

Jan. 22, 1957

W. F. SCHMIDT, JR.
MULTI BRANCH MAGNETIC AMPLIFIER WITH BENEFICIALLY
INTERRELATED MAGNETIC PATH

2,778,987

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2 Sheets-Sheet 1

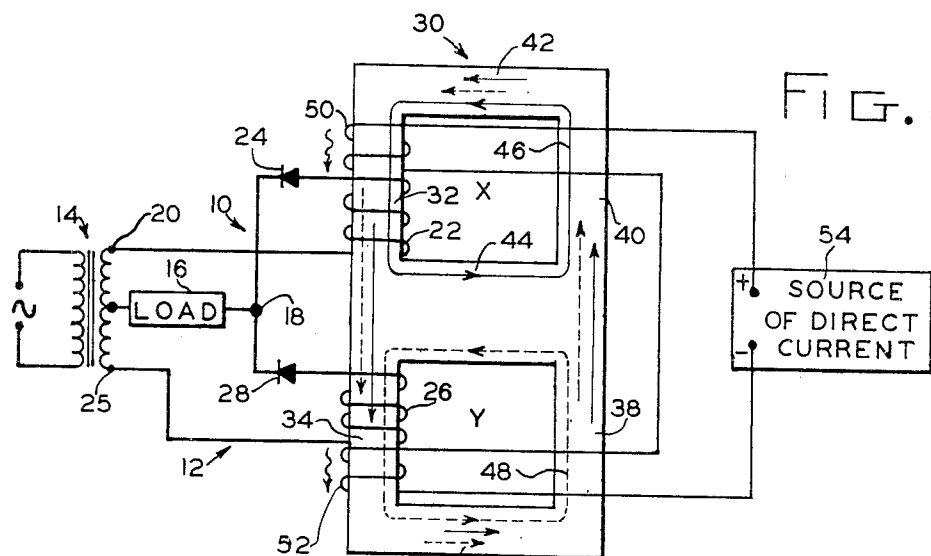


FIG. 1

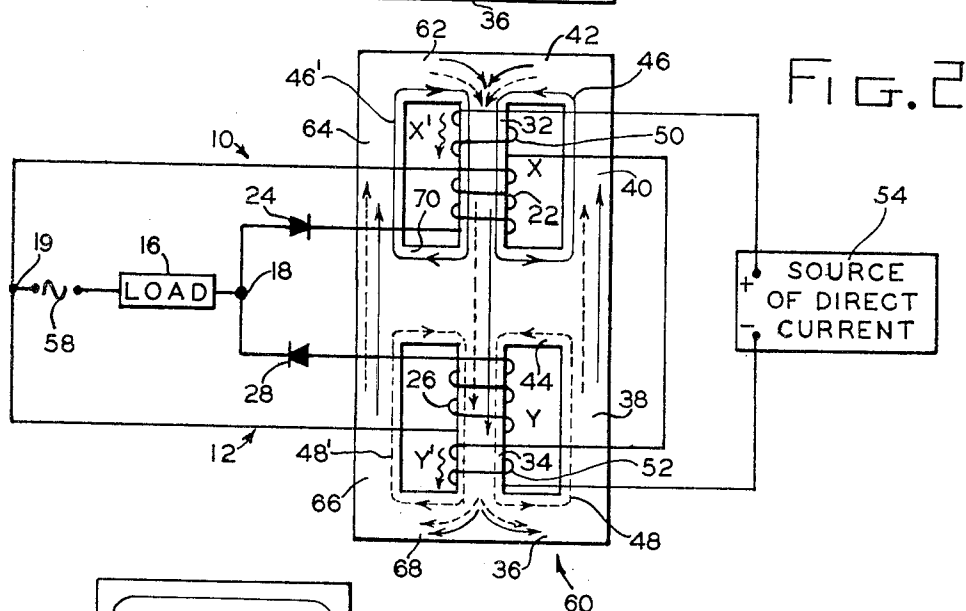


FIG. 2

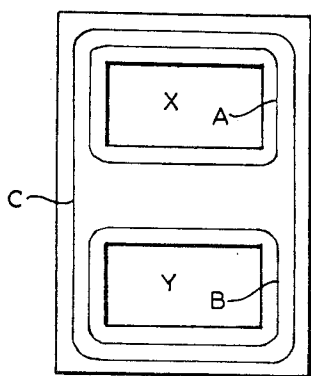


FIG. 4

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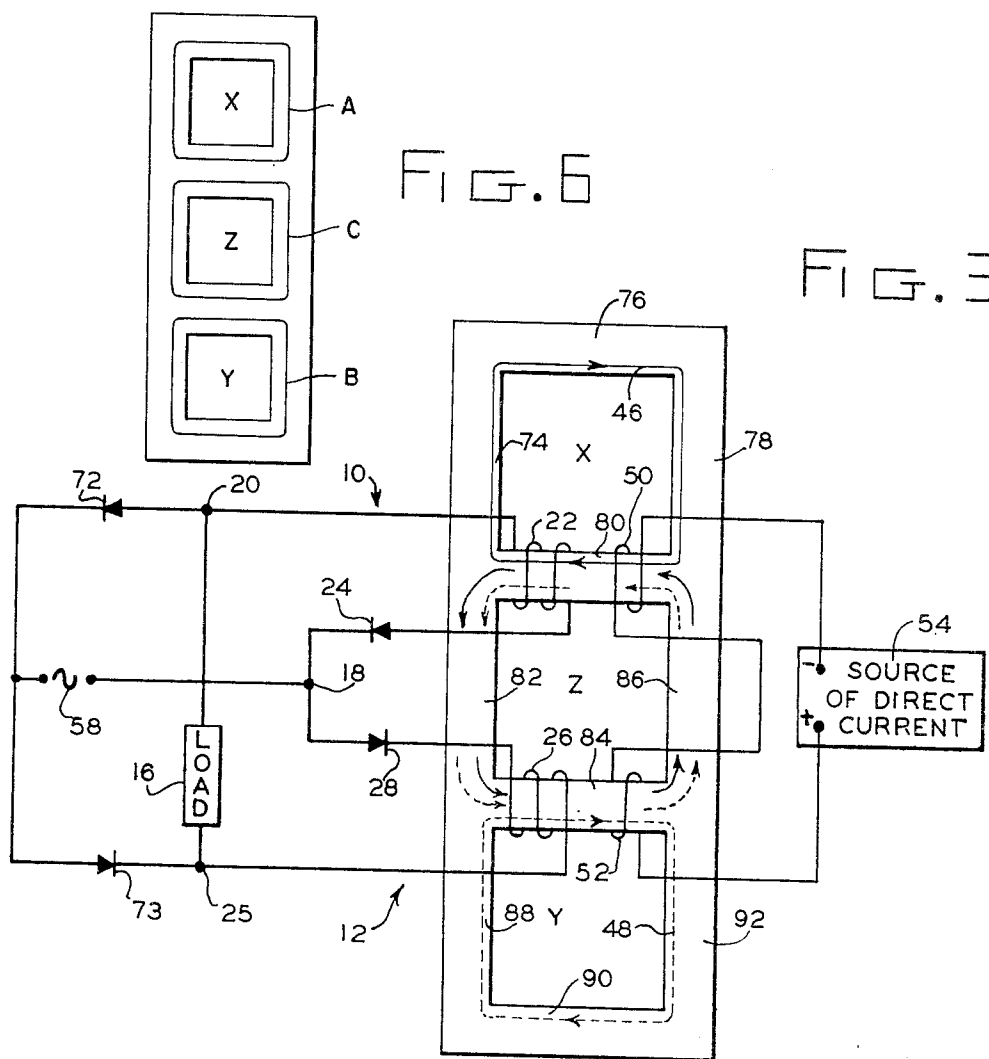
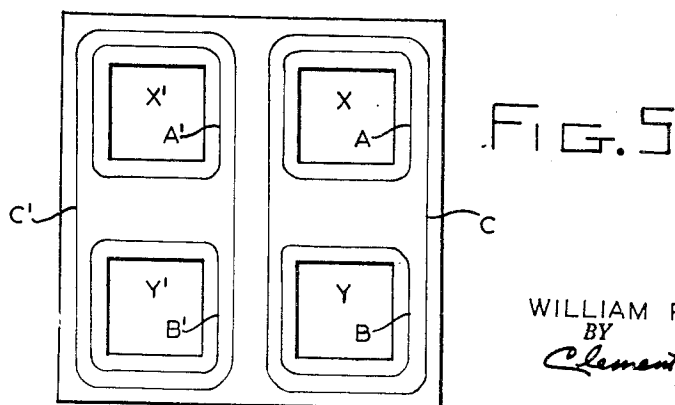
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MULTIBRANCH MAGNETIC AMPLIFIER WITH BENEFICIALLY INTERRELATED MAGNETIC PATH

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Application April 19, 1954, Serial No. 423,957

12 Claims. (Cl. 323—89)

This invention relates to power transmission and more particularly to improvements in self-saturating reactor circuits.

The term "self-saturating magnetic amplifier" has an accepted meaning in the art and refers to a circuit in which the reactance or output winding of a saturable-core reactor is always in series with a switching device having cyclic active and inactive periods, the device being conductive during the active periods and less conductive or nonconductive during the inactive periods, for example, a half-wave rectifier, which switching device neglecting leakage if any, allows periodic, unidirectional, current pulses to flow in the reactance winding during the conductive or active periods of the switching device thereby resulting in the reactor having direct current premagnetization during the inactive periods of the switching device and to "fire" or go into magnetic saturation during the active periods of the switching device. Magnetic saturation resulting from direct current premagnetization obtained as a result of intermittent, unidirectional, current pulses passing through the reactance winding is known as self-saturation. In the ideal and otherwise uninfluenced circuit, this premagnetization is the point of residual magnetism of one polarity. Hereinafter, current flowing through the reactance winding in the direction which provides or aids the premagnetization will be referred to as saturating current, and the direction of such flow shall be referred to as the saturating direction. Likewise M. M. F.'s and resulting fluxes which provide or aid the premagnetization shall be referred to as saturating M. M. F.'s and fluxes and as being in the saturating direction. Thus current flowing through the winding and the series switching device, e. g., half-wave rectifier, in the conductive direction of the device during its active period is referred to as saturating current and the flux it creates at that time is in the saturating direction and is conveniently referred to as saturating flux. On the other hand, current which flows through the reactance winding in a direction to oppose the premagnetization will be referred to as desaturating current; and the direction of its flow, the desaturating direction. Also, M. M. F.'s and fluxes which oppose premagnetization shall be referred to as desaturating M. M. F.'s and fluxes and as being in the desaturating direction.

