

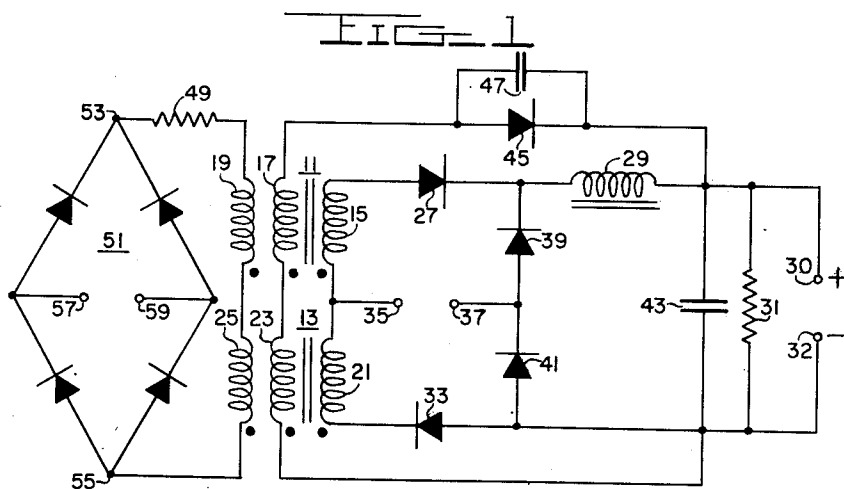
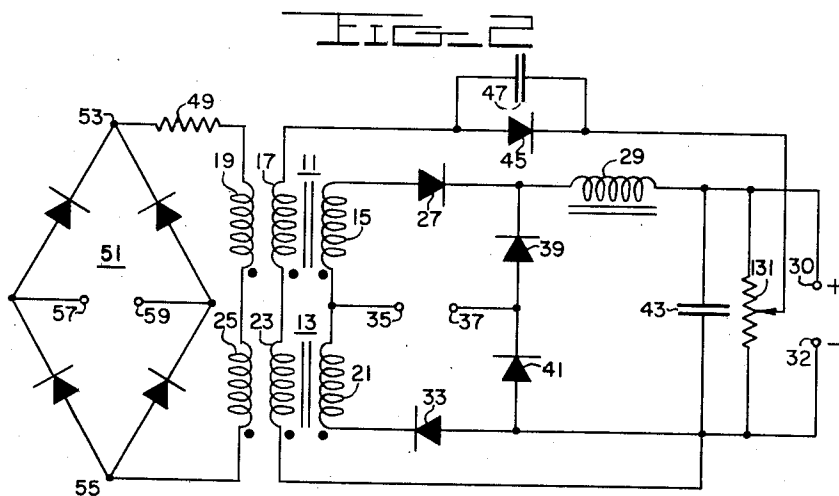
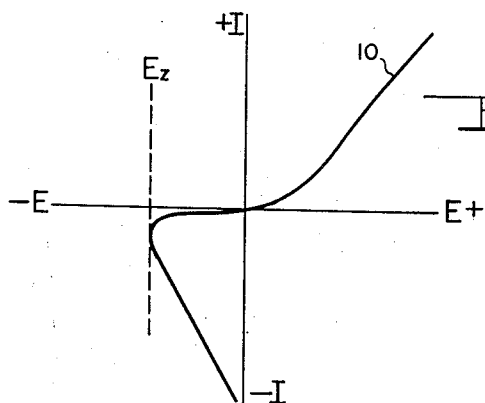
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REGULATED D. C. POWER SUPPLY

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REGULATED D. C. POWER SUPPLY

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The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

This invention relates to voltage regulated rectifiers and more particularly to rectifiers employing magnetic amplifier circuits and the Zener breakdown characteristic of a silicon-junction diode. In this invention the regulated D.-C. voltage is produced from non-electronic components. The voltage reference is the Zener breakdown voltage of a crystal rectifier such as a silicon-junction diode, when such voltage is applied to the diode in a polarity reverse to that of the normal polarity of the voltage application to the diode.

With silicon-junction diodes the Zener breakdown voltage can be established in a range from about 5 to 20 volts. By applying a silicon-junction diode in the control winding of a reset type magnetic amplifier circuit, voltage regulation is achieved.

