

June 14, 1938.

S. BALLANTINE

2,120,882

MODULATOR

Filed March 28, 1935

2 Sheets-Sheet 1

Fig. 1.

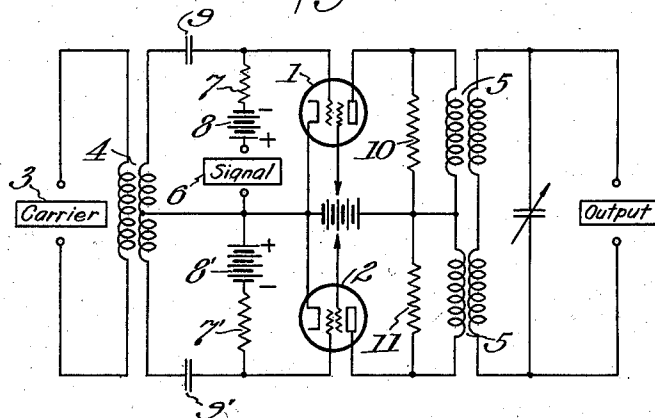
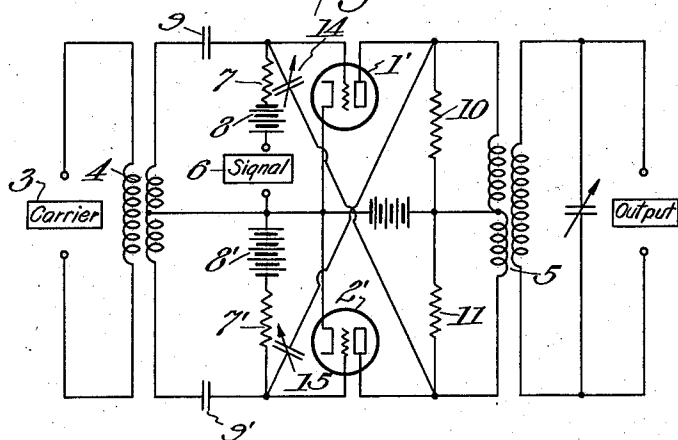


Fig. 2.



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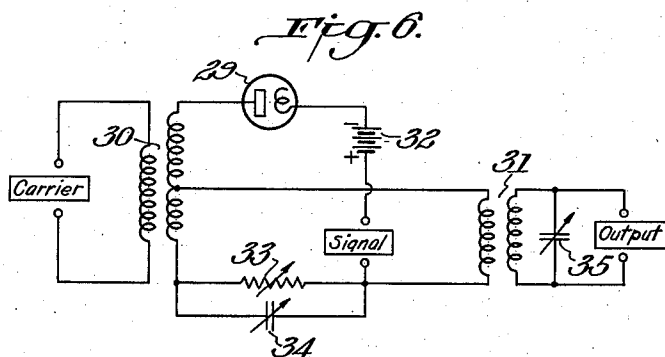
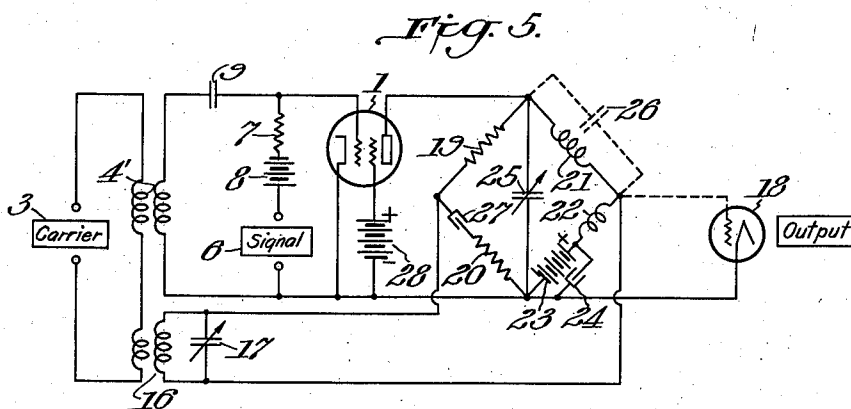
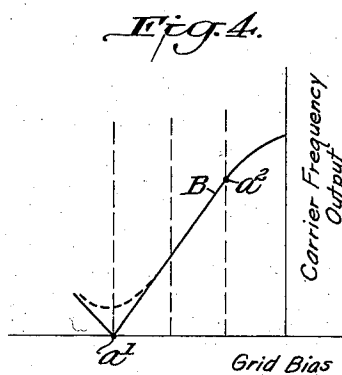
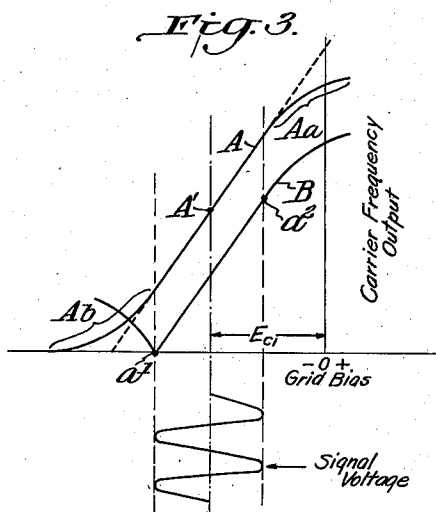
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2 Sheets-Sheet 2



