

May 10, 1938.

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2,116,559

MODULATING SYSTEM

Original Filed May 3, 1934

2 Sheets-Sheet 1

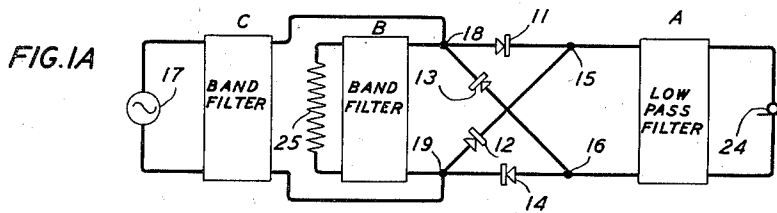
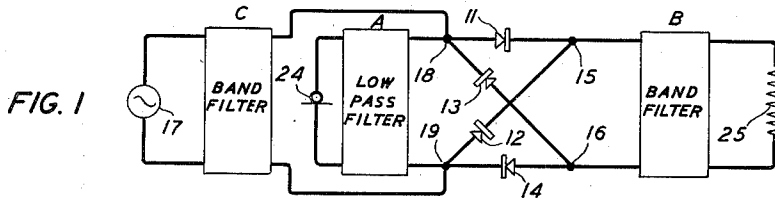
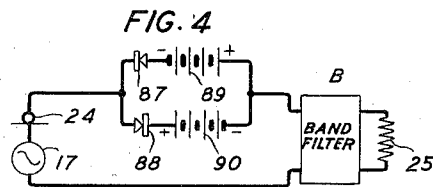
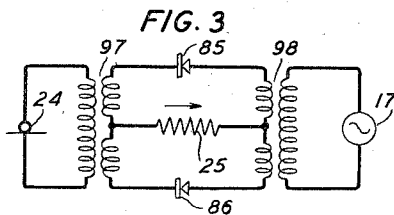
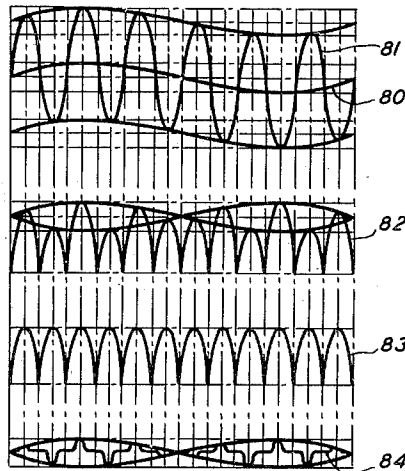


FIG. 2



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2 Sheets-Sheet 2

FIG. 5

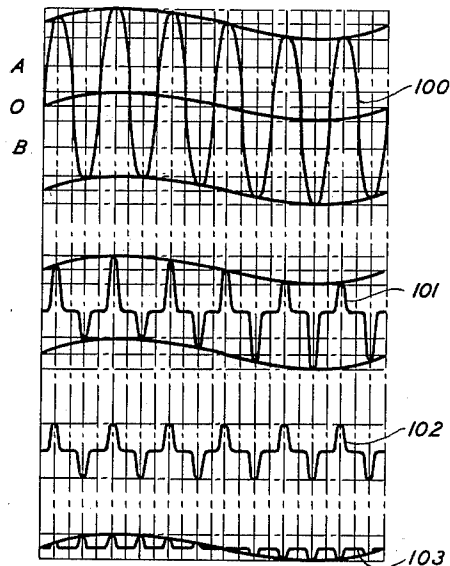


FIG. 6

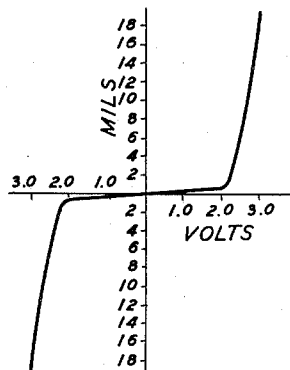


FIG. 7

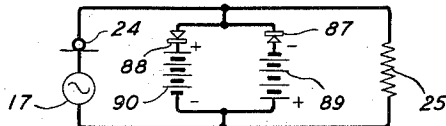


FIG. 8

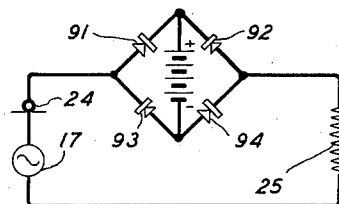
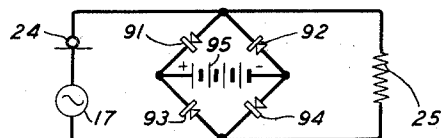


