

Oct. 22, 1940.

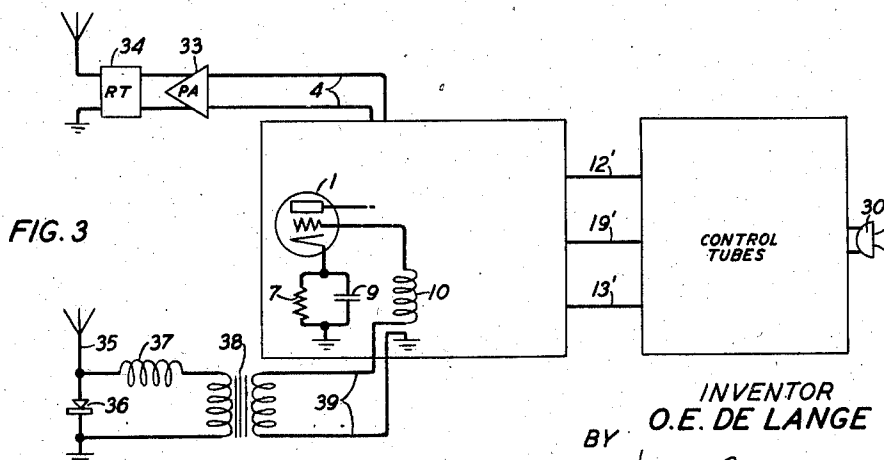
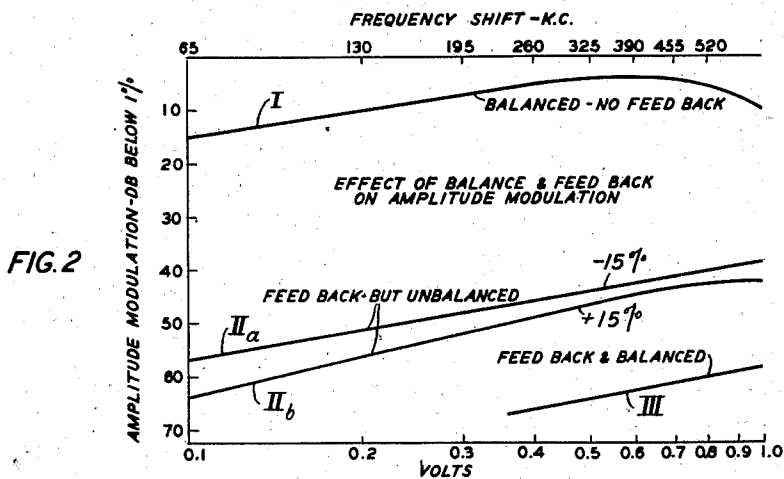
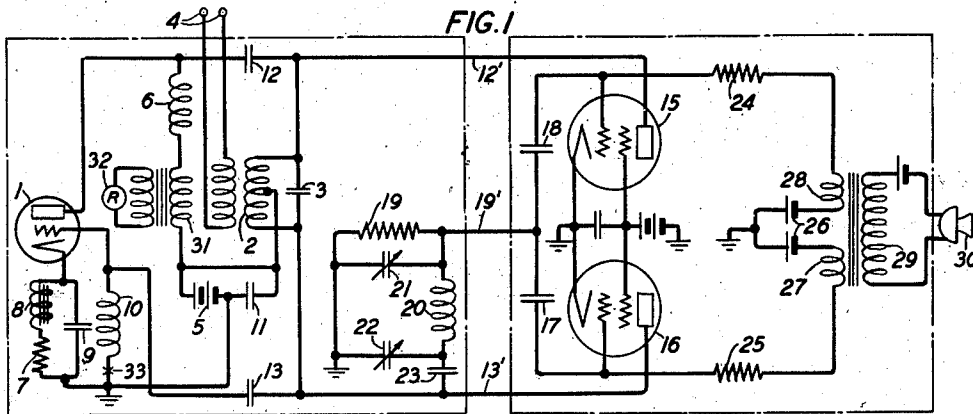
O. E. DE LANGE

2,218,526

TRANSMISSION OF FREQUENCY-MODULATED WAVES

Filed March 31, 1939

2 Sheets-Sheet 1



INVENTOR
O. E. DE LANGE
BY *H. A. Burgess*
ATTORNEY

Oct. 22, 1940.

