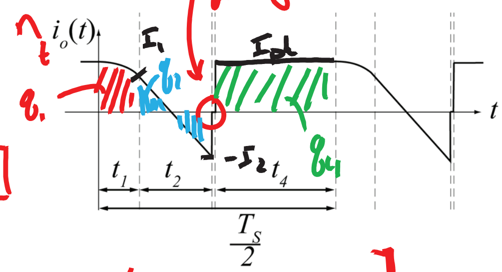
Averaging Step



$$n_t \langle i_{out} \rangle = \frac{2}{T_s} \int_0^{T_s/2} n_t i_{out}(t)\, dt$$

$$n_t \langle i_{out} \rangle = \frac{2}{T_s} \left[q_1 + q_2 + q_3 + q_4 \right]$$

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

$$J = \frac{n_t \langle i_{out} \rangle}{I_{base}} = \frac{2}{T_s} \left[\frac{2 C_p V_g}{V_g} \sqrt{\frac{L_r}{C_p}} + t_2 \frac{J_1 - J_2}{2} + t_4 J_{pk} \right]$$

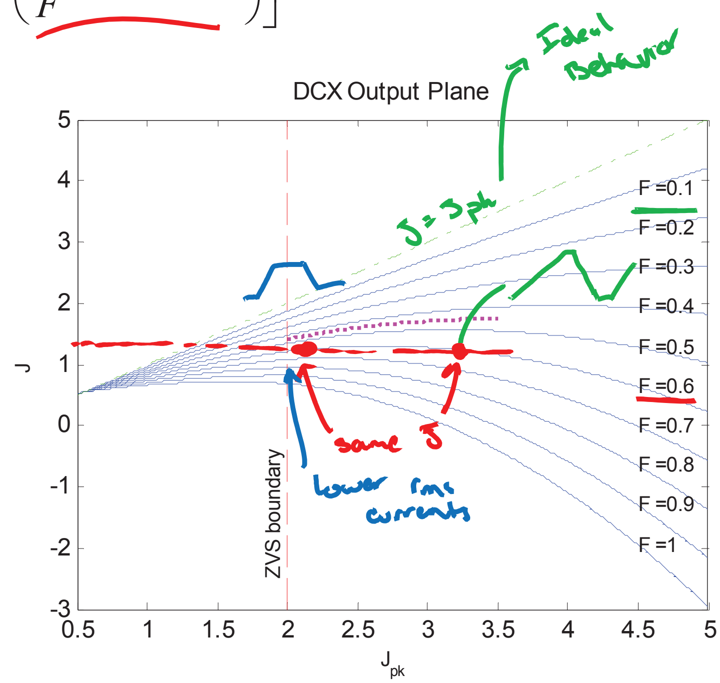
$$J = \frac{2}{T_s} \frac{1}{\omega_0} \left[2 + \theta_2 \frac{J_1 - J_2}{2} + \theta_4 J_{pk} \right]$$

$$\frac{2 f_s}{2\pi f_0} = \frac{F}{\pi} \rightarrow \boxed{J = \frac{F}{\pi} \left[2 + \theta_2 \frac{J_1 - J_2}{2} + \theta_4 J_{pk} \right]}$$

