Oct. 25, 1932. E. PETERSON 1,884,845

MAGNETIC AMPLIFIER

Filed Sept. 23, 1930

FIG. 1

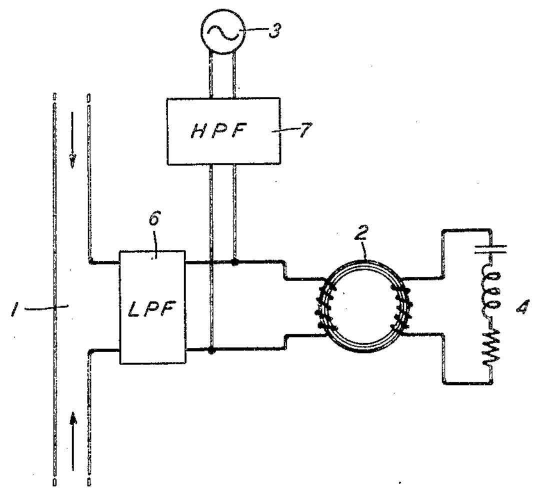
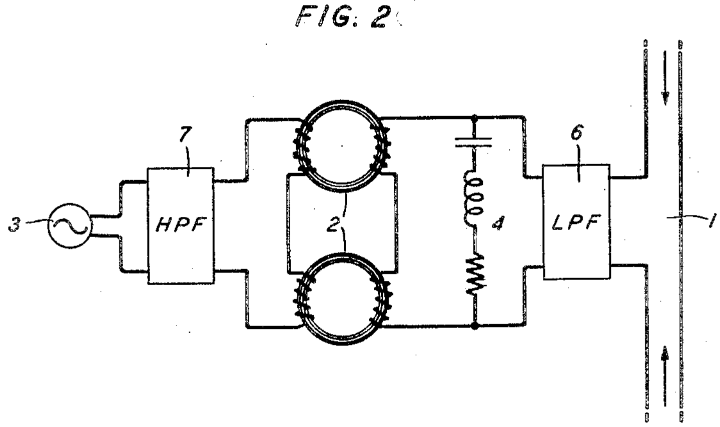


FIG. 2



INVENTOR
E. PETERSON
BY Guy T. Morris
ATTORNEY

Patented Oct. 25, 1932 **1,884,845**

UNITED STATES PATENT OFFICE

EUGENE PETERSON, OF NEW YORK, N. Y., ASSIGNOR TO BELL TELEPHONE LABORATORIES, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK

MAGNETIC AMPLIFIER

Application filed September 23, 1930. Serial No. 483,800.

This invention relates to magnetic core apparatus and particularly to an organization of circuits including a magnetic core and its magnetizing structure, for the amplification of waves impressed thereon.

An object of the invention is to employ the magnetic modulation principle to accomplish regenerative amplification of an impressed wave.

A more specific object of the invention is to utilize the non-linear B—H characteristic of a magnetic core coil, whereby a given wave may derive the energy in an auxiliary wave used jointly therewith to magnetize the core, to achieve amplification directly of the given wave.

A still more specific object of the invention is to utilize a magnetic core modulator to achieve direct amplification of an impressed wave.

It has been known and appreciated for some years that intermodulation of a given wave, usually denominated the signal wave, with a higher frequency wave usually denominated the carrier wave, in a magnetic modulator device, results in the production of combination products similar to those resulting from other types of modulation. It has also been known that, under proper conditions, a particular one at least of these combination frequencies may attain a greater content of energy than the low frequency component wave concerned in its production. This principle has been utilized in the past for the eventual amplification of a given wave, the operation, beyond the above step, comprising a further step of modulation (that is, demodulation) whereby the original low frequency impressed wave is reproduced in amplified form from the proper combination frequency.

The present invention uses much the same mechanism, and probably also the same basic principle, to achieve a quite distinctive result. Applicant has discovered that under certain conditions the production of the usual combination components is attended by a regenerative amplification of the low frequency wave so that amplification may be achieved by his invention directly, that is, without necessitating further operation on the combination frequency.

