SGS-THOMSON MICROELECTRONICS

APPLICATION NOTE

POWER SEMICONDUCTORS FOR HIGH FREQUENCY AC/DC CONVERTERS SUPPLIED ON THE 380/440V MAINS

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INTRODUCTION

This paper is the result of the development in our laboratory of different switches and converters able to operate at ultrasonic frequency, supplied directly from the rectified 380/440V mains.

This paper presents, in the first part, a typical specification for the converter and power switches.

The second part describes several switches and driving circuits optimized for those requirements.

1. SPECIFICATION :

Our objective was to develop switches and drivers optimized for AC/DC converters supplied on the industrial 380/440V mains, switching at ultrasonic frequency as used in Switch Mode Power Supply, battery charger or welding converter applications.

We based our development on the design of a 5KW asymetrical half bridge (2 transistor forward) converter. An equipment of 10kW could be design with the same switches mounted in full bridge or in the assembly of two asymetrical half bridge operating in antiphase.

Because of the high voltage supply, the blocking voltage capability of the switches is 1000V. In order to minimize the transformer and filters size and the acoustic noises a switching frequency over 20kHz is required.

In a 5kW asymetrical half bridge supplied on the 380V mains, the maximum duty cycle of conduction of the power switches is 50% of the total period. The current in the switch is 15A. Consequently the RMS current in the switch is 11A.

In order to use a very small heatsink the conduction losses in each switch are minimized (30W).

Auxiliary supplies for the power switches are also excluded in order to minimize the volume and the cost of the auxiliary circuitry.

2. A 1000V MOSFET SWITCH :

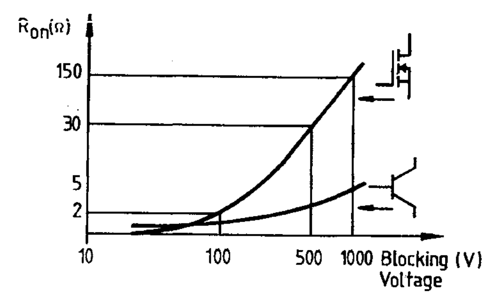
Power MOSFET technology is well adapted for the design of switches able to operate at high frequency. 1000V MOSFETs exist and they present the classical advantages of the MOSFET technology : low drive consumption, good turn-off safe operating area, high over current capability, ...

But the resistance of the epitaxial layer required to withstand the blocking voltage V_{DS} (if 250V) is approximately proportionnal to $V_{DS}^{2.5}$. Consequently, the on resistance R(on) of the Power MOSFET increases rapidly with the blocking voltage capability V_{DSS}.

The only way to reduce the conduction losses with a 1000V MOSFET is to operate at very low current density and to use very large die areas.

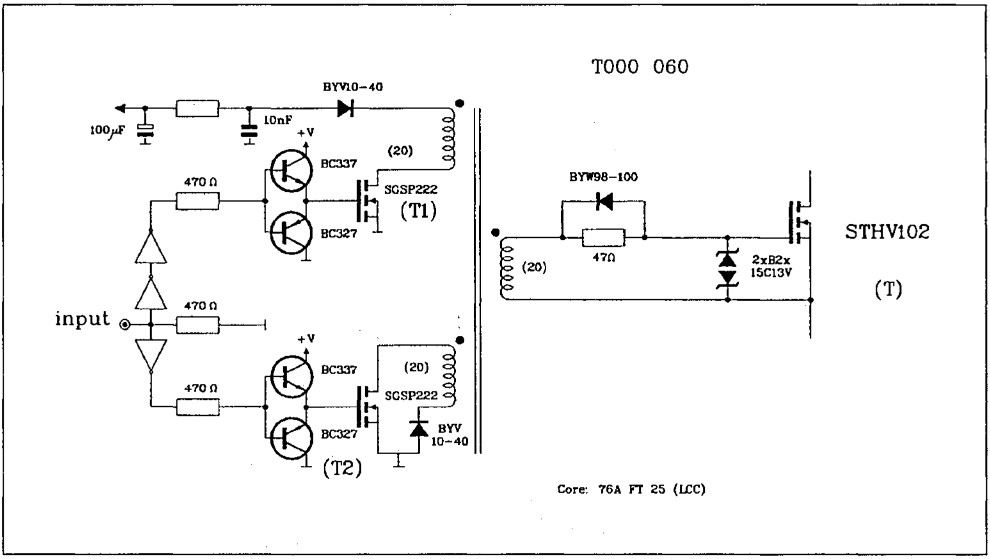
In our design, one switch requires a Ron of 0.15 ohm (Tj = 25°C). That means the paralleling of 25xSTHV102 (3.5 ohms in SOT93 package) or more reasonably 5xST5MG40 (0.7 ohm in ISOTOP package).

Figure 1 : ON Resistance $R_{(on)}$ versus Blocking Voltage V_{off}.
(die area = 1mm2 - junction temperature = 100°C).



