May 12, 1942. J. FAGOT 2,282,714

METHOD AND MEANS FOR THE LINEAR TRANSMISSION OR AMPLIFICATION OF AN AMPLITUDE-MODULATED CARRIER WAVE

Filed Dec. 1, 1939 3 Sheets-Sheet 1

Fig. 1.

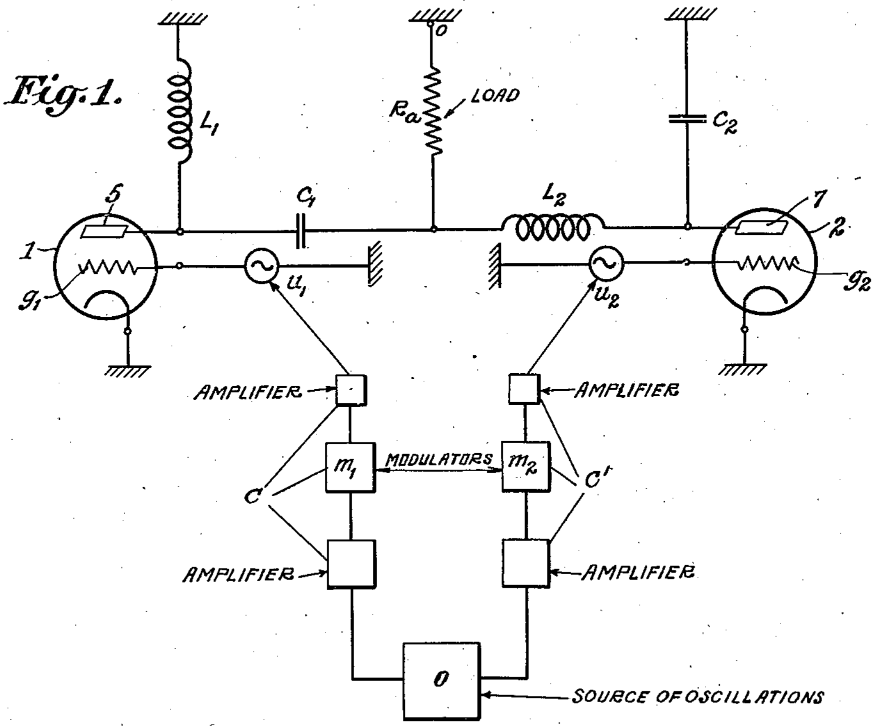


Fig. 3.

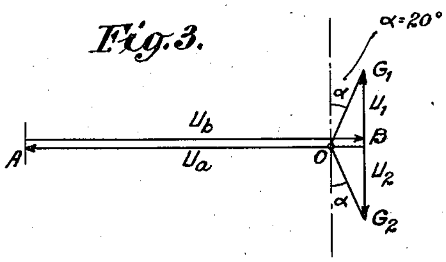
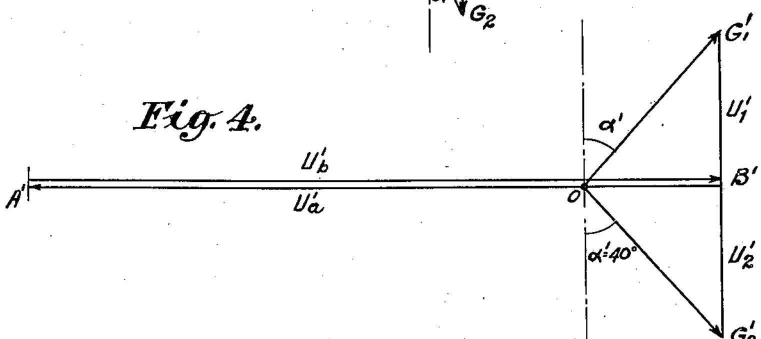


Fig. 4.



Inventor

Jacques Fagot,

By H. S. Grover

Attorney

May 12, 1942. J. FAGOT 2,282,714

METHOD AND MEANS FOR THE LINEAR TRANSMISSION OR AMPLIFICATION OF AN AMPLITUDE-MODULATED CARRIER WAVE

Filed Dec. 1, 1939 3 Sheets-Sheet 2

Fig. 2.

