

Driver Circuit For Bridge Circuit Employing a Bootstrap Diode Emulator

The present invention relates to a driver circuit for driving a bridge circuit comprising lower and upper power transistors connected between an output terminal and respective lower and upper rails of a high voltage DC supply, and for charging a bootstrap capacitor having first and second ends, the first end being coupled to said output terminal,

5 said driver circuit comprising:

power supply means for generating at a power supply output a control voltage with respect to said lower rail;

a lower drive module coupled to the power supply output for being powered by said control voltage and comprising means for applying a lower drive control
10 signal to a control electrode of the lower power transistor for rendering the lower power transistor alternately conductive and non-conductive;

an upper drive module adapted to be coupled to the the bootstrap capacitor for being powered by a bootstrap voltage across said bootstrap capacitor and comprising means for applying an upper drive control signal to a control electrode of the
15 upper power transistor for rendering the upper power transistor alternately conductive and non-conductive; and

bootstrap diode emulator means for charging said bootstrap capacitor to said bootstrap voltage, said bootstrap diode emulator means comprising a LDMOS transistor having a source electrode coupled to said power supply output, a drain electrode adapted to
20 be coupled to the second end of the bootstrap capacitor, a gate electrode coupled to the lower drive module via load control circuitry for driving said LDMOS transistor to a conducting state when the lower power transistor is driven to a conducting state, and a backgate electrode.

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Such a driver circuit is known from US 5,373,435, which was only published after the priority date of this patent application. Bridge circuits can be applied in electronic ballasts for discharge lamps, in switched mode power supplies, motor drives and DC-AC-converters. The known driver circuit is realized as a high voltage integrated circuit.

The upper drive module is accommodated in an insulated well formed in this monolithic integrated circuit and the LDMOS transistor is formed along a portion of the periphery of this well. Current through the LDMOS transistor flows perpendicular to the periphery of the well, enabling the required current carrying capacity to be obtained by choosing a sufficient length of the LDMOS along the well periphery. The breakdown voltage of the LDMOS transistor is governed by the properties of the insulation of the well periphery because the floating well is formed at its periphery by structure equivalent to that used in forming an LDMOS.

An important advantage of the use of such a bootstrap diode emulator is that this emulator can be realized together with the rest of the components of the driver circuit on a single chip. This way the diode function can be realized in a way that is cheaper and more reliable than by means of the use of a discrete component.

A disadvantage associated with the diode emulator means as described above is that inherent in an LDMOS device are parasitic transistors, one of which is a parasitic PNP transistor whose emitter and base are respectively the backgate and drain of the LDMOS and whose collector is the substrate of the IC. It has been found that during startup of the LDMOS in the charging cycle, the parasitic PNP transistor will shunt some current from the backgate to the substrate reducing the current available for charging the bootstrap capacitor.

The present invention aims to provide a driver circuit in which the bootstrap diode emulator more effectively charges the bootstrap capacitor.

A driver circuit as described in the opening paragraph is therefore equipped with biasing and limiting means coupled to the backgate electrode of the LDMOS for biasing the backgate electrode while limiting the current that said parasitic device can shunt away from said bootstrap capacitor.

It has been found that by using these biasing and limiting means, the current flowing from the backgate electrode to the LDMOS transistor can be suppressed to a substantial extent.

A very effective suppression of the amount of current flowing from the backgate electrode of the LDMOS via the parasitic device can be realized in case said biasing and limiting means comprises a clamping transistor and a current source connected to said backgate electrode. Preferably said current source comprises a current mirror.

The load control circuitry can be realized in a relatively simple and dependable way by means of a buffer for producing a buffer output signal having a voltage

range between said lower rail and said control voltage, and means for translating the voltage range of said buffer output signal to a range of voltage difference between a point coupled to said gate electrode and said high source electrode. The means for translating preferably comprise capacitive means.

5 Spurious driving of the LDMOS transistor into a conducting state in response to a voltage spike produced when the lower power transistor turns off can be prevented by equipping the load control circuitry with means for clamping said gate electrode to said source electrode of said LDMOS transistor in response to displacement current flowing in a Miller capacitance of said LDMOS transistor coupled between the drain and
10 gate electrodes. These means for clamping are preferably realized making use of a PNP transistor.

To collect the charge that the backgate injects during a voltage transient at the drain capacitive means can be coupled between the backgate electrode and the source electrode of said LDMOS transistor.