The gate drive presented in figure 2 provides the galvanic isolation of the drive signal and avoids auxiliary supplies.
When the signal MOSFET T1 is on, the power MOSFET T is on. When the signal MOSFET T2 is on, the driving transformer is short circuited and discharges the gate source capacitance of T, turning Power MOSFET T 'off'.

Figure 2 : Schematic of the Power Switch and Driver.



3. A CASCODE/EMITTER SWITCHING SWITCH :

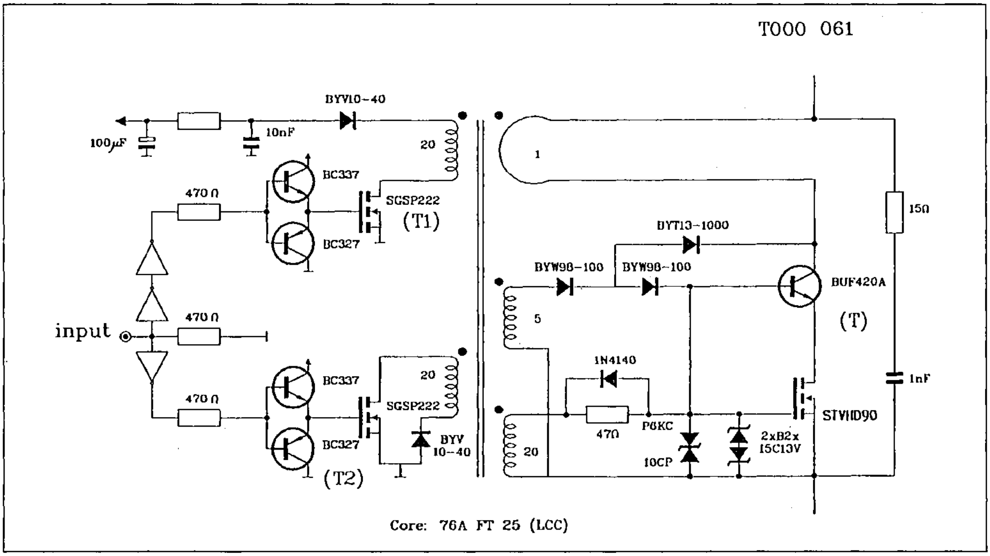
50V high density Power MOSFET can operate at a current density 100 times the current density of 1000V MOSFET for the same conduction losses (typically 2A/mm2 instead of 0,02A/mm2).
The current density of a 1000V bipolar transistor is in the region of 0.4A/mm^2. For applications requiring the same current capability and the same dissipation, the 1000V MOSFET requires about 30 times more silicon than the equivalent bipolar solution resulting in a substantially higher power switch cost.
Bipolar transistors developed with highly interdigitated technologies such as the Easy-To-Drive technology (ETD) have a very fast fall time compatible with operation at high frequency.

Consequently a solution using a high density 50V Power MOSFET (STVHD90) and a 1000V bipolar in ETD technology (BUF420A) in cascode configuration has been developed.

The driving circuit presented in figure 3 requires only one transformer to provide the voltage control of the MOSFET and the base current of the bipolar.

When the signal MOSFET T1 is on, the power switch T is on. The turn-on of the signal MOSFET T2 turns-off T.

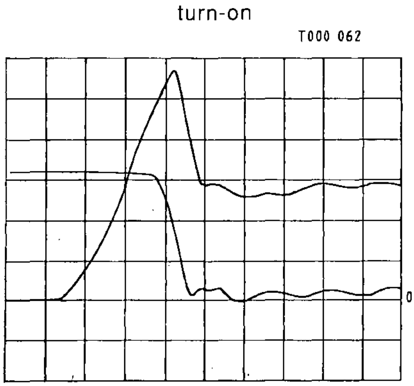
Figure 3 : Schematic of the Cascode Switch and Driver.

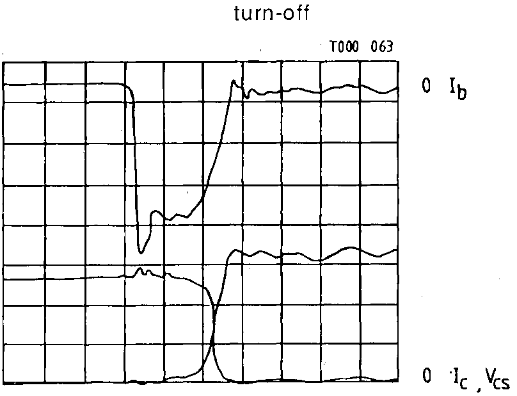


As presented in figure 4, the cascode switch is very fast at turn-off. A Storage time less than 500ns and fall time less than 20ns have been obtained. The rate of fall of the collector current is very high (2000A/μs). The use of low inductance wiring methods and packages is a condition for the design of this circuit. A turn-off snubber (R, C) limits oscillations and maintains the bipolar switch inside its specified Reverse Bias Safe Operating Area.

