

Dec. 26, 1939.

A. W. VANCE

2,184,571

MODULATION SYSTEM

Filed May 27, 1938

2 Sheets-Sheet 1

FIG. 1.

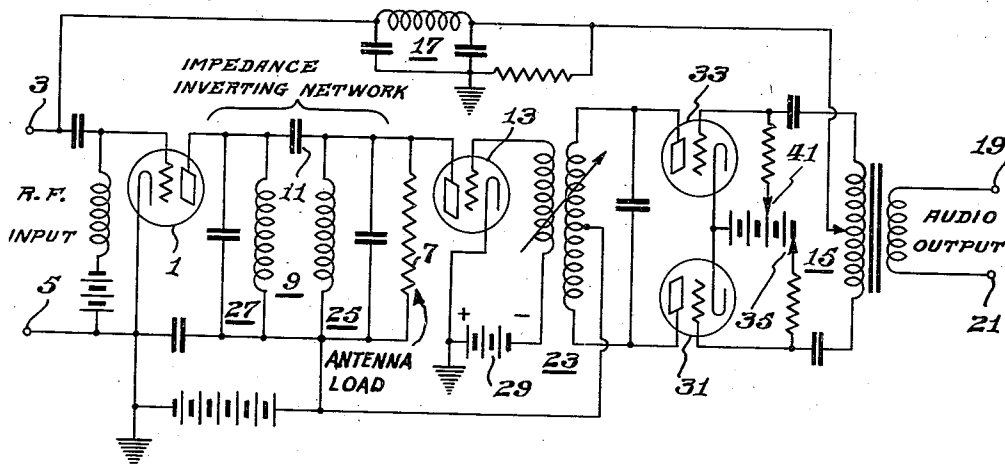
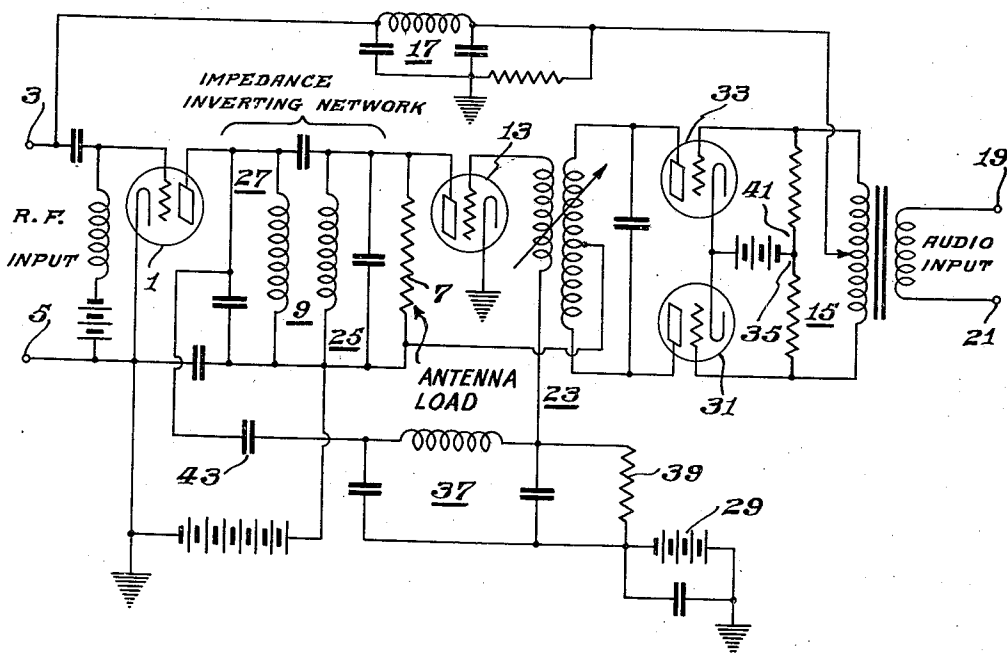


FIG. 2.



