Jan. 3, 1928. 1,654,932

R. A. HEISING

MAGNETIC AMPLIFYING SYSTEM

Filed June 29, 1922 2 Sheets-Sheet 1

Fig. 1.

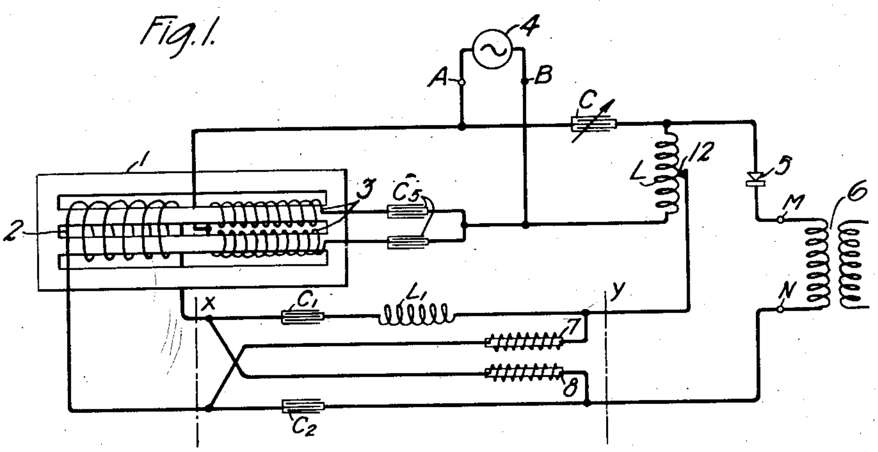


Fig. 3.

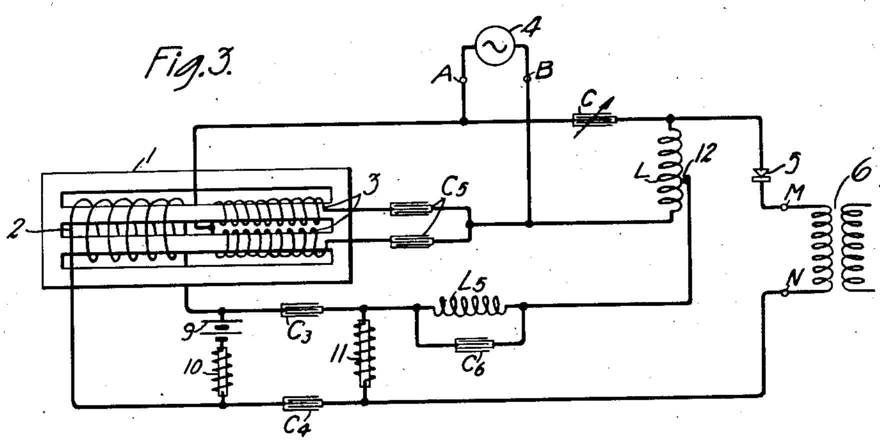


Fig. 2.

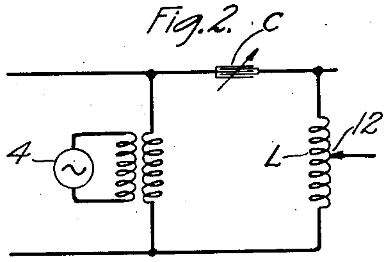
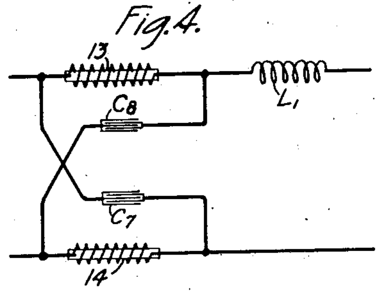


Fig. 4.



Inventor:
Raymond A. Heising.
by E. V. Griggs Att'y.

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Fig. 5.