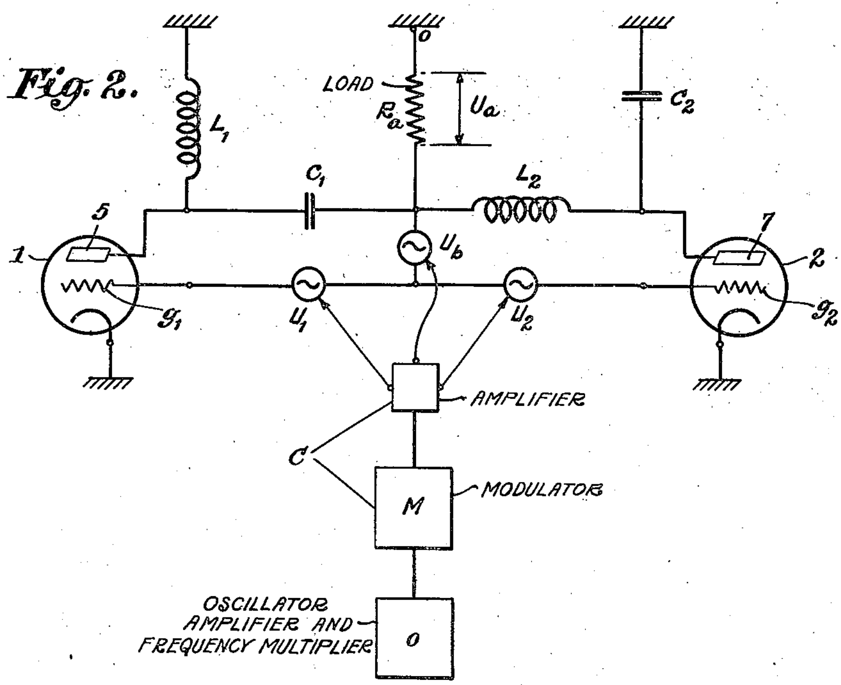
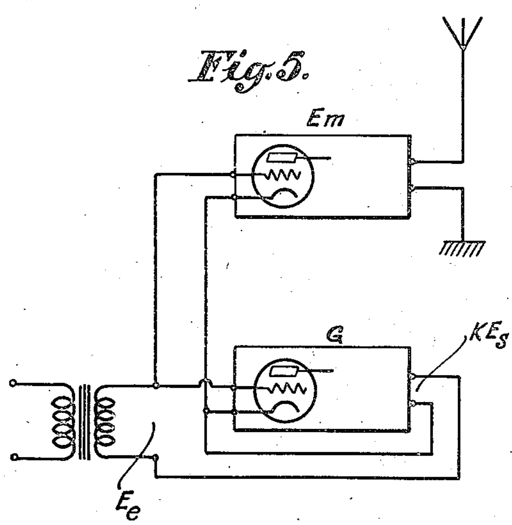


Fig. 5.



Inventor
Jacques Fagot,

By H. S. Grover

Attorney

May 12, 1942. J. FAGOT 2,282,714

METHOD AND MEANS FOR THE LINEAR TRANSMISSION OR AMPLIFICATION OF AN AMPLITUDE-MODULATED CARRIER WAVE

Filed Dec. 1, 1939 3 Sheets-Sheet 3

Fig. 6.

