April 18, 1944. E. I. GREEN 2,347,098

ELECTRICAL WAVE MODULATION

Filed Jan. 9, 1942

FIG. 1

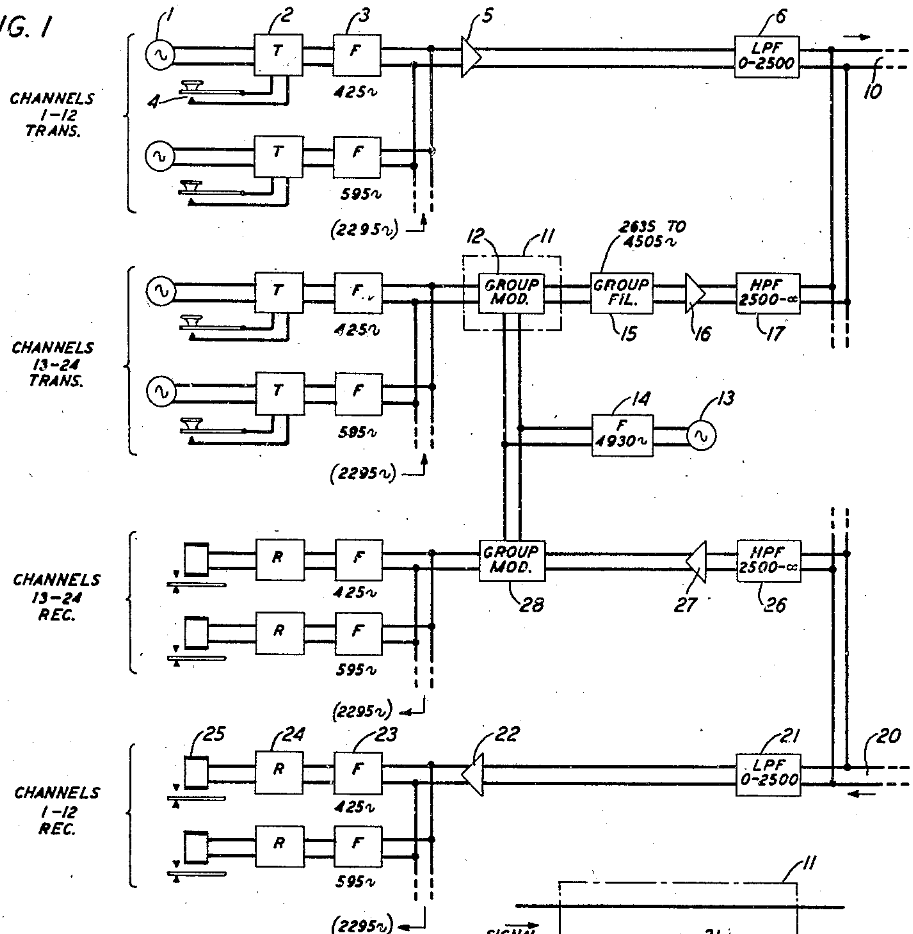


FIG. 2

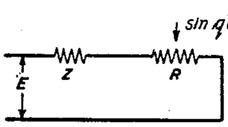


FIG. 3

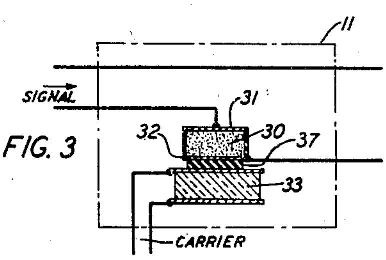


FIG. 4

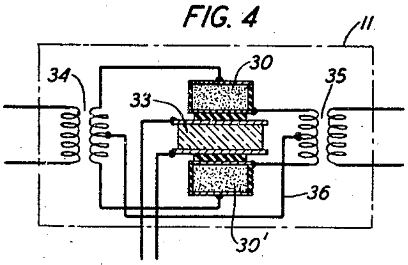
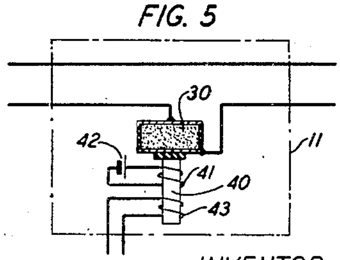


FIG. 5



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ELECTRICAL WAVE MODULATION

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5 Claims. (Cl. 179—171.5)

The present invention relates to the production of modulated electrical waves for carrier wave signaling or other purposes.

