

Averaging Step

$$\bar{n}_t \langle i_{out} \rangle = \frac{2}{T_s} \int_0^{\frac{T_s}{2}} n_t i_{out}(t) dt$$

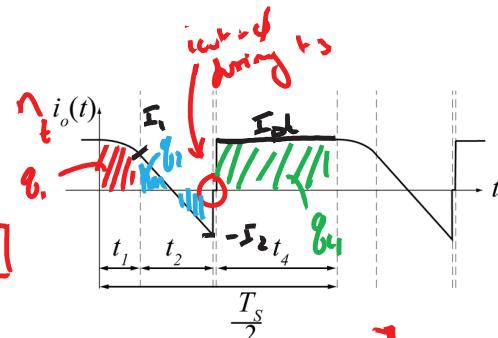
$$n_t \langle i_{out} \rangle = \frac{2}{T_s} [g_1 + g_2 + g_3 + g_4]$$

$$= \frac{2}{T_s} \left[C_p (2Vg) + t_2 \frac{I_1 - I_2}{2} + \phi + t_4 S_{pk} \right]$$

$$J = \frac{n_t \langle i_{out} \rangle}{I_{base}} = \frac{2}{T_s} \left[\cancel{2C_p \frac{Vg}{\sqrt{g}}} \sqrt{\frac{L}{C_p}} + t_2 \frac{S_1 - S_2}{2} + t_4 S_{pk} \right]$$

$$J = \frac{2}{T_s} \frac{1}{\omega_0} \left[2 + \theta_2 \frac{S_1 - S_2}{2} + \theta_4 S_{pk} \right]$$

$$\cancel{\frac{1}{2\pi f_0}} = \frac{F}{\pi} \rightarrow J = \frac{F}{\pi} \left[2 + \theta_2 \frac{S_1 - S_2}{2} + \theta_4 S_{pk} \right]$$

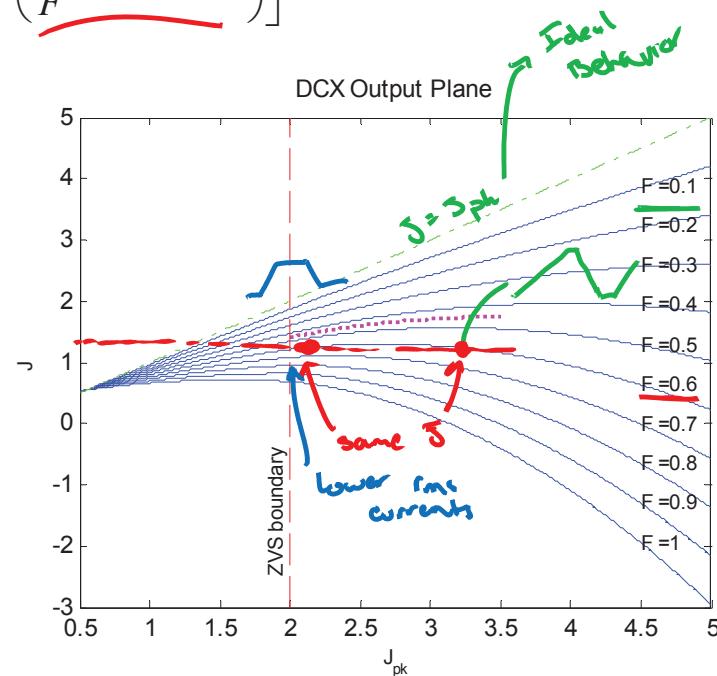


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Output Plane

$$F \approx \frac{f_1}{f_0}$$

$$J = \frac{n \langle i_{out} \rangle}{I_{base}} = \frac{F}{\pi} \left[2 + \frac{1}{4} \left(J_1^2 - J_2^2 \right) + J_p \left(\frac{\pi}{F} - \alpha - \theta_2 - \delta \right) \right]$$