Certain conditions are necessary for the efficient accomplishment of the objects of the invention. For example, the core should be substantially hysteresisless. If odd order modulation is used as in a preferred form of the invention the core should be devoid of magnetic bias so that only odd order combination frequencies result. Applicant's invention requires that a lower modulation side band current which may be represented (for the selected case of third order modulation) by the quantity $2P-Q$, in which P and Q are respectively the higher and lower of the two impressed frequencies, be dissipated at a given rate. It has been found that this dissipation results effectively in the introduction of resistance in the circuits of the impressed waves, this being positive with respect to the higher frequency and negative with respect to the lower frequency. A similar result would be secured by using other, higher, odd orders of modulation, or by using even order modulation of any order. In any event, a lower side band component is the one concerned in the amplifying operation. For the production of even order side bands of course, the modulator must be biased. When there is no dissipation of the combination frequency wave there is no introduction of resistance in the impressed wave circuits. If the dissipative circuit includes reactance as well as resistance, the effect of the reactance will be reflected in the condition of the impressed wave circuits as by similarly introducing reactances therein. The signs of the resistances and reactances will always be different in the two impressed wave circuits. The energy dissipated is equal to the algebraic sum of the energies absorbed from the high frequency impressed wave circuit and generated in the low frequency impressed wave circuit. In other words, the net resistance introduced to the impressed waves is just sufficient to account for the transfer of energy to the dissipative circuit. This, among other things, demonstrates that the energy for the amplification defined by the presence of the negative resistance in the low frequency circuit, is derived from the high frequency circuit. As the dissipation is caused to increase, the singing point is approached. For practical purposes, of course, it should be insured that regeneration does not go to the point of singing.

In a practical embodiment of the invention, the circuit described above may be conveniently modified so as to function as a bilateral circuit, the low frequency impressed wave circuit being symmetrically related to transmission lines extending in either direction. Also filters would be used to insure that the two impressed frequencies function individually with respect to the common magnetic device and the output circuit would include circuits tuned respectively to the frequency of the waves to be amplified and to the frequency of the lower side band used in the amplifying process, this latter circuit also containing the optimum amount of resistance.

The invention both as to its theoretical principles and its practical embodiments will be better understood by reference to the following detailed description when considered with the accompanying drawing, the two figures of which illustrate typical forms of circuit in which the principle of the invention may be embodied.

In the modification illustrated by Fig. 1 reference numeral 1 indicates a circuit carrying an alternating current which it is desired to amplify. The circuits at the right of line 1 are so organized as to amplify such current. They cooperate with line 1 to constitute the whole effectively a bilateral amplifying circuit.

Amplification is achieved by means of magnetic device 2 and its immediately associated circuits. Amplification is attendant on the combination of the wave to be amplified with a wave from a higher frequency source 3 in the magnetic device, which therefore has the characteristics of a modulator. Essentially the magnetic device, or magnetic modulator comprises a core having a non-linear magnetic or B—H characteristic and a magnetizing circuit therefor. In a simple magnetic modulator device of the invention so far described the modulation products and the attendant amplified wave may be derived from any circuit arranged so as to be affected by the magnetic flux set up by the impressed wave or waves and therefore the magnetizing circuit itself could also be used as the derivatory circuit.

In the specific magnetic modulator circuit of Fig. 1 it has been found convenient to employ a secondary circuit for such modulator units constituting a separate derivatory circuit for modulation products. Tuned circuit 4 is connected in series with the secondary circuit. On account of the well known equivalence of a two-winding transformer and an auto-transformer it is evident that the use, effectively, of a two winding transformer in the present invention does not significantly affect the operation of the principle of the invention as has been described in the statement of invention. Low-pass filter 6 and high-pass filter 7 are inserted in the connections from the low frequency circuit 1 and high frequency circuit 3 respectively to insure that only those currents are permitted to partake in the amplifying function that are necessary therefor and also to prevent interchange of energy between the impressing circuits themselves. The filters and circuits are connected in parallel to better insure that such circuits, including the filters, have high impedance outside their transmission ranges of frequency, and especially to more nearly insure that the circuit as a whole has low impedance to the lower side band and a high impedance to the upper side band. This is desirable since, as has been suggested, the dissipation of lower side band energy results in the desired introduction of negative resistance that implies amplification into the signal current path, whereas the dissipation of upper side band energy results in the introduction of positive resistance into the carrier and signal current paths and is therefore opposed to amplification.

