

Nov. 4, 1952

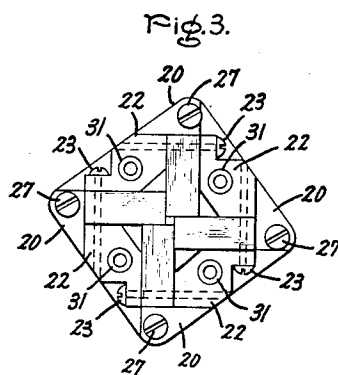
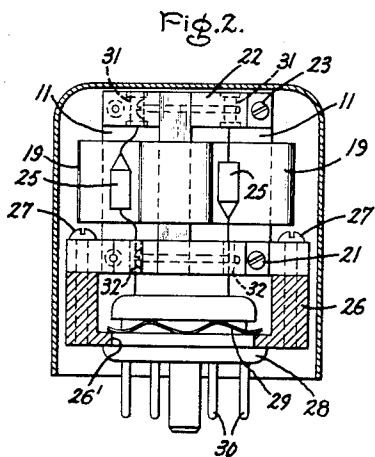
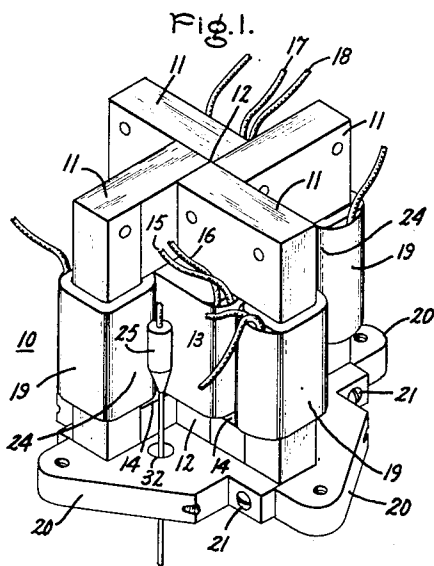
H. M. OGLE

2,617,090

SATURABLE REACTOR APPARATUS

Filed June 17, 1950

2 SHEETS—SHEET 1



Inventor:
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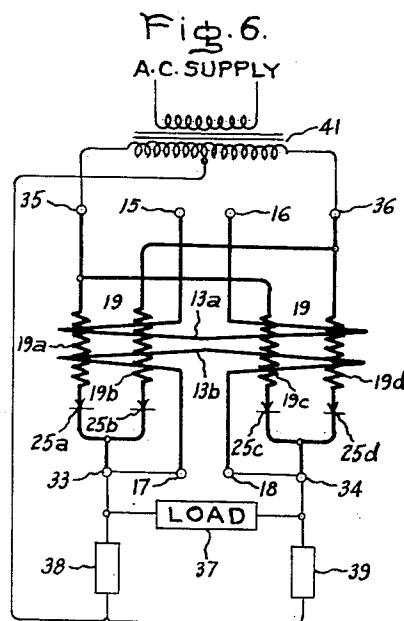
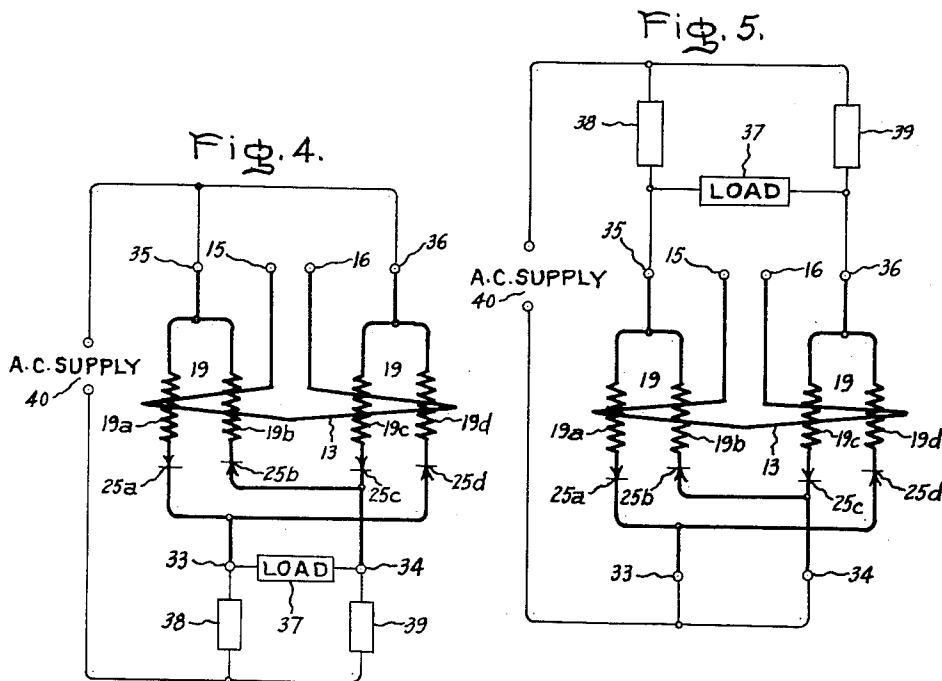
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SATURABLE REACTOR APPARATUS

