Aug. 12, 1941. F. E. TERMAN 2,252,049

LINEAR AMPLIFYING SYSTEM

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FIG. 1.

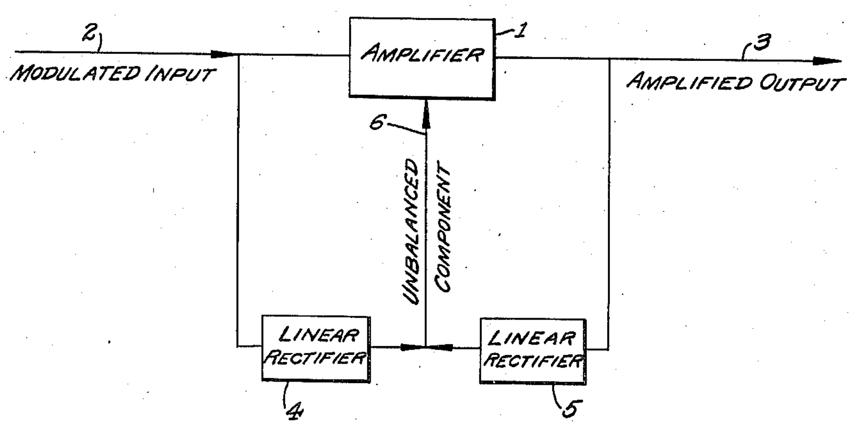
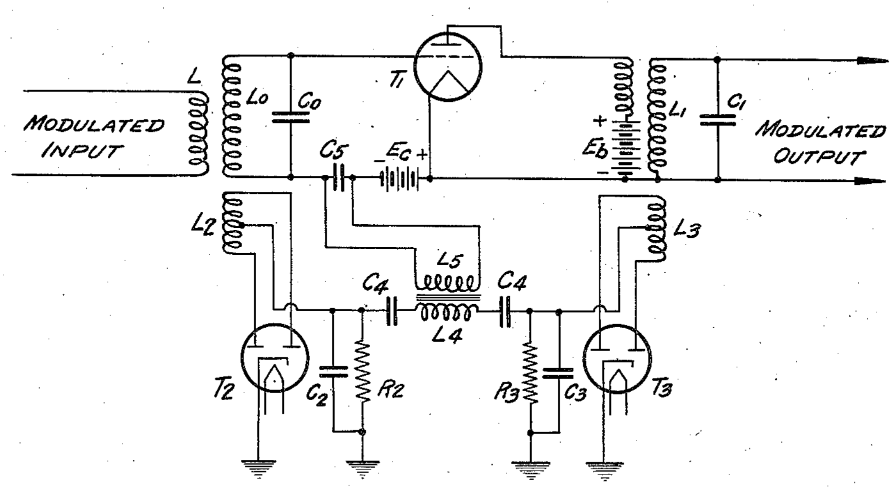
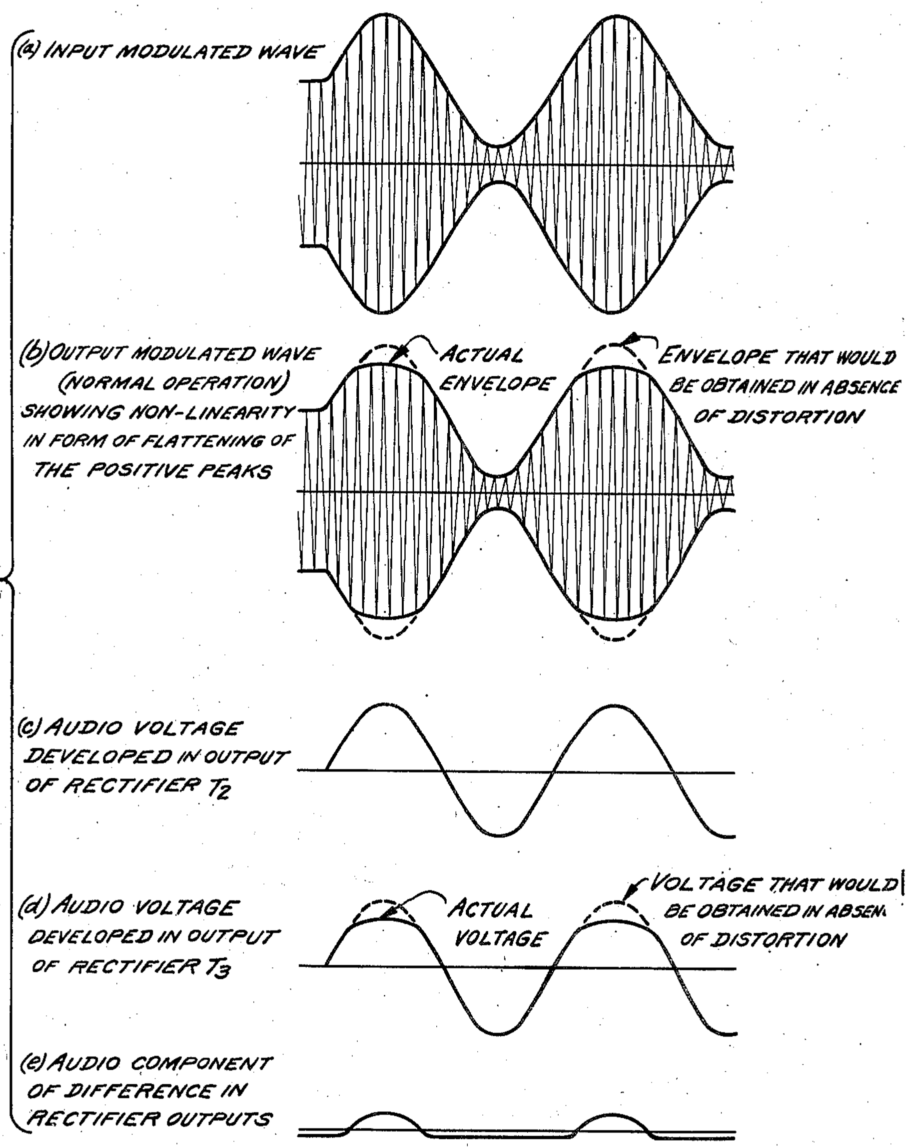