Many ways of producing electrical wave modulation have been devised since the advent of wireless telephony and wire carrier telephony, the most commonly used types of modulators being those using some form of vacuum tube circuit and those using solid element varistors such as copper-oxide rectifiers or blocks of composite material having a non-linear volt-ampere characteristic. To a lesser extent, magnetic modulators have been used.

While these types have proved generally satisfactory for most uses, they have the drawback of causing intermodulation products between all impressed wave components and where the signal itself has a number of different frequency components of comparable amplitude the intermodulation products between such components will in some uses prove troublesome. These have commonly been kept to negligibly low value by use of a large carrier amplitude relative to signal amplitude.

One use in which the intermodulation products between input waves in the same input circuit are particularly troublesome is instanced in group modulators and demodulators, which are used for shifting an entire group of modulated carrier waves upward or downward in frequency by modulating a constant frequency wave by the group of carrier waves as a block. Group modulators and demodulators are commonly used in multiplex carrier telephony and telegraphy. In such case, it is often uneconomical to make the amplitude of the constant frequency wave high relative to the other input waves since the modulated wave channels incoming to the group modulator or demodulator are often at fairly high level because of transmission requirements placed on the system. In certain prior art systems the incoming channels have been provided with loss pads to lower their level to help bring about the high amplitude relation of the shifting wave with respect to the channel amplitudes. This procedure requires amplification after modulation to restore the channel levels to desired value for transmission purposes.

Other cases in which it is desired to keep the intermodulation products at low level include high quality speech systems, measuring systems and similar situations.

For convenience of expression the constant frequency wave that is to be modulated will be termed herein the carrier wave whether it be actually used as the transmission carrier wave or merely for frequency shifting purposes in a local circuit, as in a superheterodyne system or beat wave system or certain types of measuring circuits using a frequency shift.

A general object of the present invention is a modulating system or method of such character that the intermodulation products between different components of the signal or other modulating wave are inherently kept at a low or substantially zero value.

This object is attained in accordance with the invention, as specifically disclosed herein, by use of a modulator of the contact resistance type and varying its resistance by mechanically varying the contact pressure at the carrier frequency.

The nature of the invention and its various features and objects will be more fully understood from the following detailed description taken in conjunction with the accompanying drawing, in which:

Fig. 1 is a circuit diagram in block schematic of one terminal of a two-way carrier telegraph system incorporating group modulators in accordance with the present invention;

Fig. 2 is a simplified circuit diagram showing impedance relations to be referred to in the description; and

Figs. 3, 4 and 5 are apparatus diagrams showing three different forms which the group modulator in accordance with the invention may take, these forms being applicable also to other types of modulation.

Referring to Fig. 1, the general plan of this circuit is old in the art, the feature of novelty inhering in the use in such circuit of the group modulators in accordance with the present invention, the nature of these modulators to be referred to subsequently in the description. As shown in the drawing, one group of carrier telegraph channels comprising channels 1 to 12, inclusive, transmit directly to the eastward line 10. Two of these channels are indicated in some detail. There is a source 1 of carrier waves of suitable frequency such as 425 cycles per second, followed by a transmitting circuit 2 and a 425-cycle filter 3, the pass-band of which is sufficiently wide to accommodate the essential frequencies of which the signal in this channel is composed. The transmitter 2 is indicated as under the control of a key 4. The next higher channel is indicated as using a carrier frequency of 595 cycles. This same frequency separation of 170 cycles between channels is used throughout the group so that channel No. 12 of this group uses a frequency of 2,295 cycles as indicated on the figure. These twelve channels transmit out through the transmitting amplifier 5 and low-pass filter 6 to the outgoing line 10.

The second group of channels comprising channels 13 to 24, inclusive, may be entirely similar to channels Nos. 1 to 12 up to the point where the group modulator 12 is connected into the circuit. The purpose of the group modulator 12 is to raise the frequencies of these channels 13 to 24, inclusive, as a group up to a frequency range lying immediately above that used for transmitting channels 1 to 12 over the line 10. For this purpose the group modulator 12 is supplied with a frequency of 4,930 cycles from the source 13 through filter 14. The lower side-band resulting from such modulation lies between frequencies 2,635 and 4,505 cycles and this side-band is transmitted through the group modulator filter 15 while the opposite side-band is suppressed. The selected side-band is amplified at 16 and transmitted through high-pass filter 17 to the line 10.