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Example Waveforms

$$f_o = 1\text{MHz}$$

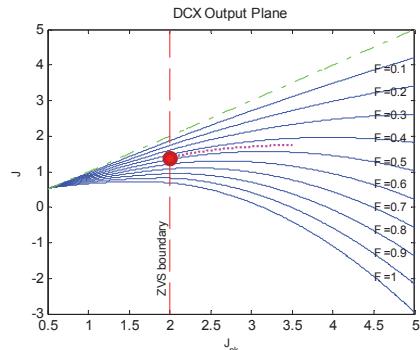
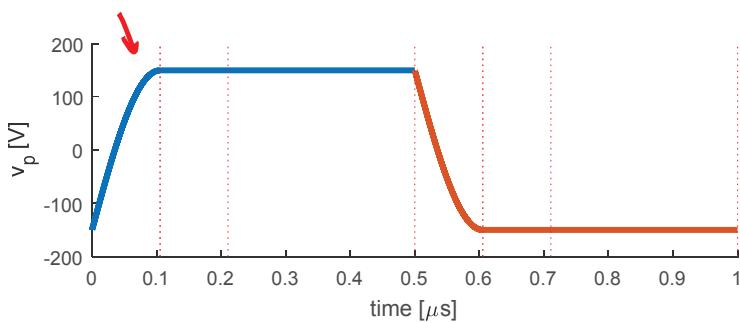
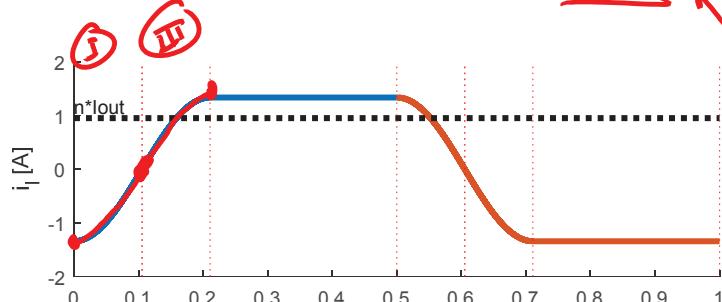
$$V_d = 150\text{V}$$

$$V = 12\text{V}$$

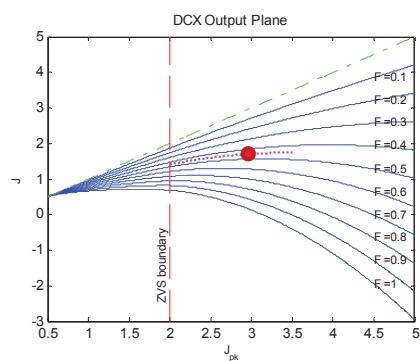
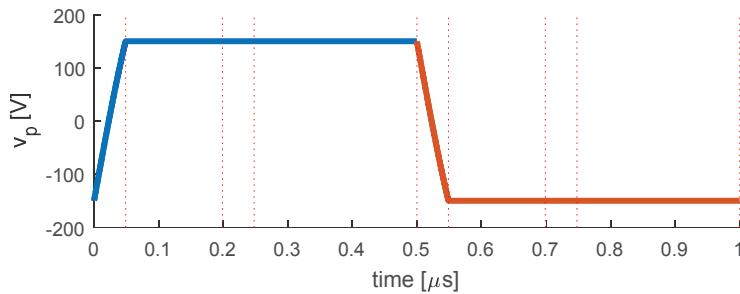
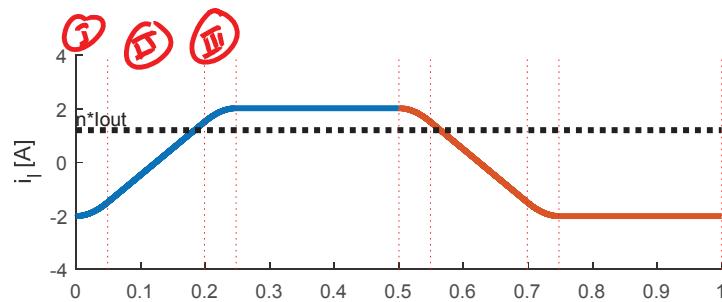
$$L_C = 15\mu\text{H}$$