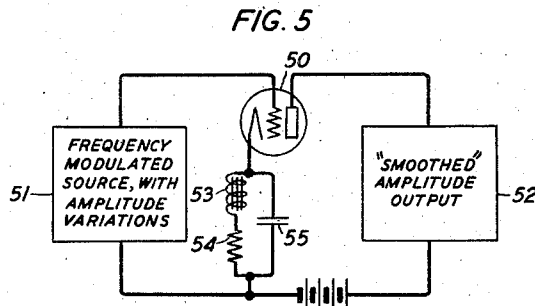
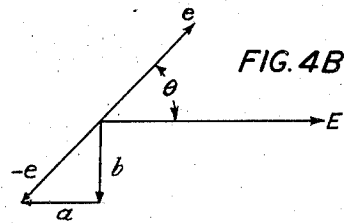
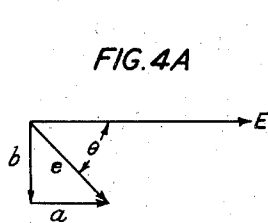
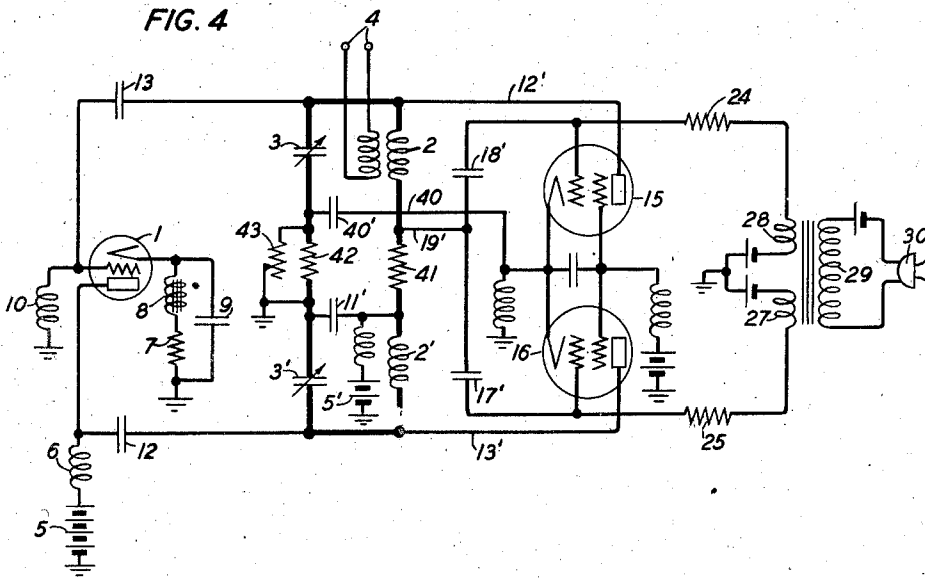
O. E. DE LANGE

2,218,526

TRANSMISSION OF FREQUENCY-MODULATED WAVES

Filed March 31, 1939

2 Sheets-Sheet 2



INVENTOR
O. E. DE LANGE
BY *K. A. Burgess*
ATTORNEY

UNITED STATES PATENT OFFICE

2,218,526

TRANSMISSION OF FREQUENCY-MODULATED WAVES

Owen E. De Lange, New York, N. Y., assignor to
Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Application March 31, 1939, Serial No. 265,098

12 Claims. (Cl. 179-171.5)

The present invention relates to electrical wave transmission in which signals are sent by varying a characteristic of the waves other than the amplitude, such as by varying the frequency or phase.

A general object of the invention is to facilitate modulation of the wave frequency and/or transmission of the modulated wave while preventing or reducing accompanying amplitude modulation.

It has heretofore been proposed to rid a frequency-modulated wave of undesired amplitude modulation by detecting a portion of the wave in an amplitude detector and applying the detected audio wave in reverse phase to a suitable part of the system, such as to the grid of an amplifier or to the plate of an oscillator to produce reverse amplitude modulation of the right amount to cancel the original undesired amplitude modulation.

Such schemes, as heretofore proposed, used a special detector for deriving the audio or low frequency modulation component and involve difficulties in attaining optimum phase relations. Especially in the case where the correcting component is used to modulate the plate of the oscillator, complication is involved in securing requisite amplification together with the required phase relation.

