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# Application of Insulated Gate Bipolar Transistor in Transcranial Magnetic Stimulation System Development


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As one of the most widely used non-invasive brain stimulation method, transcranial magnetic stimulation (TMS) requires its power source to deliver high current pulse into stimulators. A high power switch device is needed to perform the control. In commercial TMS, a silicon controlled rectifier (SCR) in the driving circuit is used as the high power switch. This type of device can be turned on by a proper gate voltage, however, to turn the switch off, it requires reversed voltage applied to the anode and cathode, which can only be provided by an AC power supply system and is not applicable to a capacitor discharging power supply system like those used in TMS tools.

Although there is also a choice of using gate turn-off thyristor (GTO), the control will require both positive and negative pulses. To simplify the complexity of switching a TMS system, we selected the insulated gate bipolar transistor (IGBT) as the high power switch in our study. The on/off status is only controlled by the gate voltage switching between a positive voltage and ground. So by sending a pulse with proper amplitude to the IGBT gate, we are able to obtain a high current pulse going through the stimulator. We tried 3 types of IGBTs as shown in figure 1: a. small IGBT chips array connected in parallel (high voltage low current, IXBX50N360HV); b. small IGBT module (high voltage high current, QID4515002); c. large IGBT module (high voltage high current, Infineon FZ1200R45KL3). Figure 2a illustrates the diagram of our TMS system. The group of capacitors (overall 1160uF capacitance) are the power source, which is directly charged by a DC power supply (Maximum output: 2000V 3A). The IGBT gate is driven by a pulse generator and its emitter shares the same ground with both pulse generator and power supply. To reduce the pulse turn-on and turn-off time, the pulse from the pulse generator is sent into a gate driver as shown in figure 2b, which consists of a PNP and a NPN transistor. An RC snubber circuit is also connected in parallel to the IGBT collector and emitter for IGBT protection, which contains a diode, a resistor (51ohms) and a capacitor (15.5uF). Due to the continuity of the current in the stimulator at the time IGBT turns off, a high voltage spike will be generated at the IGBT collector by the back fired reaction from the inductor. The peak voltage could be more than 10 times higher than the applied voltage on the DC power supply. Without the protection of the snubber circuit, the IGBT can be broken down by the spike. It was found that by using the snubber, the IGBT turn-off voltage spike peak was reduced to only 1.5-4 times of the applied voltage on the capacitors. The higher the capacitance of the snubber has, the more efficient the snubber will be. Figure 3 compares the IGBT collector and emitter voltages with and without the snubber. As shown in the figure, the peak voltage of the spike is only 4 times of the applied DC voltage, while if the snubber is not added in the circuit, the peak increases to almost 4500V, 30 times higher than the applied DC voltage.

Besides the IGBT protection issue, the equivalent internal circuits of these high power switching modules significantly affect their performance when we are using these high power devices. Gate drivers usually are required to operate them. The turn-on and turn-off time was significantly reduced by the gate driver as figure 4 indicates, about a 20-30us decrease. The oscillations at the IGBT gate after the pulse turned off in figure 4a were also efficiently weakened by the gate driver. Taking the advantage of the extremely low turn-on resistance of the IGBT, the current in the loop that formed by the capacitors, the stimulator and IGBT was able to reach $10^3$A level to create a very strong transient magnetic field from the stimulator for electric field induction. Without a gate driver, the IGBT is not fully turned on, which can cause high output impedance and major part of the capacitor output voltage is dropped across the IGBT instead of the coil. Parasitic inductance inside the IGBT module seemed to be much higher when the driving current is not sufficient. Turn-on and turn-off oscillations started to take place without the gate driver as illustrated in figure4b and 4c. By measuring with a search coil type of magnetic field probe, which was calibrated with commercial TMS, we can probe these high power semiconductor modules in operations.

