High Efficiency Resonant Gate Driver for High Frequency Switching of SiC Power MOSFETs

Corresponding Author A. Sebastian Mitchison[a]

[a] *Electrical and Electronic Engineering, University of Nottingham, United Kingdom, eeysm@nottingham.ac.uk.*

Power converters have restricted operating frequencies due to unacceptable losses in 'hard' switched gate drivers at high frequency and the limited switching frequency of Si MOSFETs. High frequency switching capabilities reduce the energy storage demands of the circuit which decreases the size of passive components (inductors and capacitors) allowing for more effective integration. It also allows for a faster transient response and an increase in power density, efficiency and reliability. Efficiency in power converters is restricted due to switching losses in transistors and gate drivers. Novel techniques must therefore be introduced to reduce these losses.

The main switching losses are caused by charging intrinsic parasitic elements in the MOSFET. SiC power devices offer lower switching losses, higher switching frequencies, higher operational temperatures and a significant reduction in size when compared to their Silicon (Si) counterparts. SiC power devices are therefore of interest in power conversion systems.

To exploit the high switching frequencies available from the SiC MOSFET, very high frequency, low loss gate drivers must be implemented. Resonant gate drivers operate at high frequency with low losses by charging and discharging parasitic capacitances in the MOSFET prior to changing state enabling energy recovery. Resonant gate drivers can also supply the MOSFET gate with a higher voltage swing than that supplied introducing a negative voltage during the 'off' cycle if required. Resonant gate drivers as such are of interest in this study.

This study exploits the advantages offered by resonant gate drivers and Silicon Carbide (SiC) semiconductors; MOSFETs and diodes when implemented within a 210V input, 400V output, 1kW, SiC, DC-DC Boost converter. The converter was designed based on the case study in [1]. The resonant gate driver was based on [2] but the component values were deduced through a series of mathematical models derived in MAPLE. These models were based on the 2nd order ordinary differential equations (ODE) that represented the system. Both topologies underwent extensive simulations in pSpice to confirm theoretical calculations were correct before the hardware was designed.

The aim of this study was to achieve a +20V to -4V voltage swing at the gate of the SiC MOSFET from the resonant gate driver and achieve a 400V output from the converter at high frequency with a high efficiency.

Switching Frequency (kHz)	Output Voltage (V)	Efficiency (%)	Overall Losses (W)	RGD Losses (% of Overall Losses)
200	398.32	98.46	11.3	4.17
400	398.23	98.21	20.6	4.54
600	398.12	95.97	30.25	4.62
800	397.98	94.73	40	4.65
1000	397.53	93.52	49.7	4.69

Table 1: Results from pSpice simulations.

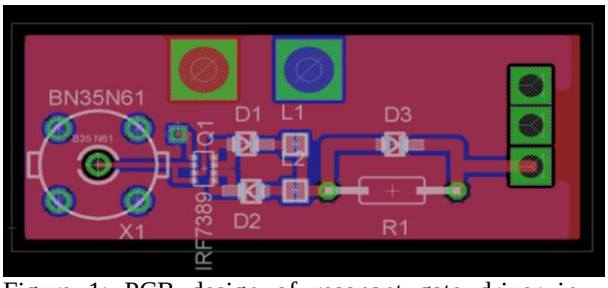

Figure 1: PCB design of resonant gate driver in Eagle.

Interestingly as the overall losses increased with frequency, the proportion of the overall losses caused by the resonant gate driver remained fairly constant regardless of switching frequency. A high efficiency has been achieved even at frequencies of 1MHz. The resonant gate driver has been designed on a PCB (45mm x 20mm) and has been designed to be as small and straight as possible to achieve high efficiency at high frequency operation. The boost converter (225mm x 85mm) has been designed on copper board due to the high voltage seen across it. Experimental proofs are currently being carried out to confirm the simulations.

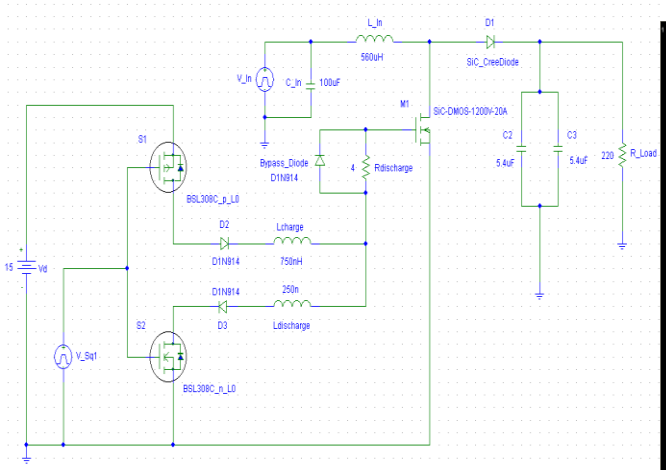

Figure 2: Resonant Gate Drive and SiC Boost Converter Topology.

