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(54) **COLLECTORLESS DIRECT CURRENT MOTOR, DRIVER CIRCUIT FOR A DRIVE AND METHOD OF OPERATING A COLLECTORLESS DIRECT CURRENT MOTOR**

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(21) Appl. No.: **08/243,331**

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PCT Pub. Date: **Apr. 23, 1987**

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**Related U.S. Patent Documents**

Reissue of:

(64) Patent No.: **4,804,892**  
Issued: **Feb. 14, 1989**  
Appl. No.: **07/072,264**  
Filed: **Jun. 22, 1987**

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(30) **Foreign Application Priority Data**

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(57) **ABSTRACT**

(51) **Int. Cl.<sup>7</sup>** ..... **H02P 6/08**  
(52) **U.S. Cl.** ..... **318/254; 318/472**  
(58) **Field of Search** ..... 318/138, 254,  
318/439, 471, 472, 473, 599

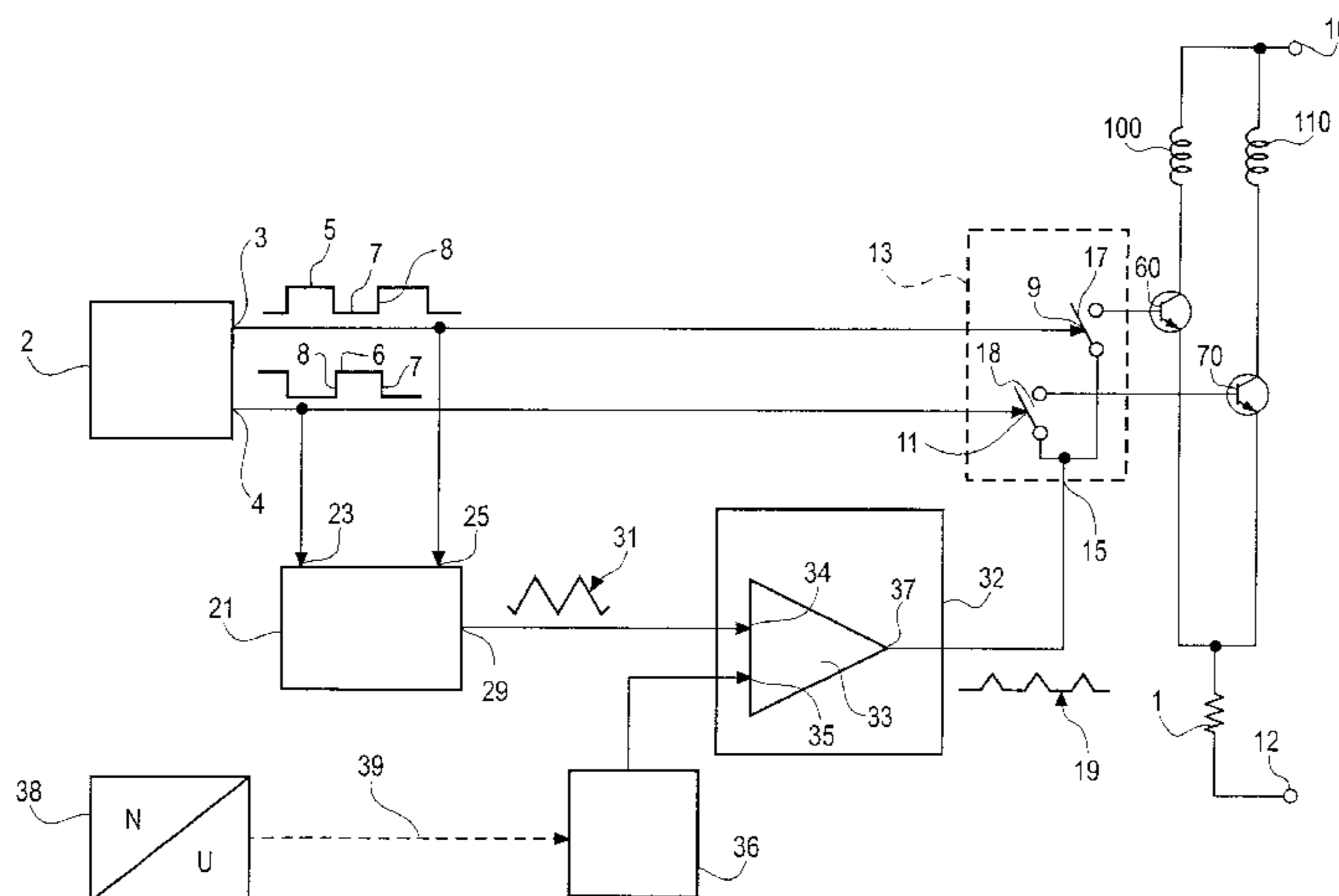
A method for the low-loss regulation of a collectorless direct current motor and a semiconductor circuit has, during the commutation phase given by a position sensor and with reduced motor output and number of revolutions, transistors or one end transistor which initially operates temporarily as a switch and thereafter operates temporarily as an analog amplifier element. During the analog period, a current is available which changes slowly according to a ramp function.

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**9 Claims, 10 Drawing Sheets**



