EMITTER DRIVE: A TECHNIQUE TO DRIVE A BIPOLAR POWER TRANSISTOR SWITCHING AT 100kHz

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Abstract

Theoretical support and experimental results concerning the application of a emitter driven bipolar power transistor to a 400V, 10A power switch are presented. The central idea of the emitter drive is to turn off and on the bipolar transistor controlling the flow of the emitter current, using another switch. This switch was implemented with a low voltage power mosfet. In this way it is possible to achieve a power switch with fairly high voltage rating, without excessive forward voltage drop (not achievable using power mosfets), and greater speed than by means of a bipolar transistor using the traditional base drive.

Fundamental characteristics of the emitter drive configuration

The basic configuration is shown in figure 1. The mosfet commands the switch. When the mosfet is on, the bipolar transistor is also on because the VB power supply delivers base current; when the mosfet is turned off the bipolar transistor turns off due to the interruption of the emitter current.
This technique was initially employed using pairs of bipolar transistors. The present availability of power mosfets has given to this method new impetus [1], [2] and [3].

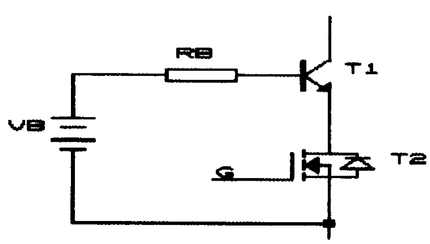

Fig. 1: Basic configuration.

Voltage and current ratings of the mosfet

The voltage rating of the mosfet is given by the base voltage of the bipolar transistor (shown as VB in the simplified circuit of figure 1). This fact was experimentally verified and is also supported by numerical simulations made using Ebers and Moll model for the transistor and modelling the cut off mosfet as a resistor. The value of this resistor was estimated as the quotient of the mosfet voltage rating and its leakage current. This point allows the use of very low voltage mosfets, with the consequent advantages concerning availability and price. The current rating is fixed by the maximum current of the switch. It should be noted that in this configuration we cannot take advantage of the mosfet important capability of handling surge current, because the series bipolar transistor does not present this characteristic.

Voltage and current ratings of the bipolar transistor

A common problem occurring in bipolar transistors is the current focusing under the emitter at turn off [2],[3] and [4]. As a consequence a high current density takes place at the emitter center which may cause damage to the transistor. The cause of this high current density is the unequal reverse bias of the B - E junction due to the distributed base resistance.
In the emitter drive configuration the charges stored in the collector zone are evacuated through the base in no more than some tens of ns during the mosfet turn off, when the emitter current is interrupted. Although the reverse base current is rather high, the current focusing under the emitter does not take place.
For this reason the bipolar transistor shows an improved turn off RBSOA in comparison with the resulting using a base drive. References [2] and [3] agree that this improvement gets to the point of making the RBSOA almost rectangular.
The emitter drive blocking voltage capability is also increased to the Vcbo rating (greater than Vceosus), for the reason that in the off state the emitter is "open" and the applied voltage must be supported by the B-C junction without entering the breakdown zone.
The current rating is the same that in the mosfet case.

Switching characteristics

The transistor storage time is greatly reduced because the load current flow through the B-C junction at turn off, causes a fast elimination of the stored charge.
The fall time reduction it is not so remarkable [1],[2] and [3].
The reduction of the storage time is the reason for reaching switching speed greater than that of a bipolar transistor with traditional base drive.

Drive of the switch

The switch state is controlled by means of the mosfet gate with the associated

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advantages of a very simple drive circuit. The input impedance seen from the drive circuit is the mosfet input capacitance, and the required current is just the necessary for charging this capacitance. This capacitance is also smaller than in another configurations because the Miller effect is reduced due to the low voltage applied to the mosfet. The Miller effect is the well known fact that the mosfet input capacitance is not only the Cgs capacitance because the necessary current to discharge the drain - gate capacitance must be provided. This effect is proportional to the voltage to be switched.

Switch design

The implemented switch is intended to be used in the construction of several configurations in a power electronics laboratory, basically as a didactic tool.
For this reason it was designed having in mind the following goals:
* Modularity
* Versatility
* Overcurrent and overvoltage selfprotection

Figure 2 shows the block diagram of the switch.

