

Feb. 16, 1937.

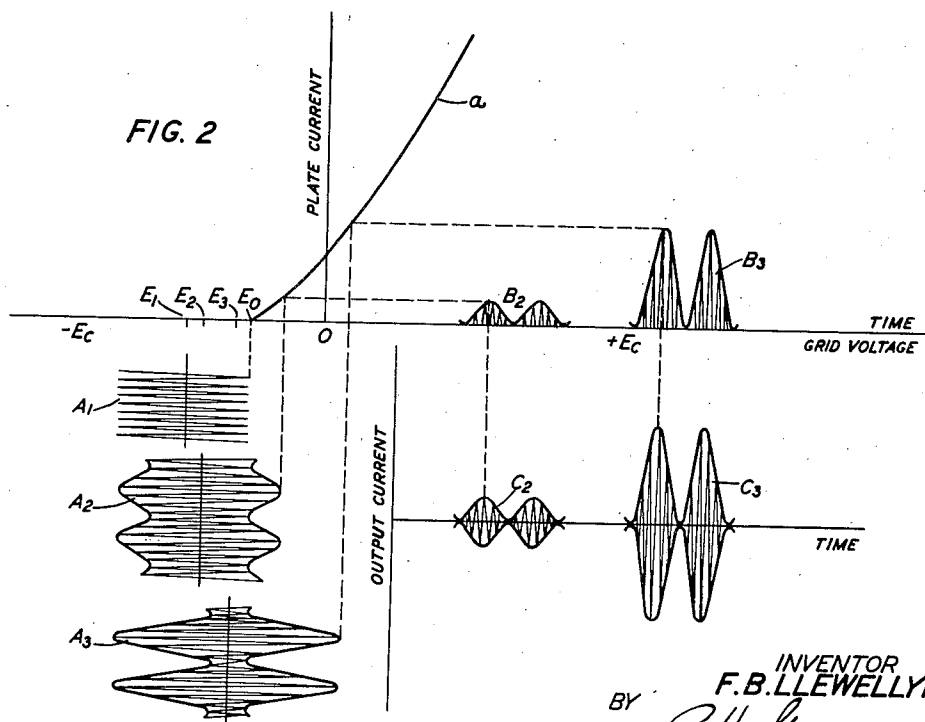
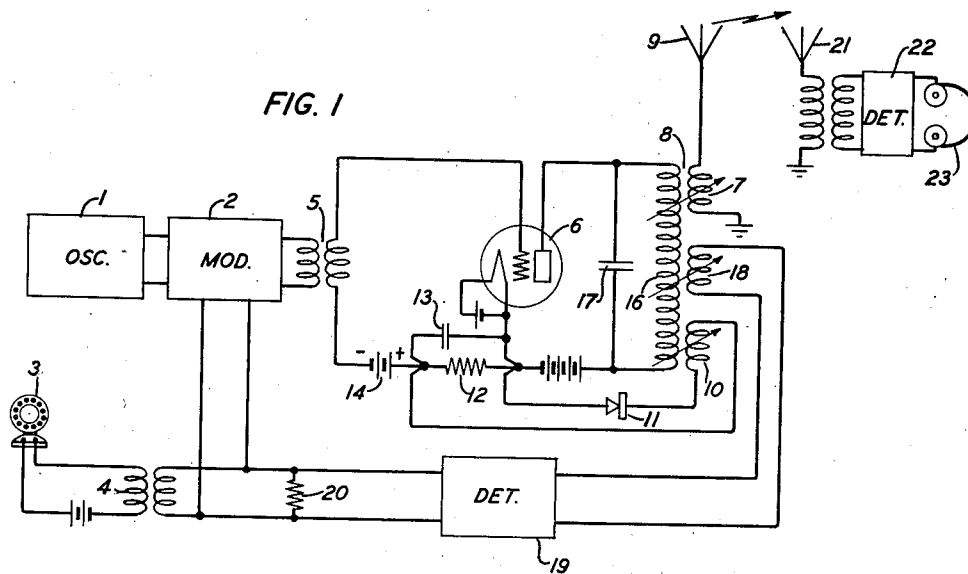
F. B. LLEWELLYN

