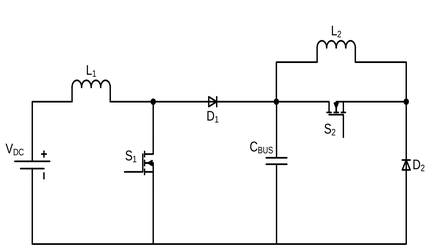
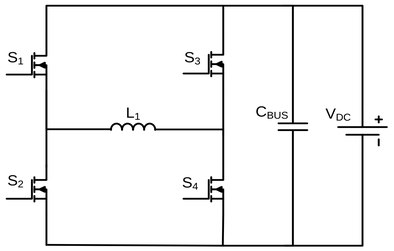
A Full Power Emulation Platform for Evaluating Power Semiconductors

Juncheng (Lucas) Lu, Yajie Qiu, and Di Chen
GaN Systems Inc.

Proposed Full Power Emulation Platform

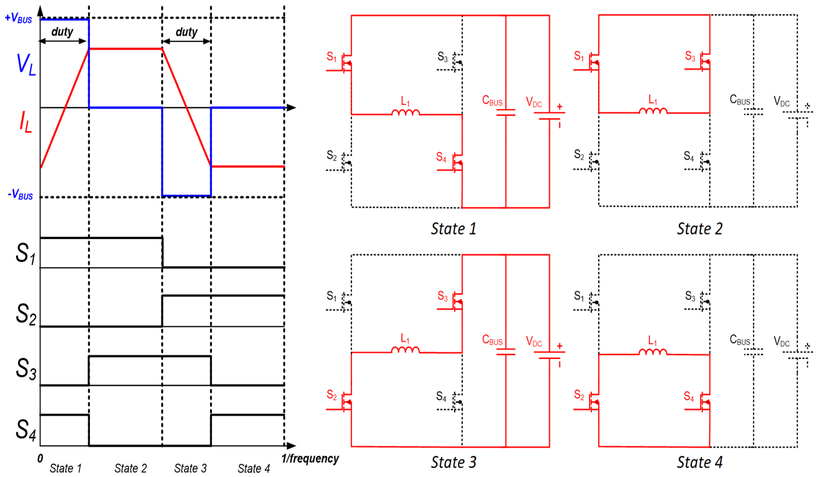


Existing Cascaded Boost/Buck SCRC Circuit



Proposed Full Power Emulation Platform

Operation Rules in ZVS mode



Operation Rule of Proposed Full Power Emulation Platform in ZVS Mode

Circuit Equations in ZVS mode

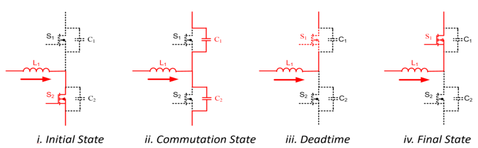
$$i_L(t)=\begin{cases}-\frac{V_{DC}}{L_1}\cdot\frac{duty}{2\cdot freq}+\frac{V_{DC}}{L_1}\cdot t & if\ 0\le t\le\frac{duty}{freq}\\ \frac{V_{DC}}{L_1}\cdot\frac{duty}{2\cdot freq} & if\ \frac{duty}{freq}<t\le\frac{1}{2\cdot freq}\\ \frac{V_{DC}}{L_1}\cdot\frac{duty}{2\cdot freq}-\frac{V_{DC}}{L_1}\cdot\left(t-\frac{1}{2\cdot freq}\right) & if\ \frac{1}{2\cdot freq}\le t\le\frac{2\cdot duty+1}{2\cdot freq}\\ -\frac{V_{DC}}{L_1}\cdot\frac{duty}{2\cdot freq} & if\ \frac{2\cdot duty+1}{2\cdot freq}\le t\le\frac{1}{freq}\end{cases}$$

$$V_{bridge}(t)=\begin{cases}V_{DC} & if\ 0\le t\le\frac{duty}{freq}\\ 0 & if\ \frac{duty}{freq}<t\le\frac{1}{2\cdot freq}\\ -V_{DC} & if\ \frac{1}{2\cdot freq}\le t\le\frac{2\cdot duty+1}{2\cdot freq}\\ 0 & if\ \frac{2\cdot duty+1}{2\cdot freq}\le t\le\frac{1}{freq}\end{cases}$$