The angle or point during the active periods of the switching device at which a self-saturating reactor fires, is dependent on the premagnetization level during the inactive period. The higher the premagnetization, the earlier the firing point and the longer the load current conduction period during the active period of the switching device.

If the switching device is a rectifier subject to leakage in its nonconducting direction, such leakage produces desaturating M. M. F.'s which lower the premagnetization and cause the reactor to fire at a later time during the active period of the rectifier (conductive half cycle), resulting in a lower quiescent output for the reactor. The premagnetization may be raised or lowered by saturating

M. M. F.'s or desaturating M. M. F.'s supplied by current through a control winding on the reactor core. It is known to use alternating current or direct current in such control windings.

The circuit consisting of only one load winding in series with a switching device such as a half-wave rectifier results in a "half-wave" magnetic amplifier which is not practical for many purposes. Because of this, it has been the practice to operate two half-wave sections on opposite half cycles of a cyclic supply voltage, which sections may be connected to supply either unidirectional or alternating current to a load.

There are three basic conventional core and winding relationships which are used to operate two "half-wave" magnetic amplifier sections with unidirectional control current. One uses a pair of separate toroidal or rectangular single window type cores; the second uses the commonly known three-legged core (two windows); and the third employs a four-legged core (three windows).

In the arrangement employing the two separate single window cores, each core carries one of the load windings and a direct current control winding. If the cores are close together one control winding may embrace both cores. In both cases the arrangement is such that either alternating current fluxes or induced alternating current voltages cancel out with respect to the control winding arrangement.

The two load windings in the second basic arrangement are wound respectively on the outer legs of the three-legged core in such manner that the saturation fluxes of both windings pass through the center leg in the same direction but on opposite half cycles. The direct current control winding may be wound on the center leg or may be split and partly wound on each of the outer legs.

In the third basic arrangement employing the common four-legged core the two load windings are wound on the two inner legs, one winding on each leg, and in such direction that the respective saturation fluxes of the two windings are oppositely related in the center cross members connecting the two inner legs. A direct current control winding encompasses both inner legs or may be split partly on one inner leg and partly on the other inner leg.

It should be borne in mind that in all of these cases the two load windings are respectively in two different reactor branches which are conductive on alternate half cycles of an applied supply voltage. Thus, the saturation fluxes of the respective windings occur on alternate half cycles and not on the same half cycle.

In the first case, that of the completely separated cores, there is no appreciable magnetic field interaction between the cores and no appreciable change in output is indicated by changing the orientation of the spaced cores with respect to each other.

I have discovered that in the second and third basic arrangements described above using the common three-legged and four-legged core, the relation of the load winding and the flux paths in the cores is such that a stray part of the saturation flux of each load winding passes through the leg carrying the other load winding in the desaturating direction during the nonconductive half cycle of the other winding, thus, lowering the premagnetization of the main flux path related to the other winding. I have further discovered a novel relationship of core and load windings thereon that not only avoids the desaturating effect of one load winding on the other, but actually acts in the opposite manner, that is, part of the saturation fluxes of one load winding pass through the leg carrying the other winding in the saturation direction of the other winding, thus aiding the premagnetization of the other winding.

In accordance with one embodiment of the invention a direct-current controlled magnetic amplifier with two self-saturating reactor branches operating respective-

ly on opposite half cycles of an applied alternating supply voltage has a reactor arrangement having a plurality of magnetic paths, the reactor load winding of one branch encompassing one path; the load winding of the other branch encompassing another path, the two load windings being linked by a third path in such manner that the saturation fluxes due to the current in one winding aid the premagnetization of the core section encompassed by the other winding.

It is therefore an object of the present invention to provide new and useful core and winding arrangements in self-saturating reactor circuits.

Another object of the present invention is to provide a new and improved core and load winding arrangement in a direct-current controlled self-saturating magnetic amplifier in which load windings cause their respective core sections to go into saturation on alternate half cycles of a voltage applied to the load windings and in which amplifier the direct current control affects both load windings in the same manner for a control current of given polarity.

Another object of the invention is to increase the output of a direct-current controlled self-saturating magnetic amplifier for a given value control signal, especially at the upper end of the output characteristic by employing novel core and winding arrangements.

Still another object of the invention is to utilize a portion of the saturation flux of one self-saturating reactor branch operating on one half cycle of the applied supply voltage to directly aid in the premagnetization of another self-saturating reactor branch operating on the opposite half cycle of the supply voltage.

A further object of the invention is to provide a novel core and winding arrangement wherein alternately conducting load windings of a direct-current controlled self-saturating magnetic amplifier are so related that part of the saturation flux of each winding threads the core section encircled by the other winding in the latter's saturation flux direction, thereby aiding the premagnetization of the core section carrying the other winding and increasing the output of the reactor for a given value of input signal.

Further objects and advantages of the present invention will be apparent from the following description, reference being had to the accompanying drawings wherein a preferred form of the present invention is clearly shown.

In the drawings:

Figs. 1, 2 and 3 are diagrams of magnetic amplifiers illustrating different core and winding arrangements embodying the present invention. Figs. 4, 5 and 6 are magnetic path diagrams.

