

March 16, 1948.

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2,437,872

PHASE MODULATOR

Filed Sept. 14, 1944

3 Sheets-Sheet 1

FIG. 1.

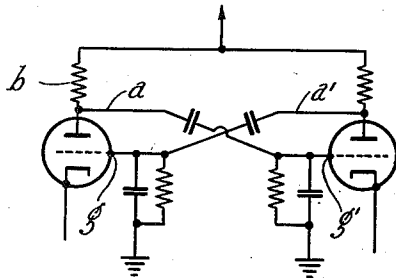


FIG. 2.

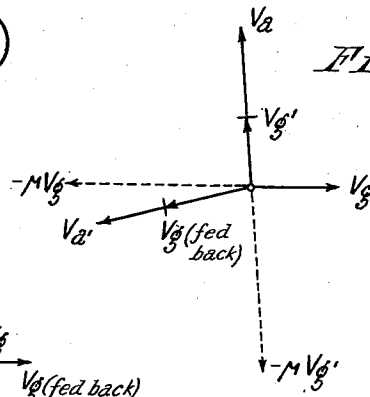


FIG. 3.

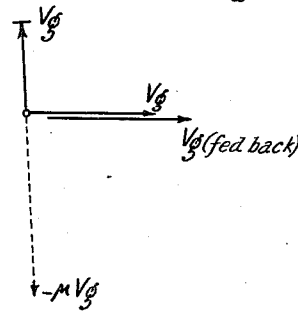
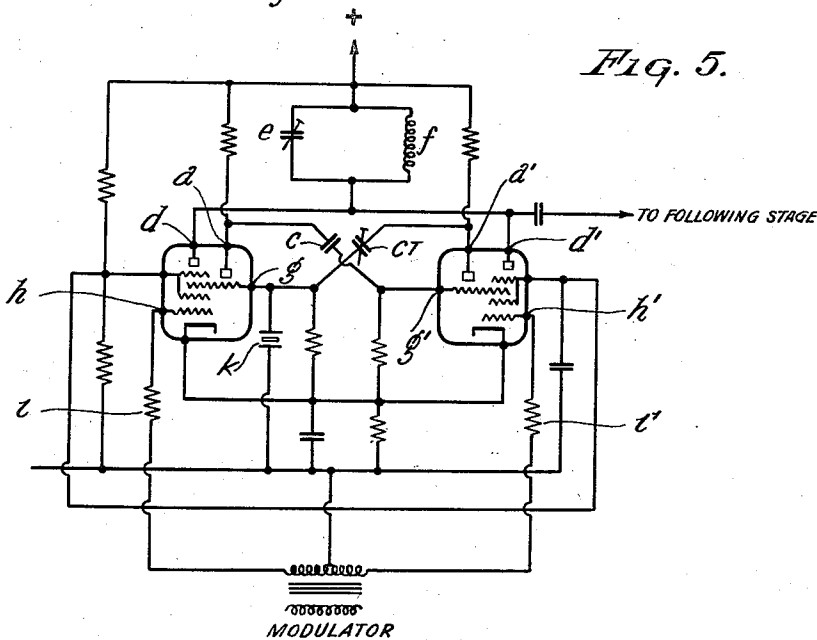


FIG. 5.



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Fig. 4.