The manner in which these channels terminate at the opposite terminal may be seen from considering the west terminal for westward line 20 at the lower part of the figure. Channels 1 to 12 incoming over line 20 are selectively transmitted through directional low-pass filter 21 and receiving amplifier 22 to the input side of the twelve channel filters, one of which is shown at 23. These channel filters separate the message currents belonging to the individual channels and direct them into the various receivers, such as 24, the outputs of which are connected to relays, such as 25, for receiving the message.

The upper group comprising channels 13 to 24 is selectively transmitted through the high group directional filter 26 and receiving amplifier 27 and impressed on group modulator 28. This group modulator is also supplied with some of the group shifting frequency 4,930 cycles from the output of filter 14, by virtue of which these channels as a group are stepped downward in frequency to occupy the same frequency position as they originally had before reaching the group modulator of the distant transmitting station. From this point on the manner in which these channels are terminated is entirely similar to that described for receiving channels 1 to 12.

Each of the transmitting wave sources 1 and the group shifting source 13 may in practice be a separate source or all of these frequencies may be obtained from a multifrequency generator or by means of a harmonic generator from a single base frequency of 85 cycles per second frequency. The details of the individual channel apparatus form no part of the present invention and may be in accordance with prior art practice. Such channel terminal apparatus may, for example, be of the type disclosed in a paper entitled "Voice frequency carrier telegraph system for cables" by Hamilton, Nyquist, Long, and Phelps, published in the Journal of the American Institute of Electrical Engineers, Volume XLIV, No. 3, March 1925, or may be of the type shown in United States Patent 1,615,988 to M. B. Long, February 1, 1927.

In the operation of the system shown in Fig. 1 and described above, the twelve transmitting channels comprising channels 1 to 12, inclusive, communicate directly over the line 10 with the corresponding receiving channels at the distant station or stations by means of their individual carrier frequencies and without the necessity of frequency translation. Channels 13 to 24 have their frequencies stepped up by the group modulator 12 at the transmitting point for transmission over the line 10 to the distant terminal station or stations where their frequencies are stepped downward as a group by a modulator corresponding to group modulator 28 for reception by the channel terminal apparatus. If desired, other blocks or groups of channels may be similarly superposed in the frequency spectrum and transmitted over the same line by use of similar group modulators with appropriate shifting frequencies. It is important in this process of shifting the frequencies of the twelve channels as a group that intermodulation between individual channels be kept down to a minimum to avoid interference or crosstalk and reference will now be made to a type of modulator in accordance with the present invention which may be advantageously used as the group modulator in a system such as that shown in Fig. 1. It will be understood, of course, that the modulator of the invention is also capable of general application and that when used as a group modulator the actual system may differ widely from that shown in Fig. 1 which is to be taken merely as illustrative of the use of the modulator of the invention for group modulating purposes. While the multiplex system chosen for illustration is a carrier telegraph system, this is not to be construed as limiting the invention, which is applicable to multiplex carrier telephony or other kinds of signal transmission systems.

Referring to the elemental circuit diagram of Fig. 2, the modulators to be described in accordance with the present invention comprise in each case a variable resistance R connected in series with the source of signal voltage E and with the load impedance Z. The instantaneous value of the modulator resistance R is mechanically varied at the carrier frequency of q radians per second. Further reference to this Fig. 2 will be made later on in the description in connection with the explanation of the theory of operation involved.

One form which the group modulator of the invention may take is indicated in Fig. 3. It comprises a variable resistance composed of granular carbon 30 contained between an upper electrode 31 and a lower electrode 32. This variable resistance is serially connected into the circuit by means of terminals on the conductive members 31 and 32. The lower member 32 is mounted to be vibrated at the carrier frequency by means of the piezo crystal 33 having upper and lower plates connected to the source of carrier waves. The upper plate is shown mechanically connected by insulating layer 37 to the bottom conductive plate 32 of the carbon chamber. By this means mechanical pressure is exerted on the carbon granules, varying at the carrier frequency and the instantaneous value of the resistance offered by the granular carbon mass is therefore varied at the carrier frequency. This resistance varying in carrier frequency is serially included between the source of signals and the load circuit.

Fig. 4 is similar to Fig. 3 except that two such granular carbon resistances **30** and **30'** are connected in push-pull relation and are mechanically driven by a common crystal **33**. Input transformer **34** and output transformer **35** with a mid-tap connection **36** leading from the mid-point of secondary winding of transformer **34** to the mid-point of the primary winding of transformer **35** are provided for coupling the modulator proper to the external circuit.

