US00RE36860E

United States Patent [19]

Müller

[11] E **Patent Number: Re. 36,860**

[45] **Reissued Date of Patent: Sep. 12, 2000**

[54] **BRUSHLESS DIRECT CURRENT MOTOR**

[75] Inventor: **Rolf Müller**, München, Germany

[73] Assignee: **Papst Licensing GmbH & Co. KG**, Germany

[21] Appl. No.: **08/710,734**

[22] Filed: **Sep. 20, 1996**

Related U.S. Patent Documents

Reissue of:

[64] Patent No.: **5,349,275**
Issued: **Sep. 20, 1994**
Appl. No.: **08/126,677**
Filed: **Sep. 24, 1993**

U.S. Applications:

[63] Continuation of application No. 07/928,976, Aug. 12, 1992, abandoned, which is a continuation of application No. 07/448,760, Dec. 11, 1989, abandoned, which is a continuation of application No. 07/177,692, Apr. 5, 1988, abandoned, which is a continuation of application No. 07/079,100, Jul. 29, 1987, abandoned, which is a continuation of application No. 06/635,253, Mar. 27, 1984, abandoned, which is a continuation-in-part of application No. 06/447,688, Dec. 7, 1982, Pat. No. 4,535,275.

[30] **Foreign Application Priority Data**

Dec. 23, 1981	[DE]	Germany	3150922
Dec. 23, 1981	[DE]	Germany	3150923

[51] **Int. Cl.**^{7} **H02P 6/14**

[52] **U.S. Cl.** **318/254**; 318/138

[58] **Field of Search** 318/138, 254, 318/439

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,559,013	1/1971	Burch et al.	318/138
3,559,014	1/1971	Rakes	318/138
3,584,280	6/1971	Inagaki et al. .	
3,668,414	6/1972	Norian et al. .	
3,716,769	2/1973	Brunner	318/254
3,759,051	9/1973	Ohnishi et al. .	
3,769,555	10/1973	Dolbachian et al. .	
3,873,898	3/1975	Müller	318/138
3,887,844	6/1975	Yoshida	318/254 X
3,898,544	8/1975	Tanikoshi	318/254
3,909,690	9/1975	Sugiura	318/138
3,988,652	10/1976	Endo et al.	318/254 X
4,015,182	3/1977	Erdman .	
4,070,606	1/1978	Morozumi et al.	318/254

(List continued on next page.)

FOREIGN PATENT DOCUMENTS

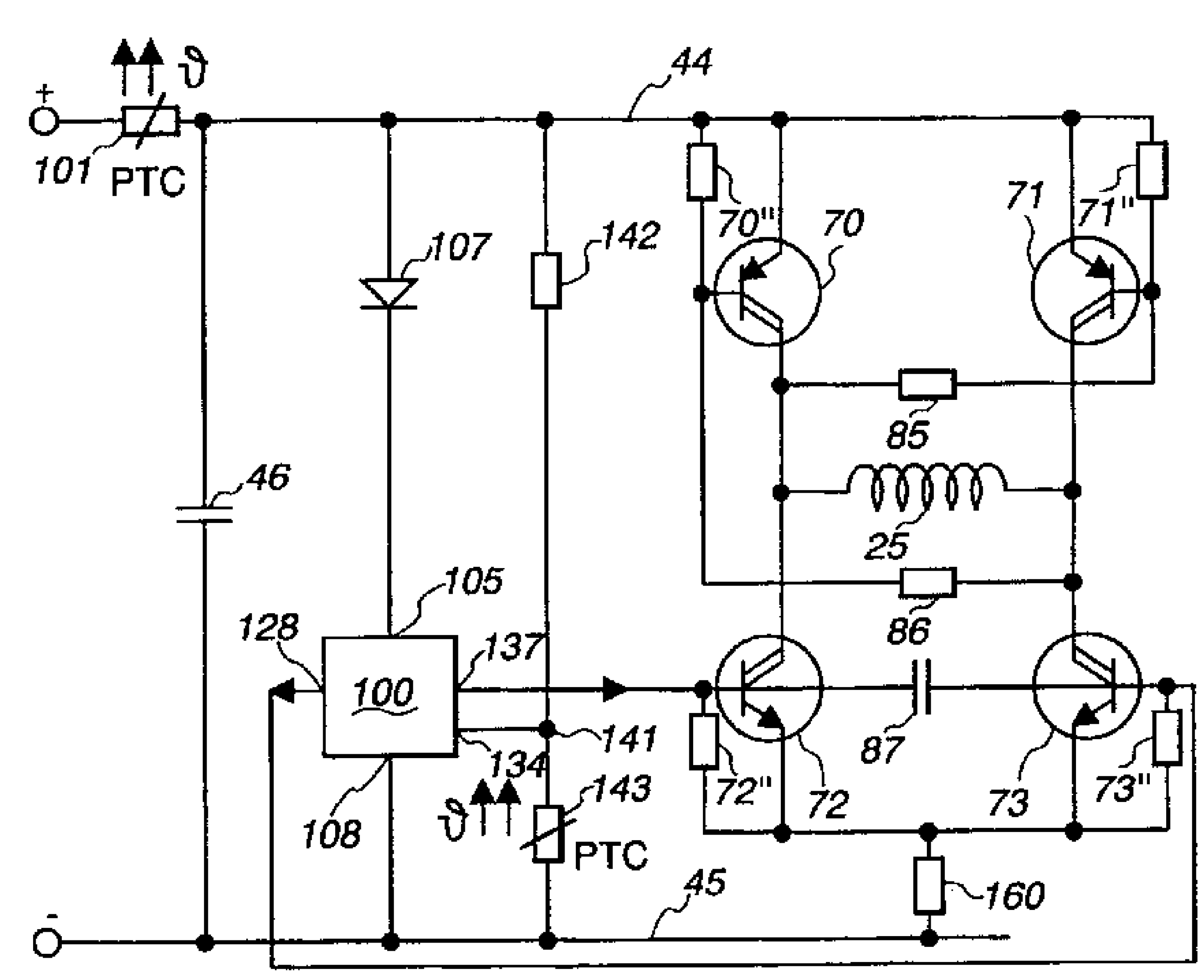
51-22012	2/1976	Japan .	
53-19512	2/1978	Japan .	
54-67620	5/1979	Japan .	
56-19394	2/1981	Japan	318/254
56-159986	12/1981	Japan	318/254
57-115575	1/1982	Japan .	
1528573	10/1978	United Kingdom	318/254
2 071 939	9/1981	United Kingdom .	

Primary Examiner—Bentsu Ro
Attorney, Agent, or Firm—Welsh & Katz, Ltd.

[57] **ABSTRACT**

The stator winding of a brushless D.C. motor receives two current pulses per 360°-el. of rotor rotation, each current pulse being furnished via a respective current path. Each current path contains at least one power transistor switch having conductive and non-conductive states. These states are determined by respective driver transistor switches; when the driver transistor switch is in a high-output-impedance state the respective power transistor switch is rendered conductive, but when in the low-output-impedance state it renders the power transistor switch non-conductive. In various ways disclosed herein measures are taken to prevent the power transistor switches of both current paths from being simultaneously conductive. This may be accomplished using inherent or discrete base-emitter capacitances so connected that a power transistor switch is switched off abruptly but switches-on only after the elapse of a predetermined delay. Alternatively, the Hall voltage produced by the motor's rotor-position-sensing Hall cell may be applied to comparators such that the power transistor switches are not even commanded to conduct except during respective periods each shorter than 180°-el.

