

March 3, 1936.

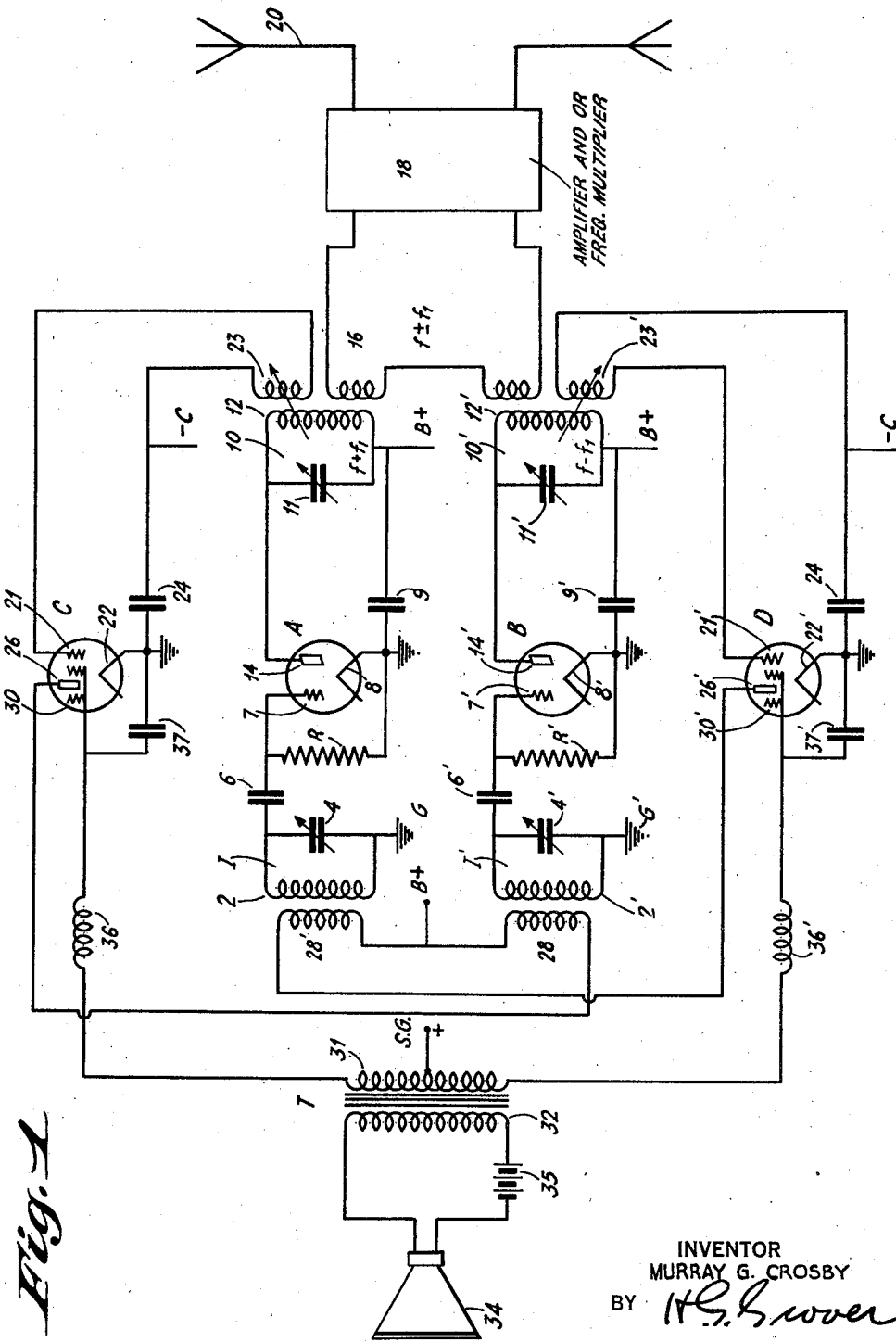
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2,032,403