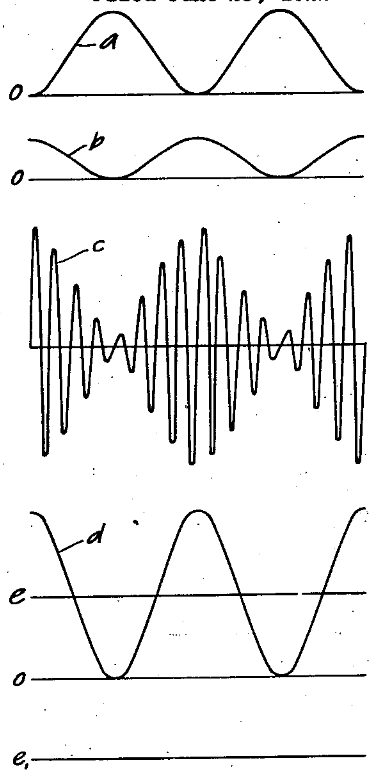
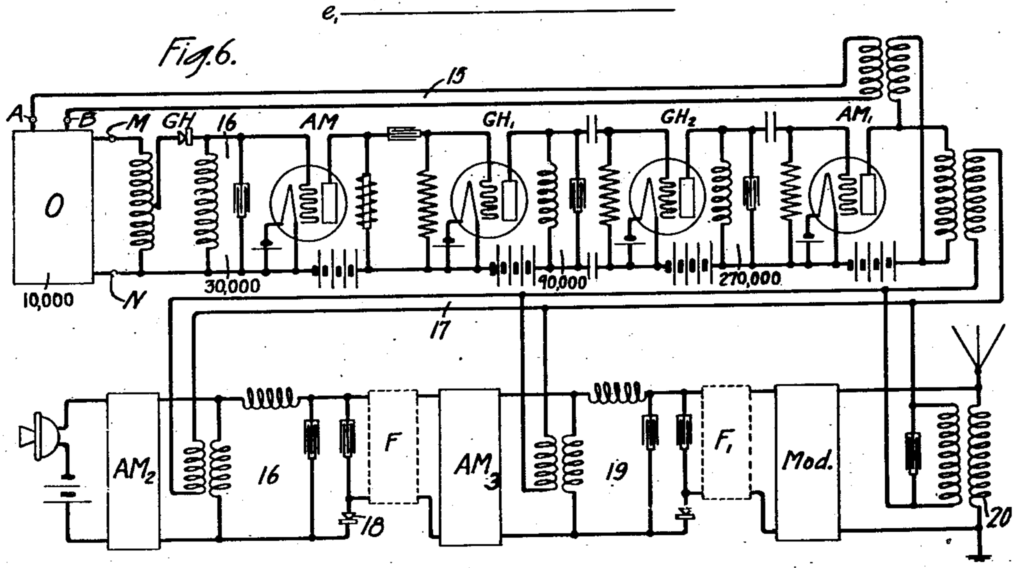


Fig. 6.



Inventor:
Raymond A. Heising.
by E. V. Griggs
Att'y.

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UNITED STATES PATENT OFFICE.

RAYMOND A. HEISING, OF MILLBURN, NEW JERSEY, ASSIGNOR TO WESTERN ELECTRIC COMPANY, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK.

MAGNETIC AMPLIFYING SYSTEM.

Application filed June 29, 1922. Serial No. 571,597.

This invention relates to magnetic amplifying systems and more particularly to regenerative connections for such amplifiers to adapt them to produce oscillations.

An object of the invention is to produce a stable oscillation source free from moving parts and from elements which rapidly deteriorate and require frequent renewal.

A more specific object is the provision of means involving the magnetic amplifier principle for converting direct current energy into alternating current energy of any given frequency.

As is well known, any amplifying device may be made to produce sustained oscillations if its output circuit be so connected to its input circuit as to feed back thereto energy of the proper amplitude, wave form, and phase. The present invention relates to feed back circuits for amplifiers of the magnetic type.

Briefly described, the magnetic amplifier consists of a core of magnetic material and two circuits each having a winding associated with the core. One of these, the controlling circuit, is traversed by direct current or varying controlling current and serves to produce in the core a magnetic flux of correspondingly varying density. As a consequence of the variations in flux density in the core, the higher frequency current traversing the other of the two circuits is subjected to a varying impedance and the energy changes produced in this higher frequency current may be much greater than those of the controlling current (see Proc. Institute of Radio Engineers, April, 1916, vol. 4, No. 2, page 104). As thus far described the effect of variations in the controlling current is to produce greater power variations in a high frequency current. If the high frequency current be rectified or otherwise demodulated it will yield a component of the frequency and wave form of the controlling current itself. It is therefore possible to utilize the magnetic amplifier to amplify control currents of any character such as speech or other signal currents.

According to the present invention high frequency currents are varied in accordance with control currents supplied to the controlling winding of a magnetic amplifier and are then rectified to produce amplified control currents. A portion of the amplified control current is then supplied through a suitable phase shifting network to the controlling winding to maintain the action. In order to maintain the average magnetization of the core at the proper density a steady field may be set up by direct current from a separate source or by the effective direct current component obtained in the rectifying action. If the latter method be used the high frequency source becomes the ultimate source of energy for the low frequency control current and for the unidirectional polarizing current. The frequency of the "control current" or, in other words, of the sustained oscillations produced, may be readily determined by properly tuning the controlling circuit of the magnetic amplifier or by associating closely therewith a properly tuned circuit.