The present invention represents a simplification over the prior art and makes for increased efficiency in that, in the preferred forms, the correcting component is derived by plate rectification in the oscillator or repeater tube itself and is directly applied to the grid of the same tube in reverse phase so as to cancel the amplitude modulation.

The successful practice of the invention requires use of a circuit which is effective as a modulator for modulating waves impressed on the grid. In the case of an oscillator applicant has found it very advantageous to use a type of circuit in which the grid at all times has a negative voltage and does not draw grid current. The usual grid-leak type of circuit is a poor modulator for modulating waves impressed on the grid. In the grid-leak oscillator the oscillations are limited in amplitude by the grid losses, that is, losses due to grid current flow. The grid is driven positive in each cycle by such an amount that a balance is reached between the maximum instantaneous grid voltage and the negative grid bias which is, in turn, a function of the grid current. When a modulating wave is placed on the

grid, it tends to vary the bias and this tends to be offset by a corresponding change in grid current.

In an oscillator of the type in which no grid current is allowed to flow, however, the oscillations must be limited by losses in some other part of the circuit from the grid circuit, for example, by plate circuit losses. In the preferred arrangement the grid is biased from a drop of potential in the plate circuit and the oscillations are limited in amplitude by the balance between plate rectification and the resulting grid bias. Now, when the wave has amplitude variations representing noise, signal modulation or the like, this plate rectification also serves to derive the noise, signal or other modulating component of the high frequency wave. Either the same coupling which serves to bias the grid, or an additional coupling or partly one and partly the other, may serve to impress the detected modulating component back on the grid. The fact that the circuit is an efficient modulator for modulating waves applied to the grid, means that the circuit is also effective in wiping out the amplitude modulations. In its simplest form the circuit may use an audio frequency impedance in the cathode lead common to the plate and grid circuits, with supplemental grid bias means where necessary. The low frequency amplitude modulating wave is directly recovered by plate circuit rectification and put back on the grid in proper phase by the coupling afforded by the common impedance in the cathode lead. This effect can be brought about, though usually to a lesser degree, by insertion of a high audio frequency impedance in series with the oscillator plate circuit. Such an impedance results in inverse plate circuit modulation even for oscillators drawing grid current.

In certain specific disclosures to follow of preferred embodiments of the invention, a space discharge tube oscillation generator is frequency modulated in the general manner disclosed in my prior application Serial No. 152,674, filed July 9, 1937, by use of control tubes having their plate impedances in shunt relation to the tank circuit and varied by the signals and also by waves in phase quadrature to those in the tank circuit. Amplitude modulation is reduced, in accordance with a feature of the present invention, by use of a negative feedback at signal frequency around the oscillator. Further reduction in amplitude modulation is obtained in accordance with this invention by providing a very accurate control over the phase of the waves applied from the

tank circuit to the grids of the control tubes whereby the required phase quadrature relation is obtained with high accuracy.

The negatively fed-back low frequency wave need not be taken directly from the oscillator plate. It can be fed to the oscillator grid from a point beyond the oscillator plate, such as from a point in the load circuit, in which case it causes reduction of amplitude variations arising anywhere inside the feedback loop and representing amplitude modulation, power disturbances, noise, harmonics, distortion or other forms of amplitude variations.

In its broad aspects the invention is not dependent upon the use of this or any particular way of effecting the frequency modulation, and it will be understood that the specific circuits disclosed are given as preferred forms and for illustrative purposes.

The nature and objects of the invention will be made more apparent from the detailed description which follows when read in connection with the accompanying drawings, in which:

Fig. 1 is a schematic circuit diagram of a complete generating and modulating system in accordance with the invention;

Fig. 2 shows performance curves for the circuit of Fig. 1;

Fig. 3 shows the application of the circuit of Fig. 1 to a radio transmitter with a modified type of amplitude reducing negative feedback;

Fig. 4 shows a system generally similar to that of Fig. 1 but with a different type of circuit for deriving phase quadrature waves;

Figs. 4A and 4B show diagrams explanatory of phase relations obtained with the system of Fig. 4; and

Fig. 5 shows a generalized smoothing circuit for frequency modulated waves in accordance with the invention.