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Embodiments of the invention will be illustrated further making use of a drawing. In the drawing

Figure 1 is a schematic diagram of the driver circuit of the present
20 invention in which components comprised in an integrated circuit chip are enclosed in a dashed box labelled IC; and

Figure 2 is a schematic plan view of the integrated circuit chip corresponding to the dashed box IC in Figure 1, including an elongated area in which a high voltage LDMOS T_3 is formed.

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Referring first to Figure 1, there is shown a driver circuit in accordance with the present invention, contained in a monolithic high voltage integrated circuit IC, connected for driving an external half-bridge formed by power MOSFET's T_1 and T_2
30 connected in series across a high voltage (up to about 500 Volts) DC supply. The general circuit architecture of the half-bridge and driver is the same as shown and described in the aforementioned U.S. Patent No. 4,989,127, with the exception of the provision of an on-chip bootstrap diode emulator BDE in accordance with the present invention.

In the half-bridge, power transistor T_1 is referred to as the upper transistor

because its drain electrode is connected to the high side or upper rail of the DC supply, indicated in Figure 1 as at the potential V_{cc} and power transistor T_2 is referred to as the lower transistor because its source electrode is connected to the low side or lower rail of the DC supply, indicated in the figure as at the potential of power ground. The source electrode of upper transistor T_1 and the drain electrode of lower transistor T_2 are joined at the output terminal OUT of the half-bridge which is also connected to one end of a load LD. In power supply applications such as powering gas discharge lamps, the other end of the load may be maintained at a potential of half the supply voltage by being connected to the midpoint of a capacitive voltage divider (not shown) across the DC supply. As is well known, the transistors T_1 and T_2 are operated in a switch mode with respect to a high frequency (greater than 20kHz) repetitive cycle, e.g. on the order of 100KHz, where each is turned on (i.e. driven into a conducting state) during a different one of two time intervals or phases during a cycle, which are separated from each other by relatively small dead zone intervals on the order of about 500ns. Switching transients at current turnoff due to load LD having in many applications a somewhat inductive impedance are limited by the inherent body diodes D_1 and D_2 of T_1 and T_2 , respectively. D_1 is directed for limiting a positive voltage transient produced at output terminal OUT when the lower power transistor T_2 is turned off and diode D_2 is directed for limiting a negative voltage transient produced at the output terminal when the upper power transistor T_1 is turned off.

These cycles are established by a controller CON, which in response to an external input signal IN produces an essentially binary command signal IN_L and its logical inverse INN_L for controlling the conducting state of lower transistor T_1 and via level shifter LS produces pulse command signals T_{ON} and T_{OFF} for controlling the conducting state of the upper transistor T_2 . Command signal IN_L has one binary state only during the time interval or phase when lower transistor T_1 is to be driven into a conducting state. The command signals T_{ON} and T_{OFF} are provided in pulse form for noise and transient immunity purposes; T_{ON} and T_{OFF} indicate the instants when the upper transistor T_2 is to be turned on and off, respectively. The lower transistor command signals IN_L and INN_L are fed to a lower drive module DL which in response thereto drives the gate G_L of lower transistor T_2 to turn on the lower transistor only during the phase defined by the lower transistor command signals. In a similar manner, command signals T_{ON} and T_{OFF} are fed to an upper drive module DU which in response thereto drives the gate G_U of upper transistor T_1 to turn on the upper transistor during the phase defined by the upper transistor command signals. An R/S flip flop (not shown) within the upper drive module DU converts the command signals T_{ON} and T_{OFF} to

binary form similar to IN_L and IN_{LL} in order that the balance of the upper drive module may be of the same design as the lower drive module DL.

Lower drive module DL is powered by a relatively low power supply voltage V_{dd} , e.g. 12 Volts, and upper drive module is powered by the voltage V_1 across an external bootstrap capacitor C_1 , having a capacitance on the order of 70 nf, which is too large to be produced in integrated circuit IC with reasonable cost of area. The other end of bootstrap capacitor C_1 is coupled to the supply voltage V_{dd} via on-chip bootstrap diode emulator BDE, so that a charging current flows in C_1 when the output terminal OUT is maintained substantially at ground potential during the time when lower transistor T_1 is in a conducting state, to bring V_1 to a voltage of V_{dd} less any small voltage drops across BDE and T_2 .