The rate of rise of the collector current (dI/dt)on at turn-on is limited in the converter by the leakage inductance of the power transformer. Therefore turn-on speed of the switch is not very critical. A (dI/dt)on of 50A/s has been obtained.

Figure 4 : Cascode Switching Waveforms.





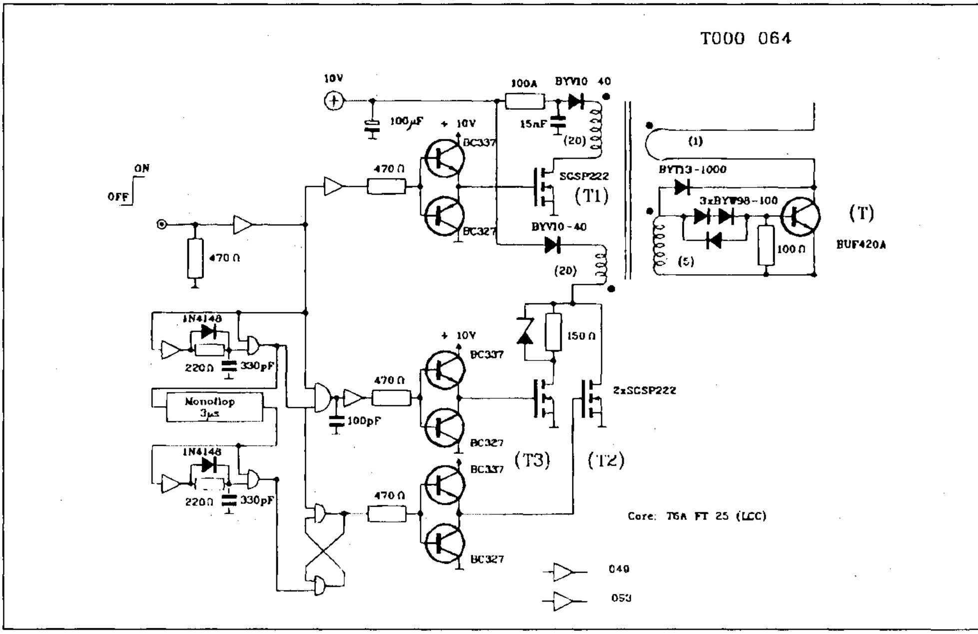
Ic, Ib : 5A/div. Vcs : 200V/div. t : 0,2μs/div.

4. BIPOLAR SWITCH :

The elimination of the 50V high density MOSFET is the last step to reduce the conduction losses and the number of power packages. But the remaining bipolar transistor must be driven with a negative bias on the base/emitter junction in order to obtain fast turn-off and a blocking voltage capability extended up to V_{CEV}.

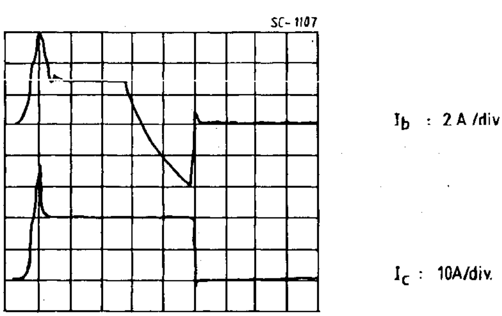
In the circuit presented in figure 5, when T1 is on the power switch T is on. T is turned-off when T2 and T3 are on. T2 drives the negative base current of T and is turned-off after 3µs. T3 resets the magnetic flux in the driver transformer before the next turn-on of T.

Figure 5 : Bipolar Switch and Driver.



With this circuit, a BUF420A switches 20A with a storage time of 2µs and a fall time of 50ns at Tj = 100°C, see figure 6.

Figure 6 : The Bipolar Switching Waveforms.



5. CONCLUSION :

This paper proposes different switches and drivers able to operate in AC/DC converters switching at ultrasonic frequency and directly supplied from the rectified 380/440V mains.

The availability of 1000V MOSFET makes possible the design of switches with high frequency capability, large turn-off safe operating area, large overcurrent capability and easily controlled gate drive. A limitation of this solution is in the trade-off between the conduction losses and the current density. A medium current 1000V MOSFET switch needs several packages in parallel or a big heatsink.

A switch developed with 1000V bipolar transistor has low conduction losses and few parallel packages. Thanks to the use of highly interdigitated very fast technology (ETD) the switching speed is comparable to the MOSFET solution. But the turn-off delay time is longer and the driving circuitry is more complex than a MOSFET circuit.

A Cascode circuit has the advantages of both bipolar and MOSFET technologies. It allows low dissipation with short turn-off delay time and simple driving circuitry. High density low voltage MOSFETs minimises the increase of the forward drop. Because of the very fast turn-off speed, special care must be taken with the wiring.

Driving circuits using only one transformer to provide the galvanic isolation power/logic and the energy to drive the power switches are also presented and adapted to each configuration of power switch.

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