A new high voltage half bridge driver IC concept for consumer electronics and home appliances

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Abstract

Consumer electronic applications, computing and home appliances strive continuously for higher efficiency of applications and smaller form factors. A new family of half bridge gate drive IC is described, which supports this. Additionally, an integrated bootstrap function is presented for the first time in the market for driver IC with more than 2A output current. The high voltage gate drive IC family contains two current classes with output currents of 0.5A and 2.3A. This paper will point out the operation range and properties of the bootstrap function in terms of dependency on temperature and IC supply.

1. Introduction

Only a few half bridge driver IC ([1], [2]) offer so far integrated bootstrap function for the high side supply. The reasons are a rather high voltage drop at low duty cycles and the additional high power dissipation in the IC at high switching frequencies. These devices are therefore limited to applications, such as consumer drives. These kind of driver IC are covering the market of 600 V blocking voltage, which is the low power drives market. Other half bridge driver IC, which do not have an integrated bootstrap diode, such as [3], [4] are covering the low end switch mode power supply (SMPS) applications. Since there is no bootstrap function integrated into the IC, these products have a slightly better temperature budget due to less power dissipation.

However, the advantages of a powerful integrated bootstrap function are striking: simpler layout, less PCB space and better component placement in respect of distance to the gate terminal of the power transistor. This keeps also the EMI low and optimizes the switching performance, hence the switching losses. This paper proposes a new concept of a half bridge gate drive IC, which fully supports the design considerations of consumer electronic equipment and home appliance drive systems.

The new half bridge driver IC is designed to support all mega trends in low power drives designs, such as ease of use, short bill of materials at simultaneously high number of features.

2. Technology

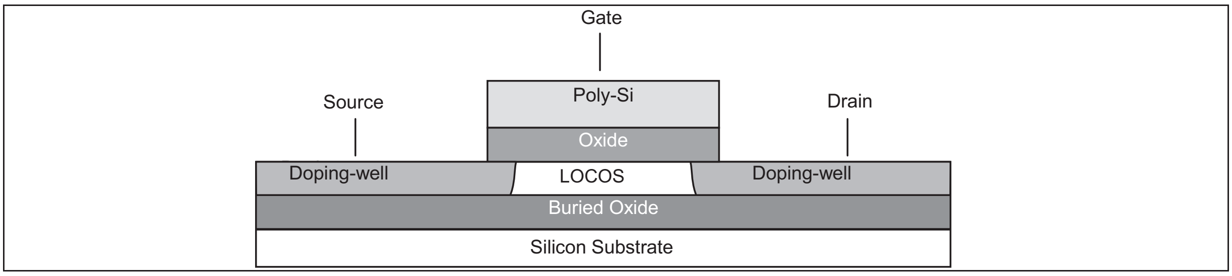

Fig. 1. Silicon-On-Insulator transistor

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The Thin-Film-SOI (Silicon-On-Insulator) technology is an advanced technique for MOS/CMOS fabrications. Based on conventional bulk process the SOI technology uses an insulator called buried oxide underneath the active device layer, as shown in Fig. 1.

The lateral insulation of elements inside the silicon film is achieved by a simple local oxidation (LOCOS) process. In this way all active device regions are fully insulated from each other. Thus, there is no need for CMOS-wells for preventing the “latch-up” effect. Additionally the leakage current and junction capacitances are reduced significantly. The small size of PN-junctions inside the thin silicon film leads also to higher switching speed.

Table 1: Devices and characteristics of the thin-film-SOI process

Element	**Characteristics**
CMOS analogue transistors	30 V / 12 V / 5 V
CMOS digital transistors	5 V
SOI-PIN-diode	30 V
Z-diodes	5.2 V
Resistors	18.5 Ω/square – 7.5 kΩ /square
Capacitor	0.84 fF/µm²
HV bootstrap SOI-diode	600 V, -50 V
High-voltage SOI-transistor	600 V (N-Channel)

Different devices inside the individual silicon regions can be implemented as shown in Table 1. The presented technology contains 600 V devices like level-shift transistor and high-voltage bootstrap diode, which are also realized in the thin silicon film. The 600V voltage ability is achieved by special junction termination structures, which allow monolithic realization of circuits like half or full bridge drivers for 600V applications.