2,070,666

MODULATING SYSTEM

Filed Dec. 29, 1934

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

FIG. 3-A

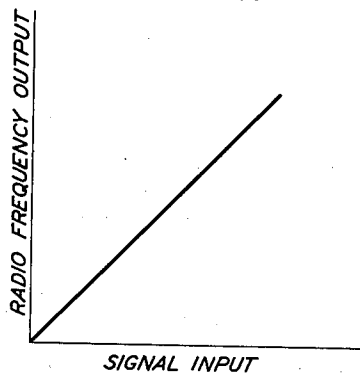
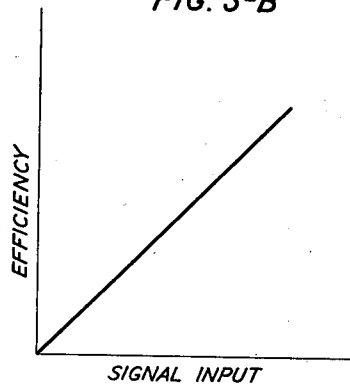


FIG. 3-B



WITHOUT DEGENERATION

FIG. 3-C

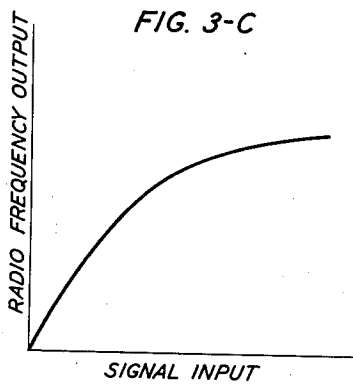
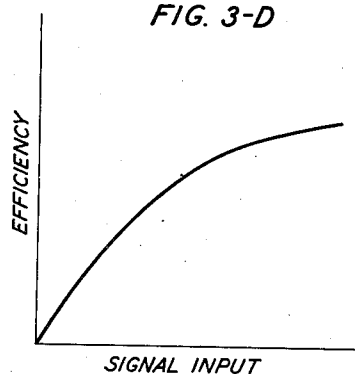


FIG. 3-D



WITH DEGENERATION

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2,070,666

MODULATING SYSTEM

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6 Claims. (Cl. 250—6)

This invention relates to modulating systems and particularly to means for controlling the transmission characteristics of such systems.

A general object of the invention is to improve the overall power efficiency of a communication system without sacrificing the quality and fidelity of reproduction of signals. A particular object is to neutralize signal distortion arising in a receiving system. Another particular object is to neutralize signal distortion in certain types of detectors where distortion accompanies variations in the average amplitude of the carrier component in a modulated wave as received at the detector.

It is known that the introduction of a linear modulator and a linear detector into a transmission system results in no distortion of signals transmitted therethrough. It is also known that if either the modulator or the detector is non-linear the signals will be distorted unless it be arranged that the non-linearity of the one device is complementary to the non-linearity of the other in such a way that all distortion is neutralized. In the modern high quality broadcasting systems the transmitting station has a modulator which is substantially linear. The typical receiving station in the possession of the average member of the listening public contains, under present commercial conditions, a detecting device in which the low frequency response is proportional to the square of the high frequency excitation, such a device being commonly known as a square law detector. Linear detectors are not yet in widespread use in this field. However, a close approach to linear detection is commonly secured in square law detectors due to the fact that a strong component of unmodulated carrier is supplied from the transmitting station. Such liberal distribution of the carrier power is expensive and to reduce the expense without necessitating the use of local carrier sources at the receiving stations, it has been proposed to vary the carrier component in accordance with the signal strength, providing at each instant only so much carrier as can be completely modulated by the signal. A transmission system of this type is disclosed in U. S. Patent No. 1,691,990, issued November 20, 1928, to R. K. Potter. The practical difficulty in introducing this method of transmission in the broadcast field has been the large number of square law detectors which would be rendered obsolete by the change. The variability of the carrier supply accentuates the non-linearity of the square

law detector by introducing amplitude distortion of the broadcast program.