The operation of each switch is exactly symmetrical. There are two degrees of freedom – frequency (freq) and duty cycle of inductor voltage (duty), to control the inductor RMS current (i_{RMS}) and switching off current ($i_{Switching}$) of DUT independently

$$i_{RMS}=\frac{V_{DC}\cdot duty}{L_1\cdot freq}\cdot\sqrt{\frac{(3-2\cdot duty)}{12}}\qquad i_{Switching}=\frac{V_{DC}}{L_1}\cdot\frac{duty}{2\cdot freq}$$

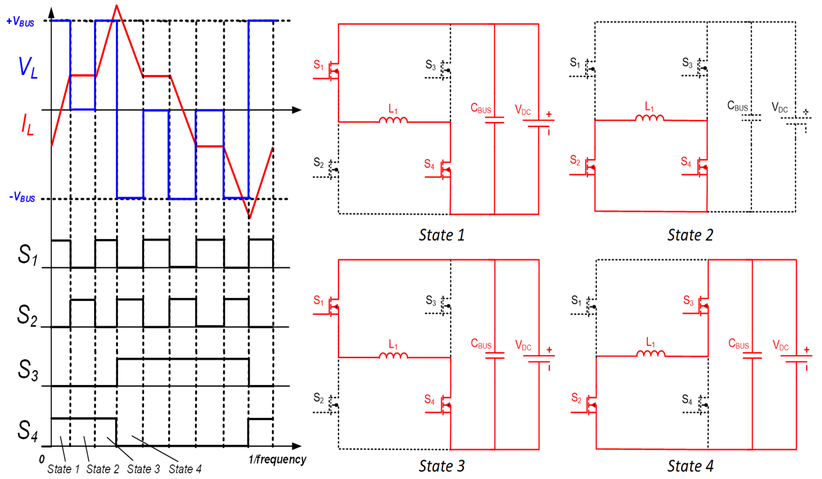
ZVS Boundary



ZVS transition of a half bridge power stage

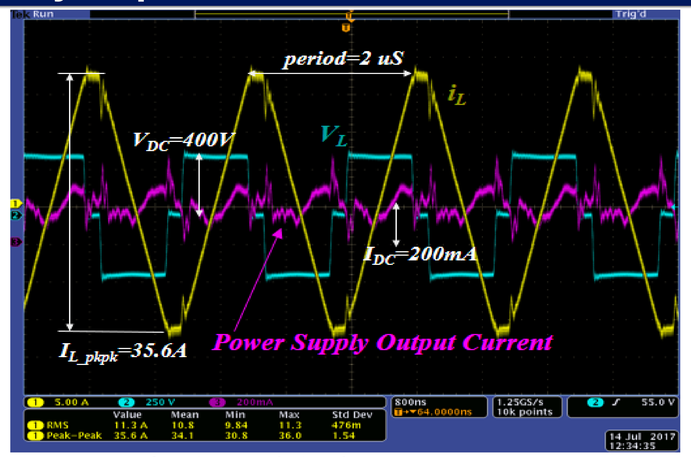
$$duty>\frac{2\cdot freq\cdot L_1}{V_{DC}}\cdot i_{Smin}$$