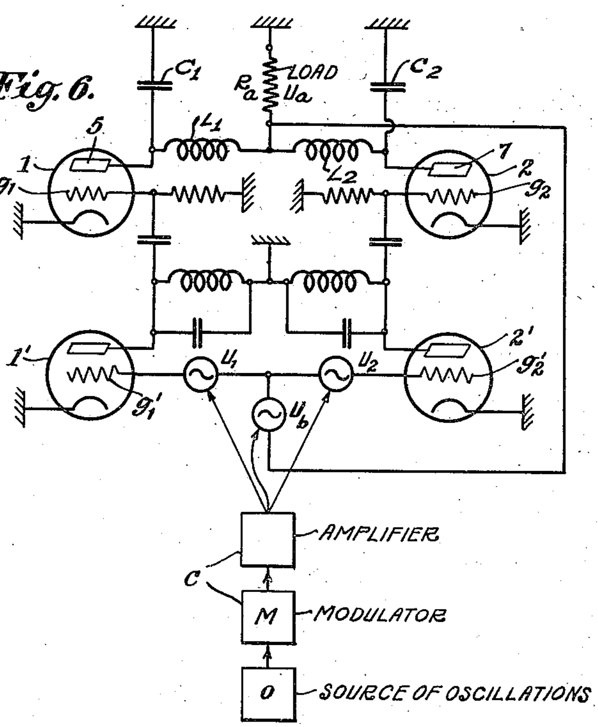
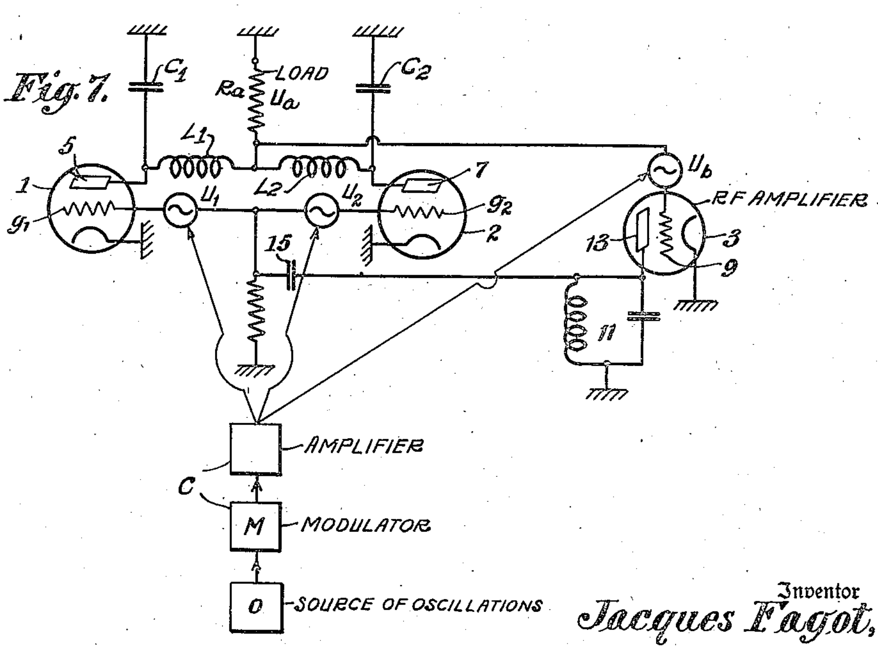


Fig. 7.



Inventor
Jacques Fagot,

By H. S. Grover

Attorney

Patented May 12, 1942

2,282,714

UNITED STATES PATENT OFFICE

2,282,714

METHOD AND MEANS FOR THE LINEAR TRANSMISSION OR AMPLIFICATION OF AMPLITUDE-MODULATED CARRIER WAVES

Jacques Fagot, Paris, France, assignor to Compagnie Generale de Telegraphie Sans Fil, a corporation of France

Application December 1, 1939, Serial No. 307,022
In France December 2, 1938

4 Claims. (Cl. 179—171)

The transmitter system of the present application has for its object to provide a modulated wave amplifying means and method applicable to radio-telephonic transmission.

The present invention involves on the one hand the system of modulation through phase shift, which is described in older patents (see especially United States Patents Nos. 1,882,119, 1,892,383, 1,946,308 and 2,009,080. See, also, Proceedings I. R. E., November, 1935, "A Communication from H. Chireix").

The present invention involves on the other hand operation similar to that of an ordinary modulation system in which variation of the amplitude of the carrier wave is accomplished.

The present invention thus can in a certain sense be considered as improvement of the two preceding methods.

One of the objects of the invention is to provide a method and means for high efficiency operation for radio-telephonic transmitters. Another object of the invention is to provide a method and means for amplification and transmission of an amplitude-modulated carrier wave of large power.

A still further object of the invention is to provide a system for the transmission of modulated radio-frequency waves which, while utilizing large power and insuring high efficiency preserves and maintains a high degree of linearity in the transmission.

The essential arrangement of the invention resides in feeding to the end or power tubes or to an intermediate amplifier stage of a transmitter connected along the lines of a modulation system predicated upon outphasing, amplitude-modulated potentials originating from a single input amplification chain or cascade, and in the use of reverse or negative feedback in the load circuit with a view to insuring modulation based upon amplitude variation only for the points of the modulation cycle which in the load circuit correspond to an instantaneous current value below the effective or root means square value of the carrier wave, and modulation based both on amplitude variation and outphasing for points of the modulation cycle which correspond to larger load.

In certain embodiments of the essential arrangement as hereinbefore outlined, a transmitter comprises only a last symmetric stage or preceding stages that are also symmetric to which the modulated potentials may be impressed either directly or else by the intermediary of auxiliary amplifiers.

The circuit organization, moreover, includes compensating means whereby the distorting action of the modulation cycle may be diminished, this means being effective especially when distortion is due to the saturation of the load circuits.

