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- 1 -

BALLAST IC WITH SHUT-DOWN FUNCTION

RELATED APPLICATIONS

This application is related to U.S. Patent No. 5,612,597 entitled "OSCILLATING DRIVER CIRCUIT WITH POWER FACTOR CORRECTION, ELECTRONIC LAMP BALLAST EMPLOYING SAME AND DRIVER METHOD" issued March 18, 1997 (IR-1166), to U.S. Patent No. 5,545,955, entitled "MOS GATE DRIVER FOR BALLAST CIRCUITS" issued August 13, 1996 (IR-1074), to U.S. Patent No. 5,559,394, entitled "MOS GATE DRIVER FOR BALLAST CIRCUITS", issued September 24, 1996 (IR-1252), all in the name of Peter N. Wood, and to U.S. Patent No. 5,550,436, entitled "MOS GATE DRIVER INTEGRATED CIRCUIT FOR BALLAST CIRCUITS", issued August 27, 1996 (IR-1055), in the name of Talbott M. Houk, all of which are assigned to the assignee of the present application and incorporated herein by reference.

BACKGROUND OF THE INVENTION

The present invention relates to lamp ballast circuits, and, more particularly, to an improved lamp ballast circuit which protects against lamp failure.

Lamp ballast circuits, such as an International Rectifier IR2155 or IR2151 IC, are known and are described in U.S. Patent Nos. 5,545,955 (IR-1074) and 5,559,394 (IR-1252) to Peter Wood and in U.S. Patent No. 5,550,436 (IR-1055) to Talbott M. Houk.

To properly shut down a ballast IC during certain lamp application failure modes, a means of turning off the gate driver outputs upon sensing fault conditions (such as a broken filament or a lamp which

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fails to strike at startup) and then turning off the output power transistors is needed.

Because of the topology of the IR2155 and IR2151 ICs, the circuits are self-oscillating under normal operation, as shown in Figures 1 and 2.

Figure 1 shows the components of a typical lamp driver circuit. A bridge rectifier 10 derives a bus voltage (V_{BUS}) from the ac line. The bus voltage is approximately dc and is supported by capacitors 56 and 58.

The lamp driver circuit of Figure 1 includes an MOS gate driver chip 30 and its associated circuitry for controlling the operation of a high side MOSFET 40 and a low side MOSFET 41. The MOS gate driver chip 30 provides drive signals to the MOSFETs 40 and 42 which are connected to V_{BUS} . Though power MOSFETs are shown, any power device which has a MOS gate, such as an IGBT or a MOS gated thyristor, may be substituted for power MOSFETs 40 and 42.

The output of the center tap of half bridge connected MOSFETs 40 and 42 drives a circuit that includes a series LC load circuit comprised of inductor 46 and capacitor 52.

The voltage supplied at terminal V_{BUS} can range from as low as 140 volts d-c to above 600 volts d-c, depending upon the supplied AC input voltage.

The oscillating frequency of the output circuit is controlled by the resonant frequency of the inductor 46 and the capacitor 52. The desired inductance value of inductor 46 will depend on the value of the voltage V_{BUS} and is selected so that the oscillation frequency of the circuit is within desired range.

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The chip 30 may be housed in a 8-pin DIP or surface mount package and has the following pinouts:

V_{CC} - a pin which receives a chip operating voltage from the d-c supply V_{BUS} .

C_T - a single input control pin which is connected to the node between timing capacitor 14 and timing resistor 16. The signal at pin C_T controls both outputs H_o and L_o .

R_T - a pin which is connected to the other terminal of timing resistor 16.

V_B - a pin connected to the node of diode 22 and capacitor 24, which acts as a "bootstrap" circuit to provide power for the operation of the high side switch.

H_o - an output pin to the gate (or a resistor 26 to the gate) of the high side MOSFET 40.

V_s - a pin to the center tap of the totem-pole or half bridge connected MOSFETs 40 and 42.

L_o - an output pin to the gate (or a resistor 28 to the gate) of the low side MOSFET 42.

COM - a pin connected to the negative or ground terminal.