Output Plane

$$F = \frac{f_s}{f_0}$$

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



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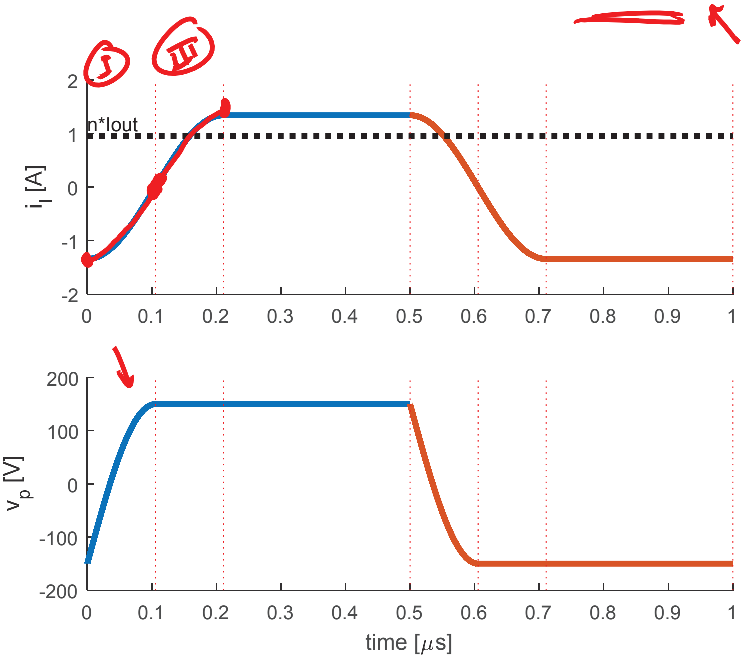
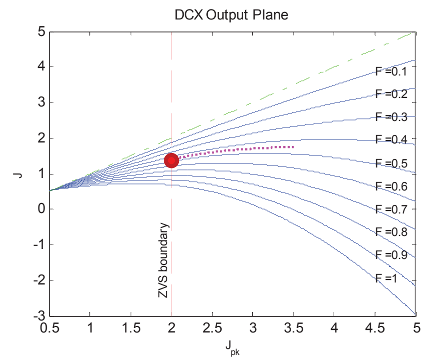
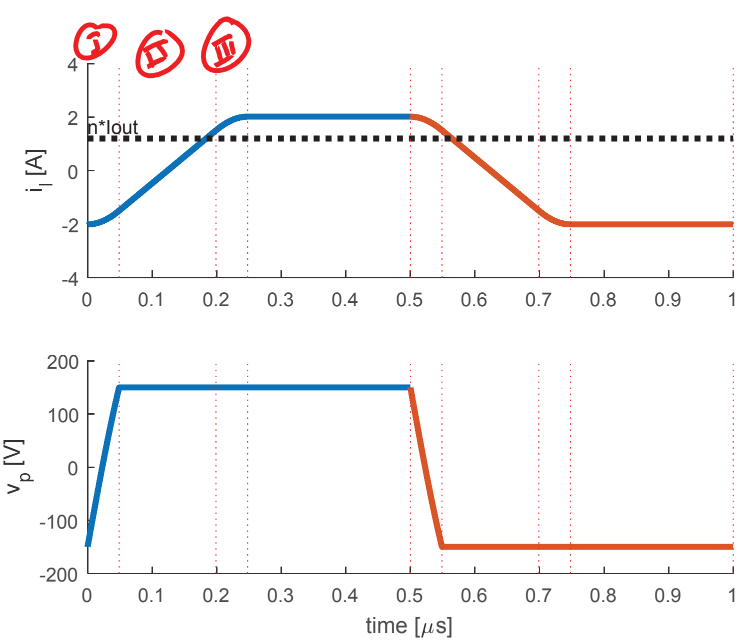
Example Waveforms

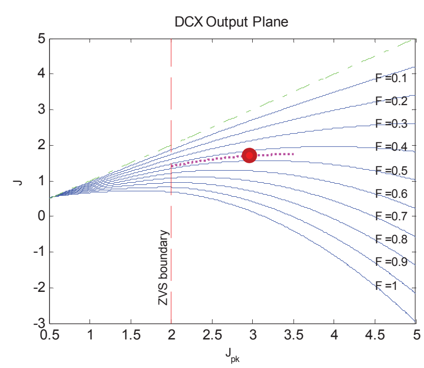
f_s = 1MHz
V_g = 150V
V = 12V
L_r = 15mH
C_p = 300pF
$C_s = \frac{C_p}{n^2}$



