State Plane Solution

$$M = \frac{V_{out}}{V_g} = n_t$$

Ⓘ $r_1^2 = \boxed{J_{pk}^2 = J_1^2 + 4}$

$$\boxed{\alpha = \tan^{-1}\left(\frac{2}{J_1}\right)}$$

Ⓘ $\frac{V_g + \frac{V_{out}}{n_t}}{L_e} t_2 = I_2 + I_1$

$$\boxed{2\theta_2 = J_2 + J_1}$$

Ⓘ $r_2'^2 = \boxed{(J_{pk}')^2 = (J_2')^2 + 4}$

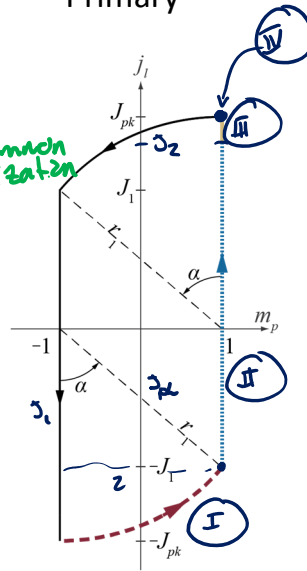$$\boxed{\delta' = \tan^{-1}\left(\frac{2}{J_2'}\right)}$$

Ⓘ $\longrightarrow X$

$\frac{T_s}{2} = t_1 + t_2 + t_3 + t_4$

$\frac{2\pi t_0}{2 t_s} = \boxed{\frac{\pi}{F} = \alpha + \theta_2 + \delta + \theta_4}$

changing to common normalization
e.g.

$\frac{\delta'}{\omega_0'} = t_3$

$t_3 \omega_0 = \delta$

Primary

Secondary
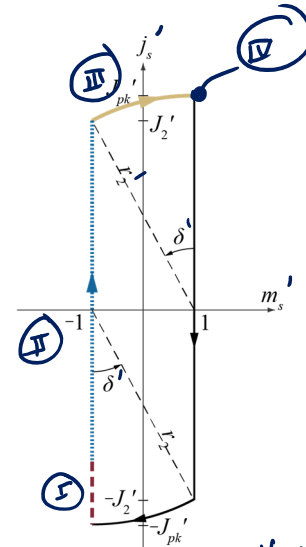

$V_{base} = V_g$

$$I_{base} = V_g \sqrt{\frac{C_p}{L_l}}$$

$V_{base}' = V_g - \frac{V_{out}}{n_t}$
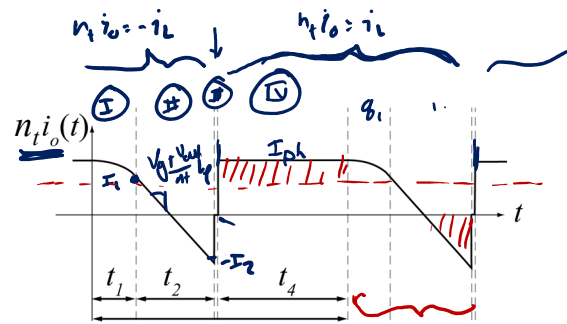
$$I_{base}' = V_g \sqrt{\frac{C_s}{n_t^2 L_l}}$$

Averaging Step

$$n_t I_{out} = \frac{2}{T_s} \int_0^{T_s/2} n_t i_o(t) \, dt = \frac{2}{T_s} \int_0^{T_s/2} \div i_L(t) \, dt$$