FIG. 2.



INVENTOR
FREDERICK E. TERMAN
BY E. O. Phinney
ATTORNEY

FIG. 3.



INVENTOR
FREDERICK E. TERMAN
BY E. W. Phinney
ATTORNEY

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FIG. 4.

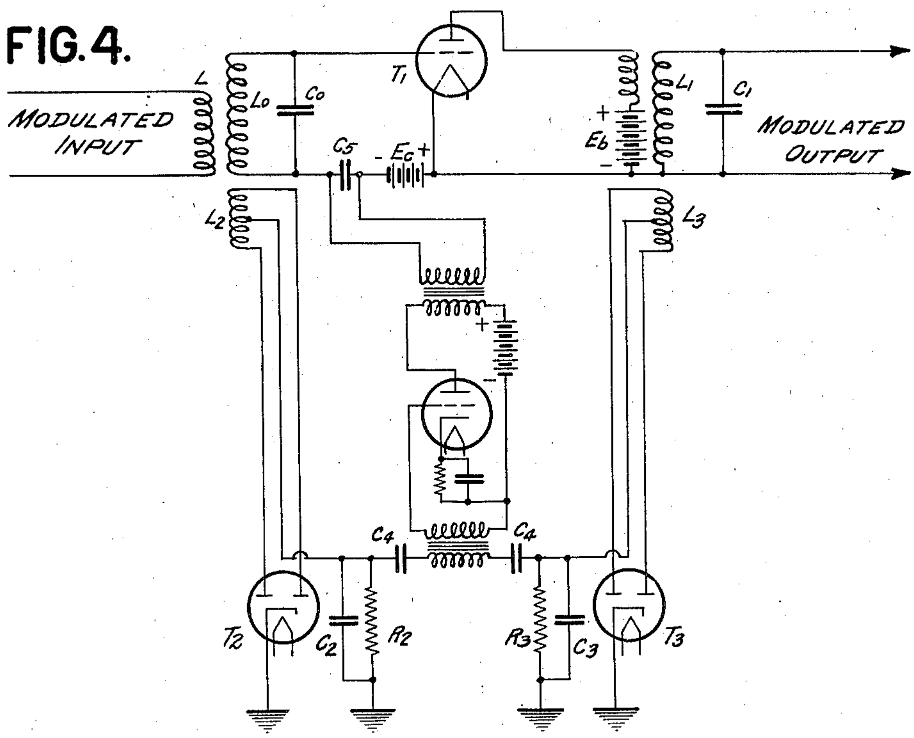
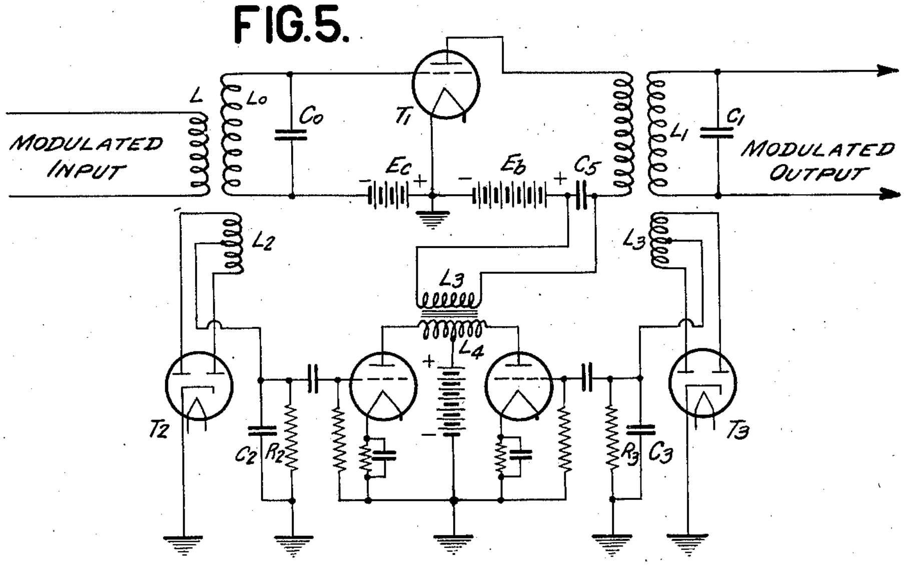