Inventor
Arthur W. Vance

J. Huff

Attorney

Dec. 26, 1939.

A. W. VANCE

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FIG. 3.

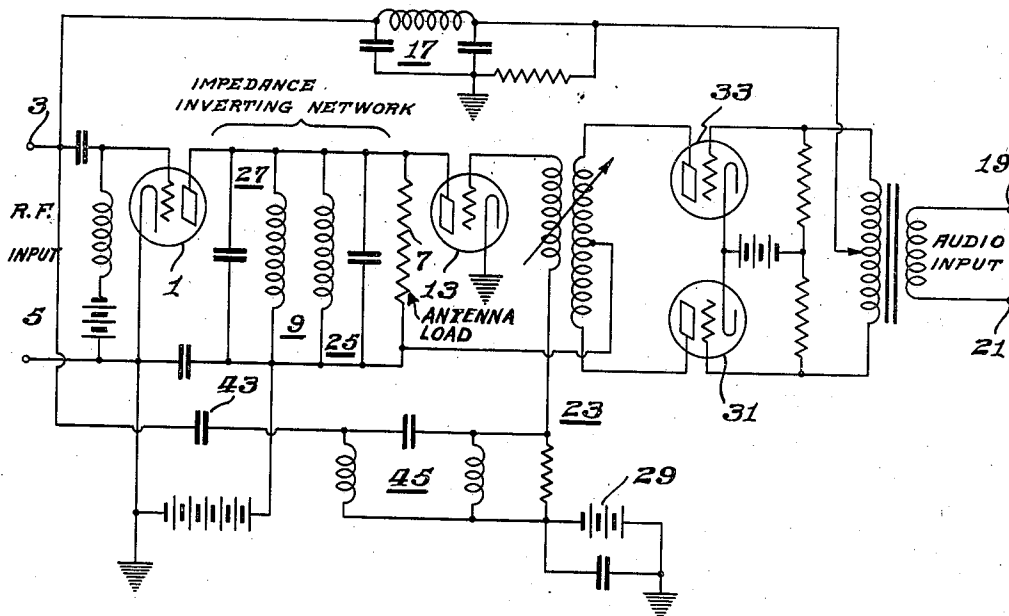
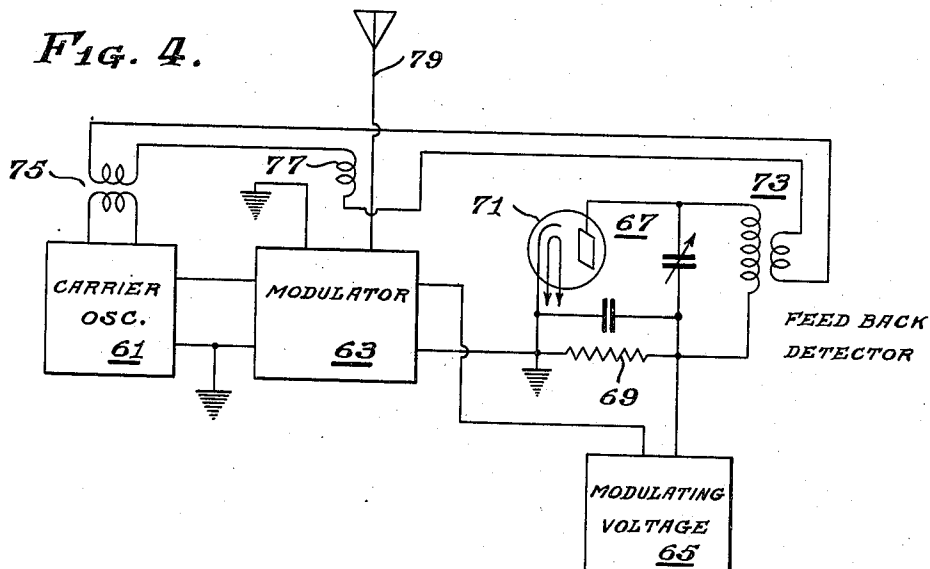


FIG. 4.



