AN52
IGBT gate drive considerations in electronic lamp ballasts

Yong Ang, Applications Engineer, Zetex Semiconductors

The use of Zetex high speed non-inverting gate drivers for IGBT half-bridge electronics ballasts

Introduction

The purpose of this note is to demonstrate the design of fast switching IGBT's gate drive for electronic ballast using bipolar transistors. The charge necessary to fully enhance an IGBT is a function of its Gate-Source and Drain-Gate (Miller) capacitances and is delivered via an external gate resistor. The gate charge and input capacitance value for an IGBT is lower compared with a MOSFET of similar current rating because of better silicon utilization. IGBTs require a driver stage to obtain the best performance particularly, when driven from low-voltage, low-current sources.

The gate drive requirement is met by the complimentary emitter-follower circuit. This should be constructed with transistors possessing a high pulse current capability, high transition frequency f_T and ideally significant gain at high collector current. A general gate drive solution is suggested below. This includes provision for minimizing the possibility of Miller-gate charge induced turn-on by methods of negative bias, non-critical turn-on, turn-off and active pull down. This can generate a design capable of sourcing up to 2.2A from a 10mA input current, when used with Zetex high speed non-inverting single IGBT gate driver ZXGD3002E6. Since the gate driver only has to carry current during the switching transition, the power dissipation is low enough that it could be tolerated in the low profile SOT23-6 package.

Gate drive considerations

In typical medium power electronic lamp ballast, a half bridge resonant inverter shown in Figure 1 is used to facilitate the ignition and to sustain the nominal running AC voltage across the lamp from a 400V intermediate rail. An IGBT could replace a MOSFET as the primary switching devices operated at sub-50kHz frequency. The power dissipated by the semiconductor devices at current level above 2A will be dominated by the on-state conduction loss. IGBTs have the advantage of having lower dependency of their on-state resistance on the junction temperature. The MOSFET on-state resistance typically increases by 2.5 times going from 25°C to 150°C junction temperature, leading to a dramatic increase in power losses under normal operation due to the elevated temperature. The static/low frequency power losses of an IGBT can be much lower incomparison with a MOSFET. However, the switching loss on the IGBT is significant due to its turn-off current tail; the MOSFET will have negligible switching loss due to Zero Voltage Switching .

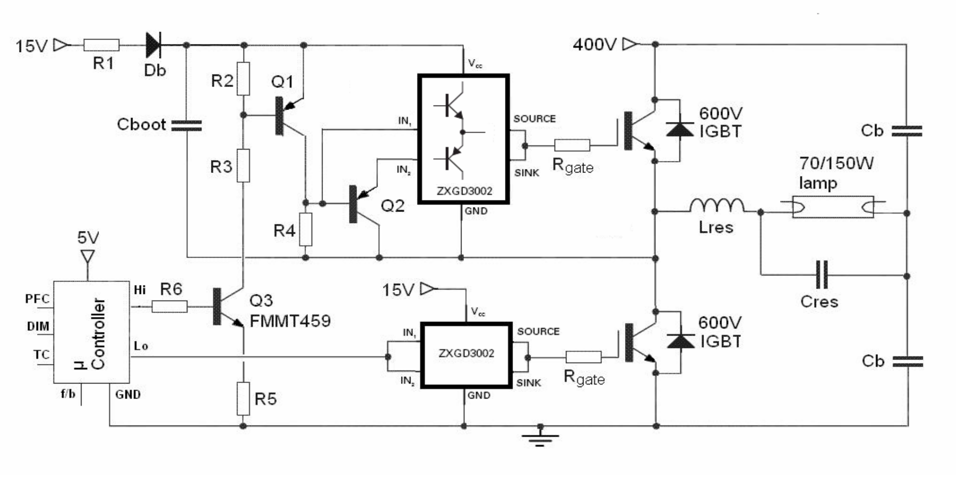

Figure 1 High current non-inverting gate drive for IGBT in medium power ballast

General requirements for a half bridge IGBT gate driver include;

1. A high side gate driver for the floating N-channel IGBT
2. Symmetrical switching of low and high side devices
3. Avoidance of cross conduction
4. Control over switch-on and switch-off time of the IGBT
5. Control of the high charge/discharge current capability

The amount of gate charge is proportional to the continuous current rating of the IGBT and the required gate current. Zetex's ZXGD3002E6 gate driver has good high frequency response and is able to provide gate current of up to 2.2A. With typical propagation delay time down to 2ns and rise/fall down to 11ns for a 1000pF load, it ensures rapid switching to minimize distortion and power losses in the power IGBT. For the implementation of a cost effective ballast solution, a discrete solution with level-shifting using appropriately chosen gate driver, transistors and passive components is shown in Figure 1 albeit requiring a larger board area.