In accordance with this invention, in combination with a variable carrier transmission system a monitoring detector is provided, preferably of the type that is most prevalent at the receiving stations. Distortion appears in the detected signal if there is any uncompensated non-linearity in any part of the system. Distortion in amplifiers has been successfully neutralized by means of a negative feed-back or degenerative reaction between the output of the amplifier and its input as disclosed in an article by H. S. Black entitled, "Stabilized feed-back amplifiers", published in the January, 1934, number of the Bell System Technical Journal, on pages 1 to 18, and in a co-pending application by Black, Serial No. 606,871, filed April 22, 1932, and assigned to the same assignee as the present application. To neutralize distortion in the system of the invention, a feed-back path is provided between the output circuit of the monitoring detector and some portion of the modulating system where a control of the modulating process can be effected, as for example, the signal input circuit of the modulator. The feed-back path is arranged in conformity with certain general principles of degenerative action as disclosed by Black. When the system is adjusted in the preferred manner the output wave of the detector is substantially an undistorted reproduction of the signal input wave. The modulated wave emitted by the transmitter must then necessarily have a suitably predistorted envelope form which will compensate for distortion in any detector similar in characteristics to the monitoring detector. For convenient control it is usually preferable to locate the monitoring detector in the immediate vicinity of the transmitter. Where the receivers are of various types, the monitoring detector may be identical with the receiver of the type most numerous, or the monitoring detector may be one the use of which is found to result in the most pleasing reception in the majority of receivers.

The invention will be more clearly understood by reference to the accompanying drawings, of which

Fig. 1 shows in schematic form a radio transmitter embodying the invention;

Fig. 2 shows the form of the modulated output of a vacuum tube amplifier under different conditions of grid excitation; and

Fig. 3 shows the manner of variation of output and efficiency with signal input, with and without the application of feed-back.

Referring to Fig. 1, high frequency oscillations from an oscillator 1 are modulated in a modulator 2 by signals from a telephone transmitter 3, which is coupled to the modulator by means of a transformer 4. The modulator may be of the type disclosed in U. S. Patent No. 1,350,752 to H. J. Van der Bijl, August 24, 1920 or may have any other suitable internal arrangement. By means of a coupling transformer 5 the output circuit of the modulator 2 is connected to an amplifier 6 and thence through the secondary winding 7 of a tuned transformer 8 to a transmitting antenna 9.

Coupled to the output of the amplifier 6 is a rectifier circuit comprising the secondary winding 10 of transformer 8, a rectifier 11, and a resistance 12 connected in the grid circuit of the amplifier 6, the resistance being by-passed for radio frequency oscillations by a condenser 13. The rectifier 11 is so connected that the direction of the rectified current through resistance 12 is such that the voltage across the resistance terminals in its effect upon the grid of tube 6 is of opposite polarity to a negative biasing battery 14 associated therewith.

Coupled to the output of amplifier 6 by means of the secondary winding 18 of transformer 8 is a monitoring detector 19 of a non-linear type. A common example of a non-linear detector is shown at S in Fig. 2 of Langmuir Patent 1,282,439, October 22, 1918, and is often referred to as a "grid leak detector". The output circuit of detector 19 is connected to a resistance 20 in the voice frequency input circuit of the modulator 2. A tuning condenser 17 is associated with the primary winding 16 of the transformer 8, which winding is loosely coupled to the other windings. A typical receiving station is shown having a receiving antenna 21, a detector 22 and an indicating device illustrated by a telephone receiver 23.

In the operation of the system of Fig. 1, the signal wave from the transmitter 3 and the carrier wave from the oscillator 1 are combined in the modulator 2 to produce a modulated wave which is amplified in tube 6 and impressed upon the antenna 9 by means of the transformer 8. A portion of the modulated wave is intercepted by the secondary winding 10 and applied to the rectifier 11. Due to the relative poling of the rectifier and the grid biasing battery 14, an increase in rectified current results in the grid of tube 6 becoming less negative. On the other hand, when the rectified current decreases the grid becomes more negative. This arrangement constitutes a specific means for controlling the carrier amplitude to maintain a constant degree or depth of modulation as will be shown more fully hereinafter.