Inventor

Arthur W. Vance

By

J. Huff

Attorney

UNITED STATES PATENT OFFICE

2,184,571

MODULATION SYSTEM

Arthur W. Vance, Haddonfield, N. J., assignor to
Radio Corporation of America, a corporation
of Delaware

Application May 27, 1938, Serial No. 210,304

13 Claims. (Cl. 250-17)

My invention relates to radio modulation systems, and more particularly to method and means for providing a modulation system which has high operating efficiency and at the same time is economical from the point of view of the number of tubes and other parts which are required.

It has been recognized for some time that modulated oscillators or power amplifiers cannot be operated at a high average efficiency. This is partly due to the widely varying conditions under which they are operated. In order to provide ample reserve power for conditions of maximum modulation, transmitters must be designed to have an output greatly in excess of the average value. This, of course, decreases the average transmitter efficiency, and increases its cost.

It is highly desirable therefore to provide means for operating a tube, on the average, more nearly at its optimum rating. The general method of accomplishing this is to divide the output between several tubes, for example, by operating one tube at optimum conditions at 50% modulation and supplying the increased output required for 100% modulation by another tube which is called into operation only at the high modulation levels.

It has been proposed to accomplish this by coupling the antenna to the power output stage through an impedance inverting network. The output of a second power tube is also connected across the antenna. The input to the second power tube is then excited in such a manner that the tube delivers radio frequency current to the antenna in phase with that delivered by the first power tube, for positive peaks of the audio signal, and out of phase for negative peaks of the audio signal.

One serious drawback to the prior methods which operate on this principle is overcome by the present invention. Since the plate of the second power tube is connected to the antenna, its direct current plate voltage will have superimposed on it a carrier frequency voltage from the first power output tube. As is well known the grid voltage-plate current operating characteristic of a triode is dependent upon the plate voltage applied. Consequently in a system such as that mentioned above the tube operating characteristic will be varied by the impressed radio frequency voltage, and it will be impossible to maintain a uniform operating condition.

It is well known that in a pentode tube having a high internal plate impedance the grid voltage-plate current characteristic is nearly independent

of the plate voltage over the operating range. However, pentodes are not available in the high power ratings. Most power tubes are triodes. Consequently, it is desirable to be able to use a triode efficiently in the manner mentioned above.

Another difficulty which the present invention overcomes arises from the fact that the phase reversal due to overmodulation downward prevents successful application of overall audio degenerative feedback to transmitters of this type. In accordance with one modification of the invention this difficulty is overcome.

It is an important object of this invention to provide means for efficiently operating a triode power tube which is subject to widely varying plate voltages.

It is a further object of this invention to provide a variable bias which will maintain constant operating conditions for a triode operating under conditions of variable plate voltage.

Another object is to provide a system for satisfactorily applying overall audio feedback to a transmitter operating on this principle.

It is a further object of this invention to provide a simplified and improved modulating means for a radio transmitter.

It is a still further object of this invention to provide a highly efficient modulation means which has a low first cost and low operating and maintenance costs.

This invention will be better understood from the following description considered in connection with the accompanying drawings, and its scope is indicated by the appended claims. Similar reference numerals refer to similar parts throughout the several drawings.

Referring to the drawings,

Figure 1 is a schematic diagram of a modulator system according to a preferred embodiment of my invention in which variable bias is obtained by an unbalanced condition on the grids of the driver tubes;

Figure 2 is a schematic diagram of another embodiment in which a variable biasing voltage, obtained from the plate of the first output tube, is applied to the grid of the second tube;

Figure 3 is another embodiment in which the biasing voltage is obtained from the grid of the first output tube; and

Figure 4 is a diagrammatic representation of a complete transmitter in which overall audio degenerative feedback is employed to reduce distortion.