Referring now to Fig. 1, a core and winding arrangement embodying the present invention is shown in connection with a full-wave center-tapped (biphase) self-saturating magnetic amplifier. This type of amplifier has a direct current output supplied through two parallel self-saturating reactor branches 10 and 12 respectively operable on opposite half cycles of the supply voltage obtained from a center-tapped alternating supply voltage source such as the transformer 14. Each branch is interposed between the supply voltage source and a load 16 and includes the load winding of a saturable reactor in series with a half-wave rectifier, the respective rectifiers of the two branches being oriented in proper relation to conduct on opposite half cycles of the supply voltage and pass direct current through load 16. Branch 10 is connected between circuit points 18 and 20 and includes a reactor load winding 22 in series with a half-wave rectifier 24, while branch 12 connected between points 18 and 25 includes a load winding 26 in series with rectifier 28. Although any suitable rectifier may be used, metallic rectifiers, such as selenium, germanium, etc., are preferred.

The load windings 22 and 26 are arranged on differ-

ent legs of a magnetizable core, which while providing for each load winding a separate main flux path for the saturating flux, also provides a flux path common to both windings through which stray saturation flux due to one winding links the other winding in the latter's saturating direction, that is, passes through the leg carrying the other winding in the same direction as the saturation flux of the other winding, thus to aid in the premagnetization of the main saturation flux path of the other winding. This is accomplished in the embodiment of Fig. 1 with a magnetizable three-legged core 30 having a plurality of sections 32, 34, 36, 38, 40, 42, and 44, defining two windows X and Y, and three magnetic paths. One magnetic path which may be designated path A is formed by sections 32, 40, 42 and 44. A magnetic path which may be designated path B is formed by sections 34, 36, 38 and 44. The third path which will be called path C is formed from sections 32, 34, 36, 38, 40 and 42.

Load winding 22 encircles paths A and C, path A being the main flux path for fluxes provided in the core by M. M. F.'s produced by current in the winding 22. Path A goes into saturation during the conducting half cycle of rectifier 24. This saturation flux is indicated by the continuous solid directional flux loop 46. Path B is the main path of the saturation flux produced by load winding 26, which flux is indicated by the dotted directional flux loop 48. Since the rectifiers 24 and 28 conduct on opposite half cycles of the applied supply voltage, path A saturates on one half cycle and path B saturates on the next half cycle. The firing angles as hereinbefore noted are influenced or determined by the premagnetization level of the respective paths A and B.

With the load windings 22 and 26 wound as they are shown on their respective core sections, a portion of the saturation flux of each strays or passes around the loop of path C in the same direction. Thus each section of the reactor when it fires aids the saturation load winding fluxes of the other section. During the half cycle when branch 12 is nonconductive, branch 10 is conductive and its reactor section consisting of load winding 22 and path A fires, that is, goes into saturation, and the main course of the saturation flux is path A, as indicated hereinbefore by the flux loop 46. However, some of this saturation flux strays around path C, as indicated by the solid flux arrows which pass, in the direction indicated, through the core section 34 which is encircled by load winding 26. This stray flux and the saturation flux due to winding 26 are in the same direction in the core section 34, thus the stray flux aids the premagnetization of the reactor section consisting of load winding 26 and path B.

On the next half cycle branch 10 is nonconductive and branch 12 is conductive. During this half cycle the reactor section of branch 12, consisting of load winding 26 and magnetic path B, goes into saturation, its saturation flux following its main path represented by the dotted flux loop 48 in the direction indicated, and also straying around the loop of magnetic path C as indicated by the dotted flux arrows. This stray flux passes through the core section 32 encompassed by the winding 22 in the saturating direction of magnetic path A, that is in the same direction as the saturation flux due to load winding 22, thus aiding the premagnetization of the reactor section consisting of load winding 22 and path A.

A pair of direct current control windings 50 and 52 connected to a source of direct current 54 are wound on the core in such manner that control current of a given polarity through the control windings will affect both load windings in the same sense, i. e., either decrease the output of both or increase the output of both. Put in other words, the control windings are wound and connected so that the current therethrough will have the same direction in both control windings, either the saturating direction or the desaturating direction. Specifically,

for a given polarity of control current from source 54, control winding 50 will affect its associated load winding 22 in the same sense as the control winding 52 will affect its associated load winding 26.

Thus, control current of one polarity will simultaneously drive the outputs of both load windings up, and if the polarity of the control current is reversed, the outputs of both load windings will be simultaneously driven downward.

In the drawing a wavy arrow placed next to each control winding indicates the direction of the control M. M. F.'s produced at the same time by both control windings when the current from the source 54 is of the particular polarity shown, assuming that current flows from positive to negative. For this particular polarity and the relations illustrated, the control M. M. F.'s of each control winding are in the saturating direction and aid the premagnetization of the respective reactor sections encircled by the load windings. Thus, for the polarities illustrated the control current tends to raise the outputs of both load windings. Reversing the control current polarity will drive the outputs of the load windings downward.

The flux paths A, B and C are indicated on the outline of core 30 in Fig. 4.

Since the unidirectional current through the load winding of a self-saturating reactor is intermittent, it generates an alternating flux component in the reactor core in addition to the unidirectional saturation fluxes. The alternating flux component in core section 32 produced by the current in load winding 22 induces a voltage in winding 50 which is instantaneously opposed by the voltage induced in the winding 52 by the alternating flux component in section 34 produced by the intermittent current through load winding 26. Thus the induced voltages in windings 50 and 52 cancel out in the control circuit.

