Aug. 31, 1937. A. M. CRAVATH 2,091,701

TRANSMITTING APPARATUS

Filed Feb. 8, 1935 2 Sheets-Sheet 1

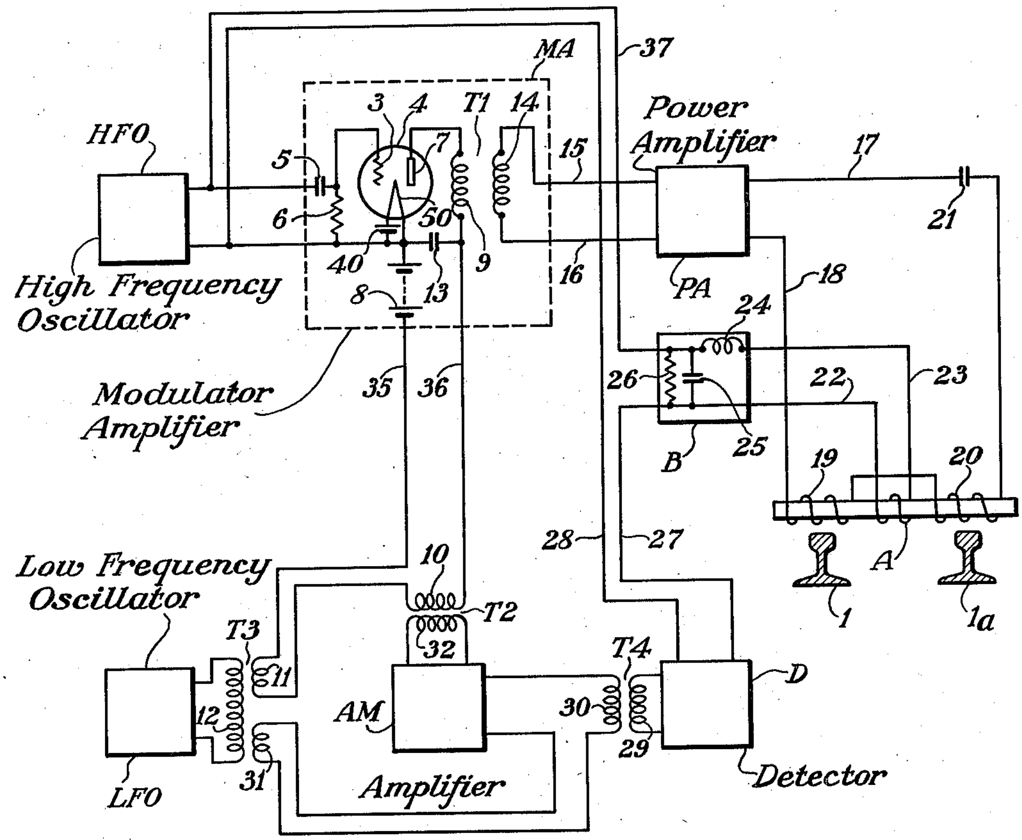

Fig. 1.

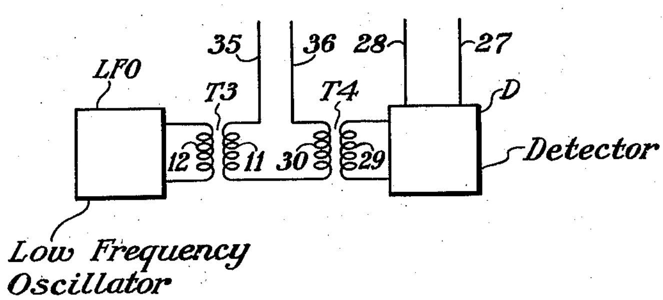

Fig. 2.

INVENTOR
Austin M. Cravath
BY A. L. Vencill
HIS ATTORNEY

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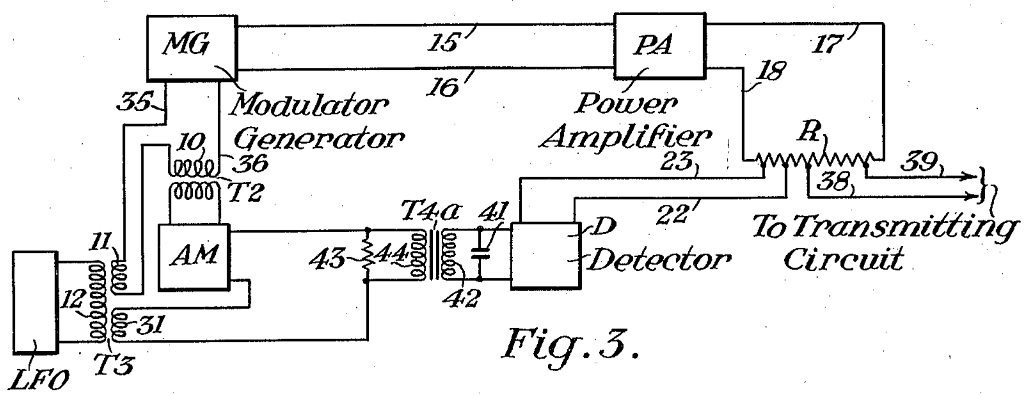

Fig. 3.

