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- (71) Applicant: **KONINKLIJKE PHILIPS ELECTRONICS N.V.** [NL/NL]; Groenewoudseweg 1, NL-5621 BA Eindhoven (NL).
- (72) Inventor: **MUSSENDEN, Georg, A.**; Prof. Holstlaan 6, NL-5656 AA Eindhoven (NL).
- (74) Agent: **DEGUELLE, Wilhelmus, H., G.**; Internationaal Octrooibureau B.V., Prof. Holstlaan 6, NL-5656 AA Eindhoven (NL).
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## Energy-recovering electroluminescent panel supply/driver circuit

**Field of the Invention**

This invention relates generally to electroluminescent lighting, and more particularly to an improved electroluminescent panel driver that substantially improves efficiency.

**Background of the Invention**

Electroluminescent lamps are thin planar light sources which are commonly employed to provide backlighting in the display panels of laptop computers, hand-held data devices, watches and a myriad of other commercial products. Many of the products which are currently being produced have large display panels.

Figure 1 is a cross-sectional view of a typical prior art electroluminescent panel 10. Disposed between a transparent front protective cover 12 and a rear protective cover 22 is a transparent front electrode 14, a phosphor layer 16, a dielectric element 18 and a rear electrode 20. During operation, voltage supply source 24 applies a high AC voltage across front electrode 14 and rear electrode 20, resulting in an electric field therebetween. Due to the electric field, the phosphor atoms in phosphor layer 16 are excited to a higher energy state. When the electric field is removed, the atoms fall back to a lower energy state, emitting photons as visible light in the process.

One of the problems experienced by prior art electroluminescent panels, however, is that they are inefficient. Especially for battery-powered, hand-held devices, it is desirable to minimize the electroluminescent panel's consumption of energy, thereby maximizing the amount of time until it is necessary to recharge the battery.

A typical electroluminescent panel driver of the prior art comprises a battery, a power supply section which boosts the battery voltage to a high voltage DC (e.g.- 80 to 150V), and a high voltage full H-bridge section. The high-voltage full H-bridge section alternately connects the electroluminescent panel across the high voltage source first in one direction, and then in the other direction. In order to discharge the panel during each such transition, the panel electrodes are short-circuited, leading to power waste during usage.

Therefore, it is an object of the invention to provide an electroluminescent panel driver which employs energy from a battery source more efficiently.

### **Summary of the Invention**

To this end, a first aspect of the invention provides an electroluminescent panel driving circuit as claimed in claim 1. A second aspect of the invention provides a display apparatus as claimed in claim 16. Advantageous embodiments are defined in the independent claims.

According to one embodiment, the present invention is directed to an electroluminescent panel driver circuit comprising a rechargeable battery and an electroluminescent panel. The electroluminescent panel comprises a front electrode and a rear electrode. The driver circuit is coupled to the battery and to the electroluminescent panel, and is configured to alternately charge the front and rear electrodes so as to cause the electroluminescent panel to emit light. The circuit is further configured to alternately discharge the front and rear electrodes to the battery, thereby re-charging the battery instead of dissipating the stored energy as heat.

Preferably the electroluminescent panel driving circuit is configured for alternately charging and discharging said front and rear electrodes.

According to one embodiment, the circuit further comprises a trans-inductor having a primary winding and a secondary winding, which is coupled to the electroluminescent panel, and a full H-bridge coupled to a positive voltage terminal of the battery and to the electroluminescent panel via the trans-inductor. Preferably, the full H-bridge comprises four low-voltage MOSFET transistors, which are coupled to and controlled by a system controller. The circuit may also comprise a pair of high-voltage MOSFET transistors coupled to the rear electrode of the electroluminescent panel, which is configured to selectively connect and disconnect the electroluminescent panel to and from the secondary winding.

The circuit may also comprise a primary winding current monitoring circuit, such as a comparator, coupled to a source terminal of two of the transistors of the full H-bridge. Advantageously, the primary winding current monitoring circuit is configured to generate and transmit a signal to the system controller when a current in the primary winding exceeds a predetermined amount. The circuit may also comprise a secondary winding charge current monitoring circuit coupled to a source terminal of each one of the pair of high-voltage

transistors, wherein the secondary winding current monitoring circuit is configured to generate and transmit a signal to the system controller when a current flowing through the electroluminescent panel is less than a predetermined amount. The circuit may further comprise a secondary winding discharge current monitoring circuit coupled to a source terminal of each one of the pair of high-voltage transistors, wherein the secondary winding current monitoring circuit is configured to generate and transmit a signal to the system controller when a current flowing through the electroluminescent panel exceeds a predetermined amount.

Alternatively, a driving circuit as claimed in claim 1 may be used for driving organic electroluminescent light emitting diodes, such as polymer light emitting diodes (PolyLED or PLED) or organic light emitting diodes (OLED). PLEDs and OLEDs are a fairly recently discovered technology that is based on the fact that certain organic materials, such as for example certain organic materials, such as for example certain polymers, may be used as a semiconductor in a light emitting diode. A disadvantage of such organic electroluminescent LED is with each LED there is an associated capacitance which is relatively large due to the thin layer of organic electroluminescent material between the front and rear electrode. When the PLED or OLED is switched on, this capacitance is charged, and when the PLED or OLED is switched off, the capacitance is discharged for example by short-circuiting the front and rear electrodes, as described in US 5,723,950.

According to one embodiment of the invention, the electroluminescent panel driving circuit is configured to discharge the front and rear electrode and thus discharging the capacitor associated with the PLED or OLED, to the battery instead of dissipating the stored energy as heat.

Furthermore, when not in use as a light source the PLED or OLED can be configured such that they may be used as a solar cell. That is, light falling on the PLED or OLED is transferred into electrical energy. Accordingly another embodiment of the invention is an electroluminescent panel driving circuit configured to discharge the electrical energy generated by the electroluminescent panel, to the battery.

### **Brief Description of the Drawings**

The present invention will be further understood from the following description with reference to the accompanying drawings, in which:

Figure 1 is a cross-section which illustrates a typical electroluminescent panel, in accordance with the prior art;

Figure 2 is a circuit diagram that illustrates an electroluminescent panel driver circuit, according to one embodiment of the present invention;

Figures 3 through 6 are flowcharts that illustrate the steps performed in order to alternately charge and discharge the front and rear electrodes of an electroluminescent panel, according to one embodiment of the invention; and

Figure 7 is a circuit diagram that illustrates an electroluminescent panel driver circuit, according to another embodiment of the invention.

### **Detailed Description of the Invention**

The present invention, according to one embodiment, is directed to an energy-recovering electroluminescent panel power supply and driver circuit.

Figure 2 is a circuit diagram that illustrates an energy-recovering electroluminescent panel driver 100, according to one embodiment of the invention. Electroluminescent panel driver 100 comprises a battery 102, preferably an electric DC power source. Battery 102 has a positive voltage terminal 104 and a negative voltage terminal 106.

Panel driver 100 drives an electroluminescent panel 124. As previously discussed, electroluminescent panel 124 operates as a capacitor. Specifically, electroluminescent panel 124 has a rear electrode 124b and a front electrode 124a. In the embodiment shown, electroluminescent panel driver circuit 100 also comprises a capacitor 126 coupled in parallel with electroluminescent panel 124. It is noted, however, that capacitor 126 is only required if the series resistance of electroluminescent panel 124 is high enough to cause a significant voltage surge on the reflected voltage on primary winding 120 (the operation of primary winding 120 is explained below). This may be the case when electroluminescent panel 124 comprises a transparent electrode which has a high resistance.

Electroluminescent panel 124 also comprises additional layers as illustrated in Figure 1, such as front and rear protective covers, a phosphor layer and a dielectric element, although for purposes of simplicity, they are not discussed further herein. When electrodes 124a and 124b of electroluminescent panel 124 are alternately charged and discharged, photons are alternately excited and unexcited, causing visible light to be emitted from electroluminescent panel 124.

Electroluminescent panel driver 100 also comprises a trans-inductor 119, which consists of primary winding 120 having a first terminal 117 and second terminal 118, and secondary winding 122 having a first terminal 123 and a second terminal 118.

Secondary winding 122 has N times the number of turns of primary winding 120. Secondary winding 122 is connected to front electrode 124a.

In the embodiment shown, electroluminescent lamp driver 100 also comprises a full H-bridge 108. Full H-bridge 108 comprises four current flow control devices, preferably low voltage switching transistors, designated herein as transistors 111, 112, 113 and 114. Transistors 111 through 114 are employed in order to bi-directionally drive primary winding 120 and to feed inductive energy stored in primary winding 120 back to battery 102. In a preferred embodiment, and as shown in the figure, transistors 111 and 112 are P-channel MOSFETs, while transistors 113 and 114 are N-channel MOSFETs.

Source terminal 111b of transistor 111 is coupled to positive voltage terminal 104 of voltage supply source 102. Drain terminal 111c of transistor 111 is coupled to terminal 117. Terminal 117 is coupled to transistor 113, as will be explained below.

Source terminal 112b of transistor 112 is also coupled to positive voltage terminal 104 of voltage supply source 102. Drain terminal 112c of transistor 112 is coupled to terminal 118. Terminal 118 is coupled to a first terminal of secondary winding 122, and to transistor 114, as will be explained below.