Referring to Fig. 5, another method of vibrating the granular carbon resistance **30** is shown comprising a magnetostriction member **40** provided with a bias winding **41** and bias source **42** and a driving winding **43** supplied with current of the carrier frequency. Elongations and contractions of the magnetic core **40** at the carrier frequency impart vibrations of corresponding frequency to the mass of carbon **30**. For further information as to how magnetostriction may be employed for such purpose reference may be made to United States Patent 1,092,453 to P. M. Rainey, April 7, 1914.

Reference is made in connection with Fig. 4 to input and output terminals. It will be clear, however, that the type of modulator shown in each of Figs. 3, 4 and 5 is bilateral so that either pair of signal terminals shown may be input or output terminals.

A consideration of the theory of operation will serve to demonstrate that theoretically no cross-modulation products between components of the signal are generated in the contact resistance modulator of the invention. The well-known vacuum tube modulator is operated on a curved part of its characteristic, which means that if the carrier voltage is removed and only the signal (such as speech) is applied, an output consisting of the original speech, reproduced and possibly amplified, is obtained along with intermodulation products between the different speech components since the input-output characteristic is assumed to be non-linear, the tube being operated as a modulator. If this simple test is applied to magnetic, capacity or rectifier type modulators, it will be found that they product at least some degree of intermodulation between signal components for the same reason that they are able to modulate a carrier wave by the signal, namely they operate with a non-linear input-output characteristic. In the case of the contact resistance modulator of the invention, if the carrier wave (in this case the source of mechanical vibration) be kept zero and the signal alone applied, no intermodulation between signal components appears since the modulator acts simply as an ohmic resistance of fixed value.

This may also be seen to be the case by inspection of the formulae applicable to this type of circuit. Referring to Fig. 2, we can write

$$R=r_0+r\sin qt$$

where r_0 is the constant component of the resistance R and r is the maximum amplitude of the variable component, the carrier frequency being q (in radians per second).

The signal input comprising several different frequencies may be designated as

$$E=a_1\sin p_1t+a_2\sin p_2t$$

a_1 and a_2 being coefficients and p_1 and p_2 being frequencies (in radians per second).

The current flowing in the circuit is

$$I=\frac{E}{Z+R}=\frac{a_1\sin p_1t+a_2\sin p_2t}{Z+r_0+r\sin qt}$$

Calling the denominator constants Z_1 this expands to

$$I=\frac{1}{Z_1}(a_1\sin p_1t+a_2\sin p_2t)\left[1-\frac{r\sin qt}{Z_1}+\frac{r^2\sin^2 qt}{Z_1^2}-\frac{r^3\sin^3 qt}{Z_1^3}+\cdots\right]$$

It can be seen from inspection that when this expression is multiplied out, it yields no term containing a product of sin p_1t times sin p_2t, which indicates that no intermodulation products between the separate signal components occur.

What is claimed is:

1. A modulating system comprising a source of signal frequency electrical waves, a load circuit and in series therewith a resistance contact whose resistance value is variable with variation of contact pressure, and means to vary the contact pressure at the frequency of the wave to be modulated.

2. In a modulating system, a source of modulating electrical waves comprising a band of frequencies, means for modulating a carrier frequency by said waves simultaneously and individually comprising a contact resistance, and means for mechanically varying the contact pressure at the carrier frequency.

3. In combination, a source of electrical waves covering a band of frequencies, a contact resistance and a load in series with said source, means to vary the contact pressure at a constant frequency outside said band, and means comprised in said load for responding to the modulated waves resulting from such variations in contact pressure.

4. In a frequency shifting modulator, a circuit carrying signal wave voltages of a plurality of different frequencies comprised within a given frequency band, a contact resistance and load in series with each other and said circuit, and means to shift the frequencies of said plurality of signal waves to a different frequency level comprising means to vary the contact pressure of said contact resistance at a frequency outside said band.

5. In a modulator, a source of mechanical vibrations of carrier frequency, a contact resistance mounted to have its contact pressure and therefore its electrical resistance varied at carrier frequency by said mechanical vibrations, a source of modulating electrical waves differing in frequency from said carrier frequency, a utilization circuit, and means connecting said utilization circuit, said contact resistance and said source of electrical waves in series with each other.

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