$$n_t I_{out} = \frac{2}{T_s} \left[g_1 + g_2 + g_3 + g_4 \right]$$

$$\left(\frac{1}{I_{base}}\right) n_t I_{out} = \frac{2}{T_s} \left[C_p 2 V_g + \frac{I_1 - I_2}{2} t_2 + \cancel{0} + I_{pk} t_4 \right] \left(\frac{1}{I_{base}}\right) \left(\frac{w_0}{w_0}\right) \frac{T_s}{2}$$
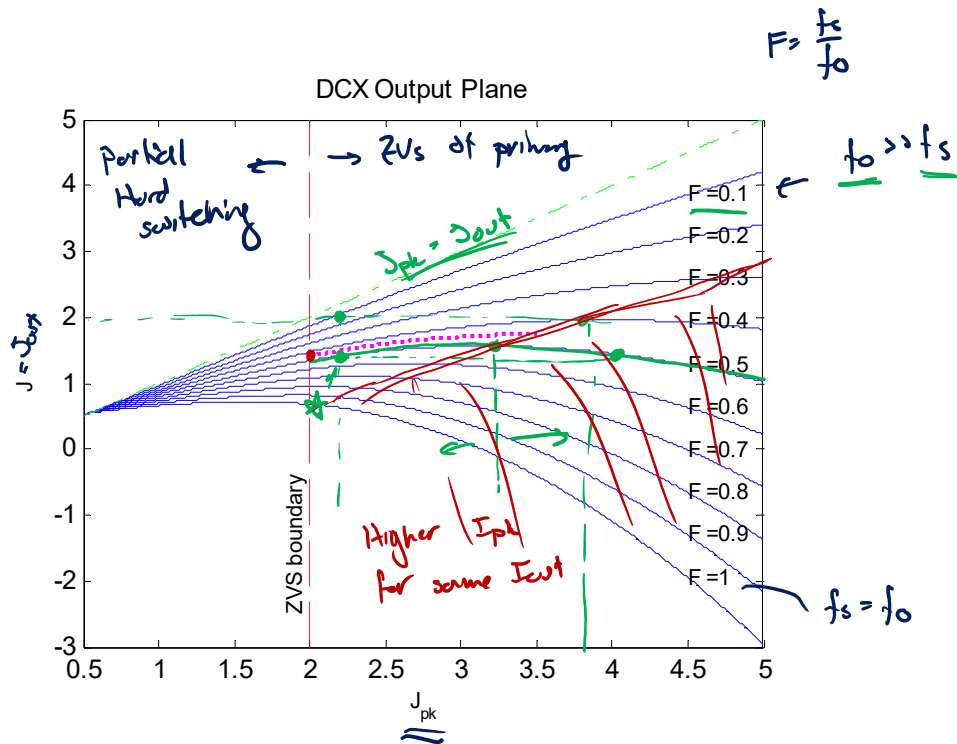
$$\boxed{n_t I_{out} = \frac{F}{\pi} \left[2 + \frac{I_1 - I_2}{2} \theta_2 + I_{pk} \theta_4 \right]}$$

$$\frac{\frac{1}{w_0}}{2 C_p R_0 w_0}$$

$$n_t i_o = -i_L \qquad n_t i_o = i_L$$

$$n_t i_o(t)$$

① ② ③ ④ g_1

I_1 $V_g, \frac{V_q}{dt}$ I_{pk}

$-I_2$

t_1 t_2 t_4

$\frac{T_s}{2}$

Output Plane

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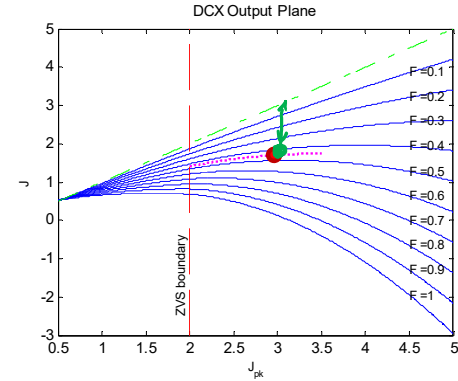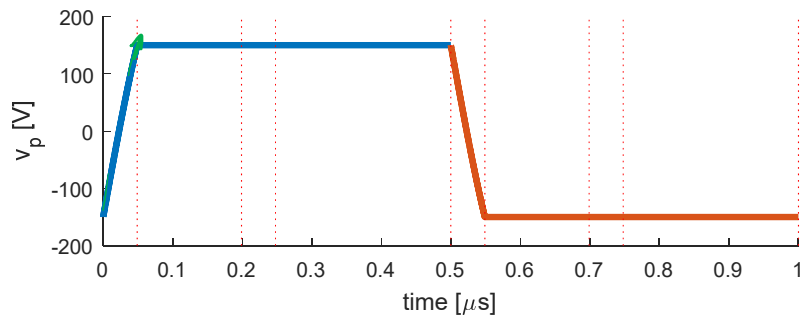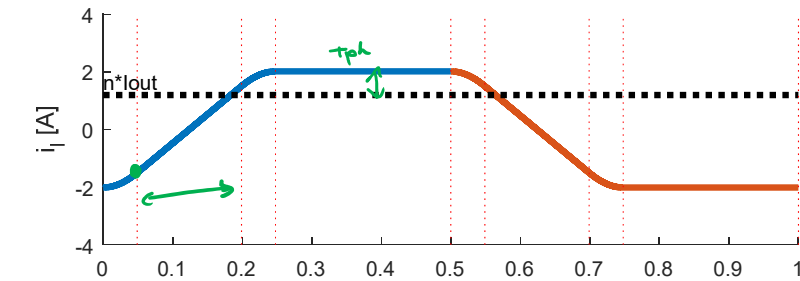