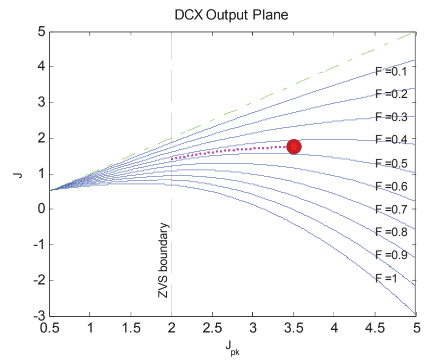


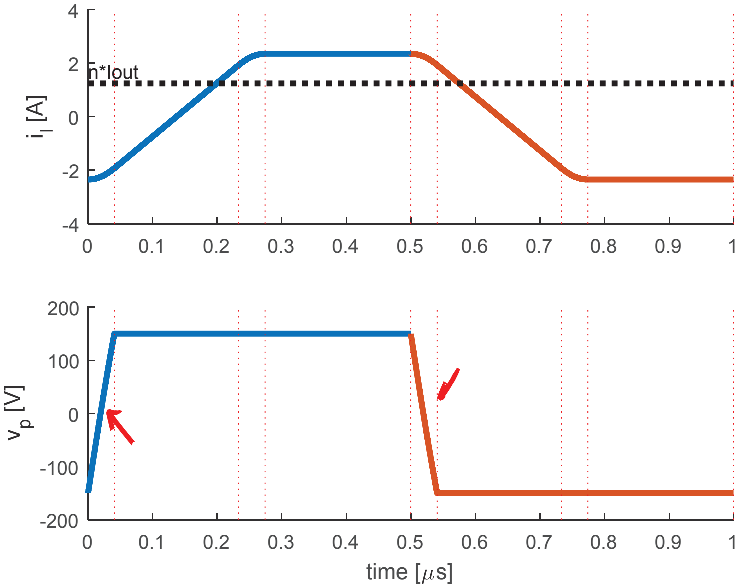
Example Waveforms



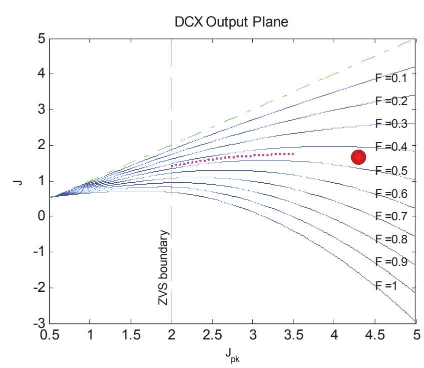


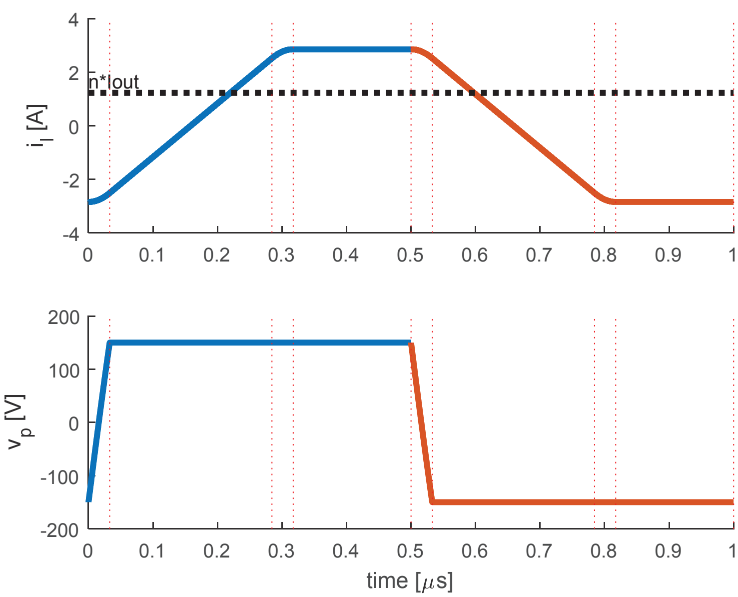
Example Waveforms