$$C_D = 300\text{pF}$$

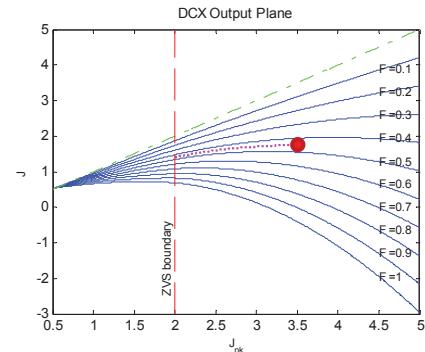
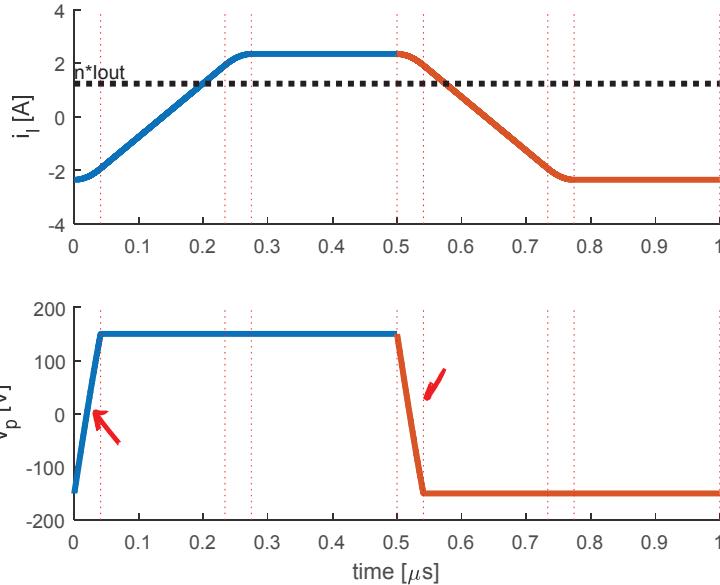
$$C_S > \frac{C_D}{n_2}$$



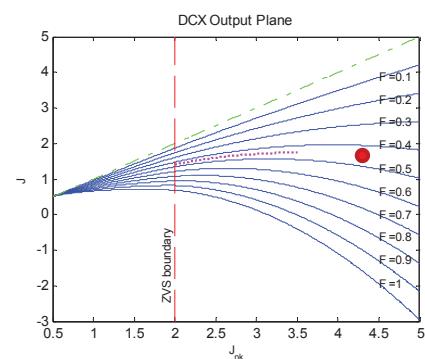
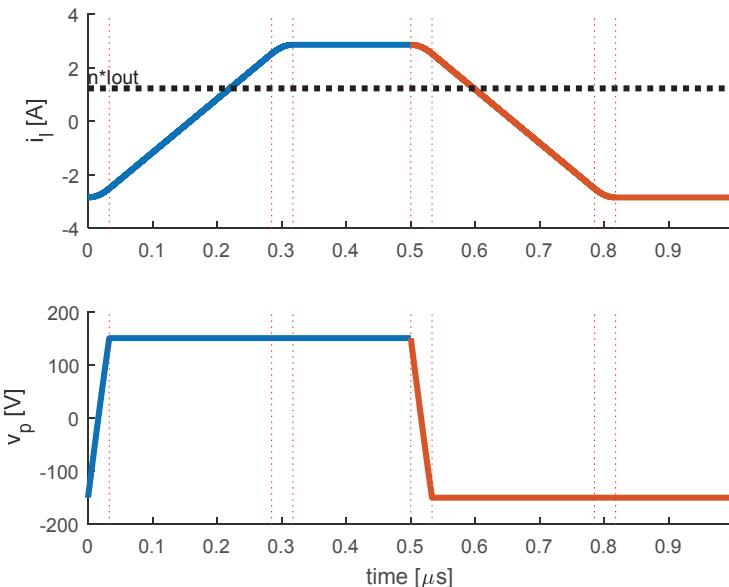
Example Waveforms