a b c

Figure 1  a. small IGBT chips array connected in parallel (high voltage low current, IXBX50N360HV); b. small IGBT module (high voltage high current, QID4515002); c. large IGBT module (high voltage high current, Infineon FZ1200R45KL3)

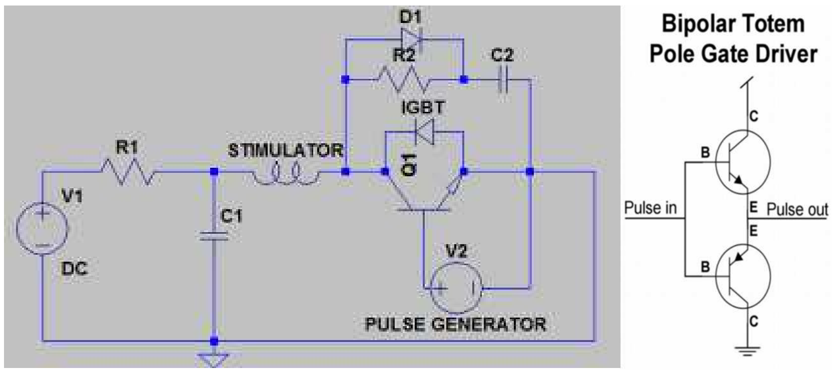


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Figure 2  a.Pulse-generating TMS stimulator drive circuit; b. Gate driver circuit

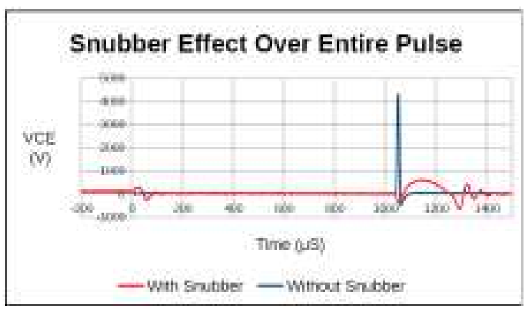
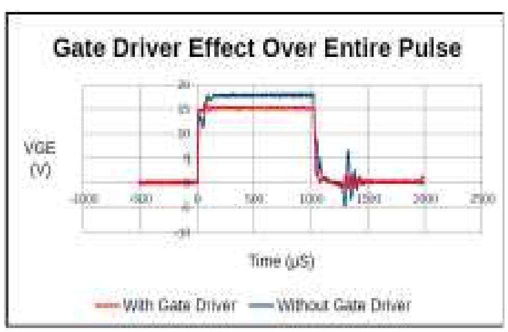



Figure 3  Comparison of IGBT collector and emitter voltage curves with and without snubber in the circuit

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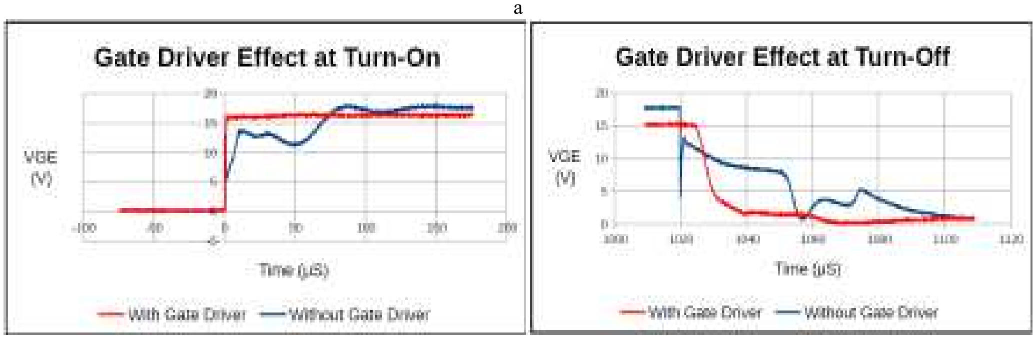


b c

Figure 4  a. Gate driver effect over the entire pulse; b. Gate driver effect at pulse turning on; c. Gate driver effect at pulse turning off