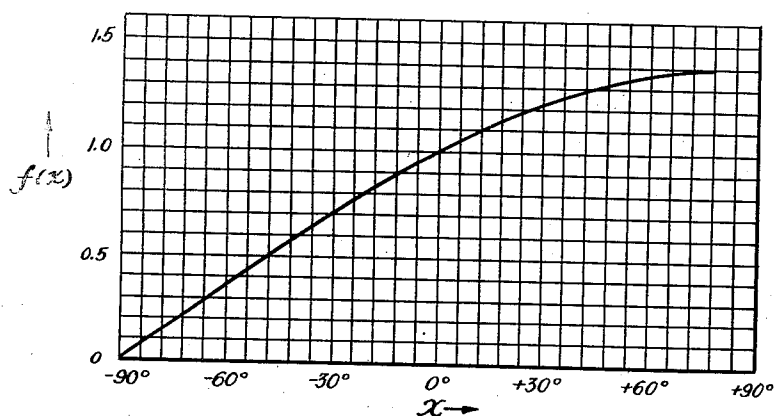
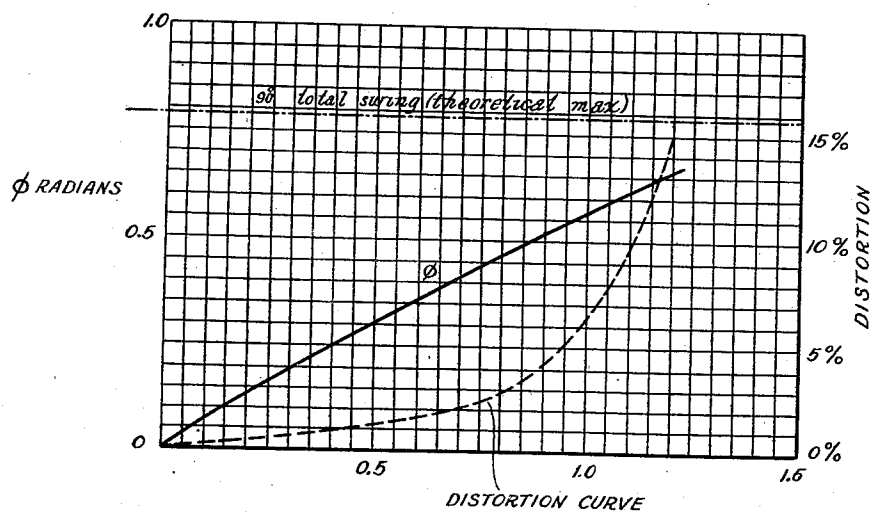


Fig. 6.



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Fig. 7.

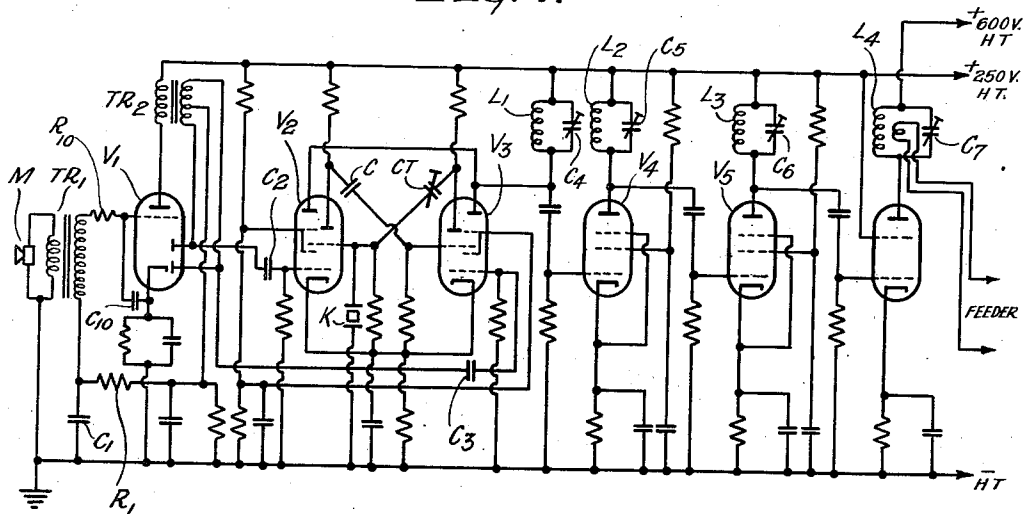
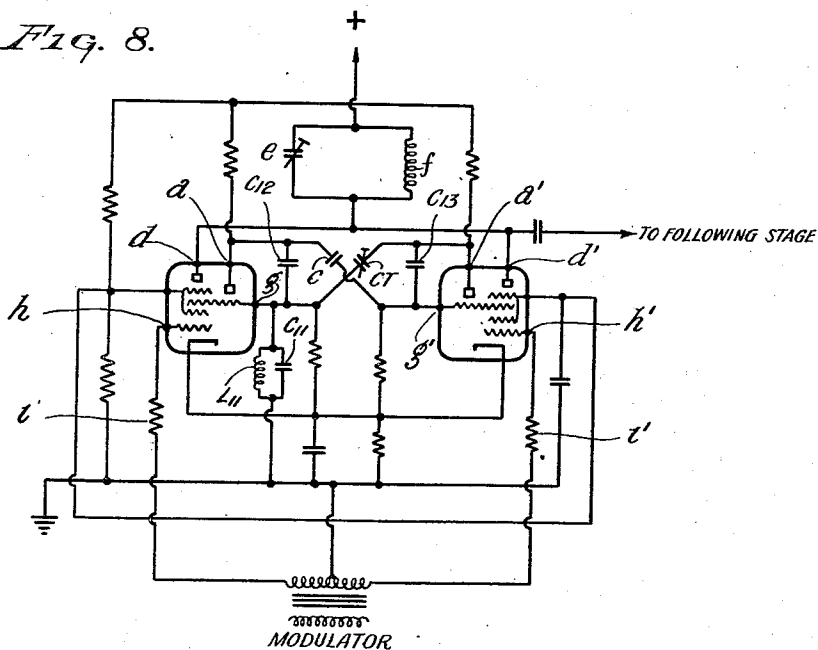