An object of this invention is to provide a voltage regulator producing a constant D.-C. voltage.

Another object of this invention is to provide a voltage regulator employing only magnetic components.

Another object of this invention is to provide a D.-C. voltage regulator using a Zener breakdown voltage as a reference level.

Another object of this invention is to provide a voltage regulator employing a reset type magnetic amplifier circuit in which a silicon-junction diode is used in the control winding.

A further object of this invention is to provide a magnetic amplifier circuit for unidirectional voltage regulation.

Other objects and many of the attendant advantages of this invention will be readily appreciated at the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawing in which like reference numerals designate like parts throughout the figures thereof and wherein:

Fig. 1 illustrates the circuit of a preferred embodiment of this invention.

Fig. 2 of the drawing illustrates an embodiment of the invention in which a variable tap is provided for connecting the control circuit to the output circuit.

Fig. 3 illustrates the Zener breakdown characteristic curve of a silicon-junction diode as used in this invention.

In the reset type magnetic circuit as used in this invention, the cycle of operation is the complete cycle of an alternating voltage source, for example, a positive and a negative half-cycle of such source. Reset magnetic amplifiers include saturable cores, a control winding and a load winding on each core and control circuits and load circuits for each winding. The control circuits and load circuits are equipped with unidirectional current flow means poled so that for a given core, the current flows in the load circuit on one half-cycle, for example, the positive half-cycle, and current flows through the control circuit on the other half-cycle, for example, the negative half-cycle. The current flow through the load winding will drive the core to saturation and the current flow

through the control winding will cause the core to deviate from saturation. The degree of desaturation accomplished during the control or reset half-cycle depends upon the bucking potential in the control circuit.

The response time for the reset magnetic amplifier is one half-cycle. During a first half-cycle, the voltage is first applied to the load winding. As soon as the core becomes saturated or "fired" the load winding appears as a short circuit and the voltage applied to the load circuit appears across the load. Since high remanence cores are used, the saturation level established by the load winding will remain until the control circuit demagnetizing current flows. During the control or reset half-cycle, voltage will be applied to the core in a direction to demagnetize the core. The extent of demagnetization may depend upon the magnitude of a bucking potential source. The degree of demagnetization effected will vary from zero demagnetization when the bucking potential is equal to the alternating voltage applied in the control circuit, to complete demagnetization when the bucking potential is zero. The magnetization level of the core thus determined by the control circuit will affect the length of time that the alternating voltage applied in the load circuit appears at the load resistor. If the demagnetization by the control circuit were complete in a half-cycle previous to a particular load half-cycle, the applied alternating voltage will appear across the load winding for a large portion of the load half-cycle and the applied voltage will appear across the load for a small portion of the load half-cycle. Hence the resulting output from the magnetic amplifier will be relatively small. If, on the other hand the demagnetization by the control circuit was zero in a half-cycle previous to a particular load half-cycle, then the applied alternating voltage source will appear across the load for the entire load half-cycle and the output from the magnetic amplifier thus is relatively large.

In the present invention the reset magnetic circuit is employed in conjunction with a silicon-junction diode to produce a voltage regulation device. The control windings of saturable cores are part of a circuit in which a voltage is applied across a silicon-junction diode in the reverse polarity. When the voltage applied to the diode exceeds the Zener breakdown voltage, current will flow in the circuit including the control windings of the saturable core. Such current flow in the windings will reduce the magnetization level of the core to effect a change in the time integral of the output voltage in the load circuit. The load resistor for the magnetic cores is also the output for the regulated voltage.

Referring now to Fig. 1 of the drawings in which a voltage regulator circuit employing a reset type magnetic amplifier is shown, saturable cores 11 and 13 each have a load winding, a control winding, and a bias winding. Core 11 has load winding 15, control winding 17, and bias winding 19, and core 13 has load winding 21, control winding 23, and bias winding 25. A load circuit includes in part, serially connected load windings 15 and 21 in series with inductor 29, load resistor 31 and rectifier 33. A line or supply voltage, E_{ac} connects between the load winding 15 and 21 at terminal 35 and between rectifiers 39 and 41 at terminal 37. The other terminal of rectifier 39 connects between rectifier 27 and inductor 29. One terminal of rectifier 41 connects between rectifier 33 and one terminal of load resistance 31. Capacitor 43 connects in parallel to the load resistance 31. Inductance 29 and capacitor 43 form a filter for the rectifier output. The control circuit comprises a series circuit containing serially connected control windings 17 and 23 in series with silicon-junction diode 45, and load resistor 31. A bias circuit includes serially connected windings 19 and 25 in series with resistor 49 and rectifier bridge 51. One end of resistor 49 connects to juncture 53 of the rectifier bridge 51

