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MODULATED WAVE AMPLIFIER

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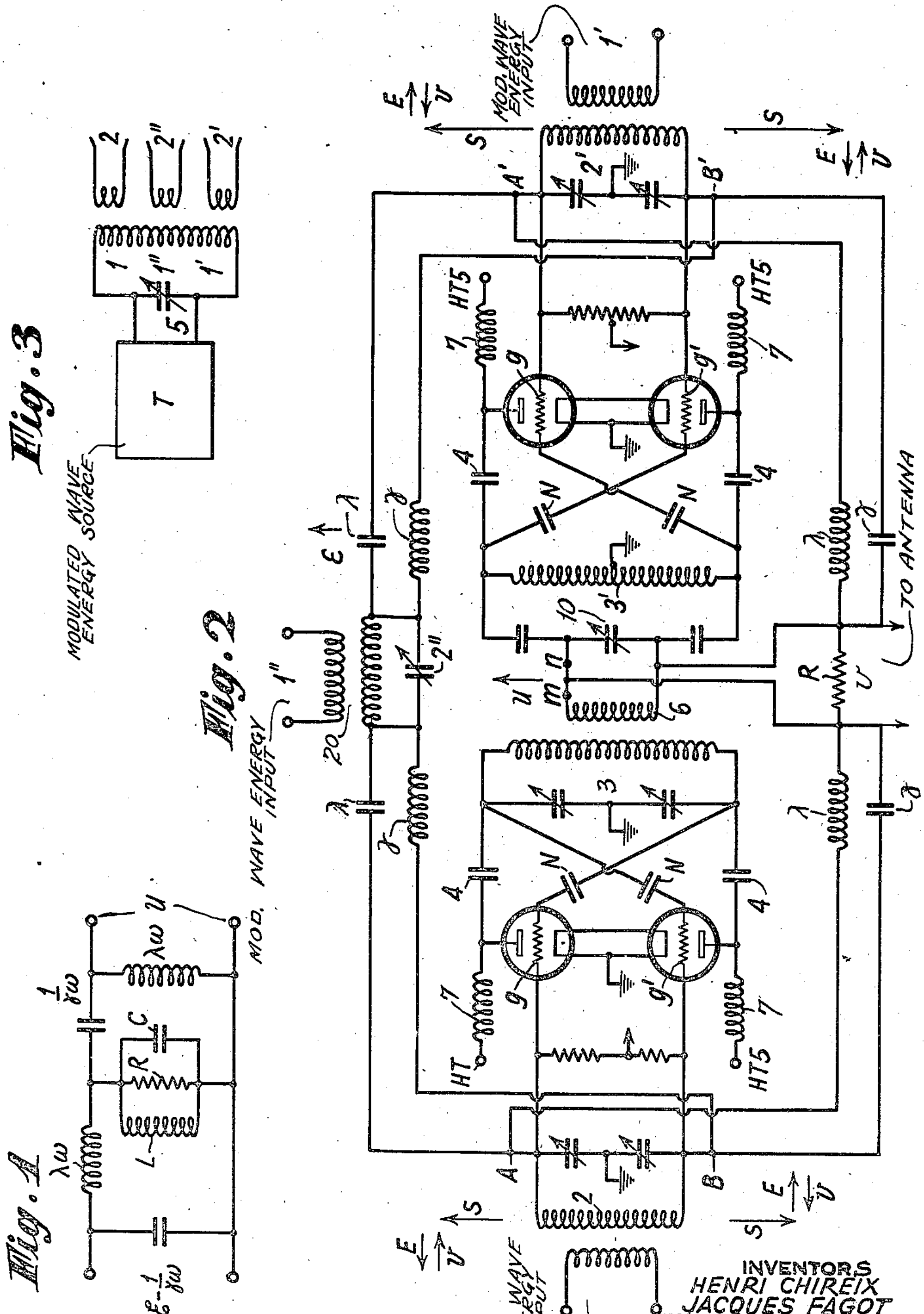

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MODULATED WAVE AMPLIFIER

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4 Claims. (Cl. 179—171)

In Fagot's United States application #307,022 filed December 1, 1939, has been disclosed a modulated wave amplifier system with a high efficiency power stage wherein means is provided to improve the linearity of the amplification system. In the said system the amplifier comprises a two tube stage the tube inputs of which are excited by out-of-phase amplitude modulated waves. The outputs of the tubes are combined and means is provided for altering the phase displacement of the combined voltage when the overall characteristic is non-linear to thereby modify the resultant of the combined voltages to insure linearity.