In Fig. 1, the oscillator tube 1 is provided with tank circuit 2, 3 tuned to the desired radio wave frequency. The load terminals 4 are shown inductively coupled to the inductance 2. Plate voltage is supplied from source 5, which may be of any suitable type, through radio frequency choke coil 6. The negative pole of the source 5 is connected to ground and to the cathode of the tube 1 through the bias resistor 7 and speech frequency choke coil 8, these two latter elements being shunted by the radio frequency by-pass condenser 9. The grid is connected to ground through radio frequency choke coil 10. The plate and grid are connected across the tank circuit 2, 3 through stopping condensers 12 and 13.

The terminals of the tank circuit 2, 3 are connected by leads 12' and 13' to the plates of two control tubes 15 and 16. These tubes are supplied with plate potential from source 5 by way of inductance 2 and leads 12' and 13'. The cathodes of control tubes 15 and 16 are connected to ground and it will be observed that the plate impedance of tube 15 is connected across the upper half of inductance 2 while the plate circuit of control tube 16 is connected across the lower half of inductance 2 so far as high frequencies are concerned.

The control tubes 15 and 16 have their grids connected to receive phase quadrature waves from conductor 19' in a manner to be described and also connected in push-pull relation to the circuit of microphone 30. For this purpose the grids are connected through resistances 24 and 25 to the outside terminals of secondary wind-

ings 28 and 27, the inner terminals of which are ground. The common primary winding 29 is connected to transmitter 30.

Between the grid terminal of the tank circuit and the conductor 19' is inserted a phase shifting network comprising series inductance 20 and variable shunt capacities 21 and 22 with terminating resistance 19. Condenser 23 is a stopping condenser. The purpose of this phase shifting network is to derive radio frequency waves from the oscillation generator circuit and apply them to the grids of the control tubes 15, 16 in phase quadrature relation to the waves in the oscillation generator circuit for the purpose of achieving frequency modulation in the general manner disclosed in my prior application referred to above.

When no speech is applied to the control tubes 15 and 16 the phase quadrature waves applied to their grids produce no effect on the frequency of the waves generated. This is because the radio frequency variations in impedance in one tube tend to introduce effective increase in inductance into the tank circuit while the opposite tube at the same time tends to introduce effective decrease of inductance, due to the 90 degree phase relation between the waves in the tank circuit and the impedance changes produced in the control tubes. Speech waves spoken into the transmitter 30 upset this balanced condition and produce a net change in the effective tuning reactance of the tank circuit. The change in the tuning is proportional to the amplitude of the speech waves. In this manner, it has been found, frequency modulation of a high degree of linearity is secured. However, since the control tubes 15, 16 are shunted across the tank circuit and have their impedances varied at speech frequency, there is a resultant tendency for the production of amplitude modulation.

It has been found that the amplitude modulation is sensitive to slight departures of the phase of the radio frequency waves applied to the control tubes from exact phase quadrature relation to waves in the tank circuit. It has been found by experiment that the amplitude modulation can be greatly reduced by adjusting these waves to exact phase quadrature relation. This is done in the circuit of Fig. 1 by varying the shunt condenser 21, and, under some circumstances, the condenser 22. In one type of circuit used by applicant where the operating frequency was 20 megacycles, the value of the resistance 19 was 500 ohms and the inductance 20 and capacities 21 and 22 had the following values: Inductance about 6 microhenries which would mean a capacity of about 10 micro-microfarads.

The effect on the amplitude modulation of lack of exact 90 degree phase relationship is shown by curves IIa, IIb and III of Fig. 2. Curve III shows the total improvement obtained by balancing the phase shifting network to exact 90 degree phase shift and by the use of the feedback to be described presently. Comparison of curve III with the two curves IIa and IIb, in which the same feedback was used, shows the increase of amplitude modulation obtained when there was a 15 per cent departure from exact 90 degree phase shift.

The amplitude modulation can also be reduced very effectively by employing a negative feedback operative at speech frequencies between the plate and grid circuits of the oscillator 1. This is secured in the circuit of Fig. 1 by the employment

of speech frequency choke inductance 8 in the cathode lead.