FIG. 5.



INVENTOR
FREDERICK E. TERMAN
BY E. D. Phinney
ATTORNEY

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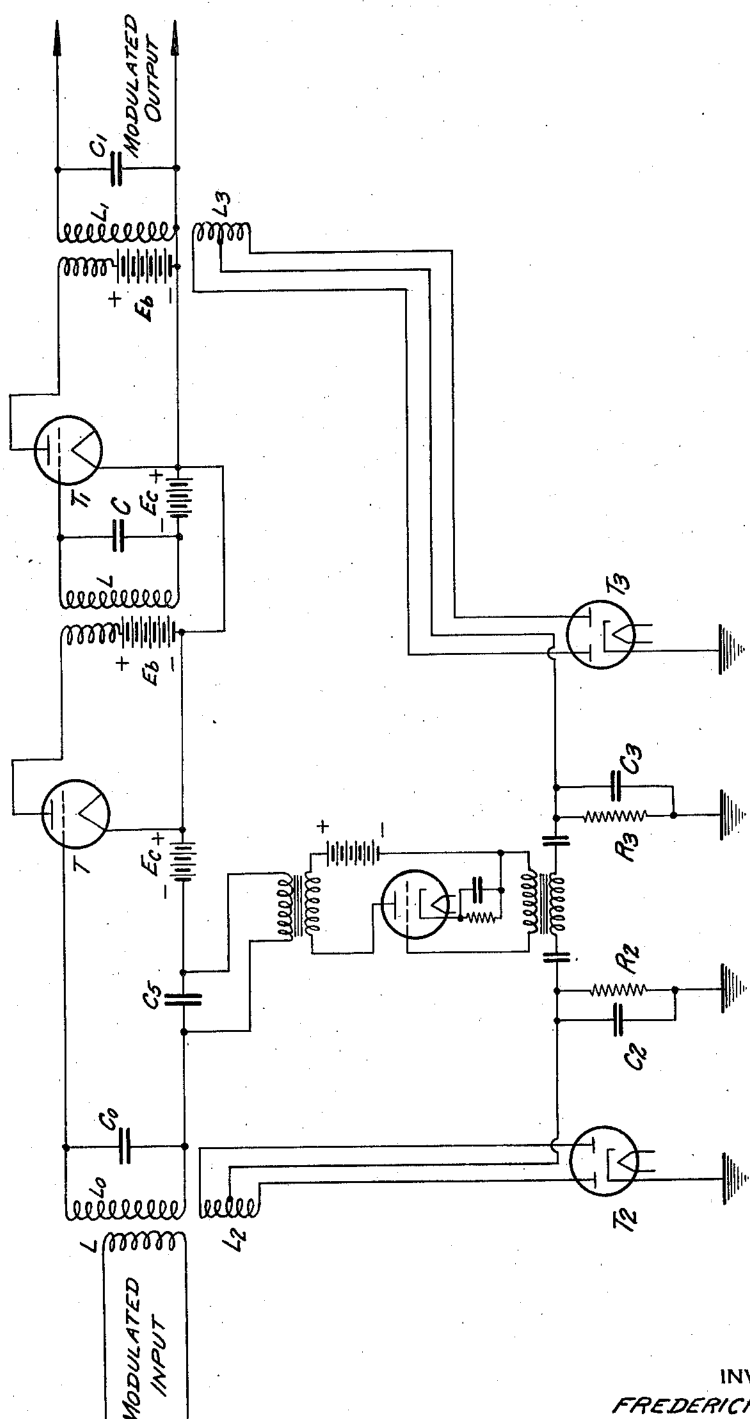
FIG. 6.