Source terminal 113b of transistor 113 is coupled to primary winding current monitoring circuit 140, which is discussed in detail below. Drain terminal 113c of transistor 113 is coupled to terminal 117. Terminal 117 is also coupled to drain terminal 111c of transistor 111.

Source terminal 114b of transistor 114 is also coupled to primary winding current monitoring circuit 140. Drain terminal 114c of transistor 114 is coupled to terminal 118. Terminal 118 is coupled to drain terminal 112c of transistor 112.

The gate terminals of each of transistors 111 through 114, designated as gate terminals 111a through 114a, are connected to a system controller 150. System controller 150 controls which of transistors 111 through 114 are turned on and off, and also synchronizes the turning on and off of the transistors. In addition, system controller 150 controls additional transistors 115 and 116, the configuration and function of which are explained below. As will be explained in greater detail in the flowcharts of Figures 3 through 6, transistors 111 through 116 are turned on and off by system controller 150 in a particular order and at specified times so as to insure that capacitive energy which is stored in the electrodes of electroluminescent panel 124 is employed to recharge battery 102 rather than being dissipated as heat.

As previously mentioned, electroluminescent panel driver 100 also comprises two current flow control devices, preferably high voltage switching transistors, designated herein as transistors 115 and 116. Transistors 115 and 116 are employed in order to connect and disconnect electroluminescent panel 124 and capacitor 126 from secondary winding 122. In a preferred embodiment, and as shown in the figure, transistor 116 is a P-channel MOSFET transistor, while transistor 115 is an N-channel MOSFET transistor.

Transistors 115 and 116 are coupled together in parallel and in series with electroluminescent panel 124. Specifically, drain terminal 115c of transistor 115 is coupled to rear electrode 124b of electroluminescent panel 124 via diode 129, while drain terminal 116c of transistor 116 is coupled to rear electrode 124b of electroluminescent panel 124 via diode 128. The source terminals 115b and 116b of transistors 115 and 116, respectively, are connected to each other and to secondary winding current detection circuit 130, which is explained in detail below.

A central node 143 of primary winding current monitoring circuit 140 is coupled to source terminals 113b and 114b of transistors 113 and 114, respectively. Primary winding current monitoring circuit 140 is also coupled at one end to positive voltage terminal 104 of battery 102 and at its other end to negative voltage terminal 106 of battery 102. Primary winding current monitoring circuit 140 monitors the charging of primary winding 120 and outputs a signal 160 (-IPS) to system controller 150 whenever the charge on primary winding 120 exceeds a predetermined maximum allowable amount.

Primary winding current monitoring circuit 140 also comprises, according to one embodiment of the invention, a pair of comparators 141 and 142. Comparator 141 outputs signal 160 to system controller 150. As previously discussed, signal 160 indicates when the charge on primary winding 120 exceeds a predetermined maximum allowable amount. Comparator 141 has two input terminals, one of which is coupled to the positive voltage terminal of a reference voltage source 144. The other terminal of comparator 141 is coupled to node terminal 143. Node terminal 143 is coupled to the negative voltage terminal 106 of battery 102 via resistor 148, to the source terminals 113b and 114b of transistors 113 and 114 respectively, and to an inverting terminal of comparator 142, which is explained below.

Comparator 142, on the other hand, outputs signal 162 (-ReChg\_End) to system controller 150. Signal 162 indicates when the charge on primary winding 120 is less than a predetermined minimum amount, or when the battery has been sufficiently re-charged. Comparator 142 has two input terminals, one of which are coupled to a negative

voltage terminal of reference voltage source 146. The other terminal of comparator 142 is coupled to node terminal 143. It is noted that comparator 142, in accordance with one embodiment of the invention, is optional to electroluminescent panel driver circuit 100, as will be described below. Furthermore, it is also noted that the invention is not limited in scope to primary winding current monitoring circuit 140, and other current monitoring circuits may also be employed.

Secondary winding current monitoring circuit 130, on the other hand, comprises four comparators, designated as comparators 132, 134, 136 and 138. Comparators 132 and 134 are employed as a discharge current cut-out detection circuit 130a. Specifically, and as will be further explained below, comparators 132 and 134 detect when the current flowing through secondary winding 122 and electroluminescent panel 124 exceeds a desired maximum amount, thus indicating that the maximum magnetic energy storage has been reached on secondary winding 122.

Similarly, comparators 136 and 138 are employed as a charge current dropout detection circuit 130b. As will be explained below in more detail, comparators 136 and 138 detect when the current flowing through secondary winding 122 and electroluminescent panel 124 is less than a desired minimum amount, thus indicating that there is no more significant amount of magnetic energy stored in secondary winding 122 to use in charging electroluminescent panel 124 and capacitor 126.

Comparator 132 has two input terminals, one of which is coupled to the source terminals 115b and 116b of transistors 115 and 116, and the other which is coupled to the negative voltage terminal of reference voltage source 160. Comparator 132 generates an output signal 133 (EL\_P\_DCHG) to system controller 150 when comparator 132 detects that the current flowing to the left through secondary winding 122 exceeds a desired maximum amount, thus indicating that the maximum magnetic energy storage has been reached on said winding.

Comparator 134 also has two input terminals, one of which is coupled to the source terminals 115b and 116b of transistors 115 and 116, and the other which is coupled to the positive voltage terminal of reference voltage source 162. Comparator 134 generates an output signal 135 (EL\_N\_DCHG) to system controller 150 when comparator 134 detects that the current flowing to the right through secondary winding 122 exceeds a desired maximum amount, thus indicating that the maximum magnetic energy storage has been reached on said winding.

Comparator 136 has two input terminals, one of which is coupled to the source terminals 115b and 116b of transistors 115 and 116, and the other which is coupled to the negative voltage terminal of reference voltage source 160. Comparator 136 generates an output signal 137 (EL\_N\_CHG\_STOP) to system controller 150 when the comparator detects that the current flowing to the left through secondary winding 122 and electroluminescent panel 124 is less than a desired minimum amount, thus indicating that all of the useful magnetic energy stored in secondary winding 122 has been delivered to electroluminescent panel 124.

Comparator 138 also has two input terminals, one of which is coupled to the source terminals 115b and 116b of transistors 115 and 116, and the other which is coupled to the positive voltage terminal of reference voltage source 162. Comparator 138 generates an output signal 139 (EL\_P\_CHG\_STOP) to system controller 150 when the comparator detects that the current flowing to the right through secondary winding 122 and electroluminescent panel 124 is less than a desired minimum amount, thus indicating that all of the useful magnetic energy stored in the secondary winding has been delivered to electroluminescent panel 124.

As previously mentioned, system controller 150 controls transistors 111 through 116 and employs an algorithm which alternately charges and discharges electroluminescent panel 124. Generally, the algorithm is employed to first charge front electrode 124a of electroluminescent panel 124, and then to discharge the stored energy in front electrode 124a back to battery 102 in order to recharge battery 102. The algorithm then charges rear electrode 124b of electroluminescent panel 124, and finally discharges the energy stored in rear electrode 124b back to battery 102 in order to recharge battery 102 again.

According to one embodiment of the invention, system controller 150 performs these steps by cycling through eight successive states, which are discussed more fully in connection with the flowcharts of Figures 3 through 6. Specifically, electroluminescent panel driver circuit 100 operates in states 1 and 2 when charging front electrode 124a, as will be shown and discussed in Figure 3 below. Additionally, electroluminescent panel driver circuit 100 operates in states 3 and 4 when discharging front electrode 124a, as will be shown and discussed in Figure 4 below. Similarly, electroluminescent panel driver circuit 100 operates in states 5 and 6 when charging rear electrode 124b, and in states 7 and 8 when discharging rear electrode 124b, as will be shown and discussed in Figures 5 and 6, respectively.

Figure 3 is a flowchart that illustrates the steps performed by system controller 150 in order to charge front electrode 124a of electroluminescent panel 124. The steps illustrated in this flow chart are the steps performed in order to operate electroluminescent panel driver circuit 100 in states 1 and 2 of the eight state cycle mentioned previously. System controller 150 places electroluminescent panel driver circuit 100 in state 1 by starting at step 300, and proceeds to step 305.

At step 305, system controller 150 turns transistors 111 and 114 on so that they conduct a current signal. A current signal from positive voltage terminal 104 of battery 102 flows through transistor 111 and flows through primary winding 120 to the right. As the current on primary winding 120 increases, voltage through resistor 148 increases until, at step 310, the voltage signal level at the negative input terminal of comparator 141 becomes larger than the reference voltage signal  $V_{Ref2}$ . When this occurs, comparator 141 generates signal 160 (-IPS), which is received by system controller 150. In response, system controller 150 turns transistors 111 and 114 off.

System controller 150 then places electroluminescent panel driver circuit 100 in state 2 by proceeding to step 315. At step 315, system controller 150 turns on transistor 113. Next, at step 320, system controller 150 turns on transistor 115. Current stored in primary winding 120 during state 1 then flows through transistor 113, through primary winding 120 and secondary winding 122, into electroluminescent panel 124 and capacitor 126. In addition, the current continues to flow through diode 129 and transistor 115, and through resistor 131 to ground.

The current continues to flow in this path until, at step 325, the voltage level at the positive input terminal of comparator 138 is larger than the voltage level at the negative input terminal of comparator 138. When this occurs, signal 139 is generated by comparator 138 for the purpose of providing an indication to system controller 150 that secondary winding 122 has delivered substantially all of its stored magnetic energy into electroluminescent panel 124. Additionally, when system controller 150 receives this signal, it measures  $V_R - V_L$ , which is the difference between the voltage on the left side of H-bridge 108 and on the right side of H-bridge 108.

