

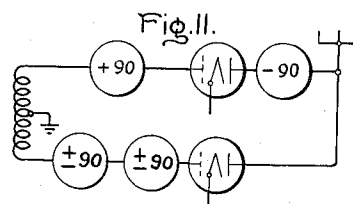
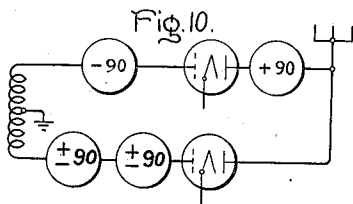
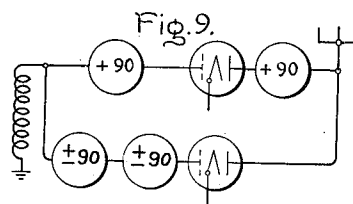
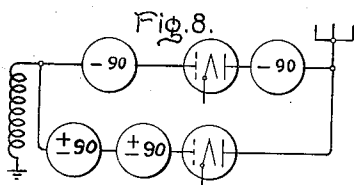
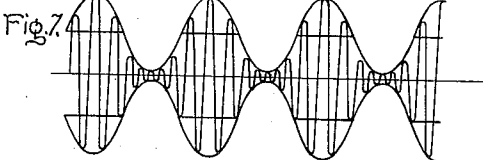
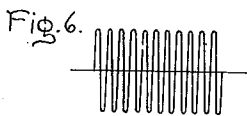
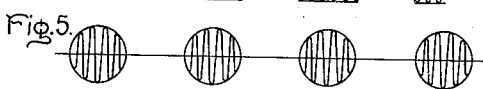
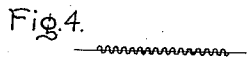
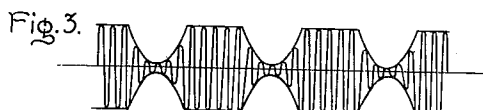
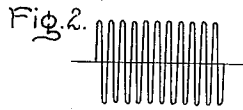
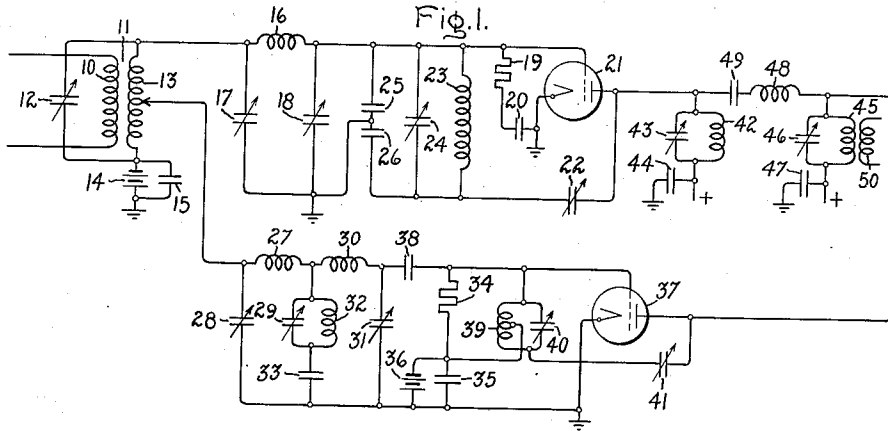
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H. P. THOMAS ET AL

2,255,476

HIGH EFFICIENCY AMPLIFIER

Filed Feb. 9, 1939



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HIGH EFFICIENCY AMPLIFIER

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16 Claims. (Cl. 179—171)

Our invention relates to electron discharge amplifiers and more particularly to power amplifiers for modulated carrier waves.

It has been recognized that power amplifiers for modulated waves cannot be operated at a high average efficiency. This is partly due to the loading condition under which they are operated. In order to provide ample reserve load capacity for conditions of maximum modulation, transmitters must be designed to have a load capacity greatly in excess of the average load. This, of course, decreases the average efficiency of the transmitter and increases its cost.