FIG. 9



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MODULATING SYSTEM

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Original application May 3, 1934, Serial No. 723,691. Divided and this application August 8, 1935, Serial No. 35,229

4 Claims. (Cl. 179—171)

This invention relates to systems for effecting modulation, demodulation and detection of electrical waves and particularly to systems employing rectifiers of the dry surface contact type.

It has for its main object to increase the simplicity, economy and reliability of such systems.

Another object is to secure more complete suppression of unmodulated carrier in cases where this is desirable.

A further object is to minimize the waste of energy in the frequency transformations incident to modulation, demodulation and detection.

A still further object is to eliminate the necessity for balancing two or more transformer windings in order to effect suppression of unwanted modulation products, of carrier or of signal input currents in the output circuit.

This is a division of my application Serial No. 723,691, filed May 3, 1934 for Modulating systems, Patent No. 2,086,601 dated July 13, 1937.

Broadly considered, a system of the kind to which the invention relates comprises a source of signal currents, a load circuit and means by which the signal currents are utilized to generate and control a current of desired form in the load circuit. Such a system is sometimes called a frequency changer, due to the fact that the input and output have different frequencies. The problem of attaining a high efficiency of energy transfer resolves itself into one of providing suitable coupling of a variable nature between source and load. If this is done, the frequency change may be effectively regulated and the amplitude of the output may be controlled in accordance with the signal variations, accompanied by the least possible waste of energy.

In accordance with the invention, improved coupling arrangements are provided which include two or more rectifiers of the dry surface contact type, with appropriate control means, inserted in circuit between the input and output branches of the system. The condition of conductivity or non-conductivity of the individual rectifiers is varied preferably in an abrupt manner, by the action of an associated source of carrier waves, supplemented in some cases by a biasing means. The resulting variation of coupling may be such that the signal source and the load are alternately coupled to and decoupled from each other, or the variation may cause phase reversals of the coupling, or any desired alteration. In many instances, it is to be preferred that the circuits be substantially decoupled during the greater part of the carrier cycle, the coupling taking effect during only a very small

portion of the cycle. An impulsive excitation of the load is thus effected, the signal source acting upon the load through the coupling in an intermittent manner. During the intervening periods, interaction with its attendant energy dissipation is prevented.

A feature of the invention is the use of a carrier voltage considerably greater than the signal voltage so that the carrier substantially controls the rectifiers, causing them to act as voltage operated switches or commutators at periodic intervals determined by the carrier frequency. Another feature is the use of a biasing means of large voltage compared with the signal source, but somewhat less than the maximum carrier voltage. By adjustment of the voltages the excitation of the load circuit through the rectifiers may be confined to whatever fractional part of the carrier cycle may be found to accompany the highest efficiency under practical conditions. Other features relate to a full-wave rectifying arrangement of the dry surface contact type for use as a modulator, and combinations of rectifiers acting in regular rotation to produce an output wave of twice the carrier frequency, that is, for third order modulation.

The invention will be more fully understood from the following detailed description of representative circuits in which it is embodied and of their principles of operation. Of the accompanying drawings,

Fig. 1 shows a full-wave rectifier arranged to operate as a modulator;

Fig. 1—A shows a modification of Fig. 1;

Fig. 2 consists of curves useful in the explanation of the system of Fig. 1;

Fig. 3 shows another form of full-wave rectifier for use in modulation;

Fig. 4 shows another arrangement of biased rectifiers for third order modulation;

Figs. 5 and 6 show curves employed in explaining the operation of the system of Fig. 4; and

Figs. 7, 8, and 9 show other forms of third order modulators employing biased rectifiers.