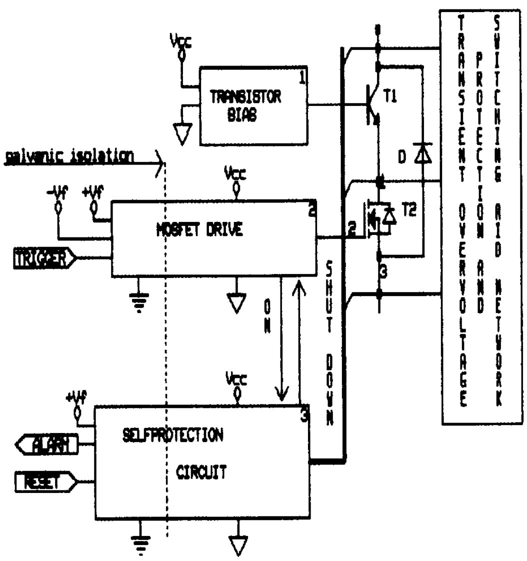

Fig. 2: Block diagram of the switch

In this figure it can be seen the power mosfet (MTH30N12, 30A, 120V), the bipolar transistor (2N6678, 15A, 400V), the reverse fast recovery rectifier of the switch (TG86, 8A, 600V, 100ns) and another four blocks which description follows.
The entire switch size is 185 x 95 mm, including all the four blocks of figure 2 and the power devices in one board.

Transistor bias

The biasing circuit used for the transistor is shown in figure 3. This configuration makes the IB value not dependent on the variations of the mosfet forward voltage drop, as a consequence of supplying the base current from a current source, without requiring an excessively high VCC value which leads to an extra power consumption in the drive. For this reason was used VCC = 5V.

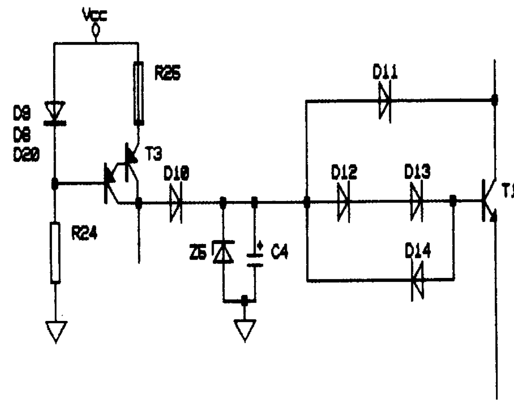

Fig. 3: Bias circuit of the bipolar transistor.

The functions of C4 are to sink the reverse base current during turn off (which equals the load current) and to deliver the initial base current at turn on. This implies the value of C4 should be as large as possible.
The circuit also includes an antisaturation circuit (Baker clamp) which has two functions: to further diminish the storage time and to prevent the current tailing effect [5].

Drive of the mosfet

A configuration based in storing the state of the switch (on or off) in the input capacitance of the mosfet was used [6],[7].
The basic idea emerges from the following circuit.

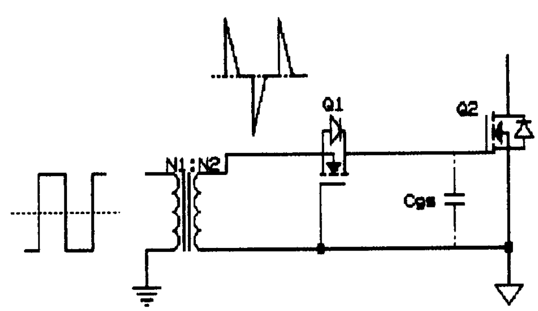

Fig. 4: Basic drive circuit

The positive pulse charges the input capacitance of Q2 through the reverse rectifier of Q1; afterwards this pulse vanishes when the transformer saturates, then the rectifier of Q1 cuts off and the capacitance remains charged. With the negative pulse, Q1 is turned on (because Vgs is positive) and discharges the input capacitance of Q2, turning Q2 off and remaining Vgs = 0.