It is highly desirable, therefore, to provide means for operating a power amplifier more nearly at its optimum load condition for greatest efficiency. The usual method of accomplishing this is to divide the load between several discharge devices and to operate each device over a portion of the wave, such that it operates more nearly at optimum conditions. In its simplest form the load is divided between two discharge devices in such manner that under conditions of no modulation one of the discharge devices supplies all of the load power, while under the condition of modulation the same discharge device supplies power during the negative portion of the modulation cycle, and during the positive portion of the modulation cycle both discharge devices, in conjunction, supply power to the load.

One very convenient method of accomplishing this division of operation was described in the French Patent Number 820,431, issued August 2, 1937, to LeMaterial Telephonique and also described by W. H. Doherty in the Proceedings of the Institute of Radio Engineers, vol. 24, No. 9, page 1163, "A New High Efficiency Power Amplifier for Modulated Waves." In practicing this method the first of the discharge devices is coupled to the power consumption circuit through a network having the property that the driving point impedance at one end of the network is inversely proportional to the driving point impedance at the other end of the network. Networks of this type have been called variously monocyclic, phase shifting, or impedance inversion networks, and were described by Charles P. Steinmetz, in the book "Theory and Calculations of Electric Circuits," published by McGraw-Hill Book Company, in 1917 (first ed.) the second of the above mentioned discharge devices is connected directly to the power consumption circuit. It is, of course, desirable to excite the two electron discharge devices from a common source of modulated carrier waves. This may be accom-

plished by placing a second network in the input circuit of either of the electron discharge devices. This second network shifts the phase of the carrier wave so that the output of the two branches recombines in proper phase. The function of the second electron discharge device, which supplies output power during the positive portion of the modulation cycle, may be performed by two or more discharge devices which are so adjusted as to operate successively as the amount of modulation is increased.

It is an object of our invention to provide means which insures that the amplified waves, including both carrier and side band waves, passing through the several branches of such an amplifier are recombined in proper phase relation at the consumption circuit.

The novel features which we believe to be characteristic of our invention are set forth with particularity in the appended claims. Our invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof may best be understood by reference to the following description taken in connection with the accompanying drawing in which Fig. 1 illustrates schematically an apparatus embodying our invention; Figs. 2 to 7 illustrate certain operating characteristics of the apparatus of Fig. 1; and Figs. 8 to 11 illustrate certain modifications of the apparatus of Fig. 1.

Referring to Figure 1, a source of modulated carrier waves is connected to the primary 10 of a transformer 11. A condenser 12 is connected in parallel with the secondary 13 of the transformer 11 to form a circuit tuned to the frequency of the carrier waves. One junction between this transformer secondary 13 and condenser 12 is grounded through a suitable source of grid bias potential 14, which is shunted by a radio frequency by-passing condenser 15. The other junction is connected to one branch of the composite amplifier circuit. The transformer secondary 13 is tapped to provide a variable voltage to the other branch of the composite amplifier circuit. The first mentioned branch of the amplifier circuit includes an inductance 16 connected at one end to the last mentioned junction of the transformer secondary 13 and condenser 12. Condensers 17 and 18 are connected in shunt from each end of inductance 16 to ground. It may be recognized that the network formed by the inductance 16 and condensers 17 and 18 is a phase shifting or impedance inversion network which has the property that the driving point im-

pedance across condenser 17 is inversely proportional to the terminating impedance connected across condenser 18. A quarter wave transmission line, or any equivalent circuit, has this property.

A terminating impedance 19 in series with a blocking condenser 20 is connected across condenser 18 and carries a substantial part of the current transmitted through the above mentioned network. This terminating impedance 19 acts as a grid loading resistor in connection with a discharge device 21. The cathode of device 21 is connected to ground. The grid of device 21 is connected to the ungrounded terminal of condenser 18. The anode of this device 21 undergoes voltage variations opposite to those applied to the grid. These anode voltage variations are coupled back by a condenser 22 to one end of a tuned grid circuit which comprises an inductance 23 and a condenser 24. The condenser 22 supplies a feedback voltage for neutralizing voltage appearing in the grid circuit due to interelectrode capacity of device 21. The other end of the tuned grid circuit is connected to the grid. Two condensers 25 and 26 in series are connected to the ends of the tuned grid circuit. The junction between these condensers is connected to ground and to the cathode of device 21 to maintain the electrical center of the tuned grid circuit at cathode potential.