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2 SHEETS—SHEET 2



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UNITED STATES PATENT OFFICE

2,617,090

SATURABLE REACTOR APPARATUS

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New York

Application June 17, 1950, Serial No. 168,679

6 Claims. (Cl. 323—89)

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My invention relates to electrical induction apparatus and, more particularly, to apparatus employing saturable core reactors for controlling the reactance of an alternating current circuit.

Saturable core reactors having a plurality of alternating current reactance windings and one or more magnetic saturation control windings are now used extensively as the electric current controlling elements in suitable alternating current circuits. Many such saturable reactor circuits perform a current or voltage amplifying function and have become known as "magnetic amplifiers."

One popular type of saturable reactor control circuits, commonly referred to as "push-pull magnetic amplifiers," employ one or two saturable reactors having, in total, four alternating current reactance windings and one or more control windings for varying the level of magnetization in the cores in accordance with an external electric signal. In such push-pull magnetic amplifiers, suitable current rectifying means are included in circuit relation with the reactance windings and a load device such that a respective two of the four reactance windings conduct current during source voltage alternations of one polarity, and the other two reactance windings are conductive during source voltage alternations of opposite polarity. The load device may appropriately be connected to be energized by either the sum or the difference of the prevailing currents.

It has heretofore been the usual practice to employ a pair of saturable reactors each having three-legged cores for such push-pull magnetic amplifier circuits; the reactance windings being wound on respective outer legs and the control windings being wound on the central leg of each core. In an arrangement of this type, there is, of course, no magnetic interaction of the flux in one reactor upon that of the other reactor, and the separate control windings of each reactor must be interconnected to respond to the same external signal.

Accordingly, an object of my present invention is to provide new and improved saturable reactor apparatus suitable for use with alternating current circuits employing a plurality of reactance windings, and particularly adapted for use with push-pull magnetic amplifier circuits.

An additional object of my invention is to provide a new and improved structural arrangement for a saturable reactor whereby two or more three-legged saturable reactor cores may be combined into a unified core structure such that im-

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proved performance may be derived from the magnetic flux interaction of the normally separate cores.

Another object of my invention is to provide a saturable reactor core structure whereby current flowing through an even plurality of at least four reactance windings of a reactor may be simultaneously and symmetrically controlled by a single saturation control winding without resorting to the expedient of "multiple-layer windings."

A further object of my invention is to provide a saturable reactor apparatus for push-pull magnetic amplifier circuits in which a convenient location is provided for current rectifying elements associated with the saturable reactor in order that a simple, compact, and rugged overall structure may be achieved.

