DRIVERS FOR HIGH SPEED SCHWITCHING MOS-FET TRANSISTORS

Jan Otýpka

Doctoral Degree Programme (2), FEEC BUT

E-mail: xotypk00@stud.feec.vutbr.cz

Supervised by: Miroslav Patočka

E-mail: patocka@feec.vutbr.cz

Abstract: In this paper is described the circuit solution in order to control the high speed switching transistors MOS-FET. These type of transistors are a silicon transistors COOL-MOS or new MOS-FETs that are manufactured from silicon carbide (SiC). The both type are very fast especially SiC transistors. The slope of collector voltage du_{DS}/dt is originated due to short times of turn-on and turn-of t_{on}, t_{off}. The slope can be exceeded the value 100kV/μs, it causes problems with galvanic separation of the control signal on the driver input. Therefore, the galvanic separation can't be realized by using the optocoupler. In this paper is described a galvanic separation with magnetic coupling.

Keywords: MOS-FET transistor, silicon carbide, SiC, driver of switching transistor

1. INTRODUCTION

The power switching MOS-FET transistors, manufactured from silicon carbide, are appeared at present. The advantage of these transistors are a short times of turn-on and turn-of t_{on}, t_{off}, i.e. decrease of switching losses due to working frequency in switching power supply can be increased (up to 200kHz). It allows the miniaturization of source, especially transformer and filter choke.

The problems are originated with increasing rate of transistor. The slope of collector voltage du_{DS}/dt is decreased an especially which can be exceeded the value 100kV/μs. Therefore, the requirements are increased on the quality of galvanic separation of control signal. These requirements are summarized in [1] and [2]. The galvanic separation between control circuit and control electrode of switching transistor must be ensured by the driver of transistor.

The submitted article describes the circuitry solution of the driver, in which the galvanic separation of the signal is realized by the magnetic coupling, i.e. by the small impulse transformer. With regard to great slope du/dt, the solution of following problems is shown in the article:

- Radical minimization of the parasitic capacitance between primary and secondary windings of the impulse transformer, when keeping the very close magnetic coupling.
- Elimination of the capacitive currents, flowing through this capacitance, with the help of the shielding (the prevention of the unwanted turn-on state of the transistor).
- Circuit solution of the safe evaluation of the control signal on the transformer output.
- Circuit solution of the driving end of the driver.
- Circuit solution of the galvanic separated supply source supplying the driver.

2. GALVANIC SEPARATION OF CONTROL SIGNAL

The ground of control circuits (μP) are on an entirely different potential than emitter of controlled transistor, it can be seen in Figure 1. It is applied for transistor T_A and T_B. Therefore, the control signal must be separated. The source of driver is separated from the same reason.