A value must be chosen for the terminating impedance or loading resistor 19 which is small relative to the input or grid impedance of the device 21, so that the resistor will tend to make the load taken from the input circuit remain nearly constant. It will be appreciated that a fundamental property of an impedance inversion network is that the output current is proportional to the input voltage. Hence, if the network is terminated in a fixed resistance the output voltage is proportional to the input voltage. On the other hand, if the value of the terminating resistance is altered as the network input voltage is changed, it is possible to have the output voltage assume practically any variation with respect to input voltage. In this particular method of obtaining high efficiency operation it is desirable that the network output voltage remain substantially constant, or increase slightly, as the network input voltage increases above carrier value and that the exciting voltage applied to the grid of device 21 follow the modulated wave as it exists at transformer 11 linearly on all values at or below carrier level.

In order to obtain high efficiency operation of discharge device 21 at carrier level the grid bias source 14 and the anode voltage of device 21 are so adjusted that the threshold of anode saturation is reached as the network output voltage approaches carrier level. Under this mode of operation the grid of discharge device 21 begins to draw current as the excitation voltage approaches carrier level. For values of excitation voltage greater than carrier level the grid of discharge device 21 attempts to draw excessive amounts of grid current and this action is tantamount to a reduction in network terminating resistance, which by the previously stated theory, is accompanied by a leveling off of network output voltage as the network input voltage increases. The voltage regulating action which occurs in the grid and excitation circuit of discharge device 21 is necessary to prevent destruction of device 21.

For the greater part of the modulation cycle where the excitation voltage is below carrier level the grid of discharge device 21 draws substantially no current and hence the network terminating resistance is constant, resulting in the network output voltage being substantially proportional to the network input voltage. For the small portion of the modulation cycle when the excitation voltage is slightly less than carrier level, the grid does draw a slight amount of current but because the network terminating resistance is low compared to the grid input resistance at this value of excitation voltage, the wave-form distortion produced is negligible.

It is desirable that the ratio of stored energy to dissipated energy, or the voltampere to watt ratio, of the tuned grid circuit including inductance 23 and condenser 24 be relatively low to assist in reducing phase lag. It has been found that a suitable voltampere to watt ratio for this particular tuned grid circuit is about 2. It is, of course, obvious that higher ratios may be used, although this low ratio is preferred. Such a low ratio reduces the phase errors of the grid circuit of discharge device 21 at high modulating frequencies to as low a value as can be readily obtained.

Proceeding to the other branch of the composite amplifier, there are connected to the tapped point of transformer secondary 13 a pair of impedance inversion or monocyclic networks of the type described above, and a tuned circuit which couples them together. Certain of the component parts of these three circuit elements have been consolidated. The first impedance inversion network includes a series inductance 27, a shunt condenser 28, and a shunt capacitance which is part of condenser 29. The second inversion network includes a series inductance 30, a shunt condenser 31, and a shunt capacitance which is another part of the condenser 29. The tuned circuit which electrically couples the two impedance inversion networks comprises an inductance 32, and a capacitance which is the third part of the condenser 29. This tuned circuit is connected in shunt between the two lines and has connected in series with it a blocking condenser 33 to prevent the bias source 14 from being short circuited to ground. It has been found that the voltampere to watt ratio of this tuned circuit should preferably be reduced to about 8, although, of course, other ratios may be used. This low ratio assists in reducing phase lag as with the grid circuit for device 21.