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FIG. 1

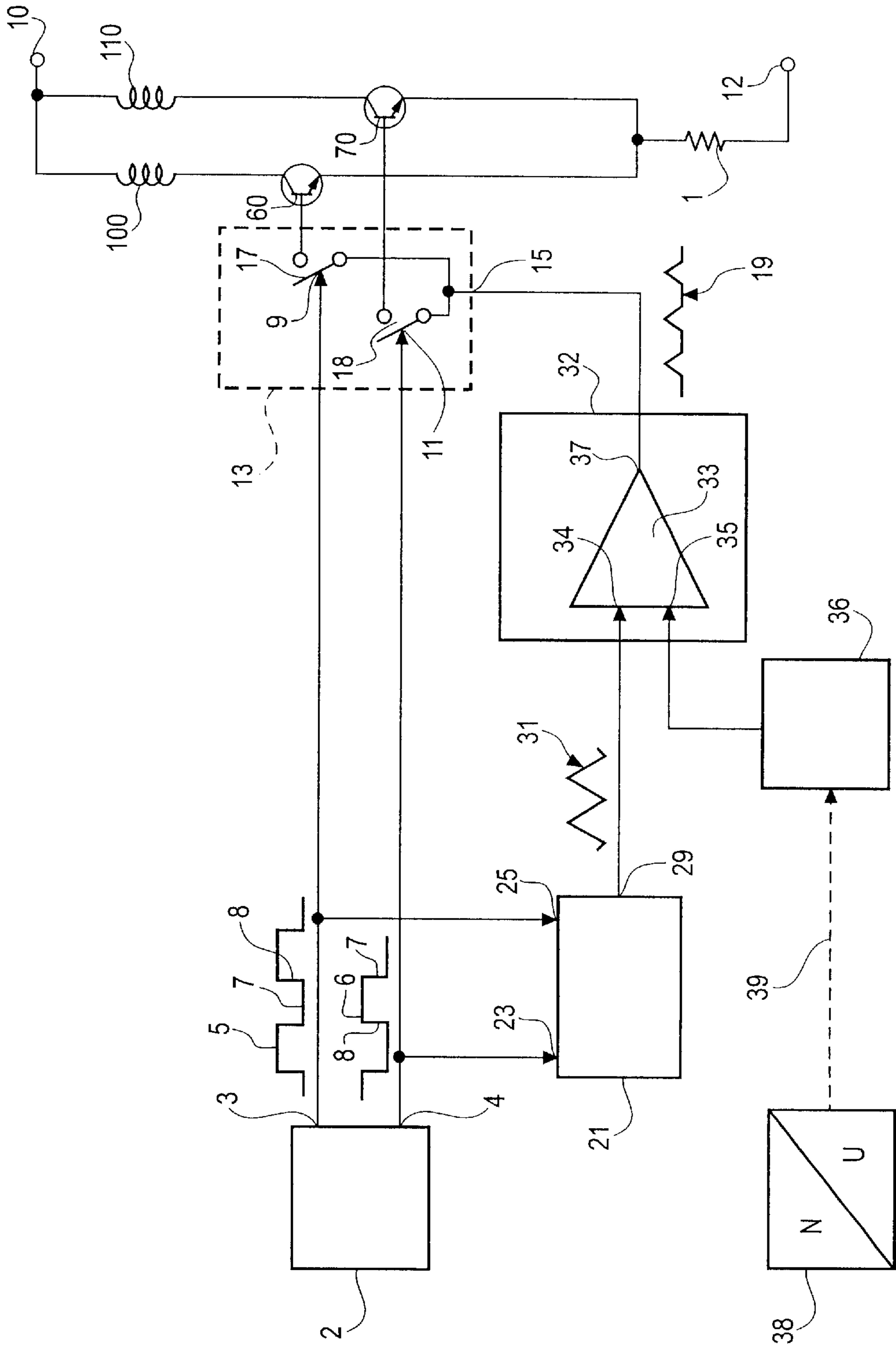


FIG. 2

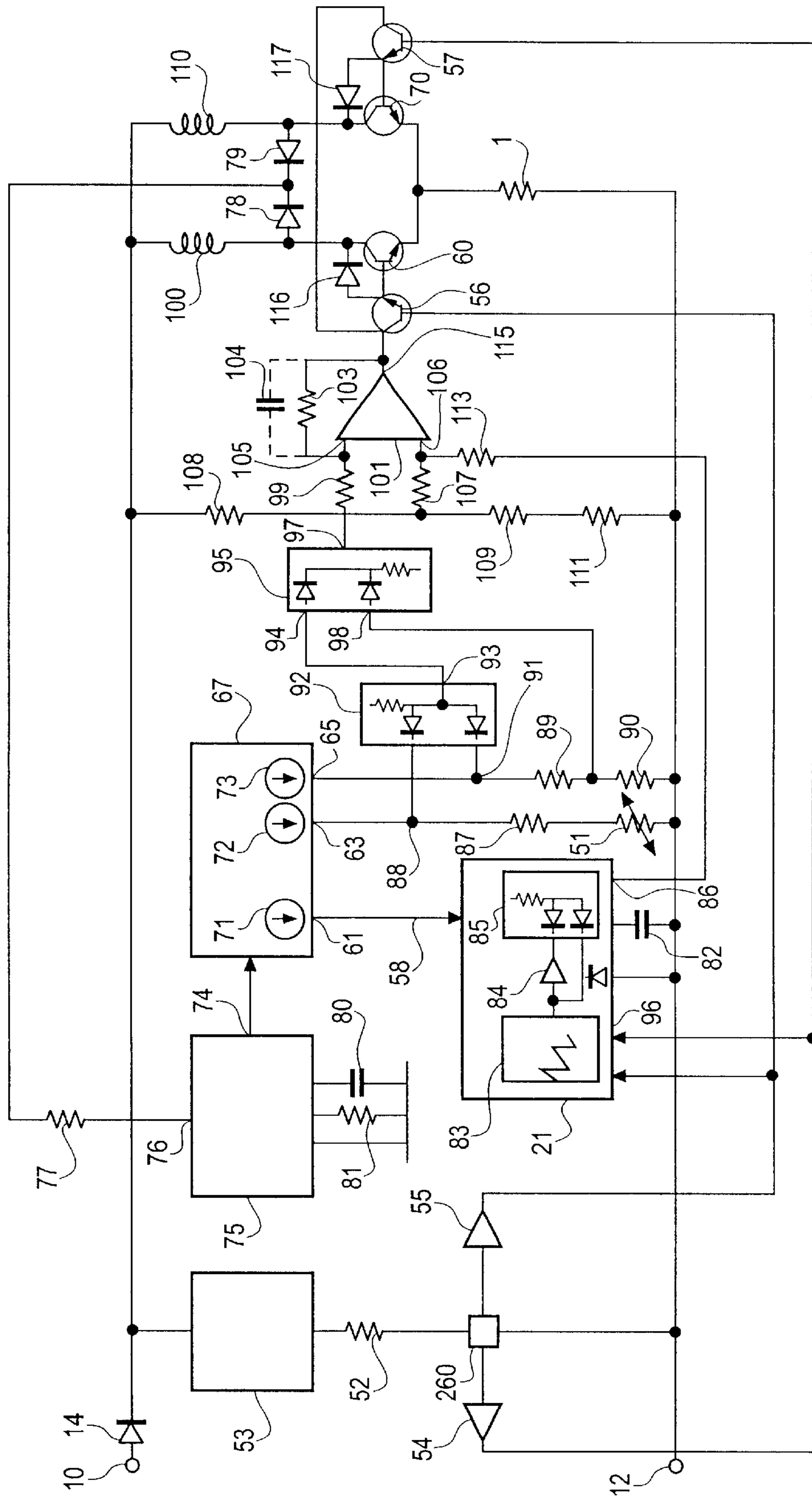
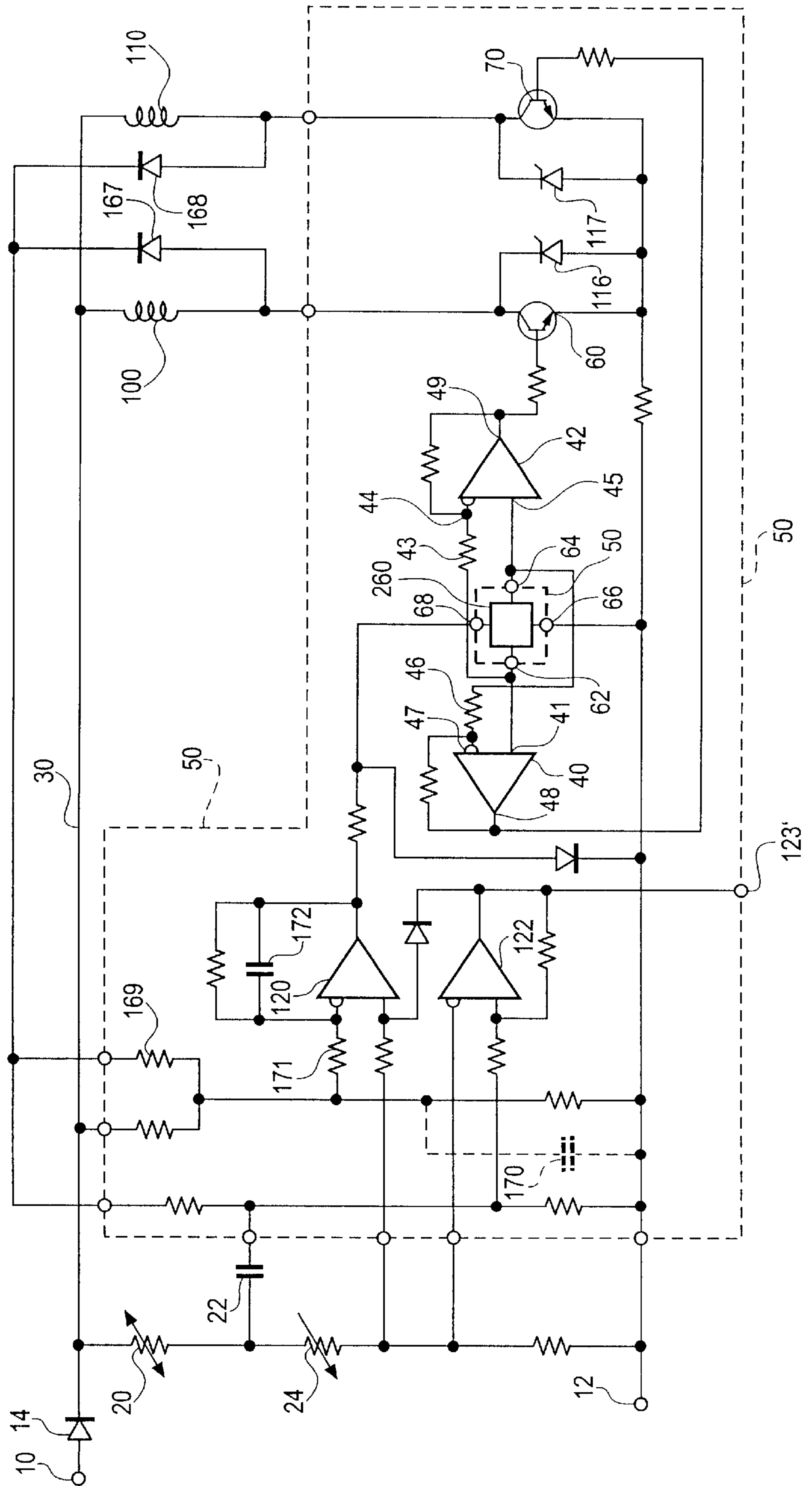