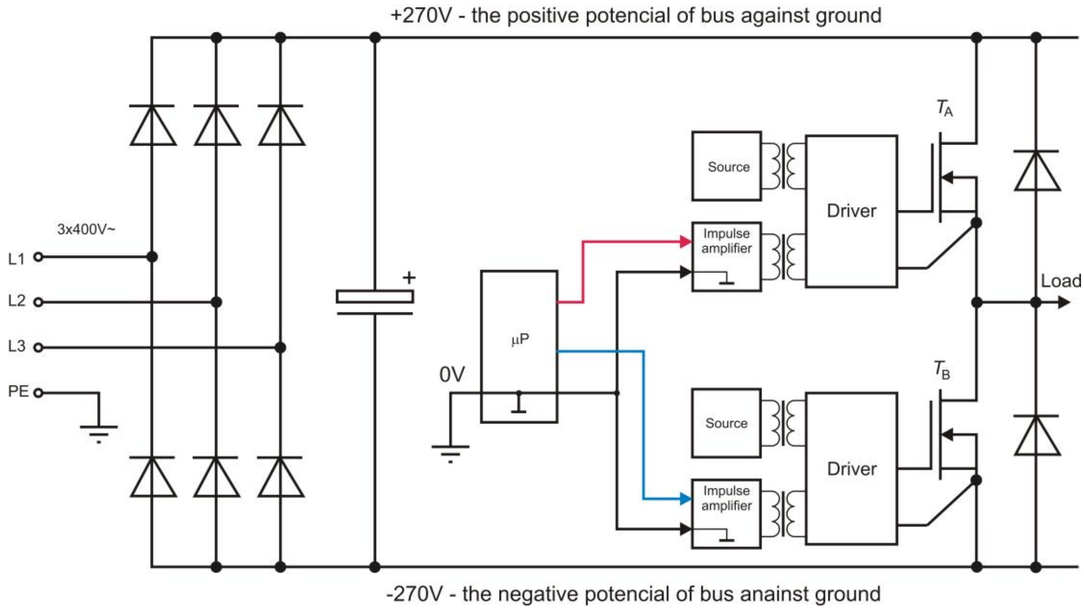

Figure 1: Galvanic isolation of control signals by drivers.

The galvanic separation must be sufficient electric strength (at least 2kV) and the least possible parasitic capacity C_p between signal and power section of converter. If the parasitic capacity C_p is strained the voltage slope du_{DS}/dt, the parasitic capacity is flowed the parasitic current with value:

$$i_{CP}(t) = C_P \frac{\mathrm{d}u_{DS}(t)}{\mathrm{d}t}. \tag{1}$$

Elimination of the capacitive currents, flowing through this capacitance, with the help of the shielding, because it is the prevention of the unwanted turn-on state of the transistor.

The galvanic separation can be realized by the following ways:

a) optocoupler,

b) magnetic coupling.

The problems for high slope of collector voltage du_{DS}/dt is the realize of galvanic separation of signal. At the slopes above 100kV/µs, it is not possible to use the classic optocouplers because of their immunity against du/dt (guaranteed by the producer) does not reach 30kV/µs usually and 50kV/µs exceptionally in [3]. Although the development of optocouplers is shifted the considerable progress, the optocouplers are not used for the value 100kV/µs. Therefore, the magnetic coupling (impulse transformer) is used between a control and power circuit of converter.

For realization of transformer is important the tight coupling between primary and secondary winding ($k \geq 0.995$). The tight coupling is introduced the significant problem, because the parasitic capacity C_p is increased with the tightness of coupling. The parasitic current i_{CP} is increased by the relationship (1) which is flowed from power parts to the control circuits. The current can be eliminated with help of shielding (shielding winding) which is placed between primary and secondary winding.

3. CIRCUIT SOLUTION OF DRIVER

The circuit solution of driver can be seen on Figure 2. The controlled electrode of power transistor Q3 is excited from the output of driver over electric resistance R_G. The output stage can be supplied the impulse signal levels +15V and -5V with frequency 50 until 150kHz and maximal peak current ±4A for charging and discharging input capacity C_{GS} of switching transistor Q3.

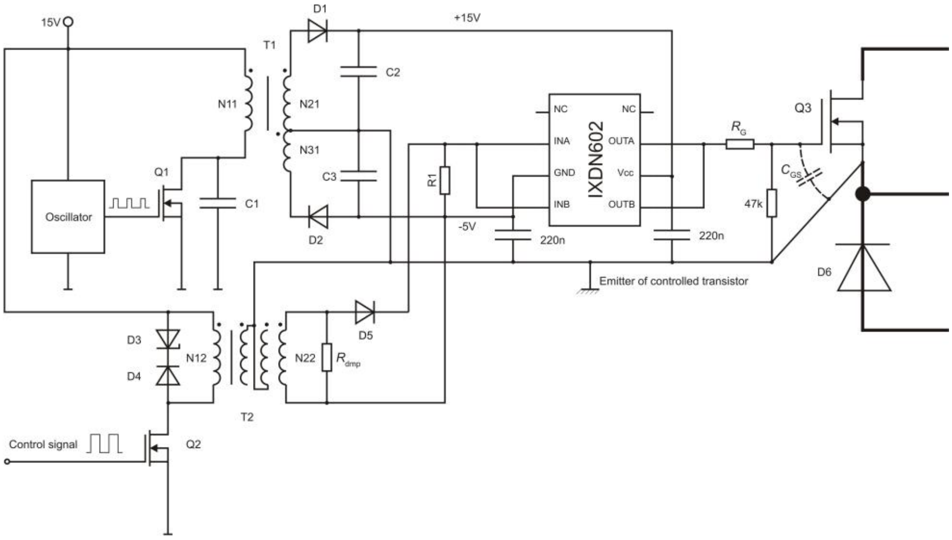

Figure 2: The circuit solution of driver.