The second impedance inversion network which includes inductance 30 is terminated by a grid loading resistor 34, which serves the usual purpose of a grid loading resistor. It is adjusted in a manner similar to the grid loading resistor 19. A condenser 35 is connected in series with the resistor 34 and serves as a by-pass around the bias source 14. The cathode of a discharge device 37 is connected to the grounded terminals of the condenser 35 and condenser 31. The grid of device 37 is connected to the other terminal of condenser 31 through a blocking condenser 38. This blocking condenser 38 is connected between the grid loading resistor 34 and the inductance 30 in order to prevent the grid bias of discharge device 37 from interfering with that of discharge device 21. As is indicated in the French Patent No. 820,431 and in the article mentioned above, the discharge device 37 must be biased to a much higher negative value than

device 21 in order to prevent transmission of current through device 37 except upon values of signal voltage above carrier level.

A tuned grid circuit comprising an inductance 39 and a condenser 40 is connected at one end to the grid and at the other end through neutralizing condenser 41 to the anode of discharge device 37. The electrical center of this tuned grid circuit is grounded for radio frequencies through condenser 35. It has been found that reduction of the voltampere to watt ratio for this tuned grid circuit to about 8 aids in reducing phase lag of signals. Higher ratios may be used if it is so desired.

A tuned anode circuit including an inductance 42 and a capacitance which is a part of condenser 43 is connected at one end to the anode of discharge device 21 and at the other end to the cathode through a suitable source of anode potential. A condenser 44 is provided to by-pass signal currents around the source of anode potential. A second tuned anode circuit is provided which is connected to one end to the anode of discharge device 37 and which comprises a transformer primary 45 and a capacitance which is a part of condenser 46. The other end of this second tuned anode circuit is connected to the cathode of device 37 through a suitable source of anode potential. A condenser 47 is provided to by-pass signal currents around this source of anode potential. An impedance inversion network is connected between these two tuned anode circuits and comprises an inductance 48, a shunt capacitance which is a part of condenser 43, and a second shunt capacitance which is a part of condenser 46. A blocking condenser 49 is provided in series with inductance 48 to prevent a direct current connection between the anodes of devices 21 and 37. A secondary winding 50 is coupled to the transformer primary 45. The secondary winding may be connected to supply amplified power to any desired consumption circuit, such as a radiating antenna or the like.

It has been found that the tuned anode circuit which includes inductance 42 may suitably have its voltampere to watt ratio reduced to about 5. The other tuned anode circuits, which includes primary 45 may also have its voltampere to watt ratio reduced to about 5. Any other desired ratio may be used for either or both of these tuned circuits, although these low ratios are preferred because they reduce phase lag of the signals.

It may be seen by inspection that the circuit elements of the two branches of this composite amplifier are identical. Each branch includes two monocyclic networks, two tuned circuits, and one discharge device. It should be noted that the tuned circuit including transformer primary 45 is actually common to both branches of the amplifier. Hence, signals which are of a slightly different frequency than the carrier, such as side bands, are shifted in phase an identical amount in each branch of the composite amplifier and accordingly reach the transformer secondary in phase.

Referring to Fig. 2, the curve represents the anode voltage of device 21 when a pure carrier wave is being transmitted. The curve of Fig. 3 represents the anode voltage of device 21 during transmission of a modulated carrier wave. It may be noted that the voltage at no time exceeds that present during conditions of modulation. At all values of the modulated wave at or below carrier level the anode voltage reduces linearly with respect to the voltage applied in the grid

while at values of the modulated wave above carrier level it remains substantially constant or increases slightly. Discharge device 21 operates at high average efficiency, since the voltage of the direct current plate supply is only slightly greater than the average peak value of anode voltage.

The curve shown by Fig. 4 represents in exaggerated fashion the anode current in discharge device 37 when a pure carrier wave is being transmitted. A very small value of current is transmitted, since discharge device 37, due to its slightly non-linear characteristic, is not biased precisely to current cut off but, only substantially thereto. The curve of Fig. 5 represents the anode current transmitted by discharge device 37 during the same conditions of modulation as are represented by the curve of Fig. 3. The discharge device 37 operates at moderately high efficiency, since its radio frequency anode voltage swing is large and hence the instantaneous anode potential is low during the portion of the modulation cycle when anode current flows.