System controller 150 then proceeds to step 330. At step 330, system controller 150 turns transistor 115 off. At step 335, system controller 150 turns transistor 113 off. At step 340, system controller 150 determines whether  $V_R - V_L$ , which was measured at step 325, is greater than  $V_{out(reg)}/(N+1)$ , wherein  $V_{out(reg)}$  corresponds to a predetermined voltage regulation limit and N corresponds to a ratio defined by the number of turns of

secondary winding 122 divided by the number of turns of primary winding 120. By monitoring the voltage at primary winding 120 in this manner, system controller 150 determines whether front electrode 124a of electroluminescent panel 124 is charged to a desirable voltage level. If system controller 150 determines that  $V_R - V_L$  is not greater, then system controller 150 returns to step 300 in order to operate in state 1 again by repeating steps 305 through 340.

If, at step 340, system controller 150 determines that  $V_R - V_L$  is greater than  $V_{out(reg)}/(N+1)$ , then system controller 150 proceeds to step 345 in order to perform the steps illustrated in the flowchart of Figure 4. According to one embodiment of the invention, system controller 150 proceeds to the steps of the flowchart in Figure 4 immediately, resulting in a voltage waveform at electroluminescent panel 124 having a triangular shape. However, it is noted that, according to other embodiments, system controller 150 proceeds to the steps of the flowchart in Figure 4 after a short time delay has elapsed, resulting in a voltage waveform at electroluminescent panel 124 having a trapezoidal shape.

Figure 4 is a flowchart that illustrates the steps performed by system controller 150 in order to discharge the energy which was previously stored in front electrode 124a of electroluminescent panel 124. As noted above, the steps illustrated in the flowchart of Figure 4 are preferably performed when system controller 150 arrives at step 345 of the flowchart in Figure 3. The steps illustrated in the flowchart of Figure 4 are the steps performed in order to operate electroluminescent panel driver circuit 100 in states 3 and 4 of the eight state cycle mentioned previously. System controller 150 places electroluminescent panel driver circuit 100 in state 3 by starting at step 400, and proceeds to step 405.

At step 405, system controller 150 turns on transistor 112. At step 410, system controller 150 turns on transistor 114. Current which is stored in electroluminescent panel 124 flows left through secondary winding 122. The current causes a negative voltage to be experienced by resistor 131. As the current through secondary winding 122 increases, the negative voltage across resistor 131 increases also.

At step 415, it is determined whether the voltage level at the positive input terminal of comparator 132 is smaller than the voltage level at the negative input terminal of comparator 132. If it is determined that the voltage level at the positive input terminal of comparator 132 is not smaller than the voltage level at the negative input terminal of comparator 132, system controller 150 proceeds to step 420. At step 420, system controller 150 inquires whether a predetermined amount of time has elapsed since step 410

was performed. If not, then system controller 150 returns to step 415 in order to determine whether the voltage level across resistor 131 has decreased sufficiently to cause the voltage level on the positive input terminal of comparator 132 to be smaller than the voltage level on the negative input terminal.

If, however, system controller 150 determines at step 420 that a predetermined amount of time has elapsed, then system controller 150 goes to step 425 and turns off transistor 116. System controller 150 then performs step 430 and proceeds to the flowchart in Figure 5, which will be explained in detail below. The inquiry performed by system controller 150 at step 420 enables the system to determine whether the voltage stored in electroluminescent panel 124 and capacitor 126 has essentially been depleted.

Returning to step 415, if it is determined that the voltage level at the positive input terminal of comparator 132 is smaller than the voltage level at the negative input terminal of comparator 132, system controller 150 proceeds to step 435. At step 435, comparator 132 generates signal 133 (EL\_P\_DCHG), which is received by system controller 150. In response to the receipt of signal 133, system controller 150 proceeds to step 440 and turns off transistor 116, then proceeds to step 445 and turns off transistor 112.

System controller 150 then places electroluminescent panel driver circuit 100 in state 4 by proceeding to step 450. At step 450, system controller turns on transistor 114. Stored inductor current will flow left through primary winding 120 and up through transistor 114 and transistor 111. According to a preferred embodiment, a short, predetermined time period elapses. Next, system controller 150 proceeds to step 455. At step 455, system controller 150 determines when  $V_L - V_R$  is less than  $V_{\text{battery}} + V_{\text{Bodydiode}}$ , wherein  $V_L$  is the voltage level at terminal 117 (i.e.-to the left of primary winding 120),  $V_R$  is the voltage at terminal 118 (i.e.- to the right of primary winding 120),  $V_{\text{battery}}$  is the voltage at battery 102 and  $V_{\text{bodydiode}}$  is the voltage at transistor 111. When system controller 150 determines that  $V_L - V_R$  is less than  $V_{\text{battery}} + V_{\text{Bodydiode}}$ , the stored inductive energy in primary winding 120 has been exhausted and transistor 114 is turned off.

After step 445, system controller 150 returns to step 405 and re-performs steps 405 through 455. Thus, system controller 150 alternately operates in states 3 and 4 until it is deemed that there is no appreciable amount of energy left in electroluminescent panel 124 and capacitor 126. In states 3 and 4, energy which was previously stored in front electrode 124a of electroluminescent panel 124 is discharged until it is determined that no appreciable amount of energy remains.

Figure 5 is a flowchart that illustrates the steps performed by system controller 150 in order to charge rear electrode 124b of electroluminescent panel 124. The steps illustrated in this flow chart are the steps performed in order to operate electroluminescent panel driver circuit 100 in states 5 and 6 of the eight state cycle mentioned previously. System controller 150 places electroluminescent panel driver circuit 100 in state 5 by starting at step 500, and proceeds to step 505.

At step 505, system controller 150 turns on transistor 112. At step 510, system controller 150 turns on transistor 113. Current flows through primary winding 120 to the left. As the current on primary winding 120 increases, voltage through resistor 148 increases until, at step 515, the voltage level at the negative input terminal of comparator 141 becomes larger than the voltage level at the positive voltage terminal of comparator 141. When this occurs, comparator 141 generates signal 160 (-IPS), which is received by system controller 150. In response, system controller 150 proceeds to step 520 and turns off transistor 112, then proceeds to step 525 and turns off transistor 113.

System controller 150 then places electroluminescent panel driver circuit 100 in state 6 by proceeding to step 530. At step 530, system controller 150 turns on transistor 114. Next, at step 535, system controller 150 turns on transistor 116. Stored current flows through transistor 114, through secondary winding 122, into electroluminescent panel 124 and capacitor 126. In addition, the current continues to flow through diode 128 and transistor 116, and through resistor 131 to ground. The current continues to flow in this path until, at step 540, the voltage level at the positive input terminal of comparator 136 is larger than the voltage level of the negative input terminal of comparator 136. When this occurs, signal 137 (EL\_N\_CHG\_STOP) will be generated by comparator 136. When system controller 150 receives this signal, it proceeds to step 545 and measures VL-VR, which, as previously noted, is the difference between the voltage on the left side of H-bridge 108 (at node terminal 117) and on the right side of H-bridge 108 (at node terminal 118).

System controller 150 then proceeds to step 550. At step 550, system controller 150 determines whether VL-VR is greater than  $V_{out(reg)}/N$ , wherein  $V_{out(reg)}$  corresponds to a predetermined voltage regulation limit and N corresponds to a ratio defined by the number of turns of secondary winding 122 divided by the number of turns of primary winding 120. By monitoring the voltage at primary winding 120 in this manner, system controller 150 determines whether rear electrode 124b of electroluminescent panel 124 is charged to a desirable voltage level. If system controller 150 determines that VL-VR is not greater, then system controller 150 proceeds to step 555 and turns transistor 116 off. Next, at

step 560, system controller 150 turns transistor 114 off. System controller 150 then returns to step 500 in order to repeat the steps of this flowchart. Thus, system controller alternately operates in states 5 and 6 until it is deemed that the voltage in rear electrode 124b of electroluminescent panel 124 is greater by a desired amount than the voltage in front electrode 124a of electroluminescent panel 124.

If, however, system controller 150 determines that  $V_L - V_R$  is greater than  $V_{out(reg)}/N$ , it proceeds to step 565 and turns transistor 116 off. Next, at step 570, system controller 150 turns transistor 114 off. System controller 150 then proceeds to step 575 in order to perform the steps of the flowchart illustrated in Figure 6. Thus, once system controller 150 determines that the voltage in rear electrode 124b of electroluminescent panel 124 is greater by a desired amount than the voltage in front electrode 124a of electroluminescent panel 124, system controller is ready to operate in states 7 and 8. As explained in connection with the flowchart in Figure 3, system controller 150 may proceed immediately, resulting in a voltage waveform at electroluminescent panel 124 having a triangular shape, or may proceed after a short time delay has elapsed, resulting in a voltage waveform at electroluminescent panel 124 having a trapezoidal shape.

Figure 6 is a flowchart that illustrates the steps performed by system controller 150 in order to discharge the energy which was previously stored in rear electrode 124b of electroluminescent panel 124. Specifically, the steps illustrated in the flowchart of Figure 6 are preferably performed when system controller 150 arrives at step 575 of the flowchart in Figure 5. The steps illustrated in the flowchart of Figure 6 are the steps performed in order to operate electroluminescent panel driver circuit 100 in states 7 and 8 of the eight state cycle mentioned previously. System controller 150 places electroluminescent panel driver circuit in state 7 by starting at step 600, and proceeds to step 605.