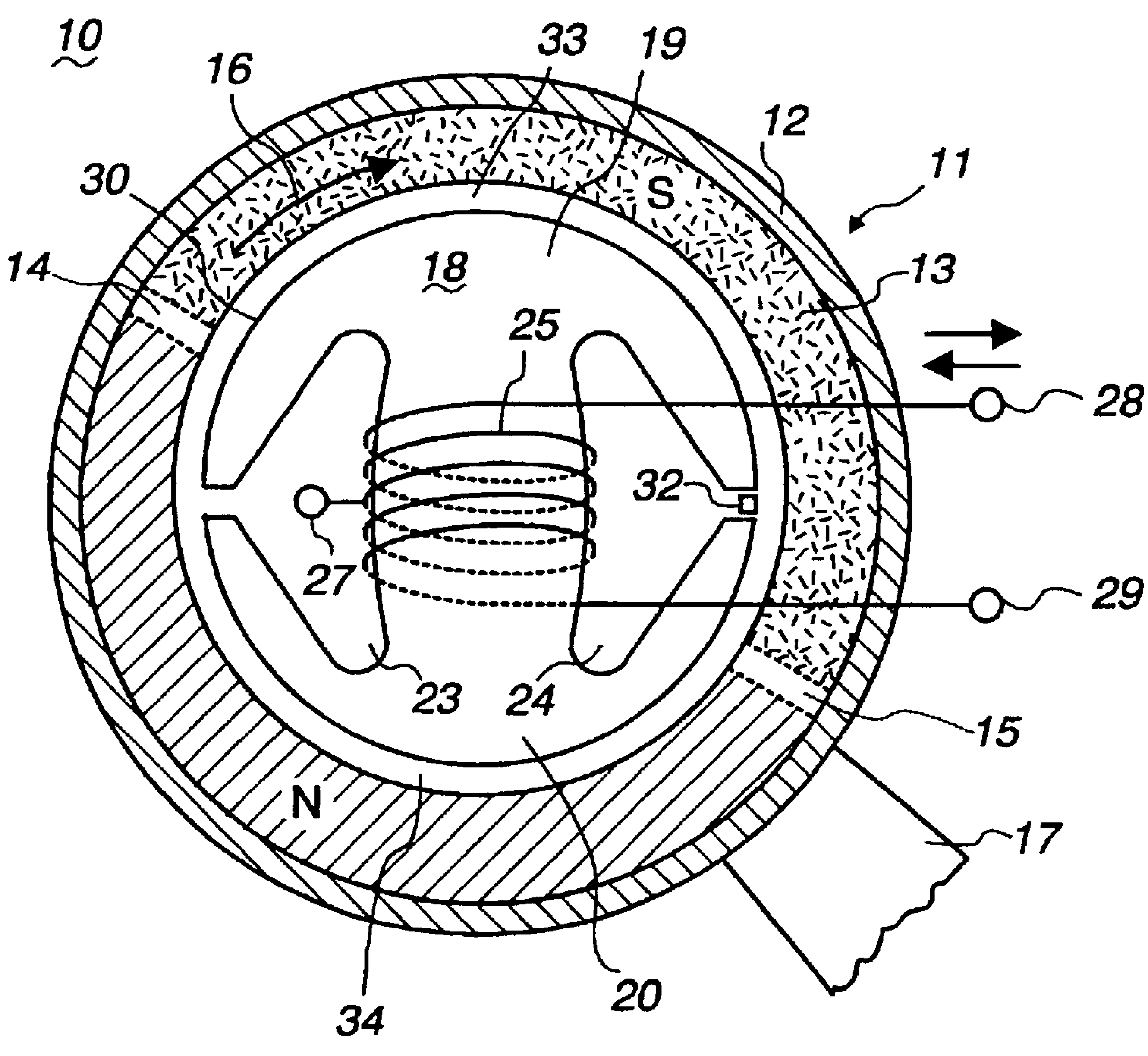
14 Claims, 6 Drawing Sheets



U.S. PATENT DOCUMENTS

4,097,788	6/1978	Nygaard et al. .	
4,105,940	8/1978	Kuhnlein	318/254 X
4,119,895	10/1978	Muller	318/254
4,129,808	12/1978	Bregeault et al. .	
4,135,120	1/1979	Hoshimi et al.	318/722 X
4,292,575	9/1981	Kuhnlein et al.	318/254
4,296,362	10/1981	Beasley	318/439 X
4,347,464	8/1982	Park et al.	318/439 X
4,356,437	10/1982	Saito et al.	318/439 X
4,365,187	12/1982	McDaniel et al.	318/254
4,368,411	1/1983	Kidd	318/254
4,393,339	7/1983	Kimura	318/254
4,403,174	9/1983	Miyazaki et al.	318/138 X
4,429,262	1/1984	Utenick	318/254
4,447,771	5/1984	Whited	318/254 X
4,449,081	5/1984	Doemen	318/254
4,473,781	9/1984	Nielsen	318/254
4,484,114	11/1984	Ebbs	318/138
4,535,275	8/1985	Müller	318/254

Fig. 1



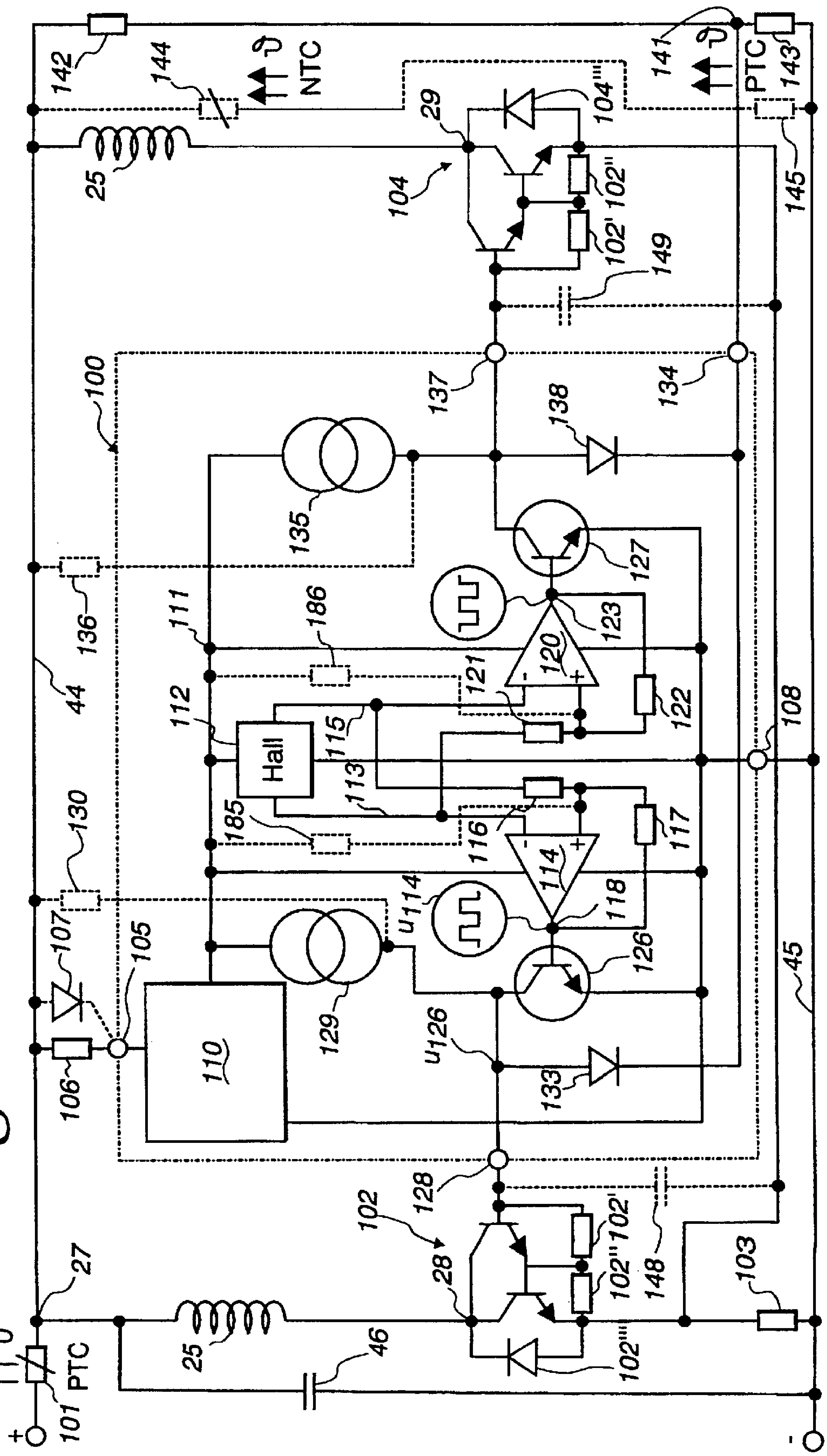

Hall
PTC
NTC
PTC
110
100
25
25
27
28
29
44
45
46
101
102
102'
102''
102'''
103
104
104'''
105
106
107
108
111
112
113
114
115
116
117
118
120
121
122
123
126
127
128
129
130
133
134
135
136
137
138
141
142
143
144
145
148
149
185
186
u_{114}
u_{126}
+
-

Fig. 2

Fig. 3

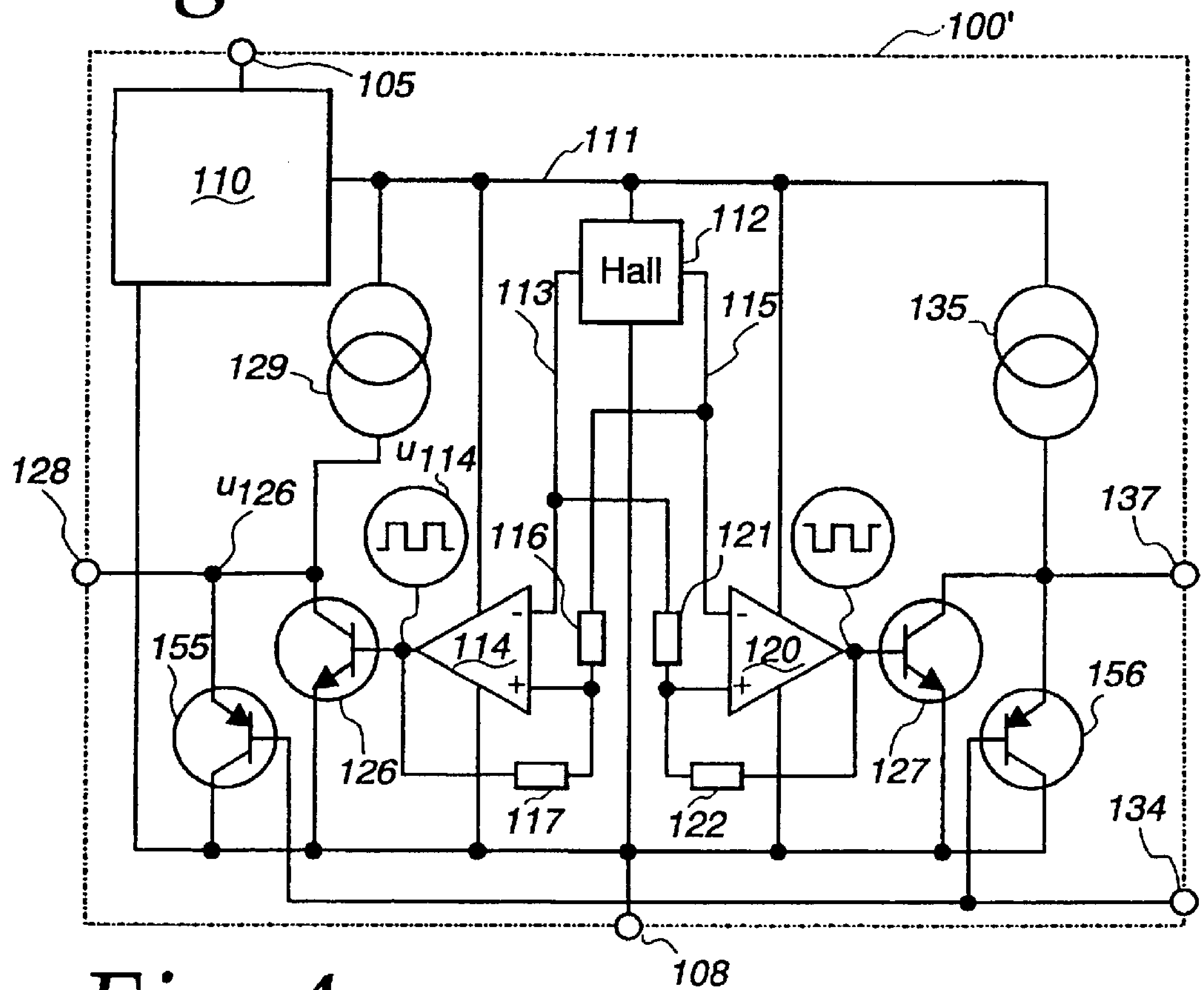

100'
105
110
111
112
Hall
113
115
129
135
128
u126
u114
116
121
137
155
114
120
156
126
127
117
122
134
108