The effect of the arrangement upon the character of the output wave may be seen by reference to Fig. 2, where the curve *a* represents the grid voltage versus plate current characteristic of the amplifier tube 6. In this figure the curve *A*₁ represents the carrier input wave when there is no signal impressed by the transmitter 3, and for this condition the grid biasing battery 14 is preferably adjusted to a value *E*₁ such that the positive peaks of the unmodulated carrier just reach the cut-off point *E*₀ and therefore cause no plate current in the output circuit. When a signal of small amplitude is impressed so that the input wave is modulated to only a small degree as represented by curve *A*₂ (assuming the signal input to be a single frequency sine wave, for convenience),

there is a small modulated output current in the plate circuit. The rectifier feed-back circuit acts to diminish the negative bias on the grid from the value *E*₁ to some value *E*₂ such that the minimum positive peaks of the modulated carrier wave just reach the cut-off point *E*₀, giving a completely modulated output wave as shown by curve *B*₂. Similarly, when the percentage modulation of the input wave increases, giving the wave shape shown by curve *A*₃, the output current increases and the feed-back rectifier still further decreases the negative bias to some value *E*₃, so that as before the minimum positive peaks just reach the cut-off point *E*₀, resulting again in a completely modulated output wave *B*₃ of greater amplitude than *B*₂. Thus, by means of the rectifier feed-back circuit, the output wave can be adjusted so that it is always completely modulated and has a peak amplitude proportional to that of the signal wave, while in the absence of signal input there is no output of carrier.

With respect to the shape of the output waves *B*₂ and *B*₃ of Fig. 2, it is seen that the lower halves of these waves are cut off, since there is no plate current during the negative swings of the corresponding input waves. However, by virtue of the tuning of the primary winding 16 and the loose coupling between the primary 16 and the secondary windings of transformer 8, the shape of the waves in the secondary windings 7, 10 and 18, and of the waves radiated from the antenna 9, will be symmetrical and similar to the waves *C*₂ and *C*₃ in Fig. 2.

In the above description it has been assumed that the variation of the biasing grid voltage effected by the feed-back rectifier 11 was such as to accomplish a constant, one hundred per cent modulation of the output wave. However, it is not required that the degree of modulation be fully one hundred per cent, nor that absolutely no carrier be transmitted when there is no modulating signal, since a small departure from these optimum conditions will result in no substantial decrease in economy.

The following analytical treatment of a modulated wave form of *A*₃ or *C*₃, in Fig. 2, is believed helpful in order to supplement the description of the invention. Either wave may be represented by the equation

$$e = E_A(1 + m \cos Bt) \cos At \quad (1)$$

in which

- e* = the instantaneous value of the modulated voltage;
- E*_A = the peak value of the unmodulated carrier frequency voltage;
- m* = the modulation factor;
- A* = $2\pi f_A$, where *f*_A is the carrier frequency;
- B* = $2\pi f_B$, where *f*_B is the modulating frequency.

When such a wave is impressed upon a non-linear detector, among the audio-frequency components appearing in the output there will be a current of the modulating frequency and a current of twice this frequency, the second harmonic, which will be given by the following equations, respectively,

$$i_B = C_1 m E_A^2 \cos Bt \quad (2)$$

$$i_{2B} = C_2 \frac{m^2}{4} E_A^2 \cos 2Bt \quad (3)$$

where *C*₁ and *C*₂ are constants depending upon the characteristic curve of the detector and upon the output circuit impedance. There will

be other harmonics also, but their amplitudes will in general be smaller than that of the second and for the purposes of this discussion their equations need not be written.

The presence of these harmonics in the output is of course a distortion of the signal, which may be called frequency distortion. In the carrier control mode of transmission which has just been described, E_A is not constant but varies with the amplitude of the signal input, while m is constant. This is in contrast to the commonly used transmission mode where E_A is constant while m varies with the amplitude of the signal. From Equation (2) it is apparent that in the former case the signal will suffer additional distortion because it is proportional to the square of E_A instead of the first power. The variation of E_A is a syllabic frequency variation and its effect in the output is that, in addition to the distortion owing to the presence of the harmonic, the signal is further distorted because of the disproportionate loudness of strong and weak syllables, which may be called syllabic distortion, or amplitude distortion. The invention provides a means for reducing both of these distortion effects.