At step 605, system controller 150 turns on transistor 113. At step 610, system controller 150 turns on transistor 115. Current which is stored in electroluminescent panel 124 flows right through secondary winding 122. The current causes a voltage drop across resistor 131. As the current through secondary winding 122 increases, the voltage across resistor 131 also increases.

At step 615, it is determined whether the voltage level at the negative input terminal of comparator 134 is larger than the voltage level at the positive input terminal of comparator 134. If it is determined that the voltage level at the negative input terminal of comparator 134 is not larger than the voltage at the positive input terminal of comparator 134, system controller 150 proceeds to step 620.

At step 620, system controller 150 inquires whether a predetermined amount of time has elapsed since step 610 was performed. If not, then system controller 150 returns to step 615 in order to determine whether the voltage on resistor 131 has increased sufficiently to cause the voltage level on the negative input terminal of comparator 134 to be larger than the voltage level on the positive input terminal. If, however, system controller 150 determines at step 620 that a predetermined amount of time has elapsed, then system controller 150 performs step 625 and turns off transistor 115. The inquiry performed by system controller 150 at step 620 enables the system to determine whether the voltage stored in electroluminescent panel 124 and capacitor 126 has essentially been depleted. System controller 150 then performs step 630 and proceeds to perform the steps of the flowchart in Figure 3, which was previously explained, thereby repeating the process of charging and discharging the front and rear electrodes of electroluminescent panel 124.

Returning to step 615, if it is determined that the voltage level at the negative input terminal of comparator 134 is larger than the voltage at the positive input terminal of comparator 134, system controller 150 proceeds to step 635. At step 635, comparator 134 generates signal 135, which is received by system controller 150. System controller 150 then proceeds to step 640 and turns off transistor 115, thereby completing the operation of electroluminescent panel driver circuit 100 in state 7, and places electroluminescent panel driver circuit 100 in state 8 by performing step 645.

At step 645, system controller 150 turns on transistor 113. Stored inductor current will flow right through primary winding 120 and up through transistor 113 and transistor 112. According to a preferred embodiment, a short, predetermined time period elapses. Next, system controller 150 proceeds to step 650. At step 650, system controller 150 determines when  $VR - VL$  is less than  $V_{\text{battery}} + V_{\text{Bodydiode}}$ , wherein  $VL$  is the voltage at node terminal 117 (i.e.-to the left of primary winding 120),  $VR$  is the voltage at node terminal 118 (i.e.- to the right of primary winding 120),  $V_{\text{battery}}$  is the voltage at battery 102 and  $V_{\text{bodydiode}}$  is the voltage at transistor 112. When system controller 150 determines that  $VR - VL$  is less than  $V_{\text{battery}} + V_{\text{Bodydiode}}$ , the stored inductive energy in primary winding 120 has been exhausted and transistor 113 is turned off.

After step 650, system controller 150 returns to step 605. Thus, system controller 150 alternately performs the steps of states 7 and 8 until it is deemed that there is no appreciable amount of energy left in electroluminescent panel 124 and capacitor 126.

Although not shown in the flowcharts of Figures 3 through 6, optional comparator 142 may be employed by the present invention, according to one embodiment, to determine whether a significant amount of current remains stored in the trans-inductor. For instance, instead of sensing VL-VR or VR-VL, as discussed at steps 325 and 545 of Figures 3 and 5 respectively, comparator 142 may be employed to generate signal 162 (-ReChg\_End) when the voltage at its negative input terminal becomes larger than the voltage at its positive input terminal. The use of comparator 142 is advantageous in that it does not require the inductor current to drop to zero, but rather to a predetermined level, allowing for higher power transfer. In addition, the circuit is no longer dependent on the voltage of battery 102.

Figure 7 is a circuit diagram that illustrates an energy-recovering electroluminescent panel driver 200, according to another embodiment of the invention. Electroluminescent panel driver 200 comprises a battery 202, preferably an electric DC power source. Battery 202 has a positive voltage terminal 204 and a negative voltage terminal 206.

Panel driver 200 drives an electroluminescent panel 224. As previously discussed, electroluminescent panel 224 operates as a capacitor. Specifically, electroluminescent panel 224 has a rear electrode 224b and a front electrode 224a. In the embodiment shown, electroluminescent panel driver circuit 200 also comprises a capacitor 226 coupled in parallel with electroluminescent panel 224.

Similar to the electroluminescent panel shown in Figure 2, electroluminescent panel 224 also comprises additional layers as illustrated in Figure 1, such as front and rear protective covers, a phosphor layer and a dielectric element, although for purposes of simplicity, they are not discussed further herein. When electrodes 224a and 224b of electroluminescent panel 224 are alternately charged and discharged, photons are alternately excited and unexcited, causing visible light to be emitted from electroluminescent panel 224.

Electroluminescent panel driver 200 also comprises a trans-inductor 219, which consists of primary winding 220 having a first terminal 217 and a second terminal 218, and secondary winding 222 having a first terminal 223 and a second terminal 218. Secondary winding 222 has N times the number of turns of primary winding 220. Secondary winding 222 is connected to front electrode 224a.

In the embodiment shown, electroluminescent lamp driver 200 also comprises a full H-bridge 208. Similar to the previously explained bridge 108, full H-bridge 208 comprises four current flow control devices, preferably low voltage switching transistors,

designated herein as transistors 211, 212, 213 and 214. Transistors 211 through 214 are employed in order to bi-directionally drive primary winding 220 and to feedback inductive energy stored in primary winding 220 to battery 202.

Source terminal 211b of transistor 211 is coupled to positive voltage terminal 204 of voltage supply source 202, while drain terminal 211c of transistor 211 is coupled to terminal 217 and terminal 217 is coupled to transistor 213. Source terminal 212b of transistor 212 is also coupled to positive voltage terminal 204 of voltage supply source 202, while drain terminal 212c of transistor 212 is coupled to terminal 218 and terminal 218 is coupled to a first terminal of secondary winding 222, and to transistor 214. Source terminal 213b of transistor 213 is coupled to primary winding current monitoring circuit 240, while drain terminal 213c of transistor 213 is coupled to terminal 217 and terminal 217 is also coupled to drain terminal 211c of transistor 211. Finally, source terminal 214b of transistor 214 is also coupled to primary winding current monitoring circuit 240, while drain terminal 214c of transistor 214 is coupled to terminal 218 and terminal 218 is coupled to drain terminal 212c of transistor 212.

The gate terminals of each of transistors 211 through 214, designated as gate terminals 211a through 214a, are connected to a system controller 250. As in the previously described embodiment, system controller 250 controls which of transistors 211 through 214 are turned on and off, and also synchronizes the turning on and off of the transistors. In addition, system controller 250 controls additional transistors 215 and 216, the configuration and function of which are explained below. Transistors 211 through 216 are turned on and off by system controller 250 in a particular order and at specified times so as to insure that capacitive energy which is stored in the electrodes of electroluminescent panel 224 is employed to recharge battery 202 rather than being dissipated as heat.

As previously mentioned, electroluminescent panel driver 200 also comprises two current flow control devices designated herein as transistors 215 and 216. Transistors 215 and 216 are coupled together in series with electroluminescent panel 124. Specifically, drain terminal 215c of transistor 215 is coupled to rear electrode 224b of electroluminescent panel 224, while source terminal 215b of transistor 215 is coupled to drain terminal 216c of transistor 216. Source terminal 216b of transistor 216 is coupled to node 269. Node 269 is coupled to gate terminal 238a of transistor 238, source terminal 236b of transistor 236 (both of which are explained more fully below) and to resistor 231.

Unlike the previously explained embodiment, which comprised various comparators for generating signals to the system controller, driver 200 comprises

various transistors for accomplishing the same purpose. For instance, transistor 270 is configured such that its collector terminal 270c is coupled via resistor 268 to positive terminal 204 of battery 202, its emitter terminal 270b is coupled to negative terminal 206 of battery 202, and its base terminal 270a is coupled to resistor 267 and full H-bridge 208.

Transistor 238, on the other hand, is configured such that its collector terminal 238c is coupled via resistor 264 to positive terminal 204 of battery 202, its emitter terminal 238b is coupled to base terminal 234a of transistor 234, and its base terminal 238a is coupled to node 269. Transistor 232 is configured such that its collector terminal 232c is coupled to positive terminal 204 of battery 202, its emitter terminal 232b is coupled to resistor 262 and its base terminal 232a is coupled to negative terminal 206 of battery 202. Transistor 236 is configured such that its collector terminal 236c is coupled via resistor 265 to positive terminal 204 of battery 202, its emitter terminal 236b is coupled to node 269, and its base terminal 236a is coupled to emitter terminal 232b of transistor 232. Transistor 234 is configured such that its collector terminal 234c is coupled via resistor 266 to positive terminal 204 of battery 202, its emitter terminal 234b is coupled to negative terminal 206 of battery 202, and its base terminal 234a is coupled to emitter terminal 238b of transistor 238. Resistor 261 is coupled between transistors 216, 236 and 238, and preferably has a smaller resistance value than resistor 262.