A still further object of my invention is to provide a core arrangement for saturable reactors in push-pull magnetic amplifier circuits which is particularly well adapted for a self contained or "packaged" construction.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself, however, together with further objects and advantages thereof can best be understood by reference to the following description taken in connection with the accompanying drawing in which Fig. 1 is a perspective view of the core structure and windings of a saturable reactor in accord with my invention, Fig. 2 is a side sectional view of saturable reactor apparatus showing the saturable reactor of Fig. 1 assembled in a self-contained or packaged form, Fig. 3 is a top plan view of the apparatus of Fig. 2 with the cover removed and the various reactance and control windings omitted, and Figs. 4, 5, and 6 are schematic diagrams of magnetic amplifier circuits employing my invention illustrating the versatility of my invention as well as preferred internal connections of the reactor apparatus of Fig. 2 when in packaged form.

In general, my invention comprises an even plurality of at least four peripherally closed magnetic core elements which are preferably rectangular in shape, and which are arranged in radial fashion such that one side portion or leg of each core element is contiguous a corresponding leg of each other core element to form a central unified hub of a resulting "star-shaped" core arrangement. Each of a corresponding plurality of reactance windings are positioned on a respective outer leg of each core element, and one

or more saturation control windings surround this central hub. A very convenient accommodation for current rectifying elements associated with the reactance windings is provided by the recesses between the windings of adjacent extending core elements which result from this arrangement. Consequently, a sturdy and compact saturable reactor apparatus may be achieved when the components are assembled into a self-contained package.

Referring to Fig. 1, I have shown one embodiment of my invention as comprising a saturable reactor 10 having four peripherally closed centrally apertured core elements 11 which are preferably quadrilateral and in the form of a hollow rectangle. The core elements 11 may conveniently be formed of U or L-shaped laminations stacked in a manner well known in the art. The core elements 11 are arranged in radially extending fashion with one side or leg of each core element alongside a corresponding side or leg of each other core element so that an internal unified central core hub 12 is formed by the four mutually adjacent legs of the core elements.

At least one, and usually two or more magnetic saturation level control windings designated generally by numeral 13 are arranged to encircle the unified hub 12 of the core elements 11. The turns of these control windings 13 pass through central apertures 14 provided in each of the core elements 11 in order to enable this encirclement of the central hub 12. One control winding, designated by the extending leads 15 and 16 functions as the signal receiving winding, while a second control winding, designated by the leads 17 and 18 may conveniently function as a feed back winding which may be connected to provide suitable regeneration or degeneration as a result of energy coupled back from a suitable load device (not shown). Additional control windings (not shown), such as a magnetic biasing winding to adjust the magnetic operating level of the reactor and means for mixing additional signals may, of course, also be included.

Four alternating current reactance windings 19 of the reactor are arranged on the respective outer sides or legs of the four core elements 11, each passing through a corresponding aperture 14 of its associated core element alongside the central control windings 13.

A saturable reactor is thus provided in which the control windings 13 are arranged on a separate hub or leg 12 of the reactor 10 and function to control the flux in symmetrical magnetic paths to respective ones of a plurality of alternating current reactance windings 19. In addition, the central hub 12 of the reactor constitutes a region of flux interaction for the magnetic flux produced by the respective currents flowing in the alternating current reactance windings 19. As will be more fully explained in connection with preferred circuit arrangements for the saturable reactor to be described below, this region of interaction functions when connected in push-pull circuits to produce a cancellation of reactance winding flux in the central unified hub 12 of the reactor so that there is negligible alternating current induced in the control windings 13.

The core elements 11 are preferably supported and firmly held together in this "star-shaped" arrangement by such means as four somewhat triangular non-magnetic base members 20 which are secured together and to the core elements by such means as screws 21 which pass through

suitable holes provided in the laminations of the core elements 11 and are threaded into adjoining ones of the base members 20. Similar upper non-magnetic supporting members 22, best seen in Figs. 2 and 3, are wedged between the upper side portions of adjacent core elements 11 and are fastened together by such means as screws 23 in order to rigidly support the core elements 11 at the top.