Fig. 1 shows a modulating system in which a lattice type circuit or Wheatstone bridge network containing rectifiers is connected between a signal source 24 and a load circuit 25. An input filter A adapted to pass the essential frequencies of the signal is interposed between source 24 and the bridge. Likewise, an output filter B is placed between the bridge and load 25 to select a desired output wave. The bridge includes rectifiers 11 and 12 which have a common terminal 15 and are so poled that each is conduc-

tive toward the common terminal, as indicated by the direction of the arrowheads in the schematic representation. The bridge also includes rectifiers 13 and 14 which have a common terminal 16 and are so poled that each is conductive away from the common terminal. A carrier generator 17 is connected between the two other common terminals 18 and 19 as indicated. Due to the bridge arrangement of the circuits the pair of terminals 15, 16 and the pair 18, 19 are conjugately related, the carrier source and load circuit appearing in the respective conjugate branches. A filter C adapted to pass the carrier frequency is connected between the carrier generator and the points 18 and 19.

The circuit of Fig. 1 comprises a modulating system in which a full-wave rectifier is inserted between the sources of impressed waves and the load circuit. The rectifier is in the form of a bridge network of rectifying elements. With suitable adjustments of the amplitude of the carrier wave the bridge network may be controlled to effect periodical reversals of the signal current in synchronism with the carrier. In the drawings, the bridge network is represented in the lattice form in order to illustrate more clearly the manner in which the reversals are effected.

The operation of the system of Fig. 1 may be explained by reference to the curves shown in Fig. 2. Curve 80 represents a sinusoidal signal wave upon which is superposed a carrier wave having an amplitude several times larger. The resultant wave 81 represents the voltage impressed upon the bridge network in Fig. 1. The effect of passing the wave 81 through a full-wave rectifier is shown by the curve 82, which is readily analyzed into its approximate components, a rectified carrier wave 83 containing only even harmonics of the carrier, and a modulated wave 84 which consists of alternately directed pulses which occur at the rate of two in each cycle of the carrier wave. Curve 84 is evidently a modulated wave of a common sort, namely, a second order wave having the fundamental carrier suppressed. The carrier harmonics being usually of considerably higher frequency are readily separated from the modulated wave in the output filter with the result that only the modulated wave is transmitted to the load.

Considered from a slightly different viewpoint, the bridge in Fig. 1 is equivalent to a reversing switch or commutator, which equivalence is emphasized in the drawings by showing the bridge in lattice form. The reversing action is brought substantially under the control of the carrier by making the carrier voltage great in comparison with the signal voltage. Evidently, it is then possible to interchange the signal input and the load circuit without disturbing the commutating or reversing action of the bridge as far as it affects the modulation of the signal wave. Fig. 1—A shows this modification. The main difference in operation is in the transmission of the carrier to various parts of the system. Whereas in the system of Fig. 1 the carrier is suppressed in the load but transmitted to the signal input circuit, in the modified arrangement the carrier is transmitted to the load but suppressed in the signal input circuit. The systems of Figs. 1 and 1—A have the further property of suppressing not only the impressed signal wave but all harmonics thereof in the load circuit.

Fig. 3 shows a modified system with a mode of operation similar to that of the system of Fig. 1. By introducing two transformers with balanced

windings the number of rectifying elements is reducible to two, while still providing full-wave rectification. In the figure the signal source 24 and carrier source 17 are connected to rectifiers 85 and 86 through transformers 87 and 88, respectively. For simplicity all filters are omitted but may be employed, of course, wherever desirable. The load 25 is connected between the mid-points of the divided secondary windings of the two transformers.

In the operation of the system of Fig. 3, one-half of the impressed wave is transmitted to the load through rectifier 85 and the other half through rectifier 86. Both rectifiers are poled in such a direction that the resulting currents in the load pass from left to right as shown in the diagram. The wave forms resulting from the rectification are the same as illustrated in Fig. 2.

Fig. 4 shows another combination of biased rectifiers for third order modulation. In this circuit the second harmonic of the impressed carrier wave is suppressed while the fundamental carrier is either transmitted to the load or removed by means of filter B. In the specific arrangement shown the signal source 24 and carrier source 17 are connected to a pair of rectifiers 87 and 88 with polarizing batteries 89 and 90, respectively. The rectifiers are connected serially with a filter which is connected in turn to the load 25. The rectifiers are oppositely directed so as to provide a path for currents in either direction between the sources and the load. The biasing batteries are arranged so that both rectifiers are normally non-conductive.