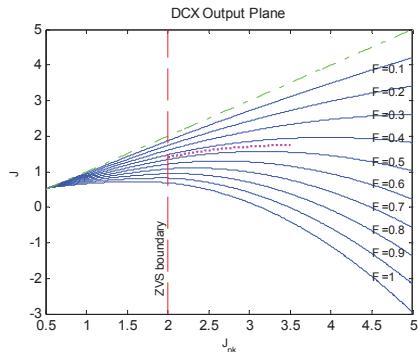
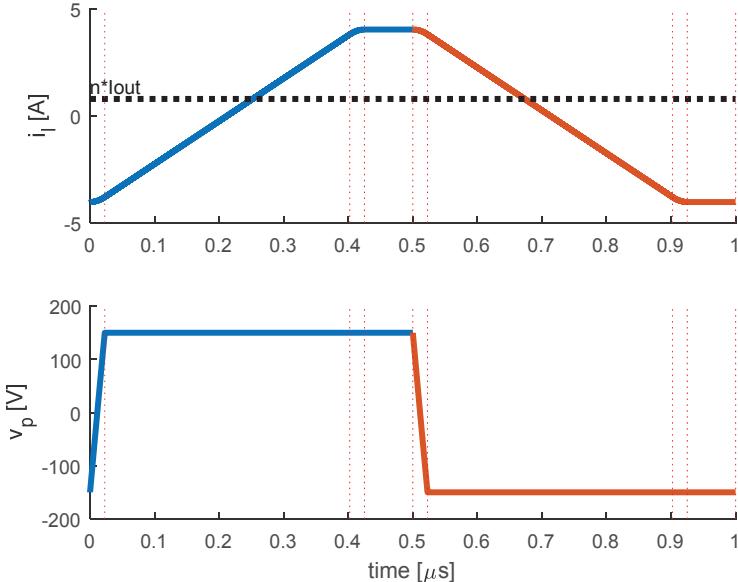
Example Waveforms