Our present application discloses in detail and with precision improved means to be used in such a system where a large power transmitter is dealt with, the final amplifier of which comprises two stages each having at least a pair of tubes in symmetric circuits and therefore comprising at least four tubes in the output end or multiples of four tubes. It will be an easy matter for the man trained in the art, by omitting certain elements, to adapt our circuit organization to the use of only two tubes, i. e., two single tube stages, thus resulting in and forming a simple or plain arrangement.

It has been pointed out in the said prior application referred to above that the amplification system or method therein disclosed resembles in some respects the so-called "phase-shift modulation" or the Chireix system of "outphasing" modulation. The underlying theory of the Chireix system has been set forth especially in Proceedings of the Institute of Radio Engineers, November 1935.

In the Chireix phase shift amplitude modulator the load is coupled to a wave source over two separate paths wherein the waves are displaced relatively in phase, each path including a phase modulator the two modulators being operated differentially so that the two paths supplied to the load two components the phase relation between which is modulated continuously in accordance with modulating potentials to produce a resultant the amplitude of which as a consequence varies in accordance with said modulating potentials. Systems of this general nature have become known in the art as outphase modulation systems.

In the system disclosed herein and in said prior application we have an amplifier system which in some respects in some parts of its operation resembles the said Chireix system. We supply modulated wave energy to a load by tubes excited by three voltages two of which are opposed in relation and a third of which is out of phase with respect to the first two. Assume, for the time being, that the two opposed voltages are about equal and cancel so that the third voltages of varying amplitude excites the tubes. The tubes as excited provide an output comprising phase displaced components which combine to produce a resultant the amplitude of which depends on the amplitude of the components. In this manner, the modulation is repeated. The operation as described above takes place for outputs equal to and less than carrier output; that is, for outputs below which saturation in the load is not involved. However, as the output grows, above carrier output, saturation may take place in the load. To prevent this, one of the opposed voltages is caused to represent the output voltages and when saturation takes place this voltage no longer grows linearly with respect to the excitation voltage so that the phase relation between the two output components changes; that is, the phase displacement changes bringing the phases closer together and the resultant increases to counteract the effects of saturation.

Briefly, in our system, the two output components are in fixed phase relation and variable amplitude for outputs below the amplitude at which saturation occurs and are of varying phase and varying amplitude for outputs of carrier amplitude and greater.

The object of our present application is to provide a new and improved circuit arrangement in a system broadly as described in the prior application.

Our end or power amplification circuit is in a preferred embodiment of the system in application #307,022. The essential difference in operation between our system and the said Chireix system resides in the fact that for all states of an instantaneous power below carrier power, the system behaves just like the ordinary modulated radio-frequency system, whereas for all states where the instantaneous power exceeds and surpasses the carrier state, recourse is had in this system to phase (shift) modulation, this latter state being automatically assumed by virtue of an inverse reaction circuit organization causative of the desired phase shifts or rotations as soon as the radio-frequency alternating potential set up in the output circuit of the tubes attains the saturation point.

In describing our invention, reference will be made to the attached drawing wherein Fig. 2

illustrates a modulated wave amplifier arranged in accordance with our invention;

Fig. 3 illustrates means for deriving certain of the voltages used in Fig. 2; while

Fig. 1 illustrates the operation of certain elements of the system of Fig. 2 to provide voltages used in Fig. 2.

By reference to Figures 2 and 3, there shall now be described in a brief and summary form, the regulations as well as the mode of operation.