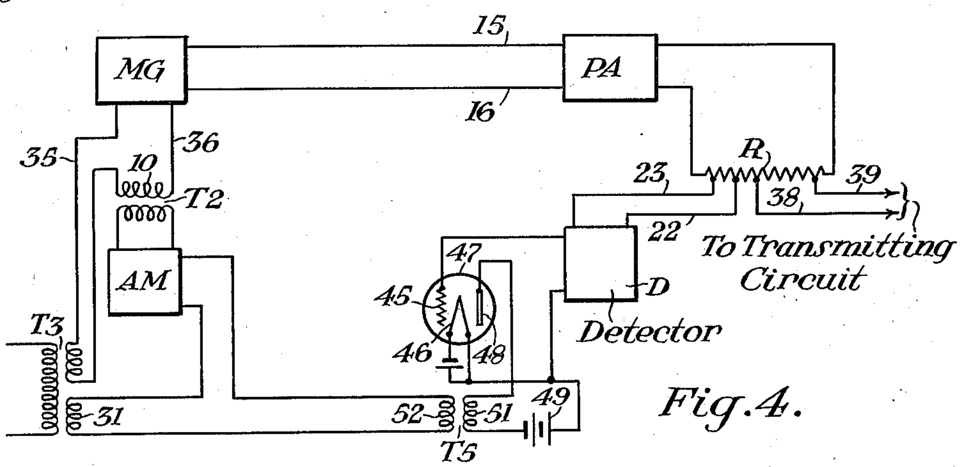

Fig. 4.

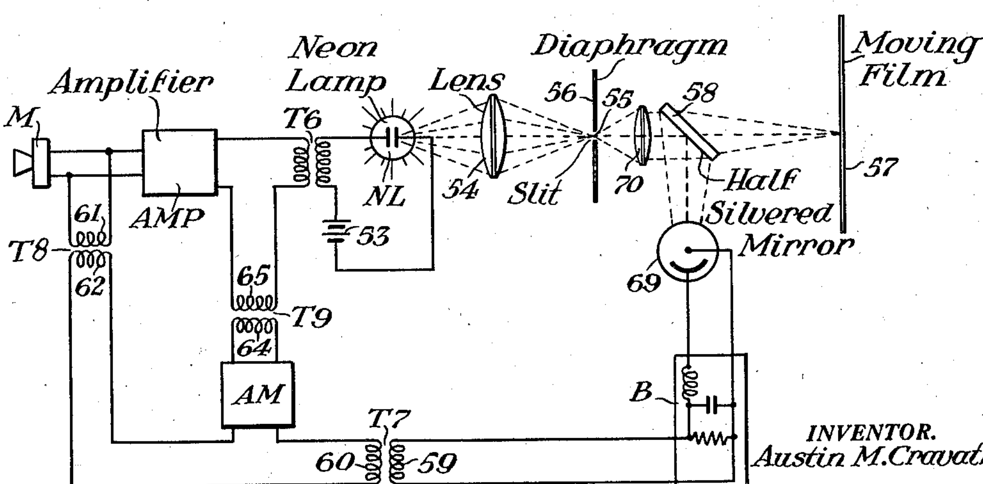

Fig. 5.

INVENTOR.
Austin M. Cravath

By *A. L. Vencill*

HIS ATTORNEY.

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UNITED STATES PATENT OFFICE

2,091,701

TRANSMITTING APPARATUS

Austin M. Cravath, Berkeley, Calif., assignor to The Union Switch & Signal Company, Swissvale, Pa., a corporation of Pennsylvania

Application February 8, 1935, Serial No. 5,605

3 Claims. (Cl. 179—171)

My invention relates to transmitting apparatus, and has for an object the provision of transmitting apparatus which insures modulation of a carrier current or other carrier frequency energy by a signaling current either without distortion of the modulation or with an intentional distortion of the modulation. A further object of my invention is the provision of apparatus effective to produce a feed-back electromotive force proportional to the modulation of transmitted energy and to combine the feed-back electromotive force with a control electromotive force proportional to the modulation energy, such combination being effective to correct distortion or to introduce a desired distortion.

I will describe several forms of apparatus embodying my invention, and will then point out the novel features thereof in claims.

In the accompanying drawings, Fig. 1 is a diagrammatic view of one form of transmitting apparatus embodying my invention. Fig. 2 is a diagrammatic view of a modification of a portion of the apparatus of Fig. 1 and also embodying my invention. Figs. 3 and 4 are each a diagrammatic view of transmitting apparatus embodying my invention wherewith intentional distortion of the modulation may be introduced. Fig. 5 is a diagrammatic view of transmitting apparatus for sound on film production with correction of distortion, which apparatus likewise embodies my invention.