Resistor 18 and a capacitor 12 provide the IC 30 with its dc and ac power requirements. The resistor 16 and the capacitor 14 control the oscillation frequency according to the equation:

$$f = \frac{1}{1.4 R_{16} C_{14}} \quad (1)$$

A diode 22 and a capacitor 24 form the "bootstrap" supply for the floating CMOS driver circuit within the IC. Resistors 26 and 28 dampen LC ringing on

the gates of the power MOSFETS 40 and 42 and also serve to buffer the IC 30 from the power stage.

The load circuit, which includes the inductor 46 and the resonant capacitor 52, also includes blocking capacitors 56 and 58, a positive-temperature-coefficient (PTC) resistor 54, and a lamp 50. A capacitor 44 normally controls the dV/dt observed at the V_s node to minimize radiated EMI.

A drawback of this basic circuit is that if the lamp is either broken (such as at the end of its operating life) or is removed from the circuit, catastrophic failure of other components within the circuit may result. Therefore, users of the gate driver IC 30 must typically design additional external circuitry to sense the fault conditions and then turn off the IC. Preferably, both outputs of the gate driver IC turn off under a turn-off condition.

Because the gate driver IC is self-oscillating, one of the gate driver outputs L_0 and H_0-V_s is always on, except for the short "deadtime" shown in Figure 2. Under normal operating conditions, either the MOSFET 40 or the MOSFET 42 is on. As a result, turning off the gate driver IC simply by externally shunting the timing capacitor 14 to ground, as shown in Figure 3, for example, is not sufficient to protect the circuit.

Figure 3 shows the circuit of Figure 1 modified to include a transistor 60 which shunts the input control capacitor 14 to ground when the lamp is removed. A voltage divider formed by resistors 62, 64, 66 and a capacitor 68 form the sensing circuit. Under normal operating conditions, the voltage at node V_A is approximately equal to one-half the dc supply voltage, $V_{BUS}/2$, when capacitors 56 and 58 are of identical value.

The only difference between the voltage at node V_A and the voltage at the node located at the midpoint between capacitors 56 and 58 results from the voltage drop across the filament of the lamp 50.

Under normal operating conditions, the voltage drop across the filament is relatively small, namely only a few volts, and the voltage at node V_C is insufficient to turn on the shunt transistor 60. If the lamp is removed, however, the voltage at node V_A rises, as does the voltage at node V_C , such that the transistor 60 turns on. The values of the resistors 62, 64, 66 are chosen such that the circuit never turns on the transistor 60 during normal operating conditions but always turns on the transistor 60 when the lamp is removed or fails. The capacitor 68 also forms part of a low pass filter in the turn off response circuit, thereby increasing noise immunity.

The circuit shown in Figure 3, however, does not shut down both of the power MOSFET devices 40 and 42 when the lamp is removed from the load circuit. Under this no-lamp load condition, the C_T pin of IC 30 would be shunted to ground by the transistor 60, which halts the IC's internal oscillator and its output switching, as desired. However, despite having turned off the output of the half bridge, transistor 42 remains on.

Another approach to shutting down both MOSFETs 40 and 42 under a fault condition is to shunt the V_{cc} pin of the IC ground, as shown in Figure 4. Here, the sensing circuit is essentially the same as Figure 3, but an SCR 70 shunts the V_{cc} pin through resistor 72 to shut down the output.

A drawback of the circuit of Figure 4 is that when the fault condition ends, such as when the lamp is

replaced in its socket, the entire power-up sequence must be repeated because the supply voltage V_{cc} that is supplied to the chip has been discharged below its undervoltage threshold. In fact, the circuit relies on the undervoltage lockout circuit of IC 30 to turn both of power transistors 40, 42 off.

Another drawback of the circuit of Figure 4 is that the SCR 70 is a more expensive component than the NPN transistor 60 of Figure 3.

Moreover, a resistor 72 must be included into the V_{cc} capacitor discharge path to slow down the dV/dt at the V_{cc} pin. The dV/dt must be limited because the supply voltage to the gate driver output stages may turn off before the output stages have fully discharged the gates of the power MOSFETs. For example, if the upper power MOSFET 40 is on and the supply voltage is rapidly brought to 0V, the transistor 40 cannot be turned off and is effectively left with a charge (or voltage) on its gate with only the inherent gate-to-source leakage to discharge the MOSFET. The residual charge can cause catastrophic failure if the IC 30 is restarted when the upper MOSFET 40 is still on. When the IC 30 restarts, namely, when its V_{cc} voltage exceeds the rising undervoltage lockout threshold, the lower MOSFET 42 turns on first. If transistor 40 is still on when transistor 42 turns on, a short will be present across the dc bus and the ac line that will, at the very least, blow a fuse and more likely cause the failure of either one of or both of the power MOSFETs.