In Figure 3, T designates a transmitter delivering modulated radio frequency wave energy into a tuned circuit comprising a capacity 5 and an inductance 1, 1', 1'', this energy being absorbed in the tuned circuits 2, 2', 2'', shown in Figure 3 and, more completely, in Figure 2. The tuned circuits 2 and 2' loaded by resistance R represent the circuits which excite the grids g and g' of each of the tubes connected in a symmetric manner, while the tuned circuits 3 and 3' constitute output circuits of these same tubes. It is to be noted parenthetically that what is here meant by tuned circuits is that if the connection at the points m and n is cut, the load of the tubes becomes purely ohmic in nature. The condensers N are neutrodyne condensers, while 4 and 7 denote blocking condensers and blocking inductances respectively of the usual type. The output circuits 3 and 3' are respectively coupled with the antenna, represented schematically by the resistance R, by magnetic coupling means, comprising inductance 6, and an electrostatic coupling means, comprising the condenser 10. These elements 6 and 10 constitute another tuned circuit. The magnetic coupling is made equal to the electrostatic coupling. In these circumstances, theory demonstrates that the potential U (see vector adjacent 2 and 2') across the terminals of R is in phase with the symmetric excitation S and that, if the coupling impedance, z, of inductance 6 or condenser 10 is united with the load resistance R by the relation

$$-\frac{z}{R}=2\tan\theta_1$$

the tubes will still work upon a pure resistance when the interruptions at points m and n are re-closed and that the excitations across the two circuits 2 and 2', instead of being in phase, are shifted in their phase relations an angle $2\theta_1$ in the sense of a leading shift towards the left-hand side and a lag towards the right. In the system disclosed here and in the above mentioned United States application the said (angle θ_1) relation will occur when energy of carrier wave amplitude is handled and the said angle will stay fixed for all lower instantaneous outputs. This angle, however, will grow for all instantaneous states of larger power, whereas in Chireix's outphase modulation the phase modulation angle θ i. e., the angle of combination of the phase modulated components, varies throughout the entire modulation cycle. For instantaneous outputs larger than carrier output, the output circuit of the tubes thus is no longer very sharply tuned, though the power factor will stay high as soon as θ_1 is of an order ranging between 20 to 25 degrees or over.

If the circuit organization is limited to what has been outlined, it will be an easy matter to see that with the excitations at 2 and 2' being in phase the current flowing in load R would be of zero value, regardless of how large these supposedly equal excitations may be. (This would be similar to Chireix's system at minimum output.) Hence, what is necessary according to the invention as disclosed in the said prior application, is to add to the symmetric excitation represented by vector S two supplementary excitations which are also modulated, but in quadrature relation and indicated by E and U (E due to transformer 20 and U due to the antenna (R) and acting with E in counter-reaction). The small vector diagrams shown alongside the circuits 2 and 2' indicate the sense of the excitation vectors turning an angle θ defined by $\tan\theta=E-U/S$.

Adjusting the total excitations

$$V=\sqrt{(E-U)^2+S^2}$$

in such a way that at the carrier wave working state, the alternating potential set up at 3 and 3' balances the direct-current potential (small loss potential) then satisfactory efficiency and output of the last stage in the presence of the said working state will be realized (tuned circuit and low loss potential).

For lower instantaneous powers, with the system being linear, the angles of the excitations at 2 and 2' remain fixed and the output will be proportional to the instantaneous amplitude. For powers above the carrier state, and because of the saturation of the alternating potential arising in 3 and 3', U will tend to stay stable, that is will not increase linearly with respect to the original excitation voltage say S and the angle θ will grow resulting thus in a growth of U. A straight-line condition or linearity will be approached so much more closely, the greater $E-U/E$ compared with unity.

What remains to be explained is how to obtain in an easy and ready way the said potentials E and U. For this purpose, reference shall be made to Fig. 1. Assume E and U are two sources of like phase and of unequal amplitude, and that E is greater than U. If LC is a tuned circuit and $\lambda\omega$ and $1/\gamma\omega$ are two equal and opposite reactances, that is to say, if $\lambda\omega=1/\gamma\omega=Z_0$, we have the equivalent of a double or twin circuit organization of constant intensity. Denoting by E—U the potential across the terminals of R there results:

$$E-U=-j(E-U).B/Z_0$$

irrespective of what may be the values of E and of U. This, therefore, furnishes a simple means to secure the desired quadrature relationships between E or U and S. Moreover, calculation shows that E and U work upon a pure resistance.

If E and U each operate upon two arrangements like the one shown in Fig. 1, the first one for E beginning with a series inductance λ and the second one also for E with a capacity $\gamma\omega$ two tuned circuits would have to be connected in shunt relation to E and U. The embodiment of Fig. 2 already has the required circuits. Circuit 2'' excited by the transmitter and tuned is connected with terminals A and B of part of the circuit 2, and with terminals A'B' of another part of the circuit 2' by the condensers and inductances λ and γ.