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UNITED STATES PATENT OFFICE

2,120,882

MODULATOR

Stuart Ballantine, Mountain Lakes, N. J.

Application March 28, 1935, Serial No. 13,527

22 Claims. (Cl. 179-171)

This invention relates to modulators suitable for employment in electrical communication systems and for similar purposes.

Objects of the invention are to provide modulation methods and circuit arrangements which are characterized by the ability to provide complete (100%) modulation. An object is to provide a method of modulation in which the carrier is suppressed, leaving only the side bands. Further objects are to provide methods and apparatus which substantially eliminate distortion over the full range of modulation.

These and other objects and advantages of the invention will be apparent from the following specification when taken with the accompanying drawings in which:

Figs. 1 and 2 are circuit diagrams of modulators embodying the invention;

Figs. 3 and 4 are curve sheets showing the relation of carrier frequency output to grid bias; and

Figs. 5 and 6 are circuit diagrams of further embodiments.

The principles of my invention may be illustrated by means of the embodiment shown in Fig. 1, which represents a modulator suitable for radio or carrier-wave communication. Here 1 and 2 represent vacuum tubes having, preferably, a square-law relation between plate current and control-grid voltage. Carrier energy from any suitable source 3 is impressed upon the grid circuits of these tubes symmetrically by means of the split-transformer 4. The output transformer 5 includes two sections so wound and connected that the carrier outputs of the two tubes are in opposition. Tube 1 is modulated by impressing the signal voltage, from a source 6, upon its control-grid through the resistance 7. The mean grid potential is adjusted by means of battery 8 and condenser 9 serves to keep the transformer 4 from short-circuiting the voltage developed by the signal between grid and cathode of tube 1. The output from the tube 2, which I shall call the balancing-tube, is not modulated; and the tube serves simply to amplify the carrier. Its grid is biased by adjustable battery 8' through resistance 7', and a condenser 9' is added so that the circuit will be symmetrical with the corresponding circuit of tube 1 in order that the carrier phases may be equal. The values of the elements 7', 9' will in general be chosen equal to the values of the corresponding elements 7, 9 of the modulator tube circuit.

The primaries of the transformers 5 are

shunted by resistances 10 and 11 to prevent a difference in phase between the outputs of tubes 1 and 2, or a shift in phase during modulation. The values of these resistors are chosen low enough to swamp the variation of effective plate resistance with grid bias, and will depend upon the extent of this variation. The tube may be regarded as a generator having the external resistance and the plate-cathode resistance in parallel across its terminals and, when the external resistance is small and of constant value, the variation of the plate-cathode resistance has a diminished effect upon the effective plate resistance. By appropriate choice of the relative values of the two parallel resistances, the variations of the effective plate resistance can be made negligible to any desired approximation, and the combination acts as a tube of variable gain but substantially constant effective plate resistance. Tube operation of this type has special advantages in the circuits described since the phase relations in the plate circuits of each tube are not affected by the variations which take place in the tube gain when the grid bias is varied. At any value of grid bias which may occur throughout the whole cycle of modulation, the phase relationship of 180° remains intact and therefore phase modulation is avoided.