In each of the several views like reference characters designate similar parts.

Referring first to Fig. 1, a high frequency oscillator shown conventionally at HFO supplies a carrier current of any convenient frequency such as, for example, 7500 cycles per second. This oscillator may be any of the standard types well-known to the art, among them being the vacuum tube oscillator. A low frequency oscillator shown conventionally at LFO supplies a signaling current of any convenient low frequency such as, for example, 40 cycles per second. This oscillator LFO may also be of the vacuum tube oscillator type. The specific structure of this device as well as that of the high frequency oscillator HFO is not shown since the structure of neither of these devices constitutes a part of my invention. As a matter of fact, in telephone or radio communication systems where carrier transmission is contemplated the low frequency oscillator LFO will be replaced by a microphone and an amplifier or by a telephone transmitter in order that the carrier current may be modulated by the voice frequencies produced in the microphone or transmitter.

The reference character MA designates a modulator-amplifier of the ordinary plate modulation type. While I will describe the structure and operation of a particular type of modulator as an example, and for the sake of clearness, it will be understood the specific structure of the modulator constitutes no part of my invention. In fact, in certain forms of my invention to be described later, the high frequency generator and the modulator-amplifier are replaced by a single modulator-generator. The operation of the particular modulator-amplifier here shown is as follows: The carrier frequency current supplied from the high frequency oscillator HFO is applied to the grid 3 and the filament 50 of an electron tube 4, a grid condenser 5 being interposed between the oscillator and the grid 3, and a resistor 6 being interposed between the terminal of the condenser 5 adjacent the grid and the usual filament battery 40. The tube 4 is provided with a plate circuit which can be traced from the battery 8 over wire 35, secondary winding 11 of a transformer T3, secondary winding 10 of a transformer T2, wire 36, primary winding 9 of a transformer T1, plate 7, and the intervening space and filament of the tube 4 to the battery 8. The signaling frequency current produced by the oscillator LFO is supplied to the primary winding 12 of the transformer T3 and, consequently, an electromotive force of the signaling frequency is induced in the secondary winding 11 of that transformer, which secondary winding 11 is included in the plate circuit of the tube 4 as just explained. It follows that the high frequency current in the plate circuit of tube 4 is modulated by the signaling current fed into the plate circuit through the medium of the secondary winding 11. A condenser 13 is preferably connected between the filament of the tube and the terminal of primary winding 9 remote from the plate 7 for by-passing the high frequency but not the modulation frequency. An electromotive force of the frequency of the modulated carrier current will be induced in the secondary winding 14 of the transformer T1, and in turn will be supplied to the input terminals of a power amplifier PA over the wires 15 and 16. A small correcting voltage having the same frequency as the signaling current supplied by the secondary winding 11 of the transformer T3 is introduced into the plate circuit through the medium of the secondary winding 10 of the transformer T2 in a manner hereinafter explained.

The power amplifier PA may be of any convenient type such as, for example, two electron tubes connected in the customary push-pull arrangement. By means of this device, the modulated carrier current supplied by the secondary winding 14 of the transformer T1 is amplified to a relatively high energy level and is delivered over wires 17 and 18 to inductor coils 19 and 20 disposed in inductive relation to a transmitting circuit, a tuning condenser 21 preferably being interposed in the wire 17. The transmitting circuit may be of any desired form suitable for conveying such modulated carrier current. By way of illustration, the transmitting circuit is here shown as including the traffic rails of a railway track, the inductor coils 19 and 20 being disposed in inductive relation to the rails 1 and 1*a*, respectively.

It will be seen, therefore, that the carrier current of 7500 cycles per second is modulated by the signaling current of 40 cycles per second, the combination is amplified to a relatively high energy level, and an electromotive force of corresponding frequency is induced in the traffic rails 1 and 1*a*. It will be understood, of course, that my invention is not limited to the above-cited frequencies for the carrier and signaling currents, nor to a transmitting circuit which includes the traffic rails of a railway track, and that the frequencies given and the transmitting circuit disclosed are used only for illustration in order to aid in the understanding of my invention. Such frequencies and circuit have been proposed, however, for use in signaling systems for railway trains. What is essential to my invention is that carrier frequency energy modulated by a control or signaling current is furnished.