In describing my invention, reference will be made to the attached drawings wherein:

Figure 1 illustrates a modulated wave amplifier system wherein two radio-frequency waves are fed to a common load in phase-displaced relation to produce a resilient radio-frequency wave the amplitude of which depends on the phase relation which, in turn, is controlled by the signals.

Figure 2 illustrates a modulator and modulation amplifier arranged in accordance with the present invention. In this system I make use of modulation by phase shift and by carrier wave amplitude variation;

Figures 3 and 4 are voltage vectors used in illustrating the manner of operation of my system as illustrated in Fig. 2;

Figure 5 shows means for compensating nonlinearities occurring in the transmitter of Figure 2; while

Figures 6 and 7 are modifications of the arrangement of Figure 2.

It is known in fact that the two modulation methods referred to hereinbefore differ essentially by the manner in which there is obtained the modulation of antenna currents under the action of the speech currents, this modulation producing in the two cases, amplitude variations of the carrier wave.

In the customary modulation system, this amplitude variation of the carrier wave is obtained by applying to the antenna a high frequency potential, already modulated in amplitude by the signals.

In the modulation system by means of phase shift the amplitude variation of the carrier wave is obtained in that under the action of the speech currents instead of causing the variation of the amplitude, there is being varied the relative phase of the two high-frequency potentials which are applied to the antenna. In the absence of modulation, provision is made whereby these two potentials, which are substantially equal, form between each other a rather wide angle (140° for instance). Under the action of a phase modulation in the reverse sense of these two elementary potentials, their relative phase shift varies, for example, between 120 and 160° and this has the effect that the instantaneous current amplitude in the antenna likewise varies between two extreme I_0 and I_1 which, for a deep modulation of the transmitter, may be in the neighborhood of zero for the one value, while the other is twice the effective value of the carrier I_m.

The greatly simplified nature of such a system can be represented as is indicated in the Figure 1, attached herewith. In this figure, two tubes **1** and **2** having their anodes **5** and **7** connected to circuits tuned substantially to the same carrier frequency feed into a common load circuit, represented in a highly schematical fashion in the form of a resistor R_a which is the equivalent, for instance, of the total antenna resistance which would be coupled in practice in a suitable manner with the two anode circuits L_1 C_1 and L_2 C_2.

According to the method of modulation by phase shift which has just been recalled summarily, the grids g_1 g_2 of the two tubes **1** and **2** are excited respectively by two potentials u_1 and u_2 obtained from the same high-frequency oscillator O through two separate amplification chains C and C′, these two potentials being modulated in modulators in m_1 and m_2 by opposite phase variations. The resultant current in the load is correspondingly modulated in amplitude.

The amplifying system forming the subject matter of the present invention is represented schematically in Figure 2. It differs from the preceding one by the mode of excitation of the grids g_1 and g_2 of the tubes **1** and **2**, the plate circuits of these tubes being the same and being controlled in the same manner.

The modulated alternating potentials applied to the grids g_1 and g_2 in my system result from the composition of four elementary high frequency potentials U_1, U_2, U_a and U_b, as will be explained hereinafter.

The potentials U_1, U_2 and U_b coming from the high-frequency source O across a single amplification chain C, permits use of a modulator M of any type of means of which the amplitudes of said potentials are varied in accordance with the amplitude of the speech currents.

The potentials U_1, U_2 which are substantially equal to each other are applied respectively to each of the grids g_1 g_2 but in opposite phase with respect to each other, while the potential U_b is applied substantially cophasally to the two grids with a phase in quadrature relative to the two preceding potentials V_1 and V_2.

The potential U_a finally is furnished by the resistor R_a of the load circuit (antenna circuit for instance). V_a is likewise a high-frequency potential modulated in amplitude and the arrangement is such that this potential U_a is also in opposition to the potential U_b. The potential U_a can thus be considered as in inverse reaction.

The resultant alternating potentials which are applied to the grids g_1 and g_2 are represented by the diagram of Figure 3.

In this figure there is drawn from the point O corresponding for instance to the ground potential (point O of Figure 2), a vector OA equal to the potential U_a arising in the impedance R_a, then in the opposite direction a vector AB equal to U_b, and finally two vectors BG_1 and BG_2 equal respectively to U_1 and to U_2 but displaced in phase each by 90° relative to the preceding vectors, the one in advanced phase and the other one lagging in phase. The resultant potentials applied to the grids g_1 g_2 of the two tubes **1** and **2** (Fig. 2) are then represented respectively by the two vectors OG_1 and OG_2 which form between each other an angle of $180°-2\alpha$.