If the change of plate resistance with control-grid bias is negligible, the resistors may be omitted. If the change is significant, they may advantageously be given values which are low compared with the plate resistances. Since the plate resistance of screen-grid tetrodes, as shown in Fig. 1, and pentodes, is usually high (0.5 megohm and more), the resistance of 10 and 11 can be made relatively large so as to obtain a high output. The combination thus behaves as a tube having a constant plate resistance 10 (or 11) at all values of grid bias. In this respect, tubes having high internal-plate resistance, of the tetrode or pentode types, are more advantageous than triodes.

Another advantage of the screen-grid tube is the fact that there is negligible capacity coupling between the control grid and plate with the result that the direct transmission from grid to plate is reduced to a tolerable value. The importance of this will be explained presently.

When triodes are used, as in the Fig. 2 circuit, it is advisable to neutralize the transmission from grid to plate through the grid-plate inter-electrode capacity. A suitable method, utilizing crossed condensers, is described in my U. S. Patent No. 1,560,332, granted Nov. 3, 1925.

The neutralizing condensers 14, 15 are connected between the grid and plate elements of the triodes 1', 2', and the remainder of the circuit is the same as that of Fig. 1 and corresponding parts are identified by the reference numerals of that figure.

The operation of the modulator will now be described. For minimum distortion in the process of modulation, it is desirable that tube 1 shall have a linear relation between output and grid bias for a fixed carrier input. This would be obtained in the case of the screen-grid tube and circuit shown in Fig. 1 if the transconductance were a linear function of grid bias, or if the plate current varied as the square of the grid bias. Most tubes have a range of grid bias over which such a relation holds and for this purpose the greater the range the more suitable will be the tube.

The relation between the carrier frequency output and grid bias for a representative tube of this type is shown by curve A in Fig. 3. The desired linearity is obtained at the point of inflection A'. In the prior art when grid modulation has been employed, a grid bias equal to E_{c1} would have been chosen and the signal voltage allowed to alternate about this point. Although complete modulation could be obtained with sufficient signal voltage amplitude, the curvature of curve A in the regions Aa, and Ab would introduce considerable distortion for high percentages of modulation. To avoid this distortion, I operate over a narrow range where the curve A is substantially straight and, in order that full modulation can be obtained with these limits of signal voltage amplitude on the grid of tube 1, I balance out by means of tube 2, part of the output of tube 1 so that at the most negative value of the chosen grid voltage swing, point a^1 , the output is zero. The resultant relation between output and grid voltage of the tube 1 is shown by the curve B. The bias of tube 1 is adjusted, by means of the battery 8, to the point of inflection A' and variation of the signal voltage around this point, between points a^1 and a^2 , produces complete, or 100 per cent, modulation. Since a substantially linear part of the modulation characteristic of tube 1 is employed, the modulation is practically distortionless up to 100 per cent.

A perfect balance at point a^1 demands that the phases of the outputs of tubes 1 and 2 shall be in opposition, and in order to avoid phase modulation, they should stay in opposition throughout the modulation cycle. Balance may be obtained when the conditions are such as to prevent phase modulation by adjusting the gain of tube 2 by varying the grid bias by means of battery 8', the screen-grid voltage, input voltage or any other way. In one method which I use to adjust the modulator, I impress a small sinusoidal signal voltage on tube 1, after setting the grid bias to point a^1 . The modulation can be listened to on a suitable rectifier and telephones coupled to the output. The gain of tube 2 is then varied until the fundamental audio modulation note disappears and is replaced by a note of double frequency. The bias of tube 1 is then readjusted back to the normal operating point A' midway between the values a^1 and a^2 .