The operation of the invention has something in common with that of conventional magnetic modulators although there are distinctive differences both in the mechanics of the operation and the results thereof. While it is true that the relatively low frequency wave from circuit 1 may be combined with a relatively high frequency wave from source 3 in the modulator 2 to produce upper and lower modulation side bands with attendant amplification so that the lower frequency impressed wave may be reproduced in amplified form by demodulation of one or both of said side bands, in the present instance use is not made of this specific type of amplification characteristic. Although the amplification secured by the present invention is attended by the phenomena above noted the amplification nevertheless is direct and therefore the amplified low frequency, for example, wave may be derived directly from the modulator circuit.

The invention also has much in common with that disclosed in U. S. patent to Heegner 1,656,195 granted January 17, 1928 and in a large number of other patents having quite similar disclosures. Heegner has disclosed that if several oscillation circuits are coupled to a magnetic core which is magnetized by a given alternating current, oscillations may be set up in the oscillation circuit whenever the sum of the natural frequencies of said oscillation circuits is equal to an even multiple of the frequency of the magnetizing current. Using his nomenclature, if W_1 is the magnetizing current frequency, waves of the two frequencies W_2 and W_3 will be generated if the oscillation circuits are tuned to such frequencies and if they satisfy the relation $NW_1=W_2+W_3$, where N is any even number.

Applicant's circuit differs essentially from that of Heegner in that instead of self-generating his current of lower frequency he utilizes somewhat the same continuity of circuit to regeneratively amplify a current of like frequency when impressed on the magnetizing circuit with the higher frequency current. If the frequency of the current from circuit 1 be indicated by Q and correspondingly the frequency of the current from relatively high, or carrier, frequency source 3 by P the significant frequencies in the operation of applicant's system will be for example 2P−Q and Q. This is seen to satisfy Heegner's equation. However the mechanics of the system of applicant's invention is different to the extent that it utilizes a second impressed current as a necessary factor. Applicant achieves his result by making use of a modulation product resulting from a combination of his two impressed currents. That is, not only does applicant's system differ from that of Heegner in that it makes possible a regenerative amplification of an impressed wave but also in that it utilizes an inter-modulation process which concerns the wave to be amplified. Further, Heegner does not disclose the availability of his circuit, or therefore of applicant's, to self generate, or to regeneratively amplify, a wave by use of even order lower side band dissipation, a result that applicant discovered could be secured.

Specifically the circuit 4 is tuned to the lower side band frequency to be used, for example 2P−Q if third order modulation is to be used. This tuned circuit also contains a selected amount of resistance. It has been found that the dissipation of the lower side band current in this tuned circuit is a significant factor in the achievement of the amplification. It results in, effectively, the introduction of a positive resistance into the circuit connected to the carrier current source 3 and the introduction of a negative resistance, (therefore implying amplification) into the circuit 1. In other words the current of frequency Q is amplified. The amount of the dissipation of the side band current is an exact measure of the transfer of energy of the carrier current source to the circuit to which the current is to be amplified, that is, the expedient of the invention has enabled the energy from a source having a frequency indefinitely greater than the frequency current to be amplified to be used to amplify such current.

In order to insure that self-oscillations of frequency Q, or in the neighborhood thereof, do not occur, the impedance of the circuit in which current of that frequency is designed to flow may be adjusted to exceed a critical value. Alternatively this condition may be avoided by adjustment of the amplitude of the carrier.

If the dissipating circuit 4 is not tuned to exact resonance with the dissipating current frequency, the effect will be reflected in the conditions of the impressed wave circuits somewhat similarly as the effect of resistance in the same circuit. For example, the effect will be to introduce a reaction in the circuits of the impressed currents. If the dissipating circuit is inductive the introduced reactance will be inductive for the lower frequency and capacitive for the higher frequency and the converse for a capacitive dissipative circuit.