Similar to electroluminescent panel driver 100 which is shown and described in connection with Figure 2, electroluminescent panel driver 200 of Figure 7 employs an algorithm via system controller 250 to cycle through eight successive states, for the purpose of alternately charging and discharging the front and rear electrodes of electroluminescent panel 224. Specifically, electroluminescent panel driver 200 operates in states 1 and 2 to charge front electrode 124a of electroluminescent panel 224 and the left electrode of capacitor 226. Electroluminescent panel driver 200 then operates in states 3 and 4 to discharge front electrode 224a and capacitor 226. Next, electroluminescent panel driver 200 operates in states 5 and 6 to charge rear electrode 224b of electroluminescent panel 224 and the right electrode of capacitor 226. Finally, electroluminescent panel driver 200 operates in states 7 and 8 to discharge rear electrode 224b and the right electrode of capacitor 226.

More specifically, during state 1 of the eight state cycle, system controller 250 turns on transistors 211 and 214, in order to charge primary winding 120 from the left. When the current on primary winding 220 has climbed to a desired amount, signal

260 (-IPS) is generated at collector terminal 270c of transistor 270, and transistors 211 and 214 are turned off.

During state 2 of the eight state cycle, system controller 250 turns on transistors 213 and 215 in order to charge front electrode 224 of electroluminescent panel 224 and capacitor 226. When the current flowing to the right through primary winding 220 and electroluminescent panel 224 is less than a desired minimum amount, signal 239 (-EL\_P\_CHG\_STOP) is generated at collector terminal 238c of transistor 238, thereby indicating that the energy stored in the secondary winding 222 has been essentially depleted. System controller 250 then determines whether  $V_R - V_L$  is greater than  $V_{out(reg)}/(N+1)$ , wherein  $V_{out(reg)}$  corresponds to a predetermined voltage regulation limit and  $N$  corresponds to a ratio defined by the number of turns of secondary winding 222 divided by the number of turns of primary winding 220, and if so, turns off transistors 215 and 213 and proceeds to operate in state 3. If not, then driver 200 returns to operate in state 1.

During state 3 of the eight state cycle, system controller 250 turns on transistors 212 and 216 in order to discharge energy which was previously stored in front electrode 224a of electroluminescent panel 224 and capacitor 226. When the rising current flowing to the left through secondary winding 222 and electroluminescent panel 224 exceeds a desired amount, signal 233 (-EL\_P\_DCHG) is generated at collector terminal 232c of transistor 232, thereby indicating that secondary winding 222 has been charged to its maximum current capacity. System controller 250 then turns off transistors 216 and 212 and proceeds to state 4. If, however, signal 233 (-EL\_P\_DCHG) is not asserted after some predetermined time in state 3, then system controller 250 then turns off transistor 216 and proceeds to state 5.

Electroluminescent panel driver 200 then operates in state 4 of the eight state cycle by turning on transistor 214. When it is determined that the stored inductive energy on primary winding 220 has been exhausted (i.e.- when voltage level difference  $V_L - V_R$  is less than  $V_{battery} + V_{bodydiode}$ ), system controller 250 turns off transistor 214 and returns to operate in state 3 to complete the discharge of energy from front electrode 224a and capacitor 226.

In state 5, system controller turns on transistors 212 and 213 in order to charge primary winding 220. When the current signal level on primary winding 220 has climbed to a desired amount, signal 260 (-IPS) is again generated at collector terminal 270c of transistor 270. In response, system controller 250 turns off transistors 212 and 213.

During state 6 of the eight state cycle, system controller 250 turns on transistors 214 and 216 in order to charge rear electrode 224b of electroluminescent panel 224 and the right electrode of capacitor 226. When the current flowing to the left through secondary winding 222 and electroluminescent panel 224 is less than a desired minimum amount, signal 237 (-EL\_N\_CHG\_STOP) is generated at collector terminal 236c of transistor 236, thereby indicating that the energy stored on secondary winding 222 has essentially been depleted. System controller 250 then determines whether  $V_L - V_R$  is greater than  $V_{out(reg)}/(N+1)$ , and if so, turns off transistors 216 and 214 and proceeds to operate in state 7. If not, then driver 200 returns to operate in state 5.

During state 7 of the eight state cycle, system controller 250 turns on transistors 213 and 215 in order to discharge rear electrode 224b of electroluminescent panel 224 and capacitor 226. When the rising current flowing to the right through secondary winding 122 and electroluminescent panel 124 exceeds a desired maximum, signal 235 (-EL\_N\_DCHG) is generated at collector terminal 234c of transistor 234, thereby indicating that secondary winding 222 has been charged to its maximum current capacity. System controller turns off transistor 215 and proceeds to operate in state 8, unless the current flow does not exceed a desired maximum after a predetermined amount of time, in which case system controller 250 turns off transistor 213 and returns to operate in state 1.

Finally, in state 8 of the eight state cycle, system controller 250 turns on transistor 213. When it is determined that the stored inductive energy on primary winding 220 has been exhausted (i.e.- when voltage level difference  $V_R - V_L$  is less than  $V_{battery} + V_{bodydiode}$ ), system controller 250 turns off transistor 213 and returns to operate in state 7.

It is also noted that, while the present invention is described in connection with rechargeable (e.g.- secondary) batteries, it is conceived that the present invention may instead employ, in accordance with one embodiment thereof, conventional disposable batteries. Because the charge and discharge cycles of the electroluminescent panels employ very small amounts of energy, a disposable battery is typically able to reaccept the small amount of energy that was taken from it during a previous cycle.

The present invention, according to various embodiments, has significant advantages over the electroluminescent panel driver circuits of the prior art. For example, electroluminescent panel driver circuit 100 significantly reduces the battery power consumption of electroluminescent panel 100 as compared to circuits of the prior art. The battery power consumed by electroluminescent panel 124 is approximately one-third to one-fifth of the battery power consumed by a typical electroluminescent panel, by virtue of the

fact that electroluminescent panel driver circuit 100 is configured to re-charge the battery whenever the charge on electroluminescent panel 124 is discharged.

In addition, the gradual charging and discharging of electroluminescent panel 124 increases the panel life, as well as minimizes the audible noise caused by the panel. A complete discussion regarding audible noise generated by electroluminescent panels is included in Applicant's co-pending application having Reference No. 700503, which is incorporated by reference herein as fully as if set forth in its entirety.

The electroluminescent panel driver circuit of the present invention also has the advantage that it has only two high-voltage transistors, i.e.- high-voltage transistors 115 and 116. By contrast, the electroluminescent panel driver circuits of the prior art have four high-voltage transistors. The reduction in the number of high-voltage transistors from four to two yields a significant cost savings. In addition, the low-voltage transistors are easier to realize, generate less EMC emissions, and can be integrated inside a low-voltage digital VLSI chip allowing for easier implementation of sophisticated circuit control. The high-voltage transistors can, according to one embodiment of the invention, be placed on a separate 4-pin package of small dimensions.

In addition, electroluminescent panel driver circuit 100 experiences very small power losses due to sensing. This follows because the voltage feedback of the high voltage side is done through primary winding 120, which is the low voltage side of the trans-inductor. By contrast, circuits of the prior art perform sensing on the high voltage side, where a small amount of current drain translates into a significant depletion of power.

While there has been shown and described particular embodiments of the invention, it will be obvious to those skilled in the art that changes and modifications can be made therein without departing from the invention, and therefore, the appended claims shall be understood to cover all such changes and modifications as fall within the true spirit and scope of the invention.

## CLAIMS:

1. An electroluminescent panel driver circuit (100) comprising:  
a rechargeable battery (102); and  
an electroluminescent panel (124) comprising a front electrode (124a) and a rear electrode (124b), wherein said circuit is coupled to said battery and to said electroluminescent panel, and is configured to charge said front and rear electrodes so as to cause said electroluminescent panel to emit light, said circuit further configured to discharge said front and rear electrodes to said battery.
2. The circuit (100) of claim 1, wherein said circuit is configured to alternately charge and discharge said front and rear electrodes.
3. The circuit (100) of claim 2, wherein said circuit further comprises a trans-inductor (119) having a primary winding (120) and a secondary winding (122), said trans-inductor coupled to said electroluminescent panel.
4. The circuit (100) of claim 3, further comprising a full H-bridge (108) coupled to a positive voltage terminal of said battery and to said electroluminescent panel via said trans-inductor..
5. The circuit (100) of claim 4, wherein said full H-bridge comprises four MOSFET transistors (111-114).
6. The circuit (100) of claim 5, wherein said transistors (111-114) are low voltage transistors.
7. The circuit (100) of claim 5, further comprising a system controller (150) coupled to, and configured to operate, said transistors.

8. The circuit (100) of claim 7, further comprising a pair of high-voltage MOSFET transistors coupled to said rear electrode of said electroluminescent panel (124), and configured to selectively connect and disconnect said electroluminescent panel to and from said secondary winding.

9. The circuit (100) of claim 8, wherein each of said pair of transistors (115, 116) is coupled to said rear electrode (124b, 126b) of said electroluminescent panel via a diode (128, 129).

10. The circuit (100) of claim 4, wherein said circuit further comprises a primary winding current monitoring circuit (140) coupled to a source terminal of two said transistors of said full H-bridge, said primary winding current monitoring circuit configured to generate and transmit a signal (160) to said system controller when a current in said primary winding (120) exceeds a predetermined amount.