FIG. 3



**FIG. 4**

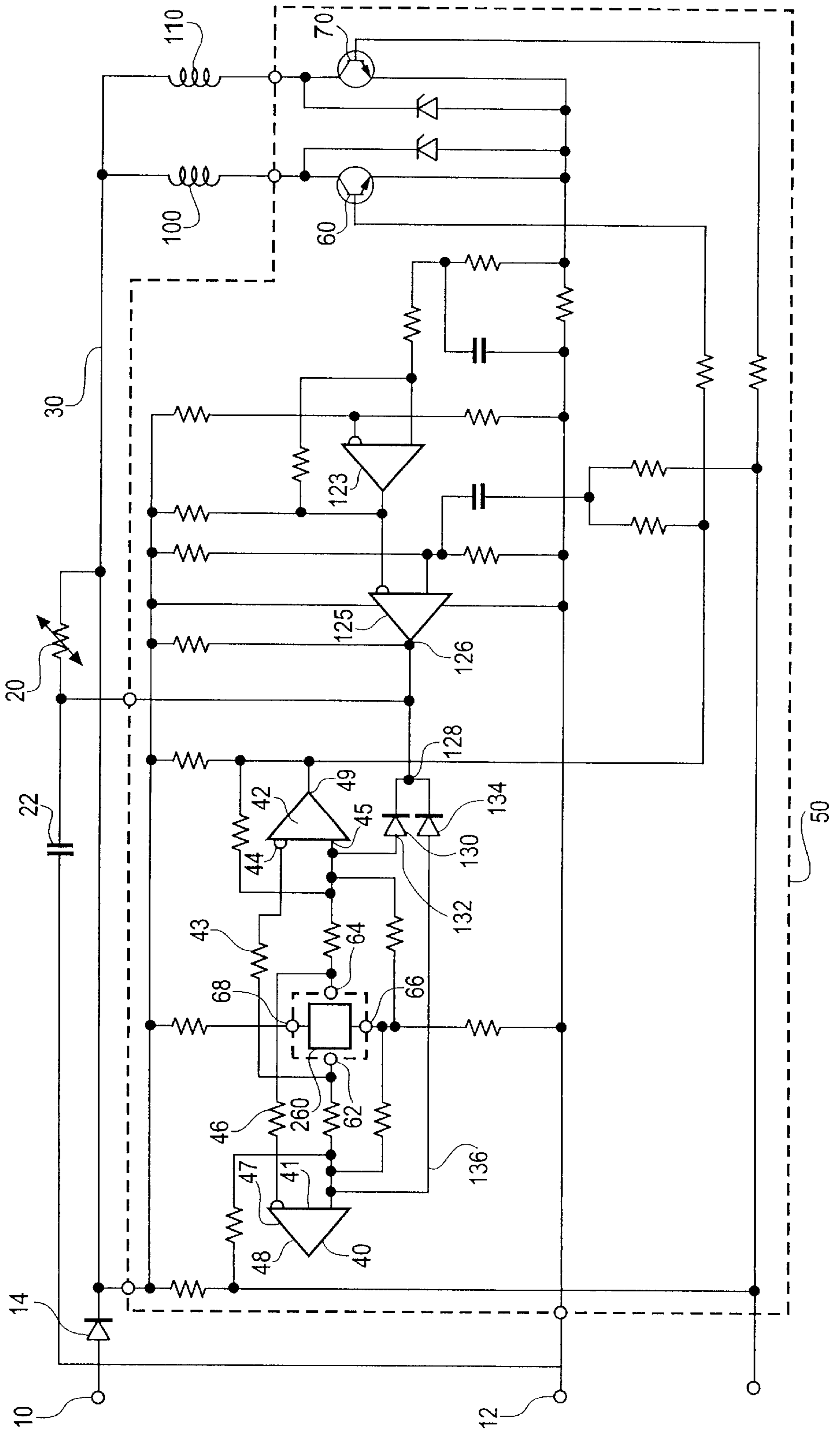


FIG. 5

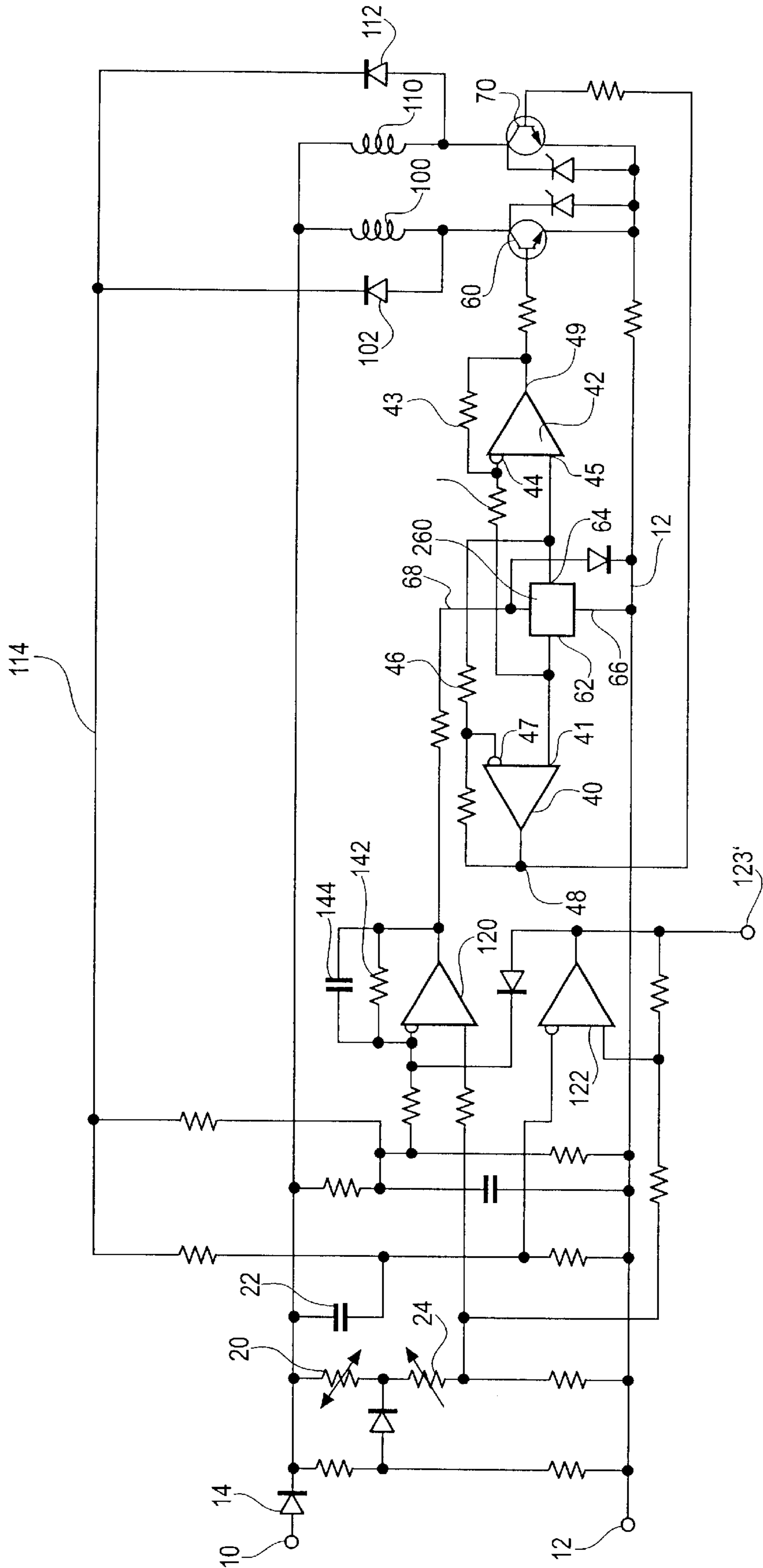


FIG. 6

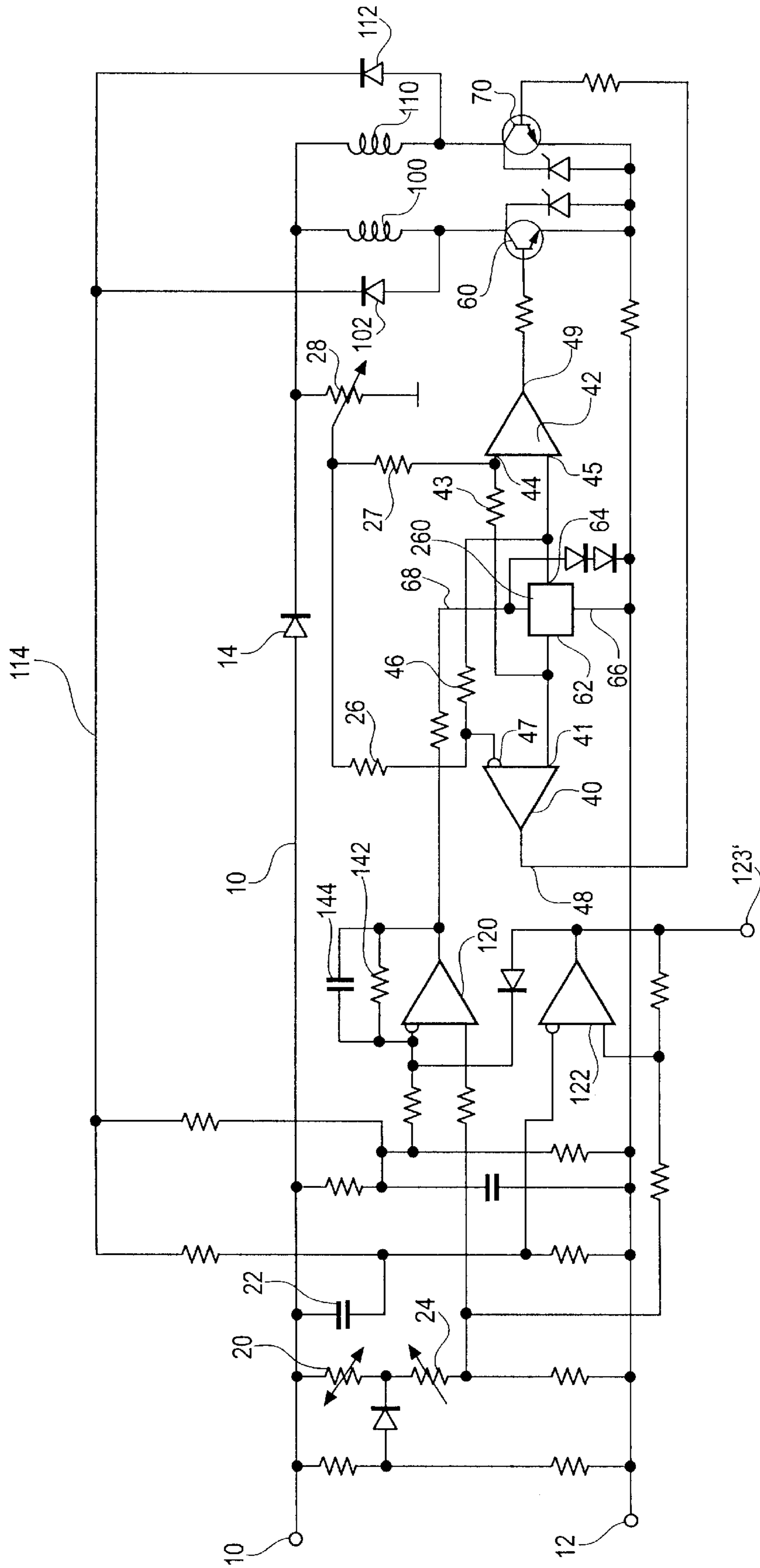




FIG. 7

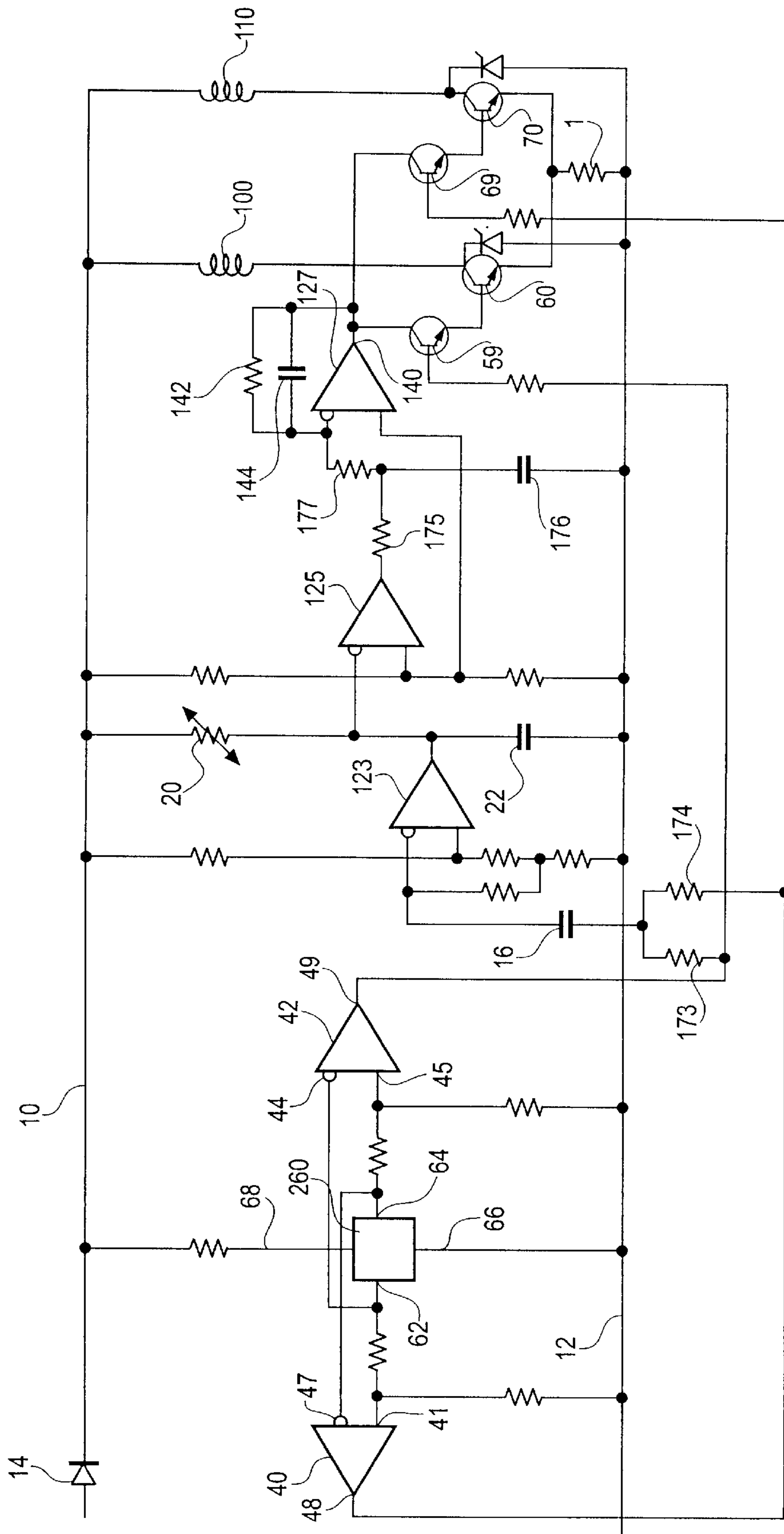


FIG. 8

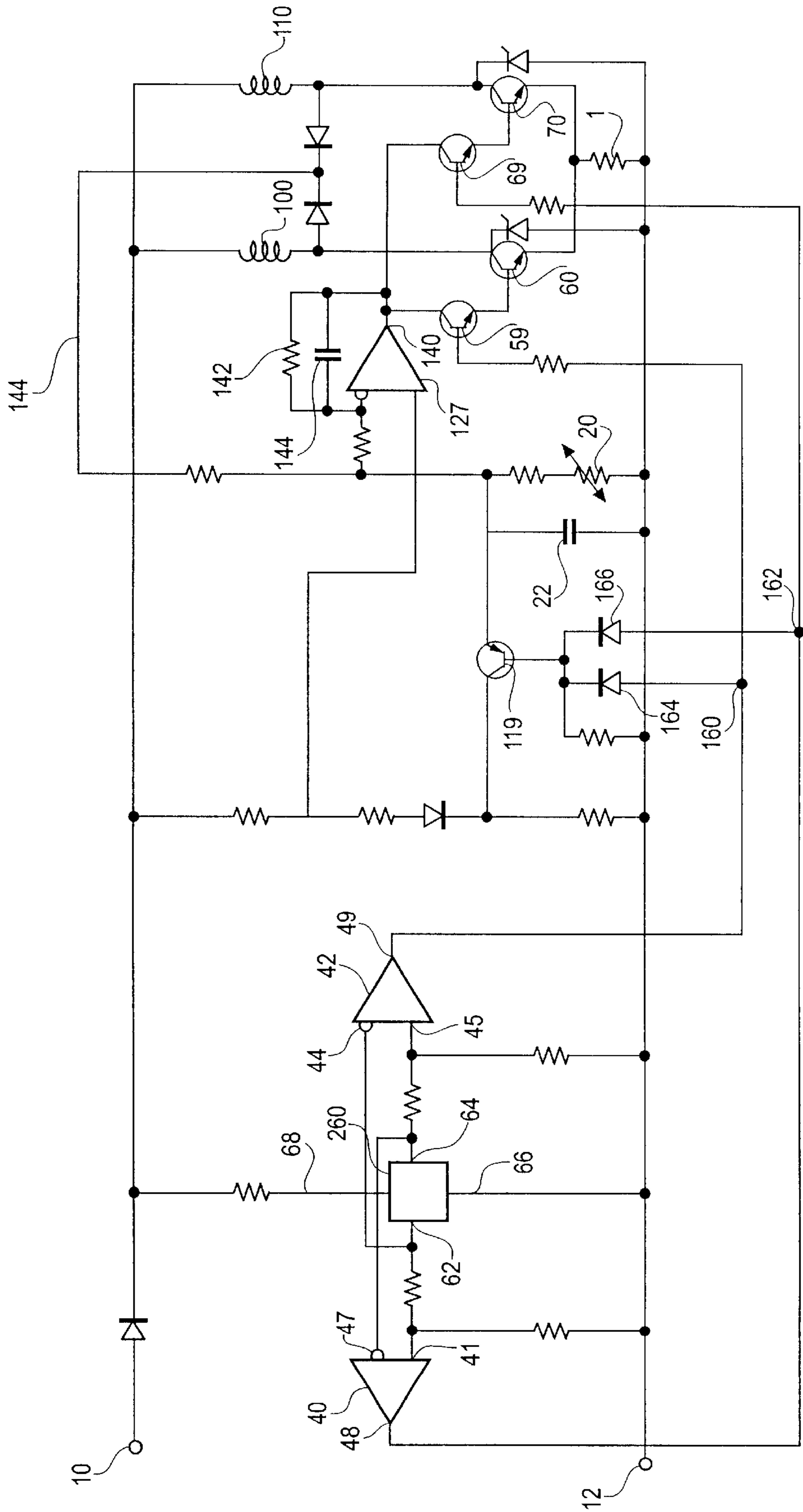


FIG. 9

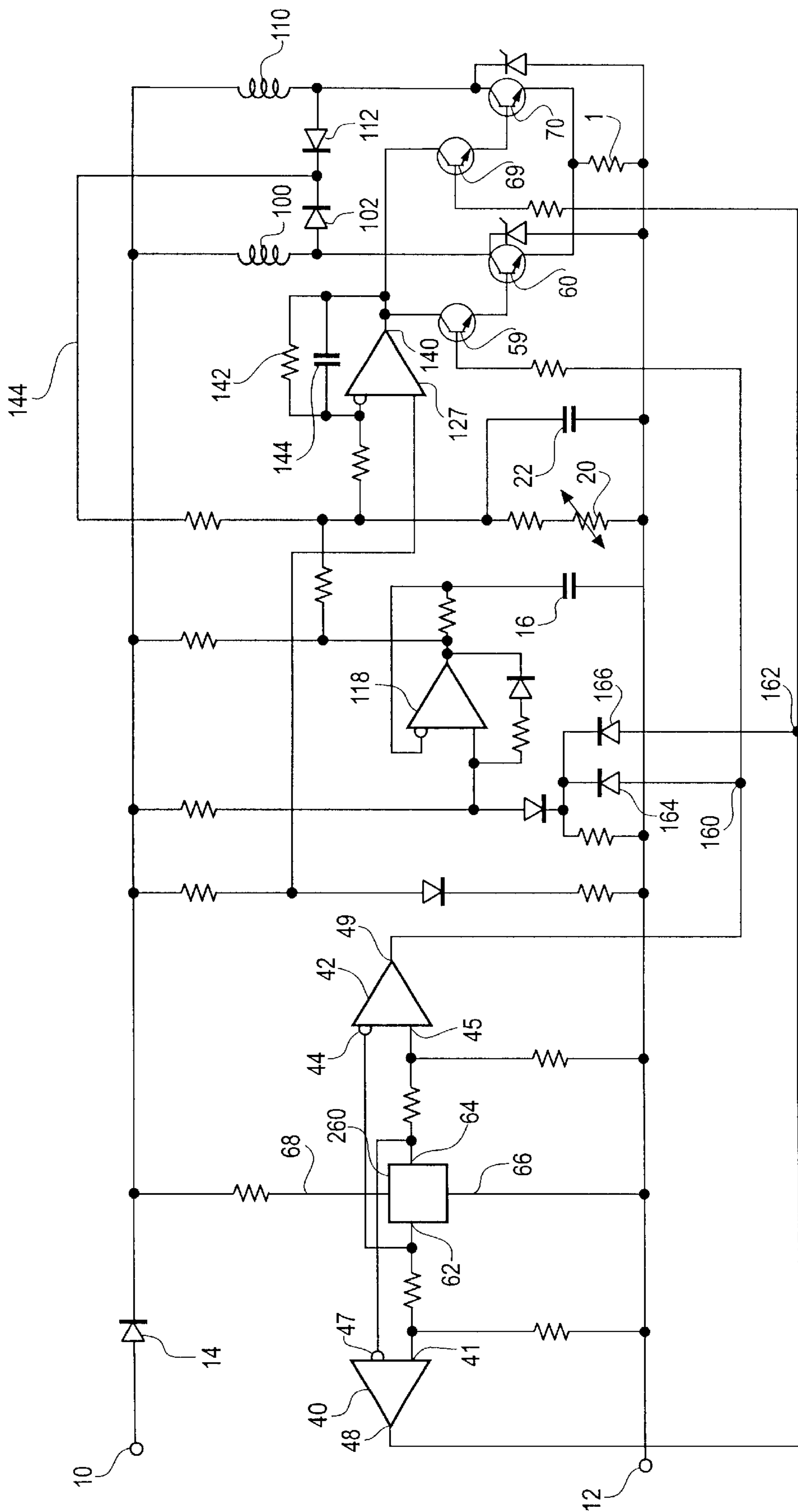
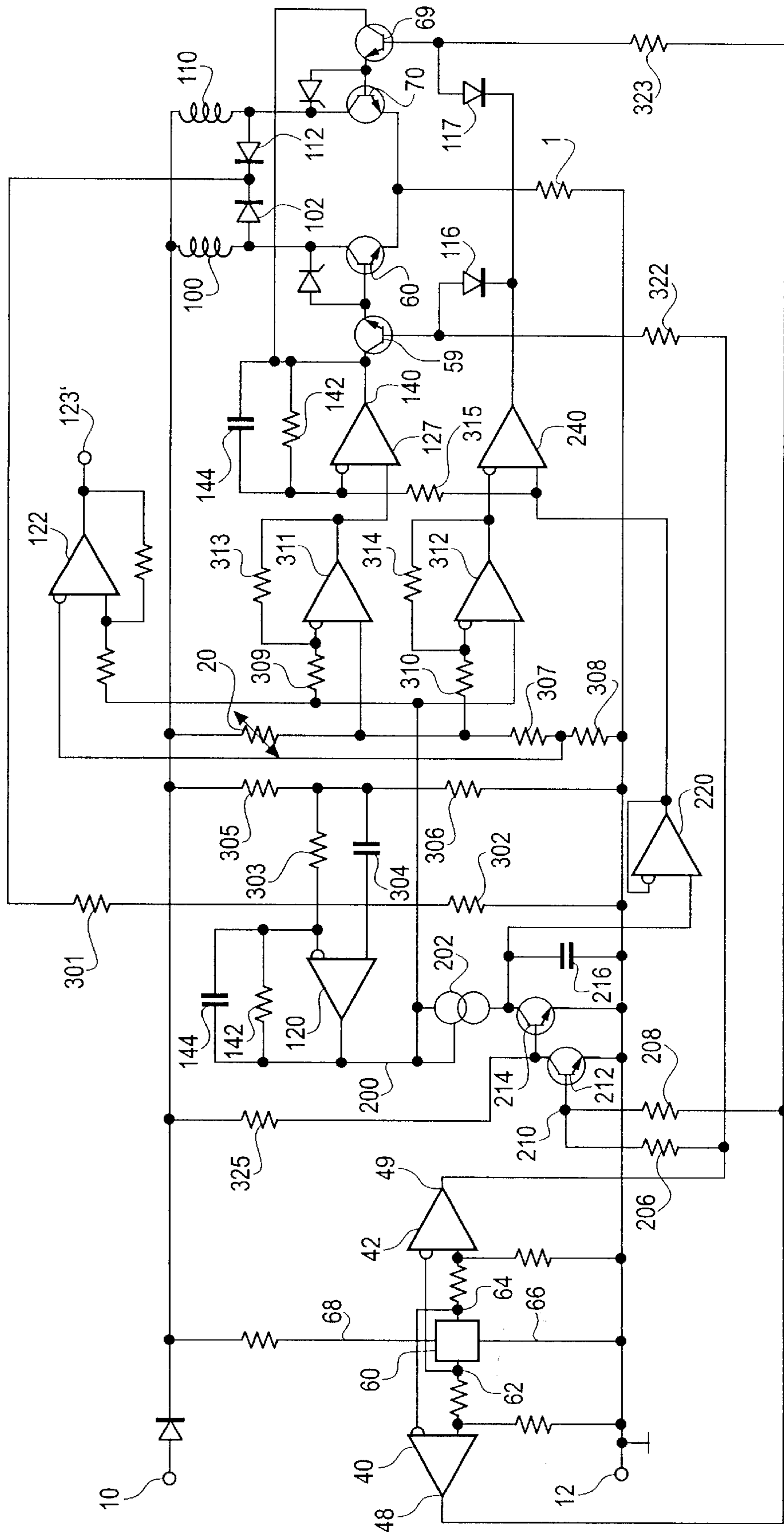


FIG. 10



**COLLECTORLESS DIRECT CURRENT  
MOTOR, DRIVER CIRCUIT FOR A DRIVE  
AND METHOD OF OPERATING A  
COLLECTORLESS DIRECT CURRENT  
MOTOR**

**Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.**

*This application is a continuation of reissue application Ser. No. 07/654,493, filed Feb. 13, 1991, now U.S. Pat. No. RE 34,609, which is a reissue application of application Ser. No. 07/072,264, filed Jun. 22, 1987, now U.S. Pat. No. 4,804,892.*

**BACKGROUND OF THE INVENTION**

The present invention relates to a collectorless direct current motor equipped with a fan or for driving a fan and including a permanent magnet rotor in the field of at least one stator winding and to a method of operating such a motor. In particular, the invention relates to a driver circuit for a collectorless direct current motor including a permanent magnet rotor having at least two poles and at least one stator winding connected to the driver circuit end stage which temporarily operates as a switch and a sensor detecting the position of the rotor, with the control signal fed to the end stage during each commutation phase causing the current in the stator winding to have a ramp-shaped configuration.