The windings 22 and 50 can encircle the path A anywhere except the section 44. For example, either or both windings can be on section 32 as shown, or on sections 40 or 42. Likewise windings 26 and 52 can be disposed anywhere encircling path B except section 44. However, for greatest efficiency windings 22 and 26 should be mounted as shown with the shortest length of stray flux path between them. With load windings properly positioned and connected as described and shown the saturation fluxes produced by the respective load windings will be in opposite directions in the center leg and the stray portions of both saturation fluxes will be in the same direction around path C as indicated by the dotted and solid arrows around the periphery of the core. Thus, the stray flux from one load winding aids the output of the other load winding and vice-versa. This is in contrast to the conventional three-legged core and winding arrangement of the prior art wherein the saturation fluxes of the respective load windings are in the same direction in the center leg resulting in low efficiency due to the stray fluxes being in the demagnetization direction with respect to both load windings.

Fig. 2 shows a core and winding arrangement embodying the present invention in connection with the well-known "doubler" circuit self-saturating magnetic amplifier. The doubler circuit is an alternating current output magnetic amplifier having two parallel self-saturating reactor branches 10 and 12 respectively operable on opposite half cycles of the supply voltage obtained from an alternating supply voltage source 53. As in the circuit of Fig. 1 each branch is interposed between the supply voltage source and the load 16 and includes the load winding of a saturable reactor in series with a half-wave rectifier, the respective rectifiers of the two branches being oriented or poled to conduct on opposite half cycles of the supply voltage and deliver alternating current through the load 16. Branches 10 and 12 are connected between circuit points 18 and 19 and include the same elements as the branches bearing the same reference numerals in Fig. 1.

In Fig. 2 as in Fig. 1 the load windings 22 and 26 are

arranged on different legs of a core, which while providing for each load winding a separate main flux path for the saturating flux, also provides a flux path common to both windings through which stray saturation flux due to one winding links the other winding in the saturating direction, that is, passes through the leg carrying the other winding in the saturation direction, thus to aid in the premagnetization of the main saturation flux path of the other winding.

This is accomplished in the embodiment of Fig. 2 with a core 60 having a magnetic section with four outwardly extending legs in the shape of a cross, the outward ends of the legs being connected by a peripheral magnetic portion. The cross and the connecting peripheral portions define four windows, one in each quadrant. The core has a plurality of magnetic sections 32, 34, 36, 38, 40, 42, 44, 62, 64, 66, 68 and 70 which make up the cross and the connecting peripheral portions and define the four windows and a number of magnetic paths. A path which will be designated path A is formed by sections 32, 42, 40 and 44 which define the window X. A magnetic path referred to as path B is formed by sections 34, 36, 38 and 44 which define a window Y. A path which will be referred to as path C is formed by sections 32, 34, 36, 38, 40 and 42. A path to be referred to as path A' and complementary to path A is formed by sections 32, 62, 64 and 70 which define window X'. A magnetic path to be referred to as path B' and complementary to path B is formed by sections 34, 66, 68 and 70 which define window Y'. A magnetic path to be called path C' and complementary to path C is formed by sections 32, 34, 68, 66, 64 and 62. Section 70 is excluded from path C', and section 44, as in Fig. 1, is excluded from path C. It will be noted that the relations between the core and the load windings which alternately fire their respective core sections are very similar to the arrangements in Fig. 1.

Load winding 22 encircles the paths A—A' and paths C—C', paths A—A' being the main flux paths for saturation fluxes provided in the core by M. M. F.'s produced by current in the load winding 22. Paths A—A' go into saturation during the conducting half cycle of rectifier 24. This saturation flux is indicated by the continuous solid directional flux loops 46—46'. Paths B—B' are the main paths of saturation flux produced by load winding 26, which flux is indicated by the dotted directional flux loop 48—48'.

Paths B—B' are fired into saturation by load winding 26 during the active period of rectifier 28. Since the alternately active rectifiers 24 and 28 conduct on opposite half cycles of the applied supply voltage, load winding 22 fires its path A—A' into saturation during one half cycle and the load winding 26 fires its paths B—B' into saturation on the next half cycle, the firing angles being influenced or determined by the premagnetization level of the respective paths A—A' and B—B'.

In Fig. 2 as in Fig. 1 a portion of the saturation flux due to each load winding strays or passes through the loops of paths C—C' aiding the load winding fluxes due to the other load winding. During the half cycle when branch 12 is nonconductive, branch 10 is conductive and its reactor section consisting of load winding 22 and paths A—A' fires, that is, goes into saturation, and the main course of the saturation flux is path A—A', as indicated hereinbefore by the flux loops 46—46'. However, some of this saturation flux strays around path C—C', as indicated by the solid flux arrows which pass, in the direction indicated, through the core section 34 which is encircled by load winding 26. This stray flux and the saturation flux due to winding 26 are in the same direction in the core section 34, thus the stray flux aids the premagnetization of the reactor section consisting of load winding 26 and paths B—B'.

The various flux paths A—A', B—B' and C—C' are indicated on the outline of core 60 in Fig. 5.