3. Device family

The proposed new concept covers the full range of peak output currents from 0.5 A to 2.3 A. The 0.5 A category is available in SO8 package and SO14 package, while the 2.3 A category in only available in SO14. All products in SO8 package concentrate on providing a floating high side section with a limited functional set and feature set.

A suitable part for SMPS is the 2EDL05I06BF, which does not have a dead time and interlock function, so that both the high side output and the low side output can be activated simultaneously.

Table 2: Individual function set realized in new concept

part number	Ipk	Asym. UVLO	BS diode	UVLO for	EN	/FLT	PGND	OCP	DT	Pack.
2EDL05I06PF	0.5 A	✓	Yes	IGBT	-	-	-	-	✓	DSO8
2EDL05I06PJ	0.5 A	✓	Yes	IGBT	-	-	-	-	✓	DSO14
2EDL05I06BF	0.5 A	✓	Yes	IGBT	-	-	-	-	-	DSO8
2EDL05N06PF	0.5 A	-	Yes	MOSFET	-	-	-	-	✓	DSO8
2EDL23I06PJ	2.3 A	✓	Yes	IGBT	✓	✓	✓	✓	✓	DSO14
2EDL23N06PJ	2.3 A	-	Yes	MOSFET	✓	✓	✓	✓	✓	DSO14

A full set of protection functions and features, such as an enable function, a failure indication, separate return path for the gate current (power ground) incl. an overcurrent protection (OCP), is realised in the 2 parts with high output current of 2.3 A. Therefore, all applications with higher integration and safety requirements can be addressed.

4. Bootstrap diode

There are several components in the market, which provide a bootstrap function ([1], [2]). So far, this is only realized by integrated high voltage MOSFET structures according to the left part in 0. The MOSFET structures are turned on and off in phase with the LS transistor. This is a crucial point, because the driver IC is neither aware of the delay times of the power transistors nor of the power factor of the motor. Thus, the control of the bootstrap FET must consider this by additional bootstrap delays. These delays reduce the available time for bootstrapping, so that the bootstrap voltage is further reduced.

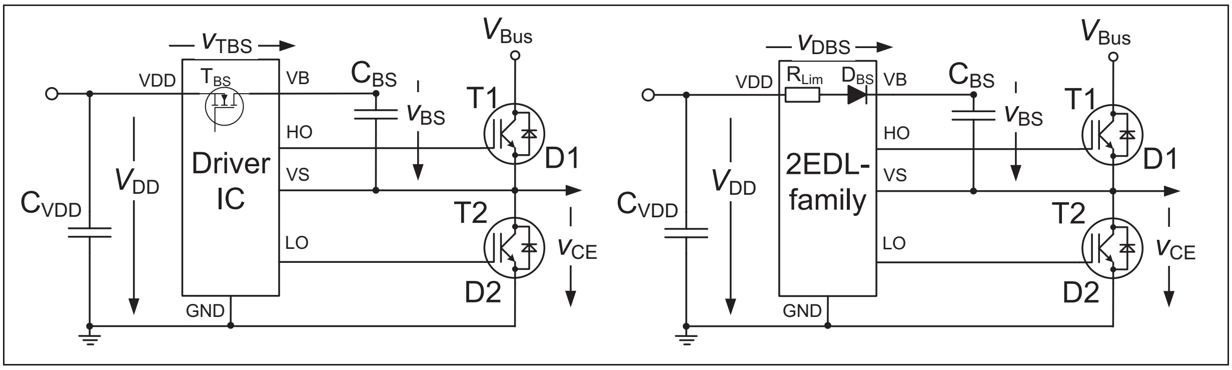

Fig. 2. Bootstrap circuit of a half bridge

Another negative aspect of MOSFET used for bootstrapping is the temperature dependency of MOSFET over temperature. Usually, MOSFET double their $R_{DS(on)}$ – value when the junction temperature increases by 100 °C. This means, that the above mentioned situation gets worse even more. The higher $R_{DS(on)}$ causes also more power dissipation inside the driver IC as well and limits the thermal safe operation area in respect to switching frequency and gate charge. It can be seen in Fig. 3, that the bootstrap diode is superior to existing bootstrap functions as soon as the diode forward characteristic is above the MOSFET characteristic. This is the case for a forward current of approx. 5 mA – 10 mA under elevated temperature.

