Oct. 3, 1961 J. B. McFERRAN 3,003,102

SINGLE WINDING SATURABLE CORE IMPEDANCE DEVICES

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Fig. 1.

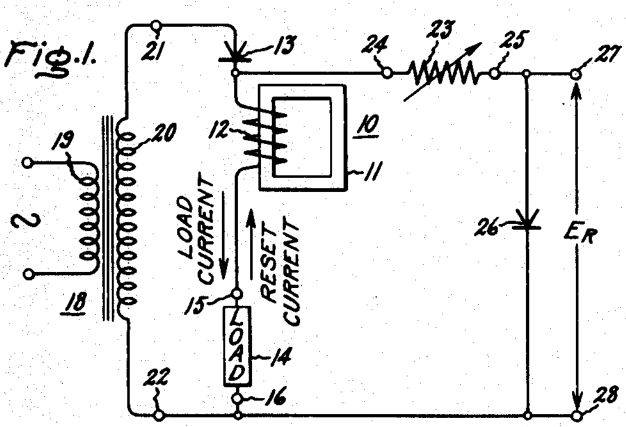

Fig. 2.

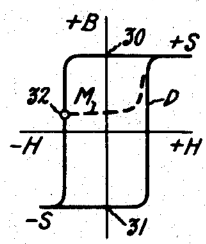

Fig. 3.

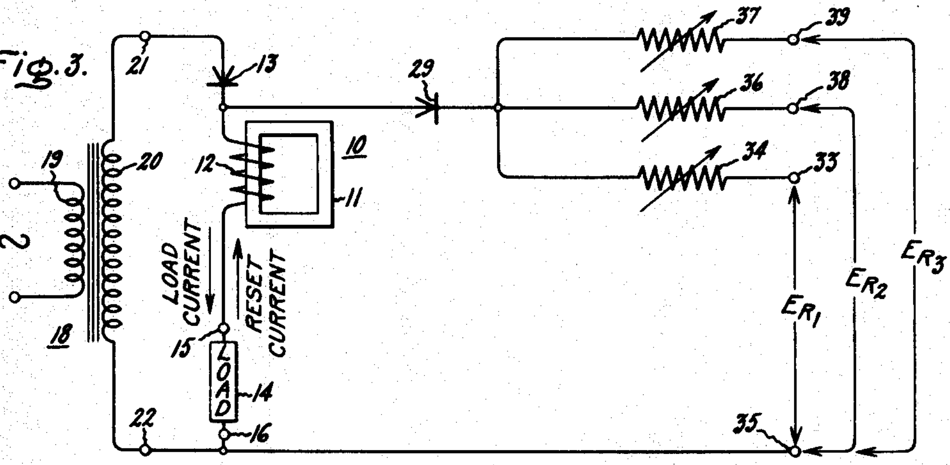

Fig. 4.

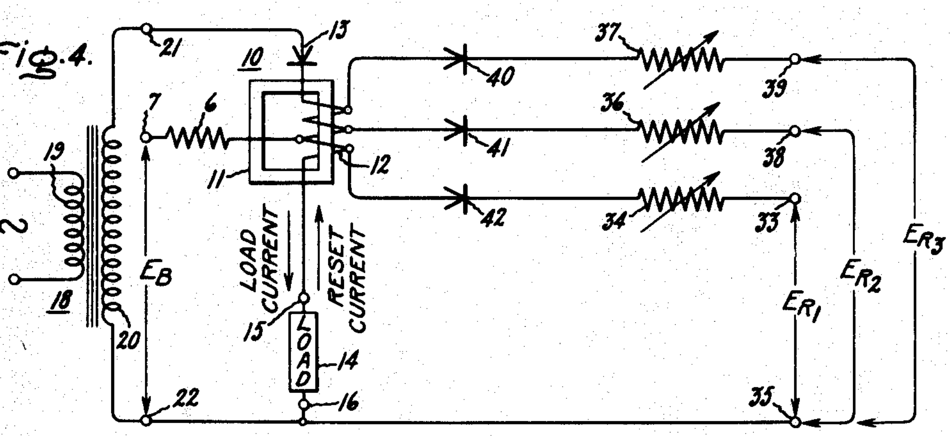

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Fig. 5

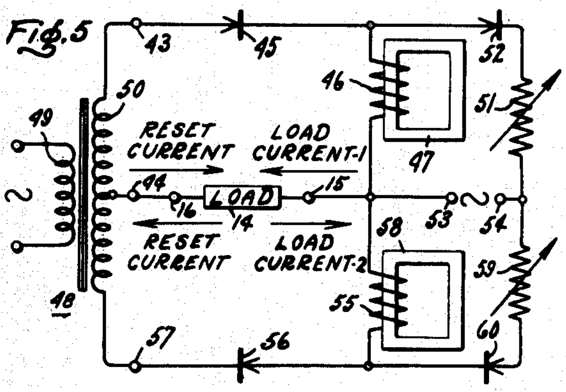

Fig. 7

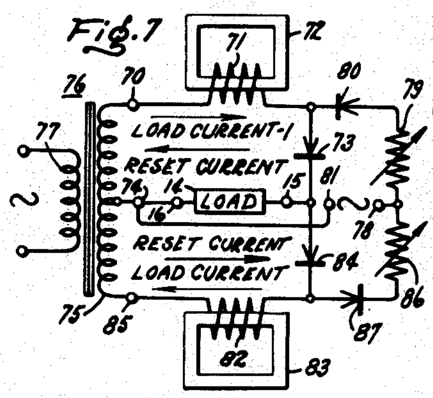

Fig. 6

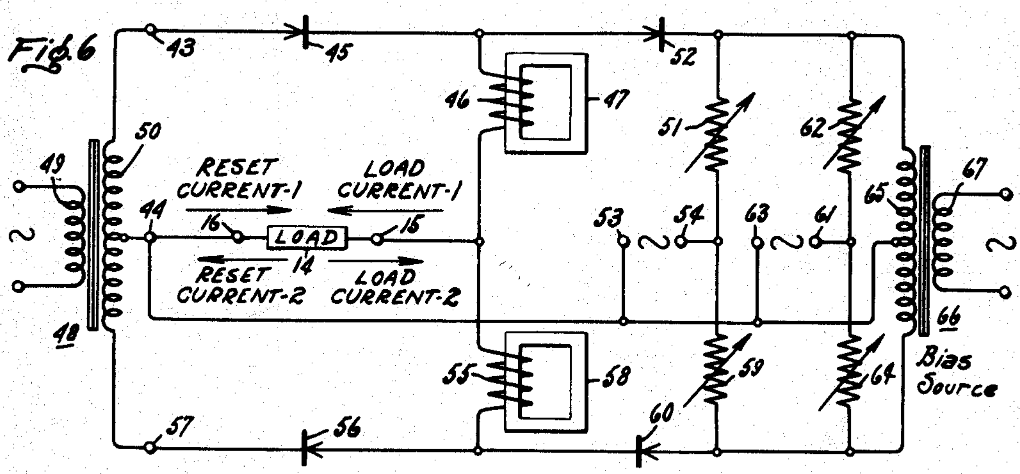

Fig. 8

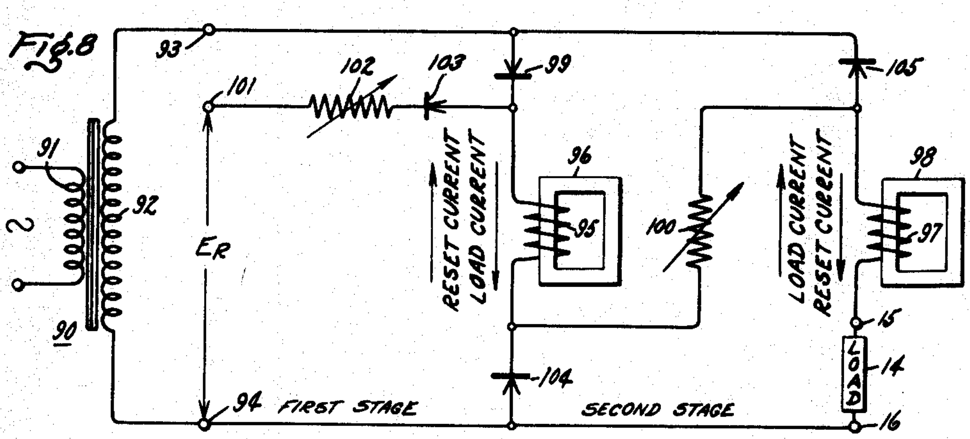

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Fig. 9.