Fig. 4

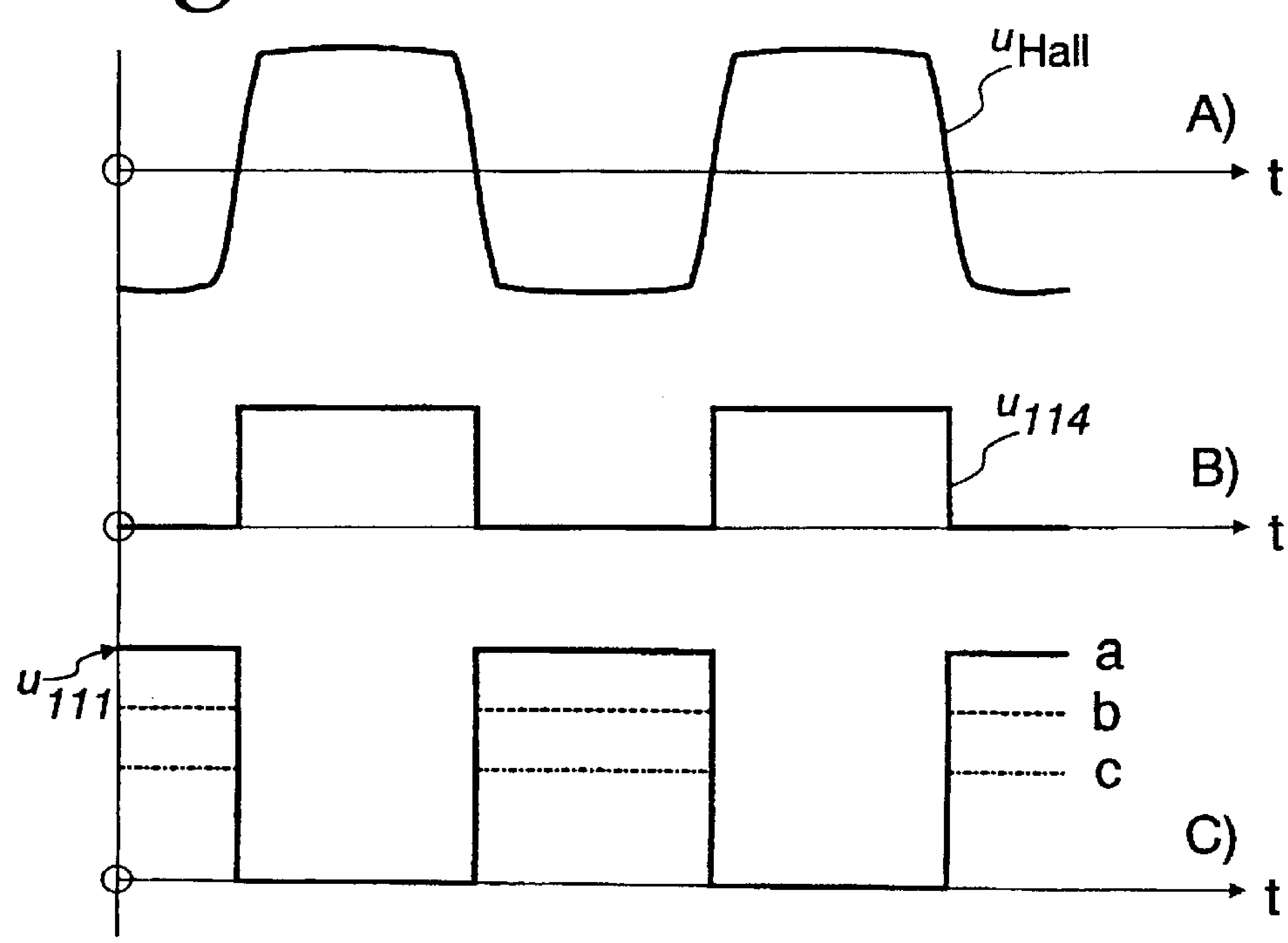
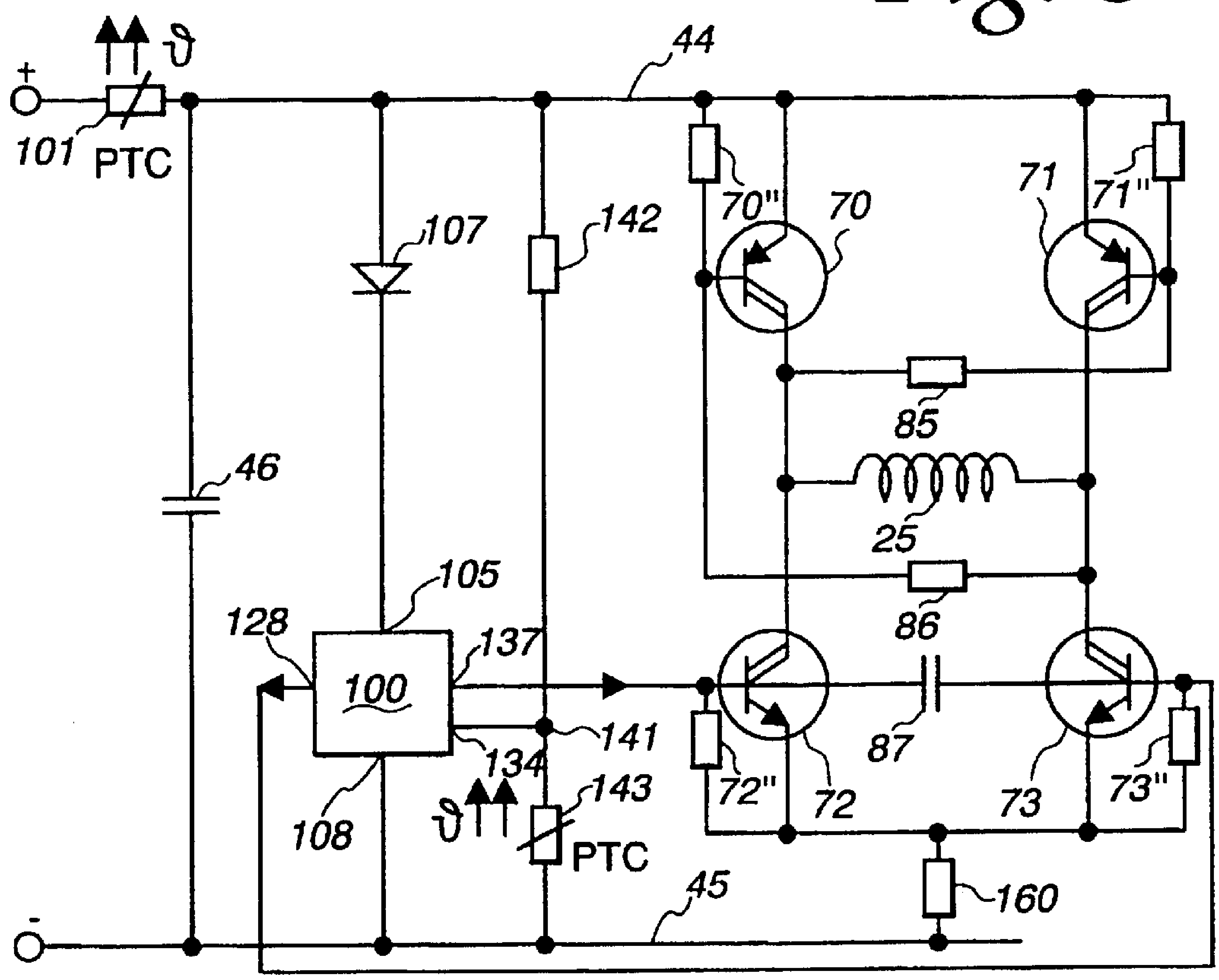
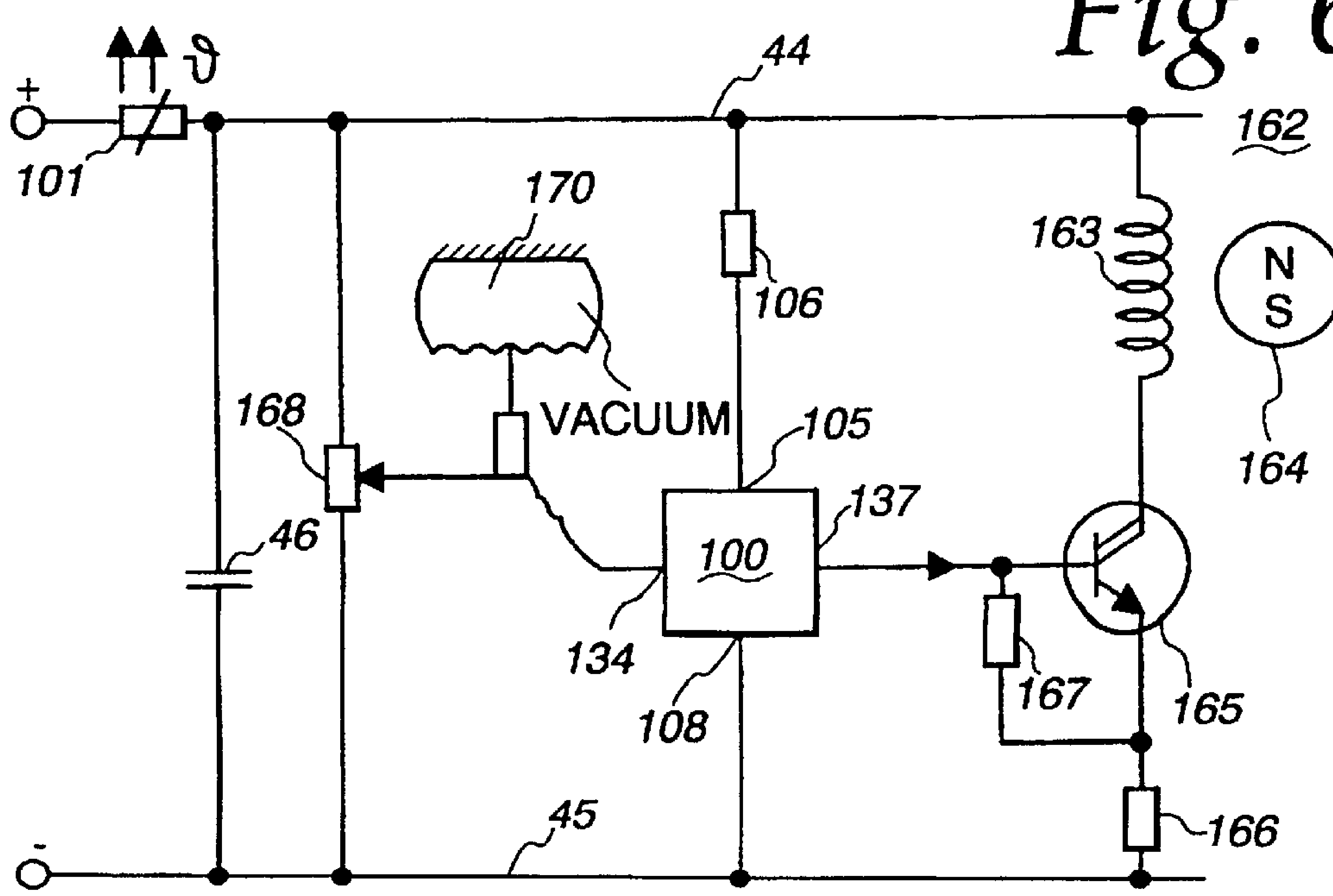