The curve of Fig. 6 represents the current transmitted to the consumption device by the transformer secondary 50 when a pure carrier wave is being transmitted and the curve of Fig. 7 represents the current in secondary 50 when the same degree of modulation exists as was represented by the curves of Figs. 3 and 5. It may be said figuratively that the discharge device 37 which produces the wave tops shown by the curve of Fig. 5, places these tops on the wave portions shown by the curve of Fig. 3 in order to produce the composite modulated carrier shown by the curve of Fig. 7. Of course, if the current impulses represented by Fig. 5 are displaced in time with respect to the envelope represented by Fig. 3, then the composite envelope represented by Fig. 7 is distorted. In accordance with our invention such distortion is avoided by making the two branches identical insofar as phase shift is concerned. At the same time, by proper design of the input circuits of the discharge devices, as above described, any excessive loading of the supply circuit to which winding 10 is connected is avoided, and abuse of the discharge 21 is eliminated.

The identity of the components in the two branches of our amplifier may be seen by inspection of Fig. 1 wherein one branch includes in order a monocyclic network, a tuned grid circuit, a discharge device, a tuned anode circuit, and a second monocyclic network. The other branch includes, in order, a monocyclic network, a tuned circuit, a second monocyclic network, a tuned grid circuit, and a discharge device. As mentioned before, there is an output tuned circuit common to both branches.

In tests on an amplifier of this type before addition of our improvements it was determined that distortion at 8000 cycles due to the second harmonic was 9 per cent.. After addition of the networks in Fig. 1, including inductances 27 and 30 and the tuned circuit therebetween it was found that distortion at 8000 cycles due to the second harmonic was reduced to $4\frac{1}{2}$ per cent. It was then found after reducing the kilovolt ampere to kilowatt ratio of the tuned anode circuit including inductance 42 from about 16 to 5 that the distortion at 8000 cycles due to the second harmonic was further reduced to about 1 per cent. Measurements indicated that the total RMS distortion was correspondingly reduced.

Equal side band phase lag may be obtained in

the two branches by positioning the components in other orders, for example, by placing the two monocyclic networks in the second branch in the anode circuit rather than in the grid circuit. This, of course, is not economical because of increased cost of parts and power loss. It is possible to use different types or numbers of components in the two branches of the amplifier so long as side band phase lag is maintained equal by proper adjustment of the voltampere to watt ratios of the various tuned circuits in the two branches and the grid of the carrier channel be excited properly. Other changes will be apparent to those skilled in the art.

It should be understood that the four monocyclic or impedance inversion networks shown in Fig. 1, such as the network including inductance 16 and condensers 17 and 18 represent only one of the possible types of monocyclic networks which may be used. It is possible, for example, in each network to replace the inductance by a capacitor and each capacitor by an inductance, in which case the current flowing from the output terminals of the monocyclic network will lead the voltage applied to the input terminals by 90 degrees or one-quarter wave length rather than lagging that voltage by the same amount, as is the case with the networks shown in Fig. 1. It is, of course, obvious that if an even number of these monocyclic networks are changed in type, the currents produced at the consumption device by the two branches will remain properly phased. However, if an odd number of networks, such as are shown in Fig. 1, are changed without other change of the apparatus of Fig. 1, the currents delivered to the consumption device by the two branches would be opposite in phase and would cancel. An obvious way to correct this condition is by the use of a balanced input transformer instead of the single ended input transformer 11, which is shown in Fig. 1. The choice between the various types of monocyclic networks will usually depend upon the economics involved. It may be found that at relatively high frequencies the inductances necessary in the network of the type shown in Fig. 1 may be made larger and hence may be more easily constructed than the inductances which would be required in a network whose output current would lead the input voltage by 90 degrees.