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SUMMARY OF THE INVENTION

The present invention provides for a lamp driver integrated circuit which protects against damage to the components of driver circuit when a lamp fails or is removed by disabling both of the driver outputs.

When the lamp is replaced, the IC automatically restarts the lamp driver circuit without cycling the lamp power switch.

According to an aspect of the invention, an integrated circuit formed in a silicon substrate drives first and second MOS gated power semiconductor devices. The power semiconductor devices are connected in a half bridge circuit which has a first and second dc terminals and which has a common terminal located at a node between the first and second MOS gated power semiconductor devices. The common terminal supplies an output signal to a load circuit. A timer circuit has an input control terminal which is connected to a low logic level signal. A first latch circuit is coupled to the timer circuit and controls the frequency at which the first and second MOS gated power semiconductor devices are switched on and off and supplies an output which is switched on and off in response to the signal applied to the input control terminal. High side and low side dead time delay circuits are each coupled to the first latch circuit and delay transmission of the latch output signal for a time interval following the switching of the output of the latch circuit to prevent simultaneous conduction of the first and second MOS gated power semiconductor devices. High side and low side driver circuits are coupled to the high side and low side dead time circuits, respectively, and have high side and low side output terminals, respectively, which supply high side and low side outputs

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for turning off the respective first and second MOS gated power semiconductor devices in response to the signal supplied to the input control terminal. A protective circuit is coupled to the low logic level signal and prevents the supply of the high side and low side outputs when the low logic level signal is below a threshold value.

According to this aspect of the invention, the protective circuit may include a threshold voltage sensing circuit which is coupled to the low logic level signal and a second latch circuit which is coupled to the sensing circuit and whose outputs are supplied to the high side and low side dead time delay circuits. The threshold voltage may be less than the lowest value of the lower logic level signal voltage at which outputs are supplied for turning on and off the first and second MOS gated power semiconductor devices. When the low logic level signal falls below the threshold voltage, the high side and low side dead time delay circuits may be prevented from transmitting the latch output signal.

According to another aspect of the invention, a circuit drives a load circuit from a dc bus supply and includes first and second MOS gated power semiconductor devices and a self-oscillating driver circuit.

In accordance with a further aspect of the present invention, a circuit drives a gas discharge illumination device and includes first and second MOS gated power semiconductor devices and a self-oscillating driver circuit.

Other features and advantages of the present invention will become apparent from the following description of the invention which refers to the following drawings.



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BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a diagram showing a typical known lamp ballast circuit.

Figure 2 shows the waveforms of the circuit shown in Figure 1.

Figure 3 shows a known lamp ballast circuit which includes a shunt transistor that disables the circuit in the event of lamp failure.

Figure 4 shows a known lamp ballast circuit in which an SCR shunts the V_{CC} pin in the event of a lamp failure.

Figure 5 shows a block diagram of a lamp driver integrated circuit according to an embodiment of the invention.

Figure 6 shows the waveforms of the lamp driver integrated circuit shown in Figure 5.

DETAILED DESCRIPTION OF THE INVENTION

The invention enables the use of the simple circuit, such as is shown in Figure 3, by modifying the internal IC circuitry. The circuit shown in Figure 3, however, represents only one example of a shutdown circuit. Other similar circuits are also possible.

Figure 5 is a block diagram of the circuit of the IC chip 30 of the invention that is suitable for inclusion in the circuit of Figure 3. The eight pinouts of chip 30 are repeated in Figure 5. All circuit blocks to be described in Figure 5 are typically integrated into a common silicon chip.

The leftmost circuit block shown in Figure 5 is the clamp circuit 110, typically comprising a plurality of zener diodes. The clamp circuits connected from pin V_{CC} and pin V_{SS} which is connected to the silicon



substrate which acts as the chip ground. A digital supply line and analog supply line both extend from pin V_{cc} . An analog ground line and a digital ground line are also connected to pin V_{ss} .