Referring to Fig. 1, the input electrodes of a power amplifier triode 1 are connected to a pair

of input terminals 3, 5. A driving voltage of carrier frequency is connected to the input terminals from a source which is not shown. The triode 1 is a Class C amplifier which drives the load 7, which may be an antenna, for example, through an impedance inverting network shown at 9. This network consists of the tank circuit 25 shown across the load 7 and the tank circuit 27 in the plate of the triode 1. Both are tuned so that they present an inductive reactance X_L at the carrier frequency, which is equal to the capacity reactance X_C of the series capacity 11. It is well-known that a class C amplifier, when sufficiently excited, constitutes a nearly constant voltage generator for load impedances sufficient to produce plate voltage saturation. Therefore, for purposes of explanation it will be assumed that the tube 1 forces a constant radio frequency voltage E_c across the input to the impedance inverter at all points of the operating cycle.

It can readily be shown that a constant current is forced through the load 7 regardless of its value, or its effective value when shunted by the second amplifier 13. The magnitude of this current is

$$\frac{E_c}{Z_0}$$

where Z_0 is the characteristic impedance of the network

$$\sqrt{\frac{L}{C}}$$

The load 7 has a value of

$$\frac{Z_0}{2}$$

so that a two to one voltage transformation is obtained. The current through the load leads the voltage on the input by 90° for a high-pass network as shown. Tube 13 in Fig. 1 is a class B, R. F. amplifier triode which is excited through a coupling transformer 23 by a balanced modulator 15 of a conventional type. The R. F. excitation to the balanced modulator is obtained through the phase shifting network 17 shown from the same carrier source as that which drives the tube 1. This network 17 introduces 90° phase shift to compensate for the phase characteristic of the impedance inverter 9. The network 17 gives 90° lag but the only difference between lag or lead would be a reversal in the polarity of modulation. For no modulation, the triode 13 is biased very near to plate current cut-off and the modulator is in balance so that the triode 13 draws negligible plate current. Thus, carrier is supplied to the load 7 at the class C efficiency of the amplifier 1 which efficiency is limited only by the tubes and voltages used.

The audio input to the balanced modulator 15 is applied to input terminals 19, 21 from a source which is not shown. The audio voltage is applied out of phase to the modulator grids, but the carrier is supplied in phase to the grids. Consequently the balanced modulator delivers no carrier frequency energy to the amplifier 13, but only side-band energy. When the audio input voltage is positive with respect to the grid of one of the balanced modulator tubes it is negative with respect to the grid of the other. Each tube is therefore alternately blocked by the audio voltage. The radio frequency voltage which is induced on the grid of the second amplifier 13 will be of one phase when delivered by current

flowing through one of the balanced modulator tubes, and will reverse 180° when delivered to the amplifier by the other modulator tube, due to the push-pull connection of the balanced modulator output transformer primary.

For upward modulation the balanced modulator drives the amplifier 13 so that it delivers current to the load 7 of like phase to that flowing in the load due to the amplifier 1. As the current in the load increases due to tube 13, amplifier 1 continues to supply the same current as before and so delivers more energy since the same current is driven by it into a higher effective resistance. At 100% modulation upward, amplifier 13 has approached voltage saturation and is delivering a current to the load 7 equal to that from the amplifier 1, and each is delivering twice the power that the first amplifier 1 supplied on no modulation. Both tubes are working at relatively high efficiencies since both are at, or near, plate voltage saturation.

For downward modulation, the audio voltage drives the balanced modulator so that it delivers radio frequency current to the amplifier 13 of such a phase that the tube 13 delivers current to the load 7 in phase opposition to that flowing in the load due to first amplifier 1. This causes the apparent load resistance to decrease and amplifier 1 delivers less power since it maintains the same current through a lower resistance. At 100% modulation downward the current from the second amplifier 13 exactly balances that from the first amplifier 1, and the apparent load resistance becomes zero. In this case, the load presented to the output of amplifier 1 becomes extremely small, and the tube supplies only its circuit losses. The second amplifier 13, however, delivers a current of average carrier value into a short circuit, so it is subject to considerable instantaneous plate dissipation at this point in the modulating cycle. The average dissipation in this second amplifier over a 100% sine wave modulation cycle is not excessive, however. In actual use, with typical program modulation, the dissipation in the second amplifier 13 is always much less than that in the first.