FREQUENCY MODULATION

Filed July 9, 1932

3 Sheets-Sheet 1



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Fig. 2

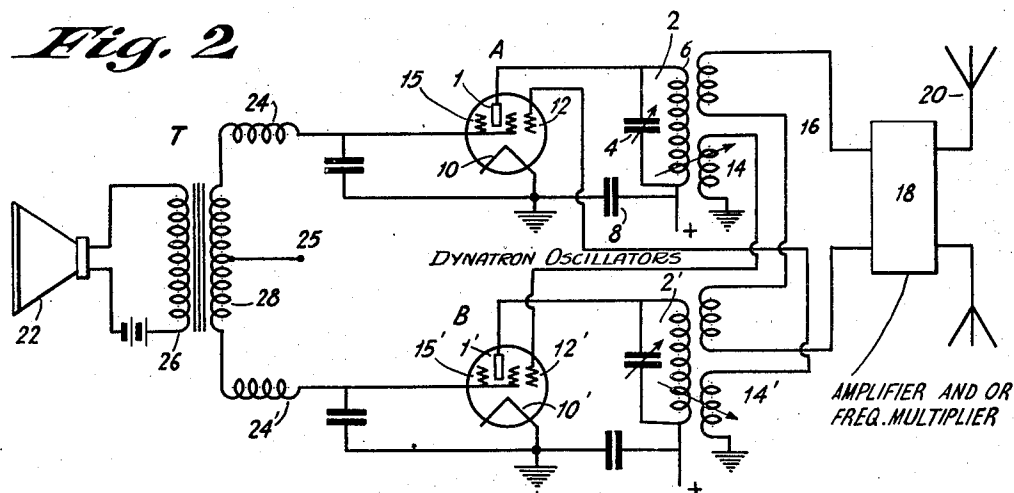
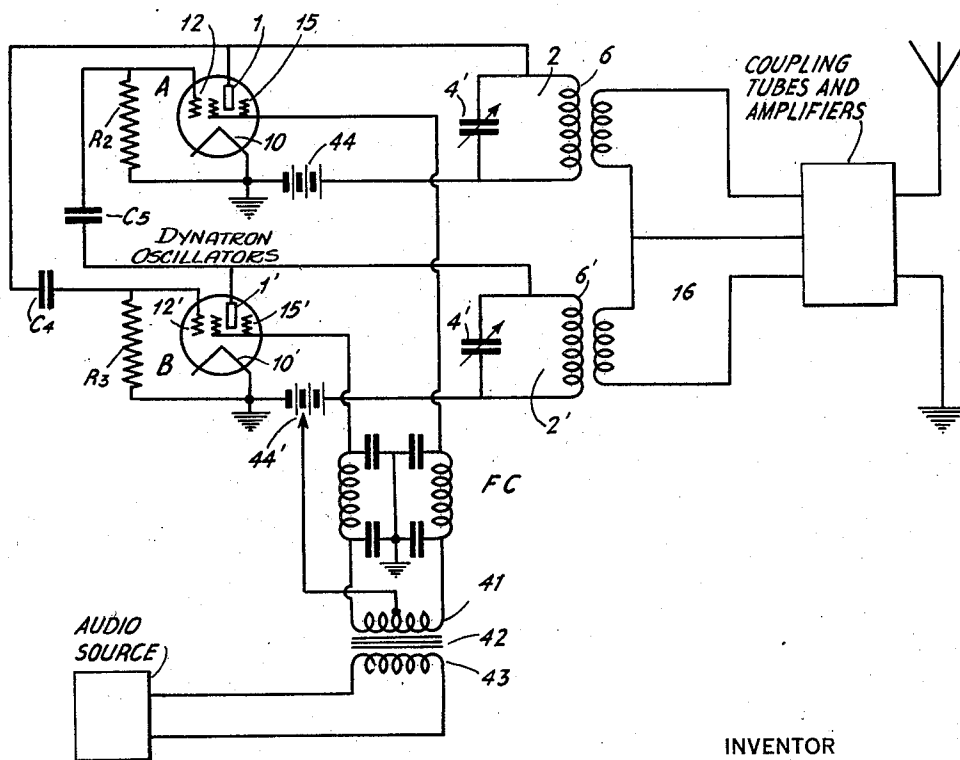