The next group of circuit blocks form a timer circuit. The blocks include a divider circuit 112, which is connected to the analog supply line and to the analog ground, an N comparator 114, a P comparator 116 and an RS latch 120. Two taps from divider 112 are connected to the positive inputs of comparators 114 and 116 and supply voltages VR1 and VR2, respectively, thereto. Input pin C_T is connected to the negative input of comparators 116 and 114. The output of comparators 114 and 116 are connected to the RS latch 120 as shown.

The RS latch 120 is also connected to an under-voltage lock-out circuit 122 which is integrated into the chip circuit. Thus, if V_{cc} reduces too low, the RS latch 120 is locked out.

A bias circuit 132 provides bias outputs to the lockout circuit 122, and to dead time delay circuits 126 and 130 in the high side and low side circuit lines. Dead time delay circuits 126 and 130 provide a dead time or delay of about 1 microsecond between the turn on of the high side or low side switch after the turn off of the other. This dead time ensures that a "shoot through" circuit cannot be formed in which both power MOSFETs 40 and 42 of Figure 3 are simultaneously on.

The output of dead time delay circuit 130 is applied to low side delay circuit 140 and, in turn, to low side driver 142 which is connected to pin L_0 .

The output of dead time delay circuit 126 is applied to a level shift pulse generator 128 in the high

side output line. The high side line also includes a dv/dt filter circuit 134 which filters noise from the pulse passed by pulse generator 128. The supply to the dv/dt filter 134 is connected to pin V_B .

The output of the dv/dt filter 134 is applied to latch circuit 136 whose output is connected to buffer 138 which contains gain stages and which drives pin H_0 . Note that pin V_s is connected to circuits 134, 136, 138.

The invention maintains all of these functions within the IC, which exist as in the IR2155 and IR2151 ICs described in the above-noted patents of the present assignee, but also adds a novel shutdown feature using the C_T pin. According to the invention, two additional circuit blocks have been added: (1) a third C_T -sensing comparator 118, and (2) a shutdown latch circuit 124. Input pin C_T is connected to the negative input of the third comparator 118 which senses when the C_T pin voltage is less than a predetermined threshold, denoted as $VR3$, that is supplied by divider 112. The third comparator 118 then supplies its output to the shutdown latch 124 and to the low side dead time delay circuit 130. The output of the shutdown latch is supplied, in turn, to the input of the high side dead time delay circuit 126.

The threshold voltage $VR3$ at which the third comparator 118 changes state is chosen to be less than the lower of the threshold voltage $VR2$ used for self-oscillation. An example of the operation is illustrated in Figure 6. Here, the values of $VR1$ and $VR2$ are chosen to be $2/3 V_{CC}$ and $1/3 V_{CC}$, respectively, and the value of $VR3$ is chosen to be $1/6 V_{CC}$ primarily for convenience. Other particular ratios could be chosen, as long as $VR3 < VR2 < VR1$.

Figure 6 depicts how the C_T -pin voltage regulates the operation of the outputs. At system startup, all of the IC input and output node voltages and currents are initially zero. The rectifier 10 (see Fig. 3) will quickly develop a dc bus voltage (e.g., +320V) and cause capacitor 12 to charge up through resistor 18. Capacitor 12 supplies a voltage to the Vcc terminal of the IC 30, which in turn supplies power to all of the internal circuits of IC 30.

When sufficient voltage is developed on capacitor 12, the UVLO block 122 (see Fig. 5) presets many of the other circuits in a desired state. Specifically, (1) the gate driver output LO is held low to prevent unwanted conduction of the power MOSFET 42, (2) the R_T pin is set high (to the Vcc potential), (3) the C_T pin begins to charge and (4) the bias circuit block 132 is set in a "micropower" mode, where most of the IC circuit blocks are unbiased. This "micropower" startup mode is desirable because it reduces the current requirement from startup resistor 18, which enables the user to use a higher valued, lower wattage resistor (i.e., power consumption is reduced). Much like the circuit block UVLO 122, circuit block HS latch 132 ensures that for a VB-to-Vs potential of less than a preset, designed voltage level (e.g., 8.5V), and that output HO is held at the Vs level, preventing unwanted conduction of the upper power MOSFET 40.