It will be appreciated that with the above-described star-shaped arrangement of the core elements and associated windings, a wedge-shaped space 24 is provided intermediate any pair of adjoining core elements 11 and between the upper and lower supporting members. This space 24 provides a very convenient accommodation for current rectifying elements, such as selenium or germanium rectifiers 25, which are commonly associated with the alternating current reactance windings of a saturable reactor in magnetic amplifier circuits. Consequently, this core arrangement lends itself to the construction of a self-contained or packaged saturable reactor apparatus which can conveniently be used in magnetic amplifier circuitry.

Referring now to Figs. 2 and 3, I have shown such packaged saturable reactor apparatus as it might be arranged in "plug-in" form. The saturable reactor 10 of Fig. 1 is secured upon a quadrilateral box-like spacing member 26 and secured to the non-magnetic base members 20 of the reactor 10 by such means as screws 27. Terminal means are provided such as a plug-in terminal 28 inserted within a circular aperture 26' in the bottom of the spacing member 27 and securely positioned by such means as a snap ring 29. Sufficient space is provided between the top of the terminal 28 and the bottom of the saturable reactor base to accommodate the leads of the saturable reactor 10 and associated current rectifying elements 25 as they pass to connection (connections not shown) to the terminal connectors or prongs 30 of the terminal 28.

In order to provide a support for the current rectifying elements 25 as well as to provide a convenient internal connection between the alternating current reactance windings 19 and associated current rectifying elements 25, four hollow rivets 31 are extended through the center of the upper supporting members 22. One lead of each rectifying element 25 as well as one lead of an associated reactance winding 19 is inserted into the hollow center of each rivet 31. Suitable interconnection and support for these leads is accomplished by dropping molten solder into the center of the rivets 31. The other leads of the rectifying elements 25, the control windings 13, and reactance windings 19 are passed through suitable holes 32 in the base members 20 of the reactor 10 and are connected (connections not shown) to suitable prongs 30 of the plug-in terminal 28.

The preferred internal connections for the saturable reactor apparatus shown in Fig. 2 as well as a fuller understanding of the magnetic relationship between the various windings of the reactor, can best be obtained by reference to the schematic diagrams of Figs. 4, 5 and 6. Referring specifically to Figs. 4 and 5, I have shown the saturable reactor apparatus of Figs. 1, 2 and 3 connected to serve as the controlling element in either a strict "magnetic amplifier," as in Fig. 4, or as a "magnetic amplifying inverter," as in Fig. 5. In both these Figs. 4 and 5, I have shown only one control winding although it is evident that

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additional control windings may be employed if desired. With one control winding only six terminals are necessary as shown. If, for example, two control windings are used, eight terminals would, of course, be needed.

In this preferred arrangement of Figs. 4 and 5, one pair of reactance windings, such as windings 19a and 19b, are connected from respective "output" terminals 33 and 34 through separate reversely poled rectifiers 25a and 25b to a common source voltage "input" terminal 35. The other pair of reactance windings 19c and 19d are connected in a similar manner through reversely poled rectifiers 25c and 25d from the output terminals 33 and 34 to a second source voltage input terminal 36. However, each pair of reactance windings 19 are connected or wound in reversed flux relation with respect to the common control winding 13 in order that the saturating effect of the core elements 11 caused by the control winding 13 in one pair of the reactance windings, such as windings 19a and 19b, is in a direction opposite to the effect produced upon the other pair of reactance windings 19c and 19d.