Figs. 8 to 11 show four possible variations of the circuit of Fig. 1 in schematic form. The skeleton circuit shown in Fig. 8 corresponds to the apparatus of Fig. 1. The circles enclosing the symbols -90 represent monocyclic networks of the type shown in Fig. 1, wherein the output current lags the input voltage by 90 degrees. In these Figs. 8 to 11 the symbol $+90$ indicates the type of monocyclic networks wherein the output current leads the input voltage by 90 degrees, and the symbol ± 90 indicates that either type of network may be used. It will be noticed that the two monocyclic networks in the lower or peak amplifier branch of the apparatus in Fig. 8 are indicated as being either type of network. They must of course both be of the same type in the particular type of circuit shown, in order that the signal currents which traverse the two branches reach the transformer secondary 50 in phase.

The skeleton circuit in Fig. 9 indicates an apparatus which is identical with that of Fig. 8 except that the two monocyclic networks in the upper or carrier branch are $+90$ degree networks

rather than -90 degree networks, as in Fig. 8 and Fig. 1.

Fig. 10 illustrates an apparatus in which the circuit of Fig. 8 has been changed by changing the second of the monocyclic networks in the upper or carrier branch to a $+90$ degree network and by changing the single ended input transformer to a double ended one.

The circuit of Fig. 11 is the same as that of Fig. 10 except that each monocyclic network in the upper or carrier branch has been changed to the opposite type.

These circuits are intended to be illustrative of various modifications which may easily be made in the circuit illustrated by Fig. 1. Other modifications will be apparent to those skilled in the art. Choice between circuits such as these will depend on economic considerations. It is, of course, to be understood that either discharge device 21 or 37 may be a plurality of such devices operating in parallel rather than a single discharge device as shown. It is also obvious that these discharge devices may be a plurality of such devices operating in multi-stage relation if it be so desired. The device 37 may furthermore be replaced by a plurality of smaller devices, each of which is individually biased so that it will transmit its share of the total power only as the modulation wave exceeds the carrier level by a predetermined value. Somewhat more efficient operation may be obtained by this last mentioned arrangement.

While we have shown a particular embodiment of our invention, it will, of course, be understood that we do not wish to be limited thereto, since different modifications may be made both in the circuit arrangement and instrumentalities employed, and we contemplate by the appended claims to cover any such modifications as fall within the true spirit and scope of our invention.

What we claim as new and desire to secure by Letters Patent of the United States, is:

1. An amplifier for modulated carrier waves comprising a first branch and a second branch, said branches each being connected between a source of said waves and a consumption device, electron discharge amplifier devices in each of said branches, said device in said second branch being adjusted to pass current only upon greater intensities of said carrier waves than exist without modulation, impedance inversion means in said first branch between said consumption device and said discharge device, means included in said first branch between said source and said discharge device to reduce the load on said source during periods of maximum applied voltage, and means included in said second branch for producing side band phase shift substantially equal to that in said first branch.

2. An amplifier for modulated carrier waves comprising a source of waves, a resistance terminated impedance inversion means energized by said source, electron discharge apparatus connected to said means and adjusted to its peak capacity at the carrier level of said modulated carrier waves, a second impedance inversion means connected to said apparatus, a consumption device connected to said last mentioned means, a circuit connected between said source of waves and said consumption device, said circuit including a second electron discharge apparatus, and means in said circuit for producing side band phase shift substantially equal to that in the path including said two impedance inversion means.

3. In a high efficiency linear amplifier for amplitude-modulated signal waves, the combination with two signal amplifying channels each including an amplifier tube, of means for biasing said amplifier tubes whereby one channel conveys a carrier wave and both of said channels operate in response to peak signals above the carrier wave level, an impedance-inverting network interposed between the carrier wave channel and the peak amplifier channel, a phase-correcting network in one channel operative to provide a phase shift of substantially 180° in the output of said channel through said impedance-inverting network, and means comprising a phase-shifting network in the other amplifier channel for reducing distortion at high audio frequencies caused by envelope phase shift in the network of said one amplifier channel.