Fig. 4



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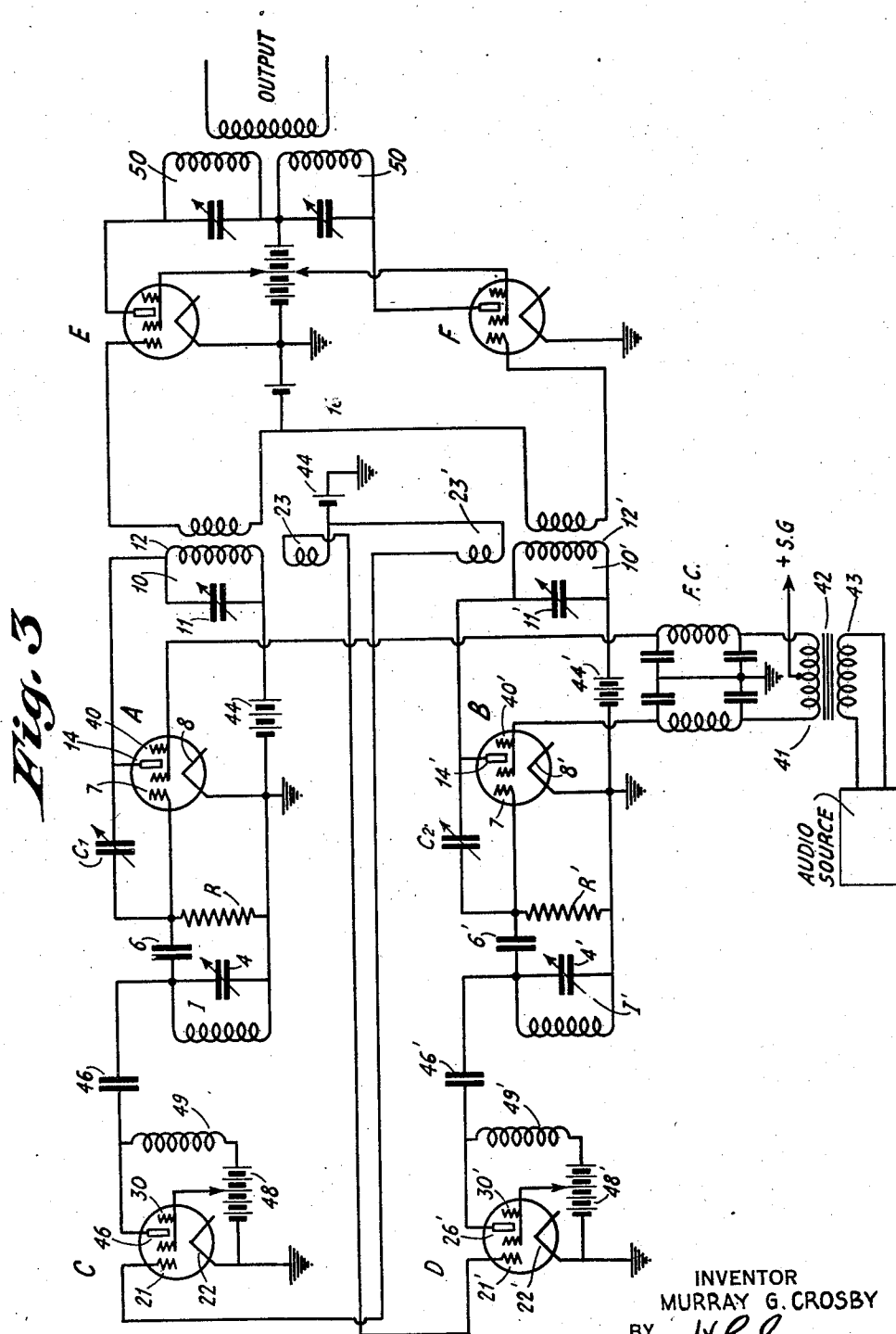
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3 Sheets-Sheet 3



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2,032,403

FREQUENCY MODULATION

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Application July 9, 1932, Serial No. 621,569

13 Claims. (Cl. 179—171)

This invention relates to an improved method of and means for imparting to a radio wave or to high frequency oscillations certain characteristics which are representative of a signal to be transmitted in order that said wave when received may be reduced or separated into its components and the characteristics thereof representative of the signal rendered intelligible.

More in detail, the present invention relates to a method of and means for impressing on a radio wave or high frequency oscillations variations in frequency which are characteristic of a signal to be transmitted.

More in particular, this invention relates to a new and improved frequency modulation transmitter wherein two oscillators, tuned to frequencies on either side of the wave or carrier frequency oscillations, are coupled together and held in step by two modulator tubes. The modulator tubes are differentially modulated so that the resultant frequency is frequency modulated between the separate individual frequency of the oscillations produced by each oscillator.

Frequency modulated transmitters have been known heretofore in the art. In the design of frequency modulated transmitters of the kind known heretofore in the art, it has been the practice to couple the two oscillator tubes directly together by means of capacity or inductive coupling between the grid or plate circuit of the two oscillators. This sort of coupling is very unsatisfactory due to the fact that the oscillators can not be tuned separately and then coupled together by the capacities and/or inductances since coupling one oscillator to the other changes the tune of both. Consequently, the two oscillators must be separately tuned while they are coupled together and this becomes a cut-and-try system in which the required adjustment is difficult to obtain.

The above disadvantages are overcome in accordance with the present invention by providing the coupling between the oscillator tubes through vacuum tubes so that there is no reaction of one oscillator upon the other. In a particular form of the present invention this coupling is obtained through the thermionic modulator tubes used for impressing the signal modulations on the carrier wave.

An apparent advantage to be gained by the use of a transmitter constructed as described in the present invention is that each oscillator may be tuned to its correct frequency separately and independently, and subsequently coupled to the other oscillator without destroying the individual tune and adjustment of the oscillator circuits. This results in making tuning of the circuit a straightforward and simple process.

The novel features of the present invention

have been pointed out with particularity in the claims appended hereto.