Figure 1 Circuit operation

A logic high level at the output of controller IC turns level shifting transistor Q3 to drive Q1 on. This, in turn delivers the gate charge current to the high side IGBT through the push-pull transistor ZXGD3002 and gate resistor. Gate turn-off is initiated by floating Q2, which is driven on once Q1 turns off through R4. During the IGBT conduction state, the collector current of transistor Q3 is determined by R5. By making sure that Q3 does not saturate, the switching transition time of the IGBT can be kept relatively low for low loss. Also, maximum Q3 current must be less than 150mA to stay within the device power dissipation limit.

To decrease turn-on time, R2 can be reduced in value to discharge the base of Q1 and turn it off quicker. A smaller R2 does not appreciably increase power dissipation when Q1 is on. Similarly, by decreasing R4 value, larger Q2 base current flows during turn-off which causes a higher IGBT gate current to discharge through ZXGD3002, thus turning it off quicker. Although a smaller value of R2 increases the amount of on-time drive current from Q1, as this current is a lot less than the gate charging current, R2 can be made relatively small without adverse effect.

Inherently, an IGBT does not require a negative gate bias on the gate to ensure proper operation, unless the gate voltage could not always be held safely under the threshold level due to noise. Assuming that the high side IGBT in Figure 1 is off and the low side IGBT turns on, its anti-parallel diode reverse-recovers and the Collector-Emitter's voltage increases rapidly. The amount of voltage overshoot depends on the rate of fall of the Collector current as well as the diode transient response. The high diode dv/dt is also seen across the Collector-Emitter terminals of the high side IGBT, which effectively delivers charge to the Collector-Gate (Miller) capacitance of the device. This induces a gate current flow to raise the gate voltage. The magnitude of the induced current is dependent upon, the size of the Miller capacitance, the value of dv/dt, as well as the value of both external and internal gate resistance. If there is a large resistance connected to the device's gate, this could lead to the gate voltage exceeding the threshold voltage momentarily, thus turning on the high side IGBT. The problem of induced current 'shoot-through' becomes apparent at elevated temperature considering that the Gate-Emitter threshold voltage $V_{GE(th)}$ has a temperature coefficient of -4mV to -6mV/°C.