The system just described provides for the generation of a relatively low frequency oscillation by utilizing a prime energy source which produces waves of a higher frequency. The invention comprises, further, an arrangement whereby the high frequency wave may itself be generated within the system. To accomplish this, the low frequency wave generated as explained above may be amplified and impressed on a harmonic generator and amplifier from which a higher frequency wave may be derived. As many stages of harmonic generation as desired may be used, the output of the final stage being fed back to the magnetic amplifier to constitute the high frequency source above described. The system is, accordingly, substantially a magnetic amplifier combination in which an alternating current wave of any desired frequency may be derived ultimately from continuous current sources as the prime sources of energy.

The features of the invention which are considered novel are pointed out with particularity in the appended claims. The invention itself, however, together with further objects and advantages may best be understood by reference to the following description taken in connection with the accompanying drawings in which Fig. 1 shows one modification of the invention in which the output circuit of a magnetic amplifier system is connected directly to the controlling circuit. Fig. 2 a modification of a detail of Fig. 1; Fig. 3 a modification of Fig. 1 in which a separate source of unidirectional polarizing current is provided; Fig. 4 a modification of the circuits between lines X and Y of Fig. 1 to provide for reversal of the alternating current instead of the direct current component; Fig. 5 illustrates diagrammatically the relations between the various currents and Fig. 6 illustrates a system similar to that of Fig. 1 but in which a separate source of high frequency is not required, the high frequency energy being derived from the system itself.

Referring to Fig. 1, the magnetic core 1 is shown associated with a controlling or input circuit winding 2 and divided or two-part output circuit winding 3. A source 4 supplies high frequency currents through condensers C_5 to windings 3 in parallel. The function of condensers C_5 is explained on page 109 of the I. R. E. publication previously mentioned. They prevent the induction of low frequency current from the controlling circuit in the series circuit constituted by the coils 3 which would be short-circuited except for these condensers. They are designed to have high impedance for the controlling current and low impedance for the high frequency current. The two branches of winding 3 are magnetically relater to winding 2 in opposite senses, as illustrated. It follows that when the current through winding 2 tends to set up a flux in a given direction it will be aided by one of the windings 3 and opposed by the other. There will accordingly be no effective direct induction of low frequency controlling energy from the input circuit to the circuit of source 4 and no direct induction of high frequency energy in the reverse direction. However, the rise and fall of the controlling current in winding 2, will be attended by a correspondingly varying density of magnetic flux in the limbs of the core 1 and the effective permeability of the core for the high frequency flux set up by windings 3 will be varied in like manner. When the current in winding 2 is of such intensity as to cause magnetic saturation of the limbs of the core 1 which are associated with windings 3 the core will be effectively non-magnetic for the high frequency flux and the impedance of windings 3 will become so low as to practically short circuit source 4. When the current in winding 2 is small and the core 1 is not saturated the impedance of windings 3 may be extremely high. Preferably the average controlling flux is of substantially the same order of magnitude as the high frequency flux and effects a change from substantially zero magnetization to complete saturation of the core.

The source 4 also supplies high frequency oscillations to a circuit LC which is connected in shunt to windings 3 and is tuned by means of variable capacity C so that the circuit as a whole, including the generator is tuned to resonance with the high frequency oscillations when the current in controlling winding 2 is zero. At such times the source 4 supplies large amplitude oscillations to circuit LC. When the controlling current is a maximum the windings 3 operate to substantially short circuit source 4 and the circuit LC as previously explained. Connected across a portion of inductance L is an output circuit path including a rectifier 5 of any desired type and the primary winding of an oscillation output transformer 6.

This path is directly connected to feed back energy to the input or controlling winding 2 through a network consisting of series blocking condensers C_1 and C_2, a series inductance L_1, and two bridging choke coils 7 and 8 which are of extremely high impedance for alternating current. An electromotive force tending to force unidirectional current downwardly through the primary winding of transformer 6 will cause such current to traverse the path consisting of choke coil 8, winding 2 right to left, choke coil 7 and back through L and 5. A similarly directed alternating or pulsating current will take the path consisting of blocking condenser C_2, winding 2 left to right, condenser C_1, inductance L_1 and back as before. Accordingly the pulsating current and direct current components of the output current supplied through rectifier 5 will be opposed in winding 2. The loop consisting of elements C_2, 2, C_1, L_1, the upper portion of L, 5 and primary winding of transformer 6 is tuned to the frequency of the oscillations to be generated and accordingly determines the frequency of the controlling currents.