The nature of the invention, the mode of operation thereof, and the advantages resulting from the use thereof will be apparent from the detailed description which follows, and therefrom when read in connection with the drawings, throughout which like reference numerals indicate like parts, and in which:

Fig. 1 shows a circuit arrangement illustrating the transmitter of the present invention, while

Figs. 2, 3, and 4 show modifications of the arrangement shown in Fig. 1.

Referring to the drawings, and in particular to Fig. 1 thereof, A is a self-excited oscillation generator having a tuned input circuit 1 comprising an inductance 2 and variable capacity 4 connected through a grid condenser 6 to the grid electrode 7. The input circuit is completed by way of the ground G and cathode 8 of tube A. In order that a normal direct current biasing potential may be applied to the control electrode 7, a resistance R is connected between the control electrode 7 and the cathode 8. A tank circuit 10, comprising a variable condenser 11 and inductance 12, is connected with the anode 14 of the tube A. The lower terminal of the tank circuit 10 is connected, as indicated, to a positive terminal of a source of potential not shown. In order that the radio frequency oscillations generated in tube A do not pass through the potential source, a condenser 9 is connected between the lower terminal of the tuned circuit 10 and the cathode 8 of tube A.

A second oscillator B has its electrodes 7', 8', and 14' connected in circuits similar to the circuits associated with the electrodes of tube A. The inductances 12 and 12' of the output circuits 10 and 10' of oscillation generators A and B are both inductively coupled to the input circuit 16 of a power amplifier and/or frequency multiplier 18. The oscillations produced by A and B together and modulated in a manner which will appear more in detail hereinafter are impressed on the input circuit 16 of the frequency amplifier or multiplier 18 and passed from there to radiating circuit 20. The nature of the radio frequency amplifier and/or multiplier and of the radiating circuit forms no part of the present invention and will not be described in detail here.

The oscillators A and B are exactly similar to each other except for the fact that, if it is assumed that the frequency of the oscillations to be normally produced is equal to f , the tank circuit 10 in the output circuit of the tube A is tuned to a point such that tube A oscillates at a frequency $f+f_1$ whereas the tuned tank circuit 10' in the oscillation circuit of B is tuned to a point such that the tube B oscillates at a frequency 60

$f-f_1$. In order that the two oscillators A and B develop oscillations constant in frequency and separated by a constant different frequency means is provided to lock the two oscillators "in step". This is accomplished in accordance with the present invention by the use of two thermionic buffer tubes C and D which also serve as modulators. The control electrode 21 of modulator tube C is connected to the cathode 22 by way of a coupling inductance 23 inductively coupled to the inductance 12 in the output circuit of the tube A. Biasing potential for the control electrode 21 is supplied, as indicated, at C— from a source not shown. Radio frequency oscillations appearing in the input circuit of tube C are prevented from passing through the biasing source by means of a by-pass condenser 24. Potential variations are impressed from inductance 12 on to inductance 23 and on to the input electrodes 21, 22 of tube C, in which tube they are amplified and relayed and appear on the anode electrode 26. The anode electrode 26 is connected in circuit with an inductance 28 coupled to the inductance 2' in the input circuit of oscillation generator circuit B so that potential oscillations are impressed on the inductance 2' and govern to some extent the frequency oscillations developed by B. Charging potential for the anode 26 of tube C is supplied, as indicated, at B from a source not shown. In a similar manner the output inductance 12' of oscillation generator B is coupled by way of thermionic modulator tube D and inductance 28' to the inductance 2 in the input circuit of oscillation generator A, in that way governing to a certain extent the frequency of the oscillations developed by A.

The two oscillators A and B when oscillating uninfluenced by each other oscillate at frequencies $f+f_1$ and $f-f_1$ respectively. Therefore for tuning and adjusting the arrangement the modulator tubes C and D are switched off.

During operation however the tubes C and D are energized and oscillators A and B mutually influence each other to produce oscillations of a frequency f . This tendency of two oscillators mutually coupled to pull into step and generate a single frequency is inherent, is understood and need not be gone into here.

Applicant has up to this point disclosed a novel arrangement whereby two distinct high frequency oscillations of constant frequency, and separated by a constant frequency difference, may be developed in two separate oscillators, and means whereby the said oscillators may be caused to influence each other to produce a single mean frequency. These means and the oscillations produced thereby may be utilized in any manner. Applicant has however provided further novel means whereby these two constant frequencies form the upper and lower limits between which a carrier frequency may be varied in frequency relative to the mean frequency in accordance with the signals which it is wished to transmit on the carrier.

This frequency modulation is accomplished in accordance with the present invention by differentially modulating the oscillations produced in each of the oscillators. This modulation may be accomplished in any manner. Preferably it is accomplished by applying differentially to the oscillators or to the modulators the modulating signals.