Fig. 8.



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PHASE MODULATOR

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5 Claims. (Cl. 179—171.5)

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This invention relates to thermionic valve circuits and aims at the provision of improved apparatus for the production of electrical oscillations modulated in phase, but with substantially zero amplitude modulation.

With these ends in view, the invention consists in apparatus for producing electrical oscillations modulated in phase, with substantially zero amplitude modulation, comprising an oscillation generator operating on the thermionic valve feedback principle wherein the required feedback phase is obtained with the aid of two successive phase rotations each of substantially 90°, and thermionic valve modulators operating on voltages derived from the said oscillation generator and feeding energy to a common output circuit.

Preferably the oscillation generator consists of a multivibrator comprising two thermionic valves of which the anode of each is coupled to the control grid of the other by a capacity of the same order of magnitude as the capacity between the grid-anode terminals of the valve, provided with means such as an oscillatory crystal or a parallel resonant circuit connected between the grid of one of said valves and earth, adapted to maintain quadrature relationship between the phases of the E. M. F.'s respectively applied directly and fed back to the grid of each valve, thus ensuring oscillation of the circuit.

The invention will be clearly understood from the following description of the principles underlying it and a few forms which it may assume, and this description will be more readily followed by reference to the accompanying drawings.

In the drawings,

Fig. 1 represents a circuit adapted with modification to form a simple multivibrator, in respect of which the principles of the invention can conveniently be explained;

Fig. 2 is a vector diagram showing the operation of the circuit of Fig. 1;

Fig. 3 is a vector diagram of the circuit of Fig. 1 when modified by the incorporation of one feature of the invention;

Fig. 4 is a curve showing the relationship between the audio-frequency input and the high frequency output of a modulator employed in accordance with the invention;

Fig. 5 shows the diagram of a practical circuit for carrying the invention into effect;

Fig. 6 shows performance curves of a circuit such as shown in Fig. 5;

Fig. 7 represents the circuit diagram of a mobile transmitter incorporating the invention;

Fig. 8 is a schematic diagram of a circuit simi-

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lar to that shown in Fig. 5 and embodying certain modifications hereinafter to be pointed out.

The principles of the invention will be readily understood by reference to Figs. 1 to 4 inclusive of the drawings. Consider the circuit represented in Fig. 1 when the capacities of the coupling condensers are reduced to the order of the grid-anode capacities of the valves. It can be shown that such a circuit will not oscillate at very low frequencies. For, as will be seen from Fig. 2, assuming an E. M. F., V_g , in zero phase applied to the grid of the left-hand valve, and regarding the valve anode circuit a as a generator providing an E. M. F., $-\mu V_g$, in series with the resistance b forming the anode load, the generator E. M. F. has a phase of 180° and the anode E. M. F., V_a , a phase of almost 270°. The E. M. F., V_g' , on the grid g' of the right-hand valve is of the same phase as the anode E. M. F., V_a , but has a smaller amplitude. The generator E. M. F., $-\mu V_g'$, of the right-hand valve has a phase of almost 90°, and the anode E. M. F., V_a' , of that valve a phase of almost 180°, this E. M. F. being fed back to the grid g of the left-hand valve. Since the fed back E. M. F. and the originally applied E. M. F. are substantially in opposition the circuit is clearly not set into oscillation.