uHall
A)
t
u114
B)
t
u111
a
b
c
C)
t

Fig. 5



+
-
ϑ
101
PTC
44
107
142
70"
70
71
71"
85
25
86
87
46
105
128
137
100
141
134
108
143
PTC
72"
72
73
73"
45
160

Fig. 6



+
-
ϑ
101
44
162
170
106
163
N
S
164
168
VACUUM
105
46
137
100
134
108
167
165
45
166

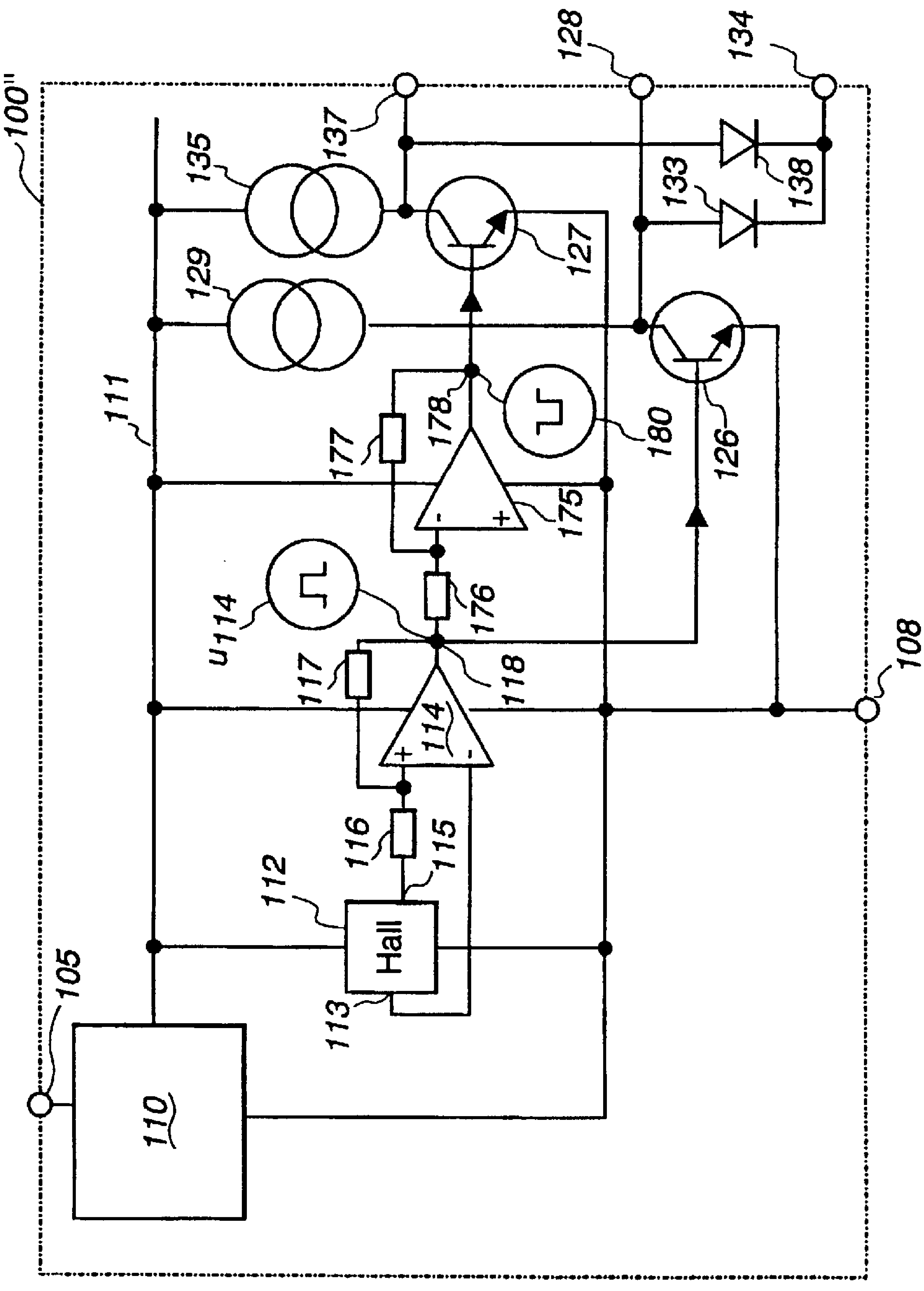

100"
105
108
110
111
112
113
114
115
116
117
118
126
127
128
129
133
134
135
137
138
175
176
177
178
180
Hall
u_{114}