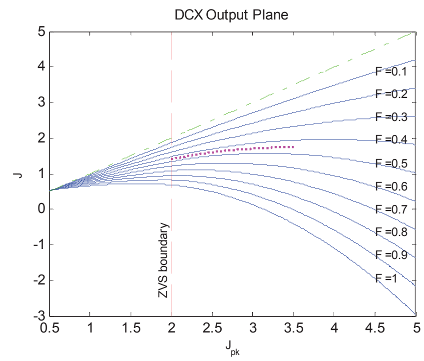


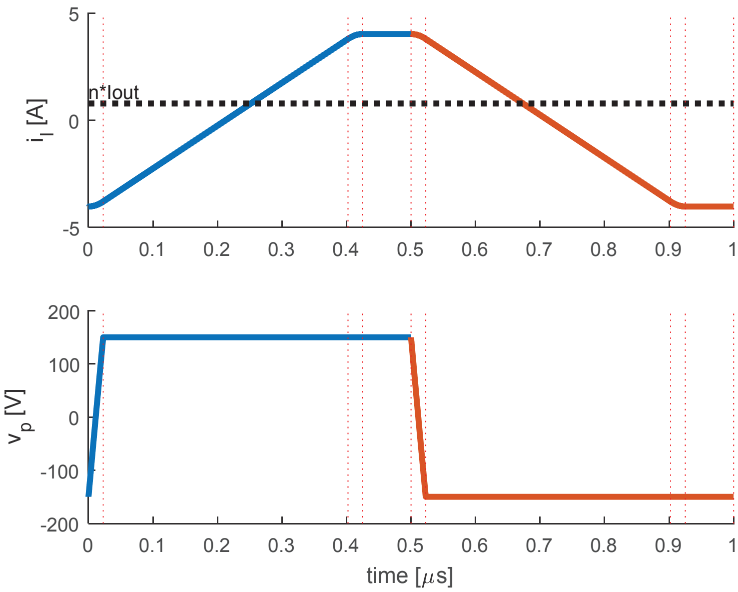
Example Waveforms



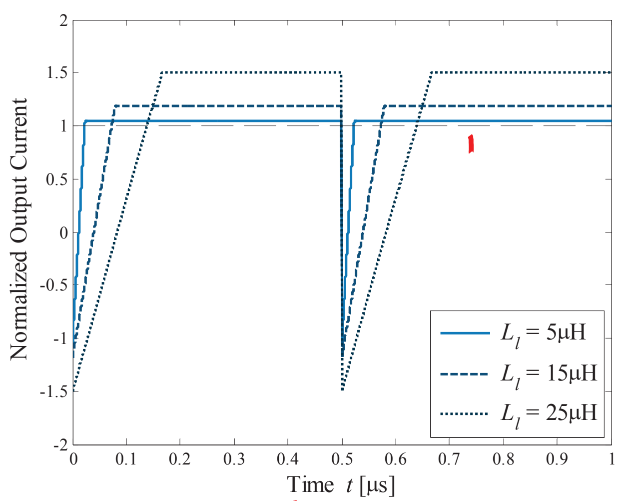


Example Waveforms



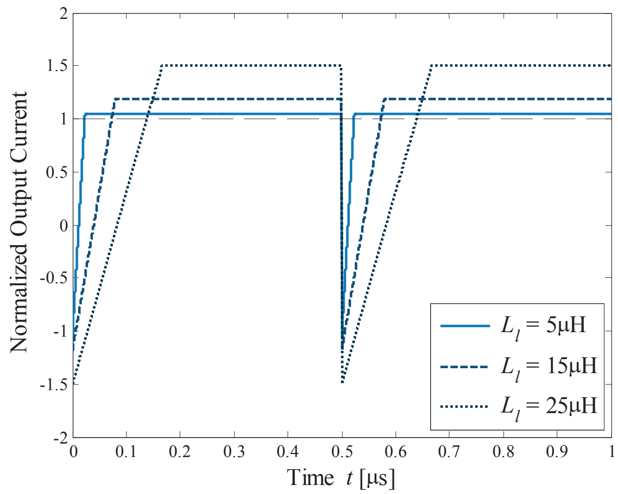