As here shown, a conductor A is disposed in inductive relation to either one or both the inductor coils 19 and 20 for inductively receiving an electromotive force which is proportional to the electromotive force induced in the traffic rails. This conductor A may be of several turns or it may be a single conductor as desired. If the inductor coils 19 and 20 have iron cores, these cores may contribute to the distortion of the electromotive force induced in the rails. However, the electromotive force induced in conductor A is subject to the same distortion, except for a small difference due to the difference in the iron paths of the magnetic fluxes through conductor A and around the rail, which difference can be made negligible. If, as is theoretically possible, such high power were used that there were distortion due to the steel of the rail, then conductor A would be placed in inductive relation to the rail at a distance from the inductors 19 and 20 such that the magnetic flux density was low enough to avoid distortion. The conductor A is connected over wires 22 and 23 with the input terminals of a circuit network designated by the reference character B, one of the output terminals of such network being connected by a wire 27 with an input terminal of a detector D and the other output terminal of the network B being connected by a wire 37 to one terminal of the high frequency oscillator HFO. A wire 28 connects the other terminal of the high frequency oscillator HFO with the second input terminal of detector D. As here shown, the network B consists of a reactor 24, a condenser 25, and a resistor 26. This network is inserted for the purpose of bringing the voltage obtained from conductor A approximately in phase with the voltage obtained from the high frequency generator. Considerable phase displacement is permissible, especially if the voltage from the high frequency generator is large compared to that from conductor A. Therefore, network B will not always be needed. The voltage supplied by conductor A through network B and the voltage supplied by generator HFO are fed in series into the detector D. The parts are so proportioned that the relative magnitudes of the two voltages even when the output of the network B is completely modulated are such that the percentage of modulation of the input to the detector D is sufficiently low to insure undistorted detection.

The detector D may be any one of many forms well-known to the art, it being shown conventionally for the sake of simplicity since its specific structure constitutes no part of my present invention. It is sufficient that the modulated carrier voltage supplied to the detector D is detected, and an electromotive force having the same frequency, wave form, and phase as the modulation of the carrier frequency energy is caused to appear in the output circuit of the detector D. This output circuit here includes the primary winding 29 of a transformer T4. The current flowing in the primary winding 29, as the result of such electromotive force, is effective in turn to induce a proportional electromotive force in the secondary winding 30 of the transformer T4.

It is clear that an electromotive force of the signaling frequency will be induced in the secondary winding 31 of the transformer T3 which is in phase with that induced in the secondary winding 11 of that transformer, the latter being utilized for modulation of the carrier as explained hereinbefore. Hence, the voltage of the secondary winding 31 of the transformer T3 and the voltage of a secondary winding 30 of the transformer T4 are of the same frequency, the voltage of the latter being proportional to the instantaneous value of the modulation of the transmitted current and the voltage of the former being proportional to the instantaneous voltage used to modulate the carrier. The secondary windings 30 and 31 and the input of an amplifier AM are connected in series, the windings being so disposed that the respective voltages are at every instant opposing, with the result that the difference between these two voltages is amplified and reproduced in the primary winding 32 of the transformer T2, where it is effective to induce an electromotive force in the secondary winding 10 interposed in the plate circuit of the tube 4.

The several devices and elements are so proportioned and adjusted that if the input circuit of the amplifier AM were open so that no electromotive force were induced in the secondary winding 10 of the transformer T2, the carrier current would be almost completely modulated by the signaling current supplied by the secondary winding 11 of the transformer T3, and the power amplifier PA would deliver substantially its maximum power to the inductor coils 19 and 20. Furthermore, the electromotive forces induced in the secondary windings 30 and 31 would be about equal in magnitude. Under such conditions, distortion of the current delivered to the transmitting circuit would, of course, be high. However, if the voltage induced in the conductor A had an absolutely undistorted modulation, the detector D would produce a voltage in the secondary winding 30 of the transformer T4 that would be equal to the voltage induced in the secondary winding 31 of the transformer T3, and the input to the amplifier AM would be zero.

Actual correction of the distortion of the outgoing energy is obtained as follows: If there is distortion and at a certain point in the modulation cycle the voltage of the secondary winding 30 is a little less than the voltage of the secondary winding 31, a voltage equal to the difference is fed into the amplifier AM where it is amplified and a relatively large electromotive force is induced in the secondary winding 10 of the transformer T2. The instantaneous polarity of the voltage of the secondary winding 10 with respect to the instantaneous polarity of the voltage of secondary winding 11 in this instance is such as to increase the plate voltage of the tube 4. Such increase in the plate voltage of the tube of the modulator-amplifier obviously tends to increase its output and in turn to correct the distortion of the transmitted current. The output of the detector D is increased in response to such increase in the output of tube 4 and correction of the modulation of the transmitted current, with the net result that the voltage of the secondary winding 30 is raised. This action persists until the voltage of secondary winding 30 is nearly equal in value to that supplied by the secondary winding 31 so that the input to the amplifier AM is made substantially zero. Conversely, if at some other point in the modulation cycle, the voltage of the secondary winding 30 is a little greater than the voltage of the secondary winding 31, the net voltage is fed to the amplifier AM to create a voltage in the secondary winding 10 of the transformer T2. The instantaneous polarity of the voltage of the secondary winding 10 with respect to the instantaneous polarity of the voltage of secondary winding 11, this time, is such as to decrease the plate voltage for the tube 4 with the result that the output of the modulator-amplifier MA is decreased and the distortion of the transmitted current is corrected. The output of the detector D is now decreased to bring the voltage of the secondary winding 30 back to a magnitude nearly equal to that of the secondary winding 31.

