High Temperature Gate Drive for SiC-JFETs

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High temperatures in the propulsion system of Hybrid Electrical Vehicles (HEV) provide a harsh environment for power electronic systems such as DC-DC converters and inverters. The same environmental conditions also apply for military, space exploration or energy exploration applications and demand High Temperature (HT) capable electronics. Silicon Carbide (SiC) semiconductors are especially valuable in these fields of application due to the SiC material properties. The only available SiC switch is the normally-on JFET that offers larger forward current ratings and lower on resistance, whereas normally-off devices like SiC-BJT, SiC-MOSFETs and IGBTs are being researched by semiconductor manufacturers for future application.

Since it is necessary to place the gate drive physically close to a SiC-JFET, operation at elevated ambient temperature of above 200°C is required and a switching frequency of approximately 250kHz is desired to benefit from the SiC dynamic properties. Furthermore, for a DC-DC converter application a large duty cycle range is essential and the capability to statically turn off the normally-on device is required for protection reasons.

The selection of HT components is challenging since the materials and packaging of standard components are not rated for HT operation. Therefore, NPO Ceramic capacitors with a stable temperature coefficient, SOI (Silicon on Insulator) MOSFETs and SiC diodes are utilized for the gate driver. Furthermore, the isolation transformer is made of a ferrite core with a Curie temperature of 300°C. In a first step, the components are assembled on a PCB made of Rogers RO4530B substrate that shows a high glass transition temperature of $T_g >$ 280°C and a low CTE-z of 35ppm/K instead of an expensive ceramic substrate.

For a cost-optimized gate driver design the number of HT components, especially of non-standard active components like MOSFETs needs to be minimized. On the other hand, active components are essential to achieve fast switching speeds of the driver circuit. Thus, different driver architectures are compared in regard to limitations, performance and circuit complexity, including purely passive drivers, a high frequency carrier driver, a Edge-Triggered driver and a Phase-Difference driver. The Edge-Triggered Driver, consisting of a pulse transformer, a SOI-MOSFET, a SiC diode and a low number of passive components, shows a cost-effective design and additionally the best performance in the comparison.

Short control pulses at the primary side of the isolation transformer of the Edge-Triggered Driver turn on or off the SiC-JFET: When a negative voltage is applied, the transformer secondary current is conducted by the anti-parallel body diode of the SOI-MOSFET that is connected in series to the secondary winding and charges the gate capacitance of the SiC-JFET. The JFET turns off, when the gate voltage drops below the pinch-off voltage. When a positive voltage is applied, the MOSFET is turned on, since a separate secondary winding is connected to the MOSFET gate. The transformer secondary current is conducted by the MOSFET channel and discharges the JFET gate, the JFET turns on. The positive voltage is clamped to 0V by a SiC diode connected in parallel to the JFET gate. When no voltage is applied to the transformer primary, the MOSFET blocks and thus prevents that the JFET gate is discharged via the secondary winding.

The HT operation of the proposed Edge-Triggered Driver is verified by switching an 150μH inductive load with a 1200V, 6A Si-JFET at 600V, 5A, whereas the gate driver and the power parts are operated in a heating oven up to a maximum temperature of 200°C without a drop in the switching performance. The maximum measured dv/dt levels of the JFET Drain-Source voltage of -57.1kV/μs and +41.7kV/μs demonstrate a very high performance of the HT Edge-Triggered Driver and the usability for high switching frequencies above 250kHz. Furthermore, the driver output voltage shows a low temperature drift of only 7.4mV/K.