The sourcing of driver is galvanic separated by the transformer T1 and the control signal by transformer T2.

3.1. GALVANIC SEPARATION OF POWER SUPPLY

The driver is supplied from the single acting buck converter Q1, T1, with demagnetization to capacity C1. The converter must be transferred the power for turn-on and turn-off switching transistor. Basically it is a power which is converted to heat in resistance R_G:

$$P_{T1out} = f_{SW}\, C_{GS}\ \ (U_{GS+}^2 + U_{GS-}^2)\,, \tag{2}$$

where f_{SW} is working frequency of switching transistor, C_{GS} is input capacity of transistor, U_{GS+} is positive and U_{GS} is negative level of control voltage on electrode of transistor. The impulse transformer work on frequency 180kHz. Number of primary threads is determined by the relationship:

$$N_{11} = \frac{U_{cc}}{2\ f_1\ B_{\max}\ S_{Fe}}, \tag{3}$$

where U_{cc} = 15V, B_{max} is amplitude of magnetic density in core, S_{Fe} is diameter of core.

3.2. GALVANIC SEPARATION OF CONTROL SIGNAL

The signal is galvanic separated and transmitted by the single acting buck converter with demagnetization of transformer T2 to Zener diode. The shielding winding is bifilar wound so that the self-inductance has been suppressed. The shielding must be connected to the emitter of controlled transistor Q3, i.e. ground of driver.

The design of transformer must be based on the chosen demagnetization power $P_{Z,max}$ which is transformed in Zener diode on heat. The Number of primary threads can be determined by relationship in [4]:

$$N_{12} = \frac{U_d \; s_{\max}}{\sqrt{2 \; f_2 \; \mu_0 \; \mu_r \; \frac{S_{Fe}}{l_{Fe}} \; P_{Z,\max}}} , \qquad (4)$$

where $s_{\max}$ is maximal duty cycle of converter, f_2 is frequency of signal, l_{Fe} is median length of field lines of core, S_{Fe} is diameter of core, $P_{Z,\max}$ is dissipation power in Zenner diode. The quality of signal, i.e. the slew-rate of fall time, is dependent on a value of demagnetization current. The greater current is, the faster slew-rate is. The current is directly proportional to the volume of core the equation:

$$I_{\mu\max} = \frac{U_d \; t_{z,on}}{\mu_0 \; \mu_r \; \frac{S_{Fe}}{l_{Fe}}} = \frac{U_d \; t_{z,on} \, V_{Fe}}{\mu_0 \; \mu_r \; S_{Fe}^2} , \qquad (5)$$

where $t_{z,on}$ is the pulse duration and V_{Fe} is the volume of core.

The damping resistance R_{dmp} is connected on output of transformer T2. The value of resistance must be chosen so that the value could be eliminated the resonance between output capacity of switching transistor Q2 and inductance of primary coil L_{1T2} and the fast demagnetization of winding.

3.3. OUTPUT STAGE OF CONVERTER

The output stage is implemented by the integrated circuit IXDN602, we can see in Figure 3. The own consumption is only 10μA. Each output can be supplied the peak current ±2A for sourcing voltage to value 35V. The both canals is connected to parallel in driver. The output current achieve to ±4A which is the sufficient value for charging and discharging of input capacity C_{GS} of controlled transistor.

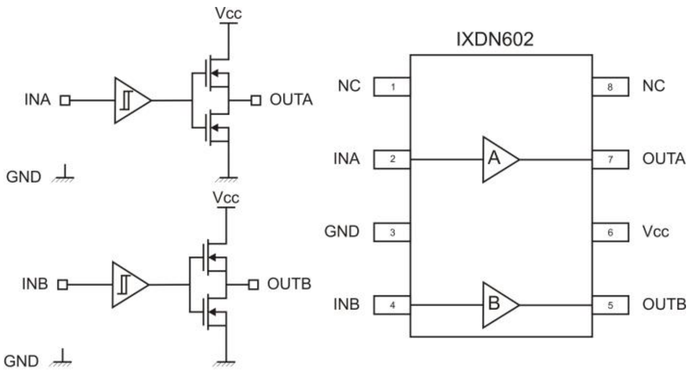

Figure 3: Internal stricture of output stage of driver with circuit IXDN602 [taken from 5]