It is clear, therefore, that under all conditions the output voltage of the detector D is made to follow the voltage of the secondary winding 31 with a precision that is limited only by the amount of amplification which it is found practical to use in the amplifier AM. Since the output of the detector D is a faithful reproduction of the envelope of the modulated electromotive force induced in the conductor A, and since the electromotive force induced in the transmitting circuit is proportional to that induced in the conductor A, the envelope of the transmitted current will also follow the voltage of the secondary winding 31, that is to say, the modulation of the transmitted current will be substantially undistorted.

A modification in which the amplifier AM is omitted is disclosed in Fig. 2. Here the input wires 27 and 28 for the detector D lead respectively to a terminal of the network B and to a terminal of the high frequency oscillator HFO, as in Fig. 1. Also, the wires 35 and 36 of Fig. 2 lead to the battery 8 and to the primary winding 9 of the transformer T1, as in Fig. 1. It will be understood, therefore, that the circuits above the wires 27, 28, 35 and 36 of Fig. 2 are the same as in Fig. 1 and it is thought to be unnecessary to reproduce them.

In Fig. 2, the parts are so proportioned that the voltage of the secondary winding 30 of the transformer T4 has a predetermined value which averages somewhat, say 10 per cent, less than the voltage of the secondary winding 11 of the transformer T3. In other words, the magnitude of the voltage of the secondary winding 30 averages only about 0.90 of the magnitude of the voltage of the secondary winding 11. Furthermore, the voltage of the secondary winding 30 is substantially 180° out of phase with the voltage of the secondary winding 11. It follows that the difference between these two voltages is the modulation voltage applied over wires 35 and 36 to the modulator-amplifier MA. Assuming that, due to distortion of the transmitted current, at a certain point in the modulation cycle the voltage of the secondary winding 30 is only 0.89 of the voltage of the secondary winding 11, so that the voltage of winding 30 is slightly below the above-mentioned predetermined average which I have assumed to be 0.90 of the magnitude of the voltage of the winding 11, then the voltage of secondary winding 30 will be approximately 1.1 per cent less than its predetermined average value. The modulation voltage, which is the difference between the voltage of the secondary winding 11 and that of the secondary winding 30, is now 10 per cent greater than the above mentioned predetermined value of the modulation voltage. The net effect of such change in the modulation voltage will be to correct the distortion of the transmitted current and to bring the voltage of the secondary winding 30 back toward its predetermined value. Hence, a 10 per cent change in the modulation voltage, which change tends to correct the distortion of the modulation, has resulted from only 1.1 per cent of distortion in the modulation. The degree of correction to be obtained by the apparatus of Fig. 2 depends on the ratio of the voltages of the low frequency oscillator LFO, or of the detector output, to the voltage necessary for modulation.

Hereinafter, it will be shown mathematically that this ratio takes the place of the amplifier AM of Fig. 1, so that theoretically the performance of the apparatus of Fig. 2 may be identical with the performance of the apparatus shown in Fig. 1. Where the highest degree of correction is required, the amplifier of Fig. 1 may be preferable in practice.

Since it is the detector output which is rendered free from distortion, any distortion in the detector will cause an inverse distortion in the modulation of the transmitted current. In view of this fact, apparatus embodying my invention permits an intentional introduction of distortion, which may be made to compensate a distortion known to exist in some portion of the receiving apparatus used to receive the transmitted current. For example, if the distortion in detector D is made the same as the distortion in the detector of the receiving apparatus used to receive the transmitted current, then the distortion of the transmitted modulation compensates the distortion caused by the detector of the remote receiving apparatus. That is, any desired distortion of the modulation of the transmitted current may be obtained if the inverse distortion is introduced in the detector D or its input or output circuits.

Apparatus for introducing intentional distortion is shown in Fig. 3. The modulated carrier frequency energy is applied to the input terminals of the power amplifier PA over wires 15 and 16 the same as in Fig. 1, and is amplified to a relatively high energy level. In Fig. 3, the output terminals of the power amplifier are connected across a resistor R to at least a portion of which the transmitting circuit is tapped by wires 38 and 39. The transmitting circuit including the wires 38 and 39 may be any suitable circuit for conveying such modulated carrier frequency energy to some remote receiving apparatus (not shown) responsive thereto. Part of the voltage that appears across the resistor R is tapped off and fed to the input of the detector D over wires **22** and **23**. It will be understood, of course, that this voltage from resistor R may be fed through a network B and combined with a voltage obtained from the high frequency source before it is fed to the detector D, as is done in Fig. 1, if it is found desirable to do so. In this form of the invention the high frequency oscillator and the modulator-amplifier are replaced by a single unit consisting of a modulator-generator MG. This modulator-generator MG may be any one of several forms such as, for example, a vacuum tube oscillator having the modulation electromotive force introduced in series with the plate circuit supply, and is here shown diagrammatically by a rectangle since its structure forms no part of my invention. The signaling frequency for modulating the carrier energy is supplied to the modulator-generator MG from the low frequency oscillator LFO through transformer T3 and over wires **35** and **36** the same as explained for Fig. 1, the secondary winding **10** of the transformer T2 being interposed in the circuit. The output circuit of the detector D includes an iron core transformer T4*a* having a suitable condenser **41** connected across its primary winding **42**, and a resistor **43** connected across its secondary winding **44**. The voltage of the secondary winding **44** of the transformer T4*a* is combined with the voltage of the secondary winding **31** of transformer T3, and the resultant voltage is fed to the input of the amplifier AM the same as explained for Fig. 1, the output of the amplifier AM being combined with the signaling modulation voltage through the transformer T2. If it is desired to make correction for a distortion which is known to be caused by an iron core coil of the remote receiving apparatus, the flux density of the transformer T4*a* should be adjusted to give the same amount of distortion as that for which correction is desired. The phase of the output of transformer T4*a* may be adjusted by means of the condenser **41** and resistor **43**. It follows that a desired distortion of the modulation of the transmitted current may be introduced through the medium of the detector D and its related circuits.