INVENTOR
FREDERICK E. TERMAN
BY E. D. Phinney
ATTORNEY

Patented Aug. 12, 1941

2,252,049

UNITED STATES PATENT OFFICE

2,252,049

LINEAR AMPLIFYING SYSTEM

Frederick E. Terman, Stanford University, Calif., assignor to International Standard Electric Corporation, New York, N. Y., a corporation of Delaware

Application May 13, 1939, Serial No. 273,404

9 Claims. (Cl. 179—171)

The present invention relates to amplifying systems for amplifying modulated waves, and more particularly to such systems which operate at comparatively high power and/or high efficiency and which are intended to give a so-called "linear" amplification of the modulated wave.

By a linear amplification of a modulated wave is meant an amplification which introduces substantially no distortion of the modulation envelope regardless of whether or not some distortion of the carrier wave may be introduced. In other words, linear amplification of a modulated wave is such an amplification that the resulting output wave has an envelope of the same wave form as the envelope of the input wave, although the wave form of the individual carrier undulations may perhaps be slightly distorted from that of the input wave.

The ordinary linear amplifier used in many radio broadcast transmitters is essentially a tuned amplifier biased approximately to cut-off and operated under conditions such that the amplitude of the voltage developed in the output tank circuit is substantially proportional to the amplitude of the voltage exciting the amplifier. In order to achieve a high degree of linearity in such an arrangement it is necessary, however, to take considerable care in the circuit adjustments, and also to make compromises that involve sacrifices of efficiency and power output.

It is an object of the present invention to provide a novel method of performing amplification and a novel amplifying system which shall overcome the above mentioned limitations of the ordinary linear amplifier. In particular it is an object to provide a method and a system which shall give substantially linear amplification even when the amplifying means are operated under conditions which ordinarily introduce appreciable non-linearity. It is also an object to provide a method and a system which shall perform amplification with higher efficiencies than have been heretofore obtainable in amplifiers of the linear type.

In particular it is an object of my invention to provide a method and system which shall permit the biasing of the amplifying tube to a point of greater efficiency than was heretofore possible in the case of linear amplifiers, while at the same time yielding an amplification that is more nearly linear than the amplification heretofore obtainable with tubes biased to anywhere near comparable efficiency.

In general, the novel method of my invention comprises detecting some of the input energy to the amplifier as well as some of the output energy from the amplifier to obtain two different waves of envelope frequency, which respectively represent the wave forms of the envelopes of the input to the amplifier and the output from the amplifier. In accordance with the method of my invention these two envelope-frequency waves are then mutually opposed to yield a corrective control wave corresponding to the difference between them, which difference represents the distortion of the envelope which has been introduced by amplification. This control wave so derived is then used to modulate the amplifier in such sense as to tend to reduce the differences between the two detected waves, i. e. as to tend to reduce distortions in the envelope which are introduced by the amplifier.

In the above brief description of the method of my invention it will be seen that this method has some points of resemblance to the so-called negative feedback system as applied to modulators, wherein a modulator, alone or in cascade with preceding and/or succeeding amplifier stages, is controlled to reduce distortion in its output envelope by detecting its output and feeding such detected wave back to the speech frequency input channel in negative feedback fashion. In fact, the present invention may in certain applications be employed instead of the above outlined negative feedback system with very considerable advantage from the standpoint of simplicity and convenience of adjustment, and in certain other types of systems the present invention may be used in conjunction with the aforesaid principle of negative feedback of envelope frequencies in order to yield a complete combined system which shall be superior to such a system employing the negative feedback arrangement alone.