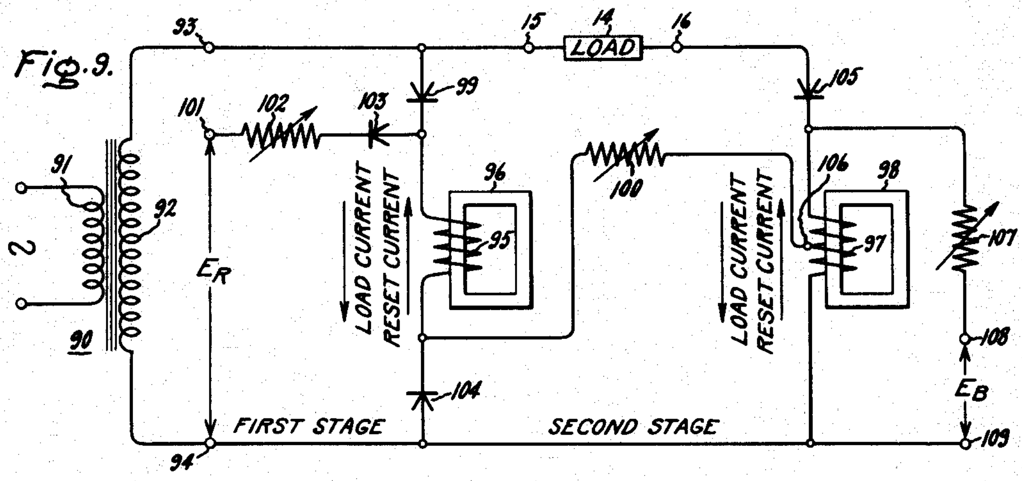


Fig. 10.

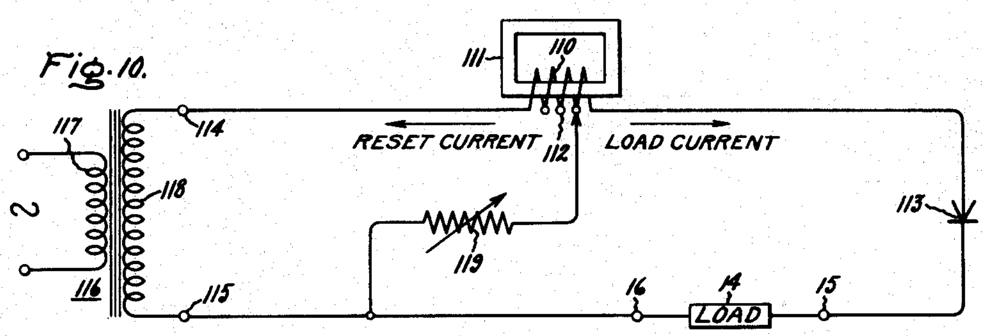
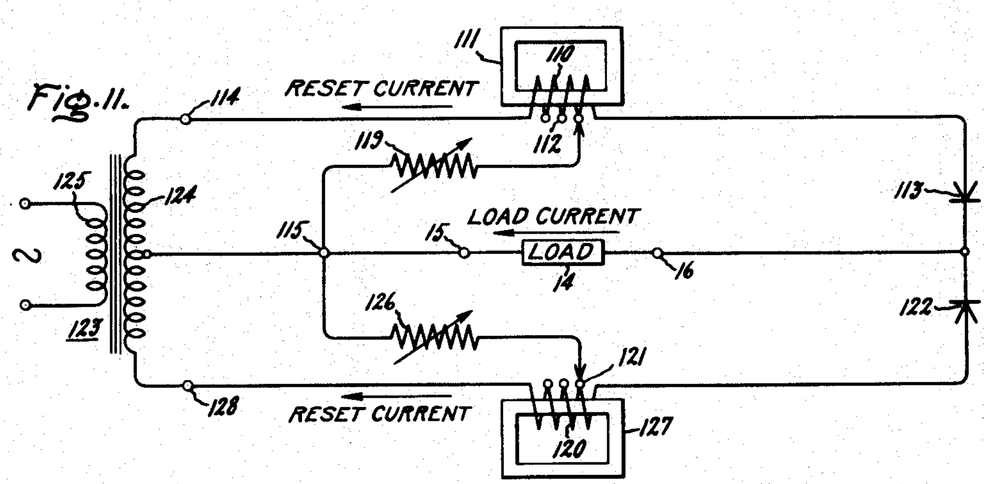


Fig. 11.



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United States Patent Office

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SINGLE WINDING SATURABLE CORE IMPEDANCE DEVICES

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Filed July 5, 1956, Ser. No. 595,961
11 Claims. (Cl. 323—89)

This invention relates to saturable core impedance devices of the type commonly referred to as magnetic amplifiers and, particularly, to such devices known as single winding magnetic amplifiers.

The application of magnetic amplifiers has been limited in large measure by the complexity of the apparatus involved and the resulting expense thereof. Much time and effort have been expended trying to simplify the apparatus and make it inexpensive without reducing the reliability. A number of single winding magnetic amplifier circuits which utilize the magnetic core "reset" principle have been developed for relatively low power work (below about 25 watts). The "reset" principle is more fully described below in connection with the circuit description.

One such basic circuit is described and claimed in the application of John D. Harnden, Jr., Serial No. 588,349, filed May 31, 1956, and assigned to the assignee of the present invention. The present invention is an improvement over the invention described and claimed in the Harnden application and therefore I do not claim anything shown or described in said Harnden application.

Although the circuitry conceived and disclosed by Harnden is generally basic in character, he does not specifically provide for certain applications. For example, there is no direct provision for biasing the amplifier and there is no direct provision for performing addition, subtraction or mixing of a number of control or signal voltages. In addition, as with all single winding magnetic amplifiers, difficulty is had in cascading stages and in obtaining discriminator action.

Accordingly, it is an object of this invention to provide a saturable core impedance device of the single winding magnetic amplifier type which may readily be used in push-pull or cascade.

A further object of this invention is to provide a saturable core impedance device of the character set forth wherein addition, subtraction and mixing of control voltages or signals may be readily carried out.

Another object of this invention is to provide single winding saturable core impedance apparatus wherein discriminator action may be obtained.

In utilizing magnetic devices for control purposes there has long been a need for developing a reliable voltage and frequency reference.

Accordingly, it is a further object of this invention to provide a single winding saturable core impedance device which may be utilized as a voltage and frequency reference.

It is to be particularly understood that the magnetic amplifier devices referred to in this application may utilize separate voltage sources to supply the main reactor supply voltage and the magnetic core reset voltage. Thus, the circuits disclosed herein have the economy of apparatus which accompanies operating with the various parts of the circuit at the optimum voltage level.

Briefly stated in accordance with this invention, certain of the improvements in saturable core impedance devices set forth above are accomplished by providing a magnetic amplifier having a single magnetic core and a single winding in flux exchange relationship therewith and providing a means for utilizing one or more separate voltages to supply the energy necessary to reset the magnetic core and still another separate voltage to supply the power for the reactor. The number of voltages utilized to supply the energy to reset the magnetic core and the particular manner in which they are applied and controlled determine the operation of the amplifier.

In order to provide a summing amplifier, a differential amplifier or a mixing amplifier wherein alternating current voltages and direct current voltages may be mixed, a plurality of reset voltages are applied to a desired portion of the single main winding of the amplifier through separate reset impedances. The reset impedances may have their magnitudes determined in accordance with desired control parameters. Biasing of the amplifiers may be provided by the same general expedient. Further, in accordance with this invention, the magnetic amplifier circuits provided may be cascaded by connecting the output of the first magnetic amplifier stage to the second magnetic amplifier stage through a control or reset impedance in such a manner that the first magnetic amplifier stage provides a control signal to the second magnetic amplifier stage whereby the degree of reset of the second stage is determined.

The novel features which are believed to be characteristic of this invention are set forth with particularity in the appended claims. This invention, however, both as to its organization and method of operation together with further objects and advantages thereof may best be understood by reference to the following description taken in conjunction with the accompanying drawings in which:

FIGURE 1 diagrammatically illustrates a single sided self-saturating half wave circuit;

FIGURE 2 illustrates a typical dynamic hysteresis for a magnetic core material which is utilized in explaining the principles of operation of the present invention;

FIGURES 3 and 4 diagrammatically illustrate single sided self-saturating half wave circuits embodying the present invention with connections to provide circuit biasing, addition or subtraction of control signals, or to provide mixing control signal voltages of direct current and alternating current;

FIGURES 5, 6 and 7 illustrate push-pull versions of the single winding self-saturating half wave circuits embodying the present invention;

FIGURES 8 and 9 illustrate diagrammatically cascaded stages of single winding magnetic amplifiers of this invention; and

FIGURES 10 and 11 illustrate single sided and full wave connections respectively of the single winding magnetic amplifier of the present invention which may be used as a voltage and/or frequency reference.