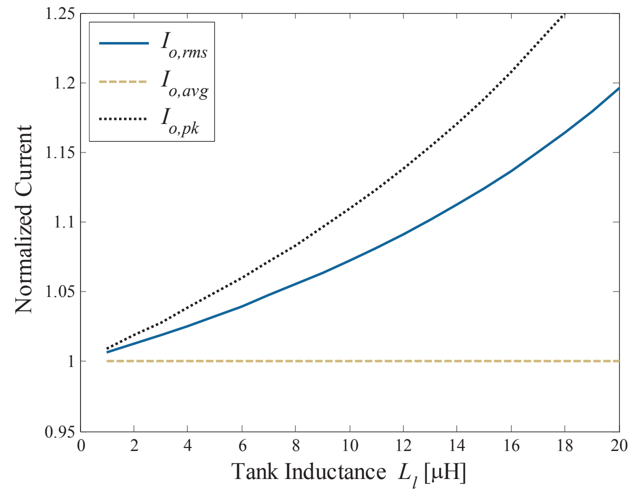
Output Current Vs. Inductance



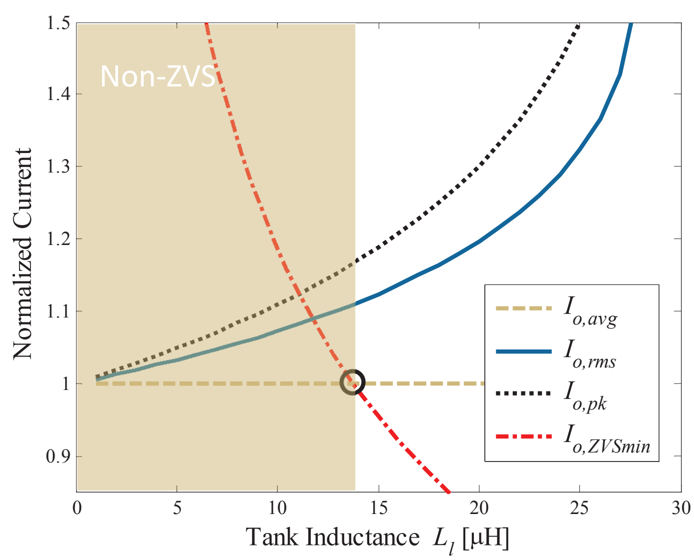
low (small) inductance is best for minimizing conduction losses.