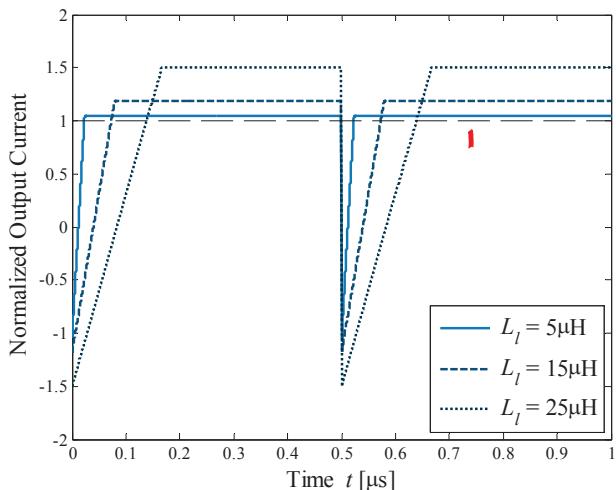
Example Waveforms



Example Waveforms



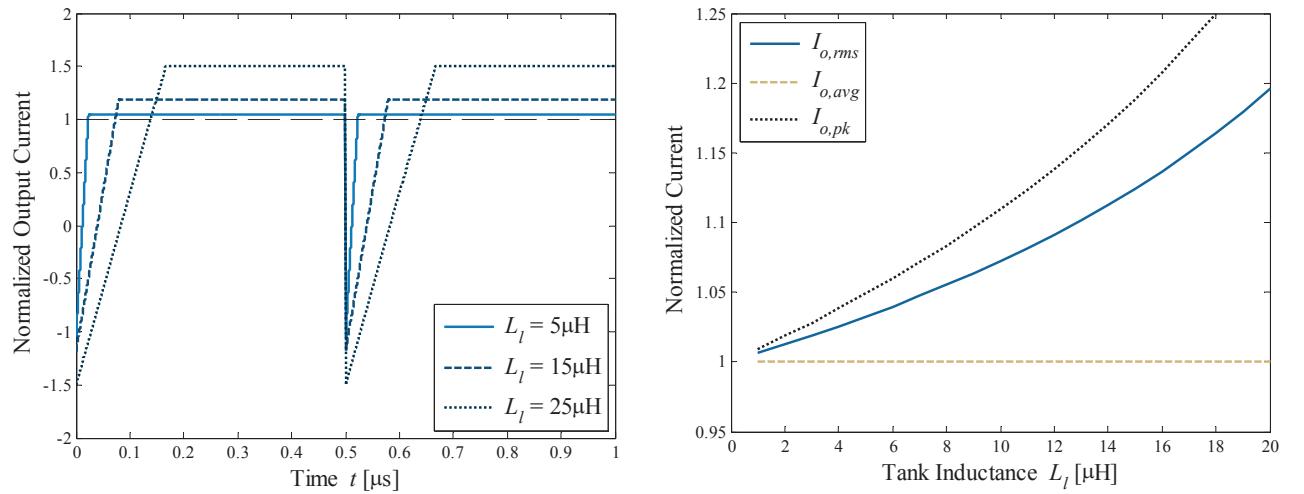
Output Current Vs. Inductance



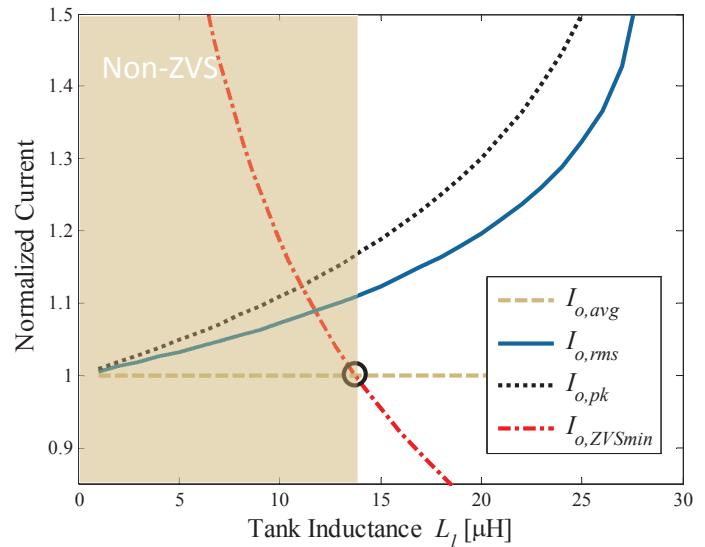
low (small) inductance is
best for minimizing conduction
losses.