The effects of an imperfect balance at the point a^1 are shown in Fig. 4 by the dotted curve. The output no longer goes to zero at this point for negative signal peaks and distortion results. A condition of this type may arise from residual transmission due to capacity coupling between

grid and plate. This transmission is in phase quadrature with the amplified carrier output and therefore does not balance out. The means shown in Fig. 1 (shield-grid tube), or Fig. 2 (neutralization), are therefore resorted to to avoid this. Other extraneous couplings between input and output circuits are likewise to be avoided.

The function of the tube 2 is merely to supply carrier 180 in phase to balance out some of the carrier which is transmitted through the tube 1 channel. It is not necessary to use a vacuum tube amplifier for this purpose, since any equivalent method of supplying the required currents will serve.

In the arrangement shown in Fig. 5, the tube 2 has been replaced by a network. To reduce feedback between the plate and grid circuits of the tube, the output and plate circuits are arranged in the form of a Wheatstone bridge as shown. The carrier input to tube 1 is through a transformer 4' and the signal input is the same as in the Fig. 1 circuit. The plate-cathode circuit forms one diagonal of the Wheatstone bridge network and the balance circuit, i. e., the secondary of transformer 16 and its shunt condenser 17, form the conjugate diagonal. The output from the bridge is taken off of one arm and comprises the grid circuit of a succeeding tube 18 and, as this output circuit is substantially of infinite impedance, it does not disturb the balance of the bridge. The network includes, as viewed from the plate of tube 1, the two resistive arms 19, 20 in parallel with the two inductive arms 21, 22. Plate voltage is supplied by a battery 23, shunted by condenser 24, in series with inductance 22, and the plate circuit is tuned by the condenser 25. If necessary, the input capacity of tube 18 can be balanced by a condenser 26 in the adjacent arm. An isolation condenser 27 is placed in one of the resistive arms to prevent a shorting of the plate battery. The constants of the bridge network are so chosen that $L_{22}R_{19} = L_{21}R_{20}$, under which conditions the bridge will be balanced and there will be no coupling between the plate-cathode circuits of tube 1 and the balancing network, although both will be coupled to the output.

The resistors 19 and 20 in series reduce the effect of variation in plate-cathode resistance of tube 1 upon the phase of the output current during a modulated cycle.

Balancing energy is derived from the carrier input circuit by means of the transformer 16 and the phase is adjusted to exact opposition by means of the condenser 17. The relative amplitudes can be adjusted in several ways which will be obvious to those skilled in the art; for example, by varying the mutual or self-inductances of transformers 4' and 16, varying the voltage applied to the screen-grid of tube 1 by source 28, etc.

I may also point out that this method of modulation is also adapted to suppressed-carrier operation. If the battery 8 is adjusted to the point a^1 , Fig. 3, at which the two outputs balance out, the carrier will be suppressed leaving only the side-bands.

Another arrangement using a two-electrode rectifier 29 is shown in Fig. 6. The carrier energy is introduced into the rectifier circuit through the transformer 30 and traverses the rectifier 29 and the output transformer 31. The battery 32 biases the rectifier so as to operate on a conductive part of its curved characteristic. The signal voltage from source 6 is introduced in

series with the bias voltage and varies the conductance of the rectifier, thus modulating the output. The balancing circuit comprises a second winding on transformer 30 and the resistance 33. The polarity of the second winding of the transformer is such as to cause the alternating current in circuit 31—33 to be in phase opposition with that in circuit 29—31. The elements 33 and 34 are the electrical equivalents of the rectifier 29 at the balancing bias and signal levels so that exact phase opposition is obtained. A capacity 34 is shunted across the resistance to bring the balancing current into exact phase opposition. The adjustment of this circuit is the same as of that described previously. The amount of reduction in carrier output is conveniently controlled by varying the resistance 33 and, if desired, the resistance 33 can take the form of a rectifier, or tube, similar to the rectifier 29. The output circuit may be tuned to the carrier frequency by a condenser 35.