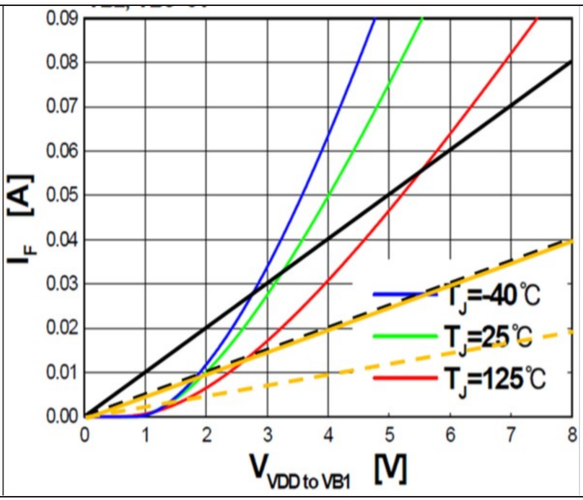

Fig. 3. Bootstrap diode forward characteristic compared to MOSFET with $R_{ds(on)} = 100\ \Omega$ (black $T_j = 25°C$, dashed: $T_j = 125°C$) and $R_{ds(on)} = 200\ \Omega$ (orange, $T_j = 25°C$, dashed: $T_j = 125°C$)

The effects of the output characteristics are visible in a diagram, which shows the nominal voltage reduction of the bootstrap capacitor voltage in respect to the supply voltage versus the duty cycle. As an example, a single half bridge configuration is used as a representative of a SMPS topology. A small duty cycle of the low side transistor or diode leads to an uncompleted recharging of the bootstrap capacitor C_{BS} according to 0. As a consequence, the bootstrap voltage decreases until a new steady state operation is reached in respect to the supply voltage of the driver IC. Fig. 4 shows the diagram for operating conditions of switching frequency f_p = 20 kHz and a bootstrap capacitor of C_{BS} = 22 µF.

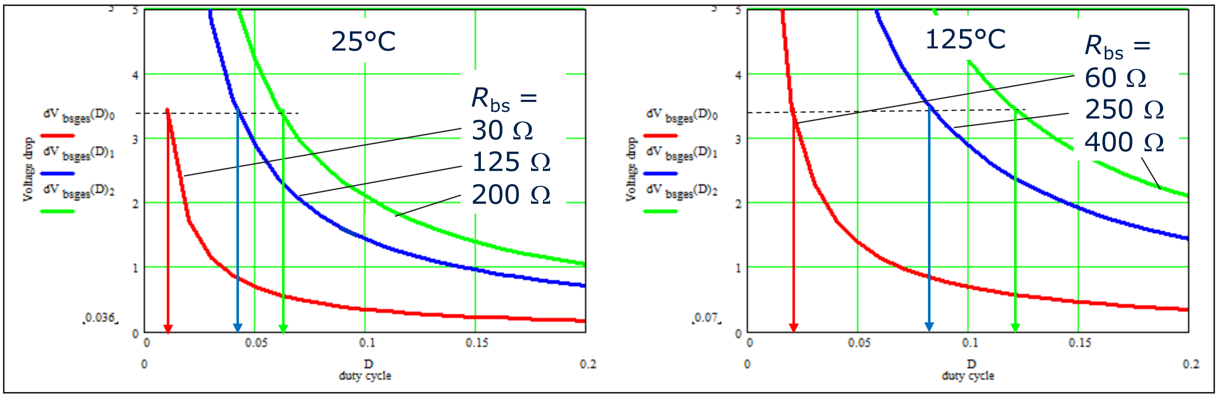

Fig. 4. Calculation of steady state bootstrap capacitor voltage drop vs. duty cycle for a buck converter

The left part in Fig. 4 shows the conditions at a junction temperature of T_j = 25°C and the right part shows the same parameter at T_j = 125°C. The proposed driver IC concept realizes a bootstrap resistance of R_{BS} = 30 Ω at a junction temperature of T_j = 25°C, while other concepts have R_{BS} = 125 Ω or R_{BS} = 200 Ω. It is assumed for reasons of simplicity, that also the bipolar drift region resistance of a pn-diode doubles its resistance every 100°C. Please note, that the size of the bootstrap capacitor is not influencing the diagrams of Fig. 4. It only influences the transition phase from one bias point to another.