Operation Rules in ZVS mode

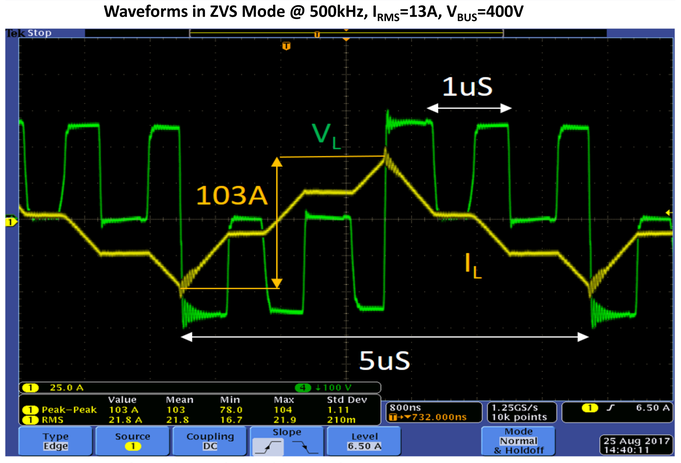


Operation Rule of Proposed Full Power Emulation Platform in Hard Switching Mode

Theory Experimental Verification

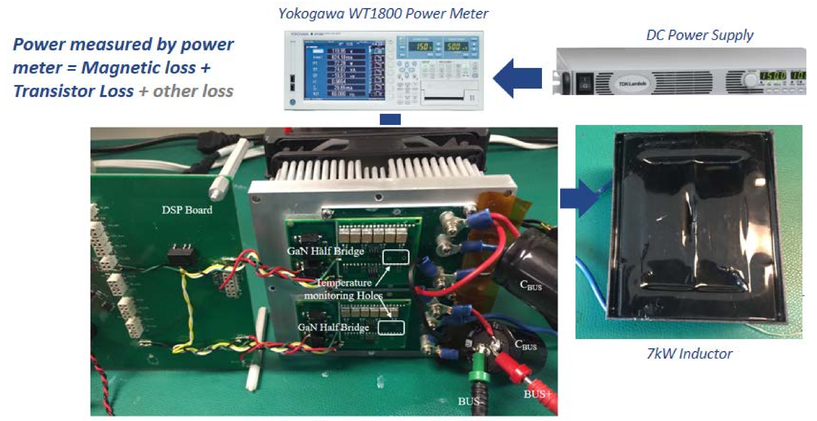


Waveforms in ZVS Mode @ 500kHz, I_{RMS}=13A, V_{BUS}=400V

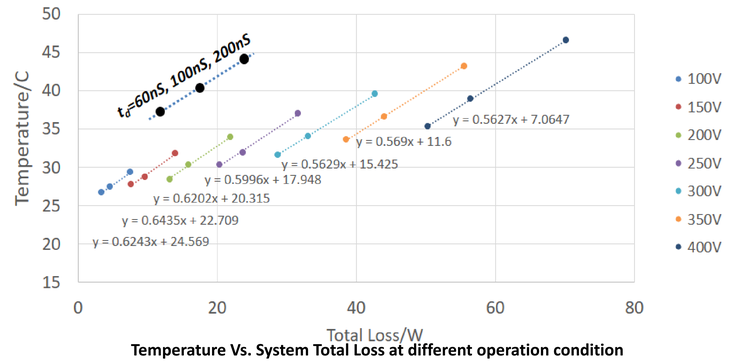


Waveforms in Hard-switching Mode @ 1MHz, I_{RMS}=20A, V_{BUS}=400V

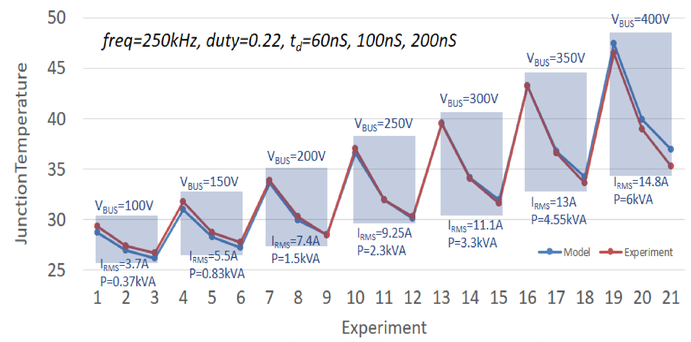
Device Modeling with Proposed Platform



DUT: two GaN Half Bridege IMS Modules
Full Power Emulation Platform and Device Under Test



Temperature Vs. System Total Loss at different operation condition



Experiment Vs. Simulation of different operation conditions

Conclusion

The operation principles of the full-bridge energy recirculation and storage circuit are explored and extended to evaluate power semiconductors under both soft switching and hard switching conditions. An IMS-based 120 A/ 650 V GaN power module is evaluated by proposed full power emulation platform. A strong correlation has been shown between simulation and experiment results under all test conditions.