11. The circuit (100) of claim 10, wherein said primary winding current monitoring circuit (140) comprises a comparator.

12. The circuit (100) of claim 9, wherein said circuit further comprises a secondary winding charge current monitoring circuit (130) coupled to a source terminal of each one of said pair of high-voltage transistors, wherein said secondary winding current monitoring circuit is configured to generate and transmit a signal to said system controller (150) when a current flowing through said electroluminescent panel (124) is less than a predetermined amount.

13. The circuit (100) of claim 12, wherein said secondary winding charge current monitoring circuit (140) comprises a pair of comparators (141, 142).

14. The circuit (100) of claim 9, wherein said circuit further comprises a secondary winding discharge current monitoring circuit (140) coupled to a source terminal of each one of said pair of high-voltage transistors, wherein said secondary winding current monitoring circuit is configured to generate and transmit a signal to said system controller (150) when a current flowing through said electroluminescent panel (124) exceeds a predetermined amount.

15. The circuit (100) of claim 14, wherein said secondary winding discharge current monitoring circuit (140) comprises a pair of comparators (141, 142).
16. A display apparatus comprising an electroluminescent panel and an electroluminescent panel driver circuit as claimed in claim 1.
17. A display apparatus as claimed in claim 16, wherein the electroluminescent panel comprises and organic electroluminescent material.