The value Vgs = 0 when the mosfet is off is important drawback, since the noise margin set by the conduction threshold of Q2 is too small (equal to VT, approximately 4V), specially taking account of the high impedance seen from Q2 gate when Q1 is cut off.

The circuit in figure 5, based in the same idea as the circuit of figure 4, has the effect of charging Cgs with the negative pulse, resulting in Vgs negative.

The advantages of this configuration for the mosfet drive are:

* Presents galvanic isolation between the power stage and the control signal.
* Good speed performance.
* Does not requires a power supply at the power stage side. This is a very important point in the emitter drive configuration because the mosfet drive would require at least a 10V power supply, however 5V were enough for the bias of the bipolar transistor.
* High efficiency because it only consumes energy during switching.

The circuit has as a disadvantage a limit in the maximum time the switch can be on, which implies a limit in the minimum frequency. This is originated in the fact that the information of the switch state is stored in the input capacitance of the mosfet and therefore affected by the leakage currents of the other circuit elements.

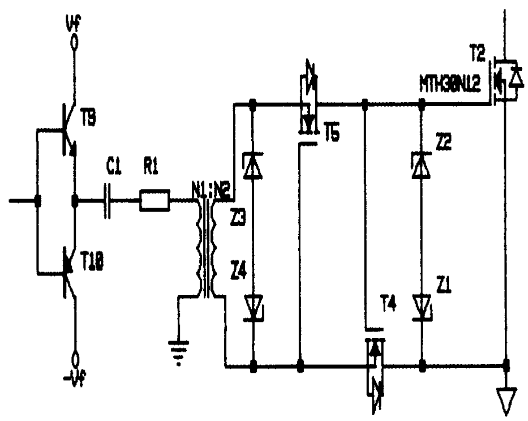

Fig. 5: Mosfet drive.

It is of great importance for the correct operation of this circuit a precise design of the R1 and C1 values. The inclusion of C1 implies the already remarked advantage of a high efficiency, but C1 produces a negative pulse when trying to turn T2 on (after the desired positive pulse) that may cause a undesired turn off of the mosfet. A symmetrical problem arises at T2 turn off. R1 must be designed so as to dump these undesired pulses.

Self-protection circuit

The block named as self-protection circuit in figure 2 implements protection against overcurrent and desaturation of the switch. The switch current is measured by means of the mosfet voltage which is related in a linear way through rds on with Ids (switch current).

The desaturation of the bipolar transistor is detected measuring the Vce voltage.

The fundamentals of the circuit operation are as follows: the Vds and Vce voltage are compared with adjustable reference values; if either of this signals exceeds its reference value, for longer than about 1.5µs, being the ON signal in its active state, the SHUT_DOWN and ALARM signals are generated (see figure 2). The SHUT_DOWN signal turns off the switch and prevents the switch from turning on until the self-protection circuit is reset by the RESET signal.

The ON signal must be active all the time the protection circuit is intended to work. This time is the interval the switch is on, excepting an adjustable initial interval since the TRIGGER signal orders the switch to turn on. This interval is essentially the total rise time of the switch current (ton). In order to make sure a correct operation of the circuit the ON signal must go to its inactive state simultaneously with the switch turn off order. The ON signal is obtained directly from the Vgs voltage where the switch state is stored. To measure Vgs without loading the input capacitance of the mosfet, another mosfet is used.

Overvoltage protection and switching aid networks

The switch includes a conventional C-D-R turn off switching aid network [8], and protection against transient overvoltage by means of transient suppressors (essentially zener diodes with increased junction area, achieving high energy absorption capability [9]).

Experimental results

This section shows some of the practical results obtained using the designed switch. The configuration shown in figure 6 was used for testing the switching performance of the device.