A further portion of the modulated wave is intercepted by the winding 18 and impressed upon the detector 19. The detected wave is applied to the resistance 20, where together with the original signal wave it affects the modulator 2. The connections between the detector 19 and resistance 20 are preferably poled in such manner that the detected wave is substantially in phase opposition to the original signal wave. The output of the detector contains the undistorted audio-frequency signal together with the distortion that is introduced by the various elements of the system, including the detector itself. In accordance with the degenerative principle as explained in the article and application by H. S. Black previously referred to, this output, fed back to the signal input circuit in phase opposition to the voltage from the input of the transmitter 3, will result in a lower output signal than before, depending upon the amount of the negative feed-back. In any transmission system such as that under consideration, nearly all of the distortion arising from non-linearity of the elements is produced in the plate circuit of the final tube where the amplitude is greatest, and the distortion produced there is directly dependent upon the amplitude at that point. In the negative feed-back action described above, therefore, a reduction in the output signal will at the same time reduce the distortion components. But since a portion of the distortion present is simultaneously fed back through the system and arrives at the output in phase opposition to the distortion there remaining, the final result in the output of the detector is that the distortion is reduced still further below the signal, the additional reduction caused by feed-back being approximately equal to the reduction in the signal. For illustration, two systems which are initially identical in every respect, may be compared. The signal output and distortion are initially the same in both. In the first system, let the signal output be reduced 20 decibels by reducing the gain of the amplifier. The distortion will in general be reduced somewhat more than this, say 30 decibels. In the second system, let the signal output be reduced 20 decibels by feed-back, keeping the gain of the amplifier constant. The distortion in this

system will be reduced 30 decibels by reduction of signal and 20 decibels more by feed-back, resulting altogether in a 50 decibel decrease in distortion. The feed-back system therefore has the same signal output as the system without feed-back, but has 20 decibels less distortion. Thus it will be seen that the improvement in linearity will be proportional to the gain that is sacrificed by the negative feed-back. For the utilization of this principle, therefore, an excess of gain in the amplifiers must be provided. The increase in gain may be introduced at any convenient point, as, for example, in the signal input circuit or in the high frequency amplifier.

The use of negative feed-back also decreases the effects of amplitude, or syllabic distortion, as will be evident from the following considerations. This type of distortion, as has been explained above, arises from the fact that the signal is proportional to the square of the varying carrier amplitude, making the loud syllables of speech signals too loud in proportion to the weak ones. In the feed-back action described, however, the amount of signal fed back in phase opposition through the system is also proportional to the square of the carrier amplitude and hence the loud signals in the output of 19 will be cut down in greater proportion than the weak signals. The consequence, therefore, is that the ratio of loud to weak signals is reduced and brought nearer to the ratio existing in the input.

As a means for controlling the amount of negative feed-back employed, provision may be made for varying the coupling between the secondary winding 13 and the primary winding 16 of the transformer 3.

In the transmission system described, the output signal that has been thus far referred to as being improved in quality is the output of the monitoring detector 19, which is preferably located in the vicinity of the transmitting antenna 9 and arriving at the receiving antenna 21 will have impressed upon them the effects of the negative feed-back and will therefore in a manner be predistorted; but if the detector 22 has the same detecting characteristics as the non-linear monitoring detector 19 it is obvious that its output will be of the same quality as that of detector 19. If, however, detector 22 has the characteristics of a linear detector the received signal may still be of improved quality with respect to frequency distortion but will suffer a certain degree of volume compression, that is, the ratio of loud to weak signals will be somewhat less than that existing in the original signal.

The effects of the variable carrier control and of the degeneration, or negative feed-back, upon the input-output characteristics of the modulation system of the invention may be illustrated by the typical curves of Fig. 3. The performance of the carrier control system without degeneration is shown by the curves (a) and (b). The radio frequency output amplitude of the amplifier 6 is a linear function of the signal input amplitude, curve (a), as is likewise the power efficiency of the amplifier, curve (b). Thus, if the power efficiency for peak signal amplitudes were 80 per cent, the efficiency for half that amplitude would be, for the curve shown, 40 per cent. The main advantage of the carrier control system lies in the fact that during periods of silence no power is radiated, so that if a computation of power consumption per hour were to

be made, the variable carrier system would be found the more economical.