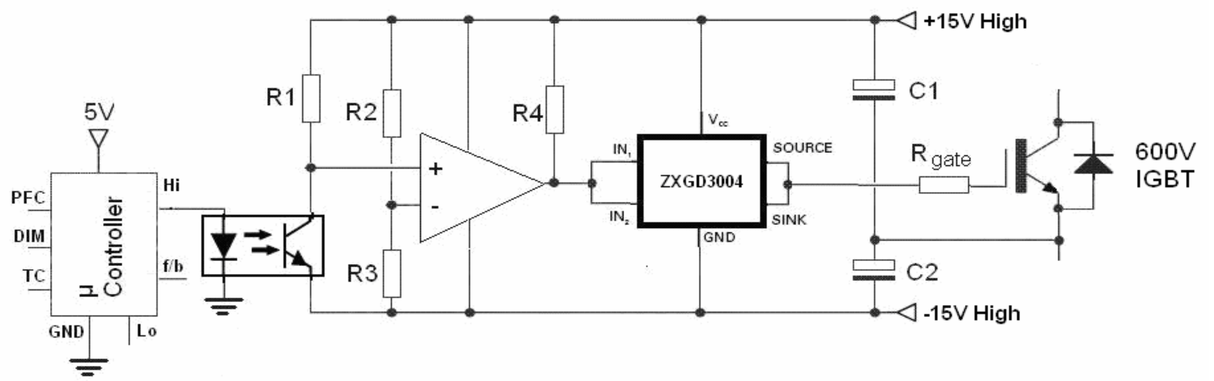

Figure 2   Possible IGBT gate drive with negative gate bias

Other Circuit Considerations

The general practice is to provide a negative gate bias of -15V as shown in Figure 2. This ensures adequate turn-off for the application and to negate the effect of Miller induced current in a bridge configuration if a high dv/dt is applied to the devices. This circuit uses a transformer to provide isolation for the gate drive power supply, and opto-couplers to give signal isolation. The IGBT's Gate-Emitter voltage now swings from -15V to 15V during the switching transition. This can be satisfied by ZXGD3004E6 which has a 40V V_{CC} breakdown voltage rating. The gate drive circuit for the low side IGBT can be constructed similarly, apart from the fact that it is referenced to it's emitter and therefore to a common ground with the control IC. Although initial turn-off may be sped up, it must be noted that the tail-current section of the IGBT turn off waveform is associated with the internal BJT and cannot be controlled externally using the negative supply voltage.

Implementing the negative bias adds to gate drive complexity. It is difficult to use a high voltage IC driver because they are designed to operate at ground reference - the same as the control circuitry. In Figure 3(a), a capacitor is inserted between the Gate and Emitter terminals to take up additional charge originating from the Miller capacitance. Since the total input capacitance of the IGBT equals the sum of Miller capacitance and Gate-Emitter capacitance, the required gate charge to turn on the device is increased. The switching behavior during normal turn-on switching transition is affected, demanding higher driver power and the IGBT exhibits higher switching losses.

Another measure to prevent parasitic turn-on through employing separate gate resistors is shown in Figure 3(b) where $R_{toff} < R_{ton}$. A lower resistance on the turn-off path facilitates prevention of capacitive turn-on via Miller capacitance, albeit higher voltage over-shoot on the collector terminal and stray inductance associated oscillation during turn-off. Consequently, design optimization between lower parasitic Miller voltage, switching losses, over-shoot voltage and voltage oscillation of both on and off gate resistors has to be made. Furthermore, as the dv/dt increases at high frequency an impractical gate resistance could be required to ensure that the device remains off.

Alternatively, Figure 3(c) shows an active Miller clamp set up that could be effective to minimize possibility of the IGBT gate voltage rising above the threshold, thereby enabling it to be used with a simple, low-cost uni-polar gate drive circuit. This can be achieved by using a Zetex transistor with high pulse current capability as an active pull down transistor between Gate and Emitter. This measure shorts the Gate-Emitter region after a time delay, as long as the driver shows a 0V signal at its output. The design gives enhanced reliability in several areas. The high pulse currents through the Miller capacitance are now shunted by the transistor instead of flowing through the output driver pin. This guarantees safe switching. The low power loss of the ZXTP25020DFL transistor also minimizes temperature rise in the gate drive - important in terms of reliability.