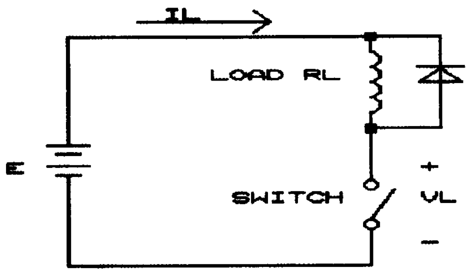

Fig. 6: Test circuit

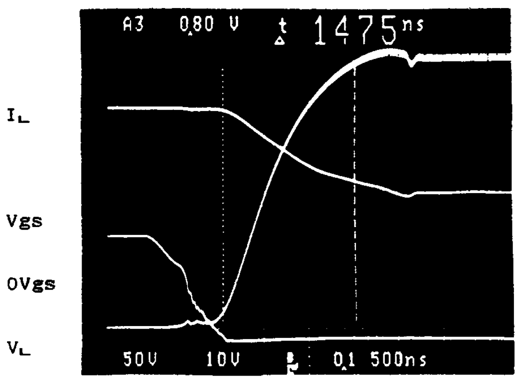

Fig. 7: Turn off of the switch.
Voltage (V_L), 50V/div.
Current (I_L), 5A/div.
Vgs Voltage, 10V/div.
Time 500ns/div.

The figure 7 shows the switch current and voltage, and the mosfet gate - source voltage at turn off. It is remarkable that the storage time is diminished to a value of approximately 250 ns, in comparison with the value established in the data sheets for base drive (2.5µs @ 15 A, 25°C).
The voltage waveform reveals the effect of the turn off switching aid network, which slows the voltage rise.

The figure 8 shows the same magnitudes of figure 7 at turn on.

The figure 9 shows the switch working at a frequency of 103KHz. It can also be appreciated the effect of the reverse recovery current of the load parallel diode, on the current waveform.

A half inverter bridge configuration with middle point DC supply was implemented using a pair of this switches. The switches were controlled by means of a microcomputer with the Z80 microprocessor. A sinusoidal voltage waveform was generated in this bridge applying PWM (pulse width modulation) which switching angles were previously computed for obtaining the desired value of the fundamental and simultaneously eliminating chosen harmonics.
The figure 10 shows the 50Hz output waveform, previously filtered with a LC low pass filter, with 600 Hz cut frequency. This waveform was generated to eliminate up to the 29th harmonic inclusive. It can also be seen the effect of the harmonic number 31 (first no eliminated, with a frequency of 1550Hz), which is attenuated to a 13% of its original value by the LC filter.

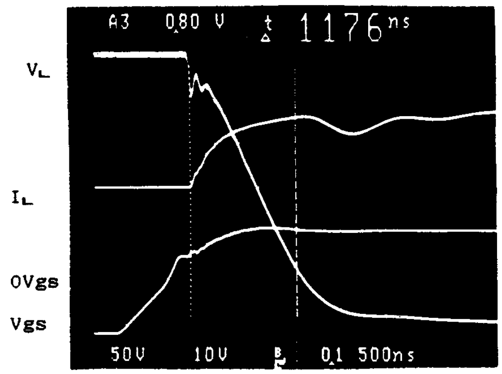

Fig. 8: Turn on of the switch.
Voltage (V_L), 50V/div.
Current (I_L), 5A/div.
Voltage Vgs, 10V/div.
Time 500ns/div.

Fig. 9: Waveforms for the switch operating at 100KHz.
Voltage (V_L), 50V/div.
Current (I_L), 5A/div.
Voltage Vgs, 10V/div.
Time 2µs/div.

Conclusions

The results presented in this work shows that the emitter drive configuration is an option to be considered for applications which require power switches suitable for working with rectified 220V line voltage, also requiring switching speed greater than that achievable using bipolar transistors in conventional configurations.

The conception of a self protected switch in the way it was implemented, proved to be very robust and resistant to an intense laboratory use.

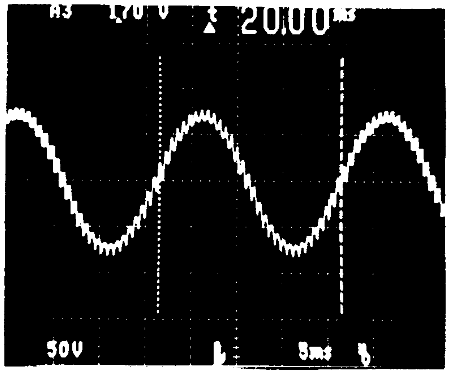

Fig. 10: Waveform obtained with harmonic elimination using PWM and filtering.

Acknowledgements

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