Distortion caused by an amplifying tube of the receiving apparatus may be corrected by distortion intentionally introduced in the transmitting apparatus embodying my invention. One way such intentional distortion may be introduced is disclosed in Fig. 4. In Fig. 4, the modulated carrier frequency energy is supplied from the modulator-generator MG to the transmitting circuit through the power amplifier PA and resistor R the same as in Fig. 3. Likewise, the signaling frequency for modulation of the carrier frequency energy is supplied to the modulator-generator MG through transformer T3 and over wires **35** and **36** as in Fig. 3, the secondary winding **10** of transformer T2 being interposed in the circuit. A portion of the voltage across the resistor R is supplied over wires **22** and **23** to the input of the detector D and the output voltage of the detector is applied between the grid **45** and cathode **46** of an amplifier tube **47**. The plate **48** of tube **47** is supplied with voltage from a battery **49**, the primary winding **51** of a transformer T5 being interposed between the battery **49** and plate **48**. The secondary winding **52** of transformer T5 and the secondary winding **31** of transformer T3 are connected in opposing series relation and connected to the input of the amplifier AM as can be seen from Fig. 4. The characteristic of the tube **47** is adjusted to be similar to that of the tube of the remote receiving apparatus the distortion of which is to be corrected. It will be easily seen that this procedure produces in the output of the amplifier AM a voltage which is the correction to be applied to the modulation of the transmitted current.

In the form of the invention disclosed in Fig. 5, the carrier frequency energy consists of light which is electrically modulated, for example, as in a sound on film recording apparatus, or television receiver. One particular form of such apparatus consists of a microphone M connected with the input terminals of an amplifier AMP, the output energy of which is applied through a transformer T6 to a neon lamp NL for modulation of its light beams, the lamp NL being supplied with energizing current from a battery **53**. The light from the lamp NL is concentrated through a suitable lens **54** on a slit **55** of a diaphragm **56**. Part of the light passing through the slit **55** is projected on a moving film **57** for recording the voice frequencies produced in the microphone M. It will be seen without further discussion that as the microphone picks up sound a narrow band of varied exposure will be produced along the film which, by the use of suitable apparatus, may be made to reproduce the sounds picked up by the microphone.

To correct distortion due to the apparatus of Fig. 5, I provided for feeding back a portion of the modulated energy into the control circuit. A half-silver mirror **58** is placed in the path of the light beam between the slit and the film to divert part of the light away from the film to a suitably placed photoelectric cell **69**. The light striking this cell **69** gives rise to a voltage which can be made to be within wide limits proportional to the intensity of the light. This voltage is impressed upon a phase-correcting network B similar to the network B of Fig. 1, and is then passed to the primary winding **59** of a transformer T7. Hence, an electromotive force proportional to the instantaneous intensity of the light beam is induced in the secondary winding **60** of transformer T7. The primary winding **61** of a transformer T8 is connected across the terminals of the microphone M in parallel with the input circuit of the amplifier AMP and hence an electromotive force proportional to the instantaneous voltage of the voice frequency energy used to modulate the light is induced in the secondary winding **62** of transformer T8. The secondary winding **62** of transformer T8 and the secondary winding **60** of transformer T7 are connected in opposing series relation to the input terminals of the amplifier AM the output circuit of which includes the primary winding **64** of a transformer T9. The secondary winding **65** of the transformer T9 is interposed in the output circuit of the amplifier AMP as will be understood by inspection of Fig. 5. It follows that a feed-back voltage proportional to the modulation of the transmitted energy and a control voltage proportional to the modulating energy are combined and the difference is amplified and made effective to correct distortion similar to that explained for Fig. 1. If it is desired to introduce intentional distortion, this can be done by placing between the network B and the transformer T7 suitable apparatus such, for example, as that shown in Figs. 3 and 4.