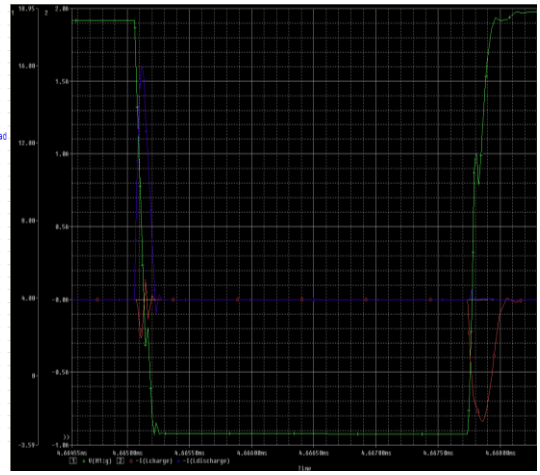

Figure 3: Simulated waveforms indicating the gate voltage and half sinusoidal pulses of current in the charge and discharge inductors which charge and discharge the gate-emitter capacitance as the MOSFET switches state.

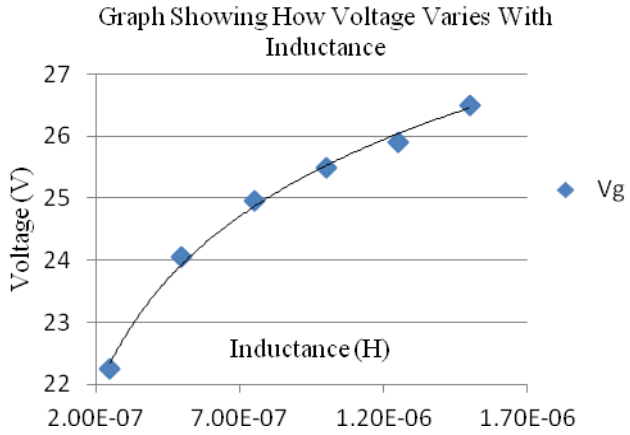

Figure 4: Trend line to deduce inductance equation.

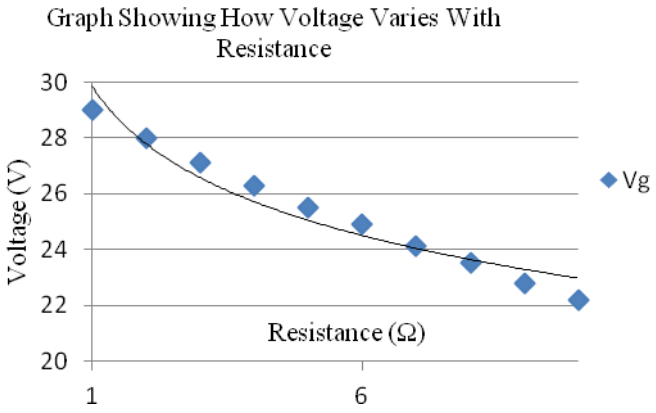

Figure 5: Trend line to deduce resistance equation.

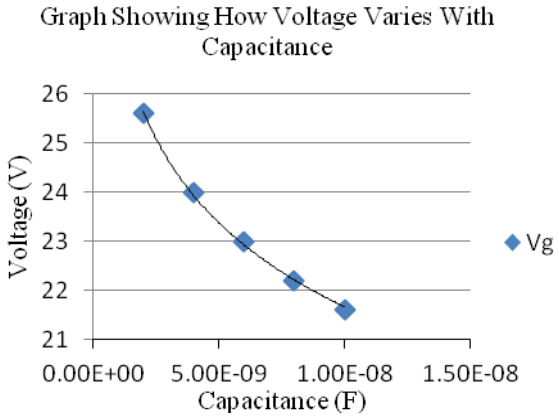

Figure 6: Trend line to deduce capacitance equation.

Vg = 2.3ln(L) + 57.3 (Equation 1: Affect of inductance on gate voltage)

Vg = -2.99ln(R) + 29.86 (Equation 2: Affect of resistance on gate voltage)

Vg = -2.48ln(C) - 24.05 (Equation 3:Affect of capacitance on gate voltage)

Equations were modeled in excel from mathematical modeling results. The 2nd order ODE $V_S - V_F - \frac{CLd^2V_C}{dt^2} - \frac{RCdV_C}{dt} - V_C = 0$ representing the resonant system was modeled in MAPLE software allowing design equations to be deduced with set parameters.

References

[1] Omid Mostaghimi - "Design and Performance Evaluation of SiC Based DC-DC Converters for PV Application" - 2012

[2] Iain D. De Vries – "A Resonant Power MOSFET/IGBT Gate Driver" 2002