While I have illustrated this invention by means of a control grid modulator tube, I also contemplate any suitable method of modulation. For example, in the case of a screen-grid tube, the carrier may be introduced into the control grid and the signal voltage into the screen grid. In this case the screen grid would be provided with a filter passing the audio or signal voltage but presenting a low impedance for the carrier voltage so as to prevent the building up of carrier frequency potentials on the screen grid which would interfere with its shielding function. Or conversely, the carrier might be applied to the screen and the signal to the control grid. In this case, as in the case of the triode, some method of overcoming the coupling due to grid plate capacity may be necessary. The circuit shown in Fig. 2 would be suitable for this purpose.

It is therefore to be understood that there is considerable latitude in the design and construction of modulator systems which are to operate in accordance with the invention as recited in the following claims.

I claim:

1. In the operation of a vacuum tube modulator having a plurality of electrode circuits, the method which comprises impressing a voltage from a carrier frequency source upon an electrode circuit, impressing the signal frequency voltage upon an electrode circuit, adjusting the bias on the latter circuit to the point of inflection upon the curve of carrier output against electrode voltage, and combining with the modulated carrier output of said modulator additional carrier frequency energy derived from said source and of phase reversed with respect to the modulator output to reduce the output to a value which is algebraically greater than zero for a value of signal voltage equal to zero.

2. In the operation of a vacuum tube modulator having a plurality of electrode circuits, the method which comprises impressing a voltage from a carrier frequency source upon an electrode circuit, impressing the signal frequency voltage upon an electrode circuit, adjusting the bias on the latter circuit to a point of inflection upon the curve of output against electrode voltage, and combining with the modulated output of said modulator additional carrier frequency energy derived from said source and of phase reversed with respect to the modulator output to reduce the output to a value substantially equal to zero at one maximum of signal voltage and

differing from zero for all other values of signal voltage.

3. In the operation of a modulator of the type comprising a source of carrier frequency and a vacuum tube having a modulating electrode and a plurality of electrode circuits including a modulator output circuit, the modulator being characterized by a substantially linear relation between carrier output and voltage on the modulating electrode over a range of the latter voltage, the method of modulation which comprises biasing the modulating electrode to the midpoint of said linear range, impressing the signal voltage on said modulating electrode, introducing the carrier voltage into an electrode circuit, transmitting carrier frequency energy from said source to the modulator output circuit, and superposing such transmitted energy with reversed phase upon the modulator output circuit to reduce the output to a value which is algebraically greater than zero for a value of signal voltage equal to zero.

4. In the operation of a modulator of the type including sources of carrier and modulation voltages, a vacuum tube having a modulator electrode upon which modulation voltages may be impressed, means for adjusting the bias voltage on said modulator electrode to place the normal operating point at the midpoint of the linear portion of the carrier output-modulator electrode bias curve of the tube, and a balancing circuit for combining unmodulated carrier energy from said carrier voltage source with the modulated output from said tube to reduce the amplitude thereof, the method of adjusting the modulator which comprises biasing the modulator electrode more negatively than the normal operating point by an amount equal to the maximum value of the modulator voltage, adjusting the transmission of the balancing circuit to bring the algebraic sum of the combined carrier outputs of the tube and the balancing circuit to zero, and then adjusting the bias on the modulator electrode to the normal operating point.

5. The modulation process which comprises transmitting carrier frequency energy from a source along a modulating path and a balancing path, combining signal energy with the carrier frequency energy during transmission along the modulating path to effect modulation of the carrier energy by the signal, combining in phase opposition the modulated output of the modulating path and unmodulated carrier frequency energy transmitted along the balancing path, and adjusting the relative transmission efficiencies of the two paths to reduce the output to a value which is algebraically greater than zero for a value of signal voltage equal to zero.