Differential modulation of the oscillations may be accomplished as illustrated in Fig. 1 by connecting the screen grid electrode 30 of tube D

with one terminal of the secondary winding 31 of a modulation transformer T while the other terminal of the winding 31 is connected, as shown, to the screen grid electrode 30' of modulator tube D. Potential variations at signal frequency are set up in the primary winding 32 of transformer T in any manner. These signal oscillations may be impressed on the winding 32 from a microphone 34 connected in series with the biasing source 35 with the winding 32. It will be understood that the means 34 may be replaced by keying means or by any other means which will produce potential oscillations at signal frequency. Any radio frequency oscillations appearing on the screen grid electrodes 30 or 30' of tubes C and D are blocked out of transformer winding 31 by means of inductances 36 and 36'. This is to prevent said frequency oscillations from being transferred from the secondary winding 31 into the primary winding 30 and reaching the modulating means. To further insure that these high frequency oscillations do not reach the secondary winding 31, by-pass condensers 37 and 37' provide a path for such high frequency oscillations between the screen grid electrodes 30 and 30' and the cathodes 22 and 22' respectively.

The operation of the device is as follows:

If modulating potentials are applied to the winding 31 they appear differentially on the screen grid electrodes 30 and 30' and alter the characteristics of these valves sufficiently to change the amount of coupling between the output of one oscillator circuit and the input of the other differentially, thereby swinging between the limits $f+f_1$ and $f-f_1$ the carrier frequency f . This variation in frequency of the carrier f is directly representative of the character of the signal oscillations impressed on 31. Consequently, this system produces oscillations of varying frequency, the frequency of which is truly characteristic of the signal to be transmitted.

In a modification two dynatrons serve the purpose of producing two distinct high frequency waves separated by a constant difference and varying at signal frequency the carrier between said limits. The nature of this circuit will be understood by reference to Fig. 2 of the drawings in which A is a dynatron oscillator having its anode 1 connected through a tank circuit 2 to the positive terminal of a source of potential not shown. Oscillations at a frequency determined by the value of the inductance 6 and variable capacity 4 of the tank circuit 2 are produced in circuit 2. In order that these oscillations do not reach the source of potential, a path including a by-pass condenser 8 is provided between the lower terminal of tank circuit 2 and the cathode 10 of tube A.

The anode 1 of this tube is maintained at a potential less than the potential applied to the screen grid electrode thereof so that a negative resistance effect is produced in the anode cathode circuit, thereby insuring the development of potential variations of a high frequency determined by the nature of the tank circuit 2. This renders unnecessary the use of the impedance of the tube between the cathode and control electrode to produce oscillations. This impedance or conductance of the tube is therefore utilized in accordance with the present invention to couple the oscillation generators together to maintain them in step so that together they produce a frequency which is a mean between their individual tunings. In this manner therefore the present modifica-

tion obviates the necessity of using the separate modulator tubes C and D of the circuit of Fig. 1.

In a similar manner the electrodes of thermionic dynatron B are connected with a tank circuit 2' to produce oscillations in the same manner in which oscillations were produced in the output circuit of A. The oscillations produced by A alone i. e., without being coupled to B, however, as determined by the constants of the oscillation circuit 2, are equal to a frequency $f+f_1$ where f is the carrier, whereas the frequency of the oscillations produced in the tank circuit 2' (without coupling to A) connected to the anode of B, are of a frequency equal to $f-f_1$. In order to couple the oscillation circuit 2 of tube A with the control electrode 12' of tube B and inductance 14 variably coupled to the inductance 6 has one terminal connected to the control electrode 12' of tube B and the other terminal connected to ground. Since the cathode 10' of tube B is grounded, the circuit between the control electrode 12' and cathode 10' is completed by way of the ground. In a similar manner the oscillation circuit 2' of tube B is coupled to the control electrode 12' of tube A as shown. The oscillation circuits 2 and 2' are coupled to the utilization circuit 18 by way of coupling inductances 14 and 14' respectively, as shown. When the two tubes are mutually coupled in this manner they will influence each other so that instead of each oscillatory at its distinct frequency they will entrain and cooperate to produce a single mean frequency f .

Up to this point applicant has disclosed a novel arrangement whereby an oscillation variable between two different frequencies, may be produced and impressed on the utilization circuit.

In order that the frequency of the carrier produced may be varied between the two limits $f+f_1$ and $f-f_1$, the oscillation generators A and B are differentially modulated at signal frequency. This is accomplished in the same manner in which modulation frequencies were differentially impressed on the modulators C and D of Fig. 1. A detailed description thereof is therefore thought unnecessary at this point. It will be noted, however, that the modulation frequencies appearing in 22 are impressed on the primary winding 26 and from the primary winding 26 to the secondary winding 28, and from there to choking inductance 24 and 24' and to the screen grid electrodes 15 and 15' of tubes A and B. Charging potential of a direct current potential higher than that applied to the anodes 1 and 1' is applied at a point on 25 to the screen grid electrodes 12 and 12'. In operation the oscillations produced at 2 and 2' are varied between frequencies $f+f_1$ and $f-f_1$ at signal frequency and are impressed on the utilization circuit 18.