In the operation of the system of Fig. 4, when the impressed voltages from the sources are sufficient to overcome one or the other of the biasing voltages an impulse is transmitted through the associated rectifier to the load. As two paths of opposite conductivity are provided, the impulses transmitted may go either way and may alternate in direction. The action of the circuit is more readily understood by reference to the curves in Fig. 5 of which curve 100 represents the impressed wave made up of carrier and signal superposed. The ordinates OA and OB represent the biasing voltages. Curve 101 shows schematically the wave tips which exceed the biasing voltages and are transmitted through the rectifiers. The transmitted curve is readily analyzed by inspection into the components 102 and 103. The part shown in curve 102 is a train of impulses having the fundamental carrier frequency, the other component consisting of impulses at twice the carrier rate controlled in accordance with the form of the signal wave. It will be evident from further inspection that the curve 103 has the distinguishing characteristics of a third order modulated wave, particularly one in which the second harmonic of the carrier frequency is suppressed. As the modulated wave alone is usually desired, the fundamental carrier may be suppressed in the output filter.

High efficiency in the system of Fig. 4 is promoted by employing biasing voltages that are large compared with the signal voltage and making the maximum carrier voltage somewhat greater than the bias. A pair of biased rectifiers has a combined current-voltage characteristic of the general form illustrated in Fig. 6. The curve shows that when the impressed voltage is less than the bias and the current is very small. The absolute value of the current in this region is determined by the amount of reverse current which is passed by the particular rectifiers em-

played. The more perfectly unidirectional the rectifier, the smaller the reverse current. At voltages in excess of the bias, however, the current increases very rapidly with further increase in voltage.

The curve of Fig. 6 may be approximately represented by the formula

$$I = AE^n \quad (1)$$

in which I is the current, E is the voltage, A is a factor of proportionality and n represents an odd integer. The larger the value of n the more sharply the curve bends and the more efficient is the device as a modulator. The increase in efficiency with increased value of n may be illustrated mathematically in the following manner: Assuming that $C \cos c$ is the carrier voltage impressed upon the modulating element and $V \cos v$ is the signal voltage, then the total impressed voltage is

$$E = C \cos c + V \cos v \quad (2)$$

Substituting this value of E in Equation (1) gives the current

$$I = A(C \cos c + V \cos v)^n \quad (3)$$

To investigate the value of the efficiency for a particular value of n the desired value may be substituted in Equation (3). For example, when $n=3$, the current is

$$I = A(C \cos c + V \cos v)^3 \quad (4)$$

Expanding the right-hand side of Equation (4) by means of known trigonometrical transformations, it is a simple matter to collect the terms of interest, namely, those of signal frequency and those corresponding to one of the third order side-bands. The result is as follows:

$$I = \left(\frac{3}{2} C^2 V + \frac{3}{4} V^3 \right) A \cos v + \frac{3}{4} C^2 V A \cos (2c + v) + B \quad (5)$$

where B represents all the terms that are not of interest. The value of the efficiency is found by taking the ratio of the signal current to the side-band current which is as follows:

$$\frac{\frac{3}{2} C^2 V + \frac{3}{4} V^3}{\frac{3}{4} C^2 V} = 2 + \left(\frac{V}{C} \right)^2 \quad (6)$$

Highest efficiency is indicated by a low value of the ratio and hence

$$\frac{V}{C}$$

in Equation (6) should be made always as small as possible. This requires that the carrier voltage be made several times as large as the signal voltage. If the carrier voltage is increased very greatly it is evident that the efficiency ratio approaches the value 2, the signal current being then twice the amplitude of the side-band current. The side-band current is six decibels below the signal current. Higher assumed values of n substituted in Equation (3) give the following values of current ratio:

n	Current ratio
5	1.5
7	1.33
9	1.25
11	1.2

In general, the value of the current ratio is found to equal

$$\frac{n+1}{n-1}$$

which has the limiting value of one as n is made very large. Calculations of this sort indicate that the modulating efficiency may be considerably increased by any means which will increase the value of n , or which is the same thing, will increase the sharpness of the band of the characteristic curve.