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and one end of winding 25 connects to juncture 55 of rectifier bridge 51. An alternating voltage is supplied to terminals 57 and 59 and a direct voltage appears at junctures 53 and 55 to supply a direct magnetizing voltage to cores 11 and 13. Resistor 49 limits the current flow through the bias windings.

The dots on the end of core windings indicate the polarity or winding sense. For example, a core having windings with dots at the same end will be magnetized in the same sense in response to voltages of the same polarity applied to each winding. The dots at one end of the winding indicate a winding sense such that if a particular polarity voltage is applied, the core will be magnetized in a particular direction and if the dot is at the other end, with the same polarity of voltage applied, the core will be magnetized in the opposite direction. The relationship of the voltage polarity to the direction of magnetization as shown by the dots in Fig. 1 is consistent throughout the drawing. The winding sense as indicated by the dots is the same for all the windings in cores 11 and 13.

In Fig. 3 of the drawings the approximate relationship of the applied voltage to the current flow for a silicon-junction diode is illustrated. $+E$ indicates a voltage polarity for normal operation and $-E$ indicates a voltage of reverse polarity applied to the silicon-junction diode in which the reverse direction current flow is plotted as $+I$ and $-I$ along the ordinate. Curve 10 indicates approximately the relationship between voltage applied to the rectifier and the resultant flow. As the positive voltage increases, the current flow increases. When voltage is applied in the opposite polarity or $-E$ direction, the current flow is extremely small increasing slightly until the voltage E_z or the Zener breakdown voltage is reached. When the breakdown voltage is reached, the current flow will increase sharply.

In operation, an alternating voltage is applied to terminals 35 and 37. On the positive half-cycle, that is for example, when terminal 35 is positive and terminal 37 is negative, the current flow path is through rectifier 41, load resistor 31, inductor 29, rectifier 27, load winding 15 on core 11. In the initial portion of this half-cycle, core 15 will be unsaturated and the winding impedance will be high until the core becomes saturated. The greatest part of the applied voltage during the time interval that the core is unsaturated will appear across winding 15. As soon as core 11 becomes saturated, the greatest part of voltage E_{ac} applied at terminals 35 and 37 will appear across load resistor 31.

As pointed out earlier, the time portion of the half-cycle in which the applied voltage E_{ac} appears across load resistor 31 depends upon the state or level of saturation of the core at the beginning of the half-cycle which in turn depends on the degree of demagnetization accomplished by the control circuit in the previous half-cycle.

Consider now the control circuit including the silicon-junction diode 45 and control windings 17 and 23 with respect to the rectifier operation. Viewing saturable cores 11 and 13 as parts of a magnetic amplifier circuit, core 11 is 180° out of phase with core 13. A saturating voltage is applied to core 11 during the half-cycle in which there is current flow through winding 15 and core 13 is saturated during the other half-cycle in which there is a current flow through winding 21. The silicon-junction diode 45 is poled for current flow from the positive terminal 30 through diode 45 through winding 17 and winding 23 and then to negative terminal 32. When the potential across silicon-junction diode 45 in reverse polarity exceeds the Zener breakdown voltage, current will flow in the control circuit in the direction of the reverse polarity. If the breakdown voltage is exceeded during the first half-cycle or the half-cycle in which current is flowing through winding 15 and since the current flow through winding 17 is of the opposite direction of that through winding 15, the resulting current flow through winding 17 tends to reduce the saturation level of core 11. On the second

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half-cycle of operation, current flows through winding 21 until core 13 reaches the saturation level. At this point the E_{ac} will be applied to terminals 30 and 32. However, since on the previous half-cycle the control current through winding 23 has partially or fully desaturated or reset core 13, the output voltage will be applied to terminals 30 and 32 for a shorter period of time, and hence the effective D. C. level of the output voltage is reduced. Should the output voltage level during the second half-cycle create a voltage drop across silicon-junction diode 45 greater than the reverse breakdown potential, current will again flow through the control windings 17 and 23 at the beginning of the second half-cycle, core 11 is at a particular saturation level as set by the previous half-cycle. Current flow through winding 17 will partially or totally desaturate or partially saturate in the reverse sense core 11 such that in the succeeding half-cycle of operation a greater portion of the applied alternating voltage will be used to saturate core 11. This will reduce the time portion of the half-cycle of the voltage appearing at the output terminals and hence the D. C. level will be reduced.