Such a driver circuit is disclosed in No. DE-OS 3,107,623 and includes an RC member with the aid of which rectangular signals are reshaped to control the direct current motor in order to reduce the steepness of their edges, thus reducing the winding noise of the motor. However, in the known driver circuit, there exists neither a possibility to change the number of revolutions nor a possibility to regulate the number of revolutions as a function of an external physical value independently of the operating voltage.

It is known to detect the position of the rotor by means of at least one galvanomagnetic element, a Hall generator or the like, and to use the signal generated in this element, which is a function of the rotor position, to control, by way of semiconductor elements, the currents in one or a plurality of stator windings.

The control circuits employed for this purpose are supplemented by members which regulate the number of revolutions as a function of externally detectable physical values with an otherwise constant operating voltage. Regulation of the number of revolutions may be controlled as a function of various parameters or it may involve an adjustment of the number of revolutions of a fan driving motor which provides ventilation that is automatically adapted to demands for a stream of air. In this case, the fan may be part of a device to be cooled which heats up to different temperatures and whose heat is to be dissipated by the fan. In that case, the heat to be dissipated would be the external physical command variable which determines the regulation of the number of revolutions.

Not only for this exemplary case of use but quite generally, users or manufacturers of such direct current drives desire to make available the smallest possible motors for their space-saving advantages. Power losses should be kept low.

To vary the output of motors operated with a constant operating voltage, it is known to pulse width modulate the

motor current. In this case, a low pulse frequency in the audible frequency range is selected. Such a frequency does not produce much additional power loss and does not radiate much interference onto adjacent devices, but it does have the drawback of developing a considerable amount of additional noise. Therefore it is also known to select a high pulse frequency in order to reduce noise. Then, stray high frequency fields result which interfere with the devices with which the fans and the corresponding direct current drives are associated. The simplest regulation employs a rough turn-on and turn-off range with the drawback of restless, rumbling motor operation. The demand for small structures gives rise to the additional desire to integrate the components employed in the circuits and to combine them in a chip. Therefore, the power losses in the integrated active and passive components employed must be kept low so that the components can be placed in close, juxtaposition and encapsulated. This demand is counter to the necessity of allowing sufficient current to flow in the electromagnetic peaks then occur in the control circuits and the heat generated by these peaks must not be permitted to destroy the integrated electronic components.

**SUMMARY OF THE INVENTION**

It is an object of the invention to make available a driver circuit for a collectorless direct current motor so as to permit changes in output power and number of revolutions with small amounts of circuitry and at a constant operating voltage; power losses in the components should be low, particularly in the semiconductor paths and here again particularly in the amplifying semiconductor paths, e.g. the end stage transistors. Moreover, additional motor noise and stray high frequency interferences should be kept low.

To solve these problems it is proposed, in general, to permit the active components, i.e. inserted semiconductor paths, to act differently in the same circuit in dependence on given external conditions or external physical command variables. For example, some of the semiconductor elements for controlling the currents for the stator winding or windings may operate as analog amplifier elements and, near the maximum possible number of revolutions, as switches, to thus shorten the turn-on duration, for example, during a commutation phase. As one feature of this solution, ramp-shaped current curves can be generated in the circuit over time, along which the switch positions may be varied. Another possible solution can be realized by means of a delay circuit which delays the moment of turn-on given by the position detector as a function of the external command variable.

As a whole, the invention is based on the idea of avoiding power losses in all components. Thus it becomes possible to integrate the components. The external conditions for the different operating states are detected by at least one component. It is known to employ temperature sensitive components in a ventilation stream to regulate the number of revolutions or power of a collectorless direct current motor used in conjunction with a fan. This, however, is effected by directly setting the power output in the end stage semiconductors. Although this does not produce any additional high frequency fields which could interfere with the devices to be ventilated and such a regulation does not produce any additional noise, a considerable amount of additional power loss develops in the partial load range concomitant with heating of the semiconductor paths. This heating is an impediment for integration of the components. The present invention is based on the realization that, over long "on" periods, these motors are driven only in the partial load

range. According to the invention, the motor current is therefore regulated within this range, for example by way of pulse width modulation with a frequency equal to the commutation frequency of the motor and by operating the actuated end stage semiconductor within one turn-on phase as a switch and subsequently in an analog mode. During this analog operation, the motor current can be reduced, for example, according to a ramp function generated in the driver circuit.

The combination of switch operation and analog operation, preferably in connection with a low rate of revolution at synchronous switching frequencies, permits a significant reduction of the losses in the semiconductor paths and also of electromagnetic and acoustic interferences.

As a further feature of the present invention, the instant at which the motor current is turned on, when the motor is under partial load, is delayed with respect to the turn-on instant which is indicated by a position indicator. This produces a further smoothing of motor operation. Evidently two effects are here at work. The generation of a parasitic axial force which has its maximum in the commutation range is reduced. Secondly, the counter-emf which rises rapidly after the theoretical moment of commutation now considerably reduces the current rise rate so that in spite of pure switch operation, the current increases relatively slowly.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Further features, aspects, configurations and advantages of the invention will become evident from the claims and the description below of embodiments which are illustrated in the drawing figures.

FIG. 1 shows a block circuit diagram to illustrate the basic function of a driver circuit according to the invention;

FIG. 2 shows a block circuit diagram for a first embodiment of the driver circuit according to the invention;

FIG. 3 shows a circuit for a dual-pulse, two-wire, collectorless direct current motor with or without reluctance moment in which the number of revolutions is regulated as a function of an external physical value without an internal auxiliary value;

FIG. 4 shows an embodiment modified, compared to FIG. 3, with respect to the initiation of a control voltage;

FIG. 5 shows a circuit example including an additional control voltage generated across the stator coils;

FIG. 6 shows a modified embodiment compared to FIG. 5;

FIG. 7 shows a first simple embodiment including a generator inserted to generate a ramp edge;

FIG. 8 shows a modified embodiment for generating the ramp edge;

FIG. 9 shows a further modified embodiment of FIG. 8; and

FIG. 10 shows a further modified embodiment of an inserted sawtooth generator.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The block circuit diagram shown in FIG. 1 shows a driver circuit for a collectorless direct current motor including a first stator winding 100 and a second stator winding 110. Stator windings 100, 110 are connected, with their one winding end, to a first terminal 10 to supply the operating voltage for the collectorless direct current motor. First stator

winding 100 lies in the collector circuit of a power transistor 60 of the driver circuit while second stator winding 110 lies in the collector circuit of a power transistor 70. The emitters of power transistors 60, 70, which form the end stage of the driver circuit, are connected, via a feedback resistor 1, with a second terminal 12 for the operating voltage. By alternately periodically actuating power transistors 60 and 70, magnetic fields are generated alternately by stator windings 100, 110 to cause the permanent magnet rotor of the collectorless direct current motor to rotate.

The continuous rotary position of the rotor (not shown in the drawing) of the direct current motor is detected with the aid of a sensor circuit 2 which may contain, for example, a Hall element associated with an amplifier and a pulse shaping member. Corresponding to the rotation of the rotor, pulse-shaped periodic sensor signals 5, 6 offset by 180° appear at outputs 3, 4. The negative edges 7 of pulse-shaped sensor signals 5 lie, in time, shortly before the positive edges 8 of pulse-shaped sensor signals 6. Correspondingly, the negative edges 7 of sensor signal 6 lie, in time, shortly before the positive edges 8 of sensor signal 5.

As can be seen in FIG. 1, the periodic sensor signals 5, 6 do not directly actuate power transistors 60, 70 as is the case in conventional driver circuits for collectorless direct current motors.

As can be seen in FIG. 1, outputs 3, 4 of sensor circuit 2 are connected with control inputs 9, 11 of a linkage circuit 13. Linkage circuit 13 makes it possible to apply an end stage control signal 19 present at input 15 of linkage circuit 13 selectively to the base of power transistor 60 or to the base of power transistor 70 in dependence on the signals at control inputs 9, 11. Linkage circuit 13 fixes a time frame for actuation of power transistors 60, 70 corresponding to the commutation periods of the direct current motor, with such time frame being defined by the closed position of switches 17, 18 which symbolically represent linkage circuit 13. If, for example, control input 9 is charged by a positive edge of sensor signal 5, switch 17 closes so that the end stage control signal 19 present at input 15 of linkage circuit 13 is able to reach the base of power transistor 60. If the negative edge appears, switch 17 opens and end stage control signal 19 is prevented from acting on power transistor 60. However, as soon as switch 18 of linkage circuit 13 is closed via control input 11, end stage control signal 19 reaches power transistor 70.

The driver circuit according to FIG. 1 is configured in such a way that the pulses of the likewise pulse-shaped end stage control signal 19 are less in duration than the pulses of sensor signals 5, 6. In this way it is possible to effect the actuation of power transistors 60, 70 each time only within part of the time frame given by the pulses of sensor signals 5, 6. If the respective pulses present at input 15 become shorter compared to the pulses present at control inputs 9, 11, the times during which current flows through power transistors 60, 70 and stator windings 100, 110 become shorter. The pulse lengths in end stage control signal 19 thus permit influencing the torque and/or the number of revolutions of the collectorless direct current motor. Moreover, the signal shape of the pulses of end stage control signal 19 can be designed in such a manner that the leading and/or trailing edges of the currents flowing through stator windings 100, 110 become flatter, keeping motor noise and power losses in power transistors 60, 70 as low as possible.

According to the block circuit diagram shown in FIG. 1, end stage control signal 19 is generated by a ramp generator 21 which is connected, via two control inputs 23, 25, with

outputs **3**, **4** of sensor circuit **2**. Ramp generator **21** is, for example, a sawtooth or delta voltage generator which makes available at its output **29** a delta voltage **31** whose frequency is double the frequency of sensor signals **5**, **6**.

Between output **29** of ramp generator **21** and input **15** of linkage circuit **13** lies a pulse width shaper **32**. Pulse width shaper **32** includes a comparison amplifier circuit, abbreviatedly called comparator **33** which receives the delta voltage signal **31** at its first input **34** and the output signal of a number of revolutions setting circuit **36** at its second input **35**. The output signal of number of revolutions setting circuit **36** serves to preset a threshold value in such a manner that a signal appears at output **37** whenever delta voltage **31** lies above the respectively set threshold value. In this way, output **37** furnishes an end stage control signal **19** of delta voltage pulses whose maximum amplitude and whose base lengths are dependent on the signal at the second input **35** of comparator **33**. If, for example, number of revolutions setting circuit **36** sets a lower threshold value, the edges of end stage control signal **19** approach one another in that the pulse shape of end stage control signal **19** approximates the pulse shape of delta voltage **31**, with the base length of the pulses and their maximum amplitude at the delta voltage peaks becoming greater.