It is to be noted that, as the second amplifier 13 starts upward modulation, it must start to draw plate current at minimum plate voltage (approximately equal to ½ the D. C. applied voltage), and as it starts modulation in a downward direction, it must draw current at maximum plate voltage (about equal to 1½ times the applied D. C. voltage). If the second amplifier 13 is a triode, and if the D. C. grid bias is to be adjusted so that the tube will draw negligible plate current at unmodulated carrier condition, as mentioned above, it will have to be biased to cut-off for maximum plate voltage, and therefore the tube will be far beyond cut-off for minimum plate voltage. Thus the excitation voltage of the phase which produces upward modulation must be very high for any plate current to be drawn by the tube at minimum plate voltage, and upward modulation started. Violent distortion results in such circumstances. This distortion can be overcome by reducing the bias of the amplifier 13 so that large currents are drawn at maximum plate voltage, and small but definite currents at minimum plate voltage. However, this causes the amplifier to absorb a great deal of power and thereby greatly reduce the efficiency at the unmodulated carrier condition.

It is therefore desirable that the amplifier 13

be biased off so that it draws the same plate current at both minimum and maximum plate voltage. The solution which I have discovered is to supply a radio frequency bias to the tube such that the grid voltage is more negative when the plate voltage is maximum, and less negative when the plate voltage is minimum. The procedure is first to apply a negative D. C. bias 29 which is sufficient to bias off the amplifier tube 17 to the desired extent for the existing applied D. C. voltage with no radio frequency component present on the plate, and then to apply a radio frequency biasing voltage equal to $-\mu E_c$, where E_c is the normal carrier voltage across the load and μ is the amplification constant of the amplifier tube 13. The effect of such a radio frequency bias is obtained, according to a preferred embodiment of my invention, by applying unbalanced D. C. biases 35 and 41 to the grids of the two balanced modulator tubes 31 and 33. This effectively compensates for the changes in operating plate potential of the amplifier 13, for a high excitation voltage from the balanced modulator 15 is applied to the grid of the amplifier 13 during the phase which produces upward modulation. As noted above, this is necessary due to the fact that at the start of the upward swing the plate voltage of the amplifier 13 is a minimum.

Consider the effect of a deviation of the carrier bias from the value which provides complete compensation for the varying plate voltage. If the radio frequency bias is less than this amount, the compensation will not be complete, and the plate current will increase during the positive peaks of the radio frequency component of the plate voltage. The amplifier will thus absorb power from the load. On the other hand, if the radio frequency bias is greater than that necessary to compensate for the variations in plate potential, the plate current will tend to increase during negative peaks of the plate voltage. The amplifier therefore delivers some in-phase power to the load.

By taking advantage of this fact, the efficiency of the transmitter can be still further increased. Efficiency of the order of 30%, or better, is possible for the amplifier 13 if a small amount of over-bias is employed. I have found that where the efficiency of the first class C amplifier 1 is 75%, if the carrier bias is adjusted to exactly compensate for the plate voltage variations, the overall efficiency of the carrier circuits is approximately 66%. This decrease is due to the fact that the second amplifier 13 is drawing a uniform current through the radio frequency cycle. This current represents a pure loss as it does not deliver any current to the antenna.

If the carrier frequency bias of the amplifier 13 is lowered slightly so that more current is drawn during positive peaks of plate voltage, the overall efficiency drops to about 63%, due to the absorption of power from the load. If, however, a small amount of over-bias is applied to the amplifier tube, I have found that an increased efficiency may be obtained. By increasing the carrier frequency bias until amplifier 13 is delivering about 5% of the total power to the load, with no modulation, the overall efficiency of the carrier system increases to 70%. Thus, the most efficient condition results when a small excess of radio frequency bias is applied to the second amplifier 13.