In practice, the circuits will be controlled such that in the absence of modulation the angle α has a small value, 20°, for instance.

Thus, it is seen that in the absence of modulation, the alternating potentials which are applied to the grids g_1 g_2 of the two tubes are similar to those which they would receive in accordance with the usual scheme of modulation by phase shift as illustrated in Fig. 1.

For reasons of economy, it is known, moreover, that it becomes expedient in general to control the transmitter in such a manner that this operation (non-modulated carrier wave) corresponds substantially to the appearance of saturation phenomena in the output circuits of the two power tubes **1** and **2**.

When examining thus the performance taking place at modulation it is found that for all points of a modulation cycle for which the amplitude in the load circuit is smaller than that which would correspond to the carrier alone, the potentials U_1 U_2 U^a and U^b vary (in amplitude **only**) in a linear fashion, i. e., the diagram of the potentials applied to the grid (Fig. 3) becomes larger or diminishes but without its form being varied, i. e., by remaining homothetical to itself.

The final stage thus behaves like a simple amplification stage modulated in amplitude and with inverse reaction.

In fact, this inverse reaction acts in accordance with the phase but the latter plays hereby but an intermediate role.

The output of the power stage for all these points is by the way the more favorable the more the amplitude approaches the value of the carrier. It becomes poor only for the smallest amplitudes but since the power which presents itself is then low, the influence of said amplitudes upon the overall output is of slight importance.

However, for the points of a modulation cycle which correspond to larger amplitudes than the means value of the carrier, the potential U_a owing to the saturation of the load circuits has the tendency of not increasing according to a linear law, while the potentials U_1, U_2 and U_b continue to increase proportionally. The result is that, at the same time that the diagram becomes larger, it also undergoes a deformation. The angle α which at first was 20°, for instance, will be increased and for the points of the cycle which correspond to the maximum amplitude there will be obtained, for instance, the diagram shown in Fig. 4. The potentials U'_1 U'_2 and U'_b are equal respectively to 2 U_1, 2 U_2 and 2 U_b while U'_a is less than 2 U_a. It follows for instance that $U'_b—U'_a$ has not become equal to 2 $(U_b—U_a)$ but equal to $(U_b—U_a)$ and that the angle α' has become equal to 2α namely equal to 40°.

When assuming, for instance, that Fig. 3 corresponds to a point of the modulation cycle such that the instantaneous power of the transmitter be equal to the means power of the carrier wave, Fig. 4 will then correspond to the crest point of the same cycle.

Thus, it is seen that in my novel system for the high values of the modulation cycle operation is similar to that of the system of modulation through phase shift, with the difference, however, that in my system at these high values of the modulation cycle the amplitudes of the excitation potentials on the grids of the amplifier tubes are also increased.

In this part of the cycle, situated above the effective value of the carrier, the output is in all points high and more especially equal to that of a pure continuous wave transmitter.

When considering finally the overall operation of the transmitter in any modulation, it is seen that the output which is higher than 60% for the carrier and above the latter and which is only low for the very small loads, remains very favorable in the arrangement.

In order to give an illustration there is chosen in Fig. 3 $U_b=10$ (U_b-U_a). Then, it can be seen that there suffices a relative drop of 10% of U_a at the crest value in order to double the relative value of U_b-U_a and, therefore, to have the angle α pass substantially from 20° to 40°, i. e., for doubling substantially the antenna current and the circuits of the plate of the last stage is adapted for this as in the system of modulation through phase shift.

The amplitude curve will under these conditions indicate a relative drop of 10% in the crest which value does not appear exaggerated.

It is clear on the other hand that this drop will be lower if for U_a and for U_b higher values relative to their difference are chosen respectively.

Moreover, in accordance with a further feature of the invention, this drop can be overcome in various ways.

For instance, instead of applying to the grids g_1 g_2 the potential U_a proper or a potential which is proportional thereto, a potential may be applied which tends itself to fall towards the crest in accordance with the same law.

In accordance with another variation of the invention as illustrated in Fig. 5, this correction may further be effected by means of an auxiliary transmitter of very low power or simple amplifier G possessing the same distortion characteristic as the main transmitter E_m.

Negative feedback is added to this auxiliary transmitter or to this amplifier serving as a compensator.

In designating by E_e the input potential and by E_s the output potential of the compensator, the effective potential applied between grid and cathode will be equal to $E_e-K\ E_s$ wherein K is the coefficient of the inverse reaction. This potential will contain aside from the fundamental term all the harmonics of the principal transmitter E_m (since the distortions of these two transmitters are similar) but in phase opposition with respect to the fundamental term.