In order to understand the concepts of the present invention reference should be made to FIGURE 1 wherein a single winding self-saturating half wave magnetic amplifier **10** which utilizes the reset principle of operation is diagrammatically illustrated. The magnetic amplifier **10** includes a single magnetic core **11** the main or gate winding **12** wound on one leg of the core in flux relationship therewith, and a saturating rectifier **13** connected in a series circuit which includes an electric load device **14** (connected between load terminals **15** and **16**). As illustrated this series circuit is energized by a conventional alternating current transformer **18** which has a primary winding **19** connected to an alternating current voltage source and a secondary winding **20** connected to the input terminals **21** and **22** of the magnetic amplifier. If desired, the load impedance device **14** may also be connected between the main reactance winding **12** and the saturating rectifier **13** or between the upper input terminal **21** and the saturating rectifier **13**.

The portion of the magnetic amplifier described thus far includes the main or power developing circuit. In order to provide control for the magnetic amplifier a reset circuit is necessary. The components of this circuit will be described first and then an explanation of the term "reset" and the reset principle will be given in some detail.

The reset components include a reset impedance **23** connected between reset impedance terminals **24** and **25** and a reset rectifier **26**. In order to render these components operative to reset the core, the reset impedance is connected in a series circuit which includes the main power winding **12** of the magnetic amplifier **10** and the load device **14**. This series circuit is connected between reset supply terminals **27** and **28** which are connected to receive a reset voltage E_r and the reset rectifier **26** connected directly in shunt with the reset supply terminals **27** and **28**. The polarity of the reset rectifier is such that the reset supply voltage E_r will only cause current to flow through the main reactor winding **12** in the direction indicated by the arrow labelled "reset current."

The circuit will operate without a reset rectifier as long as the reset voltage E_r does not exceed the main reactor supply voltage. It is only essential that the current set up in the main winding **12** of the magnetic amplifier **10** due to the reset voltage supply, flow when the load current set up in this winding by the main reactor supply voltage is not flowing and that the reset current and load current flow in opposite directions or senses through the main winding **12**. This relationship is assured by adjusting the relative polarity of the reset rectifier **26** and the saturating rectifier **13** as well as the relative phase relationships or polarities of the main reactor supply voltage and the reset voltage. It will be noted that the same function may be accomplished by placing the reset rectifier **26** in the series circuit which includes the reset impedance **23** in the proper sense as well as by placing it in shunt with the reset supply terminals as illustrated.

Considering a full cycle of operation of the circuit of FIGURE 1 and taking the situation where the main reactor supply terminal **21** is positive with respect to reactor supply terminal **22** and the upper reset supply voltage terminal **27** is positive with respect to the lower reset supply terminal **28**. Current will not flow through the reset circuit due to the fact that the reset voltage E_r is shunted by the reset rectifier **26**. However, the saturating rectifier **13** will conduct and therefore magnetizing current will flow through the main winding **12** of the magnetic amplifier **10** and the load impedance **14** in the direction indicated by the arrow labeled "load current." As is explained more fully later, the magnetic amplifier **10** absorbs the entire volt-time integral from the voltage applied between its input terminals **21** and **22** until the core member **11** becomes saturated. Once the core member **11** is saturated load current flows in this series circuit and, consequently through the load device **14**, during the remainder of this half cycle of the supply voltage.

During the next half cycle of supply voltage (and reset voltage) the lower supply terminal **22** and the lower reset supply terminal **28** are both positive with respect to their upper terminals **21** and **27**, respectively. Thus during this half cycle current flows through the reset circuit which includes load device **14**, main reactor winding **12** and reset impedance **23** in the direction indicated by the arrow labeled "reset current." This reset current flows through the main winding **12** in a direction which is opposite to the load current and therefore acts to drive the reactor flux away from positive saturation. The magnitude of the reset flux thus established is determined by the magnitude of the reset impedance **23** and the reset voltage E_r.

As stated above, the value of the reset impedance **23** and the reset voltage E_r determines the core reset flux setup by the main power winding and therefore determines the amplification of the circuit. In order to understand the action of the flux reset principle more clearly reference should be made to FIGURE 2 of the drawing which illustrates the dynamic hysteresis loop of a typical ferromagnetic material which might be used in the core **11** of the magnetic amplifier **10** illustrated in FIGURE 1.

The dynamic hysteresis loop represents a plot of flux density B in the core **11** against the external magnetizing force H applied to the core when the applied magnetizing force is varied at a finite speed. The finite speed at which the magnetizing force is varied to obtain the dynamic hysteresis loop being considered is the frequency of the reactor power supply. The area enclosed by the loop is a measure of the core losses of the material at the operating frequency when the operation of the circuit takes place around the major loop. The energy necessary to supply the core losses must be applied to the core **11** before it becomes saturated and permits load current to flow in the main winding **12**. The points +S and −S respectively represent positive and negative saturation of the core material.

Assume that the current in the main winding **12** on the core **11** is such that the core is operated on its major loop. For this condition, it is necessary to supply sufficient energy to the main winding **12** to supply the energy represented by the area of the loop before current will flow (current other than magnetizing current) in the load device **14**.

The operation of the circuit may best be understood assuming first that the reset impedance **23** is so large that no current can flow through the reset circuit. For this condition, the load current is the only current which will flow in the main winding **12**. As a consequence, the core **11** is not reset on the non-conducting half cycle and the operation of the apparatus is as follows: Assuming that the upper main reactor input terminal **21** is positive with respect to the lower input terminal **22** and the core is at some point past positive saturation +S, as the alternating current voltage supplied between the terminals **21** and **22** reduces to zero the current in the main winding **12**, also passes through zero and the applied magnetizing force becomes zero. However, the flux density therein remains at the point **30** on the saturation curve since there is no leakage current through the saturating rectifier **13**. Since no current flows in the main winding **12** during the negative half cycle of the supply voltage, there is no demagnetizing energy supplied to the core. Therefore, the flux density in the core cannot be driven below the point **30**. Thus on the next positive half cycle of the supply, very little magnetizing force (energy) is required to drive the core to positive saturation, the impedance of the magnetic amplifier **10** is a minimum, and the current conducted by this winding is a maximum. Since the energy used in supplying core losses is a minimum, the power supplied to the load device **14** is a maximum.

For the opposite limiting condition, i.e., with the magnitude of the reset impedance **23** very small, a maximum current flows through the reset circuit for the reset (negative) half cycle of the supply voltage. Once again, starting the explanation for the time when the supply voltage is passing through zero (from positive to negative), there is no magnetizing force applied to the core **11** at this instant and the flux density in the core is again at the point **30** on the saturation curve of FIGURE 2. Reset current then starts to flow through the main winding **12** in the opposite direction or sense to that which flowed during the positive half cycle. The demagnetizing energy thus supplied drives the flux density of the core material down along the back side of the hysteresis loop until the core **11** reaches negative saturation −S at the maximum reset voltage. As the alternating supply voltage reverses, the magnitude of the reset voltage and, consequently, the magnetizing force applied to the core **11** by the main winding **12** is reduced to zero, the core is reset, and the point of operation for the core is at **31** (i.e., at the magnetizing force axis and at the maximum negative flux density). In order to develop an output voltage across the load device **14** on the next (positive) half cycle of the reactor supply voltage, it is necessary to supply sufficient energy to the core to drive the flux density of the core material to positive saturation +S (up along the front side of the hysteresis loop from point 31 to positive saturation). Thus, when the amplifier 10 is operated in this manner, i.e., the magnitude of the reset impedance 23 is at a minimum, the output is at a minimum whereas operation of the device with zero reset current provides a maximum output.

By varying the magnitude of the reset impedance 23, or the magnitude of the reset voltage E_r, or both, it is possible to set the operation of the magnetic amplifier at any point between the two points of operation just described. For example, if the impedance 23 is such that the reset current is sufficient to set the point of operation at the point 32 on the back side of the hysteresis loop, then on the next positive half cycle of the reactor supply voltage, it will be necessary to supply sufficient energy to the core 11 to drive the core material up along the minor hysteresis loop illustrated by the broken line M within the dynamic hysteresis loop D. The energy required to perform this is somewhere between that required to drive the core to saturation +S for the two limiting conditions.