Figure 2 shows an alternative arrangement by

which a carrier frequency bias may be obtained. The circuit of the amplifier 1, impedance network 9, and balanced modulator 15 is identical to that shown in Fig. 1 except that the D. C. biases on the two balanced modulator tubes 31 and 33 are now identical. In addition the D. C. bias 29 is applied to the grid of the second amplifier 13 in series with a resistor 39 which terminates a 90° phase shifting network 37. The input to this network is derived from the plate of the first amplifier tube 1 through a capacitor 43. The network 37 shifts the phase of the radio frequency voltage in an opposite sense to that caused by the impedance inverting network 9. Consequently, the radio frequency bias which is applied to the grid of the amplifier tube 13 is out of phase with the radio frequency plate voltage component, and tends to maintain a uniform effective bias.

Fig. 3 illustrates still another embodiment of my invention for obtaining the biasing voltage. The same circuit is shown as that of Fig. 2 except that the input of a phase inverter 45 is connected to the grid of the first amplifier 1. Since the grid voltage is 180° out of phase with the voltage on its plate, it becomes necessary to shift the bias 180° also. This is accomplished by utilizing a network 45 which gives a 90° change in the opposite direction to that given by the network 37 of Fig. 2. The result is a radio frequency bias for the second amplifier tube 13 which effectively maintains uniform operating conditions throughout the varying range of plate voltage.

Since the impedance facing the amplifier tube 1 varies from a high impedance at 100% modulation upward to zero for 100% downward, it is to be expected that the gain of the amplifier 1 will be higher for downward modulation than for upward, and thereby tend to produce even-harmonic distortion. This is particularly true when the amplifier tube is a triode. This effect is off-set by the regulation of the amplifier 1. This stage, in practice, is not a constant voltage generator as assumed in the previous discussion, so that the output voltage will rise as the load impedance increases. From zero modulation to 100% modulation upward, the load varies two to one, while from zero modulation to 100% down, the load may vary 20/1, or more. Therefore, in most cases the output voltage will rise more on the downward modulation part of the cycle than it falls on the upward part of the modulation cycle. This tends to compensate somewhat for the increased gain of the amplifier on the downward cycle. The actual compensation so obtained will, of course, depend on the tube, the load at no modulation, and the exciter characteristics. This distortion can also be reduced by unbalancing the center tap of secondary of the audio input transformer to the balanced modulator so that its output will be greater on the upward part of the modulation cycle. This is illustrated in Figs. 1 to 3 by the variable tap which connects the radio frequency input to the balanced modulator.

When audio degenerative feedback is used, as is usually the case, this distortion is of little moment since it is of a smooth, low-order character and relatively easily removed by degeneration. In practice, the zero signal current of the second amplifier 13 is kept as low as possible to permit the highest possible efficiency, and the resultant odd harmonic distortion removed by

the use of feedback in a manner which is well known to those skilled in the art.

The radio frequency bias which I have described is not necessary when two tubes are used to replace the single amplifier tube 13. One tube may then be used for upward modulation and the other for downward modulation. Separate plate voltages and D. C. biases would be required for each tube. The downward modulating tube would then be supplied with only enough D. C. plate voltage to enable it to supply radio frequency current of average carrier value into a short circuit. The upward modulating tube would require the same D. C. plate voltage as in the present system. Each tube would be biased so as to draw equally small zero signal currents. This system has some merit in that the dissipation at 100% modulation down is greatly reduced. However, the extra power tube complement and the necessity for an extra power supply, more than off-set the higher efficiency at 100% modulation down since this condition exists a negligible part of the time.

It is worthy of note that with all systems which operate upon the general principle here described, overmodulation in the downward direction results in a different type of distortion than that ordinarily produced. If the excitation on the amplifier 13, of downward modulating phase, is increased to such an extent that this tube delivers more current to the load than the first tube 1, then there results a reversal of phase of the load, that is, the load current is over-compensated, and begins to rise again beyond the 100% modulation downward point. Since the amplifier 13 is far from voltage, or emission saturation at this point it is capable of forcing considerable reversed current through the load.