In order to make clear what is essential about my invention, I will now describe it in general terms, without reference to a particular form of apparatus, and will give a mathematical description of its operation. Any suitable apparatus, which I will call G, furnishes carrier frequency energy which is modulated by a modulating electromotive force of instantaneous value E_c supplied to G. The instantaneous modulation of this carrier frequency energy I will call E_a. Any suitable source furnishes a modulation frequency control electromotive force of instantaneous value E_b in accordance with which the carrier frequency energy is to be modulated. If G were entirely free from distortion E_a would be proportional to E_c and would be given by the equation $E_a=mE_c$ where m is a constant. G actually introduces a distortion, the correction of which is the object of my invention. Hence, if m is the average value of E_a/E_c, then E_a will be greater than mE_c part of the time and will be smaller part of the time, the difference constituting the instantaneous distortion introduced by G, that is, constituting the instantaneous distortion of E_a relative to E_c. Hence, if x is the corresponding percentage of distortion,

$$x=100(E_a-mE_c)/E_a$$

Whence

$$E_a=mE_c+E_ax/100 \qquad (1)$$

Any suitable apparatus, which I shall call D, is actuated by the carrier frequency energy so as to produce a feed-back electromotive force E_d of the same frequency and phase as E_a, the modulation of the carrier frequency energy. For instance, if the carrier frequency energy is a modulated light beam, D might consist of a photoelectric cell with any necessary auxiliary apparatus, such as battery and amplifier.

If y is the percentage of distortion caused by D, that is the percentage of distortion of E_d relative to E_a,

$$E_d=KE_a+E_d\,y/100 \qquad (2)$$

where the constant K is the average value of E_d/E_a.

Any suitable apparatus is actuated by the electromotive forces E_b and E_d so as to supply to G a modulating electromotive force E_c equivalent to the difference between a first component proportional to the control electromotive force E_b, and therefore equal to gE_b where g is a constant, and an opposed second component proportional to the feed-back electromotive force E_d, and therefore equal to hE_d where h is a constant. In other words, this last apparatus supplies G with a modulating electromotive force E_c given by the equation:

$$E_c=gE_b-hE_d \qquad (3)$$

It will be immediately obvious that the form of apparatus shown in Fig. 2 supplies such a modulating electromotive force to the modulator-amplifier. I will show that the modulating electromotive force supplied by the form of apparatus shown in Fig. 1 is also of the form expressed by Equation (3). The input electromotive force to amplifier AM is clearly equal to bE_b-dE_d where b and d are constants. Hence the output, neglecting distortion, is $f(bE_b-dE_d)$ where f is a constant. The justification for neglecting the distortion is that bE_b and dE_d are nearly equal and nearly cancel each other, giving a relatively small input voltage so that even a relatively large percentage of distortion will result in only a relatively small absolute distortion.

Hence the total electromotive force supplied to the modulator-amplifier is:

$$E_c=CE_b+f(bE_b-dE_d)$$
$$=(C+fb)E_b-fdE_d$$
$$=gE_b-hE_d$$

where CE_b is the electromotive force of secondary 11, $g=C+fb$, and $h=fd$.

This shows that the two forms of apparatus shown in Figs. 1 and 2 respectively are equivalent, performing the same function in different ways. From Equations (1) and (2) it follows that

$$E_c=E_a(1-x/100)/m \qquad (4)$$

and

$$E_d=E_aK/(1-y/100) \qquad (5)$$

With these values of E_c and E_d, Equation (3) becomes

$$E_a(1-x/100)/m$$
$$=gE_b-hE_aK/(1-y/100), \qquad (6)$$

Whence

$$E_a=\frac{mg}{1+mKh}E_b-\frac{mKhy/100-x/100+xy/10,000}{(1+mKh)(1-y/100)}E_a. \qquad (7)$$

When there is no distortion, that is, when $x=0$ and $y=0$, the last term vanishes. The term

$$\frac{mg}{1+mKh}E_b$$

is the part of E_a representing a modulation which is proportional to the control electromotive force E_b and is therefore undistorted relative to E_b. The last term is the part of E_a constituting the distortion. Hence the percentage of distortion of the modulation E_a relative to the control electromotive force E_b is

$$w=100\frac{x/100-mKh\,y/100-xy/10,000}{(1+mKh)(1-y/100)}=\frac{x-mKhy-xy/100}{(1+mKh)(1-y/100)} \qquad (8)$$

It will be remembered that:

m is the average value of E_a/E_c,

K is the average value of E_d/E_a, and

hE_d is the value of the second, or feed-back component of the modulating electromotive force E_c. Therefore the important quantity mKh in Equation (8) is equal to the average of hE_d/E_c, that is, it is simply the average value of the ratio of the feed-back component of the modulating electromotive force E_c supplied to the source G for modulating its output to the whole of this modulating electromotive force. mKh is thus a sort of feed-back amplification factor.