It is here pointed out that the oscillation generator shown in Fig. 1 is of the "no-grid current" type operating somewhat similarly to a class B amplifier. This differs in action from the type of oscillator using a grid leak in that in the case of the latter it is difficult or in some cases practically impossible to change the amplitude of oscillation to any appreciable extent by superposing a voltage on the grid circuit. In the grid leak type of oscillator it is necessary that grid rectification take place and it is the grid rectification which limits the amplitude. The oscillator of Fig. 1 has its grid biased negatively from the drop of potential in resistance 7 and the drop in the direct current resistance of coil 8. The plate circuit acts as a two-electrode rectifier supplying direct current through 7 and 8. When the tube is turned on, it begins to generate oscillations, at first of low amplitude but increasing rapidly with time. As the full load amplitude is approached the amplitude will be limited because the gain through the tube will be reduced in two ways. First, because of rectification, the direct current is increased. This increases the grid bias. This means that for a given drive the grid does not swing as far positive and the peak pulse current in the tube will not be so great. Second, because of the increased bias the width of the plate pulse is reduced. This means that the fundamental component of the plate current will not be as large a fraction of the pulse amplitude. When the voltage gain ratio of the tube has been reduced by these means until it is equal to the reciprocal of the feedback ratio there will be no further increase in amplitude.

Such an oscillator has been found especially suited to the present uses in that the amplitude modulating component is directly obtained by plate rectification and the negative feedback of the signal frequency is very effective in counteracting signal frequency amplitude variations in the high frequency output. The rectification in the plate circuit furnishes a speech frequency component directly, assuming there is some amplitude modulation, without the use of any further detecting action, so that the mere provision of the speech frequency impedance in the form of inductance 8 in the common cathode lead produces the required negative feedback action in the oscillator circuit.

The effect of the negative feedback in reducing the amplitude modulation may be seen from comparing curve I of Fig. 2 with curve III. Curve I shows the best results obtainable by adjustment of network 21, 22, etc. but without feedback. When the feedback was added, curve III was obtained. The curves of this figure were plotted from data taken dynamically by modulating the oscillator at a frequency of 1,000 cycles and measuring the resultant component of oscillator plate current of this frequency. For example, in Fig. 1 the audio transformer 31 inserted in the oscillator plate circuit was used. A suitable indicator R is shown at 32 connected to the secondary of this transformer. Ordinates on the curves of Fig. 2 indicate amplitude modulation in decibels below 1 per cent modulation. Curve I shows that with the condenser 21 adjusted for a minimum amplitude modulation and with no feedback, modulation to the extent of plus and minus 400 kilocycles results in nearly 1 per cent of amplitude modulation. With feedback the amount of

modulation is reduced to that shown by curve III by about 58 decibels.

The balancing of the circuit of Fig. 1 is done very simply by the following procedure. With the oscillator adjusted to the desired carrier frequency the terminals of secondary winding 32 of the plate transformer are connected through an audio amplifier to a detector or other indicator. A modulation voltage is applied and the resultant indication at 32 noted. Condenser 21 is now adjusted until this indication is a minimum. If condenser 22 does not line up perfectly with condenser 21 there may be some change of frequency due to the balancing operation but the original frequency can be restored by means of tank condenser 3. If condensers 21 and 22 are equal, the impedance looking into the phase shifting network is a pure resistance and remains so for all values of capacity as long as equality exists. Then simultaneous variations of 21 and 22 will not vary the reactive component of the tank circuit and so will not affect frequency of oscillation. If 21 and 22 are not equal, the impedance looking into the network has a reactive component which varies with condenser setting making retuning necessary with each adjustment. Except for this effect, condenser 22 could be eliminated, being effectively produced in the tank circuit.