In the arrangement of Fig. 3 the oscillation generators A and B are of the screen grid type. These oscillators are connected in substantially the same manner in which the oscillators A and B are connected in Fig. 1. However, this arrangement differs from the arrangement of Fig. 1 in that the tubes A and B here are of the 4 electrode type and the modulating frequencies are applied to the screen grid electrodes 40 and 40' of the tubes from a filter circuit FC, which is connected to the secondary winding 41 of a transformer 42, the primary winding 43 of which may be connected with a source of modulating frequency, as indicated. Charging potentials for the screen grid electrodes 40 and 40' of tubes A and B may be supplied by connecting the tap on

the secondary winding 41 to the positive terminal of a direct current source not shown, the negative terminal of which is connected to ground so that the screen grid energizing circuit is completed by way of ground to the cathodes 8 and 8' of the tubes A and B respectively. Of course, potential for charging the screen grid electrodes may be taken from the charging sources 44 and 44' in the anode circuits of tubes A and B respectively.

Where screen grid tubes are used it is often necessary to provide capacitive coupling between the anode and control grid of the tubes in addition to the inherent capacitive coupling between said electrodes. This may be accomplished by connecting the anodes 14 and 14' to the control electrodes 7 and 7' of tubes A and B respectively by way of variable capacities C_1 and C_2 . The circuits 10 and 1, and 10' and 1' are tuned to a point such that each of the tubes A and B normally, by themselves, produce oscillations at frequencies $f+f_1$ and $f-f_1$ respectively.

The thermionic coupling means whereby these tubes are mutually coupled to influence each other to produce a single mean frequency f , which is varied between the limits $f+f_1$ and $f-f_1$ when signal frequency is applied to the oscillators A and B, will now be described.

The control grid electrode 21 of coupling tube C is connected to one terminal of an inductance 23, the other terminal of which is connected to ground by way of a biasing source 44. The cathode 22 of coupling tube C is connected to ground, thereby completing the cathode control grid circuit of tube C. In a similar manner the control grid 21' of tube D is connected to the cathode 22' by way of a coupling inductance 23' and biasing source 44. Inductances 23 and 23' are inductively coupled, as in Fig. 1 to the inductances 12 and 12' in the output circuits of the oscillation generators A and B respectively.

The anode 26 of coupling tube 22 is coupled by way of capacity 46 to the tank circuit 1 of tube A. The anode 26' of tube D is coupled by way of coupling capacity 46' to the tank circuit 1'. Charging potentials for the anodes 26 and 26' and for the screen grid electrodes 30 and 30' of tubes C and D respectively are supplied from sources 48 and 48'. The anode electrodes are charged by way of radio frequency choke coils 49 and 49' in order to prevent any high frequency oscillations appearing in tank circuits 1 and 1' from reacting on the coupling tubes C and D.

In operation the oscillations produced by B, the frequency of which is determined in part by the tank circuit 10', are impressed by way of inductance 23' on to the control electrode 21 of coupling tube C. These oscillations, amplified and repeated in C, are impressed on to the tank circuit 1, connected with the input electrodes of oscillation generator A, to influence the frequency of the oscillations produced therein by determining to some extent the tune of the input circuit. In a like manner the oscillations normally produced by A, the frequency of which is determined in part by the elements in the tank circuit 10, are impressed by way of coupling inductance 23 to the control electrode 21' of tube D, are amplified and repeated therein, and impressed from the anode thereof on to the tank circuit 1' connected with the input electrodes of oscillation generator B to influence the same and to determine in part the frequency of the oscillations generated.

Here, as in the prior modifications, the oscillators A and B, when acting alone, produce os-

oscillations at frequencies $f+1$ and $f-1$ respectively, but when coupled together, by way of coupling tubes C and D, produce a mean frequency f . Here, also, as in the prior modifications, the modulating potentials applied to the oscillators A and B, and in particular to the screen grid electrodes thereof, vary the impedance of tubes A and B differentially so that the frequency developed by the two tubes acting together swings at signal frequency around the frequency f as a mean between the limits $f+1$ and $f-1$. In this manner frequency or phase modulation at signal frequency of the oscillations produced by the two generators A and B is accomplished.

The frequency modulated oscillations appearing in the tank circuits 10 and 10' are impressed upon the circuit 16 connected to the input electrodes of a pair of buffer tubes E and F, and from the output circuits of tubes E and F said frequency modulated oscillations may be fed by way of tank circuits 50 and 50' to any utilization circuit, as, for example, to an antenna. These frequency modulated oscillations may be fed by way of a frequency amplitude and/or multiplier 18 to the antenna circuit, as in Fig. 1.