If end stage control signal **19** reaches power transistors **60**, **70** with delta pulses which are spaced at a greater distance from one another, the current through stator windings **100**, **110** increases corresponding to the increasing delta edges. In this case, power transistors **60**, **70** switch through completely only if end stage control signals **19** exceed an amplitude given by the respective circuit and the impedance of stator windings **100**, **110**. Until this switching state is reached, power transistors **60**, **70** operate in the analog mode. After power transistors **60**, **70** have switched, the current curve through stator windings **100**, **110** changes only slightly until, finally, the descending edges actuate a slower current drop in end stage control signal **19**.

The change in amplitude of the output signal of a revolution rate setting circuit **36** thus makes it possible to vary the pulse lengths by means of stator windings **100**, **110** within the time frame for setting the number of revolutions as given by sensor signals **5**, **6**.

If it is desired to regulate the revolution rate in a closed control circuit, a revolution rate sensor **38** may be provided as likewise shown in FIG. 1, which converts the number of revolutions  $n$  per unit time of the direct current motor into a direct voltage  $U$  which travels through a line **39** to the revolution rate setting circuit **36**. It is then possible to set a revolution rate which is monitored with the aid of the sensor **38** and causes the revolution rate to be adjusted by a change in the output signal of the setting circuit **36**, for example, if the revolution rate drops due to a greater motor load.

FIG. 2 shows exemplary embodiments to clarify some details of the block circuit diagram shown in FIG. 1 for a driver circuit according to the invention. Components already known from FIG. 1 bear the same reference numerals. The driver circuit according to the embodiment shown in FIG. 2 likewise serves to actuate dual pulse, two-wire, collectorless direct current motors. A change in torque and/or revolution rate of the direct current motor is effected by changing the ratio of duration of turn-on to turn-off within each commutation period associated with the above-mentioned time frame. Switching of the motor current therefore takes place "gently" in order to suppress as much as possible any switching noises and high frequency interferences. For that reason, power transistors **60**, **70** operate

temporarily as linear amplifiers during turn-on and turn-off, respectively, and gradually change the current flowing through stator windings **100**, **110** according to a given ramp function having a constant edge slope. In a manner to be described below, the number of revolutions of the direct current motor is regulated with the use of the voltage induced in stator windings **100**, **110** by means of a simple power controller. The command variable for the revolution rate is the applied operating voltage to which the revolution rate is approximately proportional and, if desired, the ambient temperature which is detected with the aid of a measuring sensor including a temperature-dependent resistor **51**, for example an NTC resistor.

According to the embodiment shown in FIG. 2, the sensor circuit known from FIG. 1 includes a Hall generator **260**, whose first control input is connected to terminal **12** and whose second control input is connected, via a resistor **52** and a device **53** providing thermal overload protection, to the operating voltage supplied through terminal **10** and a diode **14**. The device **53** providing thermal overload protection includes a monitoring circuit for the temperature of power transistors **60**, **70**, so as to ensure turn-off with hysteresis if the permissible transition zone temperature of power transistors **60**, **70** is exceeded.

Hall generator **260** furnishes voltages proportional to the magnetic field of the direct current motor and these voltages are amplified via comparators **54** and **55** in order to generate the sensor signals **5**, **6** shown schematically in FIG. 1. The pulse-shaped sensor signals **5**, **6** are fed, on the one hand, to a linkage circuit formed of transistors **56**, **57** and, on the other hand, to ramp generator **21**. The effect of transistors **56** and **57** corresponds to switches **17** and **18** shown in FIG. 1.

Ramp generator **21** is configured as a delta voltage generator including a control input **58** connected with the first output **61** of a current generator **67** which has a second output **63** and a third output **65** and is connected with three controlled current sources **71**, **72** and **73**. Current sources **71**, **72**, **73** are controlled via a smoothed direct voltage which appears at output **74** of a lowpass filter **75** whose input **76** is connected, via a resistor **77** and diodes **78**, **79**, with the transistor side ends of stator windings **100**, **110**. By way of diodes **78**, **79**, a voltage induced in stator windings **100**, **110** which constitutes a measure of the number of revolutions, reaches lowpass filter **75** which, in addition to a filter capacitor **80**, includes an external fixed resistor **81** so as to make the voltage/current conversion independent of the absolute tolerances of the internal resistances. Since the driver circuit shown in FIG. 2 is realized as an integrated circuit, several stages are provided with terminals for external connections, such as, for example, the mentioned filter capacitor **80** or fixed resistor **81**.

Since the output signal at output **74** of lowpass filter **75** is a signal proportional to the revolution rate, current sources **71**, **72**, **73** are controlled according to the revolution rate of the direct current motor.

The first current source **71** serves to charge a capacitor **82** which is associated with ramp generator **21** so that a ramp-shaped voltage is generated across capacitor **82**. By regularly discharging capacitor **82**, a sawtooth voltage is formed in a sawtooth generator **83**. The amplitude of the sawtooth signal of sawtooth generator **83** is thus substantially independent of the number of revolutions and the operating voltage. With the aid of an inverter **84**, the sawtooth voltage is converted into an oppositely directed sawtooth voltage. Both sawtooth voltages, the original sawtooth voltage and the inverted sawtooth voltage, feed an

analog comparison circuit **85** which supplies the respective lower one of the two voltages at output **86**, thus producing a delta-shaped signal voltage at output **86**.

In order for the highest point of the delta voltage signal to lie approximately in the middle between two successive commutation moments of the direct current motor and to make this position independent of the operating voltage, the inverting stage including inverter **84** is connected to a fixed reference potential as indicated by a Zener diode **96**.

The second current source **72**, controlled in proportion with the revolution rate, feeds a series connection of a series resistor **87** and the temperature dependent resistor **51** which serves as a temperature measuring sensor and may be a thermistor; its characteristics can be tuned by way of series resistor **87**.

The voltage drop occurring across this series connection constitutes a measure of the momentary number of revolutions and the momentary temperature and can be picked up at circuit point **88**.

Controlled current source **73** controls a series connection composed of fixed resistors **89** and **90**. The voltage drop occurring across the associated circuit point **91** is likewise associated with the momentary number of revolutions of the direct current motor, but contrary to the voltage drop present at circuit point **88**, it is not additionally dependent upon the temperature.

Circuit points **88**, **91** are connected with the two inputs of a comparison stage **92** which at its output **93** supplies a signal associated with the respective lower value at its two inputs. Due to the selection of the respectively lower value, the revolution rate of the direct current motor is not reduced further if the temperature falls below a given limit temperature, rather the number of revolutions is held at a fixed minimum value determined by fixed resistors **89** and **90**.

The output signal of comparison stage **92** feeds the first input **94** of a further comparison stage **95**.

Further comparison stage **95** serves, on the one hand, to permit operation as a function of the revolution rate at temperatures above the lower limit temperature. Similarly to comparison stage **92**, further comparison stage **95** emits, at its output **97**, a signal which corresponds to the respective greater one of the two input signals. As its second input signal, second input **98** receives the voltage drop across fixed resistor **90**. Further comparison stage **95** also serves to prevent further increases in the regulating difference signal when a certain upper limit temperature is exceeded so that, even at the highest possible revolution rate, the pulses of end stage control signal **19** have a shorter length in time than the pulses of sensor signals **5**, **6** and thus it is still possible to control the ramps at power transistors **60**, **70** and no pure switching operation occurs in power transistors **60**, **70**, which would be undesirable since it would produce running noises and electrical interferences.

Output **97** of further comparison stage **95** is connected, via a resistor **99**, with a comparison amplifier **101** which is connected as linear amplifier having a feedback resistor **103** which is bridged by a capacitor **104** acting as attenuating element and is in communication with the first input **105**.

The second input **106** of comparison amplifier **101** is connected, via a resistor **107**, with a series connection of resistors **108**, **109**, **111** which is connected with the operating voltage source. Comparison amplifier **101** thus compares the voltage across the first input **105**—which is limited in its limit values and is associated with the temperature and/or the revolution rate—with a voltage supplied via resistor **107**

on which, however, is superposed, via a resistor **113**, the delta voltage appearing at output **86**.

Consequently, the output signal of comparison amplifier **101** is a delta-shaped voltage signal whose amplitude is a function of the comparison of the voltages across inputs **105**, **106**. With decreasing revolution rate and increasing temperature, respectively, the average amplitude of the output signal of comparison amplifier **101** increases, with a delta voltage signal always being superposed on a variable direct voltage signal.

Comparison amplifier **101** acts as a revolution rate regulator whose gain is defined by resistor **99** and feedback resistor **103**. The voltage drop picked up by way of resistor **107** here serves as the desired revolution rate value on which a delta voltage is superposed to form a ramp-like increasing and decreasing current curve in stator windings **100**, **110**. The slope of the current rise and drop, respectively, is defined essentially by the ratio of resistor **107** to **113**.

The signal appearing at output **115** of comparison amplifier **101** is alternately fed, via transistors **56**, **57** which act as analog switches, to power transistors **60**, **70** corresponding to the time frame defined by the commutation phases. Transistors **56**, **57** then decide which one of the two power transistors **60**, **70** receives the end stage control signal **19** furnished by comparison amplifier **101**. As mentioned above, this decision is made with the aid of the output signals of comparators **54** and **55**.

To ensure analog further processing of the delta-shaped end stage control signals **19** of comparison amplifier **101**, the already mentioned feedback resistor **1** is provided as feedback element.

Power transistors **60**, **70** have associated Zener diodes which serve to limit the maximum turn-off voltage across power transistors **60**, **70** so that even if the ramp control of power transistors **60**, **70** does not operate, no excess turn-off voltages are generated.

Further embodiments of the invention will be described below on the basis of the basic principles applicable to the block circuit diagram shown in FIG. 1.

The constant operating voltage  $V_{CC}$ , for example a direct current of 12 Volts, is present at terminals **10** and **12** of the circuit shown in FIG. 3. This voltage is regulated in dependence on a variable element **20**, for example a thermistor disposed in a circuit **50** in the ventilating air stream.

A line **30** conducts the operating voltage via a diode **14** directly to stator windings **100** and **110**. Outside of circuit **50**, in a suitable position with respect to the permanent magnet rotor (not shown), a Hall generator **260** is provided as position detector.