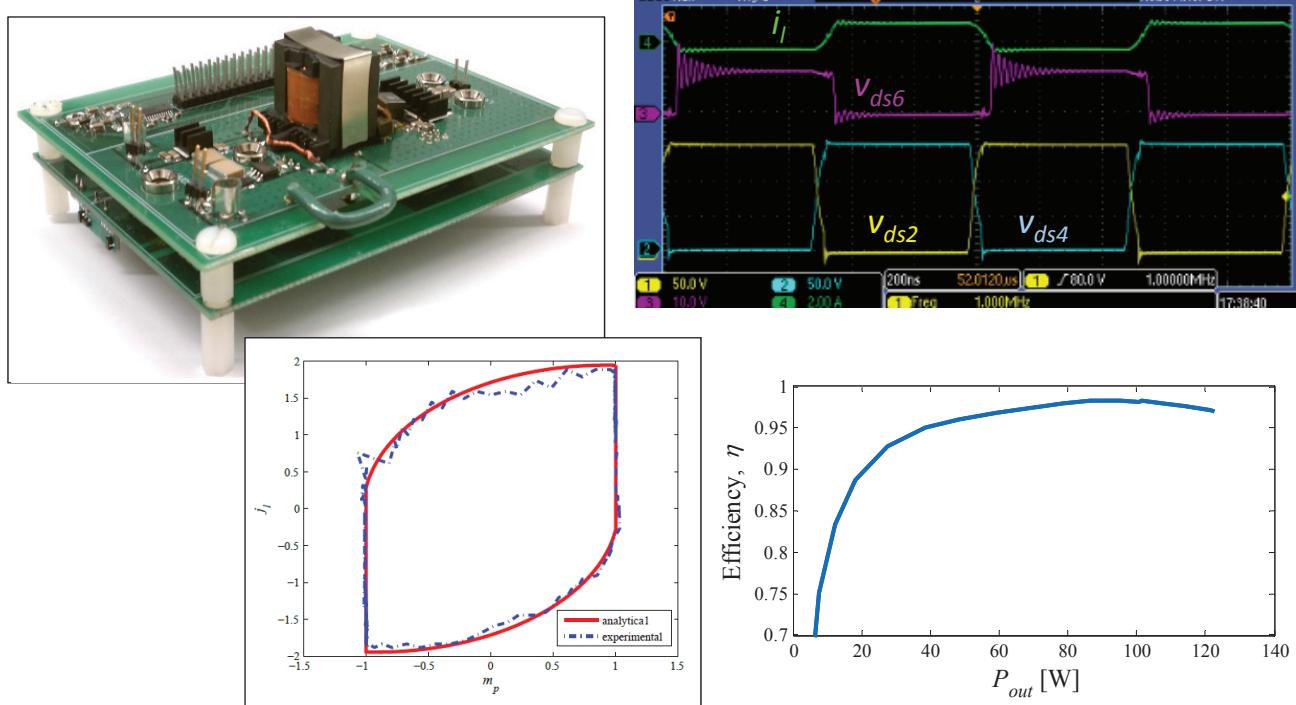
Output Current Vs. Inductance



Constraints on Inductance



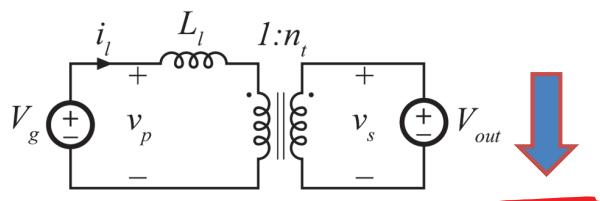
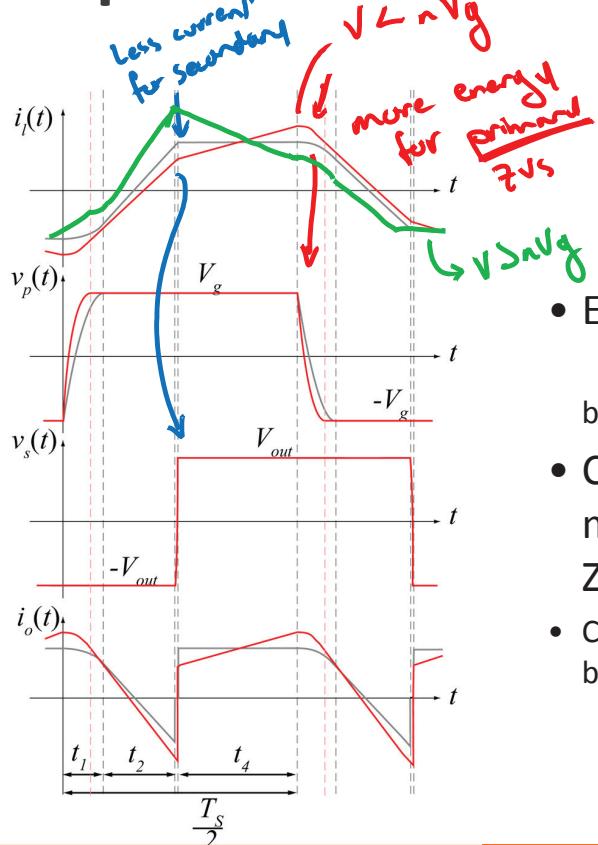
DAB: Experimental Results



D. Costinett, D. Maksimovic, and R. Zane, "Design and control for high efficiency in high step-down dual active bridge converters operating at high switching frequency," IEEE Trans. Power Electron., vol. PP, no. 99, p. 1, 2012.