When degeneration is combined with the variable carrier system the power saving becomes even more pronounced. Thus with a square law detector employed at 19 in Fig. 1, the resulting radio frequency output would approach the square root variation with input amplitude, as shown by curve (c) of Fig. 3. Likewise, the efficiency curve would have a similar shape, as shown by curve (d). If now the efficiency for speech input peaks is made 80 per cent as before, the efficiency for half the peak input would fall only to 56 per cent instead of to 40 per cent, for the curve as drawn. Thus even during continuous input it is seen that the efficiency of the combination system tends to be maintained. This feature in combination with zero radiation of power during silent periods results in improved economy of operation.

While the output of detector 19 is shown fed back to the signal input circuit (across resistance 20) it will be evident that the essential function of this feed-back arrangement is merely to effect a control or modulation of the high frequency wave in opposite phase to the control or modulation effected by the original signal wave. The two controls may be opposed at one control point as shown. In this case, the difference of the two modulating waves is effective to modulate the carrier wave. The controls may equally well be applied at separate control points, in which case they act in succession upon the carrier wave, the effect of one opposing the effect of the other.

What is claimed is:

1. In a high frequency signaling system, a transmitter adapted to send a modulated wave accompanied by an unmodulated carrier component of variable intensity dependent upon the strength of the signal being transmitted, a receiver associated with said transmitter and characterized by a distorting effect upon signals therefrom, an auxiliary receiver having a distorting effect similar to the main receiver, said auxiliary receiver being associated with the transmitter, and a reversed feedback connection for signal frequencies between the auxiliary receiver and the transmitter whereby the transmitted wave is predistorted to diminish distortion of the detected signal in the main receiver.

2. In a high frequency signaling system, a transmitter having an input circuit for low frequency signal waves, means for controlling the depth or degree of modulation in said transmitter to a substantially constant value independent of variations of intensity of said low frequency signal waves, a detector in operative relation with said transmitter, and a reversed feedback connection for signal waves between the detector and said low frequency input circuit in the transmitter whereby the envelope of the modulated wave is under joint control by the low frequency signal wave and the detected wave

fed back in order to diminish distortion in the detected wave due to the action of said control means.

3. In combination, means for transmission of signals utilizing a high frequency carrier wave, said wave containing an unmodulated carrier component proportional to the varying intensity of the signal waves being transmitted, a receiving detector and an auxiliary detector, said detectors having similar signal distorting properties and both being operatively associated with said transmitting means, a signal indicator actuated by said receiving detector to reproduce transmitted signals and reversed feed-back means for feeding detected signal waves from the output of the auxiliary detector to the input of the transmitting means, whereby distortion of the signals as finally reproduced by said signal indicator is reduced.

4. A combination in accordance with claim 3 in which the receiving detector and the auxiliary detector are substantially identical.

5. In combination, means for transmission of signals utilizing a high frequency carrier wave, said wave containing an unmodulated carrier component proportional to the varying intensity of the signal waves being transmitted, a plurality of receiving detectors of various types and an auxiliary detector having signal distorting properties similar to those of a substantial number of said receiving detectors, all of said detectors including the auxiliary detector being operatively associated with said transmitting means, signal indicators actuated by said respective receiving detectors to reproduce transmitted signals, and means actuated by the auxiliary detector to impress detected signal waves upon the transmitting means, thereby to control the same jointly with and in opposition to the original signal waves, whereby distortion of the signals as finally reproduced is reduced in a substantial group of said signal indicators.

6. In combination, means for impressing signals upon a high frequency carrier wave for transmission to a receiving station, means associated with said transmitting means for regulating the carrier output thereof proportionately to the intensity of the signal being transmitted, a receiving detector and an auxiliary detector each operatively associated with the transmitter and each having the characteristic that variations in the strength of the received carrier waves produce distortion of the signals reproduced therein, a signal indicator connected to the output of the receiving detector and means for impressing upon the transmitter reproduced signals from the auxiliary detector in substantial phase opposition to the original signals, whereby the distortion effective at the signal indicator is diminished by predistortion of the signal which is being impressed upon the carrier wave.

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