Thus, over-modulation in the downward direction does not result in distortion in the sense usually understood since it represents merely an excessive ratio of sidebands to carrier and not distortion of the modulating wave form. No new sidebands are produced so no interchannel interference is caused, as is the case when ordinary transmitters are over-modulated downward and the downward peaks are sharply cut off. In the upward direction there is no sharp limitation at 100% modulation. The only limitation is that of emission or voltage saturation of the tubes, so the distortion for over 100% modulation upward is decidedly less than that for over-modulation downward in the ordinary case. 100% modulation upward is an arbitrary value and, by design, the limitation can be set at any figure, 125%, 150%, etc. The new system permits similar control for downward modulation. It is possible to design it so that it will over-modulate to almost any desired extent without production of harmonics of modulation frequencies and consequent inter-channel interference.

When an attempt is made to use audio degeneration with a transmitter utilizing a modulation scheme of this type, the effect of over-modulation must be considered. As pointed out above, over-modulation causes a reversal of the phase of the output voltage in the antenna, and that the antenna current starts to rise again when the wave is modulated over 100% downward. This causes a reversal of the feedback phase and a certain amount of instability. This is, of course, true in all modulation systems which operate on the general principle of which this invention is an improvement.

A solution to this difficulty has been found to

lie in applying a fixed, unmodulated carrier to the feedback rectifier along with the transmitter output. Thus the percentage modulation at the feedback rectifier is reduced to the point where 100% modulation of the transmitter output still represents less than 100% modulation of the carrier utilized to drive the feedback rectifier. This is illustrated in Fig. 4.

Referring to Fig. 4, a carrier frequency oscillator is indicated by reference numeral 61. The output of the oscillator is connected to a modulator which is indicated by reference numeral 63. This modulator may be similar to one of the systems shown in the preceding figures of the drawing, or any other system which operates on the same principle. The audio modulating voltage is derived from a suitable source, indicated by reference numeral 65. This voltage is applied to the audio input of the modulator 63 in series with a rectified audio voltage which is obtained from the carrier by a feedback detector 67.

The feedback detector consists of a diode rectifier 71 which is coupled to the transmitter antenna 73 by means of a transformer 73 and a coupling coil 77. The detector is also coupled to the carrier oscillator 61 through a transformer 75. Thus, an unmodulated carrier is added to that derived from the antenna, and over-modulation at the detector is prevented in the manner described above.

When this is done, the system operates with feedback in the normal manner. Stability is determined by the phase and gain characteristic around the feedback loop. Thus, with this system, I have effectively reduced the extra sidebands, even when over 100% modulation downward is obtained. This has been impossible with systems known up to the present time.

Thus I have described a modulation system which permits efficient operation with a minimum number of tubes, and which is particularly adapted to the use of power output triodes.

I claim as my invention:

1. In a modulation system which includes a first vacuum tube for supplying main carrier currents to a load and an auxiliary tube supplying auxiliary carrier currents to said load whose phase with respect to said main carrier currents is controlled by a modulating voltage, the plate of said auxiliary tube being subject to varying potentials due to the main carrier currents in said load, the method of maintaining substantially uniform operating conditions for said auxiliary tube in the presence of said varying plate potentials, which includes the step of controlling the plate current of said auxiliary tube by a radio frequency bias, said bias having a phase which tends to oppose a change in the plate current of said auxiliary tube due to said variation.

2. In a modulation system which includes a first vacuum tube for supplying main carrier currents to a load, and an auxiliary tube supplying auxiliary carrier currents to said load whose phase with respect to said main carrier currents is controlled by a modulating voltage, the plate of said auxiliary tube being subject to varying potentials due to the main carrier currents in said load, the method of maintaining substantially uniform operating conditions for said auxiliary tube which includes the steps of deriving a radio frequency bias whose frequency is equal to that of said main carrier, but in phase opposition thereto, adjusting the potential of said bias to be at least equal to the peak potential of the radio frequency voltage on the plate of said tube, due

to the main carrier current in said load, divided by the amplification factor of said auxiliary tube, and controlling the plate current of said auxiliary tube by said derived bias.