The influence of the low resistance of the new driver IC is significant. It is easy to see, that the new driver IC concept is much more stable against high junction temperatures. The usable duty cycle range can go down to 1% with the new driver concept, without coming into an undervoltage lockout area. Other driver IC cannot serve duty cycle ranges below 4% (R_{bs} = 125 Ω) or 7% (R_{bs} = 200Ω). It means, that many applications, which requires operating at low duty cycles cannot use these IC. This is the case e.g. for SMPS operating is hard switching under high load condition or drive systems, which operate with high torque at low speed in field oriented control. In these examples the control is either in steady state or quasi steady state operating in the critical duty cycle range.

5. Asymmetric undervoltage lockout

The new driver IC come along with dedicated designs for operation with IGBT. Well known market relevant driver IC only support MOSFET transistors in respect with the undervoltage lockout (UVLO) function. Gate threshold voltage of MOSFET (approx. 3 V, [5]) compared with IGBT (approx. 4.6 V – 5 V, [6]) allows to operate MOSFET with much lower gate voltages. This is represented as well in the UVLO levels of driver IC. On the other hand, it is dangerous to operate IGBT with driver IC, which provide MOSFET UVLO levels, because the MOSFET UVLO levels are so low, that the IGBT partially or fully desaturates. This effect causes highly increased losses and temporary operation in this mode can cause severe damage at the IGBT. It is therefore essential to operate IGBT only with driver IC, which provide suitable UVLO levels for IGBT.

An important aspect of the design of undervoltage lockout (UVLO) levels is the support of integrated bootstrap diodes. They have a relatively high forward voltage drop which contributes to the bootstrap voltage reduction compared to the supply voltage VDD of the IC according to Fig. 4. The static bootstrap voltage v_{BS} is in total

$$v_{\mathrm{BS}} = V_{\mathrm{DD}} - v_{\mathrm{DBS}} - v_{\mathrm{CE}} \tag{1}$$

where v_{CE} is the transistor voltage of the low side transistor in a half bridge configuration. Please note that this converts into the diode forward voltage, when operating the low side diode.

It is easy to see, that the highside output HO generates a smaller voltage, because the voltage v_{BS} at the IC terminals VB and VS is reduced by the values v_{DBS} and v_{CE}. However, it is favourable to activate the UVLO for the high side supply V_{BS} at a similar point of time as the low side supply VDD in order to prevent a insufficient supply of the high side gate. Therefore the low side UVLO is activated at approx. 1V higher levels as the high side UVLO function. It also allows shifting the shut down levels V_{CCUV-} of the low side towards a little higher values. This can be achieved by implementing an asymmetric UVLO by considering different threshold for high side and low side as shown in Table 3.

Table 3: Asymmetric high side and low side UVLO levels

Parameter	Min. [V]	Typ. [V]	Max. [V]
V_{CCUV+}	11.8	12.5	13.2
V_{BSUV+}	10.9	11.6	12.4
V_{CCUV-}	10.9	11.6	12.4
V_{BSUV-}	10	10.7	11