In the external circuit of Fig. 4, shown in light lines, a load device 37 is connected between the output terminals 33 and 34, and a pair of substantially identical impedances 38 and 39 are respectively connected in parallel from each output terminal 33 and 34 to one side of an alternating voltage source 40 whose other side is connected to both input terminals 35 and 36. This circuit of Fig. 4 operates, with a positive signal on the control winding 13, to hasten the saturation of one pair of reactance windings, such as windings 19a and 19b, while it retards the saturation of the other pair of reactance windings 19c and 19d. Due to the reversely poled rectifiers 25 in series with each reactance winding 19 and to the crossed connection to the output terminals 33 and 34, it will be seen that voltage difference between the output terminals 33 and 34 is developed by unequal currents flowing through the impedances 38 and 39, and that this voltage difference will always be in the same direction for a given polarity of control winding signal. Consequently, the current through the load device 37 follows the variations in the signal voltage supplied to the control windings 13.

Referring now to Fig. 5, I have shown the identical saturable reactor apparatus of Fig. 4 as it might be connected in a different external circuit to form an amplifying magnetic inverter instead of a strict magnetic amplifier as in Fig. 4. In this circuit, the load 37 is connected between the terminals 35 and 36 that constituted the source voltage "input" terminals of the magnetic amplifier of Fig. 4. The pair of substantially identical impedances 38 and 39 are connected in parallel from each of these terminals 35 and 36 to one side of the alternating voltage source 40 whose other side is connected to both of the terminals 33 and 34 which constituted the "output" terminals of Fig. 4. When connected in this manner, the current in the load device 37, with a signal of given polarity supplied to the control windings 13, is dependent upon the difference in voltage at the terminals 35 and 36 produced by unequal currents flowing in the impedances 38 and 39 as a result of the oppositely directed saturation effect on each pair of reactance windings 19. However, the preponderance of voltage shifts from one of the terminals 35 and 36 to the other thereof together with the alternations in polarity of the source voltage. Consequently, an

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alternating current flows through load device 37 when a unidirectional signal voltage is supplied to control winding 13, and the magnitude and sense of this alternating current depends upon the amplitude and polarity of the unidirectional voltage signal. Conversely, with an alternating current signal derived from an alternating voltage source 40 supplied to control winding 13, a unidirectional current flows through load 37 whose polarity is dependent upon the phase of this alternating current signal relative to the phase of the alternating voltage source 40; and whose amplitude varies in accordance with the magnitude of the alternating current signal.

The above circuits shown in Figs. 4 and 5, form the subject matter and are fully described and claimed in a copending application Serial Number 169,847 of Raymond E. Morgan entitled "Electric Control Circuits Using Saturable Reactors" filed concurrently with the present application and assigned to the same assignee as the present invention.

Referring to Fig. 6, I have shown an alternative manner of connecting the saturable reactor apparatus of Figs. 2 and 3. In this circuit, the reactance windings 19 of each pair are connected to opposite source voltage input terminals 35 and 36 and the series connected current rectifying elements 25 are all similarly poled; one pair of reactance windings 19a and 19b being connected through current rectifying elements 25a and 25b to the same output terminal 33, and the other pair of reactance windings 19c and 19d being connected through the other pair of similarly poled rectifiers 25c and 25d to the other output terminal 34. In this circuit, I have also shown two control windings 13a and 13b brought out to appropriate terminals. The saturable reactor apparatus of Fig. 6 is, therefore, identical with that of Figs. 4 and 5 with the exception that the rectifying elements 25 are similarly poled and the connections to the respective input and output terminals reversed. One pair of reactance windings such as windings 19a and 19b are reversely wound with respect to the other pair of reactance windings 19c and 19d in order that a signal supplied to the control winding 13a will have oppositely directed saturation effect upon each pair of reactance windings. The magnetic interaction of the flux in the core is, therefore, identical with that of the circuit shown in Figs. 4 and 5. The external circuit of Fig. 6 constitutes a conventional push-pull amplifier circuit in which a center-tapped transformer 41 is connected to supply current to the input terminals 35 and 36, and a pair of substantially identical impedances 38 and 39 are respectively connected between the center tap of the transformer and each output terminal 33 and 34 of the saturable reactor apparatus. A suitable load device 37 is connected between the output terminals 33 and 34 and the feed back control winding 13b is connected across this load device 37. The detailed operation of this circuit is well known to those skilled in the art and need not be described here.