The system of Fig. 7 is similar to that of Fig. 4 but with the rectifiers connected in parallel with the load circuit rather than in series therewith. Again for simplicity all filters are omitted, but it is to be understood that they may be used wherever required. The rectifiers in Fig. 7 operate as a variable shunt impedance means which diverts current from the load circuit whenever the impressed wave reaches a voltage in excess of the biasing voltage in one or the other of the shunt paths, with the result that a third order modulated wave is transmitted to the load.

Fig. 8 is an arrangement similar to the arrangement in Fig. 4. Four rectifiers 91, 92, 93 and 94 are employed in a bridge arrangement. The load and the sources are connected serially in one diagonal of the bridge, the biasing battery 95 being connected in the other diagonal branch. The operation of the system is similar to that of the system in Fig. 4. An advantage of the bridge arrangement is that the battery is isolated by being placed in one conjugate branch of the bridge network.

Fig. 9 shows the bridge arrangement of rectifiers connected in parallel relation to the load and the operation is similar to the operation of the system of Fig. 8.

Any of the systems herein described will function equally well as a demodulator and may be so used simply by supplying a side-band current to the present output end of the output filter and connecting the present input end of the input filter to a receiver. In each system shown including those in which filters are not illustrated the change is made by substituting a source of side-band current for the load circuit and putting a receiver in place of the transmitter as illustrated. When the system is operating as a demodulator the incoming side-band wave is commutated or interrupted either at the carrier frequency rate or at a frequency related to the carrier, whereby there is produced an output wave which contains the desired signals as a component.

What is claimed is:

1. A modulating system comprising four rectifiers serially connected in a closed loop in the manner of a Wheatstone bridge, said rectifiers being so poled that each is flanked by two adjacent rectifiers, the conductive directions of which are opposed to one another around the loop, a source of carrier waves connected in that diagonal of the bridge determined by the two corners each lying between adjacent rectifiers whose conductive directions around the loop are the same and a signal source and a load circuit connected to the bridge in conjugate relationship to each other, the peak voltage impressed upon the rectifiers by the carrier source being several times the peak voltage impressed upon the rectifiers by the signal source, whereby modulation is accomplished by a full-wave rectifying action of the bridge substantially under the control of the carrier wave.

2. A modulating system comprising four dry surface contact rectifiers serially connected in a closed loop in the manner of a Wheatstone bridge, said rectifiers being so poled that each is flanked by two adjacent rectifiers, the conductive directions of which are opposed to one another around the loop, a source of carrier waves connected in that diagonal of the bridge determined by the two corners each lying between adjacent rectifiers whose conductive directions around the loop are the same and a signal source and a load circuit connected to the bridge in conjugate relationship to each other, the peak voltage impressed upon the rectifiers by the carrier source being several times the peak voltage impressed upon the rectifiers by the signal source, whereby modulation is accomplished by a full-wave rectifying action of the bridge substantially under the control of the carrier wave.

3. A modulating system of the carrier suppression type comprising a bridged network or loop circuit of similar rectifying devices, the rectifiers being so poled that each is flanked by two adjacent rectifiers, the conductive directions of which are opposed to one another around the loop, a carrier source connected in that diagonal of the bridge determined by the two corners each lying between adjacent rectifiers whose conductive directions around the loop are the same, a

source of signal waves, and input circuits selective to said signal waves, said input circuit being connected in the bridge diagonal containing the carrier source, an output circuit selective to a desired modulated wave, said output circuit being connected to the bridge in conjugate relation to the carrier source, whereby the input circuit is connected to the output circuit alternately by direct connection and by connection with the reverse polarity.

4. A modulating system comprising a bridge network or closed loop of rectifiers, said rectifiers being so poled that each rectifier is flanked by two adjacent rectifiers, the conductive directions of which are opposed to each other around the loop, a source of carrier waves and a load circuit connected in the bridge diagonal determined by the two corners that each lie between rectifiers, the conductive directions of which around the loop are restrained, and a source of signal waves connected to the bridge in conjugate relation to the load circuit, the peak voltage of the carrier source being several times the peak voltage of the signal source, whereby the signal source is connected to the load circuit by direct connection and by reverse connection alternately at substantially the carrier rate.

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