From the above description, it will be appreciated that the core is reset on each reset half cycle and, therefore, the amplifier provides half-cycle response. It is also seen that the reset ampere turns (i.e., the reset current times the number of turns on the main winding 12) required to swing the output of the amplifier over its entire characteristic is approximately or essentially the same as the ampere turns required to swing the saturable core impedance device 10 over its full characteristic as a conventional magnetic amplifier. Since the core is driven into saturation during the "forward" or "conducting" portion of each cycle its degree of reset is completely dependent on the previous half cycle, hence half cycle response is obtained.

The variable reset impedance 23 may take many forms and its impedance may be selected so that its magnitude varies in response to any desired parameter. The proper control parameter is then used to control the magnitude of the reset impedance used, to thereby control the system amplification. The applied reset voltage may be either alternating current or direct current. If an alternating current voltage is applied, it should be of the same frequency and phase as the supply voltage and if a direct current voltage is applied it should be of opposite polarity to the forward conducting sense of the supply voltage.

As is explained more fully below, the circuit of FIGURE 3 may be utilized for addition and subtraction of control signals and for mixing control voltages or signals. The principle of operation of this circuit is essentially the same as that described with regard to FIGURE 1, and the components are generally the same. Therefore, in order to simplify the description, the corresponding components of the two circuits are given the same reference numerals. The difference between the two circuits as illustrated, resides entirely in the reset arrangement; the main power circuits are identical.

In the circuit of FIGURE 3 three individual series reset circuits are provided, each of which includes the main reactor winding 12 and a reset rectifier 29. One such series reset circuit may be traced from reset voltage terminal 33, through variable reset impedance 34, reset rectifier 29, main reactor winding 12, and load device 14 to lower reset voltage terminal 35. If a reset voltage E_{R1} is applied between the reset voltage terminals 33 and 35 which is of the same frequency and phase as the main reactor supply voltage applied between supply terminals 21 and 22, the circuit described thus far operates in exactly the same manner as the circuit of FIGURE 1. The only difference between the two circuits being that the reset rectifier illustrated in FIGURE 2 is connected in series rather than in shunt with the reset circuit. However, the series reset rectifier operates in the same manner in that it allows reset current to flow only in the proper direction (illustrated by the arrow labeled "Reset Current"). Actually the reset rectifier 29 may be connected in shunt or it may be eliminated entirely if the total applied reset voltage never exceeds the main reactor voltage.

In order to provide a summing or differential amplifier, a number of additional reset circuits must be provided. As illustrated, reset impedances 36 and 37 are each connected between individual reset voltage terminals 38 and 39 respectively, and the saturating rectifier in such a manner that they are in each series circuit relationship with the saturating rectifier 29, main winding 12, and load device 14. The individual reset voltages E_{R2} and E_{R3} for each of these two reset circuits is then applied between the lower reset voltage terminal 35 and their respective upper reset voltage terminals 38 and 39.

With this arrangement, the net reset current through the main reactor winding 12 will be a function of the algebraic sum of the control parameters applied if the applied reset voltages E_{R1}, E_{R2}, and E_{R3} are varied in accordance with a desired control parameter or if both the applied voltages and the magnitude of the reset impedances are so varied. Thus, the amplifier is itself a summing or differential amplifier. It will also be noted that a similar relationship applies if the magnitude of the reset impedances 34, 36, and 37 are varied in accordance with individual control parameters.

Provision of the additional reset circuits also adapts the amplifier for use as a mixing amplifier to combine alternating and direct current signals. This function is accomplished by the expedient of applying an alternating current voltage to one or more of the reset circuits and a direct current voltage to the remainder of the reset circuits.

The circuit of FIGURE 4 is included to illustrate a circuit wherein the point of operation of the core member 11 may be set at some point other than the point of zero magnetizing force (point 30, FIGURE 2) by a biasing circuit. This circuit also illustrates a means of providing a means of matching the impedances of the reactor and various control signal voltage sources. This impedance matching permits voltages from sources of different impedance levels to be combined.

The principle of operation of the main reactor circuit and the reset circuits illustrated in FIGURE 4 are identical to those of FIGURE 3 and corresponding circuit elements of the two circuits are given the same reference numerals. However, for the circuit of FIGURE 4 it is assumed that the reset voltage sources E_{R1}, E_{R2}, and E_{R3} have different impedances. Therefore, in order to match these impedances so that the individual voltage sources will have identical effects on the main reactor circuit for a given applied reset voltage, it is necessary to include a different percentage of the main winding in each series circuit. This is done by providing a series of taps on the main reactance winding to which the individual reset circuits may be connected. For example, one reset circuit includes upper reset voltage terminal 39, reset impedance 37, reset rectifier 40, about ninety percent of the main reactor winding 12, load device 14 and lower reset voltage terminal 35. The reset circuit connected between reset voltage terminals 35 and 38 includes reset impedance 36, reset rectifier 41, about fifty percent of the main reactor winding 12, and load device 14. The third series reset circuit is connected between reset voltage terminals 35 and 33 and includes reset impedance 34, reset rectifier 41, about ten percent of the main reactor winding 12, and the load device 14. The three reset rectifiers 40, 41, and 42 block current in their respective reset circuits, which would flow in the wrong direction as did reset rectifier 29 in the circuit of FIGURE 3. As was previously explained, it is not necessary to include the reset rectifiers if the applied reset voltages are never greater than the main reactor voltage.

In order to provide biasing for the amplifier a biasing voltage E_B is applied to about fifty percent of the main reactor winding 12. This voltage provides an initial magnetizing force and thereby sets the operation of the core at some point on its dynamic hysteresis loop which is other than the point of zero magnetization (point **30** of FIGURE 2). For example, the initial magnetizing force may be such as to set the point of operation on the back side of the hysteresis loop at some point such as point **32** of FIGURE 2. Under these conditions, any reset voltage applied to the core drives the core further down the back side of its hysteresis loop. The reactor power supply voltage then must supply more power to drive the reactor to positive saturation +S than would be required without the bias. Therefore, the amplifier fires later in the cycle with a bias of the type described.

For the condition described above the biasing voltage E_B applied between the terminals **7** and **22** is polarized to apply a negative voltage at the terminal **7** at least during the reset half cycle of supply voltage. If the biasing voltage is reversed, i.e., arranged to apply a positive voltage to the upper terminal **7** during at least the reset half cycle, it could provide a magnetizing force which would tend to hold the core member **11** at positive saturation and larger reset voltages would be required to reset the core. The biasing circuit illustrated includes biasing resistor **6**, the lower half of main reactor winding **12**, and load device **14**. The biasing E_B voltage is applied between the biasing terminal **7** and the lower load terminal **16**. The biasing voltage E_B may, of course, be an alternating current voltage or direct current voltage.

As was explained with regard to the circuit of FIGURE 1, the specific location of the load device **14** in the main reactor circuits of FIGURES 3 and 4 is not critical. For example, in either the circuit of FIGURE 3 or the circuit of FIGURE 4 load device **14** may be connected between the main reactor winding **12** and the saturating rectifier **13** or between the upper input terminal and the saturating rectifier **13** without affecting the circuit operation appreciably.

In the circuit of FIGURE 5, a push-pull arrangement of two single winding magnetic amplifiers is shown. It will be recognized that the main reactor circuit for each of these single winding devices is identical to the main reactor circuits of the amplifiers already described. However, to avoid duplication of reference numerals in a single figure, components of this circuit are given new reference numerals.

The main reactor circuit of the first amplifier is connected between the two upper reactor supply voltage terminals **43** and **44** and includes saturating rectifier **45**, main reactor winding **46**, and load device **14** (connected between load terminals **15** and **16**). The main reactor winding **46** is wound on a magnetic core member **47**.

A transformer **48** which has a primary winding **49** connected to receive an alternating current voltage and a center tapped secondary winding is provided to supply the main reactor voltage. For this purpose, the upper half of the tapped secondary winding **50** is connected between the reactor voltage supply terminals **43** and **44**. With this arrangement load current flows through this circuit only for the half cycle of supply voltage when the upper supply terminal **43** is positive and only in the direction indicated by the arrow labeled "Load Current." This condition is established by the polarity of the saturating rectifier **45**.

In order to reset the core member **47** a series reset circuit is provided which includes a reset impedance **51**, a reset rectifier **52**, and the main reactance winding **46** connected in series with each other between reset voltage terminals **53** and **54**. A reset voltage supply is then connected between these terminals. Preferably, the reset voltage is of the same frequency and phase as the main reactor supply voltage. The portion of the push-pull circuit of FIGURE 5 described thus far constitutes a single winding magnetic amplifier which operates in exactly the same manner as the single sided single winding magnetic amplifier of FIGURE 1.