6. The process as claimed in claim 5, wherein the transmission efficiency of the modulating path is adjusted.

7. The process as claimed in claim 5, wherein the transmission efficiency of the balancing path is adjusted.

8. In a modulator, a vacuum tube having an output circuit, sources of carrier and signal voltages, means for impressing carrier and signal voltages from said sources upon said tube, thereby to develop modulated carrier energy in said output circuit, and means reducing the amplitude of the modulated output to a value which is algebraically greater than zero for a value of signal voltage equal to zero, said means comprising a transmission channel in phase opposition substantially independent of said tube and in-

cluding a vacuum tube repeater connected between said carrier voltage source and said output circuit.

9. In a modulator, a source of carrier frequency voltage, a source of signal voltage, a modulated carrier circuit coupled to said carrier frequency source through two substantially independent paths, the respective paths impressing carrier energy of opposite phase upon said modulated carrier circuit, means coupling said signal voltage source to one of said paths, and means for adjusting the relative transmission efficiencies of the said paths to reduce the modulated output amplitude at said modulated carrier circuit to zero at a predetermined signal voltage input differing from zero.

10. In a modulator, the combination with a source of carrier frequency energy, and a transmission channel working out of said source and including means upon which signal voltages may be impressed to develop a modulated carrier output at the output terminals of said channel, of a second transmission channel connecting said source and the output terminals of said first channel to superpose carrier energy of phase opposite to that of the modulated carrier output of the first channel, and means adjusting the relative transmission efficiencies of said channels to such values that the modulated carrier output at said output terminals falls to zero when the signal input voltage rises to a predetermined finite value.

11. A modulator comprising a source of carrier voltage, a source of signal voltage, a vacuum tube modulator having a modulating electrode and a pair of output terminals, said tube having a substantially linear relation between carrier output developed across said terminals and modulating electrode voltage over a limited range of modulating electrode voltage, means for impressing carrier and modulating voltages upon said modulator, means biasing the modulating electrode to the midpoint of said range of linear modulation, a transmission channel between carrier source and output terminals, means for adjusting the phase of the output current of said channel to opposition with the modulated carrier frequency output developed by said tube and means for superposing said outputs to reduce the modulated output amplitude to zero only when the bias on the modulator electrode corresponds to the more negative limit of the said substantially linear range.

12. A modulator comprising a source of carrier voltage, a source of signal voltage, a vacuum tube modulator having a modulating electrode and a pair of output terminals, said tube having a substantially linear relation between carrier output developed across said terminals and modulating electrode voltage over a limited range of modulating electrode voltage, means for impressing carrier and modulating voltages upon said modulator, means biasing the modulating electrode to the midpoint of said range of linear modulation, a transmission channel including a vacuum tube repeater between carrier source and said output terminals, means for adjusting the phase of the current in said channel to opposition with the vacuum tube modulator carrier frequency output, and means for superposing said outputs to reduce the modulated output amplitude to zero only when the bias on the modulator electrode corresponds to the more negative limit of said substantially linear range.

13. A modulator comprising in combination a

source of carrier voltage, a source of signal voltage, a vacuum tube modulator including a cathode cooperating with a control grid and plate, means for impressing carrier and modulating voltages on the control grid of said modulator, an output circuit for said modulator, a vacuum tube repeater, means for impressing unmodulated carrier voltage on the input of said repeater, means for adding the output of said repeater to the output of said modulator with reversed phase, and means adjusting the opposed outputs to reduce the modulated output amplitude to zero at a predetermined signal voltage input differing from zero.

14. A modulator comprising in combination a source of carrier voltage, a source of signal voltage, a vacuum tube modulator including a cathode cooperating with a control grid and plate, said tube modulator having a linear relation between carrier output and control grid voltage over a range of control grid voltage, means for impressing carrier and modulator voltages on the control grid, means biasing the control grid to the midpoint of said range of linear modulation, an output circuit for said modulator, a vacuum tube repeater, means for impressing carrier voltage on the input of said repeater, means for adding the output of said repeater to the output of said modulator with reversed phase, and means for adjusting the opposed outputs to reduce the output to a value which is algebraically greater than zero for a value of signal voltage equal to zero.