Where a more simplified arrangement is desired the device of Fig. 4 may be used. In this arrangement dynatron oscillators A and B are utilized in circuits somewhat similar to the circuits of Fig. 1. Here, however, mutual coupling between the separate oscillators A and B is provided by coupling the anode 1 of oscillator A by way of a capacity C_4 to the control electrode 12' of tube B and the anode 1' of tube B by way of capacity C_5 to the control electrode 12 of tube A. The control grids 12 and 12' of the dynatron oscillators A and B are maintained at an operating potential by connecting them to the cathodes 10 and 10' by way of resistances R_2 and R_3 .

Here, as in the prior modifications, the generators A and B, each, when taken separately, generate a different frequency but when mutually coupled by way of capacities C_4 and C_5 together generate a mean frequency. Here, also, as in the prior modifications, this mean frequency f generated by tubes A and B is caused to oscillate at signal frequency between the limits $f+1$ and $f-1$ by applying modulating potentials from the modulating potential source by way of transformer 42 and filter FC to the screen grid electrodes 15 and 15' of tubes A and B. Charging potential for the screen grid electrodes 15 and 15' is supplied by connecting the tap on winding 41 to either of the sources 44 or 44' as shown.

The frequency modulated oscillations are impressed on the circuit 16 from which they may be utilized in any manner. For example, they may be coupled by way of coupling tubes similar to E and F of Fig. 3 and amplifiers or frequency modulators of unit 18 of Fig. 1 to an antenna circuit, from which they may be radiated.

It will be understood that the above embodiments of my invention are given for purposes of illustration and are not intended to limit the same since it will be obvious that many modifications may be made therein without departing from the spirit of the invention and marking out in the claims appended hereto. For example, it will be obvious to anyone skilled in the art that plate modulation or grid modulation, or any type of modulation known, might be utilized in place of the screen grid modulation shown for the purpose of varying the intensities of the oscillations or the amount of coupling of one oscillator to the

other. All of the frequency modulators described above may be used to produce phase modulated carriers. This may be accomplished by the use of audio frequency correction circuits as illustrated in United States application Serial No. 608,383, filed April 30, 1932.

Having thus described my invention and the operation thereof, what I claim is:

1. Signalling means including signal generating and signal modulating means comprising, a pair of thermionic oscillation generators each having input and output circuits normally tuned to produce oscillations of different predetermined frequencies, thermionic means for coupling the output circuit of each of said generators to the input circuit of the other of said generators to entrain said generators to produce a single frequency which is a mean between the frequencies normally produced by said generators, a source of signal potentials, and means connecting said source of signal frequencies to said generators for varying at signal frequency the internal impedance of the tubes in each of said generators.

2. Signalling means including a signal generating and signal modulating means comprising a pair of thermionic oscillation generators each having input and output circuits normally tuned to produce oscillations of different predetermined frequencies, thermionic means for coupling the output circuit of each of said generators to the input circuit of the other of said generators to entrain said generators to produce a single frequency which is a mean between the frequencies normally produced by said generators, a source of signal potentials, and means for varying at signal frequency the internal impedance of the tubes in each of said generators.

3. Means for producing radio waves comprising an oscillation generator tuned to oscillate at a frequency above the normal frequency of the oscillations to be produced, an oscillation generator tuned to oscillate at a frequency below the frequency of the oscillations to be transmitted, and thermionic coupling means between the output circuit of each of said generators and the input circuit of the other generator to entrain said generators to operate at the same frequency.

4. Means for producing carrier waves comprising an oscillation generator having an input circuit and an output circuit normally tuned to oscillate at a frequency above the frequency of the carrier to be produced, a second oscillation generator having an input circuit and an output circuit tuned to oscillate at a frequency below the normal frequency of the carrier to be produced, and a thermionic tube coupling the output circuit of each of said oscillation generators to the input circuit of the other of the oscillation generators to entrain the generators to operate at the same frequency.

5. Transmitting means comprising an oscillation generator having an input circuit and an output circuit normally tuned for oscillation at a frequency above the frequency of the carrier to be produced, a second oscillation generator having an input circuit and an output circuit tuned for oscillation at a frequency below the normal frequency of the oscillations to be produced, a thermionic tube coupling the output circuit of each of said oscillation generators to the input circuit of the other of said oscillation generators to entrain the generators to operate at the same frequency, and means for varying the conductivity of said coupling tubes at signal frequency.