Fig. 7

Fig. 8

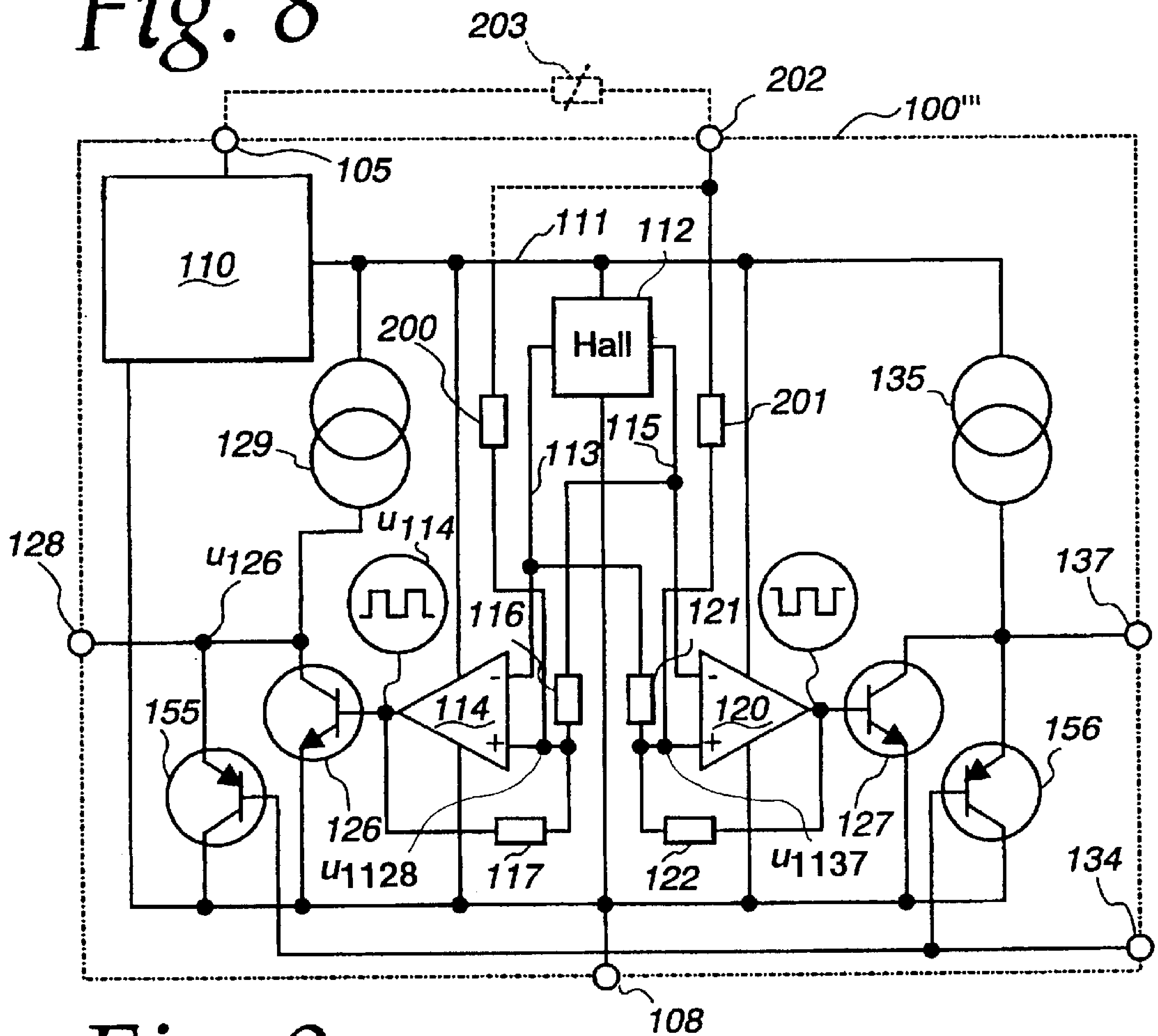
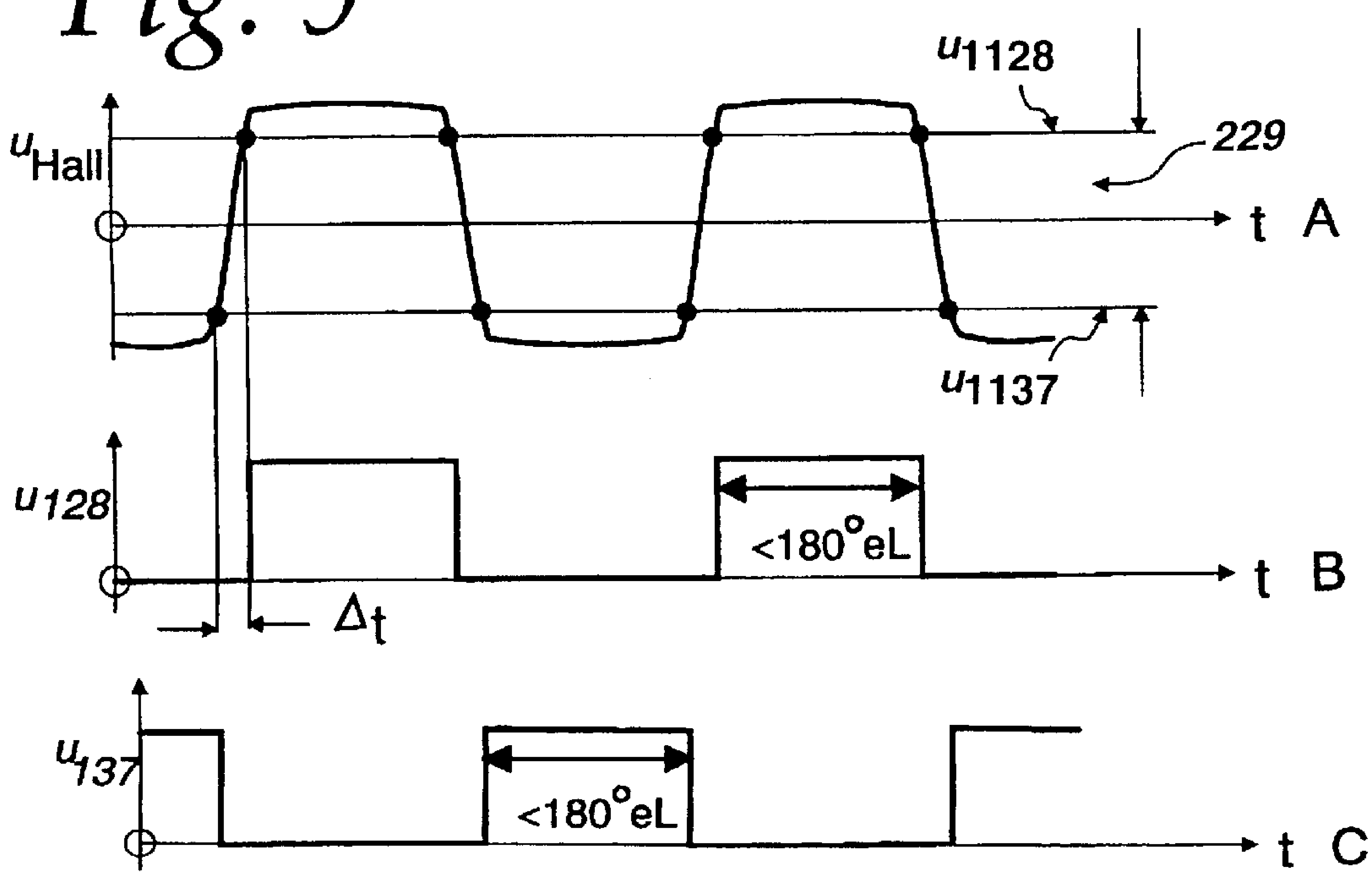

203
202
100'''
105
110
111
112
Hall
200
201
135
129
113
115
128
u114
u126
116
121
137
155
114
120
156
126
127
u1128
117
122
u1137
134
108

Fig. 9


u1128
229
uHall
t A
u1137
u128
<180°eL
t B
Δt
u137
<180°eL
t C

BRUSHLESS 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 application Ser. No. 07/928,976, filed Aug. 12, 1992, abandoned; which is a continuation of application Ser. No. 07/448,760, filed Dec. 11, **[**1969**]** *1989*, abandoned; which is a continuation of application Ser. No. 07/177,692, filed Apr. 5, 1988, abandoned; which is a continuation of application Ser. No. 07/079,100, filed Jul. 29, 1987, abandoned; which is a continuation of application Ser. No. **[**06/635,251**]** *06/635, 253*, filed Jul. 27, 1984, abandoned; which is a continuation-in-part of application Ser. No. 06/447,688, filed Dec. 7, 1982, now U.S. Pat. No. 4,535,275.

BACKGROUND OF THE INVENTION

In parent application Ser. No. 447,688, whose entire disclosure is incorporated herein by reference, commutation circuits are disclosed for a brushless D.C. motor, the exemplary motors having two independently energizable windings and per rotor rotation each winding receiving one respective current pulse; or else the winding consists of a single winding but per rotor rotation a first pulse of current is passed through the winding in one direction and then a second pulse in the opposite direction. In both instances there are two winding current paths each containing at least one power transistor switch controlled by a driver transistor switch; when the driver transistor switch assumes its high-output-impedance state the respective power transistor switch is rendered conductive, and when it assumes its low-output-impedance state the respective power transistor switch is rendered non-conductive. Also, the circuits illustrated in the parent case are provided with means for delaying switch-on of the power transistor switches, such that in the course of commutation it does not happen that the power transistor switches in both winding current paths are in conductive state simultaneously.

Although these circuits satisfactorily perform their intended functions, it has been found that they can in advantageous ways be further simplified.

SUMMARY OF THE INVENTION

In accordance with one advantageous simplification contemplated herein, the entire commutation circuit is configured as two mirror-symmetrical halves, and the rotor position sensor generates two output signals each furnished to a respective circuit half or signal channel. Although this does incidentally involve an increase in the number of circuit elements relative to certain circuits disclosed in the parent application, the mirror-symmetrical configuration is particularly well suited for integrated-circuit realization.

In the mirror-symmetrical circuit, the delayed switch-on of the power transistor switches can be implemented using the inherent input-circuit capacitance of these switches, or by providing auxiliary input-circuit capacitors. Alternatively, the delay can be effected by provision of circuit elements which establish the value which the rotor position signal must reach before the driver transistor switches assume their high-output-impedance state. This may make unnecessary the use of discrete capacitors, which is a desirable simplification. Also, such alternative circuit elements may in various ways be made adjustable and externally accessible for adjustment.

The power transistor switches, although turned on and off under the control of the driver transistor switches, may be controlled as to the magnitude of current they carry when turned on by application of an externally furnished control signal, thereby to modify motor rpm in dependence upon such control signal. If the power transistor switches exhibit high gain the control signal can desirably be of low magnitude; otherwise, the control signal can be applied via amplifying elements in a manner which will be clearer in the description, below, of preferred embodiments.

The novel features which are considered characteristic for the invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** depicts merely by way of example a motor of a type for which the illustrated commutation circuits may be provided.

FIG. **2** depicts a first embodiment of an inventive circuit.

FIG. **3** depicts a modification **100**' of the portion **100** of the circuit of FIG. **2**.

FIG. **4** is a signal diagram referred to in the explanation of the operation of the circuits of FIGS. **2** and **3**.

FIG. **5** depicts a commutation circuit in which the portion **100** of the circuit of FIG. **2** is unchanged, but wherein the remainder of the circuit is different from that shown in FIG. **2**.

FIG. **6** depicts a control circuit which again incorporates portion **100** of the FIG. **2** circuit but utilizes only half the capabilities of portion **100**, for the control of a motor receiving only one, and not two, current pulses per 360°-el. of rotor rotation.

FIG. **7** depicts a second modification **100**" of the portion **100** of the circuit of FIG. **2**.

FIG. **8** depicts a third modification **100**'" of the portion **100** of the circuit of FIG. **2**.

FIG. **9**, finally, is a signal diagram referred to in the explanation of the operation of the circuit configuration of FIG. **8**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** is identical to FIG. **1** of parent application Ser. No. 447,688, to which attention is referred, and depicts a type of brushless D.C. motor, merely by way of example, with which the circuits here illustrated may be used.

Present FIG. **2** depicts an embodiment of the invention which is an alternative to the control circuits shown in FIGS. **2**, **4** and **5** of the parent case. Present FIG. **2** depicts a circuit which can be used with a two-winding-path motor having, merely by way of example, a power of 4 W and an operating voltage between 8 and 30 V; self-evidently the circuit could be designed for higher powers and higher operating voltage values. The commutation circuit is here designed as including a commutation circuit module **100**, preferably an IC module because such approach is particularly advantageous for spatial economy for example in the case of compact fan-motors. Circuit module **100** is here designed such that, when incorporated in the complete circuit of present FIG. **2**, the connections between the circuit-module terminals and the remaining circuit elements are particularly advantageous relative to the segregation of low-energy and high-energy sections of the complete circuit; in this way, within the circuit module **100** itself, only low power losses are involved. This affords, among other things, an increased efficiency for the motor.