3. In combination, a source of main carrier frequency currents, a first amplifier connecting said source to a load, a second vacuum tube amplifier whose output is delivered to said load, said vacuum tube having grid and plate electrodes, a source of modulating voltages, means for energizing said grid by a radio frequency voltage whose phase is determined by said modulating voltages whereby the resultant current in said load is determined by said modulating voltages, and means for applying a radio frequency bias to said grid to compensate for varying plate potentials applied to said second amplifier due to voltages across said load.

4. In combination, a source of main carrier frequency currents, a first amplifier connecting said source to a load, a second vacuum tube amplifier whose output is delivered to said load, said vacuum tube having grid and anode electrodes, a source of modulating voltages, a balanced modulator comprising a pair of tubes whose push-pull outputs are coupled to said grid, means for applying said modulating voltage to said balanced modulator, means for applying carrier frequency currents to said balanced modulator, and means for adjusting said balanced modulator so that the radio frequency voltage coupled into said second amplifier is greater during modulating voltages of one polarity than during modulating voltages of the opposite polarity, whereby the undesired effect of the varying plate potential of said second amplifier, due to currents in said load, is minimized.

5. The combination which includes a source of main carrier frequency currents, a first triode amplifier connecting said source to a load, a second triode amplifier having a plate and grid electrodes whose output is delivered to said load and whose plate is affected by the voltage across said load due to currents from said first amplifier, means including said second amplifier for impressing currents across said load whose phase with respect to currents in said load from said first amplifier is determined by a modulating signal, and means for maintaining constant anode current in said second amplifier in the absence of said modulating signal.

6. The combination which includes a source of main unmodulated carrier frequency currents, an antenna, a first triode amplifier connecting said source to said antenna, a second triode amplifier having plate and grid electrodes whose output is delivered to said antenna and whose plate potential is affected by the voltage across said antenna, a source of modulating voltages, means

for energizing the grid of said second triode by a voltage which produces output currents in phase with currents in said antenna due to said first amplifier when said modulating voltage is of one polarity, and output currents out of phase with currents in said antenna due to said first amplifier when said modulating voltage is of the other polarity, and means for maintaining constant plate current in said second amplifier in the absence of said modulating voltages.

7. A device of the character described in claim 6 which is further characterized in that said means for maintaining constant plate current is a radio frequency bias.

8. A device of the character described in claim 6 which is further characterized in that said means for maintaining constant plate current is a radio frequency bias obtained from said source of main carrier frequency current.

9. A device of the character described in claim 6 which is further characterized in that said means for maintaining constant plate current includes a phase changing network which produces a 90° phase lag which derives its voltage from the output of said first triode amplifier.

10. A device of the character described in claim 6 which is further characterized in that said means for maintaining constant plate current includes a phase changing network which produces a 90° phase lead and which derives its voltage from the input of said first triode amplifier.

11. The combination which includes a source of main carrier frequency, an antenna, a first triode amplifier and an impedance inverting network connecting said source to said antenna, a source of modulating voltages, a second triode radio frequency amplifier having grid and anode electrodes, means for impressing the output of said second triode amplifier across said antenna, the phase of the radio frequency output of said second amplifier being determined by said modulating voltages, and means for causing said second triode amplifier to deliver the same amount of radio frequency current to said antenna independently of the potential appearing on said anode due to currents in said antenna from said first amplifier.

12. A device of the character described in claim 5 which is further characterized by means for obtaining audio degenerative feedback, and means for stabilizing said feedback in the presence of overmodulation.

13. A device of the character described in claim 3 which is further characterized by means operated by a signal coupled from said load for obtaining overall audio degenerative feedback, and means for reducing the percent modulation of said coupled signal to prevent overmodulation thereof.

ARTHUR W. VANCE.