The nature of my invention may best be understood from the following description in conjunction with the drawings, in which

Fig. 1 illustrates the fundamentals of the system and method of my invention;

Fig. 2 illustrates in greater detail a circuit embodying the invention;

Fig. 3 is a representation of a series of curves useful in understanding the principles of operation of the invention; and

Figs. 4, 5 and 6 illustrate modified circuits embodying the invention.

Referring more particularly to Fig. 1, a roughly linear amplifier **1**, is fed with an input of modulated carrier over an input channel **2**, and delivers a corresponding amplified output wave to an output channel **3**. A small portion of the input signal to the amplifier is, in accordance with the present invention, rectified by a linear rectifier **4**; and the output of this rectifier **4** is balanced against a corresponding output of another linear rectifier **5** which is excited from the amplifier output. By proper adjustment of relative magnitudes the output voltages of these two rectifiers may be made such that they would be identical if the amplifier **1**, were operating without distortion, and there would then be no difference voltage obtained when the rectifier outputs are balanced against each other. Since, however, the modulation envelope of the amplifier output does not reproduce exactly the modulation envelope of the modulated input the outputs of the two rectifiers are in fact not identical, and a residual unbalanced voltage results when the rectifier outputs are balanced against each other. This unbalance is then applied over channel **6** to amplifier **1** to modulate this amplifier in such a sense as to tend to correct for the distortion that the amplifier introduces, i. e. in such a way as to reduce the unbalance between the rectifier outputs.

A circuit arrangement which embodies the fundamental system indicated schematically in Fig. 1 is illustrated in Fig. 2. Here T_1 represents a class B or B—C amplifier with an input tank circuit L_0C_0 which is fed inductively from input winding L and with an input bias source E_c. This tube delivers its output to tank circuit L_1C_1, to which a suitable load (not shown) is coupled. To prevent singing or instability suitable neutralization circuits of known type are preferably employed. Such circuits are omitted from the drawings for the sake of simplification but may be assumed to be included not only in Fig. 2 now under consideration, but also in Figs. 4, 5 and 6 later described. A portion of the input power is picked up by coil L_2 that is coupled to L_0, and is used to operate the linear rectifier T_2 whose output is fed to the resistance-condenser combination R_2C_2. Similarly coil L_3 coupled to L_1 excites the linear rectifier T_3 whose output is fed to the resistance-condenser combination R_3C_3. The audio-frequency components in the outputs of the two rectifiers are then balanced against each other in such a manner that any unbalance develops a voltage across transformers L_4L_5. By adjusting the couplings properly the audio outputs of these two rectifiers can be made to have the same amplitude when there is no distortion. Under these conditions no voltage will appear across coils L_4 and L_5. However, if the amplifier **1** introduces distortion, the audio-frequency obtained from rectifier T_3 will not any longer balance exactly with the output developed by T_2. This unbalance induces in coil L_5 a voltage which acts to grid modulate the amplifier **1** with a correcting distortion of such sense as to tend to compensate for the distortions of the amplifier **1**.

Some of the details of operation of the arrangement shown in Fig. 2 are given in Fig. 3. Here the modulated wave applied to the input of the triode amplifier has the character shown at *a*, while curve *b* shows the modulation envelope of the output wave that would be obtained in normal operation under conditions such that the positive peaks of modulation were somewhat flattened. Curves *c* and *d* illustrate the corresponding audio voltages developed in the outputs of rectifiers T_2 and T_3. When these are balanced against each other it will be noted that the distortion produced by the amplifier results in a difference voltage that is shown in curve *e*. I utilize this difference voltage to modulate the amplifier in such a way as to tend to increase the total amplifier output at the peak of modulation, and thereby compensate for the distortion of the amplifier. In other words, the system operates by introducing, through modulation, a compensating distortion in the amplifier that tends to counteract the distortion that would otherwise be present.

Several variations of the embodiment of Fig. 2 are shown in Figs. 4, 5 and 6. Fig. 4 differs from Fig. 2 principally in that the unbalance in the output of the rectifiers is amplified before being applied to amplifier **1** to modulate this amplifier. This has the advantage of making available an increased amount of modulating power. In Fig. 5, the compensating distortion is introduced into the amplifier **1** by plate rather than grid modulation. Also, a center-tapped-transformer type of push-pull amplifier output is used in balancing the rectifier outputs after amplification thereof. In other respects the systems of Figs. 4 and 5 are similar to that of Fig. 2. The operation will be self-evident in comparison with the foregoing description of the operation of Figs. 1 and 2.