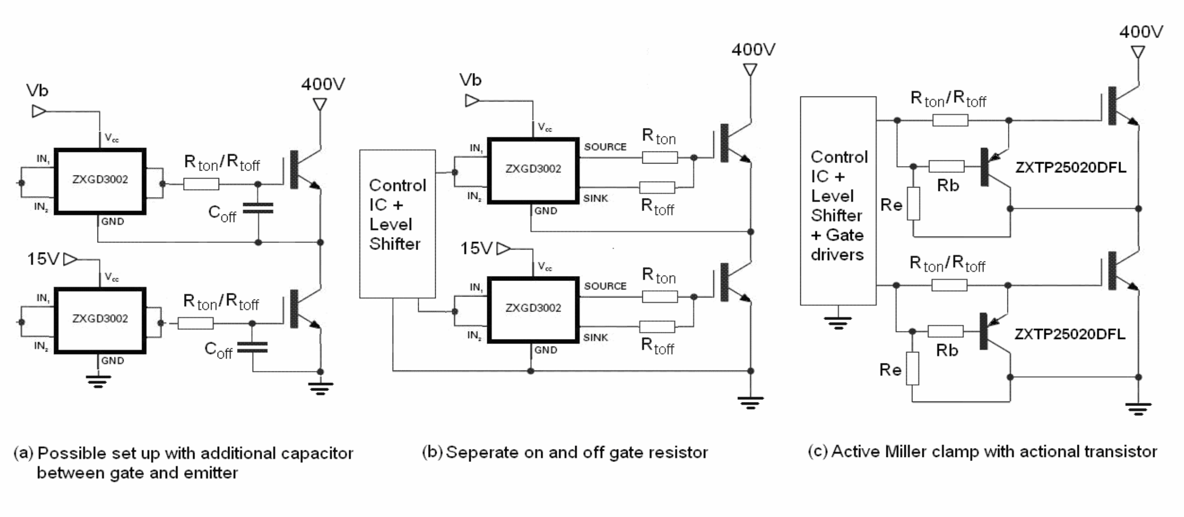

Figure 3 Gate drive configurations to avoid IGBT 'induced turn-on' in half bridge circuit

With these power losses it is clear that bipolar transistors packaged in small surface mount packages are suitable, preferably co-packaged as complimentary dual devices. Table 1 presents some of the gate drivers and the transistors available from Zetex which are suitable for the gate drive application. More details of Zetex high speed non inverting single MOSFET gate drivers available at www.zetex.com

Gate drivers							
Device	**Package**	**V_{cc} (V)**	**$I_{SINK(PK)}$ (A)**	**I_{SOURCE} (A)**	**I_{SINK} (A)**	**Prop. delay times (ns)**	**Switching Time (ns)**
				@I_{IN} = 10mA			
ZXGD3001E6	SOT23-6	12	9	4.2	2.2	<3	<11
ZXGD3002E6	SOT23-6	20	9	2.2	2.0	<1.6	<10.8
ZXGD3003E6	SOT23-6	40	5	1.6	1.4	<1.8	<8.9
ZXGD3004E6	SOT23-6	40	8	1.9	1.9	<1.1	<13.4

Single transistors					
Device	**Type**	**Package**	**BV_{CEO} (V)**	**I_{CM} (A)**	**$h_{FE\ (min)}$**
ZXTN07012EFF	NPN	SOT23F	12	10	500
ZXTP07012EFF	PNP	SOT23F	12	8	500
ZXTP23015CFH	PNP	SOT23	15	10	250
ZXTN19020DFF	NPN	SOT23F	20	20	300
ZXTP19020CFF	PNP	SOT23F	20	10	250
ZXTN25020DFL	NPN	SOT23	20	8	300
ZXTP25020DFL	PNP	SOT23	20	6	300
ZXTN07045EFF	NPN	SOT23F	45	6	500
ZXTP07040DFF	PNP	SOT23F	40	6	300
ZXTN25040DFL	NPN	SOT23	40	6	300
ZXTP25040DFL	PNP	SOT23	40	5	300
ZXTN2040F	NPN	SOT23	40	2	300
ZXTP2041F	PNP	SOT23	40	2	300
ZXTN19060CFF	NPN	SOT23F	60	12	250
ZXTN2038F	NPN	SOT23	60	2	100

Conclusion

The application note has described the implementation of an IGBT gate drive using a bipolar transistor for driving a half bridge resonant inverter used in a medium power electronic ballast application. For such an application, Zetex transistors are perfectly suitable as they show fast switching in linear mode, high pulse current capability, high current density, and a small footprint.

If necessary, the gate drive circuit can be adapted to ease the effect of Miller capacitance induced turn on. Other possible variants will drive higher power electronic ballasts, with good efficiency giving high power density, reducing heat dissipation and improving reliability.

Definitions

Product change

Zetex Semiconductors reserves the right to alter, without notice, specifications, design, price or conditions of supply of any product or service. Customers are solely responsible for obtaining the latest relevant information before placing orders.

Applications disclaimer

The circuits in this design/application note are offered as design ideas. It is the responsibility of the user to ensure that the circuit is fit for the user's application and meets with the user's requirements. No representation or warranty is given and no liability whatsoever is assumed by Zetex with respect to the accuracy or use of such information, or infringement of patents or other intellectual property rights arising from such use or otherwise. Zetex does not assume any legal responsibility or will not be held legally liable (whether in contract, tort (including negligence), breach of statutory duty, restriction or otherwise) for any damages, loss of profit, business, contract, opportunity or consequential loss in the use of these circuit applications, under any circumstances.