Now referring also to Figure 2, as is known, the upper drive module DU comprises CMOS circuitry formed in an insulated well WL, in integrated circuit chip IC, e.g. an N-well surrounded by P isolation. Thus, well WL is insulated from the balance of the integrated circuit by structure similar to that used to produce a LDMOS transistor. A high voltage diode cannot be integrated in junction isolation technologies because it results in large substrate currents. This could upset the operation of other circuitry. In accordance with the principles of the present invention, a bootstrap diode emulator provided on-chip comprises a LDMOS T_3 that is formed along the periphery of the well WL. LDMOS T_3 inherently has the same breakdown voltage as the well isolation (in excess of 500 Volts) and because current flows perpendicular to the well periphery, adequate current carrying capacity can be obtained by choice of the extent of the well periphery along which it is formed. Further, the implementation of LDMOS T_3 does not require expenditure of additional area; a small amount of additional area on the integrated circuit is however required for the circuitry to drive T_3 so that it is in a conducting state only when lower transistor T_2 is driven into a conducting state.

As shown in Figure 1, LDMOS T_3 is illustrated as an ideal device plus various inherent or parasitic elements. There is a parasitic PNP transistor T_4 whose emitter and base electrodes are the backgate B and drain D electrodes of LDMOS T_3 and whose collector electrode is connected to ground. The latter connection is because the substrate of integrated circuit IC is grounded. LDMOS T_3 also has parasitic capacitors CBD, between backgate and drain, and CGD between gate and drain and an inherent resistance R_{drn} between the drain electrode of the ideal LDMOS and its actual drain electrode D'. This resistance is determined by the width of the LDMOS and temperature of operation.

The width is chosen based on the application. A typical R_{on} at room temperature (25 C°) of the LDMOS (75 μ m rift region) is 300 Ω /mm of width.

LDMOS T_3 is operated in source follower configuration with its source electrode S connected to V_{dd} and its actual drain electrode D' connected to the higher voltage end of bootstrap capacitor C1. In response to T_3 being turned on, the drain electrode D rises to V_{dd} as bootstrap capacitor C1 is charged. During the startup of T_3 turning on, it is necessary to limit the current conducted by parasitic transistor T_5 from its emitter to its collector, since such conduction shunts current available for charging bootstrap capacitor C1 while also properly biasing the backgate of T_3 during normal operation in the charging cycle. This is done by providing a PNP transistor T_6 for clamping the backgate to a biasing voltage during normal operation and a current source feeding the backgate to limit the current through the parasitic transistor. The emitter of clamping transistor T_6 is connected to the backgate B (and therefore to the emitter of parasitic transistor T_5) and to the drain of a FET transistor T_7 which acts as current source by mirroring the current of a FET transistor T_8 . The collector of transistor T_6 is connected to ground and its base is connected to the gates of transistors T_7 , T_8 , to the drain of transistor T_8 and to one end of a current source CS. The voltage at the base of transistor T_6 must be low-ohmic to provide a constant clamp level. The other end of current source CS is connected to ground. The sources of transistors T_7 , T_8 are connected to the source S of LDMOS T_3 .

Further a capacitor C3 is connected between the backgate and source of LDMOS T_3 .

It should be appreciated that the current of current source CS flows through transistor T_8 and by current mirror action the same current is replicated flowing through transistor T_7 .

The capacitor C3 is destined to collect the charge that the backgate injects during a voltage transient at the drain D of T_3 . It is vital that the backgate B remains negatively biased with respect to the source S of T_3 . The value of C3 scales with the width of the LDMOS. As previously noted, that width is determined by the actual application.

As a result of the biasing of the backgate, a gate to source voltage of 4V is required to turn on LDMOS transistor T_3 . In order to turn the LDMOS transistor T_3 on when the lower power transistor T_2 is driven into a conducting state, the lower drive command signal IN_L is applied to a buffer amplifier BUF which produces at its output OB a signal which is at voltage V_{dd} when the lower power transistor T_2 is driven into a conducting state and at zero Volts otherwise. This voltage is applied to a one end of a second relatively