When, however, in accordance with the invention, an oscillatory crystal is connected in circuit between one of the valve grids, e. g., grid g , and earth, the impedance of this crystal at a frequency slightly below its resonant frequency is inductive and the resultant E. M. F. fed back to the left-hand valve from the right-hand anode returns to zero phase. The vector diagram of the circuit, modified by the addition of this crystal is shown in Fig. 3 and it will be clear that the circuit oscillates at a frequency close to the resonance frequency of the crystal, the E. M. F.'s, V_g and V_g' being substantially in quadrature.

An oscillator of the character described above may, in accordance with the invention, be employed in association with a modulating circuit.

Consider two identical modulators from which the R. F. outputs are in quadrature, each being a function, f , of the relevant audio-frequency input and the inputs x and $-x$ being applied in push-pull to the modulators. According to the invention it is arranged that

$$f(x) = \sqrt{1 + \sin x}$$

and the modulated outputs are combined in parallel. It will be seen that the combined output,

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$F(x)$, of the two modulators in parallel is given by the expression

$$F(x) = \sqrt{1 + \sin x} + j\sqrt{1 - \sin x} \\ = Ae^{j\phi}$$

where

$$A = \sqrt{(1 + \sin x) + (1 - \sin x)} = \sqrt{2}$$

and the phase of the output

$$\phi = \tan^{-1} \sqrt{\frac{1 - \sin x}{1 + \sin x}} \\ = \frac{\pi}{4} + \frac{x}{2}$$

It will be seen therefore that the resultant output $F(x)$ is in the form of a linear phase modulation, with zero amplitude modulation, of the input. The form of the R. F. outputs of the modulators, viz., $f(x) = \sqrt{1 + \sin x}$, from which this result may be obtained is shown in the curve of Fig. 4 herewith. It is preferred that the modulation be effected by valve modulators and since most valve modulators have a characteristic curve which is concave in an upward sense, it is not necessary when carrying the invention into effect, to take any special steps for the purpose of ensuring that the R. F. outputs shall approximate to that represented by the curve in Fig. 4 herewith.

From the above discussion it will be seen that the desirable result of linear phase modulation without amplitude modulation can readily be achieved by suitably modulating the outputs from the valves of a multivibrator such as described above with reference to Fig. 1 herewith, but including the aforementioned oscillatory crystal, and one convenient practical circuit arrangement for that purpose in accordance with the invention is shown in Fig. 5 herewith.

As seen from Fig. 5 two triode-hexodes are employed with the triodes connected in multivibrator circuit such as considered above. The anodes and grids in this circuit are identified respectively by the same references as the equivalent elements shown in Fig. 1 and the coupling condensers are shown at C, CT. The anodes d , d' of the hexodes are connected in parallel to a tuned circuit comprising condenser e and inductance f in parallel, which drives the following stage. The hexode grids h , h' are connected in push-pull to the source of modulation and for the purpose of approximating to the ideal modulation characteristic shown in Fig. 4 high series resistors i , i' are inserted in the hexode grid circuits. The crystal k is inserted between the grid g of the left-hand triode and earth. Convenient valves for the various elements in one satisfactory circuit according to the invention are represented by the usual symbols in Fig. 5.

The variable balancing condenser CT, by facilitating equalisation of the drive on the triode grids, balances even harmonics in the phase modulation. Its setting is not however, critical. It serves to compensate any differences in the quadrature components of the oscillation due to differences in valve capacities, wiring capacities, etc., and in practice may be readily adjusted by listening to a receiver and modulating with a pure tone.

Results obtained with a circuit such as shown in Fig. 5 are shown by the curves of Fig. 6, in which are plotted respectively the peak phase modulation, ϕ , and the percentage distortion, against the applied modulation voltage, V mod.,

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in R. M. S. volts applied to each grid h , h' . It will be noted that one half radian peak phase modulation (about 60° peak-to-peak) is achieved with 4% distortion at 0.85 volt modulation.

Above this valve distortion rises rapidly. When measuring these results the R. F. output was 35 volts, and the amplitude modulation was such as to be easily removed in succeeding R. F. stages.