Suppose that source 4 is supplying oscillations to windings 3 and to circuit CL in parallel therewith and that the winding 2 is in some manner supplied with controlling current of the wave form illustrated at curve *a*, Fig. 5 in which the ordinates are intended to indicate only the absolute values of the current without regard to sign since the effect on the impedance of windings 3 is independent of the direction of current. The impedance of windings 3 will accordingly vary as depicted by curve *b* of the same figure. The shunting action of windings 3 will cause the high frequency oscillations in the path LC to vary as indicated at curve *c* which represents this high frequency current. The operation of the rectifier, if it is properly poled, will accordingly yield an amplified low frequency or controlling current represented by curve *d*. If the rectifier is oppositely poled the curve will be the same except as to sign and accordingly, as in curve *a*, the ordinates of the curve can be considered as indicating only the absolute values. By reference to curve *a* it may be seen that the amplified controlling current is of the same frequency and wave form but its instants of maxima and minima do not coincide therewith, a prerequisite if the current is to be fed back to constitute the controlling current. The desired change is accomplished by supplying the amplified controlling current to winding 2 together with a properly directed unidirectional current.

Suppose that the steady unidirectional current component supplied by the rectifier 5 is as indicated by line *e* of Fig. 5, the curve *d* indicating the alternating current component if considered with reference to line *e* or the total rectified current, like curve *b*, if considered with reference to the zero axis *o*. If reversed in direction with respect to coil 2 the unidirectional current component may be represented by the graph e_1. This reversal is accomplished in the circuit of Fig. 1 by the cross-connections including choke coils 7 and 8. The net current in winding 2 is therefore the algebraic sum of the two currents represented by graphs *d* and e_1 and it will be obvious from inspection that it will have coincidence of maximum and minimum with the controlling current *a*. The initial impulse upon the input circuit C_1, 2, C_2, when source 4 is put in operation, will set up oscillatory currents of the desired frequency in this tuned input circuit. The device will accordingly supply sustained oscillations of the controlling current frequency to the work circuit connected to the secondary winding of transformer 6. On account of the amplification of the controlling current this current will build up during successive cycles until a stable value is reached as in the similar case of a vacuum tube oscillator. For the condition of steady operation, accordingly, the curves *a* and *d* would have approximately the same amplitude.

Inspection of curves *a* and *d* of Fig. 5 indicates that the necessary change in curve *d* may be alternatively accomplished by reversing the alternating, instead of the direct, current component. Circuits for accomplishing this function are shown in Fig. 4, which circuits may be substituted for those between lines X and Y of Fig. 1. It is seen that the circuits of Fig. 4 result substantially by reversing the positions of the choke coils and condensers in the corresponding circuits of Fig. 1. Since the condensers are removed from the line the direct current component can flow unchanged through winding 2. On the other hand the choke coils 13 and 14 impede the flow of the alternating component and constrain it to flow through condensers C_5 and C_6, with resulting reversal of this component.

Fig. 2 illustrates a modification in which the source 4 is inductively connected to the output circuit of the amplifier.

In Fig. 3 the circuit arrangement is altered in two respects. A separate source 9 is used to supply steady unidirectional magnetizing current to winding 2 through a choke coil 10 similar to coils 7 and 8. Blocking condensers C_3 and C_4 separate the path of this current from that of the direct current supplied by rectifier 5 and for which is provided a bridge return path consisting of a choke coil 11. The pulsating component is supplied to winding 2 through a path comprising condenser C_4, winding 2, condenser C_3 and a tuned loop C_6, L_5. The tuning of this loop substantially determines the frequency of the oscillations produced. In both of the arrangements of Figs. 1 and 3, the amplitude of the energy fed back and the resultant oscillations produced may be controlled by adjustment of the slider 12 along inductance L, thus varying the coupling.