A positive-temperature-coefficient resistor **101** is provided in the positive operating voltage line of the circuit; if the motor is blocked in any way against rotation and therefore is beginning to overheat, PTC resistor **101** serves to lower the effective operating voltage and thereby counteract overheating. One of the stator winding's two current paths has its terminal **27** connected to positive operating voltage line **44** and its terminal **28** to the collector of an npn Darlington transistor **102**, whose emitter is connected via a low-resistance resistor **103** (e.g. of between 0.1 and 3 ohms) to the negative operating voltage line **45**. The presence of resistor **103** serves to establish a negative-feedback stabilization of the magnitude of the current flowing through the collector-emitter path of power transistor **102**, and thus through winding path **25**. Resistor **103** is analogously connected between the emitter of a second npn Darlington transistor **104** and negative voltage line **45**. The collector of transistor **104** is connected to terminal **29** of winding **25**, the winding's center terminal **27** being as shown connected to the positive voltage line **44**. Transistors **102** and **104** are provided with base-emitter resistors **102'**. **102"**, **104'**, **104"** and with freewheeling diodes **102'"**, **104'"**. By way of example these transistors can be of type BD 679. When one or the other of transistors **102**, **104** is conductive, there is produced across resistor **103** a voltage drop which reduces the magnitude of the base-emitter voltage of the conductive transistor, thus implementing a negative-feedback-type, stabilizing action. In this way it is prevented that these transistors—for example, in the case they are subjected to different respective temperatures—would carry current of different respective values. These two transistors preferably have high current gain on the order of 1000 to 1500, which is advantageous for reasons which will become clearer below.

Circuit module **100** has its terminal **105** connected to positive voltage line **44** via a resistor **106**, or else via a diode **107** (shown in broken lines), or by a non-illustrated series connection of such resistor and diode; and its terminal **108** is connected to negative line **45**. Terminal **105** is connected to the accessible operating-voltage terminal of an integrated voltage-regulator stage **110** contained in circuit module **100**. Voltage regulator **110** has an output voltage of e.g. 3–5 V; the other accessible operating-voltage terminal of voltage regulator **110** is connected to terminal **108** and thereby to the negative voltage line **45**. Voltage regulator **110** furnishes regulated voltage at its output **111**.

Circuit module **100** contains a Hall cell **112** having a current input connected to output **111** and another current input connected to terminal **108**. The left Hall output **113** is directly connected to the negative input of an operational-amplifier comparator **114**, and the right Hall output **115** is connected via a resistor **116** to the positive input of comparator **114**. A feedback resistor **117** connects the comparator output **118** to its positive input terminal.

In a manner symmetrical to that just described, Hall output **115** is directly connected to the negative input of an operational-amplifier comparator **120**, whereas Hall output **113** is connected via a resistor **121** to the positive input of comparator **120**; comparator **120** has a feedback resistor connecting output **123** to the positive input terminal of the comparator. As shown, the comparators **114**, **120** have their operating-voltage terminals connected to the negative line terminal **108** and to the regulated output terminal **111**.

The output or driver stages of circuit module **100** are constituted by two npn transistors **126** and **127**. The base of driver transistor **126** is connected to comparator output **118**, and its emitter to negative terminal **108**; its collector is connected to module output terminal **108** and, furthermore, connected either (as shown) via an integrated constant-current stage **129** to the regulated-voltage terminal **111**, or else (as indicated by broken lines) is connected via a high-resistance resistor **130** to the positive voltage line **44**, in which event constant-current source **129** can be omitted. A low magnitude current of for example a few milliamperes (1–5 mA) flows to the collector of transistor **126** via the constant current source **129**, or via the resistor **130**. Also connected to the collector of transistor **126** is the anode of a diode **133**, whose cathode is connected to a terminal **134** of circuit module **100**. In a manner described below, module terminal **134** receives a low-energy control signal which can be used to increase or reduce motor speed in dependence upon a sensed or measured quantity, such as some aspect of fan operation when the motor is used for a fan.

In a manner symmetrical to the foregoing, the base of driver transistor **127** is connected to comparator output **123**, and its emitter is connected to negative terminal **108**. Its collector is connected to the regulated-voltage line **111** via a constant-current stage **135**, or alternatively is connected to the positive voltage line **44** via a high-resistance resistor **136**. Here likewise, constant current flows to the collector of transistor **127** having a magnitude of a few milliamperes. If the magnitude of this constant current is made smaller, the power loss in circuit module **100** becomes smaller; the motor efficiency becomes higher; and it becomes easier to influence the power furnished to the motor within wide limits by means of a low-magnitude control signal. The collector of driver transistor **127** is connected to output terminal **137** of circuit module **100**. Also connected to the collector of transistor **127** is the anode of a diode **138**, whose cathode is connected to module terminal **134**.

Module terminal **134** is connected to the tap **141** of a voltage divider **142**, **143** connected across the positive and negative voltage lines **44**, **45** and comprising a fixed resistor **142** and a PTC resistor **143**. PTC resistor **143** can for example be located in the air flow of the fan powered by the motor **10**. If the air moved by the fan grows warmer, the potential at voltage-divider tap **141** increases, which consequently increases the bias voltage to the base of Darlington transistor **104**, motor **10** accordingly receives higher electrical power and its rpm rises, as a result of which a greater air flow rate is established, so as to bring down again the temperature of the air.

Instead of temperature-dependent voltage divider **142**, **143**, use can be made of a temperature-dependent voltage divider **144**, **145** (shown in broken lines) containing a fixed resistor **145** is its lower part and a negative-temperature-coefficient resistor **144** in its upper part. Such alternative voltage divider in principle operates equivalently to divider **142**, **143**. However, the alternative with PTC resistor **143** is preferred; if resistor **143** is destroyed or fails, terminal **134** will automatically be established at a potential effecting an increase in motor rpm, rather than a decrease.

Connected to module output terminal **128** is the base of a power transistor **102**; connected to module output terminal **137** is the base of a power transistor **104**. A capacitor **46** is connected between the positive and negative voltage lines

44, 45; it serves to somewhat stabilize the potential difference between these two lines and, importantly, serves to receive and temporarily store energy from one or the other of the two windings **25** during the commutation process.

The illustrated circuit contains relatively few components, namely the two power transistors **102, 104**, the capacitor **46** of about 22 microfarads, the integrated-circuit module **100**, the resistor **106**, and (if provided) the voltage-divider resistors **142, 143** or **144, 145**. (The module's control terminal **134** could alternatively be connected to a source of fixed or manually adjustable potential.)

The circuit of FIG. **2** operates as follows:

The circuit module **100** with its Hall cell **112** can, for example in the case of the motor of FIG. **1**, be so arranged that Hall cell **112** is at the position of, and replaces, the Hall-IC **32** of FIG. **1**, so as to be influenced by the rotor magnet **13**. When the rotor **11** turns, there is produced between the outputs **113, 115** of the Hall cell **112** a voltage as shown in FIG. **4**A, whose waveform closely simulates the magnetization distribution of the rotor magnet **13**. The Hall voltage is applied, e.g., to the comparator **114** and a corresponding rectangular voltage u_{114} shown in FIG. **4**B appears at the output of the comparator **114**. The rectangular voltage u_{114} controls the driver transistor **126** and a voltage u_{126} shown in FIG. **4**C appears at the collector of transistor **126**. Actually, the potential level of u_{126} can be clamped by diode **133** at a predetermined (but variable) level. In particular, if the potential at voltage-divider tap **141** is high, diode **133** remains non-conductive and (as shown if FIG. **4**C) voltage u_{126} can assume the solid-line level a; this corresponds to a high temperatures of the PTC resistor **143**, and thus corresponds to maximum motor power being needed. Voltage level a corresponds approximately to the potential level u_{111} produced at regulated-voltage line **111**. As already stated, PTC resistor **143** may e.g. be located in the fan's airflow path; if it experiences a relatively lower temperature, then the potential at voltage-divider tap **141** is lower; and voltage u_{126} assumes the lower level b shown in broken lines in FIG. **4**C; i.e., the motor receives a corresponding lower level of energization. If the temperature of PTC resistor **143** is very low, there results the low potential level c shown in dash-dot lines in FIG. **4**C; i.e., the motor receives even lower current and runs still more slowly. In this way one can effect closed-loop or open-loop control of the motor rpm using very low current for a control signal, of a few milliamperes, i.e., by limiting the excursion of the collector voltages of transistors **126, 127** by means of a common control signal applied to module terminal **134**.

To effect delayed switch-on of the power transistors, there can additionally be provided (as shown in broken lines in FIG. **2**) a capacitor **148** between the base and emitter of transistor **102** and a capacitor **149** between the base and emitter of transistor **104**; these typically can have values between 1 and 10 nanofarads. When driver transistor **126** becomes conductive, capacitor **148** can very quickly discharge in order to render power transistor **102** non-conductive very abruptly. Conversely, when driver transistor **126** becomes non-conductive, power transistor **102** cannot actually become conductive until capacitor **148** charges up to a predetermined level via the constant-current source **129** (or, alternatively, via the high-resistance charging resistor **130**); thus, delayed switch-on of power transistor **102** is assured. In certain situations, capacitor **148** may be unnecessary, and the inherent base-emitter capacitance of the power transistors may be sufficient to accomplish a switch-on delay of sufficient duration. On account of the circuit's symmetry, the above remarks apply equally to power transistor **104**. In certain situations, the capacitors **148, 149** may be unnecessary, and the inherent base-emitter capacitance of the power transistors **102, 104** may be sufficient to accomplish a switch-on delay of sufficient duration; also, in the case of motors having two windings **25** as in FIG. **1**, the desired gap in current flow during commutation need not be of great duration.

The control potential applied to the aforedescribed module terminal **134** can be developed, of course, in various ways, e.g. in dependence upon a pressure value which is to be regulated or stabilized, or in deendence upon air moisture, rpm, etc., etc. If the power transistors **102, 104** are of high current gain, then they can be adequately controlled by means of low base current on the order of a few milliamperes, in which case the voltage divider **142, 143** (or **144, 145**) can be of high ohmic resistance, thereby contributing to the motor's efficiency. For this reason the circuit module **100** is particularly well suited for use in conjunction with Darlington transistors of high current gain, or equivalent transistor configurations. Of course, the power-carrying switches, instead of being such high-gain transistors, could be thyristors or SCR's, or the like.