Referring to Fig. 3 the circuit is the same as that of Fig. 1 except for the manner in which the negative feedback of the signal is obtained. The circuit of Fig. 3 has, therefore, been drawn in the form of boxes except for the parts of the circuits that are involved in the change. The speech frequency inductance 8 has been removed from the cathode lead of the oscillator, although if desired, it could be left in the circuit in which case the additional feedback to be described would merely supplement that due to the inductance 8. The output terminals 4 are shown connected through power amplifier 33 to a radio transmitting terminal RT shown at 34. 33 and 34 are to be considered merely typical of any actual radio transmitter which may include any usual amplifying, modulating, filtering or other equipment together with the necessary power sources. A small pilot antenna 35 is arranged to pick up some of the radiated wave from station 34, which is detected at 36, and the detected component is transmitted through audio transformer 38 and circuit 39 to the grid circuit of the oscillator 1. For this purpose the grid circuit is opened up at point 33 of Fig. 1 and the circuit 39 is serially included. Inductance 37 is a radio frequency choke coil and it is to be understood that the details of the pilot antenna 35 and the detecting apparatus may be varied widely to suit conditions, the form shown being simplified for illustrative purposes. Care must be taken in the design and connection of the parts to insure that the feedback is in the proper phase to achieve the desired result, that is that the feedback is negative and as nearly 180 degrees as feasible with respect to the plate current variations which it is desired to wipe out. A phase correcting network in leads 39 may be necessary to attain these results.

An advantage of the feedback circuit of Fig. 3 is that it not only minimizes amplitude modulation occurring in the portion of the circuit shown in Fig. 1 but also that it minimizes all variations of amplitude arising from any source within the feedback loop consisting of the oscillator 1, output circuit 4 and apparatus 33, 34, 35, 36, 37, 38

and 39. For example, noise arising from power sources, tubes or other causes and coming into this feedback loop, also modulation, harmonics, etc., will all be reduced approximately to the extent of the reduction in gain around the loop due to feedback, in accordance with the theory and manner of operation more fully disclosed in United States patent to H. S. Black 2,102,671, issued December 21, 1937. All such variations in amplitude of the radio frequency waves show up as variations in voltage on the grid of the oscillator 1 tending to produce amplitude modulations of reverse sign in the radio frequency output wave. In this manner reduction of the amplitude variations is brought about.

It is desirable that elements 35, 36 and 37 have a flat frequency response over the high frequency band employed, otherwise frequency modulation will result in some amplitude modulation from this lack of flatness.

Referring to Fig. 4, the description already given of Fig. 1 applies in the main to the circuit of Fig. 4 (where similar reference characters are used) except for the means used to derive quarter-phase waves from the tank circuit for application to the grids of the control tubes 15 and 16. In Fig. 4 the tank circuit is composed of divided inductance 2, 2' and divided capacity 3, 3'. Resistance 41 is included serially in the inductance branch and resistance 42 is serially included in the capacitive branch, and these two resistances are effectively connected in series in the common cathode grid circuit portion of control tubes 15, 16. This circuit may be traced beginning at the common cathode terminal of tubes 15, 16 (which is off ground for high frequencies), through conductor 40 and blocking condenser 40', to the top terminal of resistance 42, thence downward through that resistance, through blocking condenser 11' to the lower end of resistance 41, upwards through resistance 41, and through blocking condensers 18' and 17' to the grids of tubes 15 and 16. It will be seen, therefore, that, with reference to direction of voltage taken in the figure as upward or downward, the voltage applied to the grids of tubes 15, 16 consists of the potential drops in resistors 42 and 41 in series, one of which is reversed in direction with respect to the other. Resistance 42 is shown shunted by a variable resistance 43 for adjustment purposes.

The voltage across a resistance in one branch of the tuned circuit will not be exactly in phase quadrature with the voltage across the tank circuit, provided the resistance is at all comparable with the reactance of that branch. Referring to Fig. 4A, for example, if vector E represents the voltage across the grid half of the tank circuit, the voltage e across resistor 41 may be considered lagging behind E by angle θ , which is less than 90 degrees. If the parallel combination 42, 43 is adjusted to equal 41, an equal voltage e is developed but it leads the voltage vector E by the same angle θ as shown in the upper part of the diagram of Fig. 4B. Since the voltage drops in 41 and 42, 43 are added with one of them reversed in sign, in the grid circuit of tubes 15, 16, it is seen that the real components (horizontal components a , a in Figs. 4A and 4B) cancel whereas the quadrature components b , b add. Use of resistors in both legs of the tank circuit as in Fig. 4 not only reduces the deviation from exact phase quadrature but doubles the amplitude of the derived voltage.