In order to provide push-pull operation another single winding amplifier is also connected to supply the load device **14**. The main reactor circuit of this amplifier may be traced from the middle reactor supply terminal **44**, through load device **14**, through a main reactor winding **55** of the second single winding amplifier, and through a saturating rectifier **56** to a lower reactor supply terminal **57**. The main reactor winding **55** is also wound on a magnetic core member **58**. The lower half of the secondary winding **50** of the transformer **48** is connected between the reactor terminals **44** and **57** to supply the reactor voltage for the lower half of the push-pull amplifier combination and the saturating rectifier **56** is poled to pass current through this circuit only when the upper reactor terminal **44** is positive with respect to the lower terminal **57**. Thus, the load current tends to flow through the lower main reactor circuit only on the same half cycle that it flows in the upper main reactor circuit. Under these conditions, the load currents tend to flow in opposite directions through the load device **14** and at the same time (see arrows labeled "Load Current–1" and "Load Current–2"). Therefore, no load current will flow if the circuit is balanced and both core members **47** and **58** are reset by the same amount.

The core member **58** of the lower half of the push-pull amplifier is reset by a circuit which includes a reset impedance **59**, a reset rectifier **60**, and the lower main reactance winding **55** connected in series with each other across the reset supply terminals **53** and **54**. It will be noted that if this lower single winding magnetic amplifier were isolated from the upper one, its operation would be exactly the same as described with respect to the circuit of FIGURE 1.

As previously noted, the load current developed by each half of the push-pull magnetic amplifier tends to flow through the load device **14** in opposite directions and therefore if the circuit is completely balanced and each of the core members **47** and **58** are reset by exactly the same amount on the reset half cycle, the current developed by each half of the magnetic amplifier will cancel out and there will be no current flowing through the load device **14**. However, if an alternating reset voltage is applied between the reset terminals **53** and **54** the current flowing through the load device **14** on conducting half cycles is polarized in accordance with the phase of the alternating current signal. This action is insured by the polarity of the saturating rectifiers **45** and **56** and the reset rectifiers **52** and **60**. In a like manner, the load current will be polarized in accord with the polarity of a direct current signal voltage if such a voltage is applied between the reset voltage supply terminals **53** and **54**. This implies descriminator action as well as push-pull amplification.

For example, for the condition where the upper terminal **43** of the upper half of the push-pull amplifier is positive with respect to the middle terminal **44** and consequently the middle terminal **44** is positive with respect to the lower terminal **57** and for the condition where an alternating current reset voltage is applied between the reset terminals **53** and **54** in such a manner that the terminal **54** is positive with respect to the terminal **53** for this half-cycle of supply voltage, the load current in the upper half of the push-pull magnetic amplifier will tend to flow in a clock-wise direction around the loop as illustrated by the arrow labeled "Load Current–1" and the load current in the lower half of the push-pull magnetic amplifier will tend to flow in a clockwise direction as indicated by the arrow labeled "Load Current–2." At the same time the reset current for the upper half of the magnetic amplifier will be blocked by the reset rectifier **52** whereas reset current will tend to flow in the lower series reset circuit. Whether or not this reset current can flow during this half cycle will depend upon whether or not the reset voltage applied is of sufficient magnitude to oppose the voltage developed across the main reactance winding **55** of the lower half of the push-pull magnetic amplifier. Generally, this reset current can be ignored during the conducting half cycle.

On the next half cycle the middle terminal 44 is positive with respect to the upper terminal 43 and the lower terminal 57 will be positive with respect to the middle terminal 44, therefore, load current cannot flow in either of the reactive circuits due to the fact that it is blocked by the saturating rectifiers 45 and 56. However, it is during this half cycle that the reset of the cores 47 and 58 must take place. During this half cycle the left hand reset voltage supply terminal 53 is positive with respect to the right hand reset voltage supply terminal 54. For this condition reset current will tend to flow through the upper main reactance winding 46 due to the fact that the reset rectifier in this reset circuit is properly poled. The reset current through the lower main reactance winding 55 is blocked due to the polarity of the reset rectifier 60 and therefore there will be no reset of the lower magnetic core member 58. For the condition just described then, it will be obvious that the upper magnetic core member 47 is reset whereas the lower magnetic core member is not reset at all and, therefore, the load current, i.e., the current through the load device 14, will be predominantly in the direction of the arrow labeled "Load Current–2." Another way of stating this is to say that the lower half of the push-pull magnetic amplifier circuit will require less magnetizing force to cause current to flow therein due to the fact that the magnetic core member 58 of this circuit is not reset.

In a like manner if the polarity of the reset voltage applied between the reset supply voltage terminals 53 and 54 is reversed so that the terminal 53 is positive when the upper and middle reactance supply voltage terminals 43 and 44 respectively are positive with respect to the lower reactance voltage supply terminal 57, the lower core member 58 will be fully reset on the reset half cycles and the upper core member 47 will not be reset. Therefore, the current through the load device 14 will be polarized in the direction opposite to that described above, i.e. it will be predominantly in the direction of the arrow labeled "Load Current–1." It will be recognized then, that the relative degree of reset of the upper and lower magnetic core members 47 and 58 may be varied between these conditions by the varying phase of the applied reset voltage between the two extremes just described. It should be equally apparent that the two extreme conditions described above also prevail if direct current reset voltages of opposite polarity are applied between the reset voltage terminals 53 and 54.

It will also be understood that for a reset voltage of a given phase, the degree of reset of the cores may be varied by varying the magnitude of the reset voltage or by varying the magnitude of the reset impedances 51 and 59. Therefore, for the push-pull circuit of FIGURE 5, control of the load current or voltage developed across the load may be accomplished by varying the magnitude of the reset voltage, the phase of the reset voltage, or the magnitude of the reset impedances 51 and 59, or any combination of these parameters may be varied as desired.

The push-pull circuit of FIGURE 5 may be modified in all respects set forth with regard to the single sided amplifier circuits previously described by modifying both the upper and the lower halves of the push-pull circuit in the same manner. For example, the push-pull circuit may be made a summing amplifier, a differential amplifier or a mixing amplifier, and the single winding halves of the push-pull magnetic amplifier may be biased. The circuit illustrated in FIGURE 6 shows a push-pull magnetic amplifier utilizing the single winding reactors wherein provisions are made for all of the above mentioned expedients.

The main reactor circuits of both halves of the push-pull magnetic amplifier are identical to the corresponding parts of the push-pull magnetic amplifier circuit illustrated in FIGURE 5. Also the first reset circuits for each half of the magnetic amplifier of FIGURE 6 are identical to the corresponding reset circuits illustrated in FIGURE 5 with the exception that the reset voltage is applied in such a manner that the reset circuits for both the upper and lower halves of the push-pull circuit include load device 14. Since the corresponding components of this portion of the circuit of FIGURE 6 are identical to the corresponding components of the circuit of FIGURE 5 they are given the same reference numerals for the sake of simplicity.

Also since the operation of this portion of the circuit illustrated in FIGURE 6 is identical to the operation of the circuit of FIGURE 5, the operation of this part of the circuit will not be described again. However, in addition to the first reset circuits which include the reset impedances 51 and 59 and the reset rectifiers 52 and 60, a second reset circuit is added for each half of the push-pull amplifier circuit. The second reset circuit for the upper half of the amplifier which may be traced from the right hand reset voltage terminal 61 through reset impedance 62, saturating rectifier 52, main reactance winding 46, load impedance device 14, to input terminal 44 and back to the left hand reset voltage terminal 63. The second reset circuit for the lower half of the push-pull magnetic amplifier circuit may be traced from the right hand reset voltage terminal 61 through reset impedance 64, reset rectifier 60, the lower main reactance winding 55, load device 14, reactance voltage supply terminal 44 and back to the left hand reset voltage supply terminal 63. A second reset voltage is then applied between the reset voltage terminals 61 and 63.

With the circuit as described thus far it will be seen that an alternating voltage supplied between the reset voltage terminals 61 and 63 which is of the same frequency as the main reactance supply voltage will have the same effect as that described with respect to the first reset circuit of the push-pull magnetic amplifier illustrated in FIGURE 5. However, it will be appreciated that the reset control applied between the two pairs of voltage supply terminals will not be independent and that they can be mixed in any manner desired. The net effect on the reset of the individual saturable core devices 47 and 58 will represent the algebraic sum of the effect of individual reset circuit which acts upon the respective core members. Therefore, it will be appreciated that the relative phases of the individual reset voltages, the magnitudes of the reset impedances in the reset circuits, and the magnitudes of the applied reset voltages may all be varied to accomplishe control of the push-pull amplifier. It will also be recognized that one of the reset voltages may be direct current and the other alternating current having the same frequency as the main reactor supply voltage and in this manner mixing of alternating current and direct current voltages may be obtained.