Output Current Vs. Inductance

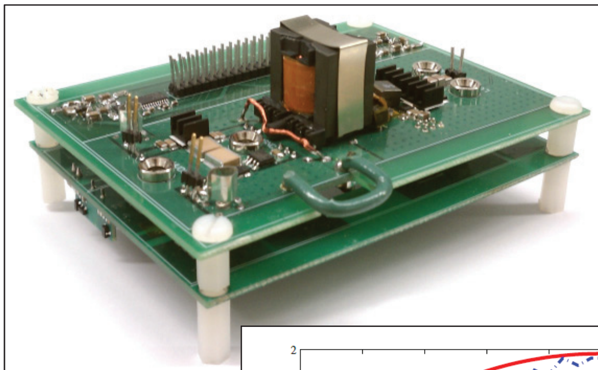


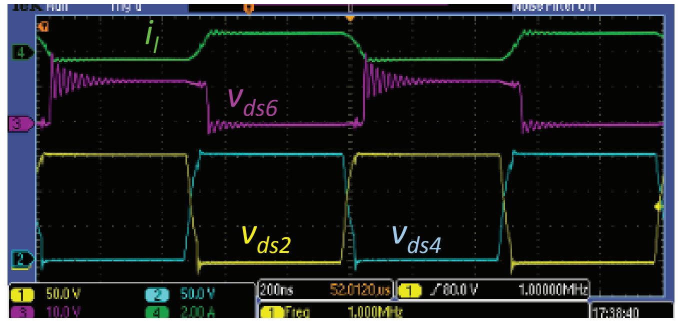


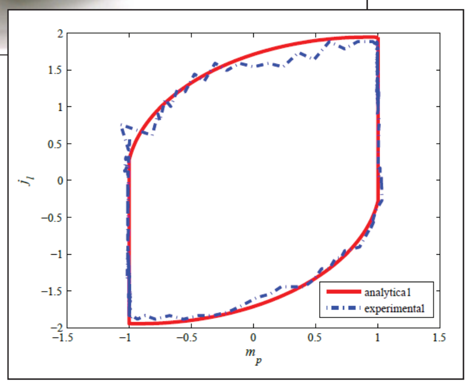
Constraints on Inductance

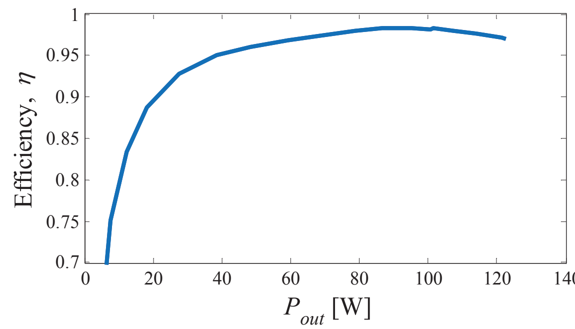


DAB: Experimental Results

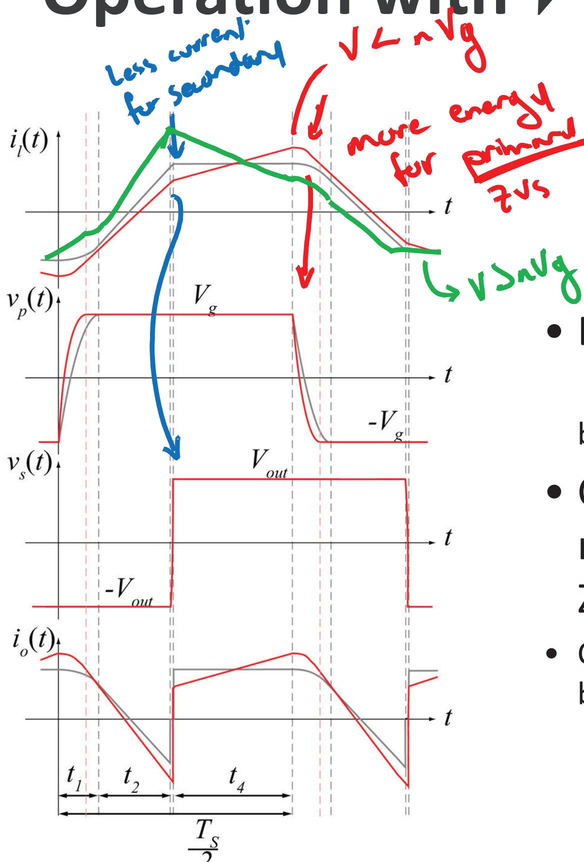


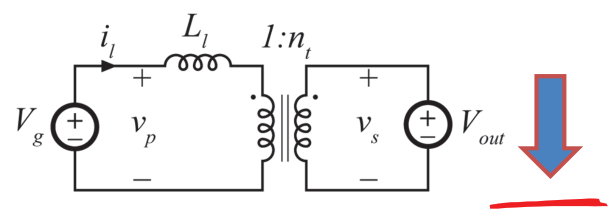






Operation with $V \neq nV_g$



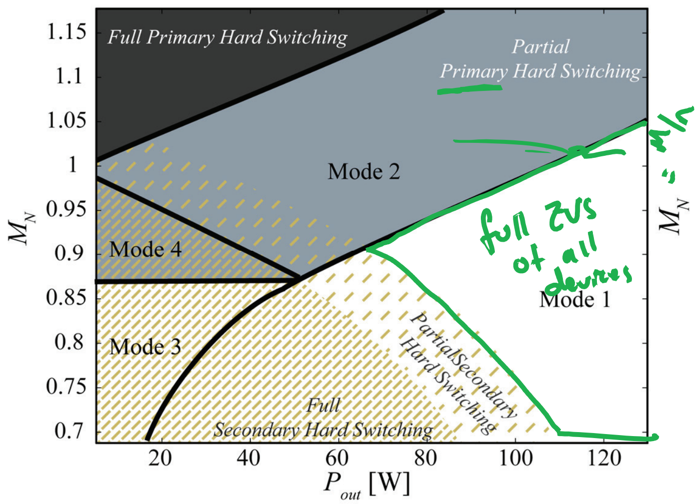


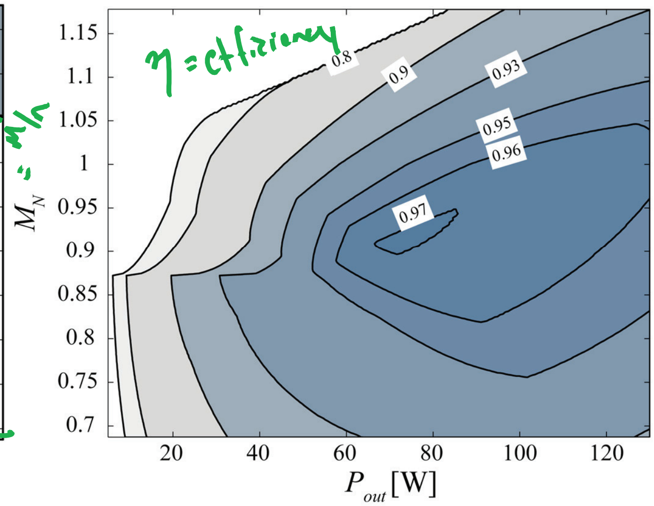
- E.g. Decrease to

  $M_N < 1$

  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}