On the next half cycle branch 10 is nonconductive and

branch 12 is conductive. During this half cycle the reactor section of branch 12, consisting of load winding 26 and magnetic paths B—B', goes into saturation, its saturation flux following its main path represented by the dotted flux loops 48—48' in the direction indicated, and also straying around the loops of magnetic paths C—C' as indicated by the dotted flux arrows. This stray flux passes through the core section 32 encompassed by the winding 22 in the saturating direction of magnetic paths A—A', that is in the same direction as the saturation flux due to load winding 22, thus aiding the premagnetization of the reactor section consisting of load winding 22 and paths A—A'.

As in Fig. 1 a pair of direct current control windings 50 and 52 connected to a source of direct current 54 are wound on the core in such manner that control current of a given polarity through the control windings will at the same time affect both load windings in the same sense, i. e., either decrease the output of both or increase the output of both.

In the drawing a wavy arrow placed next to each control winding indicates the direction of the control M. M. F.'s produced at the same time by both control windings when the current from the source 54 is of the particular polarity shown, assuming that current flows from positive to negative. Reversal of control current polarity will reverse the control M. M. F.'s.

Core and winding arrangements embodying the invention are shown in Fig. 3 in connection with a full-wave bridge type self-saturating magnetic amplifier which in common with the other amplifiers described has a pair of self-saturating alternately active reactor branches, 10 and 12 respectively operable on opposite half cycles of the supply voltage from a source 58. Each branch, as in Figs. 1 and 2, is interposed between the supply voltage source and a load 16, and includes the load winding of a saturable reactor in series with a half-wave rectifier, the respective rectifiers of the two branches being oriented in opposite relation to conduct on opposite half cycles of the supply voltage and in cooperation with rectifiers 72 and 73 supply direct current to the load 16. Branches 10 and 12 have the same winding and rectifier components as the similarly referenced branches in Fig. 1, branch 10 including load winding 22 and rectifier 24, while branch 12 includes load winding 26 and series rectifier 28. As in the other figures, the load windings 22 and 26 are arranged on different legs of a core which while providing for each load winding a main flux path for the saturating flux, also provides a flux path linked to both windings through which stray saturation flux due to one winding links the other winding in the saturating direction, that is, passes through the leg carrying the other winding in the saturation direction, thus to aid in the premagnetization of the main saturation flux path of the other winding.

This is accomplished in the embodiment of Fig. 3 by means of the common four-legged core having a plurality of sections defining three windows, X, Y and Z. The magnetic sections 74, 76, 78, and 80 defining the window X also form a magnetic path A which circles the window X. Sections 80, 82, 84, and 86 which define window Z also form a magnetic path C circling window Z. Sections 84, 88, 90 and 92 defining window Y also form the flux path B circling window Y. Fig. 6 shows the outline of the core of Fig. 3 with the paths A, B and C indicated thereon.

The flux paths A and C are directly linked and the flux paths B and C are directly linked, and the load windings are arranged to produce the saturation flux directions shown. When rectifier 24 is conductive, load winding 22 fires core section 80 and path A into saturation, the saturation flux being in the direction of the solid flux loop 46. At the same time a portion of the saturation flux due to load winding 22 strays or passes through section 84 in the direction of the solid arrows. On the next half cycle rectifier 28 is conductive and load wind-

ing 26 fires core section 84 and path B into saturation, the saturation flux being in the direction of the dotted flux loop 48. At the same time a portion of the saturation flux due to load winding 26 strays or passes through section 80 in the direction of the dotted arrows.

It will be noted that the stray flux generated by each winding passes through the core leg carrying the other winding in the same direction as the saturation flux generated by the other load winding when it is active. Thus the fluxes generated by both load windings pass through both legs carrying the load windings in the same direction. The fluxes of both load windings are in the same direction in each of the cross members 82 and 86 which connect the inner legs 80 and 84 of the core. This is in contrast with the conventional winding arrangement with a four-legged core in the prior art in which the fluxes due to the load windings are in opposite directions in each of the cross members connecting the inner legs of the core.

Direct current control windings 50 and 52 are carried by sections 80 and 84 respectively, winding 50 linking path A and winding 52 linking path B. The control windings are connected to a source of direct current 54, and are related to the core to affect the outputs of both load windings in the same sense at the same time for a given polarity of control current. Thus the control winding connections are such that the impedances of both load windings are increased at the same time by the control signal or decreased at the same time by the control signal depending on the polarity of the signal.

Each of the embodiments disclosed herein involves a magnetic amplifier having two self-saturating reactor branches each including a load winding in series with a half-wave rectifier (in all self-saturating magnetic amplifiers the load winding is in series with either a half-wave rectifier or an equivalent switching device), the half-wave rectifiers being poled to alternately conduct on opposite half cycles of the supply voltage applied to the amplifiers. In each amplifier the load windings are alternately active, and during their respective active periods each drives its associated core section into saturation. In each core and winding arrangement shown the saturation fluxes of both windings pass through a common path in the same direction. Thus at least portions of the saturation flux generated by each load winding when it fires its associated core section, pass through the associated core section of the other load winding in the same direction as the saturation fluxes generated by the other load winding. In simple terms when one load winding fires its saturation flux aids the premagnetization of the core section encircled by the other winding.

In each of the amplifiers shown the control current is direct current and its source may be any direct current signal, for example, a battery, generator output, output of another amplifier, or any other suitable signal. In each embodiment shown control windings affect both load windings in the same manner at the same time, that is outputs of both load windings are driven either up at the same time or down at the same time.