In addition to the circuitry thus far described and illustrated in FIGURE 6 biasing of the amplifier may be accomplished by connecting the opposite end terminals of a center tapped secondary winding 65 of a transformer 66 across the reset impedances 62 and 64 of the last reset circuit and connecting the center tap to the main reactor input terminal 44 which is connected to the center tap on the secondary winding 50 of the reactance supply transformer 48. The primary winding 67 of the transformer 66 is connected to a voltage source of the same frequency as the main reactor supply voltage. The relative phases of the two transformer primary voltages determines which way the amplifier is biased. Since the biasing circuit for each half of the push-pull amplifier arrangement includes the respective reset rectifiers 52 and 60 the biasing circuits are much the same as the reset circuits already traced. Therefore, it will be understood that for one polarity of the biasing voltage on the secondary 65 of transformer 66 with respect to the main reactor voltages, the biasing voltage will be applied to the upper main reactance winding **46** and for the opposite relative phases of these two voltages the biasing voltage will be applied to the main reactance winding **55** of the lower half of the push-pull circuit. Biasing of a given core has been adequately explained with respect to the circuit of FIGURE 4 and therefore is not explained again at this point.

Still another push-pull circuit arrangement utilizing the single winding magnetic amplifier is illustrated in FIGURE 7. Since the circuit components are rearranged somewhat from those corresponding components illustrated in FIGURES 5 and 6, the circuit components will be given different numbers to avoid confusion. The upper main reactance circuit of this push-pull magnetic amplifier includes an upper reactance input voltage terminal **70**, a main reactance winding **71** wound on a magnetic core member **72**, saturating rectifier **73**, a load device **14** connected between load terminals **15** and **16**, and main reactance voltage input terminal **74**. These components are connected in series with each other across the upper half of the secondary winding **75** of a transformer **76** which has its primary winding **77** connected to receive an alternating current voltage. The saturating rectifier **73** is poled in such a manner that the load current in this upper main reactance winding **71** flows in the circuit in a clock-wise direction as indicated by the arrow labeled "Load Current–1."

In order to provide a reset for the magnetic core member **72** a reset circuit is provided which may be traced from a voltage input terminal **78** through reset impedance **79**, reset rectifier **80**, main reactor winding **71**, through the upper half of the secondary winding **75** of the reactance supply transformer **76** to the reactor input terminal **74** and back through the left hand reset voltage input terminal **81**. It will be recognized that the single winding magnetic amplifier described thus far will operate in a manner similar to the single sided magnetic amplifier of FIGURE 1 with the exception that the reset circuit includes a portion of the main reactance supply voltage. Thus, the reset voltage applied to this circuit is the algebraic sum of the voltage applied between main reactor voltage supply terminals **70** and **74** during the reset half cycle and the reset voltage applied between the reset voltage supply terminals **78** and **81** during this half cycle.

The lower main reactance circuit of the push-pull magnetic amplifier circuit consists of a lower main reactance winding **82** which is wound on the magnetic core member **83**, a saturating rectifier **84**, and the load device **14**, connected in series with each other between the middle reactance voltage supply terminal **74** and the lower reactance supply terminal **85**. This series circuit is connected to receive the voltage developed across the lower half of the secondary winding **75** of the reactor supply transformer **76**.

The reset circuit for the lower half of the push-pull magnetic amplifier consists of reset impedance **86**, reset rectifier **87**, the lower main reactance winding **82**, lower half of the secondary winding **75** of transformer **76**, and the middle reactance voltage input terminal **74**. These components are connected in series circuit relationship with each other between the reset voltage supply terminals **81** and **78**. Without the upper half of the push-pull circuit it will be appreciated that the lower half will operate in substantially the same manner as described with respect to the single sided circuit of FIGURE 1, except that the reset voltage for this circuit comprises both the voltage applied between the reset voltage supply terminals **78** and **81** and the voltage applied between the lower pair of reactor supply voltage terminals **74** and **85** on the reset half cycle.

The load current in each of the main reactor circuits tends to flow in a clock-wise direction as illustrated by the arrows marked "Load Current" and as a consequence if the upper and lower reactor circuits are perfectly balanced and the cores **72** and **83** are reset on each reset half cycle by the same amount, no current flows through load device **14**. In view of the polarity of the saturating rectifiers **73** and **84** it will be recognized that the reset current flowing in either of the main reactor windings **71** or **82** must flow during the half cycle of the main reactor supply voltage when the lower main reactor voltage supply terminal **85** is negative with respect to the middle reactor supply terminal **74** and when the middle reactor supply terminal **74** is positive with respect to the upper reactor supply terminal **70**. If the reset voltage is applied in such a manner that the right reset voltage supply terminal **78** is positive for the reset half cycle of supply voltage, the reset voltage aids reset current flow through the upper main reactance winding **71** and opposes current flow through the lower main reactance winding **82**. Consequently the upper reactor core **72** resets more than the lower reactor core **82** and therefore current through the load device **14** is polarized in the direction maintained by the lower reactor circuit, i.e., from left to right through the load device **14**.

If the polarity of the reset voltage is reversed for the reset half cycle of supply voltage, i.e., reset supply voltage terminal **81** is made positive with respect to terminal **78**, reset current flow is aided in the lower reset circuit and opposed in the upper reset circuit. Thus, the above described condition is reversed and the current through load device **14** for this condition is primarily supplied by the upper reactance circuit. As a consequence, load current flows from right to left through the load device **14**.

From this description it is seen that this push-pull circuit operates in a manner similar to that described with respect to the circuit illustrated and described with regard to FIGURE 5. In this connection it should be noted that the modifications applied in the circuit of FIGURE 6 to make the push-pull circuit a summing or differential amplifier, for the purpose of mixing alternating current and direct current signals, or for applying a biasing voltage can also be applied equally well to the circuit of FIGURE 7 by connecting additional reset circuits in parallel with the reset circuits shown and by connecting a biasing circuit in the manner illustrated with regard to FIGURE 6. Also from the above description it is seen that the circuit of FIGURE 7 operates as a discriminator since its output may be polarized in accordance with either the phase of an alternating signal voltage or the polarity of a direct current signal voltage.

The circuit diagram of FIGURE 8 illustrates one arrangement whereby more than one stage of amplification may be realized using single winding magnetic amplifiers. Although the principle of operation of each stage of the two stage magnetic amplifier is the same as the circuit of FIGURE 1, it has been necessary to make certain modifications in the circuitry of the first stage in order to provide the two stages of amplification.

As illustrated, the two stage magnetic amplifier voltage source comprises an alternating current transformer **90** which has a primary winding **91** connected to an alternating current voltage source and a secondary winding **92** which is connected to a pair of main reactor supply terminals **93** and **94**. The first amplifier stage is provided with a reactor having a single main conducting winding **95** wound on a magnetic core member **96** and the second stage of amplification is provided with a reactor which has a single main conducting winding **97** wound on a magnetic core member **98**. The main reactor circuit for the first amplifier stage is connected between the reactor voltage supply terminals **93** and **94** and includes saturating rectifier **99**, the main reactor winding **95**, a reset impedance **100** for the second amplifier stage, the main reactance winding **97** of the second stage, and load device **14** which is connected between load terminals **15** and **16**. The second stage reset impedance **100**, second stage main reactance winding 97 and load device 14 may be considered the load for the first amplifier stage.

In order to provide reset of the magnetic core member 96 in the first amplifier stage a reset circuit is provided which may be traced from an upper reset voltage supply terminal 101 through a first stage reset impedance 102, a reset rectifier 103, the main reactance winding 95 of the first amplifier stage, and an isolating rectifier 104 back to the lower main reactance voltage supply terminal 94. With this arrangement it may be seen that on the forward or conducting half cycle for the first amplifier stage the load current flows down through the main reactance winding 95 as indicated by the arrow labeled "Load Current" and that the current in the series reset circuit just described is blocked by reset rectifier 103 and isolating rectifier 104. On the opposite half cycle of the supply voltage the reset current flows upwardly through the main reactance winding 95 as indicated by the arrow labeled "Reset Current." Thus, if the second stage reset impedance 100, second stage main reactance winding 97 and the load device 14 are considered to be the load for the first stage magnetic amplifier then this stage will operate in the same manner and on the same principle as did the magnetic amplifier of FIGURE 1.