It will be appreciated that if the reactance windings 19a and 19b and the reactance windings 19c and 19d were wound on the cores of separate reactors, there would be no interaction between the flux produced in one reactor by the currents flowing through windings 19a and 19b and the flux produced in the other reactor by currents flowing through the other pair of reactance windings 19c and 19d. Since current would flow

in an opposite direction in each reactance winding of each of these separate reactors during alternate half cycles of source voltage, an alternating current would normally be induced in the separate control windings associated with these separate reactors by the reversal of flux in the core. However, by combining the two reactors into a single unified structure in accordance with my invention, there is a cancellation of oppositely directed magnetic flux produced in the central unified hub or leg 12 of my saturable reactor 10 by simultaneous currents flowing in the reversely connected pairs of reactance windings 19a, 19b and 19c, 19d during both alternations of source voltage. For example, when connected in the push-pull circuits of Figs. 4, 5 and 6, the flux produced in hub 12 by the core element associated with reactance winding 19a is cancelled by the flux produced in hub 12 by the core element of reactance winding 19c during source voltage alternations of one given polarity, both reactance windings 19a and 19c being conductive during the same half cycle of source voltage. A similar cancellation of flux in the central hub 12 is produced by the simultaneous currents in reversely connected reactance windings 19b and 19d during source voltage alternations of opposite polarity. As a result, there is little or no alternating voltage induced in the control windings 13 which surround this central hub 12.

It will thus be seen that I have provided a compact and sturdy saturable reactor apparatus which is very well adapted for use in push-pull magnetic amplifier circuits. The "star-shaped" arrangement of the core not only provides improved performance due to the magnetic interaction of the flux produced by the respective alternating current windings on the outer legs of the various core members, but also enables a convenient location for the current rectifying elements associated with these reactance windings. In addition, the entire arrangement provides a compact self-contained saturable reactor apparatus which can be adapted to many different magnetic amplifier circuits.

It will be understood that although I have shown particular embodiments of my invention, many other modifications will occur to those skilled in the art. It is evident, that this same star-shaped core structure may be employed whenever it is desired to control the current through four or more reactance windings by the same electric signal. When employed in three-phase push-pull alternating current circuits, for example, six core elements, may be radially arranged into a unified reactor in accord with my above-described invention. I intend, therefore, by the appended claims to cover all such modifications as fall within the true scope and spirit of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. Saturable reactor apparatus comprising an even number of at least four similar peripherally closed centrally apertured magnetically saturable core elements extending radially with one side portion of each element alongside a corresponding side portion of each other element to form a central unified hub, at least one magnetic saturation control winding passing through the central aperture of each core element and encircling said hub, a separate alternating current reactance winding encircling an opposite side portion of each core element, and a corresponding number of current rectifying elements located

in a space intermediate the windings associated with adjoining core elements, each current rectifying element being connected to an adjacent one of said reactance windings and being polarized relative to the other rectifiers to enable simultaneous conduction through said rectifiers in respective pairs of reactance windings, each simultaneously conducting reactance winding of each pair being arranged on its core to produce oppositely directed flux in said hub relative to the other simultaneously conducting winding thereof.

2. Saturable reactor apparatus comprising a plurality of terminal connectors, an even number of at least four quadrilateral centrally apertured magnetically saturable core elements extending radially with one side portion of each element alongside a corresponding side portion of each other element to form a central unified hub in a star-shaped core arrangement, a magnetic saturation control winding passing through the central aperture of each core element to encircle said hub and connected across one pair of said terminal connectors, a separate alternating current reactance winding encircling an opposite side portion of each core element, and a corresponding number of current rectifying elements each located in a space intermediate the windings associated with adjoining core elements, each of said reactance windings being connected in series with an adjacent associated current rectifying element between preselected other ones of said terminal connectors said rectifying elements being relatively polarized to enable simultaneous conduction through said rectifiers in respective pairs of reactance windings, each simultaneously conducting reactance winding of each pair being arranged on its core to produce oppositely directed flux in said hub relative to the other simultaneously conducting winding thereof.