Fig. 6 illustrates an arrangement of circuits, involving the features shown in Fig. 1, which avoids the necessity of a separate high frequency source, the high frequency current being derived from the system itself. This figure also illustrates a magentic amplifier system which makes use of the high frequency wave from this magnetic oscillator system. The block O represents a magnetic oscillator, which may be of the type shown in Fig. 1. The parts included between terminals AB and MN of Fig. 1 may be inserted in the system of Fig. 6 as indicated by corresponding letters. This magnetic oscillator derives a high frequency current from circuit 15 in a manner to be described later. It is assumed for convenience that the generated current supplied at the output terminals MN has a frequency of 10,000 cycles and that the high frequency current supplied at the input terminals AB has a frequency of 270,000 cycles. The 10,000 cycle product current from the oscillator is impressed on the harmonic producer GH which produces current which may have several harmonic frequencies, the third harmonic (triple frequency) current of which is selected by circuit 16. Harmonic producer GH is represented in the manner conventionally used for crystal rectifiers and this type of device may be used if desired. This is, however, only one of a large class of devices familiar to the art which may be used to produce harmonic frequency currents, any one of which may be here used. The 30,000 cycle harmonic current from generator GH may be amplified by the vacuum tube amplifier AM, or the equivalent, before passing through the subsequent stages of harmonic generation. Other stages of amplification may be inserted in the system where desired. The subsequent stages of harmonic generation, or frequency transformation, are accomplished by devices GH_1, GH_2, which are shown for purposes of illustration only, as vacuum tube harmonic generators. The use of vacuum tubes for this function is well known and does not require further description here. The number of stages of harmonic generation and the harmonic selected in each instance is governed by the desired frequency of the final product, 270,000 cycles in the case selected. The high frequency current from the last stage of harmonic generation is available for use in the magnetic oscillator, as by feeding it back to the oscillator by means of circuit 15, preferably after amplification by power amplifier AM_1.

It may be pointed out that in the oscillator system described the use of a separate high frequency source is avoided. Accordingly the continuous current sources associated with the amplifiers and harmonic generators constitute the prime energy sources, as compared with the separate high frequency source of Fig. 1. The oscillator therefore closely simulates the function of vacuum tube and other types of oscillators which comprise means for converting direct current energy into alternating current energy of a desired frequency. It is further pointed out that applicant's oscillator, in effect, is a double frequency oscillator since in the case given either 10,000 or 270,000 cycle current may be derived therefrom.

The lower portion of Fig. 6 shows a circuit for utilizing the current from the magnetic oscillator. The circuit constitutes a means for radio transmission of a signal modulated high frequency wave. Since the wave from the magnetic oscillator provides the carrier wave, the higher of the two frequencies associated with the oscillator is used.

The transmission system comprises means for using a magnetic amplifier for amplifying the signal frequency wave by as many stages as desired and a magnetic modulator for modulating the high frequency wave from the oscillator in accordance with the amplified signaling wave. The circuits comprising the magnetic amplifier AM_2, the tuned circuit 16, the high frequency source 17 and rectifier 18, are identically the same as the circuits comprising the low frequency amplifier combination illustrated in the system of Figs. 1 and 2, comprising the core 1, controlling winding 2, and controlled winding 3 of Fig. 1, and the tuned circuit and means for impressing the high frequency wave shown in Fig. 2. For the last two elements the corresponding means of Fig. 1 may be substituted. The signal frequency component of the rectified current is selected by filter F which may be of the type described on pages 310 to 312, inclusive, of a paper by Colpitts and Blackwell, Carrier current telephony and telegraphy, vol. 40, No. 4, Journal of the A. I. E. E., or similar selecting means, and impressed on the succeeding magnetic amplifier AM_3, which may be identical in all respects to amplifier AM_2. This stage of amplification is followed by rectification and selection by elements 19 and F_1. As many stages of amplification may be used as desired, the circuit 17 furnishing the high frequency energy source for each stage. The signal frequency energy increases with each stage of amplification. The final product of the amplifying operation is used in magnetic modulator MOD to modulate the high frequency energy. This may be accomplished by any of the conventional magnetic modulators, or specifically, by the circuits of Fig. 1 omitting the rectifier and feed back, or in other words, by circuits similar to those shown associated with amplifiers AM_2 or AM_3, omitting the rectifier. The modulated high frequency wave may be radiated from antenna 20, but may equally well be impressed on a transmission line.

Throughout the description the oscillations of source 4 have been described as of high frequency and the controlling or generated oscillations as of low frequencies. These terms are not used to define absolute frequencies or the orders of the frequencies but merely to express the general relation between them.

It will be readily appreciated that this invention provides oscillation sources having very simple circuits, free from readily destructible elements, and capable of construction in a relatively large range of sizes.

Although the invention has been illustrated as embodied in certain specific arrangements it is to be understood that it is not limited to these but only by the scope of the appended claims.