Circuit **50** is designed so that it can be laid out as an integrated circuit. Two operational amplifiers **40** and **42**, in conjunction with Hall generator **260**, serves as comparators. One output **62** of Hall generator **260** is connected directly with the non-inverting input **41** of comparator **40** and, via a resistor **43**, with the inverting input **44** of comparator **42**. The antivalent output **64** of Hall generator **260** is connected in the same manner directly with the non-inverting input **45** of comparator **42** and, via a resistor **46**, with the inverting input **47** of comparator **40**. Output **48** of comparator **40** is connected with power transistor **70** and output **49** of comparator **42** is connected with power transistor **60**, with the power transistors themselves supplying the amplifier current to stator coils **100** and **110**, respectively. While terminal **66** of Hall generator **260** is connected directly with pole **12**, terminal **68** is regulated via an operational amplifier **120** in dependence on thermistor **20**. A comparison is made



between a desired value and the actual value with the aid of operational amplifier 120 as well as with the aid of operational amplifier 122. Depending on the voltage generated by thermistor 20 as a function of the temperature of the stream of air in conjunction with capacitor 22, transistors 60 and 70 are supplied in such a manner that, in the normal partial load range, they act as analog amplifier elements. Capacitor 22 prevents immediate turn-off by operational amplifier 122 during start-up.

In the upper revolution rate range or near the maximum possible revolution rate, the revolution rate is regulated primarily by a variation of the turn-on duration of the motor current. In the lower revolution rate range, the revolution rate is regulated at least additionally by a variation of the amplitude of the motor current. Additionally, a temperature independent safety switching voltage is available at an output 123' which turns off the motor after a settable period of time if there is an overload. Or an alarm signal can be given if a limit value is exceeded or not reached.

As can be seen in FIG. 3, the winding ends of stator windings 100, 110 on the side of the transistor are connected with diodes 167, 168 which couple out the voltages induced in stator windings 100, 110 so that voltage proportional to the revolution rate results which is fed to operational amplifiers 120, 122 for linkage purposes. Operational amplifier 122 serves to send an alarm to output 123' if a limit revolution rate is not reached. The induced voltage is filtered via RC members 169, 170 and integrators 171, 172, respectively, so that the ripple, i.e. the alternating voltage component, of this voltage is shifted preferably by 180 degrees with respect to its fundamental wave. The thus filtered signal is superposed on the control path of Hall generator 260 so that the output signals of Hall generator 260 also have a ripple which is fed to amplifier stages 40, 42 and thus to power transistors 60, 70. This causes the end stage to form current curves, if the motor output is reduced, which are approximately analogous to the ripple of the induced voltage and contain a slight amount of overshooting.

While, according to FIG. 3, the type of switching and the switching position of transistors 60 and 70 is controlled by way of Hall generator 260, FIG. 4 shows a circuit which is provided for switching and actuating transistors 60 and 70 by means of operational amplifiers 123 and 125 which generate a variable signal at output 126 which is coupled directly to the non-inverting inputs 41 and 45 of comparators 40 and 42, respectively. If the temperatures at thermistor 20 are high, the voltages across these inputs 41 and 45 are [reduced] changed to such an extent that, during the commutation phase, the "turn-on [pauses] pulses" in the current downstream of transistors 60 and 70 become longer.

The number of revolutions is changed in dependence on the temperature. Capacitor 22 is discharged during each commutation process and is recharged differently by way of thermistor 20 in dependence on the measured temperature. This voltage is present across inputs 41 and 45, respectively, via line 128 and simultaneously via diodes 130, 134 and lines 132, 136, in parallel with the voltages generated by Hall generator 260. As long as the voltage furnished by capacitor 22 is less than the voltages put out by Hall generator 260, the motor current remains turned off. Thus a greater or smaller turn-on delay is created in dependence on the temperature for the currents flowing through coils 100 and 110, respectively. This sole turn-on delay may lead to undesirable, loud motor noises.

Therefore, FIG. 5 shows a circuit, as a modification of FIG. 3, in which not the pauses but the shape of the current

curve between the pauses is influenced. This is a temperature dependent regulation of the revolution rate in a narrower sense. A measure for the existing revolution rate the generator voltage of coils 100 and 110 through which no current flows and which is applied via diodes 102 and 112, respectively, and a line 114 to the inverting inputs of operational amplifiers 120 and 122, respectively. The ripple in this voltage superposed thereby serves in an analogous manner to form rounded current curves for the currents to coils 100 and 110 between the "pauses" which are kept short since, according to this circuit, they are not being influenced. The result is a smooth and quietly running motor compared to the embodiment of FIG. 4. In this circuit embodiment as well, the desired value for the revolution rate is obtained via thermistor 20 in dependence on the temperature. By means of an adjustable voltage divider 24, a minimum revolution rate may additionally be provided. Moreover, the circuit can be arranged in such a manner that the motor can be turned off completely at a revolution rate which is 50% below a desired revolution rate.

Moreover, an alarm signal can be put out and/or processed further at output 123' if the revolution rate is too low.

FIG. 6 shows a circuit which is modified compared to FIG. 5. The shape of the turn-on current, i.e. its rounded portions, are produced as described above. The simultaneous regulation of the turn-on pauses, also described above, can additionally be given adjustable limits by way of members 28 and 26 as well as 27.

FIG. 7 shows a circuit in which the power stage is influenced directly parallel to and downstream of the Hall generator stage. Output 48 is connected, via a transistor 69, to end stage transistor 70 and output 49 is connected, via a transistor 59, to end stage transistor 60. The signal to change the turn-on pause for the current sent at the corresponding temperature by thermistor 20 to coils 100 and 110, respectively, is obtained via operational amplifier 127 at its output 140 and is fed to transistors 59 and 69, respectively, via respective semiconductor paths which produce a switching effect. The inverting input of operational amplifier 127 is bridged forward output 140 by means of a low capacitance capacitor 144 and a resistor 142.

In addition, a capacitance 16 is provided which permits, via an operational amplifier 123, an edge configuration of the current between turn-on pauses as will be described in greater detail below.

As can be seen from the circuit diagram of FIG. 7, in the driver circuit shown there, it is not the induced voltage which is used as a measure for the revolution rate, but the time interval between two commutations. The rectangular pulses obtained from the Hall signal and appearing at outputs 48, 49 of comparator stages 40, 42 are used for this purpose. They are added by way of two resistors 173, 174, with the sum signal being supplied via capacitor 16 to comparator 123. This comparator becomes temporarily conductive during each change in commutation, i.e. during each change in switching states of transistors 60 and 70, and discharges capacitor 22 which is then able to charge itself via temperature dependent resistor 20. Depending on the temperature, this charging takes place faster or slower. Moreover, the charge state of capacitor 22 is dependent on the time duration of the charging process and thus on the revolution rate. Thus, both informations required to permit temperature dependent regulation of the revolution rate are available at resistor 20 and at capacitor 22. The associated signal is compared with a voltage obtained from a fixed voltage divider and the difference signal is fed to an opera-

tional amplifier **125**. The output signal of the operational amplifier is filtered via a first filter member **175**, **176** and an integrator including a series resistor **177**, a feedback capacitor **144** and an operational amplifier **127**. Finally, the filtered signal is fed to analog switches **59** and **69**. Analog switches **59**, **69** additionally receive the output signal of comparator circuits **40**, **42**. Thus, the end stage is turned on, on the one hand, in accordance with the output voltages of comparators **40** and **42** and, on the other hand, the turn-on duration and the maximum base current of power transistors **60**, **70** is influenced by the output signal of operational amplifier **127**.

In this way it is accomplished that the motor current cannot be turned on over the full turn-on duration given by Hall element **260**, but is variable in dependence on the ambient temperature detected by element **20**. Filtering in filter stages **175**, **176** and **177**, respectively, and in filter stage **144** results in the originally delta-shaped or sawtooth shaped signal at the output of operational amplifier **125** being changed to a greatly rounded signal which constitutes a favorable prerequisite for low-noise motor operation.

While in the preceding embodiments measurement and regulation of the revolution rate as well as the determination of the shape of the current pulse were interdependent, in the last described embodiment and in the embodiments below a pulse shape for the analog regulation phase is derived directly from components provided for this purpose. For example, a sawtooth generator including elements **118** or **119** as shown in FIG. **8** or **9** can be included to generate sawtooth-shaped auxiliary signals from the turnon pulses with the aid of a capacitance, for example capacitance **16** (**22**). The embodiment according to FIG. **8** here manages with simple components and only one capacitance. It is an object of the invention to integrate the novel circuit in a chip and it is therefore of advantage to keep the number of capacitors low. The circuit according to FIG. **9** includes, like the circuit according to FIG. **8**, taps **160** and **162** at the leads from output **48** to transistor **70** and from output **49** to transistor **60**. The pulse-shaped voltage is present via diodes **164** and **166** directly at a transistor **119** (FIG. **8**) or at a further circuit configured as shown in FIG. **9** and including an operational amplifier **118**. The resulting signal shape is present at the inverting input of operational amplifier **127**.

In a basic circuit shown in FIG. **10**, measurement of the revolution rate by means of induced voltages is substantially separated from pulse shaping. The induced voltage is smoothed even better. However, at the same time, the generation of a turn-on pause and of an edge ramp along which analog regulation takes place are derived by means of a sawtooth generator. Via resistors **206** and **208**, a signal voltage is available at point **210** which is merely interrupted in a pulsating form by the turn-on pauses. From this signal, a sawtooth signal is derived with the aid of a single capacitor **216** downstream of transistors **212** and **214**. Following the remaining vertical signal voltage drop at the beginning of each switching pause, an edge which rises linearly to the full voltage is generated after a pause of a self-regulating duration, and thus a ramp is generated along which the analog regulation can be effected during the turn-on pause as a function of the signal obtained from a comparison of the desired value with the actual value. The given values can be varied by changing voltage source **202**. The actual value is supplied through output **200**. The signal provided with the ramp is included in the control circuit via operational amplifiers **220** and **240** in such a manner that it is possible to position the current pulse and set its turnoff ramp slope so as to avoid power losses.

As can be seen in the circuit diagram of FIG. **10**, two diodes **102**, **112** are used again to couple out, as a measure

of the revolution rate, the counter-emf induced in stator windings **100**, **110** which do not carry current. The counter-emf is fed via a resistor **301** to intermediate amplifier stage **120** which acts as a lowpass filter because of capacitor **144**. Intermediate amplifier **120** controls controlled current source **202** to charge capacitor **216**, the latter being discharged at regular intervals by transistors **212** and **214**. To discharge capacitor **216** it is necessary for transistor **214** to be conductive temporarily. This is effected with auxiliary pulses present at circuit point **210**.

The auxiliary pulses are generated in the following manner. Hall generator **260** furnishes its voltage to two comparators **40** and **42** at whose outputs rectangular signals appear which are shifted in phase by  $180^\circ$  and whose high states are somewhat shorter than their low states so that summation of these signals by means of resistors **206** and **208** produces short-term low pulses at point **210** during each commutation. This causes transistor **212** to be briefly turned off and enables a base current to flow for transistor **214** and a series resistor **325**. A sawtooth voltage whose amplitude is almost independent of the revolution rate appears across capacitor **216** since the loading current intensity of this capacitor is adapted proportionally to the time available between two commutation pulses. The signal, proportional to the revolution rate, obtained at output **200** of amplifier **120** is supplied for a desired value/actual value comparison. The voltage of a voltage divider including resistors **307** and **308**, which voltage is temperature dependent by way of thermistor **20**, serves as the desired value. The center point voltage of this voltage divider is fed to the non-inverting input of an amplifier **311** and, via a series resistor **310**, to the inverting input of an amplifier **312**. The respective other inputs of the amplifiers receive the signal proportional to the revolution rate from output **200**.