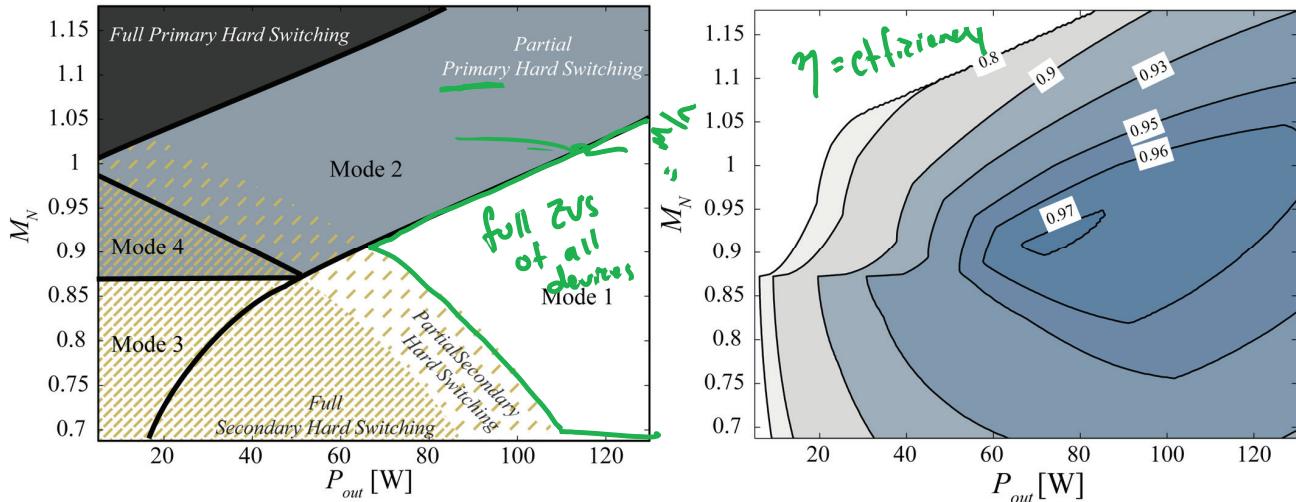


Operation with $V \neq nV_g$



- E.g. Decrease to $M_N < 1$
by decreasing output voltage
- Current now ramping, causing more energy available for primary ZVS, but higher RMS currents
- Can use behavior to extend ZVS range of one bridge

Soft Switching Range with Varying V_{out}



D. Costinett, D. Maksimovic, and R. Zane, "Design and control for high efficiency in high step-down dual active bridge converters operating at high switching frequency," IEEE Trans. Power Electron., vol. PP, no. 99, p. 1, 2012.



Application Example: Automotive

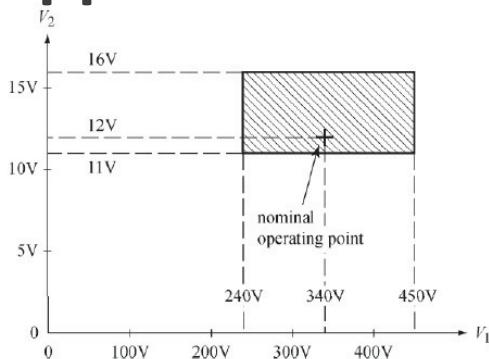


Fig. 1. Converter operating voltage ranges required for automotive application.

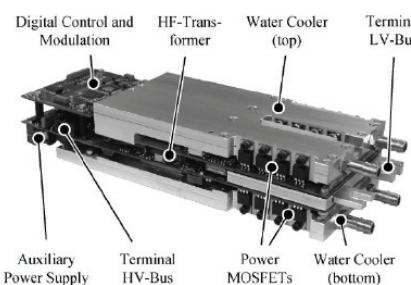
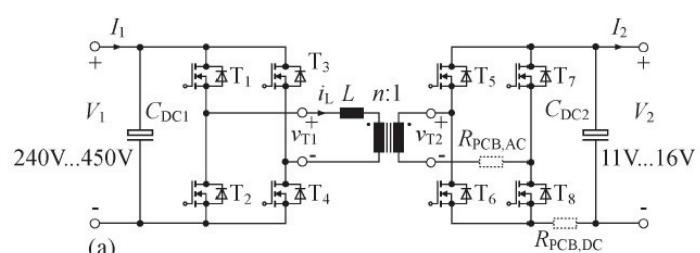


Fig. 3. Automotive DAB converter ($273 \times 90 \times 53$ mm).