The voltage appearing at the load terminals acts as a source voltage for the control circuit. When the voltage E_L at the load is less than E_z or the Zener breakdown voltage there will be no current flow in the control circuit and voltage E_L will appear across the silicon-junction diode 45. Whenever E_L becomes greater than E_z , the diode 45 breaks down and the voltage applied will be divided among control windings 17, 23 and the diode 45. Diode 45 now becomes a low resistance and the voltage E_L is divided largely between control windings 17 and 23. The voltage across the control winding will act to demagnetize the core going through its reset half-cycle. For example at the beginning of the negative half-cycle core 11 will be saturated from the previous positive half-cycle. If the voltage E_L becomes greater than E_z during this negative half-cycle, the current will flow through the control circuit and demagnetizing energy from control winding 17 will be applied to core 11.

The extent of demagnetization of core 11 will depend upon the magnitude of the voltage in the control circuit and hence the magnitude of the voltage applied to the load terminals. The higher the output voltage, the greater the voltage across the control winding and greater amount of demagnetization results. On the second positive half cycle the output voltage will depend upon the magnetization level of core 11 at the beginning of the cycle. If core 11 has been demagnetized a great amount, then the output voltage on the second half cycle will be low. If the core has not been demagnetized or demagnetized a small amount then the output voltage during the second positive half cycle will be high. Thus a control of the output voltage is effected.

In the explanation of the operation, only core 11 was discussed. However, the operation of core 13 is identical although it will operate on alternate half cycles. That is, when core 11 is experiencing the load half cycle, core 13 will be experiencing the control half cycle. With such arrangement, full wave voltage regulation is achieved.

To further regulate the magnitude of the output voltage, bias windings 19 and 25 may be supplied with demagnetizing voltage from rectifier circuit 51. If an alternating voltage is applied to terminals 57 and 59, a direct demagnetizing current will flow through windings 19 and 25. This current will be small compared to the currents flowing in the load and control circuits. With such demagnetizing bias windings, the output voltage may be reduced. With this demagnetizing effect applied to the cores, less regulation by the control circuit will be necessary. The amount of demagnetization desired by the bias winding may be controlled by changing the size of the current limiting resistor 49.

In the load circuit, inductor 29 and capacitor 43 or

a filter circuit to reduce the ripple voltage at the output terminals.

Referring now to Fig. 2 illustrating an embodiment of the invention in which a variable tap is provided, resistor 131 has tap 105 connecting the control circuit to the output circuit. By moving tap 105 along resistor 131 variable amounts of voltage can be applied to the control circuit with the tap positioned at the positive end of load resistor 131, the full output voltage of the regulator will be applied to the control circuit. With the tap positioned at any other place the voltage applied to the control circuit will be less than the output voltage of the regulator. With a variable tap on the control circuit, it is possible to operate the regulator with an output voltage larger than the Zener breakdown voltage of the silicon-junction diode.

Capacitor 47 is added to filter any pulses from the rectifier voltage reference.

Since the width of the hysteresis loop will vary with the frequency of the applied voltage, current limiting resistor 49 will be varied accordingly. For the particular frequency of operation, resistor 49 should be sized so that the current in the load circuit will remain approximately constant at fixed ambient temperatures. Silicon-junction diodes with either positive, zero or negative coefficients may be used, however since the cores may require a change in magnetizing current with a change in ambient temperature, a diode with a negative temperature coefficient may be advantageous.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

I claim:

1. A voltage regulator comprising a full wave magnetic amplifier having two cores saturated alternately upon successive half cycles of an alternating voltage, a series control circuit comprising two control windings and a diode connected across the amplifier output, said diode poled such that current flow will occur when the Zener breakdown voltage is exceeded across said diode.