4. In a high efficiency linear amplifier for amplitude-modulated signal waves, the combination with two signal amplifying channels each including an amplifier tube, of means for biasing said amplifier tubes whereby one channel conveys a carrier wave and both of said channels operate in response to peak signals above the carrier wave level, an impedance-inverting network interposed between the carrier wave channel and the peak amplifier channel, a phase-correcting network in the carrier channel operative to provide a phase shift in the output of said carrier channel through said impedance-inverting network, and means comprising a phase-shifting network in the peak amplifier channel for reducing distortion at high audio frequencies caused by envelope phase shift in the network of said carrier amplifier channel.

5. In a high efficiency linear amplifier for amplitude-modulated signal waves, the combination with two signal amplifying channels each including an amplifier tube, of means for coupling said channels at the output comprising an impedance-inverting network, means in one of said channels providing a phase-shifting network followed by a shunt-tuned circuit whereby distortion in wave form is introduced in said channel in signals transmitted thereto, and means comprising a second phase-shifting network in the other of said channels for reducing the first-named distortion in wave form at the output coupling means for said channels.

6. In a high efficiency linear amplifier for amplitude-modulated signal waves, the combination with two signal amplifying channels each including an amplifier tube, of means for coupling said channels at the output comprising an impedance-inverting network, means comprising a 90° phase-shifting network for said modulated signal waves in one channel operative to introduce distortion in wave form of said modulated signal waves, and means providing a 180° phase-shifting network in the other of said channels for compensating said wave form distortion at the output of said channels, said last-named phase-shifting network including elements whereby the side bands are shifted as in the first-named network.

7. In a high efficiency linear amplifier for modulated signal waves, the combination with two signal amplifying channels each including an amplifier tube, means for biasing said amplifier tubes whereby one channel conveys a carrier wave and both of said channels operate in response to peak signals above the carrier wave level, of an impedance-inverting network interposed between the carrier wave channel and the

peak amplifier channel, a phase-correcting network in one channel operative to provide a phase shift of substantially 180° in the output of said channel through said impedance-inverting network, and a phase-shifting network in the other amplifier channel providing substantially a 180° phase shift, said network comprising two 90° phase-shifting networks in cascade and a parallel resonant circuit interposed therebetween and tuned to the carrier wave.

8. In a high efficiency linear amplifier comprising two parallel amplifying channels, the combination with an amplifier tube in each channel, of means for operating one of said tubes and channels to amplify the carrier wave and for operating both tubes and both channels to amplify signal peaks, means providing a common anode circuit for said tubes, a load circuit coupled to said anode circuit, means providing an impedance inverting network interposed between said tubes in the anode circuit, a 90° carrier phase-shifting network followed by a tuned tank circuit in the input circuit of one tube and a 180° phase-shifting network in the grid circuit of the other tube, said last-named network including a pair of 90° phase-shifting networks connected in cascade in said grid circuit and having a tuned tank circuit interposed therebetween, said tank circuit being tuned to the carrier wave of a signal to be transmitted through said amplifier.

9. In a high efficiency amplifier comprising a carrier wave amplifying channel and a peak signal amplifying channel, the combination of means providing a common output circuit for said channels, an impedance-inverting network between said channels in said output circuit adapted to cause a 90° phase shift in the carrier wave and side bands of a signal transmitted through said amplifier, means in the input circuit of the carrier wave amplifier channel for causing a 90° phase shift in the carrier wave and side bands and modulation envelope distortion causing a shift of the side bands and the two halves of the modulation envelope from said predetermined 90° shift, and means in the input circuit of the peak amplifier channel for causing a 180° phase shift in the carrier wave and side bands thereof, said last-named means including two 90° phase-shifting networks having a tuned circuit interposed therebetween, whereby modulation envelope distortion occurring in the 90° network of the carrier channel is compensated for and the two halves of the modulation envelope may be in phase in the common output circuit of said channel.