When the C_T -pin voltage exceeds VR3, (1) the low-side gate driver output voltage LO goes high after a dead time delay t_d , turning on the low side power MOSFET 42, (2) the bias current block 132 is instructed to supply power to the oscillator comparators NCOMP 114, PCOMP 116 and COMP 118 and the dead time circuits TDEADH

126 and TEADL 130, (3) the R_T pin is held high by the oscillator latch 124, and (4) the C_T pin continues to charge up through the resistor 16.

During normal operation, after the C_T -pin voltage exceeds $VR3$, self-oscillation occurs, and the output of the half-bridge circuit V , toggles with a trapezoidal shaped output.

When the C_T pin reaches $2/3 \times V_{CC}$, the NCOMP comparator 114 gives a negative reset signal to the RSLATCH 120. This negative reset signal causes the outputs (R_T and its complement R_T/N) of the RSLATCH 120 to reverse logic states, and the R_T pin goes low (R_T/N goes high). In this particular embodiment of the IC 30, the R_T pin drives the low-side signal path to LO, and is in phase with this output. Note that the phase relationship between R_T and LO is arbitrary; certain users of this IC will require R_T to be out of phase with R_T/N , even though LO will need to come on first during startup. As a result, when R_T goes low, the LO output is driven low, turning off the low-side power MOSFET 42. The signal path from R_T to LO is intentionally made as fast as possible (minimum delay), and is designed to accurately match the turn-off propagation delay from R_T/N to HO. This ensures that a propagation delay mismatch between the high-side and low-side drivers does not systematically offset the duty cycle at the output V_s of the half-bridge from its desired 50% level.

When R_T switches logic levels from high to low, R_T/N (the second RSLATCH 120 output) goes high. This latter signal drives the high-side dead time circuit TDEADH 126, which drives the pulse generator PGEN 128, which level shifts the high-side on/off signals to the



high-side circuitry. The dead time circuits are designed to generate a small delay (e.g., 1 μ sec) to the "turn-on" signal in order to (1) provide a cross-conduction dead time for the power MOSFETs 40 and 42, and (2) facilitate zero-voltage switching techniques for drive frequencies above the L-C resonant frequency (where the load impedance is inductive). Conversely, these dead time circuits are designed to add as little delay as possible to the "turn-off" signals to the gate drivers 138 and 142. After the high-side dead time circuit TDEADH 126 timeout period (e.g., 1 μ sec), the pulse generator PGEN 128 is given the logic signal to translate a "turn-on" signal to the high-side gate driver 138. The DV/DT circuit 134 discriminates short pulses (e.g., 50-200 nsec) emitted by the pulse generator, and translates these pulses into "set" and "reset" signals for the HSLATCH 136. R_T/N going high corresponds to a "set" signal at the input to the HSLATCH, which in turn gives the HSDRIVER 138 circuit the command to drive the HO output high.

Another result of the R_T pin switching from a high to a low potential is that the resistor 16 begins to discharge the capacitor 14 from the $2/3 V_{CC}$ threshold (set by the DIVIDER 112 block) downward to the $1/3 V_{CC}$ threshold (also set by the DIVIDER 112 block). Upon reaching the $1/3 V_{CC}$ threshold, the PCOMP comparator 116 output goes high, giving a "set" signal to the RSLATCH 120. This "set" signal drives R_T high, R_T/N low, and results in the output of the half-bridge V_s going low. The antiphase relationship between R_T and C_T results in self-oscillation at a 50% duty cycle, independent of the V_{CC} potential and temperature. This duty cycle control, combined with carefully matched turn-off propagation

delays from R_T to LO and R_T/N to HO, respectively, result in a 50% duty cycle at the output of the half-bridge Vs.

If, during normal operation, a fault occurs which triggers the discharge of the capacitor 14, both of the gate driver outputs are disabled, and the output of the half-bridge stops oscillating. The R_T -pin voltage stays high to accommodate an automatic restart once the fault condition terminates.

If the fault condition is the removal of the lamp, and the circuit of Figure 3 is used, the C_T pin is discharged, and both gate driver outputs shut down. When the lamp is replaced, the transistor 60 shown in Figure 3 turns off, and the capacitor 14 again charges up.