In FIG. **2**, instead of implementing the power-transistor switch-on delay by reliance upon inherent base-emitter capacitance or the discrete base-emitter capacitors **148, 149**, it is also possible to implement the delay further upstream, i.e., closer to the output voltage of the Hall cell **112**. This alternative involves the use of the two resistors **185, 186** shown in broken lines. Resistor **185** is connected between the regulated-voltage line **111** and the positive input of comparator **114**; resistor **186** is analogously connected, but to comparator **120**. Selection of the values of resistors **185, 186** contributes to establishment, at each comparator's positive input, of the reference level determined at such positive input, and can be so done as to introduce an interval during which both driver transistors **126, 127** are conductive, so that both power transistors **102, 104** be non-conductive. For example, as shown in FIG. **4**B, comparator **114** is in the high state during 50% of each rotor rotation, and the other comparator **120** is in the high state during the other 50% of each rotation; this is because comparator **114** is assumed to convert to the high state when the Hall voltage exceeds zero, whereas comparator **120** assumes the high state when the Hall voltage falls below zero. If now by means of resistors **185, 186** the reference levels of the two comparators are somewhat raised, then comparator **114** will not assume the high state until the Hall voltage exceeds zero by a predetermined small amount; and comparator **120** will not assume the high state until the Hall voltage falls below zero by a predetermined small amount. In this way, each comparator **114, 120** will be in the high state for less than 50% of each rotor rotation, so that twice per rotation, namely at the points in time at which commutation is to occur, neither of the two power transistors **102, 104** will be conductive.

FIG. **3** depicts a modified circuit module **100'** suited where higher output currents are employed. Except for a few differences to be described, module **100'** is the same as module **100** of FIG. **2**. Elements identical or equivalent to those of FIG. **2** are denoted by the same reference numerals as there, and need not be described a second time.

Instead of the diodes **133, 138** of FIG. **2**, there are provided in FIG. **3** two pnp transistors **155, 156** (or their IC equivalents). The emitter of transistor **155** is connected to module output terminal **128**; its collector to the module's negative voltage terminal **108**; and its base to the module's control signal input terminal **134**. Analogously, the emitter of transistor **156** is connected to terminal **137**, its collector to terminal **108** and its base to terminal **134**. Thus, if the constant-current sources **129, 135** (or **130, 136** of FIG. **2**) are dimensioned to carry relatively higher current than in FIG. **2**, the control signal applied to module terminal **134** can still be of low magnitude and nevertheless effect clear control of motor power; namely, the transistors **155, 156** will be capable of controllably diverting away a sufficient fraction of the (here relatively higher) collector currents of driver transistors **126, 127**.

(The delayed switch-on of the power transistors in FIG. **3** can be effected in any of the three ways shown in FIG. **2**; i.e., inherent base-emitter capacitance, or the equivalent, discrete base-emitter capacitance, or the comparator reference resistors **185, 186** of FIG. **2**.)

FIG. **5** depicts a motor communication and control circuit which has a configuration which is very similar to that of FIG. **4** of parent application Ser. No. 447,688, to which attention is directed; corresponding elements are denoted by the same reference numerals here as there. The freewheeling diodes **70'** to **73'** of FIG. **4** of the present case are here omitted for simplicity.

In present FIG. **5** the emitters of the bridge transistors **72** and **73** are connected together and to the negative voltage line **45** via a low-resistance resistor **160** of, e.g., 0.1 to 3 ohms. The base of power transistor **72** is connected to output terminal **137** of circuit module **100**; the base of transistor **73** to the terminal **128**. The capacitor **87**, typically of 0.1–2 nF, in many instances can be eliminated, but here is connected directly between terminals **128** and **137** of circuit module **100**, in contrast to present FIG. **2** where between these two terminals there is connected the series connection of capacitors **148** and **149**. For this reason the capacitor **87** can be of lower capacitance than capacitors **148** and **149**. Operating voltage terminal **105** of circuit module **100** is connected via a diode **107** to the positive voltage line **44**, and its terminal **108** is connected to negative line **45**. As in present FIG. **2**, the tap of the PTC voltage divider **142, 143** is connected to the control terminal **134** of circuit module **100**.

The circuit of present FIG. **5** operates in the same way generally as that of FIG. **4** of parent case Ser. No. 447,688. If for example power transistor **73** has been conductive but now becomes non-conductive, the potential at its base is very quickly brought down by the driver transistor **126** internal to module **100** (see present FIG. **2**). This change in potential is transmitted by capacitor **87** to the base of power transistor **72**, causing the base potential to become more negative than the negative voltage line **45**, and thereby holding transistor **72** non-conductive. Then, via constant-current source **135** (or alternatively the resistor **136**) substantially constant current flows to the capacitor **87** to reverse the polarity of charge on the latter; after elapse of a certain time, the charge reversal is completed and transistor **72** becomes conductive, as does also the transistor **71**. When the communication is proceeding in the opposite sense, the circuit operations proceed in analogous manner, in correspondence to the mirror-symmetrical configuration of the circuit.

FIG. **6** depicts the use of the circuit module **100** in the communitation of a motor **162** of the type having only a single energizable winding portion, the winding receiving furthermore only a single pulse of current per rotor rotation (or, more generally, per 360°-el. of rotor rotation, for cases where the rotor has more than one pair of poles). Numeral **163** denotes the motor winding, and **164** the rotor. Such motors are disclosed, merely by way of example, in West German published patent application DE-OS 22 60 069 (D37), and are known to persons skilled in the art. Because only one current pulse is required per rotor rotation, only the output terminal **137** of circuit module **100** need be employed; output terminal **128** remains unused, and can (in non-illustrated manner) be connected via a resistor to the negative line **45**. Module output terminal **137** is connected to the base of an npn Darlington transistor **165**, the collector of Darlington transistor **165** is connected via the winding **163** to positive line **44**, and the emitter of Darlington transistor **165** is connected via a low-resistance resistor **166** to the negative line **45** and via a resistor **167** to the base. Connected between the positive and negative voltage lines **44, 45** is a high-resistance potentiometer **168**, whose wiper **169** is electrically connected to control terminal **134** of module **100** and mechanically coupled to a barometric transducer **170** which controls the wiper's setting; transducer **170** in conventional manner is an evacuated device. If the ambient pressure rises, potentiometer wiper **169** shifts upwards, the rpm of motor **162** increases, and, e.g., more air is transported by the fan, e.g., assuming the motor is that of a fan. The transducer **170** could instead be, for example, a differential-pressure transducer, or a hygrometric transducer used to cause the motor rpm to automatically rise in response to a rise of air moisture. Still other types of transducer **170** will suggest themselves for various other types of applications.

PTC resistor **101** serves to reduce the motor current to a low value, when as a result of the motor being blocked against rotation overheating begins to occur and the resistance of resistor **101** rises. Diode **107** protects the motor and its circuit from inadvertent wrong-polarity connection to voltage; if the motor and its circuit are wrongly connected to voltage, circuit module **100** receives no current and accordingly cannot be damaged.

FIG. **7** depicts a modified, here unsymmetrical configuration for the integrated commutation circuit module, here denoted **100"**. Its function is generally the same as that of the circuit modules **100** (present FIG. **2**) and **100'** (present FIG. **3**). Also, its configuration is to a considerable extent similar thereto. The voltage regulator **110** with its output **111** of e.g. 3–5 V, the Hall cell **112** with its outputs **113** and **115**, the comparator **114**, the one driver stage (e.g., the constant-current source **129** with its current of e.g. 1–5 mA plus the npn driver transistor **126**) are configured identically to the left part of the circuit internal to the module **100** of present FIG. **2**. Also, the current-diverting diode **133** is identically connected to module output terminal **128**. The resistor **116** is here, as in the preceding embodiments, preferably of much lower ohmic value than the feedback resistor **117**, e.g., in a ratio from 100:1 to 10:1. (This applies analogously for the resistors **121** and **122** in FIGS. **2** and **3**.)

Likewise the other driver stage (constant-current source **135** for e.g. 1–5 mA plus npn driver transistor **127**) is the same as in FIG. **2**, and likewise the current-diverting diode **138**. Also, the external terminals of circuit module **100"** are denoted by the same numerals as those of circuit module **100** of FIG. **2**, or those of circuit module **100'** of FIG. **3**, as the operation of these circuit modules (electrical characteristics, signals, operating voltages, etc.) is the same.

However, in FIG. **7**, in contrast to FIG. **2**, the second comparator **120** is omitted and in its place there is provided a phase inverter stage **175**, here having the form of an operational amplifier whose operating-voltage terminals are connected to the regulated-voltage line **111** and to the negative voltage terminal **108**. Its inverting input is connected via a resistor **176** to the junction **118**, i.e. to the output of comparator **114**, and via a resistor **177** is connected to its output **178**.

Preferably the resistors **176** and **177** are of about the same resistance value, to establish a gain of about unity. The output **178** of the phase inverter is connected to the base of driver transistor **127** and controls the latter. The phase inverter stage **175** thus effects a phase invertion of the generally rectangular signal u_{114} (at junction **118**) as indicated at **180** in FIG. **7**. In this way one obtains at the two module output terminals **128, 137** in FIG. **7** two phase-opposed signals, as was the case at the outputs **128, 137** of the module **100** of FIG. **2**. Thus, although the module **100**" of FIG. **7** has a non-symmetrical configuration, its action is the same, externally, as that of the modules **100** of FIG. **2** and **100**' of FIG. **3**. Which of these configurations is to be employed depends upon various considerations, including for example considerations of integrated-circuit fabrication in the particular context to be faced.

However, a considerable advantage of the circuits of FIGS. **2** and **3** is that, there, the Hall cell **112** furnishes two separate signals which can then be utilized in two separate signal channels; in contrast, in FIG. **7**, the Hall cell **112** is shown as producing but one signal which is used twice, i.e., in both non-inverted and inverted form.

If two separate signals are employed and applied to two comparators **114** and **120**, as in FIGS. **2** and **3**, then the comparators can be individually set, making it possible to implement either a small time separation between their respective output signals, or else such that one comparator's output signal follow the other's without a gap, or else such that the two comparator output signals actually overlap in time. Naturally, the first of these three possibilities (i.e., time separation) is for many motor types the preferred choice because of the improvement in motor efficiency; this is particularly the case for two-pulse motors, i.e. motors whose stator winding system receives two energizing current pulses per each 360°-el. of rotor rotation.