Fig. 7 represents the complete circuit diagram of a combined oscillator and phase modulator according to the invention, suitable for use as a mobile transmitter, and designed to emit frequency modulated waves with a carrier frequency of 81 mc./sec. and a useful modulation range of 300-3000 cycles/sec. The modulation is generated by a phase modulator of the kind described; but an attenuating network operative over the higher modulation frequency range results in the reduction of the overall phase modulation characteristic in this range to a characteristic approximately that of frequency modulation (i. e., the deviation is independent of the frequency). The signals emitted by this transmitter may be detected by a normal frequency-modulation receiver, the relative attenuation of the lower modulation frequencies when so detected being unimportant for the purpose of speech communication as distinct from musical broadcasting. Referring to Figure 7, a moving coil microphone M is coupled through a step-up transformer TR1 to the grid of a double diode-triode audio-frequency amplifying valve V1. Between the transformer TR1 and the grid of valve V1 is connected a low-pass resistance-capacity filter R10, C10 so proportioned as to maintain approximately constant frequency deviation over the upper range of modulation frequencies. The diodes of the valve V1 are connected as full-wave rectifiers to the secondary of the transformer TR2 of which the primary receives the output of the triode in valve V1, voltage delay being obtained from the cathode drop in that valve. The voltage rectified by the diodes is smoothed by the condenser C1 and the resistance R1, and fed to the grid of valve V1 in order to provide a measure of automatic modulation control.

The modulation is also fed through condensers C2 and C3 to the hexode control grids of triode-hexode valves V2, V3 which are connected together as a combined oscillator and modulator precisely in the manner described above with reference to Fig. 5 herewith. The coupling condensers C, CT and the crystal K have the same references and perform the same functions as heretofore described. In the unit illustrated in Fig. 7 the crystal K is adapted to resonate at 4.5 mc./sec., and the phase modulated carrier voltage output from the valves V2, V3 is fed to the resonant circuit L1C4 corresponding to the circuit e , f of Fig. 5. Owing to the attenuation of the higher frequencies in the grid circuit of valve V1, the overall modulation characteristic approximates over the higher frequency band to that of frequency modulation, and over the lower frequency band to that of phase modulation.

The output from the valves V2, V3 passes through two pentodes V4, V5, each arranged as a frequency tripler, the anode circuit L2C5 of V4 being tuned to 13.5 mc./sec., and the anode circuit L3, C6 of V5 being tuned to 40.5 mc./sec. From these stages the output is fed to output valve V6 of which the anode circuit L4, C7 is tuned to 81 mc./sec., and the output feeder line is inductively coupled to the coil L4 therein. The values of the various coupling elements in this

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circuit are so chosen and proportioned that residual amplitude modulation is removed by the limiting action of the grids in valves V₄, V₅ and V₆.

It will be noted that the frequency deviation is multiplied to 18 times the initial value, as well as the original frequency, and in the circuit described it amounts to about 9 kc./sec. at a convenient input, over the higher modulation-frequency range, falling to about 2.5 kc./sec. at 300 cycles/sec.

A unit of the kind described, when provided with an aerial and an aerial feeder connected to the points so marked in Fig. 7, and a suitable source of high tension supply such as a double-wound rotary transformer, may be installed in an automobile and used as a mobile transmitter, a purpose for which the small number of and size of the components necessary for the phase modulator especially suit it. One such unit substantially as described with reference to Fig. 7 measured 16½ inches by 4 inches by 6 inches, of which a space 4 inches by 4 inches by 6 inches was taken up by the modulator.

If desired in the circuits described above the oscillatory crystal $\frac{1}{2}$ may be replaced by a suitable parallel resonant circuit as shown at C₁₁, L₁₁ in Fig. 8, and after readjustment of the balancing condenser C_r, the same results are obtained as with the crystal. Further, if the anode-grid capacities of the oscillator valves are found insufficient to produce the effect described at the desired frequency, these capacities may be built up to the necessary value by one or more condensers joined in parallel therewith as shown at C₁₂, C₁₃ in Fig. 8. It should be understood, however, that the invention is not limited solely to the details of the forms described above, since modifications may be introduced, e. g., into the circuit arrangements and/or components employed, in order to meet various conditions and requirements which have to be fulfilled, without departing in any way from the scope of the invention.