small bootstrap capacitor C_2 whose other end, at point P, is coupled to the supply voltage V_{dd} via a diode D_4 . Bootstrap capacitor C_2 has a capacitance of at least five times the gate capacitance of the transistor T_3 . The buffer BUF has a sufficiently low output impedance that the second bootstrap capacitor C_2 is charged via diode D_4 to a voltage V_2 which equals V_{dd} less one diode drop. This has the effect of translating the range of the voltage at the buffer output OB (greater than one diode drop) to appear directed between point P and the source electrode S of LDMOS transistor T_3 . Point P is connected to the gate electrode G of transistor T_3 via a resistor R of approximately 5K ohms. This resistor is used to develop a voltage which turns on an PNP transistor T_4 whose emitter, base and collector are connected respectively to the gate electrode of T_3 , point P, and V_{dd} . To prevent spurious turning on of the LDMOS transistor T_3 due to switching transients at output OUT, a transistor T_4 actively pulls the gate of transistor T_3 down to V_{dd} in response to a voltage across resistor R due to miller current through C_{GD} . This current, which is caused by a large positive rate of change in voltage when the output voltage at output OUT slews from zero Volts to V_{cc} and the drain electrode of LDMOS transistor T_3 slews over a corresponding range, would otherwise charge the gate capacitance to a turn on level. As a result, the bootstrap diode emulator BDE conducts only at the times a bootstrap diode would have conducted to correctly charge the bootstrap capacitor C_1 .

It should now be apparent that the objects of the present invention have been satisfied in all respects. Further, while the present invention has been described in particular detail, it should also be appreciated that its principles have broad general applicability. Consequently, numerous modifications are possible in the details given within the intended spirit and scope of the invention.

CLAIMS:

1. A driver circuit for driving a bridge circuit comprising lower and upper power transistors connected between an output terminal and respective lower and upper rails of a high voltage DC supply, and for charging a bootstrap capacitor having first and second ends, the first end being coupled to said output terminal, said driver circuit comprising:

5 power supply means for generating at a power supply output a control voltage with respect to said lower rail;

a lower drive module coupled to the power supply output for being powered by said control voltage and comprising means for applying a lower drive control signal to a control electrode of the lower power transistor for rendering the lower power transistor alternately conductive and non-conductive;

10 an upper drive module adapted to be coupled to the the bootstrap capacitor for being powered by a bootstrap voltage across said bootstrap capacitor and comprising means for applying an upper drive control signal to a control electrode of the upper power transistor for rendering the upper power transistor alternately conductive and non-conductive; and

15 bootstrap diode emulator means for charging said bootstrap capacitor to said bootstrap voltage, said bootstrap diode emulator means comprising a LDMOS transistor having a source electrode coupled to said power supply output, a drain electrode adapted to be coupled to the second end of the bootstrap capacitor, a gate electrode coupled to the lower drive module via load control circuitry said LDMOS transistor to a conducting state when the lower power transistor is driven to a conducting state, and a backgate electrode, there being a parasitic transistor connected to said backgate electrode (and said drain electrode), wherein biasing and limiting means are coupled to the backgate electrode (and the drain electrode) for biasing the backgate electrode while limiting the current that said parasitic device can shunt away from said bootstrap capacitor.

20 A driver circuit as claimed in Claim 1, wherein said biasing and limiting means comprises a clamping transistor and a current source connected to said backgate electrode.

3. A driver circuit as claimed in Claim 2, wherein said current source

comprises a current mirror.

4. A driver circuit as claimed in claim 1, 2 or 3, said load control circuitry comprising a buffer for producing a buffer output signal having a voltage range between said lower rail and said control voltage, and means for translating the voltage range of said buffer
- 5 output signal to a range of voltage difference between a point coupled to said gate electrode and said high source electrode.
5. A driver circuit as claimed in claim 4, wherein said means for translating comprise capacitive means.
6. A driver circuit as claimed one or more of the previous claims, wherein
- 10 said load control circuitry further comprises means for clamping said gate electrode to said source electrode of said LDMOS transistor in response to displacement current flowing in a Miller capacitance of said LDMOS transistor coupled between the drain and gate electrodes.
7. A driver circuit as claimed in claim 6, wherein said means for clamping said gate electrode to said source electrode comprises a (PNP) transistor.
- 15 8. A driver circuit as claimed in one or more of the previous claims wherein capacitive means are coupled between the backgate electrode and and the source electrode of said LDMOS transistor.
9. A driver circuit as claimed in one or more of the previous claims, said driver circuit being integrated in a single chip.
- 20 10. Ballast circuit for operating a lamp comprising a bridge circuit and a driver circuit according to one or more of the previous claims.