What is claimed is:

1. In combination, a magnetic core, a high-frequency winding on said core, a source of high-frequency current for said winding, means for controlling said high frequency current in accordance with a low frequency current comprising a second winding on said core, and means for deriving and feeding back energy in the form of the energy of a low-frequency current from said high frequency circuit to said second winding, said last means including tuning elements for rendering the feed-back path to said second winding resonant at said low frequency.

2. An oscillator comprising a magnetic amplifier having a high frequency controlled circuit and a low frequency controlling circuit, means for feeding back from said high frequency circuit to said low frequency cir-

cuit energy of the same phase and wave form as that supplied to said controlling circuit, and a utilization circuit for deriving low frequency current from said magnetic amplifier.

3. A magnetic oscillator comprising in combination, a high frequency tuned circuit, a controlled winding, a high frequency source connected to said circuit, a controlling winding, magnetic coupling means for said windings whereby the impedance of said controlled winding may be varied in accordance with variations of current in said controlling winding but without energy transfer therebetween, and a circuit coupling said high frequency circuit with said controlling winding, said coupling circuit containing a detecting means, and means for tuning the coupling circuit to a desired oscillation frequency.

4. A magnetic oscillator comprising in combination, a high frequency circuit including a controlled winding, a low frequency circuit including a controlling winding, magnetic means for controlling the flow of current in said high frequency circuit in accordance with current in the low frequency circuit, and means coupling the high frequency circuit to the low frequency circuit, said low frequency circuit including a detecting means, tuning means, and means for reversing the direct current component of the detected current wave, said reversing means comprising blocking condensers on either side of the low frequency circuit, and a pair of highly inductive, conductive bridging circuits connecting points on opposite sides of the circuit between the blocking condensers and the detecting means with corresponding points between the blocking condensers and the controlling winding, each bridging circuit being arranged to connect points on opposite sides of the low frequency circuit.

5. A magnetic oscillator comprising in combination, a high frequency circuit including a controlled winding, a controlling winding, a magnetic circuit common to said windings and arranged in such manner as to prevent energy transfer therebetween but to permit the flow of current in the controlled winding to be varied in accordance with the variations of current in the controlling winding, a circuit coupling said high frequency circuit and said controlling winding and including a detecting means, and a circuit connected to said coupling circuit and to said high frequency circuit and including a harmonic generator and an amplifier for producing energy in said high frequency circuit.

6. In combination, a circuit, a second circuit, a device coupling said circuits for producing in the second circuit a current the frequency of which is a harmonic of that in the first mentioned circuit; and a magnetic amplifier comprising a controlled winding connected in shunt to said second circuit, and a circuit in shunt to a portion of said second circuit and including detecting means, a controlling winding, and tuning means; and means for impressing a portion of the current detected by said detecting means on the first mentioned circuit.

7. A system for producing oscillations of desired frequency comprising a circuit tuned to said frequency, a control winding energized therefrom, a load circuit, a source of relatively high-frequency energy, a high-frequency circuit connected to said source and including a winding, a magnetic circuit interlinking said two windings whereby variations in said first circuit produce variations in amplitude in the high-frequency current flowing in said high-frequency circuit, and means for deriving from said high-frequency circuit current of the said desired frequency and for applying said variations in part to said load circuit and in part to said control winding.

8. A magnetic amplifier comprising a controlling and a controlled winding interlinked by a magnetic circuit, a high-frequency circuit having associated therewith a source of high-frequency energy, said circuit being connected to the controlled winding, a circuit for supplying magnetizing direct current and controlling alternating current of relatively low frequency to said controlling winding, whereby the high-frequency energy in said high-frequency circuit is varied under control of the current in said controlling winding, and a coupling circuit for deriving both said magnetizing current energy and said controlling current energy from said high-frequency circuit, said coupling circuit containing connections for applying the magnetizing and controlling current components to said controlling winding in proper phase to sustain the action of producing said magnetizing and controlling components from said high-frequency circuit.

9. A system for converting the energy of direct current into alternating current energy comprising a magnetic amplifier system as defined in claim 8, in which said source of high-frequency energy comprises a harmonic generator for converting the energy of said direct current into high-frequency energy, said harmonic generator having an input circuit supplied by said controlling alternating current and an output circuit associated with said high-frequency circuit for supplying high-frequency energy thereto.

In witness whereof, I hereunto subscribe my name this 27th day of June A. D., 1922.

RAYMOND A. HEISING.