15. In a modulator system, a source of carrier voltage, a rectifier energized by said source, means adjusting said rectifier for operation upon a curved portion of its conductive characteristic, means for varying the conduction of said rectifier at signal frequency, a rectifier output circuit in which a modulated carrier is developed by such variation of the conduction of the rectifier, and means including a transmission circuit between said source and said output circuit for reducing the magnitude of the modulated output to a value which is algebraically greater than zero for a value of signal voltage equal to zero.

16. In a modulator, a source of carrier frequency voltage, a vacuum tube, a source of modulating voltage, means for impressing carrier voltage from said source upon said tube, means for impressing a modulating voltage upon said tube, whereby a modulated carrier output is developed by said tube, means for preventing shift of phase of said modulated carrier output during a modulation cycle, and means for superposing upon said modulated carrier output additional carrier energy derived from said source and of phase opposite that of the modulated carrier.

17. In a modulator, a vacuum tube having an output circuit, sources of carrier and modulating voltages, means for impressing carrier and signal voltages from said sources upon said tube, thereby to develop modulated carrier energy in said output circuit, means for preventing shift of phase of said modulated carrier output during a modulation cycle, and means for reducing the amplitude of the modulated carrier energy, said amplitude reducing means comprising a transmission channel substantially independent of said tube and connecting said carrier voltage source to said output circuit.

18. An electrical transmission circuit comprising a source of carrier voltage, a source of modulating voltage, a vacuum tube modulator having

a modulating electrode and a pair of output terminals, means for impressing carrier and modulating voltages upon said modulator, whereby a modulated carrier output is developed at said output terminals, means for preventing shift of phase of said modulated output during a modulation cycle, means for preventing the direct transmission of energy from modulating electrode to output circuit by other means than the repeater action of said tube, a transmission channel between carrier source and output terminals, means for adjusting the phase of the output current of said channel to opposition with the modulated carrier output developed by said tube, and means for superposing said outputs to reduce the carrier output.

19. An electrical transmission circuit comprising a source of carrier voltage, a source of modulating voltage, a vacuum tube modulator having a modulating electrode and a pair of output terminals, means for impressing carrier and modulating voltages upon said modulator, whereby a modulated carrier output is developed at said output terminals, means for preventing shift of phase of said modulated output during a modulation cycle comprising an output network having an impedance at carrier frequency small in comparison with the internal impedance of the output circuit of said tube, a transmission channel between carrier source and output terminals, means for adjusting the phase of the output current of said channel to opposition with the modulated carrier output developed by said tube, and means for superposing said outputs to reduce the carrier output.

20. An electrical transmission circuit comprising a source of carrier voltage, a source of modulating voltage, a vacuum tube modulator having a modulating electrode and a pair of output terminals, means for impressing carrier and modulating voltages upon said modulator, whereby a modulated carrier output is developed at said

output terminals, means for preventing shift of phase of said modulated output during a modulation cycle comprising in combination means for preventing direct transmission through the said tube by other means than direct repeater action and an output network having an impedance at the carrier frequency small in comparison with the internal impedance of the output circuit of said tube, a transmission channel between carrier source and output terminals, means for adjusting the phase of the output current of said channel to opposition with the modulated carrier output developed by said tube, and means for superposing said outputs to reduce the carrier output.

21. In the operation of an electrical transmission circuit comprising a vacuum tube operating as a modulator and having a plurality of electrodes and an output circuit connected between two of the electrodes, the method of varying the transmission without varying the phase relationship between output and input currents which comprises varying the voltage of an electrode of said vacuum tube, and maintaining the external impedance of the output electrode circuit at the transmission frequency at a constant value which is small in comparison with the minimum value of internal impedance of the output electrode circuit.

22. In the operation of a modulator circuit comprising a vacuum tube operating as a modulator and having a plurality of electrodes and an output circuit connected between two of the electrodes, the method of varying the transmission without varying the phase relationship between output and input currents which comprises varying the voltage of an electrode of said vacuum tube, and shunting the output electrode circuit with a resistance which at the transmission frequency is small in comparison with the minimum value of impedance of the output electrode circuit.

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