Equation (8) expresses the performance of my invention. Suppose first that it is desired to make w, the percentage of distortion of the carrier frequency energy, as small as possible. This may be done in two ways. One method, which is that used in the forms of apparatus shown in Figs. 1 and 2, is to make the distortion of the feed-back electromotive force E_d relative to the modulation of the carrier frequency energy as small as possible, that is, to make y as small as possible, and to make mHk large. Then Equation (8) becomes approximately

$$w=x/(1+mKh)-y \quad (9)$$

This shows that the resulting distortion when this method is used is made up of two parts. The first is an uncorrected part of the original distortion x introduced by G, this uncorrected part being a fraction $1/(1+mKh)$ of the whole distortion in G. The second part of the resulting distortion consists of the inverse of the distortion y introduced by D. Hence, the attainment of perfect fidelity of modulation by this method would require infinite mKh, that is, infinite feed-back factor, to make the first part of the distortion vanish and zero distortion in D to make the second part vanish.

The other method of minimizing distortion of the modulation is to make the two parts of the resulting distortion cancel each other as far as possible instead of making each as small as possible. Equation (8) shows that if the distortion in D is so chosen that $y=x/(mKh+x/100)$, then the cancellation is exact and the modulation is entirely free from distortion.

Now suppose that a certain distortion of the modulation is desired, for instance, to compensate for the distortion in other apparatus which is to be controlled by the energy from G. Then Equation (8) shows how this may be done. It is necessary to choose y so that Equation (8) gives the desired value of w. This is done by making

$$Y=\frac{(x-w)/mKh-w}{1-w/100+(x-w)/100mKh} \quad (10)$$

If the feed-back factor mKh is large relative to unity, as it usually will be when my invention is used, this equation says (approximately) that the distortion in D should be made up of two parts; first, the small fraction of the distortion in G which would remain uncorrected if D were free from distortion, and second, the inverse of the desired distortion of the modulation relative to the control electromotive force.

There is a generalization which I would like to point out. I have specifically disclaimed limitation to a particular carrier frequency. It is logical to inquire what happens when zero cycles per second is chosen for the carrier frequency. The answer is that the invention and the mathematical analysis still apply, the invention now furnishing means of correcting the amplitude or harmonic distortion of an amplifier, or of an electrically controlled source of light or other energy.

Although I have herein shown and described specifically only certain forms of apparatus embodying my invention, it is understood that various changes and modifications may be made therein within the scope of the appended claims without departing from the spirit and scope of my invention.

Having thus described my invention, what I claim is:

1. In combination, a source of carrier frequency energy subject to modulation, a source of modulation frequency control electromotive force in accordance with which the carrier frequency energy is to be modulated, feed-back means actuated by said carrier frequency energy and furnishing a feed-back electromotive force of the same frequency and phase as the modulation of the carrier frequency energy, means actuated by said feed-back electromotive force and by the control electromotive force for furnishing to the source of carrier frequency energy a modulating electromotive force comprising a first component proportional to the control electromotive force and a second opposed component proportional to the feed-back electromotive force, said second component being large enough relative to the whole of said modulating electromotive force to correct all but a small part of the modulation distortion introduced by the source of carrier frequency energy, and said feed-back means introducing into the feed-back electromotive force a small distortion for correcting said small part of the modulation distortion.

2. In combination, a source of carrier frequency current, a source of control electromotive force of modulation frequency, a modulator having connection with said sources and operative to modulate the carrier frequency current by the control electromotive force, an output circuit coupled to the modulator output and carrying modulated carrier current, means, including a detector, coupled directly to the source of carrier current and coupled to the output circuit such that an electromotive force from the carrier frequency source and an electromotive force from the output circuit are superposed to supply to the detector an electromotive force of such low percentage of modulation that the detector output electromotive force is a substantially undistorted reproduction of the modulation of the output current, and means furnishing to the modulator a modulation frequency input electromotive force equal to the difference between a first component proportional to the control electromotive force and a second component proportional to the detector output electromotive force, the parts being so designed and proportioned that the said second component is relatively large compared to the whole of said modulation frequency input electromotive force, thereby correcting distortion of the modulation of the output current.

3. In combination, a course of carrier frequency current, a source of control electromotive force of modulation frequency, a modulator having connections with said sources and operative to modulate the carrier current by the control electromotive force, an output circuit coupled to the modulator output and carrying modulated carrier current, a conductor coupled with the output circuit, a detector, circuit means to connect the input terminals of the detector with said conductor and with the output terminals of the source of carrier current for supplying to the detector an electromotive force from the output circuit and an electromotive force from the carrier current source, a circuit network associated with said circuit means to adjust the phase and wave form of the electromotive force supplied to the detector to effect a substantially undistorted reproduction of the modulation of the output circuit current in the output of said detector, means coupled with the output of the detector and with the source of control electromotive force for furnishing a correcting electromotive force equal to the difference between a first component proportional to the control electromotive force and a second component proportional to the detector output electromotive force, and means to modify the control electromotive force supplied to the modulator by said correcting electromotive force.

AUSTIN M. CRAVATH.