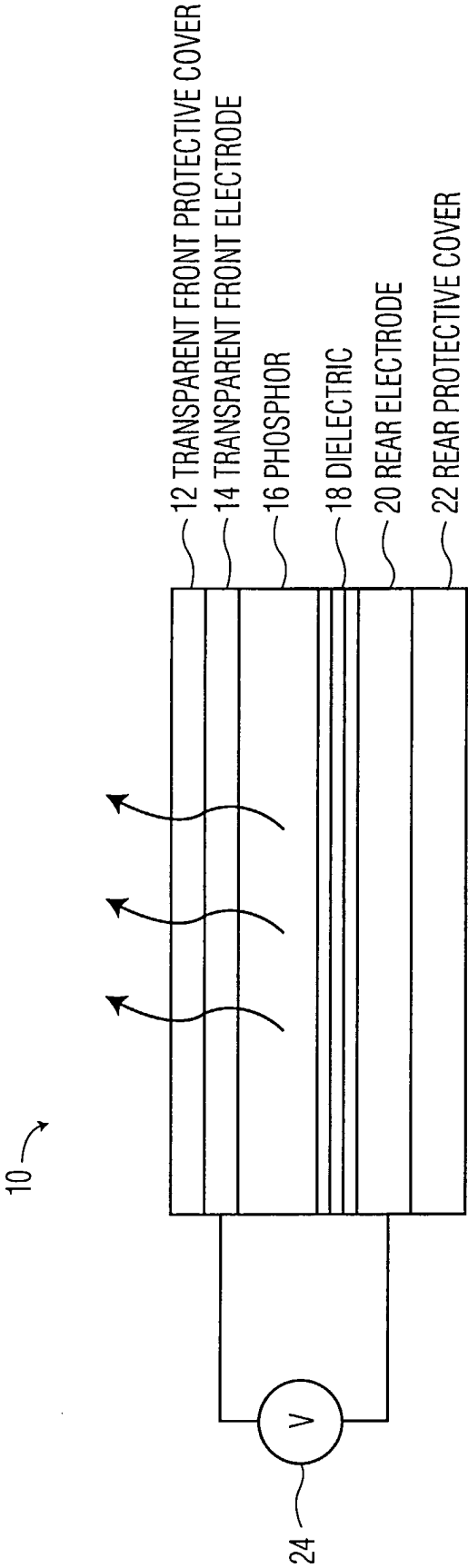


FIG. 1

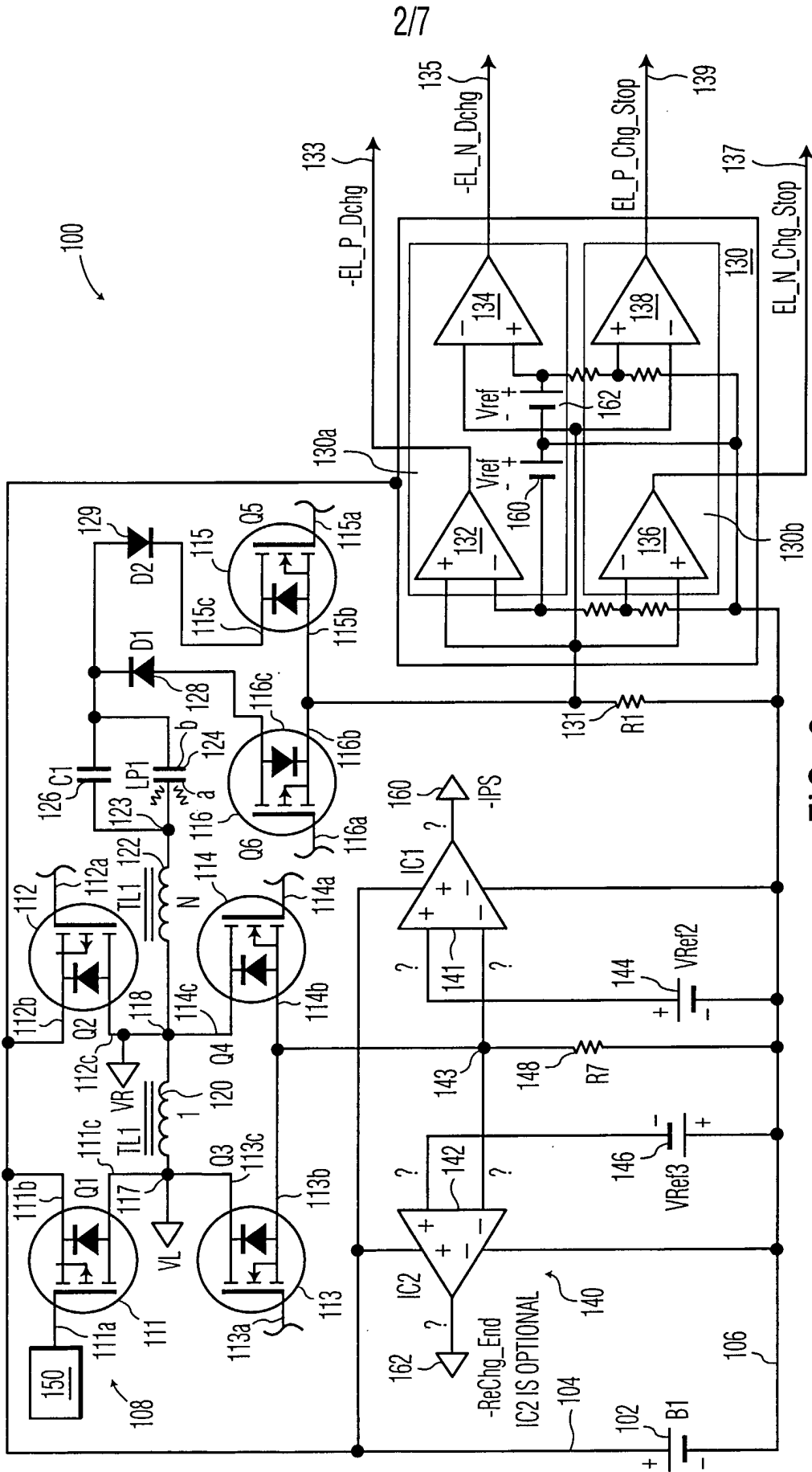


FIG. 2

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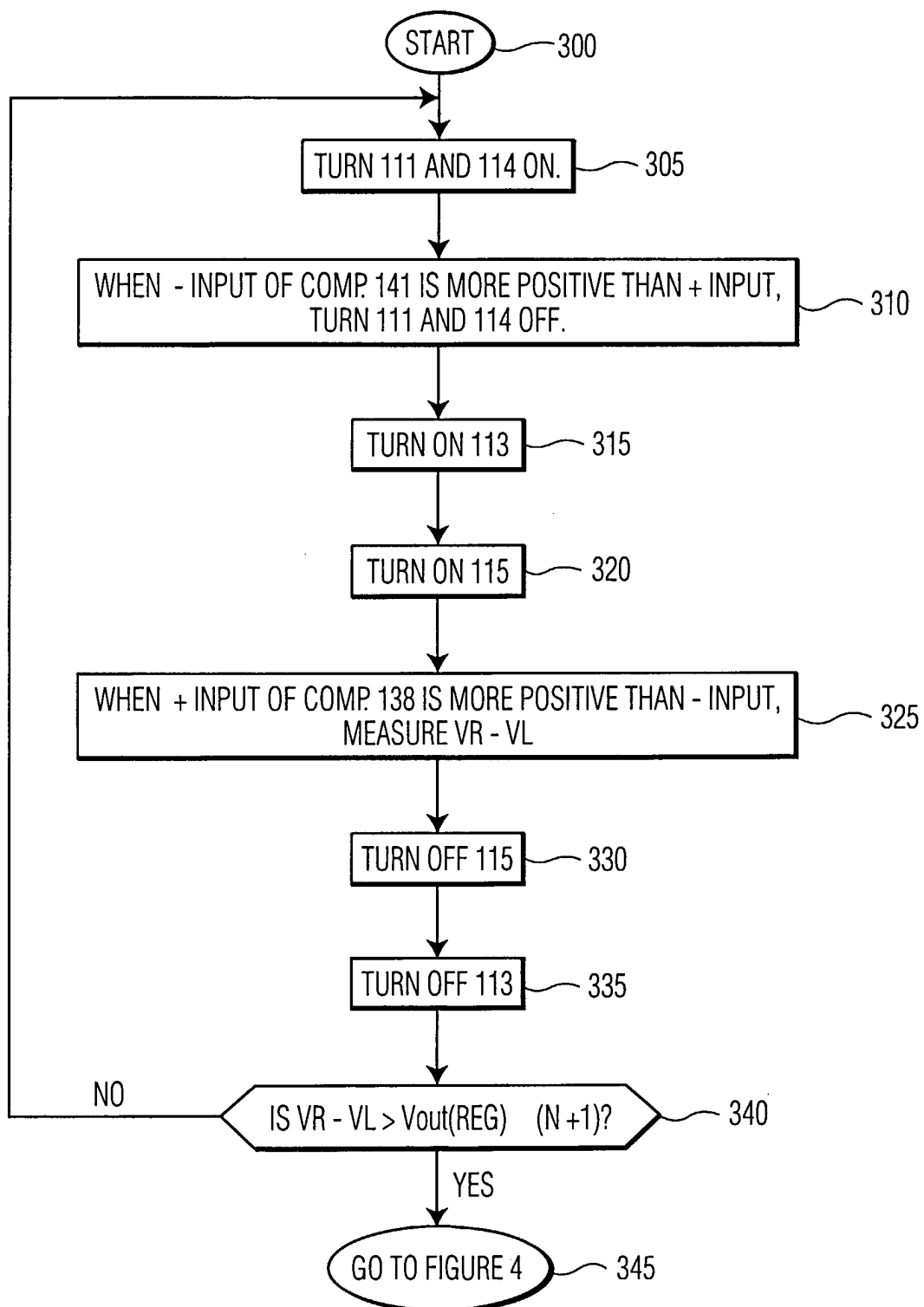


FIG. 3

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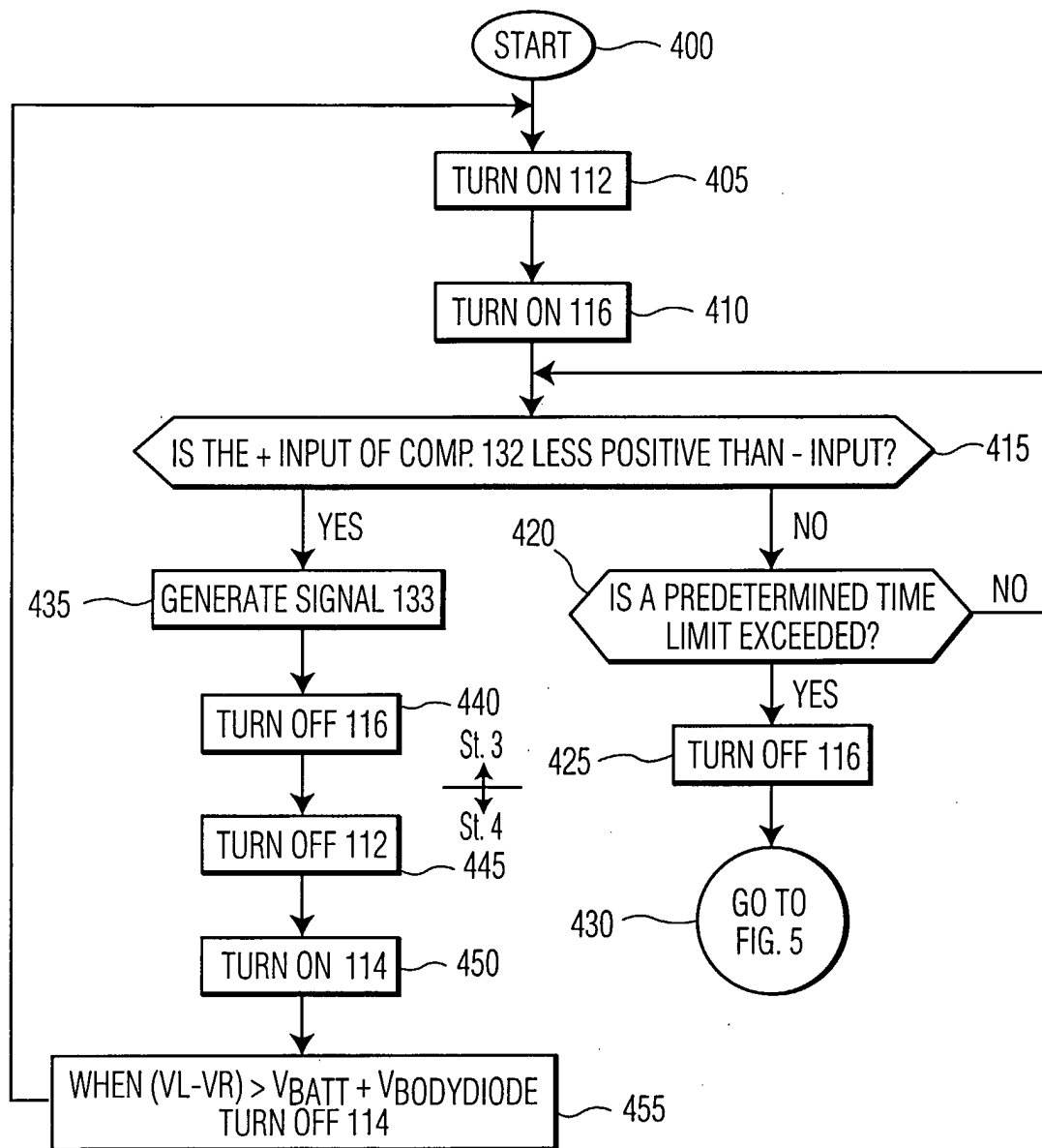
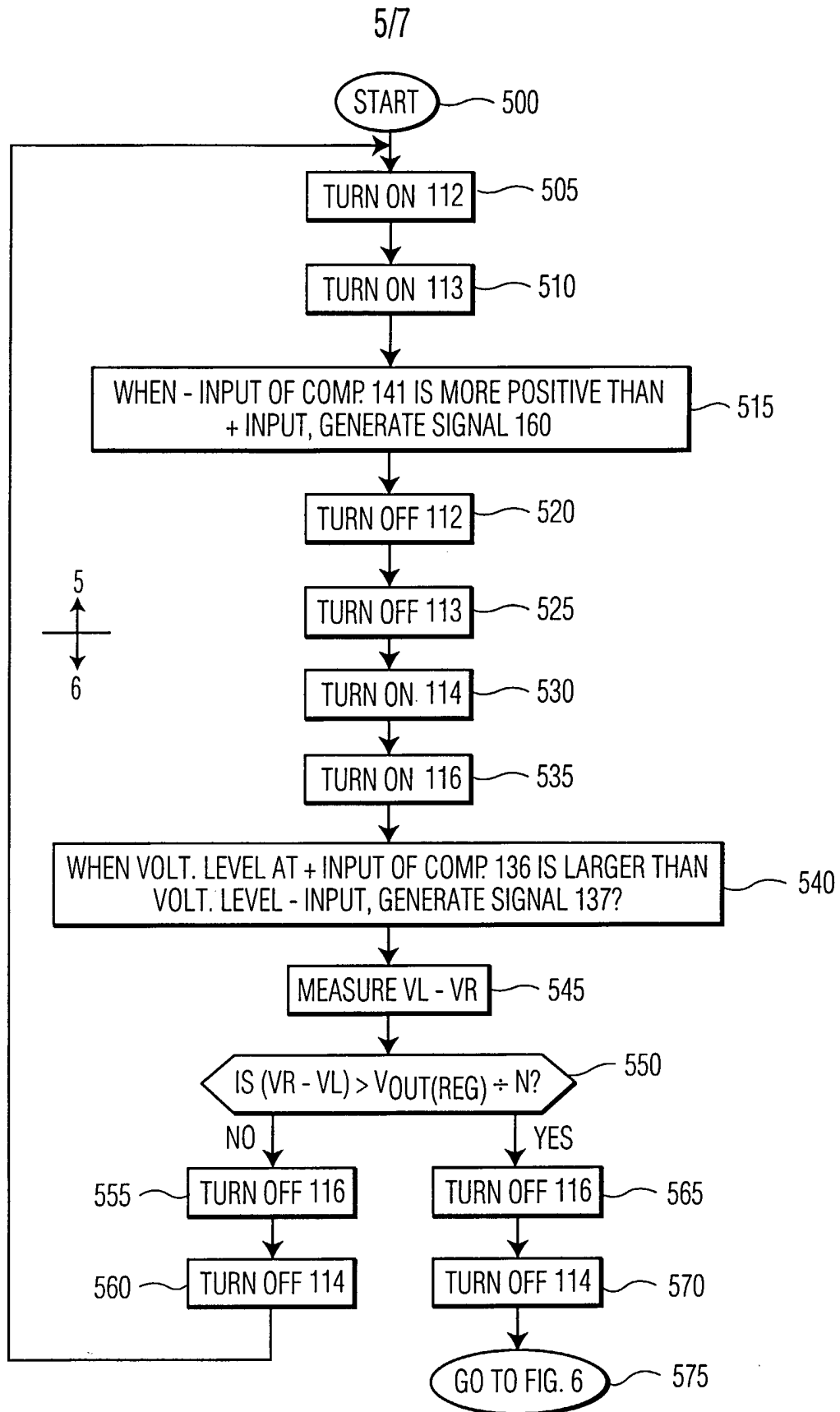