Utilized for modulating the input of the principal transmitter E_m (as indicated in Fig. 5) this potential will compensate in full or in part its distortions.

This latter method is, however, a very general one and it could be applied to correct any modulation system.

In the case in which it will be desired to apply the inverse reaction to the whole of the principal transmitter, there also exists the possibility of an impeding lagging in phase of this transmitter which will be the greater the higher the frequency.

In order to compensate the phase lag of the principal transmitter, the phase of the small transmitter could thus be made to lag to a lesser degree in order to be able to apply to the latter transmitter the inverse reaction. The potential between grid and cathode of the input tube will thus have its phase which will advance with the frequency in accordance with a law of inverse rotation.

Utilized for modulating the input of the main transmitter, this potential, will, therefore, compensate in full or in part, its phase rotations.

The action of such a compensator could be increased further if necessary by repeating it several times by means of several compensators placed in series.

Returning to the general functioning of the system in accordance with the invention and, more particularly, to Fig. 2, it should be understood that in practice the reaction potential could be applied to one of the preceding stages of the transmitter instead of to the grids of the power stage proper. Then a scheme will be obtained similar to that shown in Figure 6.

In Fig. 6, the tubes 1 and 2 are again the tubes of the power stage. The positions of the inductive and capacitive impedances L_1 and C_1 connected to the plate of the tube 1 are reversed, relatively to Fig. 2. The disposition of L_1 C_1 in the two figures is equivalent to that of Fig. 2, because the excitation voltages on the grids are rotated 180° in phase in the two figures. There is shown at 1′ and 2′ two tubes of a preceding stage. The potentials U_1 U_2 U_a and U_b obtained respectively from the chain C and from the resistance R_a are then applied to the grids g'_1 and g'_2 of the two tubes 1′ and 2′.

It may also be of advantage to apply directly to the grids of the tubes of the end stage the two potentials U_1 and U_2 and to apply to them on the contrary the potential U_b-U_a across one or several amplifier tubes. Such a circuit is shown in Figure 7 indicating in 3 such an amplifier tube. Here the voltage U_b is applied to the grid 9 of tube 3 and the resulting amplified voltage appearing in the tuned circuit 11 connected with anode 13 is fed to the grids g_1 and g_2 by blocking condenser 15.

It should be understood finally that the circuits shown can be provided or modified; without departing from the scope of the invention, in accordance with any known arrangement. Thus, instead of utilizing for the power stage of the transmitter two tubes only, for this stage also four tubes could be used which operate in pairs in symmetrical circuits or even a larger number could be utilized.

What is claimed is:

1. In a modulated carrier wave amplifier, a load circuit, a source of modulated wave energy, a pair of electron discharge devices each having input and output electrodes, means for applying voltages from said source in phase displaced relation on the input electrodes of said tubes, means for applying voltage from said source in phase on the input electrodes of said tubes, a load impedance connected with said output electrodes, and means for impressing voltages which vary in accordance with variations of the amplitude of the potentials developed in said load impedance on said input electrodes in phase opposition to said second named voltage impressed in phase on said input electrodes.

2. The method of high efficiency linear relaying of an amplitude modulated wave which includes the steps of, transmitting substantially equal amplitude components of said amplitude modulated wave energy through two paths in displaced phase relation, combining said transmitted components to produce a resultant dependent upon the components' amplitude and phase relation as combined, and modifying the phase rela-

tion of the two components as combined in accordance with non-linearity resulting from transmission and combining of said components to control the amplitude of the resultant and thereby maintain linearity.

3. The method of high efficiency linear relaying of an amplitude modulated wave which includes the steps of, transmitting substantially equal components of said amplitude modulated wave energy through two paths in substantially fixed phase displaced relation as long as said transmission is substantially linear, combining said transmitted components to produce a resultant, producing voltages representative of substantial departures of said resultant from linearity, and reducing the phase displacement of said components being transmitted as a function of said voltages to augment the resultant and to thereby maintain linearity over the entire modulation range during said relaying process.

4. In a modulated carrier wave amplifier, a load circuit, a source of modulated wave energy, a pair of electron discharge devices, each having input and output electrodes, means for applying voltages from said source in phase opposition on the input electrodes of said tubes, means for applying voltage from said source in phase on the input electrodes of said tubes, a load connected with said output electrodes, and means for impressing voltages from said load on said input electrodes in phase opposition to said second named voltage impressed in phase on said input electrodes.

JACQUES FAGOT.