In this way, a potential is generated at the output of amplifier **311** which grows with increasing temperature and decreasing revolution rate and at amplifier **312** a potential is generated which decreases with increasing temperature and decreasing revolution rate. These potentials are fed to the first inputs of amplifiers **127** and **240** at whose second inputs the sawtooth signal of impedance converter **220** is present.

Amplifier **127** is connected as linear amplifier, for which purpose resistor **315** and resistor **142** are provided. Auxiliary capacitor **144** attenuates the amplifier.

A ramp-shaped signal appears at output **140** of amplifier **127**, which signal behaves in dependence on the temperature and on the revolution rate in such a manner that the average potential at output **140** increases with increasing temperature and with decreasing revolution rate, respectively. This signal has the ramp signal of the output of impedance converter **220** superposed on it so that with increasing temperature and with decreasing revolution rate, respectively, the end stage circuit is caused to turn off later in accordance with a ramp function.

Amplifier **240** is connected as comparator. It compares the output potential of amplifier **312** with the sawtooth signal of sawtooth generator **220**. A change in potential at the output of amplifier **312** causes a shift in the switching point of comparator amplifier **240** in the sense that with increasing revolution rate and with decreasing temperature, respectively, the output of amplifier **240** remains at the low state for a longer period of time, thus keeping the end stage circuit turned off for a longer period of time before it is able to turn on. Thus a pause proportional to the revolution rate and inversely proportional to the temperature is introduced after the commutation.

In addition to measuring the revolution rate for regulation purposes, a second number of revolutions measurement is made, for which comparator 122 is provided. The latter has a lower voltage value as its desired value which is generated by means of resistors 307 and 308, i.e. this comparator 122 reacts at its output 123' if a second desired value is not reached, which value can be set arbitrarily and serves as alarm threshold.

The circuit as a whole has the characteristic that, in dependence on temperature and on the momentary revolution rate, end stage transistors 60, 70 are not turned on in a first time interval, i.e. the turn-on is delayed as indicated by the temperature and the revolution rate controller. Then, end stage transistors 60, 70 are turned on for a certain period of time. The turn-on duration also depends on the temperature and the revolution rate. In a third time interval, end stage transistors 60, 70 are turned off according to a given ramp function, with end stage transistors 60, 70 being used as analog elements and a fourth time interval during which the other end stage transistor is able to turn on remains until the next commutation.

I claim:

**[1.** Driver circuit for a collectorless direct current motor including a permanent magnet rotor having at least two poles and at least one stator winding, comprising:

a driver circuit end stage connected to the stator winding for temporarily operating as a switch,

a sensor for detecting a position of the rotor, said sensor producing sensor signals which are representative of a commutation phase,

a control signal, said control signal being supplied to said driver circuit end stage during each said commutation phase, said control signal causing a ramp-shaped current curve to arise as a function of time in the stator winding,

said driver circuit end stage having a linkage circuit which is controlled by said control signal and by said sensor signals of said sensor, said linkage circuit producing an end stage control signal whose duration is variable and is less than the duration of a respective one of said sensor signals,

said driver circuit end stage including at least one semiconductor element which operates during said commutation phase for a first period of time as a switch and for a second period of time as an analog amplifier, current in said semiconductor element being relatively constant during said first period of time and changing according to a predetermined ramp function during said second period of time.]

**[2.** Driver circuit according to claim 1, wherein said linkage circuit includes switching transistors whose switching states are controlled by comparators which are connected with the outputs of a Hall generator.]

**[3.** Driver circuit according to claim 1, wherein said linkage circuit is connected with an output of a pulse width shaper including a comparison amplifier circuit having a first input which is connected to an output of a ramp generator and having a second input which is connected with a revolution rate setting circuit.]

**[4.** Driver circuit according to claim 3, a ramp generator furnishes a delta voltage as an output signal for said pulse width shaper.]

**[5.** Driver circuit according to claim 3, said revolution rate setting circuit is connected with an output of a revolution rate sensor for forming a closed control circuit.]

**[6.** A driver circuit as claimed in claim 1, wherein a plurality of semiconductor elements are included in said

driver circuit, each one of said plurality of semiconductor elements operating during a different portion of said commutation phase for a respective first period of time as a switch and for a respective second period of time as an analog amplifier, current in each said semiconductor element being relatively constant during said first period of time and changing according to a ramp function during said second period of time.]

**[7.** Collectorless direct current motor for driving a fan, comprising:

a stator having at least one stator winding;

a permanent magnet rotor having at least two poles and being disposed in the field of said at least one stator winding,

said at least one stator winding being supplied with an operating voltage by a circuit, said circuit having

a position sensing means for detecting a position of said permanent magnet rotor to determine a commutation phase thereof,

at least one semiconductor element supplying current to said stator winding,

a temperature sensing means for detecting temperature of an air stream drawn by the fan,

and a control means for controlling said at least one semiconductor element during said

commutation phase based upon the temperature sensed by said temperature sensing means,

said at least one semiconductor element included in said circuit being controlled by said control means to operate as a switch for supplying a relatively constant current over a part of the commutation phase and as an analog amplifier element over another part of the commutation phase,

said at least one semiconductor element, during a period of time where in a reduction in revolution rate of said permanent magnet rotor occurs, operating initially as a switch and thereafter operating temporarily as an analog amplifier, current in said at least one semiconductor element being reduced during said period of time according to a predetermined ramp function.]

**[8.** A collectorless direct current motor according to claim 7, wherein, near a maximum revolution rate of said permanent magnet rotor, said control means regulates said revolution rate predominantly by varying a turn-on duration of current to said at least one stator winding during said commutation phase and, in a lower revolution rate range, regulating said revolution rate additionally by varying the amplitude of the motor current.]

**[9.** A collectorless direct current motor according to claim 8, wherein a temperature dependent safety element turns off said operating voltage after a settable time period upon occurrence of an overload condition.]

**[10.** A collectorless direct current motor according to claim 8, further comprising a first comparison means for comparing a desired revolution rate value with an actual revolution rate value for regulating said revolution rate,

an alarm signaling means,

and a second comparison means for comparing the desired revolution rate value with the actual revolution rate value for monitoring said revolution rate with respect to a given limit value at which an alarm signal is initiated by said alarm signal means.]

**[11.** A collectorless direct current motor according to claim 10, wherein said given limit value for monitoring said revolution rate is also used for initiating a stop order.]

[12. A collectorless direct current motor according to claim 10, further comprising a plurality of stator windings, wherein voltage induced by said permanent magnet rotor in one of said plurality of stator windings through which no current flows is used to measure said actual revolution rate value.]

[13. A collectorless direct current motor according to claim 8 further comprising a first comparison means for comparing a desired revolution rate value with an actual revolution rate value for regulating said revolution rate, and a second comparison means for comparing the desired revolution rate value with the actual revolution rate value and initiating a stop order for cutting off the current upon reaching a given limit value.]

[14. A collectorless direct current motor according to claim 8, wherein said control means derives a signal for regulation of said revolution rate is based upon a signal received from said temperature sensing means.]

[15. A collectorless direct current motor according to claim 14, wherein said operating voltage for driving said at least one stator winding is used as a command variable for regulation of said revolution rate.]

[16. A collectorless direct current motor according to claim 14, wherein a signal derived from the temperature sensing means and said operating voltage are command variables for regulation of said revolution rate.]

[17. A collectorless direct current motor according to claim 8, wherein, when said revolution rate is reduced to less than 50% of said maximum revolution rate, a switching duration of said at least one semiconductor element in a switch mode is reduced until said at least one semiconductor element operates purely as said analog amplifier element.]

[18. A collectorless direct current motor according to claim 7, wherein said revolution rate is controlled by varying a transition interval between switch operation and subsequent analog operation of said semiconductor elements during said commutation phase.]

[19. A collectorless direct current motor according to claim 7, wherein, upon reduction of said revolution rate, an instant at which said semiconductor element is turned on is delayed with respect to a turn-on time given by said position sensing means.]

[20. A collectorless direct current motor according to claim 7, wherein control of motor output and revolution rate are effected in an open control chain by an externally given physical value.]

[21. A collectorless direct current motor according to claim 7, wherein control of motor output and revolution rate are effected in a closed control circuit by an externally given physical value.]

[22. A collectorless direct current motor according to claim 7, wherein control of motor output and revolution rate are effected by an essentially analog circuit and necessary time functions are generated by RC members.]

[23. A collectorless direct current motor according to claim 7, wherein a plurality of semiconductor elements are included in said circuit, each one of said plurality of semiconductor elements operating during a different portion of said commutation phase for a respective first period of time as a switch and for a respective second period of time as an analog amplifier, current in each said semiconductor element being relatively constant during said first period of time and changing according to a ramp function during said second period of time.]

24. A brushless DC motor, comprising:  
at least one winding;

a rotor position sensing circuit that senses each commutation period of the motor;

a driver circuit including a number of output stages, said driver circuit operating in connection with said rotor position sensing circuit so as to control said output stages and vary the power applied to said at least one winding, said driver circuit including means for feeding to said output stages control impulses that are switched during each commutation period, said driver circuit also including means for varying a characteristic of said control impulses so as to regulate the power applied to said at least one winding, said means for varying including generator means for producing a triangular signal responsive to said rotor position sensing circuit, whereby the period of said triangular signal is about the period of one commutation of the motor, said means for varying also including means for comparing the instantaneous value of said triangular signal with a reference signal and for applying each deviation of said triangular signal from said reference signal to establish a corresponding switching duration of all of said output stages; and

wherein each one of said output stages includes at least one semiconductor element that operates during said commutation period for a first period of time as a switch and for a second period of time as an analog amplifier, and wherein current in said at least one semiconductor element is relatively constant during said first period of time and changing according to a predetermined ramp function during said second period of time.

25. The brushless DC motor of claim 24, wherein said characteristic comprises a switching duration of said control impulses.

26. The brushless DC motor of claim 24, wherein said characteristic comprises an amplitude of said control impulses.

27. The brushless DC motor of claim 24, wherein said comparing means applies to said output stages a pulse during a switching on period, wherein an increase in the duration of said pulses directly corresponds to an increase in temperature.

28. The brushless DC motor of claim 24, wherein said driver circuit further comprises a minimum speed setting circuit that limits the amount by which the pulse can become shorter during the switching on period when the temperature falls.

29. The brushless DC motor of claim 24, wherein said driver circuit further comprises a timing circuit, wherein said generator means for producing the triangular signal is included in the timing circuit.

30. The brushless DC motor of claim 24, wherein said driver circuit further comprises command signal means for providing a reference signal to said comparing means.

31. The brushless DC motor of claim 30, wherein said command signal means provides said reference signal corresponding to a desired motor speed.

32. The brushless DC motor of claim 30, wherein said command signal means provides said reference signal corresponding to a desired local temperature.