The automatic restart function is accomplished by the shutdown latch 124 in Figure 5 and the lamp user need not cycle the lamp power switch to restart the system.

Although the present invention has been described in relation to particular embodiments thereof, many other variations and modifications and other uses will become apparent to those skilled in the art. It is preferred, therefore, that the present invention be limited not by the specific disclosure herein, but only by the appended claims.



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WHAT IS CLAIMED IS:

1. An integrated circuit formed in a silicon substrate for driving first and second MOS gated power semiconductor devices which are connected in a half bridge circuit which has first and second d-c terminals and which has a common terminal located at a node between said first and second MOS gated power semiconductor devices, the common terminal for supplying an output signal to a load circuit; said integrated circuit comprising:

a timer circuit having an input control terminal which is connected to a low logic level signal;

a first latch circuit coupled to said timer circuit for controlling the frequency at which said first and second MOS gated power semiconductor devices are switched on and off and for supplying an output which is switched in response to said signal applied to said input control terminal;

a high side dead time delay circuit and a low side dead time delay circuit each coupled to said first latch circuit for delaying transmission of said latch output signal for a time delay interval following the switching of said output of said first latch circuit to prevent simultaneous conduction of said first and second MOS gated power semiconductor devices;

a high side driver circuit and a low side driver circuit coupled to said high side dead time circuit and said low side dead time circuit, respectively, and having high side and low side output terminals, respectively, which supply high side and low side outputs for turning on and off said first and second





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MOS gated power semiconductor devices, respectively, in response to said signals supplied to said input control terminal; and

a shutdown circuit coupled to said low logic level signal for preventing said supply of said high side and low side outputs when said low logic level signal is less than a threshold voltage.

2. The integrated circuit of claim 1 wherein said protection circuit comprises a threshold voltage sensing circuit coupled to said low logic level signal and a second latch circuit coupled to said sensing circuit for supplying an output to said high side and low side dead time delay circuits.

3. The integrated circuit of claim 1 wherein said threshold voltage is less than the lowest value of said low logic level signal at which said high side and said low side outputs are ordinarily supplied to said first and second MOS gated power semiconductor devices.

4. The integrated circuit of claim 1 wherein said protection circuit prevents said high side and low side dead time delay circuits from transmitting said latch output signal when said low logic level signal is less than said threshold voltage.

5. The integrated circuit of claim 1 wherein said timer circuit has a second input control terminal for controlling the frequency at which said MOS gated power semiconductor devices are turned on and off; said first and second input control terminals being connected to an external timing capacitor and an external timing

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resistor for setting the oscillation frequency of said timing circuit.

6. A circuit for driving a load circuit from a dc bus supply, said circuit comprising:

first and second MOS gated power semiconductor devices connected in a half bridge configuration which has first and second d-c terminals coupled across the d-c bus supply and having a common terminal at the node between said first and second MOS gated power semiconductor devices for supplying an output signal to the load circuit; and

a self oscillating driver circuit having first and second outputs for driving said first and second MOS gated power semiconductor devices, respectively, a dead time delay circuit for preventing the simultaneous driving of said first and second MOS gated power semiconductor devices by delaying the turning on of one of said first and second MOS gated power semiconductor devices for a time delay interval after the turning off of another one of said first and second MOS gated power semiconductor devices, and a shutdown circuit coupled to said low logic level signal for preventing said supply of said high side and low side outputs for turning on and off said first and second MOS gated power semiconductor devices when said low logic level signal is less than a threshold voltage.

7. The circuit of claim 6 wherein said protection circuit comprises a threshold voltage sensing circuit coupled to said low logic level signal and a second latch circuit coupled to said sensing circuit for

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- 19 -

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supplying an output to said high side and low side dead time delay circuits.

8. The circuit of claim 6 wherein said threshold voltage is less than the lowest value of said low logic level signal at which said high side and said low side outputs are ordinarily supplied to said first and second MOS gated power semiconductor devices.

9. The circuit of claim 6 wherein said protection circuit prevents said high side and low side dead time delay circuits from transmitting said latch output signal when said low logic level signal is less than said threshold voltage.

10. A circuit for driving a gas discharge illumination device which comprises the circuit of claim 6.

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