The main reactance circuit for the second stage magnetic amplifier may be traced from the lower reactance supply voltage terminal 94 through the load device 14, the main reactance winding 97, and through the second stage saturating rectifier 105 back to the upper reactance supply voltage terminal 93. The polarity of the second stage saturating rectifier 105 is such that the direction of load current flow in the second stage magnetic amplifier must be up through the main reactance winding 97 in the direction indicated by the arrow labeled "Load Current." Thus the first and second stage magnetic amplifiers conduct on alternate half cycles of the main reactance supply voltage. In view of this fact it will be understood that the current which flows down through the second stage main reactance winding 97 (in the direction shown by the arrow labeled "Reset Current") due to the conduction through the first stage main reactance winding 95, acts to provide reset for the second stage magnetic core member 98 and thereby determines the degree of reset of this core member. As a consequence a first stage main reactance winding 95 which has a relatively large number of turns and provides a low power output may be used to control the reset and consequently the conduction of the second stage magnetic amplifier which may be a relatively high power device. For example, such an arrangement utilizing the two stages may be readily used to supply a watt load.

It will be readily appreciated that the stages of amplification may be modified as suggested with regard to any of the single sided magnetic amplifier circuits illustrated herein. It should also be noted that the isolating rectifier 104 is only provided to prevent undesired feed back between stages and operation is possible without it.

As was pointed out with respect to the previous single sided magnetic amplifiers discussed, the load device 14 may be placed between the second stage saturating rectifier 105 and the second stage main reactor winding 97 or it may be connected in the lead between the second stage saturating rectifier 105 and the first stage saturating rectifier 99 without appreciably affecting operation of the amplifier.

Another circuit wherein stages of single winding magnetic amplifiers may be cascaded is provided as illustrated diagrammatically in FIGURE 9.

This arrangement includes the same components described with respect to the circuit of FIGURE 8 and therefore the corresponding components in the two circuits are given like reference numbers. However, the circuitry in the second stage of the magnetic amplifier illustrated in FIGURE 9 is arranged to prevent attenuation of the reset signal from the first amplifier stage by the second stage saturating rectifier 105. In this manner the problem of using taps in the second stage main reactor winding 97 to allow impedance matching between the second stage reactor and the output of the first amplifier stage is solved. The impedance matching problem here is precisely the same impedance matching problem discussed with regard to the circuit of FIGURE 4 and therefore this discussion is not repeated.

An inspection of the circuit illustrated in FIGURE 9 shows that the magnetic amplifiers are connected to be supplied from the transformer 90 as was discussed with respect to the circuit of FIGURE 8 and also that the reset and main reactor circuit of the first amplifier stage is identical to that described with respect to the circuit of FIGURE 8 with the exception that the second stage reset impedance 100 is connected to a tap 106 on the second stage main reactance winding 97. Thus the load circuit of the first amplifier stage includes only a portion of the second stage main reactance winding 97.

The main reactance circuit of the second stage may be traced from the upper reactance supply voltage terminal 93 through the load device 14, saturating rectifier 105, second stage main reactance winding 97 and back to the lower reactance voltage supply terminal 94. It will be noted that the second stage saturating rectifier 105 in the circuit of FIGURE 9 is reversed with respect to the corresponding saturating rectifier in the circuit of FIGURE 8 and therefore the load current in the second stage of this magnetic amplifier flows down in the direction labeled "Load Current." In view of this fact, the load current for both stages of the magnetic amplifier flow during the same half cycle of the reactance supply voltage. In order to render this circuit operative a bias must be applied to the second stage reactor core member 98 in such a manner as to completely reset this core once each half cycle. This biasing circuit includes a biasing impedance 107 connected in series with the main reactance winding 97 and a biasing voltage, which may be of the direct current type, is applied to this circuit between the biasing voltage terminals 108 and 109.

In order to provide control of the output of the second amplifier stage from the first amplifier stage the output of the first stage must be such as to drive the second stage in varying degrees out of reset; the degree being determined by the output of the first stage. The manner in which this function is accomplished is described below. Assume that the first stage amplifier is not reset and that the upper reactance supply terminal 93 is positive. Since the first stage amplifier is not reset it will start to conduct early in the cycle. Since the second stage amplifier is fully reset by the bias voltage, the reactance supply voltage will not cause it to fire immediately. When the first stage amplifier fires the potential of the tap 106 on the second stage main reactance winding 97 will approach the potential of the upper reactance supply voltage terminal 93. This is true since the first stage main reactance winding 95 has a low impedance when saturated and the drop across the first stage saturating rectifier 99, first main reactance winding 95 and reset impedance 100 will be fairly small. By transformer action a high potential is induced at the upper end of the second stage main reactance winding 97. The magnitude of this potential is determined by the potential applied at the tap 106 and the percentage of the main reactance winding 97 which is connected between this tap and the lower reactance terminal 94. Almost immediately upon the application of the high potential to the second stage main reactance winding 97 its core member 98 saturates and the second stage amplifier fires.

From the above description it is apparent that the second stage amplifier cannot fire until the first stage amplifier has fired and therefore the reset of the first stage controls the power output of the cascaded stages. Thus it will be appreciated that a relatively low power control signal applied to the first stage amplifier may be used to control the relatively high power output from the second amplifier stage.

The single sided magnetic amplifier illustrated in FIGURE 10 is provided specifically to obtain a circuit which may be utilized as a voltage and/or frequency reference circuit. As in the single winding amplifier circuits described previously, a reactor is provided which has a main reactance winding **110** wound on a magnetic core member **111**. The main reactance winding is preferably provided with a number of taps **112**. The main reactance circuit includes the main reactor winding **110**, a saturating rectifier **113**, and a load impedance device **14** (connected between load terminals **15** and **16**) connected in series with each other and across reactance supply voltage terminals **114** and **115**.

In order to provide a main reactance supply voltage a transformer **116** is provided with a primary winding **117** connected to receive an alternating current voltage and a secondary winding **118** connected to the reactor supply voltage terminals **114** and **115**. Reset for the circuit is provided by means of a reset impedance **119** connected between the lower reactance voltage supply terminal **115** and a tap on the main reactance winding **110**. Thus when the upper reactance voltage supply terminal **114** is positive flow current flows in a clock-wise direction around the main reactance circuit as shown by the arrow labeled "Load Current." On the opposite half cycle (the reset half cycle) the saturating rectifier **113** blocks current flow through this circuit. However, on this half cycle a reset current path is provided from the lower reactance voltage supply terminal **115** through the reset impedance **119**, the tapped portion of the main reactance winding **110**, to the upper reactance voltage supply terminal **114**. It will be recognized that this reset current flows through the main reactance winding **110** in a direction to reset the magnetic core member **111**. Since the degree of core reset is determined by the energy supplied to the core member **111** during the reset half cycle, the value of the reset impedance **119** and the percentage of the main reactance winding **110** included in the reset circuit may be adjusted to give the desired voltage across the load device **14**.

It has been found that by careful selection of the tap position on the main reactance winding **110** and the magnitude of the reset impedance **119** the voltage drop across the load device may be made relatively insensitive to supply voltage and frequency over a relatively wide range. It has been found that in general the reset circuit should encompass about ninety percent of the reactor winding **110**. This is explained by the fact that once the degree of reset is selected, a change in magnitude of applied voltage in one direction causes the degree of reset to change in the same direction and a change of supply voltage frequency simply shifts the reset point in a direction which tends to maintain the periods of current flow through the load occurring at a constant rate. For example, if the magnitude of the supply voltage increases the degree of reset increases. The reverse is true if the magnitude of the supply voltage decreases. If the frequency of the supply voltage increases (the magnitude remaining the same) the reset current will increase faster due to the steeper voltage wave front of the applied reset voltage thus tending to reset the core to a greater degree thereby causing the amplifier to fire later in the load current cycle and thus tending to keep the rate of occurrence of the periods of conduction constant regardless of the frequency change. The reverse is true if the frequency of the supply voltage decreases.