6. Other helpful features

6.1. UVLO filter

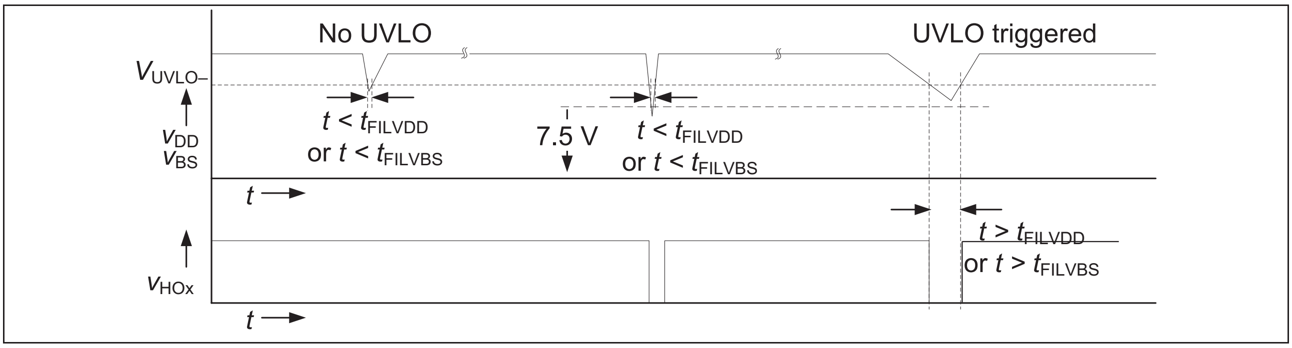

Fig. 5. Calculation of steady state bootstrap capacitor voltage drop vs. duty cycle for a buck converter

It is often very difficult for design engineers to realise a good trade-off with system boundaries, such as geometry and component placement in order to achieve the best performance. An important item is the placement of the blocking capacitors for the supply voltages V_{DD} and V_{BS}. The above mentioned restrictions lead often to some distance between the IC and the blocking capacitor. This can cause inductive voltage drops at the pin VDD or VB during the turn-on transient with the consequence of undesired UVLO events according to Fig. 5.

Therefore, a filter is suppressing such short time voltage drops and makes the IC more robust against noise on the supply lines. This is shown as an example in the very left side of Fig. 5. The filter time is approximately 1.5 µs, which is enough to filter all regular transients in respect with switching transients. However, the IC will control an UVLO and therefore the turn-off of the correlated outputs, if the voltage drop is lower than 7.5 V, which is given in the middle of Fig. 5. The IC will also shut down its outputs, if the voltage drop is longer than the filter time.

6.2. Active shut down

The active shut down function is activated as soon as the supply voltage either on VDD or VBS reaches 3 V – 4 V. Leakage currents which may flow via the gate-collector path can potentially turn-on the device. The proposed concept clamps any leakage current of IGBT gate or MOSFET gate to the supply pin. The sink transistor inside the driver IC is activated, when the supply voltage exceeds approx. 3 V. The sink transistor is operated in its linear region and will clamp the gate. Small leakage currents in the range of µA can be clamped very efficiently as shown in 0. As a consequence, gate-emitter resistors can be omitted.

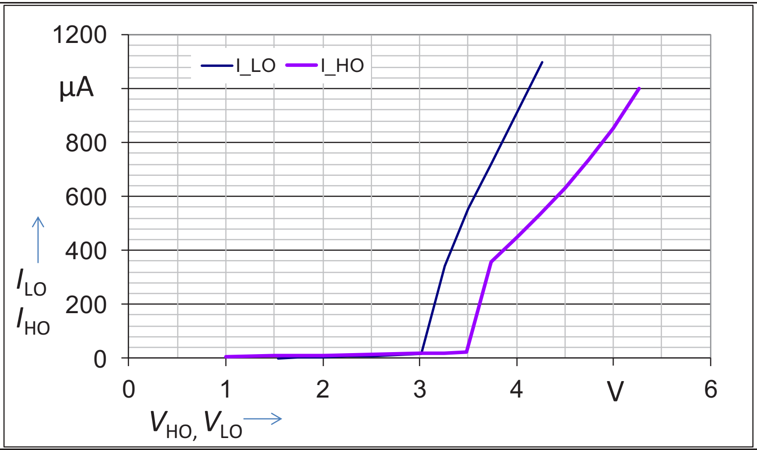

Fig. 6. Calculation of steady state bootstrap capacitor voltage drop vs. duty cycle for a buck converter

7. Conclusion

A new driver IC concept for half bridge configurations is proposed in this paper for home appliances and consumer electronics. It is optimised for the two mostly used transistor technologies, IGBT and MOSFET. The integrated bootstrap diode has a very low ohmic series resistance and hence enables the widest operating range in respect with controlled duty cycles. The bootstrap diode dissipates only little power inside the IC. This makes this IC to a benchmark in the market. Further functions, such as the asymmetric undervoltage lockout or the active shut down support especially IGBT help to match restrictions in terms of component placement and performance.

8. Literature

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