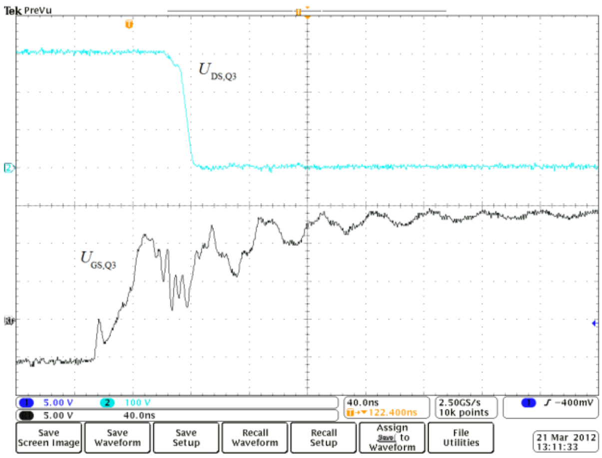

Figure 4: Voltage on control electrode of switching transistor $u_{GS,Q3}$ and voltage $u_{DS,Q3}$ for turn-on of loading transistor (I_D = 6A, U_d = 300V)

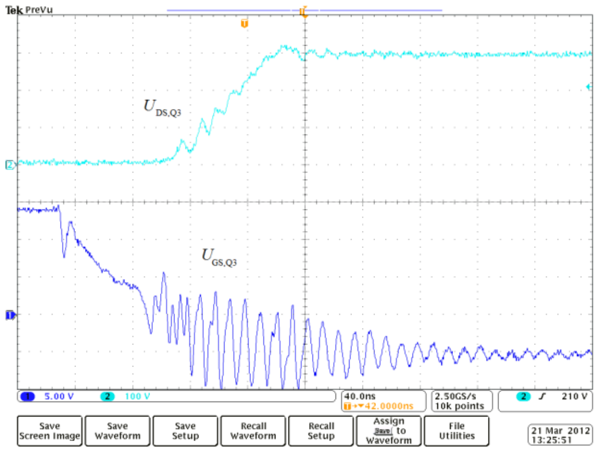

Figure 5: Voltage on control electrode of switching transistor $u_{GS,Q3}$ and voltage $u_{DS,Q3}$ for turn-off of loading transistor (I_D = 6A, U_d = 300V)

4. CONCLUSION

The described driver was tested with the transistor IPP50R350CP type COLL-MOS. In tests have been verified the correct function for slope du_{DS}/dt = 100kV/μs. the higher slopes wasn't reached in experiment. The slopes above 100kV/μs can be expected for planned testing with transistor SiC MOS/FET type CMF10120D, 1200V, 24A.

ACKNOWLEDGEMENT

This work was solved in the frame of the faculty project FEKT-S-11-14 „Využití nových technologií ve výkonové elektronice“, and CVVOZE project CZ.1.05/2.1.00/01.0014.

REFERENCES

[1] Patočka, M.: Driving circuits for power transistors MOSFET and IGBT. *ElectronicsLetters.com - http://www.electronicsletters.com*, 2004, roč. 2004, č. 1/ 7, s. 20 (s.)ISSN: 1213-161X.

[2] Vorel, P.: Budiče výkonových tranzistorů MOSFET a IGBT. *Elektrorevue - Internetový časopis (http://www.elektrorevue.cz)*, 2004, roč. 2004, č. 30, s. 1 (s.)ISSN: 1213- 1539.

[3] Fairchild Semiconductors: Optocupler Solutions – datasheet –

http://www.fairchildsemi.com/collateral/opto_selection_guide.pdf.

[4] Patočka M.: *Magnetické jevy a obvody ve výkonové elektronice, měřicí technice a elektroenergetice.* odborné knihy. odborné knihy. Brno: VUTIUM, 2011. 564 s. ISBN: 978-80-214-4003- 6

[5] IXYS: datasheet http://ixapps.ixys.com/DataSheet/IXD_602.pdf