6. Means for producing frequency modulated

waves comprising an oscillation generator having a tuned input circuit and an output circuit tuned to oscillate at a frequency above the normal frequency of the oscillations to be transmitted, a second oscillation generator having a tuned input circuit and an output circuit tuned to oscillate at a frequency below the frequency of the oscillations to be transmitted, a thermionic coupling means between the output circuit of each of said generators and the input circuit of the other generator to entrain the generators to operate at a common frequency, a source of signal potentials and means connected between said source and said coupling means for varying the impedance of said coupling means at signal frequency.

7. Carrier frequency producing and modulating means comprising, a pair of thermionic tubes of the screen grid type, each having their anodes connected in tuned circuits and their control electrodes connected in circuits, said circuits being coupled to produce sustained oscillations, said anode circuits being tuned to different frequencies, a thermionic tube coupling the anode circuit of one of said tubes to the control electrode circuit of the other of said tubes, a second thermionic tube coupling the anode circuit of said last named tube to the control electrode circuit of said first named tube, a source of modulating potentials connected in phase opposition to the screen grid electrodes of said first named pair of tubes, and a utilization circuit coupled to the anode circuits of both of said oscillator tubes.

8. Carrier frequency producing and modulating means comprising, a pair of thermionic tubes of the screen grid type, each having their anodes connected in tuned circuits and their control electrodes connected in tuned circuits, said anode circuits being tuned to different frequencies, a thermionic tube of the screen grid type coupling the anode circuit of one of said tubes to the control electrode circuit of the other of said tubes, a second thermionic tube of the screen grid type coupling the anode circuit of said last named tube to the control electrode circuit of said first named tube, a source of modulating potentials connected in phase opposition to the screen grid electrodes of said last named tubes, and a utilization circuit coupled to the anode circuits of both of said oscillator tubes.

9. A device for producing carrier frequency oscillations and modulating the same in frequency including, a pair of thermionic tubes, each having a cathode, anode, control electrode and screen grid electrode, oscillation circuits including reactances connected between the anode and cathode of each of said tubes, one of said circuits including a capacity to tune the same to a frequency slightly above the desired mean frequency and the other of said circuits including a capacity to tune the same to a frequency slightly below the desired mean frequency, a circuit including a reactance connected between the grid and cathode of each of said tubes, cross couplings between said last named circuits and said first named circuits, a source of modulating potentials, circuits connecting said source of modulating potentials in phase opposition to the screen grid electrodes of said tubes, and means for applying positive potentials to the anode and screen grid electrodes of said tubes, the potential applied to the screen grid electrodes being greater than the potential applied to the anode electrodes, whereby a negative resistance effect is

produced in said tubes to insure the development of oscillations in the anode circuits of said tubes, the frequency of the oscillations produced being varied at signal frequency in accordance with the variations in potential applied in phase opposition to the screen grid electrodes of said tubes from said source.

10. A circuit for producing radio waves including, an oscillation generator tuned to oscillate at a frequency slightly above the normal frequency of the oscillations to be produced, an oscillation generator tuned to oscillate at a frequency slightly below the frequency of the oscillations to be transmitted, thermionic coupling means between the output circuit of each of said generators and the input circuit of the other of said generators, and means for varying the frequency of the oscillations produced by said combined oscillators between the mean frequencies of said separate oscillators as limits including circuits for applying modulating potentials in phase opposition to the impedances of said coupling means.

11. Means for producing carrier waves including, an oscillation generator having an input circuit and an output circuit tuned to oscillate at a frequency slightly above the carrier frequency to be produced, a second oscillation generator having an input circuit and an output circuit tuned to oscillate at a frequency slightly below the frequency of the carrier to be produced, a separate thermionic tube coupling the output circuit of each of said generators to the input circuit of the other of said generators, and means for varying the frequency of the oscillations generated by said combined oscillators between the frequencies of the separate oscillations as limits including a circuit for applying modulating potentials in phase opposition to said generators.

12. A device for producing carrier frequency oscillations including, a pair of thermionic tubes each having a cathode, an anode and a control electrode, oscillation circuits connected between the anode and cathode of each of said tubes, one of said circuits including means to tune the same to a frequency above the desired mean frequency and the other of said circuits including means to tune the same to a frequency below the desired mean frequency, a tuned circuit connected between the control grid and cathode of each of said tubes, a coupling tube having its input electrodes coupled to the anode of one of said pair of tubes and its output electrodes coupled to the control electrode of the other of said pair of tubes, a second coupling tube having its input electrodes coupled to the output electrodes of said last named tube of said pair of tubes, and its output electrodes coupled to the control electrode of said first named one of said pair of tubes, whereby said tubes are connected in a completed cascade chain, a portion of which is tuned to oscillate at one frequency and a portion of which is tuned to oscillate at another frequency, the coupling between said portions entraining the same to oscillate at a mean frequency.

13. A device as recited in claim 12 including, means for varying the electrical characteristic of said portions oppositely at signal frequency to thereby vary the frequency generated by the entrained oscillators together at signal frequency.

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