A full wave frequency and/or voltage reference is illustrated in FIGURE 11. The upper half of this circuit is identical to the circuit illustrated in FIGURE 10 and operates in exactly the same manner as was described with respect to the circuit of FIGURE 10. The corresponding components in the two circuits are given the same reference numerals. A second single sided amplifier circuit is provided in order to provide full wave operation, the second circuit includes a second main reactance winding **120** wound on a saturable core member **127** and having taps **121** thereon and a second saturating rectifier **122** connected in series with each other and the load device **14**. Power for the full wave circuit is provided by connecting a transformer **123** having a center tap secondary winding **124** and a primary winding **125** to receive a source of alternating voltage and connecting the upper half of its center tapped secondary winding to supply the reactor voltage supply terminals **114** and **115** and the lower half of its secondary winding between lower reactor voltage supply terminals **115** and **128** to supply the main reactance voltage for the lower half of the full wave circuit. The saturating rectifiers **113** and **122** for the two halves of the full wave circuit are oppositely poled so that a load current will flow through the load device **14** in the direction of the arrow labeled "Load Current" from one each half of the circuit on the opposite half cycles. A reset impedance **126** is connected between the taps **121** on the lower main reactor winding **120** and the middle reactance voltage supply terminal **115** to provide a reset current through a portion of the main reactance winding **120** in the direction shown by the arrow labeled "Reset Current" on the reset half cycle for the lower half of the full wave circuit. Thus it will be seen that the upper half of the full wave circuit provides load current during the half cycle when the lower half of the circuit is being reset and vice versa.

Since each half of the full wave circuit acts as a voltage and frequency reference as described with respect to the single sided circuit of FIGURE 10 it will be apparent that combining the two circuits as illustrated in FIGURE 11 provides a full wave frequency and voltage reference.

While particular embodiments of this invention have been shown it will, of course, be understood that the invention is not limited thereto since many modifications both in the circuit arrangements and in the instrumentalities employed may be made. It is contemplated that the appended claims will cover any such modifications as fall within the true spirit and scope of this invention.

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

1. A push-pull saturable core impedance device comprising a first core of magnetic material, a single conducting main reactor winding on said first core, means to alternately supply said main winding with a reactor voltage of one polarity from one voltage source and a reset voltage of opposite polarity from a second voltage source, a second core of magnetic material, a single conducting main reactor winding on said second core, means to alternately supply said main winding on said second core with a reactor voltage from one voltage source and a reset voltage of opposite polarity from another voltage source, a pair of load terminals for connection to an electric load device connected in series with both of said main reactor windings and their respective reactor voltage sources in such a manner that the voltage developed across said terminals by each circuit due to said reactor voltages is in an opposite sense.

2. A push-pull saturable core impedance device comprising a transformer having a tapped secondary winding, a pair of output terminals, a pair of individual magnetic core members, a single conducting main winding on each of said individual magnetic core members, each of said single conducting main windings connected from an opposite side of said secondary winding to one of said output terminals, the remaining output terminal being connected to the tap of said secondary winding, separate similarly poled unidirectional conducting devices connected in circuit relation with each of said main conducting windings whereby said main windings tend to conduct current simultaneously, at least one pair of reset voltage

input terminals, one of said reset terminals being connected to the tap of said secondary winding, at least a pair of reset impedances each connected to the other reset voltage terminal and to an opposite reactor main winding circuit in such a manner that two reset series circuits are provided each of which includes one of said reset impedances and at least a portion of one of said single main reactor windings whereby a current is produced in each of said series reset circuits by the reset voltage to provide magnetic reset for said core members.

3. A push-pull saturable core impedance device comprising a transformer having a tapped secondary winding, a pair of output terminals, a pair of individual magnetic core members, a single conducting main winding on each of said individual magnetic core members, each of said single conducting main windings connected from an opposite side of said secondary winding to one of said output terminals, the remaining output terminal being connected to the tap of said secondary winding, separate similarly poled unidirectional conducting devices connected between each main winding and said one output terminal whereby said main windings tend to conduct current simultaneously, at least one pair of reset voltage input terminals, the remaining one of said reset voltage terminals being connected to said one output terminal, at least a pair of reset impedances each connected to the other reset voltage terminal and to an opposite reactor main winding circuit in such a manner that two series reset series circuits are provided each of which includes one of said reset impedances and at least a portion of one of said single main reactor windings whereby a current is produced in each of said series reset circuits by the reset voltage to provide magnetic reset for said core members.

4. A push-pull saturable core impedance device comprising a transformer having a tapped secondary winding, a pair of output terminals, a pair of individual magnetic core members, a single conducting main winding on each of said individual magnetic core members, each of said single conducting main windings connected from an opposite side of said secondary winding to one of said output terminals, the remaining output terminal being connected to the tap of said secondary winding, separate similarly poled unidirectional conducting devices connected between each main winding and said one output terminal whereby said main windings tend to conduct current simultaneously, at least one pair of reset voltage input terminals, the remaining one of said reset voltage terminals being connected to said one output terminal, at least a pair of reset impedances each connected to the other reset voltage terminal and to an opposite reactor main winding circuit in such a manner that two series reset series circuits are provided each of which includes one of said reset impedances and at least a portion of one of said single main reactor windings whereby a current is produced in each of said series reset circuits by the reset voltage to provide magnetic reset for said core members, and separate biasing voltages connected across at least a portion of each single conducting main winding whereby the initial condition of said core members is set.

5. A push-pull saturable core impedance device comprising a transformer having a tapped secondary winding, a pair of output terminals, a pair of individual magnetic core members, a single conducting main winding on each of said individual magnetic core members, each of said single conducting main windings connected from an opposite side of said secondary winding to one of said output terminals, the remaining output terminal being connected to the tap of said secondary winding, separate oppositely poled unidirectional current conducting devices connected in circuit relation with each of said main conducting windings whereby said main windings tend to conduct current on opposite half cycles of an alternating voltage across the secondary winding of said transformer, individual series reset circuits for each of said magnetic core members, each of said series reset circuits including an individual reset impedance and at least a portion of a single conducting main winding, said individual reset circuits being connected to receive the voltage developed across an opposite half of said tapped secondary winding.

6. A saturable core impedance device comprising a core of saturable magnetic material having a winding thereon, a load circuit for connection across a first voltage source, said load circuit including a unidirectional conducting device and said winding, and a reset circuit for connection across a second voltage source, said reset circuit being connected to said load circuit in parallel with said winding and in series with said unidirectional conducting device relative to said first voltage source whereby reset current flows to said winding during non-conducting periods of said load circuit without passing through said first voltage source.

7. A saturable core impedance device comprising a core of saturable magnetic material having a winding thereon, a load circuit for connection across a first alternating voltage source, said load circuit including a first unidirectional device and said winding, and a reset circuit for connection across a second alternating voltage source, said reset circuit including a second unidirectional conducting device and being connected to said load circuit in parallel with said winding and in series with said first unidirectional conducting device, said second unidirectional device being polarized to deliver reset current to said winding only during non-conducting periods of said load circuit, said reset current being blocked by said first unidirectional conducting device from passing through said first voltage source.

8. A saturable core impedance device comprising a core of saturable magnetic material having a winding thereon, means for developing two alternating voltages of like frequency, a load circuit including a first unidirectional device and said winding connected to receive one of said voltages and a reset circuit connected to receive the other of said voltages, said reset circuit including a reset impedance and a second unidirectional conducting device and being connected to said load circuit in parallel with said winding and in series with first unidirectional conducting device, said first and second unidirectional conducting devices being similarly poled relative to said one voltage whereby reset current flows through said winding during non-conducting periods of said load circuit in a direction opposite to load current and without passing through said one voltage source.

9. A saturable core impedance device comprising a core of saturable magnetic material having a winding thereon, a load circuit including a first unidirectional conducting device and a first pair of input terminals for connection to a first alternating voltage source, and a reset circuit including a second unidirectional conducting device and a second pair of input terminals for connection to a second alternating voltage source, said reset circuit being connected to said load circuit in parallel with said winding and in series with both said first unidirectional conducting device and said first input terminals, said unidirectional conducting devices being polarized relative to one another alternately to deliver current to said winding in opposite directions.

10. A saturable core impedance device comprising a core of saturable magnetic material having a winding thereon, a load circuit for connection across a first alternating voltage source, said load circuit including a first unidirectional conducting device and said winding, a reset circuit for connection across a second alternating voltage source, said reset circuit including a second unidirectional conducting device and being connected to said load circuit in parallel with said winding and in series with said first unidirectional conducting device whereby reset current flows through said winding in a direction opposite to load

current therein during non-conducting periods of said load circuit without passing through said first voltage source, and means connected in parallel with at least a portion of said winding for supplying a biasing voltage across said winding portion.

11. A saturable core impedance device comprising a core of saturable magnetic material having a winding thereon; a load circuit including a first unidirectional conducting device, said winding, a pair of output load terminals, and a first pair of input terminals; and a reset circuit including a second unidirectional conducting device, a reset impedance and a second pair of input terminals connected to said load circuit in parallel with said winding and said output terminals and in series with said first unidirectional conducting device and said first input terminals; said unidirectional conducting devices being polarized alternately to deliver current to said winding in opposite directions from alternating voltages supplied to said input terminals.

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