3. Saturable reactor apparatus adapted for use with push-pull magnetic amplifier circuits comprising four similar rectangular magnetically saturable core elements each having a central aperture and arranged in radial fashion with one side portion of each element alongside a corresponding side portion of each other element to form a central hub within a star-shaped unified core structure, at least one magnetic saturation control winding passing through the central aperture of each core element and encircling said hub, four alternating current reactance windings each encircling an opposite side portion of a respective one of said core elements, and four current rectifiers each located in a space intermediate the windings associated with adjoining core elements, each current rectifier being connected to an adjacent one of said reactance windings and being polarized relative to the other rectifiers to enable simultaneous conduction in respective pairs of reactance windings upon the application of an alternating voltage across said reactance windings through said rectifiers, and the reactance windings of each pair of simultaneously conducting windings being arranged on their respective cores to produce a mutual flux opposition in said hub.

4. Saturable reactor apparatus comprising terminal means having three pairs of terminal connectors, four similar quadrilateral centrally apertured magnetically saturable core elements extending radially with one side portion of each core element alongside a corresponding side portion of each other core element to form a cen-

trol unified hub within a star-shaped core structure, a magnetic saturation control winding passing through the central aperture of each core element to encircle said hub and connected across a first pair of said terminal connectors, four alternating current reactance windings each encircling an outer side portion of a respective one of said core elements, and four current rectifying elements each located in a space between the reactance windings of adjoining core elements, each reactance winding being connected in series with a respective one of said current rectifying elements from preselected ones of a second pair of said terminal connectors to preselected ones of the third pair of said terminal connectors said rectifying elements being relatively polarized to enable simultaneous conduction in respective pairs of the four reactance windings when alternating voltages are applied between said second and third pairs of terminal connectors, and each reactance winding of each simultaneously conducting pair being arranged on its core to produce flux in said hub opposing the flux produced therein by the other.

5. A saturable reactor apparatus comprising a pair of input terminals and a pair of signal receiving terminals, four rectangular centrally apertured magnetically saturable core elements extending radially with one side portion thereof alongside a corresponding side portion of each other core element to form a central inner unified hub in a star-shaped core arrangement, a magnetic saturation control winding connected across said signal receiving terminal and passing through the central aperture of each core element to encircle said hub, a separate alternating current reactance winding encircling the outer side portion of each core element and four current rectifiers each located in a space provided intermediate the windings associated, with adjoining core elements, one pair of said reactance windings being connected in series with reversely poled ones of said rectifiers from the same one of said input terminals to respective ones of said output terminals, and the other pair of said reactance windings being connected

in series with reversely poled other ones of said current rectifiers from the other one of said input terminals to respective ones of said output terminals.

6. A saturable reactor apparatus comprising a pair of input terminals, a pair of output terminals and a pair of signal receiving terminals, four rectangular centrally apertured magnetically saturable core elements extending in radial fashion with one side portion thereof alongside a corresponding side portion of each other core element to form a central inner unified hub in a star-shaped core arrangement, a magnetic saturation control winding connected across said signal receiving terminal and passing through the central aperture of each core element to encircle said hub, a separate alternating current reactance winding encircling the outer side portion of each core element, and four current rectifiers each located in a space intermediate the windings associated with adjoining core elements, one pair of said reactance windings being connected in series with similarly poled ones of said rectifiers from the same one of said input terminals to respective ones of said output terminals, and the other pair of said reactance windings being connected in series with similarly poled other ones of said current rectifiers from the other one of said input terminals to respective ones of said output terminals.

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