Moreover, the outgoing feeder brought to the tuned antenna is connected in the same fashion with points A, A', B, B'. It will be noticed that each of the points such as A, B, A', B', is connected, on the one hand, with source E by way of a reactance of a certain sign, and on the other hand, with source U by a reactance of opposite sign, there thus resulting four times the circuit organization shown in Fig. 1 since E and U are in phase.

It will also be noticed finally that all of the circuits here indicated are strictly and sharply in tune for this promotes and facilitates the regulations.

In the arrangement disclosed in Fig. 2 then voltages represented by the vectors S are supplied to each of the tubes in each stage say for example the tubes in the left hand stage from circuit 2. Voltages represented by the vectors E are also supplied to the grids of each of the said tubes from transformer 20 and the circuits connecting the same to points A and B. The resistance R and its associated antenna supplies antenna voltages U in quadrature to voltages S and in phase opposition to voltages E to the grids of the said tubes. Voltages E and U buck. The output components of the two tubes are displaced in phase so that they combine to produce a resultant which corresponds to the amplitude variations of the respective components.

As pointed out in detail hereinbefore for outputs less than saturation output, the phase relation of the output components stays fixed. However, for amplitudes which cause saturation the component U does not increase linearly with the excitation voltage and as a consequence the vectors U do not increase linearity, E is not fully opposed and phase displacement takes place. This phase displacement results in a decreasing of the phase displacement between the output components of the two tubes and as a consequence increases the combined resultant to correct the non-linearity. The stage at the right hand side operates in a like manner to produce a resultant in phase with the resultant mentioned above.

What is claimed is:

1. In a modulated carrier wave amplifier, a load circuit, a source of modulated wave energy, pairs of electron discharge devices, each having input and output electrodes, tuned circuit means for applying voltages from said source substantially in phase opposition on the input electrodes of the devices of said pairs, other means for applying voltage from said source substantially in phase opposition on the input electrodes of the devices of said pairs of devices, said last named voltages as applied being displaced in phase relative to the second named voltages applied to said devices, a load connected with said output electrodes, and additional means for impressing voltages from said load substantially in phase opposition on the input electrodes of the devices of said pairs of devices, said last voltages as applied also being in phase opposition with respect to said second named voltages as applied to the input electrodes of the devices.

2. In a modulated carrier wave amplifier, a load circuit, a source of modulated wave energy, two electron discharge devices, each device having input and output electrodes, means for applying voltages from said source on the input electrodes of each of said devices, other means for applying voltage from said source on the input electrodes of said devices, said last named voltages as applied to the input electrode of the tubes being displaced in phase relative to the applied first named voltages, a load connected with said output electrodes, and additional means for impressing voltages from said load on the input electrodes of each pair of said devices, said last voltages being in phase opposition on said input electrode with respect to said second named voltages impressed on the input electrodes.

3. In a modulated carrier wave amplifier, a load circuit, a source of modulated wave energy, pairs of electron discharge devices, each having input and output electrodes, tuned circuit means for applying voltages of like phase from said source on the input electrodes of said devices, other means for applying voltage from said source on the input electrodes of said devices, said last named voltages being applied to the input electrodes of the devices in phase displaced relation with respect to said first named applied voltages, a load connected with said output electrodes, and additional means for impressing voltages from said load on said input electrodes, said last voltages also being impressed on the input electrodes of said devices in phase opposition with respect to said second named voltages as impressed on said input electrodes of said devices.

4. In a modulated carrier wave amplifier, a load circuit, a source of modulated wave energy, two pairs of electron discharge devices, each having input and output electrodes, separate tuned circuits for applying voltages of like phase from said source substantially in phase opposition on the input electrodes of the devices of each pair, a second tuned circuit for applying voltage from said source in phase opposition on the input electrodes of the devices of each pair of devices, said last voltages as applied being displaced in phase with respect to said first applied voltages, a tuned circuit coupling said load to said output electrodes, and additional means for impressing voltages from said load on the input electrodes of the devices of each of said pairs, said last voltages being impressed in phase opposition with respect to said second named voltages on the input electrodes of said devices.

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