In Fig. 5 the tube 50, which may be a triode

or multigrid tube, has its input or grid circuit suitably coupled to a source of frequency modulated waves which are varying in amplitude in some undesired manner. The tube 50 may serve for amplifying these waves but it also performs the function of suppressing the undesired amplitude variations, so that the output waves at 52 are "smoothed" as regards amplitude variations. This figure is quite general as to the nature of the circuits 51 and 52 since these may be of any suitable character. For example, circuit 51 may be a frequency-modulating system of a type known in the art, and circuit 52 may be a transmitting circuit such as an antenna or line; or tube 50 may comprise part of a receiving system for frequency-modulated waves in which case circuit 52 would be the converting circuit or lead to the converting circuit. It will further be evident that the circuit of Fig. 5 may be a multi-stage circuit of appropriate number of stages.

The tube 50 and its associated circuits are adjusted, as hereinbefore described, to operate with plate rectification and with the grid bias obtained from the plate circuit and always negative. It should be noted that in this case, however, it is not necessary that the grid bias be derived from cathode resistance but can be obtained from a battery, since the tube is not an oscillator. Bias resistor 54 is shown for deriving a voltage from the flow of plate current and for impressing such voltage on the grid for bias. The high frequency currents are by-passed through capacity 55 while the low frequency currents are highly impeded by the circuit 53, 54, 55, the inductance 53 being a low frequency choke coil. By low frequency is meant the frequency of the amplitude variations which it is desired to suppress. In the case of a wave frequency modulated by speech with accompanying amplitude variations of speech frequency, choke 53 and condenser 55 would have high impedance at speech frequencies. Similarly, with lower frequency variations.

The plate rectification in tube 50, due to bias of the tube near its plate current cut-off or at least highly negatively, results in the flow of rectified current including the speech frequency component or components of other low frequency in the plate circuit. These produce voltage variations of corresponding form between the ends of the network 53, 54, 55, which are impressed back on the grid in such phase as greatly to reduce the resulting amplitude variations in plate current. The frequency modulated high frequency or radio frequency waves with "smoothed" amplitude appear in outgoing circuit 52 which may (as in usual practice) include tuning or filtering, if desired.

The invention is not to be construed as limited to the circuit details that have been chosen for illustrative disclosure of the invention nor to the numerical values given, since the various circuit features and manner of use may vary widely within the scope of the appended claims.

What is claimed is:

1. In a system for transmitting frequency-modulated waves and purifying such waves of accompanying amplitude modulation, a space discharge device having a cathode, an anode and a grid and serving as a transmission element for said waves, means to bias the grid negatively a sufficient amount to cause efficient anode rectification whereby the modulation component of any amplitude modulation present in said waves is caused to appear in the anode circuit of said

device, and means feeding back said component to said grid in negative sense and in sufficient amount to substantially eliminate said amplitude modulation.

2. In combination, an oscillation generator having at least the elements of a triode, means to modulate the frequency of the generated waves in accordance with signals, said means having a tendency to produce undesired amplitude modulation of the generated waves by said signals, a direct current coupling between the anode and grid for limiting the amplitude of the generated waves under control of anode rectification, and a signal frequency negative feedback connection from the output to the input of said triode to oppose said tendency to produce amplitude modulation.

3. In a frequency modulation and transmission system, an oscillation generator having at least the elements of a triode, a source of signal waves, means to modulate the frequency of the generated waves in accordance with said signal waves, with tendency for accompanying amplitude modulation, means to limit the amplitude of the generated waves under control of plate rectification in said triode, such plate rectification incidentally recovering the audio component of any audio frequency amplitude modulation in said waves, and means to impress such recovered audio component back on the grid of said triode in such phase as to counteract said amplitude modulation.

4. In combination, a space discharge device having cathode, anode and grid elements, a coupling between the anode and grid circuits causing said device to generate sustained high frequency oscillations, a source of signal waves, means to modulate the frequency of said oscillations in accordance with said signal waves, said means having a tendency to produce undesired amplitude modulation of the generated waves by said signals, means to derive a negative bias potential for said grid from the flow of current in the anode circuit and independently of the flow of any current in the grid circuit, and means for substantially reducing amplitude modulation comprising a negative feedback coupling from said anode to said grid effective at audio frequency but ineffective at radio frequency.