10. In a modulated signal-conveying channel, a network providing means for shifting the carrier wave 180° and simultaneously shifting the side bands thereof in phase from 180° by an amount depending upon the departure from the carrier frequency of said side bands, a second modulated signal-conveying channel connected in parallel with said first-named channel at the input and output ends thereof and including an impedance-inverting network between said output ends, and means in said last-named channel for causing with said impedance-inverting network a corresponding 180° shift of the carrier signal and side bands and a corresponding simultaneous shifting of side bands thereof in phase from 90° by an amount corresponding to that in the first-named channel, whereby in the coupled output circuits the side bands and the halves of the modulation envelope may be in phase.

11. In a high efficiency linear amplifier for amplitude modulated signal waves, the combination with two signal amplifying channels, each including an amplifier tube, of means for coupling said channels at the output comprising an impedance-inverting network providing a 90° phase shift in the carrier wave and side bands, a 90° phase shifting network followed by a shunt tuned circuit connected with one of said amplifier tubes for applying signals thereto, said network and tuned circuit operating to provide a 90° shift in the carrier wave and side bands and an envelope phase shift from said desired 90° shift of the carrier wave and side bands tending to produce distortion, a pair of 90° phase shifting networks and a tuned carrier wave responsive circuit connected in parallel providing means for applying signals to the other of said tubes, said last named tuned circuit being interposed between said last named networks, said networks and tuned circuit being operated to provide substantially 180° phase shift in the carrier wave and side bands and a compensating envelope phase shift respectively, providing in the output means for said channel an amplified modulated carrier wave having a minimum envelope phase shift.

12. In a high efficiency linear amplifier for amplitude-modulated signal waves, the combination as defined in claim 11 further characterized by the fact that the combined phase shift in the two first-named networks is the same as the combined phase shift in the two last-named networks.

13. In a high efficiency linear amplifier for modulated carrier waves, comprising two parallel amplifying channels, the combination with an amplifier tube in each channel, of means for operating one of said tubes beyond cut-off and the other substantially at cut-off, means providing a common anode circuit for said tubes, a load circuit coupled to said anode circuit, a phase-inverting network interposed between said tubes in the anode circuit, means providing a 90° phase shift in the modulated carrier wave and side bands in connection with the input to said one of said tubes, and means providing a 180° phase shift in the modulated carrier wave and side bands in connection with the other of said tubes, said networks providing envelope distortion of the same sign and amount to provide an output envelope distortion of substantially zero magnitude in said load circuit.

14. In a high efficiency linear amplifier for amplitude-modulated signal waves, the combination with two signal amplifying channels each including an amplifier tube, of means for coupling said channels at the output comprising an impedance-inverting network, means in one of said channels providing a phase-shifting network followed by a shunt-tuned grid circuit wherein envelope phase shift is introduced in said channel in signals transmitted therethrough, and means comprising a second phase-shifting network in the other of said channels for reducing distortion in wave form produced by said envelope phase shift at said output coupling means for said channels.

15. In a high efficiency linear amplifier for amplitude-modulated signal waves, the combination with two signal amplifying channels each including an amplifier tube having a control circuit energized by said waves, means for coupling said channels at the output comprising an impedance-inverting network, means comprising a 90° phase-shifting network for said modulated signal waves in the control circuit of one channel operative to produce envelope phase shift of said modulated signal waves, and means providing a 180° phase-shifting network in the other of said channels for compensating said envelope phase shift at the output of said channels, said last-named phase-shifting network including elements to produce envelope phase shift substantially equal to that in the first-named network.

16. In a high efficiency linear amplifier for amplitude-modulated signal waves, the combination with two signal amplifying channels each including an amplifier tube having a control circuit energized by said waves, of means for biasing said amplifier tubes whereby one channel conveys a carrier wave and both of said channels operate in response to peak signals above the carrier wave level, an impedance-inverting network interposed between the carrier wave channel and the peak amplifier channel, a phase correcting network in the control circuit of said carrier channel operative to produce a phase shift in the output thereof, and means comprising a phase-shifting network in the peak amplifier channel for reducing distortion at high audio frequencies caused by envelope phase shift in said carrier amplifier channel.

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