FIG. 4



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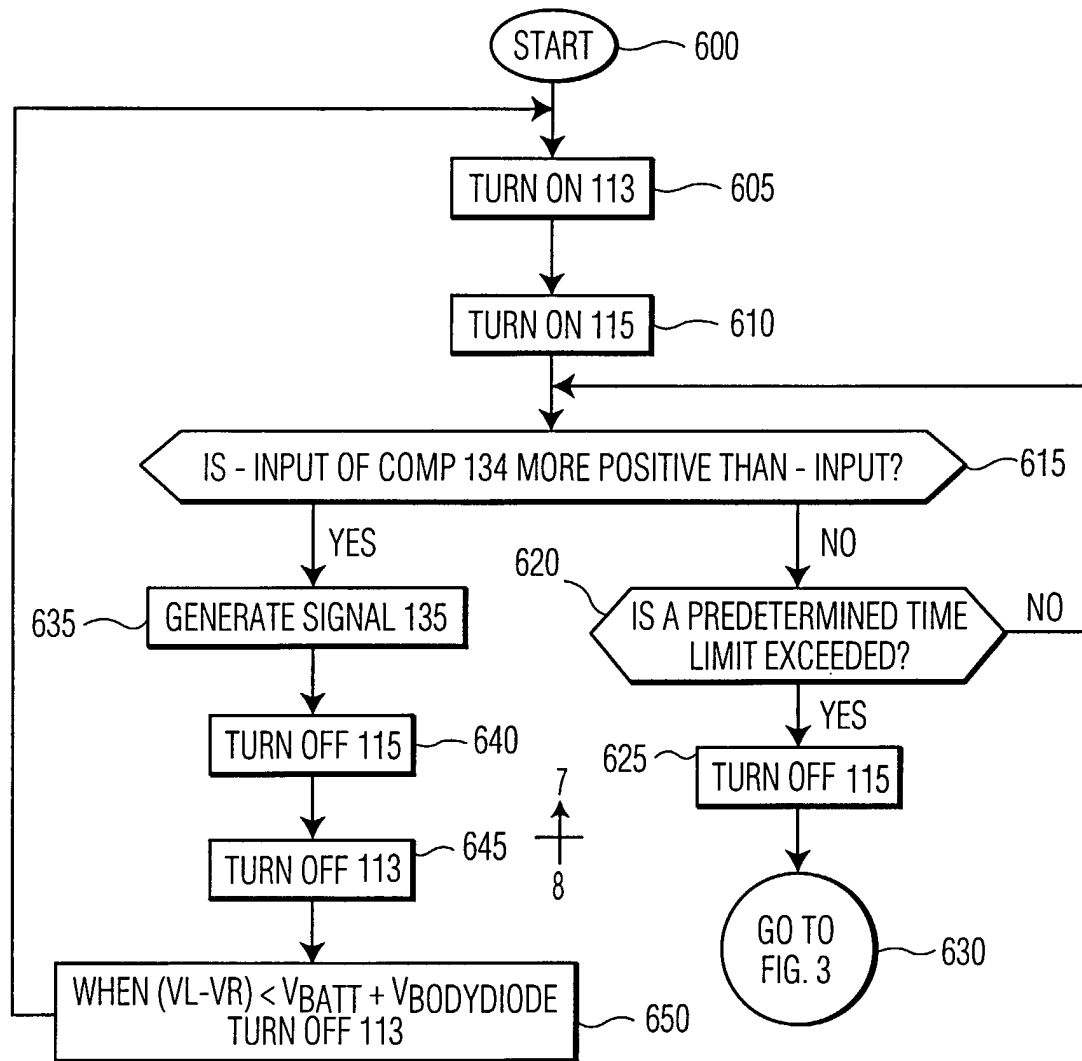


FIG. 6

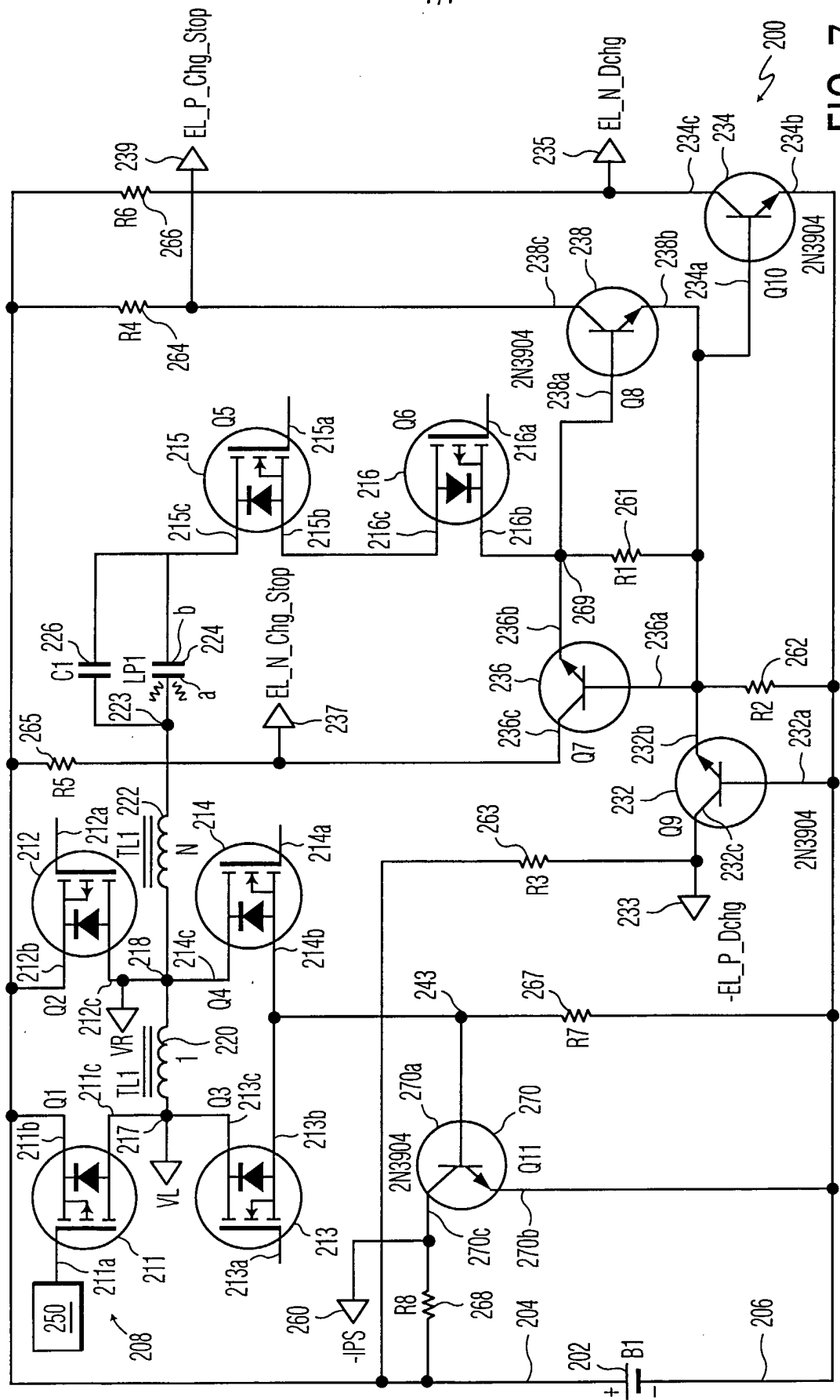


FIG. 7

|                |                                        |         |            |
|----------------|----------------------------------------|---------|------------|
| 专利名称(译)        | 能量回收电致发光面板电源/驱动电路                      |         |            |
| 公开(公告)号        | <a href="#">EP1334645A2</a>            | 公开(公告)日 | 2003-08-13 |
| 申请号            | EP2001993138                           | 申请日     | 2001-10-17 |
| [标]申请(专利权)人(译) | 皇家飞利浦电子股份有限公司                          |         |            |
| 申请(专利权)人(译)    | 皇家飞利浦电子N.V.                            |         |            |
| 当前申请(专利权)人(译)  | 皇家飞利浦电子N.V.                            |         |            |
| [标]发明人         | MUSSENDEN GEORG A                      |         |            |
| 发明人            | MUSSENDEN, GEORG, A.                   |         |            |
| IPC分类号         | G09G3/12 H01L51/50 H05B33/08           |         |            |
| CPC分类号         | H05B33/08 Y02B20/32                    |         |            |
| 代理机构(译)        | deguelle Wilhelmus科技先驱格拉德斯胡富，hendrikus |         |            |
| 优先权            | 09/704589 2000-11-02 US                |         |            |
| 外部链接           | <a href="#">Espacenet</a>              |         |            |

#### 摘要(译)

一种电致发光面板驱动电路，包括可充电电池和电致发光面板。电致发光面板包括前电极和后电极。驱动电路耦合到电池和电致发光面板，并且被配置为交替地对前电极和后电极充电，以使电致发光面板发光。该电路还被配置为交替地将前电极和后电极放电到电池，从而对电池再充电。