenser 106 supplies the degenerative variable voltage in series with the voltage across condenser C2. Improved results are obtained in this particular arrangement by the use of a condenser which is relatively small in place of the resistor R2 heretofore used, the improved results being due to improved phase relationship of grid and filament voltages. As in the prior modification, the condenser 106 permits the filament 8' to swing at radio-frequency voltage substantially in phase with the radio-frequency voltage on the grid 4 to obtain the degenerative effect and thereby control the effective size of the capacitive reactance C2. Thus, as in Fig. 1, with increased transconductance in the oscillator section of the tube 10, including the control grid 4, filament 8' and screen grid electrode 20, there is a decreased effective capacitance C2 causing increased oscillation frequency.

In this modification, the screen grid potential is modulated through a blocking condenser 110 connected with the output of an audio frequency amplifier. The audio amplifier comprises a transformer 30, the primary winding of which is coupled to a microphone or television scanner output. The secondary winding of transformer 30 is coupled to the control grid 112 of an amplifier 114, the anode of which feeds through a modulation potential modifying circuit 116 to the grid 118 of tube 120. Tubes 114 and 116 may be in a single envelope and employ a common filament. That is, the filament of tube 114 may also represent the filament shown in tube 120.

The circuit 116, as will be noted, is similar to the circuit between the secondary winding of transformer 42 and the grid 44 of tube 46 of Fig. 3. The components of this circuit have been labelled with reference numerals similar to the reference numerals used in Fig. 3 and a description thereof is believed unnecessary.

The diode element 122 of tube 114 supplies a gain control potential to the grids 112 and 118 in the presence of unduly high modulation peaks. The anode 124 of tube 120 supplies output to the resistors 126 and 128 and thence to coupling condenser 110 and to the screen grid electrode 20 of tube 10. The anode 124 also supplies potential to the diode rectifier 122 by way of blocking condenser 130. Time delay circuits in the output of the diode rectifier 122 include resistors 132 and 134 and condenser 136. Resistor 132 is of much lower value than 134, thus providing for a rapid gain reduction on excessive level peaks and a slow gain recovery after such high level peaks have ceased.

As in the modification shown in Fig. 2, the circuit comprising inductance L1 and condenser C4 may be tuned to

$$\frac{f}{n}$$

where f is the final frequency to be transmitted while the output circuit 17 of the tube 10 may be tuned to a frequency

$$\frac{nf}{N}$$

whereas in the prior case n and N are constants selected to permit the desired multiplication in the several stages and yet attain the desired output frequency f.

What is claimed is:

1. In a tube reactance, wave generator and wavelength modulator, an electron discharge device having a grid, an electrode serving as an anode, an anode and a cathode, a reactance and a radio frequency impedance connected between said grid and a point of low radio-frequency potential, a circuit connected between said electrode serving as an anode and said cathode, said last named circuit including said impedance, means for producing regeneration in said circuits whereby wave energy is produced in said device and circuits, means for modulating the potential on an electrode in said device to thereby modulate the flow of radio frequency current through said impedance and vary the voltage across said reactance, and an output circuit connected with said anode and cathode.

2. In a tube condenser, wave generator and wavelength modulator, an electron discharge device having a grid, an electrode serving as an anode, an anode and a cathode, a condenser and a radio frequency impedance connected between said grid and a point of relatively low radio-frequency potential, a circuit including said impedance connected between said electrode serving as an anode and said cathode, means for producing regeneration in said circuits whereby wave energy is produced in said device, means for modulating the potential on an electrode of said device to thereby modulate the flow of current through said impedance and vary the voltage across said condenser, and an output circuit connected with said anode and cathode.

3. An arrangement as recited in claim 2 wherein said output circuit is tuned to a multiple of the frequency of the wave generated.

4. In a wavelength modulation system, an electron discharge device having an anode, a cathode, a control grid, and a screen grid, wave generating circuits interconnecting said control grid, cathode and screen grid electrode, said circuits including a reactance and a radio frequency impedance in series between said control grid and screen grid, means connecting said impedance between said screen grid and cathode, means connecting said impedance to a point of low radio frequency potential, means for producing regeneration in said circuits whereby wave energy is generated therein, means for modulating the potential on an electrode of said device to modulate the transconductance thereof and thereby modulate the effective reactance of said reactance between said control grid and screen grid, and an output circuit connected with said anode and cathode.

5. A system as recited in claim 4 wherein said output circuit is tuned to a multiple of the frequency of the wave energy generated.

6. In a wavelength modulation system, an electron discharge device having an anode, a cathode, a control grid, a screen grid, and a suppressor grid, wave generating circuits interconnecting said control grid, cathode and screen grid electrode, said circuits including a reactance and an impedance in series between said control grid and screen grid, said impedance being also connected between said screen grid and cathode, means for producing regeneration in said circuits whereby wave energy is generated therein, means for modulating the potential on said suppressor grid to modulate the transconductance thereof and thereby modulate the effective reactance of said reactance between said control grid and screen grid, and an output circuit connected with said anode and cathode.

7. In a wavelength modulation system, an electron discharge device having electrodes including a grid, a cathode, an anode and an auxiliary

electrode connected in wave generating circuits including a reactance and a radio-frequency impedance in series between the grid and a point of low radio-frequency potential, said generating circuits also including said impedance between said auxiliary electrode and cathode, an output circuit coupled to said anode and cathode and coupled to said wave generating circuits substantially by the electron stream only of said device, and means for modulating the transconductance of said device in accordance with signals.

8. A system as recited in claim 7 wherein said output circuit is tuned to a multiple of the frequency of the wave energy generated.

9. In a wavelength modulation system, a tube having a grid, a cathode, and an electrode serving as an anode, a reactance coupling said grid to said cathode, an unbypassed impedance coupling said electrode serving as an anode to said cathode whereby, if radio frequency is applied to said grid and relayed in said tube, the cathode radio frequency voltage follows the grid radio frequency voltage to an extent depending on the transconductance of the tube and the value of said impedance, a tuned circuit including said reactance coupled with said cathode, said grid and said electrode serving as an anode, means for producing regeneration in said last-named circuit whereby oscillations are generated in said tube and circuits, and means for varying the transconductance of said tube in accordance with signals to correspondingly vary the effective reactance between said grid and cathode and correspondingly vary the wave length of the oscillations produced.

10. A system as recited in claim 9 wherein said reactance is a capacity.

11. A system as recited in claim 9 wherein said reactance is an inductance.

12. In a system for generating and wavelength modulating wave energy, an electron discharge tube having a control grid, an electron serving as an anode and a cathode, a reactance and a radio-frequency impedance connected between said control grid and a point of low radio-frequency potential, a circuit connected between said electrode serving as an anode and said cathode, said last-named circuit including said impedance, means for producing regeneration in said circuits whereby wave energy is produced in said tube and circuits, means for modulating the potential on an electrode in said tube to thereby modulate the flow of radio-frequency current through said impedance and vary the voltage developed across said reactance and connections for deriving generated wave energy from said generating circuits.

13. An arrangement as recited in claim 12 wherein said reactance is a capacity.

14. An arrangement as recited in claim 12 wherein said reactance is an inductance.

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