5. In combination, a space discharge device having cathode, anode and grid elements, a source of signal waves, means setting up in the grid and anode circuits of said device a frequency modulated radio frequency wave the frequency modulation component of which corresponds to said signal waves, a source of anode potential, an impedance having finite resistance to direct current connected between the negative pole of said source and the cathode, a grid bias connection to said impedance, applying therefrom to said grid a negative bias potential sufficient to produce efficient anode rectification whereby the modulation component of any amplitude modulations present in said frequency modulated waves is caused to appear in the anode cathode circuit, said impedance having sufficient impedance at the frequency of said modulation component to impress such modulation component back on the grid in opposite phase and with sufficient amplitude to substantially eliminate such amplitude modulation.

6. In a frequency modulating system, a space discharge tube having a cathode, a grid and an anode, means including a resonant circuit providing positive feedback from said anode to said

grid for causing said tube to generate oscillations, means for varying the frequency of the generated oscillations as a function of a signal to be transmitted, said last means having a tendency to produce amplitude modulation of said generated oscillations by the signals, and means feeding back negatively from said anode to said grid, direct current voltage for biasing the grid negatively and voltage variations of the signal frequency for substantially reducing said amplitude modulation of the generated oscillations.

7. In a frequency modulating system, a space discharge device having a cathode, grid and anode, a grid circuit and an anode circuit, a radio frequency resonant feedback coupling from the anode circuit to the grid circuit for causing said device to generate radio frequency oscillations, means for varying the resonant frequency of said feedback coupling under control of signals to produce frequency modulation of the generated waves, said last means having a tendency to produce amplitude modulation of said generated oscillations by the signals, means maintaining the grid negative at all times under control of the anode current, and a signal frequency negative feedback path from said anode circuit to said grid circuit for substantially reducing production of amplitude modulation of the generated waves.

8. In a frequency modulating system, an oscillator, means comprising a resistor common to the grid and plate circuits for biasing the grid negatively at all times, means to vary the frequency of the generated oscillations under control of signals to produce frequency modulation of the generated waves, and a signal frequency impedance in series with said resistor and common to the plate and grid circuits for opposing production of amplitude modulation in the generated waves.

9. In a frequency modulation system, an oscillation generator comprising a space discharge tube having a cathode, grid and anode, a tank circuit, suitable connections between the tube elements and the tank circuit to cause the generation of sustained oscillations in the tank circuit, a control tube having its space impedance connected across said tank circuit, means to control said space impedance in accordance with signals and also in accordance with the oscillatory voltage across said tank circuit but in quadrature phase relation thereto, whereby frequency modulation of the generated waves is produced with accompanying tendency for amplitude modulation to occur, means biasing the grid negatively as a function of average anode current flow and a negative feedback coupling for the oscillation generator tube feeding back signal frequency waves in reverse sense to counteract said tendency for amplitude modulation.

10. In a signal transmission system, a frequency-modulated grid-controlled oscillation generator, a transmission path for the frequency-modulated waves coupled thereto, and means for reducing undesired amplitude variations in the waves being transmitted comprising means for detecting such undesired amplitude variations and applying them to the grid of said oscillation generator in opposing phase relation, said oscillation generator comprising a space discharge device having a cathode, a grid and an anode, a space current source, and grid bias means consisting of a resistance connected in the space current circuit between the negative pole of the space current source and the cathode, with a

bias connection from a point on said resistance to the grid, whereby the amplitude of the generated oscillations is limited by plate rectification to substantially the amplitude of the generated waves in the absence of amplitude modulation.

- 5 waves in the absence of amplitude modulation.
11. In a frequency modulation system, a space discharge oscillation generator including a frequency determining tank circuit comprising an inductance branch and a capacity branch, a resistor in series in each branch, a control tube having its plate impedance in shunt relation to said tank circuit, means comprising a grid for controlling the plate impedance of said control tube in accordance with modulating waves,
- 10 means comprising a circuit including said two resistors in series for applying phase quadrature

voltages, in additive relation, to the grid circuit of said control tube, and a negative feedback circuit for said generator ineffective at the generated wave frequency but effective at the modulating wave frequency for reducing amplitude modulation.

12. A modulation system according to claim 9 in which the means to control said space impedance in accordance with waves of the oscillation frequency but in quadrature phase relation thereto includes a phase shifting network between the tank circuit and said control tube for producing accurate 90 degrees phase shift in the waves used to control said space impedance.

OWEN E. DE LANGE.