Fig. 6 shows the system applied to a two-stage amplifier, with the distortion-correcting modulation introduced into the first stage. In some instances it is desirable to operate the system of Fig. 6 with such bias potentials that the second stage T_1 of the amplifier introduces the greater part of the distortion, the first stage T then serving to correct the distortions of T_1.

A considerable number of other variations are obviously possible. Included among these are other rectifier arrangements, other pick-up systems for exciting the rectifiers, other balancing systems, and other methods of introducing the distortion-compensating modulation.

The arrangements that I have shown will correct for amplitude, frequency, and phase distortion introduced in the modulation envelope by the action of the amplifier. It is to be noted that in designing the circuits it is especially desirable to avoid any considerable phase shifts in the range of frequencies used for distortion corrections, i. e. at the envelope frequencies of the modulated wave. In particular the phase shifts from the point where outputs are balanced against each other, to the point where the modulation actually takes place in the amplifier should be kept small to avoid the possibility of oscillations.

The method that I have described for correcting distortion introduced by amplifiers makes it possible not only to increase the linearity obtainable, but particularly to select operating conditions particularly favorably from the point of view of efficiency and power output, but which would ordinarily be accompanied by excessive distortion. Thus the amplifier, or at least the last stage thereof, may be biased to or even beyond cut-off and/or the tank circuit impedance and magnitude of the impressed modulated signal may be chosen to give better output and efficiency than would ordinarily be possible where the amplifier tube itself must be distortion free.

The method and system for producing substantially linear amplification in accordance with my invention presents another very important advantage in that the two detectors whose outputs are to be compared tend to mutually compensate any non-linearities which may exist in the detectors. It is particularly advantageous to make the two detectors **4** and **5** alike so far as practicable, or at least similar in characteristics. When this is done it is not necessary that the individual characteristics of the detectors be linear since distortions arising in one of these detectors are balanced by the corresponding distortions in the other detector. This feature of mutually compensating detector distortions represents a further advantage of the method and system of my invention as compared to the known method of negative feedback of envelope frequencies, since it is much less difficult to make two rectifiers similar in characteristics than to make one rectifier perfectly linear.

The linear amplifying system of my invention is particularly useful in cases where it is desired to increase the power of an existing transmitter by adding thereto a further high-power, high-efficiency linear amplifying system, and employing the existing transmitter to excite such a further amplifying system. In accordance with my invention it is possible to provide such an amplifying system which may be added as a separate totally independent unit. Furthermore, the linear amplifying system of my invention when excited by an existing transmitter as above described will yield, without doing anything whatsoever to the original transmitter, all the advantages which could be realized by modifying the combination of transmitter and amplifier so as to apply the known arrangement of negative feedback previously referred to. It should be noted, furthermore, that in order to obtain by the use of negative feedback a performance comparable with that of the linear amplifying system of my invention, it would be necessary to arrange the negative feedback loop so that it would span all the stages of the combined transmitting system from the modulator stage of the existing transmitter to the final high-power added amplification stage inclusive. In many cases this original transmitter may already have feedback, and it would require extensive alterations if an additional stage of power amplification were to be included in the feedback loop.

There is also a very considerable advantage in using my system when a large number of amplifiers are connected subsequent to the modulator stage of a system, even if negative feedback around the modulator is to be used. The procedure then would be to apply my new method of control to the last one or more stages of amplification, and thereby reduce the number of stages that would have to be included in the feedback loop of the negative feedback system, with corresponding reduction in phase shift troubles.

Although certain embodiments of my invention have been shown and described by way of illustration, it will be understood that modifications, alterations and adaptations thereof occurring to one skilled in the art may be made without departing from the scope of the invention as defined in the appended claims.

What I claim is:

1. The method of linearly amplifying a modulated input wave so as to produce a modulated output wave of greater power, which comprises detecting a portion of said input wave to produce a modulation envelope wave, non-linearly amplifying another portion of said input wave to produce an amplified wave, detecting a portion of said amplified wave to produce a second envelope wave, delivering another portion of said amplified wave as said desired output wave, deriving the difference wave of said two detected portions, segregating the alternating component of said derived wave, and modulating said other portion of said input wave by said segregated component wave to render the wave-form of the envelope of said output wave substantially like the wave-form of the envelope of the input wave.