(a)

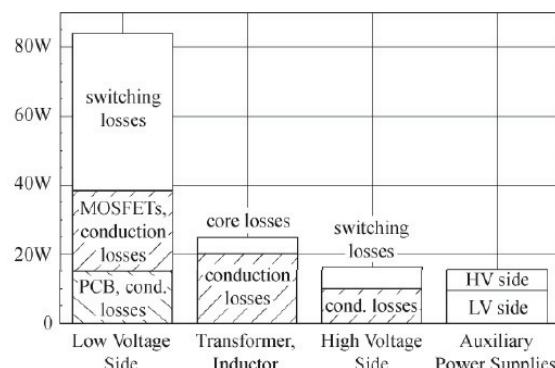
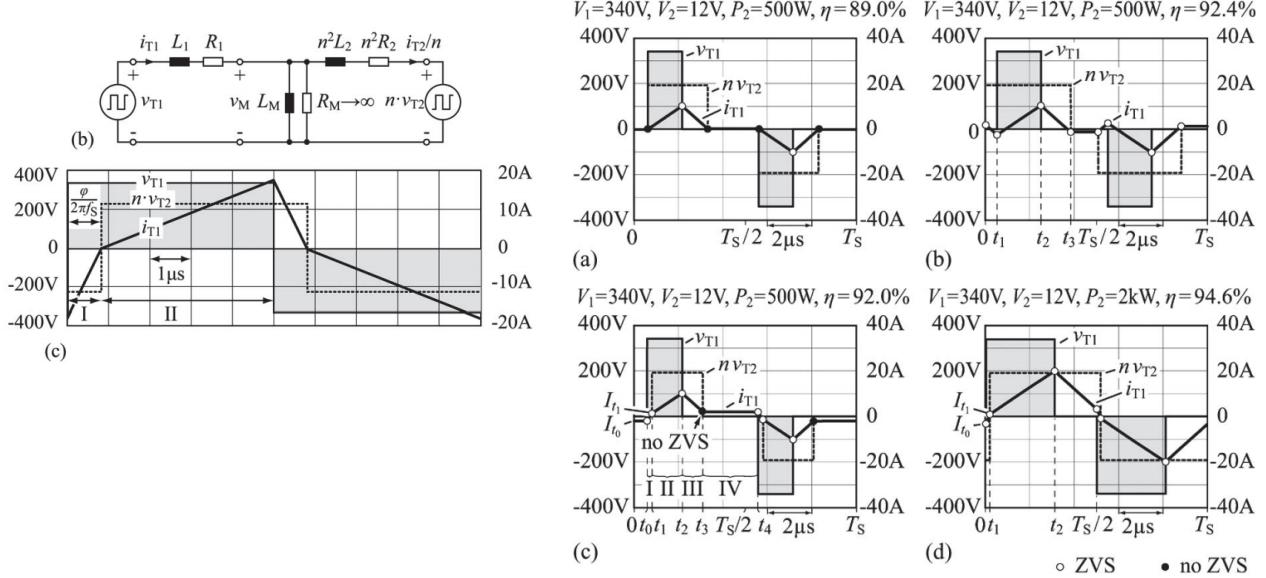


Fig. 13. Calculated distribution of the power losses for operation at $V_1 = 340$ V, $V_2 = 12$ V, and $P_2 = 2$ kW.

*F. Krismer, J.W.Kolar, "Accurate Power Loss Model Derivation of a High-Current Dual Active Bridge Converter for an Automotive Application, IEEE Trans. On Industrial Electronics, March 2010

Alternate Modulation Schemes



Florian Krismer; Johann W. Kolar, "Closed Form Solution for Minimum Conduction Loss Modulation of DAB Converters"