Present FIG. **2** is an example of this last-mentioned alternative. To this end, the positive input of comparator **114** is connected via a high-resistance resistor **185** to the regulated-voltage output **111** of voltage regulator **110**, and the positive input of comparator **120** is likewise connected via a high-resistance resistor **186** to the regulated-voltage line **111**. For example, in FIG. **2** the resistor **117** may be about ten to one hundred times greater in its resistance value than resistor **116**, and resistor **185** is about two hundred times greater than resistor **116**. Similar relationships apply to the corresponding resistors in the other half of this two-half symmetrically configured circuit. In this way comparator **114** does not change state until the potential at Hall output **115** has assumed a value more negative than would be needed without the resistor **185**. And conversely, comparator **120** does not change state until the potential at Hall output **113** reaches a value which is more negative than would be needed without the resistor **186**. In this simple way there is accomplished the desired time separation between the signals produced at the output terminals **128** and **137**. Instead of thusly influencing the comparator's reference levels at the stated input terminals thereof, equivalent influencing could be accomplished at the other inputs of the comparators.

Thus, with the very simple circuit configurations here disclosed one can achieve an optimum of operating capability and reliability. Because of the relatively small number of discrete elements, modules and stages, the illustrated circuits are particularly suited for use in the motors of fans of the type built into electrical and electronic equipment; very frequently, such fans are permitted to have an axial length of about 38 mm, thus leaving within the outlines of the fan's motor very little space for circuit elements. It will be appreciated that the principles of the invention can likewise be employed with circuits incorporating so-called half-bridge power-transistor configurations.

In the embodiments described above, and in the one yet to be described, various alternatives are depicted in broken lines or other set forth. It will be understood that these variousalternatives are not explicitly depicted repetitiously in each successive embodiment, for simplicity; however, where the configuration of one embodiment corresponds in part to that of another, the alternatives depicted or described for one can likewise be employed in the other, and are intended to be so disclosed herein.

FIG. **8** depicts a further embodiment very similar to FIG. **3**, and thus very similar to FIG. **2** of which FIG. **3** constitutes a modification. FIG. **8** differs from FIG. **3** in the provision of two further resistors **200, 201**. The lower terminal of each resistor **200, 201** is connected to the non-inverting input of a respective one of the two comparators **114, 120**, and their upper terminals are connected together and to a further input terminal **202** of circuit module **100'''**. An external adjustable resistor **203** is connected between the operating-voltage input terminal **105** of voltage regulator **110** and the module terminal **202**; the left terminal of resistor **203** is thus connected to the positive voltage line **44** (see e.g. FIG. **2**) via for example the resistor **106** (again, see FIG. **2**). Adjustment of the resistance value of adjustable resistor **203** modifies the reference potential applied to the positive inputs of the comparators **114, 120**. As shown in FIG. **9**, line A, the Hall voltage u_{Hall} has one polarity during one half a rotor rotation and the opposite polarity during the other half rotation. Line B in FIG. **9** depicts the output pulses produced at module output terminal **128** under the control of comparator **114**; line C depicts the output pulses produced at module output terminal **137** under the control of comparator **120**. As shown in lines B and C, the comparator reference potential can be so adjusted that the durations of the output pulses do not correspond to the periods in which the Hall voltage is of one polarity or the opposite polarity; instead, the output pulses can each be made to be of shorter duration than 180°-el., thus establishing a gap between the end of a pulse in line B and the start of a pulse in line C, and likewise between the end of a pulse in line C and the start of a pulse in line B. In line A, **[**u_{128} and u_{137}**]** *u_{1128} and u_{1137}* indicate the comparator reference potentials corresponding to the pulses in lines B and C, and **229** indicates the range of Hall-voltage values within which neither of the module output terminals **128, 137** produces an output pulse. As indicated in line B, each pulse commences delta-t later than the corresponding zero-crossover point of the Hall voltage; and likewise, ends delta-t before the next-following zero-crossover point occurs.

Instead of using the externally accessible, adjustable resistor **203**, the two resistors **200, 201** could each be adjustable and externally accessible to produce an equivalent result, but with the additional advantage that the durations of the pulses in line B of FIG. **9** could be selected somewhat independently of those in line C, which may sometimes be helpful in correcting for any tendency of the two symmetrical halves of the module's circuit to operate non-identically. In such case the upper terminals of resistors **200** and **201** could alternatively be connected to the regulated-voltage line **111** and adjustable resistor **203** would not need to be present at all.

It will be understood that each of the elements described above, or two or more together, may also find a useful application in other types of commutation circuits differing from the types described above.

While the invention has been illustrated and described as embodied in motor having improved commutation circuits, it is not intended to be limited to the details shown and described, since various modifications and structural and circuit changes may be made without departing in any way from the spirit of the present invention.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can, by applying current knowledge, readily adapt it for various applications without omitting features that, from the standpoint of the prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention.

What is claimed as new and desired to be protected by Letters Patent is set forth in the appended claims.

I claim:

1. A brushless direct current motor having a stator provided with at least one stator winding producing an alternating field, the stator winding comprising at least one independently energizable winding path, a permanent magnet rotor, and means for sensing rotor position and generating rotor position signals, the motor furthermore comprising

first and second power transistor means connected to the stator winding and so connected to the rotor-position-signal-generating means as to be rendered alternately conductive by the latter in order to cause the field from the stator winding to alternate between its two different field orientations,

the first and second power transistor means having like output electrodes each connected to a common line, and furthermore having like control electrodes; and

capacitor means connecting the control electrode of the first power transistor means to the control electrode of the second power transistor means in such a fashion that when either one of the power transistor means is in conductive state with the other in non-conductive state, the capacitor means develops across itself a voltage of magnitude and polarity such that when said one and said other power transistor means are thereafter to become, respectively, non-conductive and conductive, said capacitor means voltage acts to initially reverse bias said other power transistor means, thereby delaying assumption by the latter of its conductive state until after said one power transistor means has been non-conductive for a predetermined period of time, whereby to prevent the alternately conductive first and second power transistor means from becoming briefly conductive simultaneously with each other during their interchange of conduction states.

2. A motor as defined in claim **1**, said first and second power transistor means respectively comprising a first and a second power transistor, the first and second power transistors being of the same conductivity type, furthermore including third and fourth power transistors of a conductivity type opposite to that of said first and second power transistors, said stator winding comprising a coil having one terminal connected to the collectors of the first and third power transistors and another terminal connected to the collectors of the second and fourth power transistors, whereby to form a four-transistor bridge circuit with said coil being connected in the diagonal of such bridge circuit.

3. A motor as defined in claim **2**, furthermore including first and second constant-current sources each connected to the control electrode of a respective one of said first and second power transistors.

4. A motor as defined in claim **2**, furthermore including resistor means, said like output electrodes of said first and

second power transistors being connected to one terminal of said resistor means whose other terminal is connected to said common line.

5. A motor as defined in claim **1**, furthermore including first and second constant-current sources each connected to the control electrode of a respective one of said first and second power transistor means.

6. A motor as defined in claim **1**, furthermore including resistor means, said like output electrodes of said first and second power transistor means being connected to one terminal of said resistor means whose other terminal is connected to said common line.

7. Brushless direct current motor having one sensor which operates in accordance with rotor position to supply energizing pulses to adjacent energizing conductors connected in a circuit configured as two mirror-symmetrical halves that operate via amplifying means in a chronological successive manner and employ two lines each connected to a stator winding of the motor, thereby providing zero-power time-intervals of commutation when commutating from one energizing conductor to the next one in sequence, the output voltage of the sensor exhibiting inclined leading edges and inclined trailing edges forming a substantially trapezoidal shaped output signal from the sensor, the amplifying means for commutation purposes being controlled by comparators, the inputs of the comparators being supplied by an output-voltage of the sensor and an adjustable reference voltage, which adjustable reference voltage controls the duration of the zero-power time-intervals of commutation.

8. A motor according to claim **7**, wherein the energizing conductors are in a double-line, double-pulse connection on two opposite outputs of a Hall element, and include comparators connected in pairs whose two inputs receive the changing Hall voltage, the comparators connected between a voltage supply from which the switching-on voltage thresholds of the comparators are adjustable by means of a controllable potentiometer.

9. A motor according to claim **8**, wherein the adjustable output of the potentiometer is applied to respective positive entry points of the comparators via a resistor each.

10. A brushless direct current motor, comprising:

a stator including a number of radially extending pole shoes and at least one stator winding disposed on said pole shoes, a stator slot being formed between each one of said pole shoes;

a rotor mounted on said stator for rotation about an axis, said rotor having a surface upon which a continuous ring of generally radially oriented permanent magnetic material is mounted wherein a cylindrical air gap is defined between adjacent surfaces of said stator and said permanent magnetic ring, said permanent magnetic ring is magnetized to form at least two radially magnetized permanent magnets of alternating polarity, and the radial magnetization of said permanent magnets varies in a substantially trapezoidal manner in a circumferential direction;

a detector circuit mounted stationary with respect to said stator, said detector circuit operating in accordance with rotor position to generate at least one rotor position signal having a waveform which is generally representative of the magnetization distribution of said permanent magnets; and

a control circuit which receives said at least one rotor position signal and selectively energizes said at least one stator winding in a chronologically successive *manner in response thereto, the operation of said control circuit providing a number of zero-power time intervals of commutation, the duration of said zero-power time intervals being controlled in accordance with a threshold voltage, the magnitude of each of said threshold voltages being generally representative of a measured quantity relating to an aspect of operation of said motor.*

11. The brushless direct current motor 10 wherein said threshold voltage is produced by a temperature sensor.

12. The brushless direct current motor of claim 11 wherein said temperature sensor comprises a positive temperature coefficient resistor.

13. The brushless direct current motor of claim 10 wherein said waveform exhibits inclined leading and trailing edges and forms a substantially trapezoidal shape.

14. The brushless direct current motor of claim 10 wherein said continuous ring of generally radially oriented permanent magnetic material comprises a rubber-magnet.

* * * * *