The magnetic core materials required or desirable for self-saturating magnetic amplifiers are well known. It is also well known that any magnetizable or magnetic material can act as a flux path and that any such material may be used in magnetic amplifiers although an amplifier will be improved by laminating the material and by employing high permeability material with rectangular hysteresis loop characteristics. Thus, while any magnetizable or magnetic material or materials may be used in constructing the various magnetic paths called for in practicing the invention, various characteristics of the amplifier, such as gain, sensitivity, power, etc., generally may be improved by the use of laminated magnetic material and by the use of high permeability magnetic materials with rectangular hysteresis loop characteristics. Thus preferred cores for magnetic amplifiers are laminated and

made of high permeability materials with rectangular hysteresis loop characteristics.

While the form of embodiment of the invention as herein disclosed constitutes a preferred form, it is to be understood that other forms might be adopted, all coming within the scope of the claims which follow.

The practice of the invention results in increased output for a given value of control signal as compared to the conventional amplifier arrangements of the prior art. The mutual aiding effect of the flux components from both load windings becomes increasingly greater as the output of the amplifier is increased, that is, as the firing angle is advanced. Tests have shown that the present invention increases the power output and gain over twenty-five percent for a given size reactor as compared to the prior art arrangements.

What is claimed is as follows:

1. A magnetic amplifier comprising a pair of branches each including a reactor load winding and in series therewith for self-saturation a half-wave rectifier having recurring alternate active and inactive periods with respect to a supply voltage across the branches, the respective rectifiers in the two branches being poled to alternate with each other with respect to their active periods, saturable core means comprising a plurality of magnetic sections defining first, second and third magnetic paths, one load winding encircling one path and operable to fire it into saturation, the other load winding encircling the second path and operable to fire it into saturation, the third path being encircled by both loads, said windings being operable to provide flux components in the third path in the same direction, and direct current control winding means on said core means and relates to affect both load windings in the same sense at the same time in response to a control signal of given polarity.

2. Self-saturating magnetic amplifier apparatus comprising first and second branches each including a reactor load winding and in series therewith a switching device having alternate active and inactive periods with respect to a supply voltage applied to the branches, said devices in the two branches being poled to alternate with each other with respect to their active periods, core means comprising magnetic sections defining first and second magnetic paths, each encircled by a different one of said load windings, magnetic sections defining a third magnetic path encircled by both of said load windings, the load windings being so related that each load winding is adapted during the active period of its series switching device to provide flux in the portion of the third path encircled by the other load winding in the same direction as the flux produced by the other load winding during the active period of its series switching device, and direct current control winding means on said core means and related to said load windings to affect both load windings in the same sense at the same time in response to a control signal of given polarity.

3. In a magnetic amplifier comprising a pair of self-saturating reactor branches each including reactor load winding means and in series therewith a switching device having recurring alternate active and inactive periods with respect to a supply voltage across the branches and wherein the switching devices in the two branches alternate with each other with respect to their active periods, saturable core means comprising a plurality of magnetic sections defining first and second magnetic paths, one of said load winding means encircling the first path and being operable to fire it into saturation, the other load winding means encircling the second path and being operable to fire it into saturation, magnetic path means linking said first and second paths, both said load winding means being related to provide via the magnetic path means flux components in the same direction in the path portions encircled by both load winding means, and direct current control means including a source of direct current and winding means on said core means connected to

said direct current source and related to affect both load winding means in the same sense at the same time in response to a control signal of given polarity.

4. In a magnetic amplifier comprising a pair of self-saturating reactor branches alternately operable on opposite half cycles of an applied supply voltage and each branch having reactor load winding means in series with a half-wave rectifier, the combination therewith of magnetic core means having a plurality of sections defining first, second, and third magnetic paths, one load winding means encircling the first path and being operable to fire it into saturation, the second load winding means encircling the second path and being operable to fire it into saturation, said third path being linked by the first and second paths, both load winding means being operable to supply flux components in the same direction in said third path, and direct current control means including a source of direct current and winding means on said core means connected to said direct current source and related to affect both load winding means in the same sense at the same time in response to a control signal of given polarity.

5. In a magnetic amplifier comprising a pair of self-saturating reactor branches, each operable to conduct load current in a different one of recurring alternate periods, reactor means comprising core means having a plurality of magnetic legs defining a plurality of closed magnetic paths, a pair of load windings each wound on a different one of said legs, one load winding being on a leg that forms a part of one of said paths, the other load winding being on a leg that forms a part of a second one of said paths, said legs carrying the load windings also being part of a third one of said paths, each of said load windings being connected in a different one of said branches and adapted during its conductive period to provide flux in the leg carrying the other winding in the same direction as the flux produced by the other winding during its conductive period, and direct current control winding means on said core means and in inductive relation to the load windings to affect both windings at the same time in the same sense in response to a control signal of given polarity.

6. In a magnetic amplifier comprising a pair of reactor branches each including a reactor load winding and in series therewith a switching device to provide self-saturation and having recurring alternate active and inactive periods with respect to a supply voltage across the branches and wherein the switching devices in the two branches alternate with each other with respect to their active periods, the combination therewith of saturable core means comprising a plurality of magnetic sections defining a two-windowed three-legged core configuration with two outer legs and a center leg intermediate the outer legs, one outer leg and the center leg defining a main saturation flux path for and encircled by one of said load windings, the other outer leg and the center leg defining a second main saturation flux path for and encircled by the other of said load windings, said load windings being oriented so that the saturation fluxes of the respective load windings are oppositely related in said center leg, and direct current control winding means encircling said paths at other than the center leg, said control winding means being operable to affect the impedance of both load windings in the same sense for a given plurality of control current.