2. The method of controlling an inherently non-linear amplifier having at least one vacuum-tube amplifying stage biased for high efficiency and non-linearity of amplification so as to produce from a low-power modulated high-frequency input wave a desired high-power modulated high-frequency output wave of substantially the same envelope wave-form, which comprises detecting one portion of said input wave to produce a modulation envelope wave, applying another portion of said input wave to said non-linear amplifier, deriving from said amplifier an amplified wave, detecting a portion of said amplified wave to produce a second modulation envelope wave, comparing said two detected portions to derive a difference wave therefrom, segregating the alternating components of said different waves, modulating said amplifier in accordance with said segregated component and delivering the remainder of said derived amplified wave as the desired high-power output wave.

3. An amplifying system for linearly amplifying a modulated input wave, comprising an inherently non-linear amplifier having an input circuit and an output circuit, means for detecting a portion of said modulated input wave to obtain an input modulation envelope wave, means for impressing another portion of said modulated input wave on said input circuit, means for deriving from said output circuit an amplified modulated wave, means for detecting a portion of said amplified modulated wave to produce an output modulation envelope wave, and means for modulating said amplifier with an alternating wave corresponding to the alternating component of the difference between said detected portion of said modulated input wave and said detected portion of said amplified modulated wave.

4. An amplifying system according to claim 3, wherein said inherently non-linear amplifier comprises a plurality of stages in cascade at least the last stage being non-linear, and wherein said means for modulating said amplifier in accordance with the difference between the detected portions comprises means for deriving a control wave corresponding to the difference between said detected portion of the modulated input wave and said detected portion of the amplified modulated wave, means for segregating the alternating component of said derived wave, and means for applying said segregated component to a stage preceding said last stage.

5. An amplifying system according to claim 3 wherein said means for detecting a portion of said input wave and said means for detecting a portion of said amplified wave each comprise a somewhat non-linear detecting element, and wherein said two elements have similar characteristics whereby the non-linearity of one of said elements is compensated by the similar non-linearity of the other of said elements.

6. An amplifying system according to claim 3, wherein said means for modulating said amplifier in accordance with the difference between said two detected portions of waves comprises means for balancing said detected portion of the modulated input wave against said detected portion of the amplified modulated wave to derive a difference wave corresponding to the difference

between said detected portions, means for segregating the alternating component of said difference wave, means for amplifying said alternating component, and means for applying said amplified alternating component to said amplifier to vary the output thereof.

7. An amplifying system according to claim 3, wherein said means for modulating said amplifier in accordance with the difference between said two detected portions of waves comprises means for amplifying said detected portion of the modulated input wave, means for amplifying said detected portion of the amplified modulated wave, means for balancing said amplified detected portion of the modulated input wave against said amplified detected portion of the amplified modulated wave to derive a difference wave corresponding to the difference between said amplified detected portions, means for segregating the alternating component of said difference wave and means for applying said alternating component to said amplifier to vary the output thereof.

8. An amplifying system for linearly amplifying a modulated input wave comprising an amplifier which includes at least one discharge tube having cathode and grid and anode electrodes, means for biasing said electrode to such potentials that the efficiency of the tube is high but its amplification is non-linear, means for applying a portion of said modulated input wave to said grid electrode, means for deriving an amplified modulated wave from said anode electrode, a first detector connected to detect another portion of said modulated input wave to drive an input modulation envelope wave, a second detector connected to detect a portion of said amplified modulated wave to derive an output modulation envelope wave, means for deriving an alternating control wave corresponding to the difference between alternating components of said detected portions of the input and amplified waves, means for applying said control wave to at least one discharge tube of said amplifier to vary said amplified modulated wave, whereby the wave-form of the envelope of said amplified wave is rendered substantially the same as the wave-form of the envelope of the input wave, and means for delivering another portion of said amplified modulated wave to a utilization circuit.

9. An amplifying system according to claim 8, wherein said amplifier includes a plurality of discharge tubes connected successively in cascade, the tube whose electrodes are biased to non-linear amplification by said means for biasing being the last tube of said successive cascade, and wherein said means for applying said control wave to at least one discharge tube of said amplifier is connected to apply such control wave to a preceding tube of said successively connected plurality of tubes.

FREDERICK E. TERMAN.