Life support

Zetex products are specifically not authorized for use as critical components in life support devices or systems without the express written approval of the Chief Executive Officer of Zetex Semiconductors plc. As used herein:

A. Life support devices or systems are devices or systems which:
   1. are intended to implant into the body

or

   2. support or sustain life and whose failure to perform when properly used in accordance with instructions for use provided in the labelling can be reasonably expected to result in significant injury to the user.

B. A critical component is any component in a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or to affect its safety or effectiveness.

Reproduction

The product specifications contained in this publication are issued to provide outline information only which (unless agreed by the company in writing) may not be used, applied or reproduced for any purpose or form part of any order or contract or be regarded as a representation relating to the products or services concerned.

Terms and Conditions

All products are sold subjects to Zetex' terms and conditions of sale, and this disclaimer (save in the event of a conflict between the two when the terms of the contract shall prevail) according to region, supplied at the time of order acknowledgement.

For the latest information on technology, delivery terms and conditions and prices, please contact your nearest Zetex sales office .

Quality of product

Zetex is an ISO 9001 and TS16949 certified semiconductor manufacturer.

To ensure quality of service and products we strongly advise the purchase of parts directly from Zetex Semiconductors or one of our regionally authorized distributors. For a complete listing of authorized distributors please visit: **www.zetex.com/salesnetwork**

Zetex Semiconductors does not warrant or accept any liability whatsoever in respect of any parts purchased through unauthorized sales channels.

ESD (Electrostatic discharge)

Semiconductor devices are susceptible to damage by ESD. Suitable precautions should be taken when handling and transporting devices. The possible damage to devices depends on the circumstances of the handling and transporting, and the nature of the device. The extent of damage can vary from immediate functional or parametric malfunction to degradation of function or performance in use over time. Devices suspected of being affected should be replaced.

Green compliance

Zetex Semiconductors is committed to environmental excellence in all aspects of its operations which includes meeting or exceeding regulatory requirements with respect to the use of hazardous substances. Numerous successful programs have been implemented to reduce the use of hazardous substances and/or emissions.

All Zetex components are compliant with the RoHS directive, and through this it is supporting its customers in their compliance with WEEE and ELV directives.

Product status key:

"Preview"	Future device intended for production at some point. Samples may be available
"Active"	Product status recommended for new designs
"Last time buy (LTB)"	Device will be discontinued and last time buy period and delivery is in effect
"Not recommended for new designs"	Device is still in production to support existing designs and production
"Obsolete"	Production has been discontinued

Datasheet status key:

"Draft version"	This term denotes a very early datasheet version and contains highly provisional information, which may change in any manner without notice.
"Provisional version"	This term denotes a pre-release datasheet. It provides a clear indication of anticipated performance. However, changes to the test conditions and specifications may occur, at any time and without notice.
"Issue"	This term denotes an issued datasheet containing finalized specifications. However, changes to specifications may occur, at any time and without notice.

Zetex sales offices

Europe	Americas	Asia Pacific	Corporate Headquarters
Zetex GmbH Kustermann-park Balanstraße 59 D-81541 München Germany	Zetex Inc 700 Veterans Memorial Highway Hauppauge, NY 11788 USA	Zetex (Asia Ltd) 3701-04 Metroplaza Tower 1 Hing Fong Road, Kwai Fong Hong Kong	Zetex Semiconductors plc Zetex Technology Park, Chadderton Oldham, OL9 9LL United Kingdom
Telefon: (49) 89 45 49 49 0 Fax: (49) 89 45 49 49 49 europe.sales@zetex.com	Telephone: (1) 631 360 2222 Fax: (1) 631 360 8222 usa.sales@zetex.com	Telephone: (852) 26100 611 Fax: (852) 24250 494 asia.sales@zetex.com	Telephone: (44) 161 622 4444 Fax: (44) 161 622 4446 hq@zetex.com