7. In a magnetic amplifier comprising a pair of reactor branches each including a reactor load winding and in series therewith to provide self-saturation a switching device having recurring alternate active and inactive periods with respect to a supply voltage applied to the branches and wherein the switching devices in the two branches alternate with each other with respect to their active periods, the combination therewith of saturable core means comprising a plurality of magnetic sections defining a cross-shaped central section having four outwardly extending legs, first and second legs being on a first axis,

and the third and fourth legs on a second axis at right angles to the first axis, the free ends of said legs being connected by a continuous peripheral section, one of said load windings encircling said first leg, the second load winding encircling said second leg, the second axis intersecting the first axis between said load windings, said load windings being related so that components of their respective saturation fluxes will be in the same direction in said first and second legs, and direct current control winding means on said core means and related to affect both load winding means in the same sense at the same time in response to a control signal of given polarity.

8. In a magnetic amplifier comprising a pair of reactor branches each including a reactor load winding and in series therewith a switching device to provide self-saturation and having recurring alternate active and inactive periods with respect to a supply voltage across the branches and wherein the switching devices in the two branches alternate with each other with respect to their active periods, the combination therewith of saturable core means comprising a plurality of magnetic sections defining first, second and third windows, each encircled by a different flux path, the paths being referred to as first, second and third paths associated respectively with the correspondingly numbered window, one of said sections being common to the first and second flux paths and another magnetic section being common to the second and third flux paths, said one section not being included in said third path and said another section not being included in said first path, said first path being encircled by one of said load windings, said third path being encircled by the other of said load windings, said windings being so related that the saturation flux due to each load winding will thread through the magnetic section carrying the other winding in a direction to aid the saturation fluxes of the other winding, and control winding means carried by said core means and operable for a given polarity of control current to magnetically affect both load windings in the same sense.

9. In a magnetic amplifier comprising a pair of self-saturating reactor branches each including a reactor load winding and in series therewith a switching device having recurring alternate active and inactive periods with respect to a supply voltage applied to the branches and wherein the switching devices in the two branches alternate with each other with respect to their active periods, reactor means comprising core means having a plurality of magnetic legs defining a plurality of closed magnetic paths, each of said load windings being wound on a different one of said legs, one load winding being on a leg that forms a part of one of said paths, the other load winding being on a leg that forms a part of a second one of said paths, said legs carrying the load windings also being part of a third one of said paths, each of said load windings being adapted during the active period of its series switching device to provide flux in the leg carrying the other winding in the same direction as the flux produced by the other winding during the active period of its series switching device, and direct current control means including control winding means on said core means and in inductive relation to the load windings to affect both windings at the same time in the same sense in response to a control signal of given polarity.

10. In a self-saturating magnetic amplifier comprising a pair of reactor branches each including a reactor load winding and in series therewith for self-saturation a switching device having recurring alternate active and inactive periods with respect to a supply voltage applied to the branches and wherein the switching devices in the

two branches alternate with each other with respect to their active periods, the combination therewith of magnetic core means comprising a plurality of magnetic sections defining magnetic paths I, II and III, said sections including parallel magnetic legs, D, E, F and G, legs D and E being included in path I, legs F and G being included in path II, leg E being between legs D and F and leg F being between legs E and G, path I being encircled by one of said load windings, path II being encircled by the other of said load windings, path III being encircled by both windings, said windings being so related that saturating flux due to each load winding will pass through path III in the same direction, and control means including control winding means carried by said core means and operable for a given sense of control current to magnetically affect both load windings in the same sense.

11. A self-saturating magnetic amplifier comprising a pair of reactor branches each including a reactor load winding and in series therewith for self-saturation a switching device having recurring alternate active and inactive periods with respect to a supply voltage applied to the branches the switching devices in the two branches being poled to alternate with each other with respect to their active periods, a plurality of magnetic sections defining magnetic paths I, II and III, said sections including parallel magnetic legs D, E, F and G, legs D and E being included in path I, legs F and G being included in path II, leg E being between legs D and F and leg F being between legs E and G, a portion of path I being encircled by one of said load windings, a portion of path II being encircled by the other of said load windings, said portions being included in path III, each load winding being adapted during the active period of its series connected switching device to provide flux in the magnetic path portion encircled by the other winding in the same direction as the flux produced by the other winding during the active period of its series connected switching device, and control means including control winding means inductively related to said paths I and II and operable for a given sense of control current to magnetically affect both load windings in the same sense.

12. In a magnetic amplifier comprising a pair of self-saturating reactor branches each including a reactor load winding and in series therewith a switching device having recurring alternate active and inactive periods with respect to a supply voltage across the branches and wherein the switching devices in the two branches alternate with each other with respect to their active periods, the combination therewith of magnetic core means comprising a plurality of magnetic sections defining a plurality of magnetic paths, said sections including parallel magnetic legs D, E, F and G, leg E being between legs D and F and leg F being between legs E and G, leg E being encircled by one of said load windings, leg F being encircled by the other of said load windings, said windings being so related that flux created by each load winding will pass through legs E and F in the saturating direction, and control means including control winding means carried by said core means and operable for a given sense of control current to magnetically affect both load windings in the same sense.

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