2. A voltage regulator comprising a full wave reset magnetic amplifier, a control circuit including control windings and a silicon junction diode connected across the amplifier output, said diode poled reverse to the current flow polarity of the amplifier output voltage.

3. A voltage regulator comprising a pair of saturable cores, a control winding, a load winding on each of said cores, a load circuit including a load impedance serially connected to said load windings, an alternating voltage source, a plurality of unilateral impedance means connecting said source and said load winding, said impedance means poled to provide a magnetizing voltage across a first one of said load windings during the odd half cycles of said source and across a second one of said load windings during the even half cycles of said source, a control circuit including said control windings and a silicon junction diode serially connected to said load impedance, said diode connected such that a demagnetizing voltage will appear across said control windings when the voltage across said diode exceeds the breakdown voltage of said diode.

4. A voltage regulator comprising a pair of saturable cores, a control winding a bias winding and a load winding on each of said cores, a load circuit including a load impedance serially connected to said load windings, an alternating voltage source, a plurality of unilateral impedance means connecting said source and said load windings, said impedance means poled to provide a magnetizing voltage across a first one of said load windings during the odd half cycles of said source and across a second one of said load windings during the even half cycles of said source, a control circuit including said control windings and a silicon junction diode serially connected to said load impedance, said diode connected such that a demagnetiz-

ing voltage will appear across said control windings when the voltage across said diode exceeds the breakdown voltage of said diode, a bias circuit comprising said bias windings serially connected, a unidirectional voltage source connected to said bias windings poled to partially demagnetize said cores.

5. A voltage regulated rectifier comprising, a full wave reset type magnetic rectifier having two saturable cores, a load winding on each of said cores, a control winding on each of said cores, a pair of direct current output terminals, a load resistor between said terminals, an alternating supply voltage; a first load circuit including said load winding of said first core, rectifier means, said alternating voltage and said output terminals to provide a D. C. voltage output across terminals during the firing half cycle of said first core; a second load circuit including said load winding of said second core, rectifier means, said alternating voltage and said output terminals to provide a D. C. voltage output across said terminals during the firing half cycle of said second core; a control circuit including said control windings and a silicon junction diode crystal connected to said output terminals, said diode operative to breakdown and cause current flow through the control windings to desaturate the core that is on its reset half cycle.

6. A voltage regulator comprising a pair of saturable cores, a control winding and a load winding on each of said cores, a load circuit including a load resistor having a variable tap serially connected to said load windings, an alternating voltage source, a plurality of unilateral impedance means connecting said source and said load windings, said impedance means poled to provide a magnetizing voltage across a first one of said load windings during the odd half cycles of said source and across a second one of said load windings during the even half cycles of said source, a control circuit including said control windings and a silicon junction diode serially connected to the variable tap and one terminal of said load resistor, said diode connected such that a demagnetizing voltage will appear across said control windings when the voltage across said diode exceeds the breakdown voltage of said diode.

7. A voltage regulator comprising a full wave magnetic amplifier having two cores saturated alternately upon successive half cycles of an alternating voltage, a bias winding and a series control circuit comprising two control windings and a diode serially connected to the amplifier output, said diode poled such that current flow will occur when the Zener breakdown voltage is exceeded across said diode, a bias circuit comprising said bias windings serially connected, a unidirectional voltage source connected to said bias windings poled to partially demagnetize said cores.

8. A voltage regulator comprising a full wave reset magnetic amplifier, a bias winding and a control circuit including control windings and a silicon junction diode serially connected to the amplifier output, said diode poled reverse to the current flow polarity of the amplifier output voltage, a bias circuit comprising said bias windings serially connected, a unidirectional voltage source connected to said bias windings poled to partially demagnetize said cores.

9. A voltage regulator as set forth in claim 8 including a capacitor connected in parallel with said silicon junction diode.

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Disclaimer

2,816,260.—*Donald G. Scorgie*, Pittsburgh, Pa. REGULATED D.C. POWER SUPPLY. Patent dated Dec. 10, 1957. Disclaimer dated Feb. 20, 1963, by the assignee, *United States of America as represented by the Secretary of the Navy*.

Hereby enters this disclaimer to claims 1, 2, 3, 5 and 6 of said patent.
[*Official Gazette April 9, 1963.*]

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