The circuit of Fig. 2 differs from that of Fig. 1 principally as illustrating an alternative manner of associating the circuits 1 and 3 with each other and with the modulating device. This arrangement makes possible the beneficent employment of two unit magnetic modulators whose primary windings and similarly whose secondary windings are serially connected, and which function together in a manner strictly analogously as the circuit of Fig. 1. This use of the combination of two unit modulators is justified because of the possibility afforded thereby of providing an easily regulable flow of modulation current in such circuits as 4 in which, at the same time, the impressed wave carrier may be kept from flowing. In the achievement of this purpose the secondary windings of the two unit modulators are relatively reversed, that is, whereas the corresponding primary windings are assembled on the magnetic core by winding in the same sense the secondary windings are wound on the same cores in opposing sense. When so arranged zero transformed electromotive force exists at the terminals of the secondary windings adjacent to the tuned circuit 4. Not only is this result achieved, that is, the suppression of the carrier wave, but also there results the suppression in these circuits of even order modulation components. The net result is to insure that only those currents are allowed to flow in the secondary circuit and therefore in dissipating circuit 4 as are required for further operation to secure amplification of the desired wave.

What is claimed is:

1. A magnetic amplifier comprising a magnetic core, a source of waves to be amplified, an auxiliary wave source, means responsive to the wave from each of said sources for producing flux variations in said core, a circuit including a coil wound on said core and therefore adapted to have electromotive force variations generated therein responsive to variations of the flux in said core, said circuit being coupled with said sources only through said core and comprising resonant

tuning elements whereby the waves from said first mentioned source are directly regeneratively amplified.

2. The amplifier specified in claim 1 in which the core has a non-linear B—H characteristic.

3. A magnetic amplifier comprising a source of waves to be amplified, an auxiliary source producing waves of a single frequency greater than that of any wave derived from the first source, a magnetic modulator, means for energetically relating said sources and said modulator, and means comprising a circuit transformer-coupled with said modulator whereby the waves from the first mentioned source are directly regeneratively amplified.

4. A magnetic amplifier comprising a source of current having an indefinite number of frequencies in a definite range, a source of current of a single frequency outside of said range, a magnetic modulator, means for applying currents from said sources to said modulator, and an output circuit for said modulator having an impedance for a modulation product frequency which is critically valued so as to effectively introduce a negative resistance into the modulator circuit connected to said first source.

5. A magnetic amplifier comprising a source of current, a source of current of a different and higher frequency, a magnetic core, circuit means for magnetizing said core in accordance with the currents from said sources jointly whereby intermodulation products result, and additional circuit means transformer-coupled with said core directly affecting such intermodulation products and also affecting the impedance presented to the current from the first source.

6. In combination, a magnetic core apparatus, a magnetizing electric circuit, a source of currents to be amplified, a source of single frequency current, means for impressing the currents from said sources on said circuit, and means for deriving from said circuit currents which are similar as to frequency to the currents from the first source but having greater amplitude.

7. In combination, a circuit and amplifying means electrically inserted therein comprising a magnetic core having a non-linear B—H characteristic, a coil transformer-coupled with said core and means for superimposing in said coil current from said circuit and locally generated current of considerable higher frequency, a second coil also associated with said core, and an impedance controlling path connected to said second coil and selective for the frequency of a lower modulation side band.

8. The combination recited in claim 7 in which the frequency of the locally generated current is substantially higher than that of the current in said circuit and in which a lower side band of an odd order higher than the second is selected by said impedance controlling path.

9. In a transmission line system, means to transmit signal waves over the line, and means at a point in the line operating wholly by magnetic action for introducing a negative resistance in series with the line effective within the signal frequency range, said last means comprising a magnetic modulator and circuits for supplying to it the signal waves traversing said line and sustained waves of higher frequency than the signal waves, said modulator producing a lower sideband of wave components resulting from intermodulation of said supplied waves, and means presenting low impedance to said lower sideband components.

In witness whereof, I hereunto subscribe my name this 20th day of September, 1930.

EUGENE PETERSON.