I claim:

1. Apparatus for producing a phase modulated wave with substantially zero amplitude modulation, comprising a multivibrator type oscillation generator comprising two discharge tubes each having a cathode, a control grid and an anode, coupling capacitors having capacitance values of the order of magnitude of the grid-anode capacitance of said tubes cross-connecting the grids and anodes of said tubes and means to place said oscillation generator in condition for oscillation at a given frequency and to maintain the grids of said tubes at potentials substantially 90° out of phase with respect to each other, said means comprising an element having an inductive reactance at said frequency, means to derive from said grids two voltages substantially 90° out of phase with respect to each other, means to amplitude modulate each of said voltages, and means comprising a common output circuit for combining said modulated voltages to produce a phase modulated wave having substantially zero amplitude modulation.

2. Apparatus for producing a phase modulated wave with substantially zero amplitude modulation, comprising a multivibrator type oscillation generator comprising two discharge tubes each having a cathode, a control grid and an anode, coupling capacitors having capacitance values of the order of magnitude of the grid-anode capacitance of said tubes cross-connecting the grids and anodes of said tubes and means to place said oscillation generator in condition for oscillation at

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a given frequency and to maintain the grids of said tubes at potentials substantially 90° out of phase with respect to each other, said means comprising an oscillatory crystal having an inductive reactance at said frequency interconnecting the grid and cathode of one of said tubes, means to derive from said grids two voltages substantially 90° out of phase with respect to each other, means to amplitude modulate each of said voltages, and means comprising a common output circuit for combining said modulated voltages to produce a phase modulated wave having substantially zero amplitude modulation.

3. Apparatus for producing a phase modulated wave with substantially zero amplitude modulation, comprising a multivibrator type oscillation generator comprising two discharge tubes each having a cathode, a control grid and an anode, coupling capacitors having capacitance values of the order of magnitude of the grid-anode capacitance of said tubes cross-connecting the grids and anodes of said tubes and means to place said oscillation generator in condition for oscillation at a given frequency, said means comprising a parallel resonant circuit having an inductive reactance at said frequency interconnecting the grid and cathode of one of said tubes to maintain the grids at potentials substantially 90° out of phase with respect to each other, means to derive from said grids two voltages substantially 90° out of phase with respect to each other, means to amplitude modulate each of said voltages, and means comprising a common output circuit for combining said modulated voltages to produce a phase modulated wave having substantially zero amplitude modulation.

4. Apparatus for producing a phase modulated wave with substantially zero amplitude modulation, comprising a multivibrator type oscillation generator comprising two discharge tubes each having a cathode, a control grid and an anode, a coupling capacitor having a capacitance value of the order of magnitude of the grid-anode capacitance of said tubes interconnecting the grid of one tube and the anode of the other tube, a variable coupling capacitor interconnecting the grid of said second tube and the anode of said first tube and means to place said oscillation generator in condition for oscillation at a given frequency and to maintain the grids of said tubes at potentials substantially 90° out of phase with respect to each other, said means comprising an inductive reactance element interconnecting the grid and cathode of one of said tubes, means to derive from said grids two voltages substantially 90° out of phase with respect to each other, means to amplitude modulate each of said voltages, and means comprising a common output circuit for combining said modulated voltages to produce a phase modulated wave having substantially zero amplitude modulation.

5. Apparatus for producing a phase modulated wave with substantially zero amplitude modulation, comprising two discharge tubes each comprising a cathode, a triode assembly including a control grid and an anode and a hexode assembly including two control grids and an anode, coupling capacitors having capacitance values of the order of magnitude of the grid-anode capacitance of said triode assemblies cross-connecting the grids and anodes of said triode assemblies, means to place said oscillation generator in condition for oscillation at a given frequency, said means comprising an oscillatory crystal element having an inductive reactance at said frequency and inter-

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connecting the cathode of one of said tubes and the grid of the triode assembly thereof, means to couple the grids of said triode assemblies each to one of the grids of the corresponding hexode assembly, means to apply a modulating potential in push-pull arrangement to the other of the grids of said hexode assemblies, and a resonant circuit having one end coupled to said cathodes and the other end common to the anodes of said hexode assemblies.

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