Application Example: Automotive

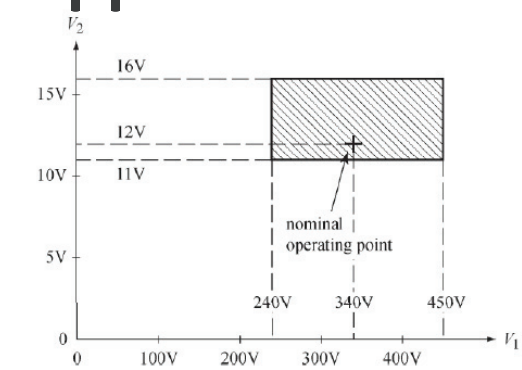


Fig. 1. Converter operating voltage ranges required for automotive application.

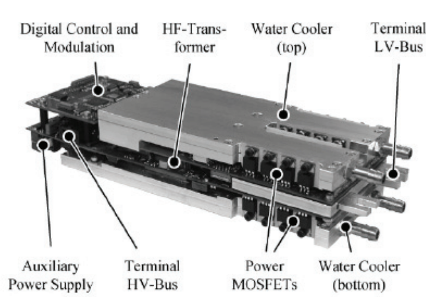
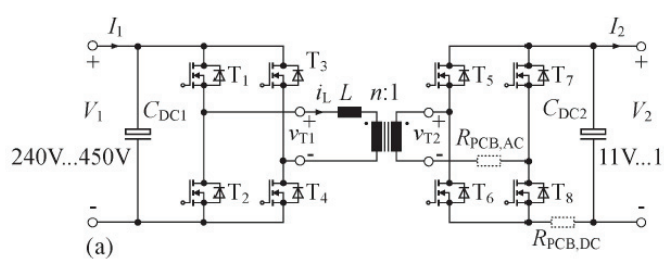


Fig. 3. Automotive DAB converter (273 × 90 × 53 mm).



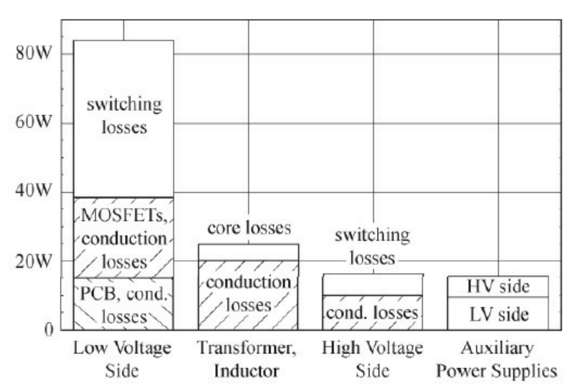


Fig. 13. Calculated distribution of the power losses for operation at $V_1 =$ 340 V, $V_2 = 12$ V, and $P_2 = 2$ kW.

*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