DCX Output Plane

Example Waveforms

$f_s = 1\,MHz$ $V_{out} = 12V$ $V_g = 150\,V$

$L_p = 15\mu H$ $C_p = 300\,pF$ $C_s = \dfrac{C_p}{n^2}$
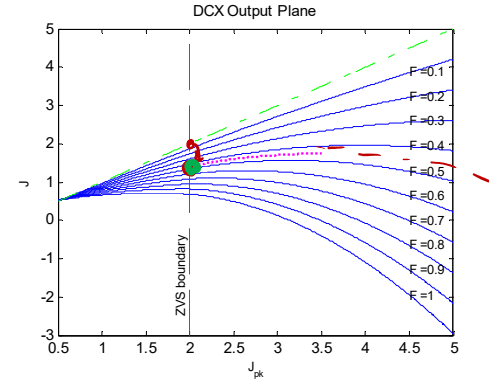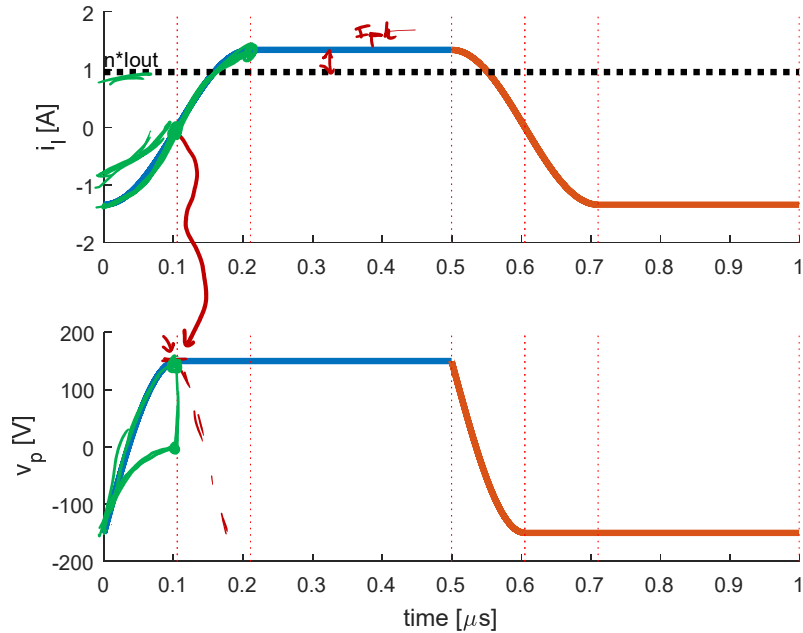
Example Waveforms
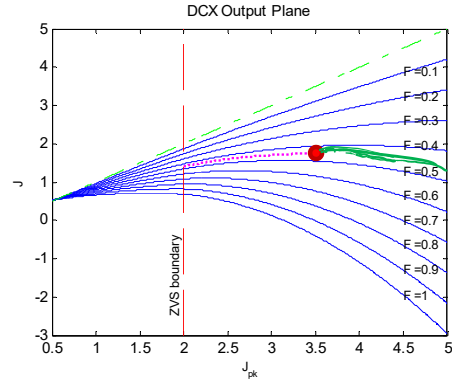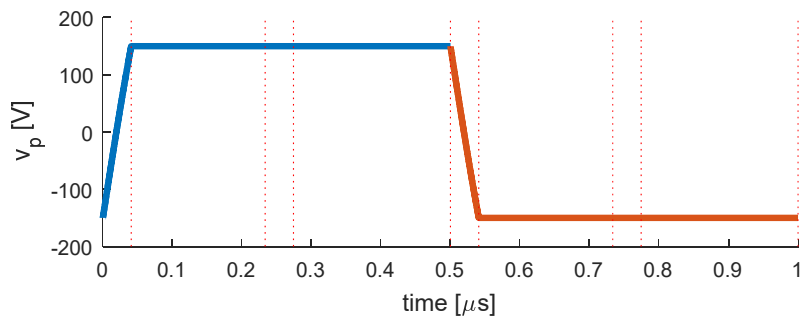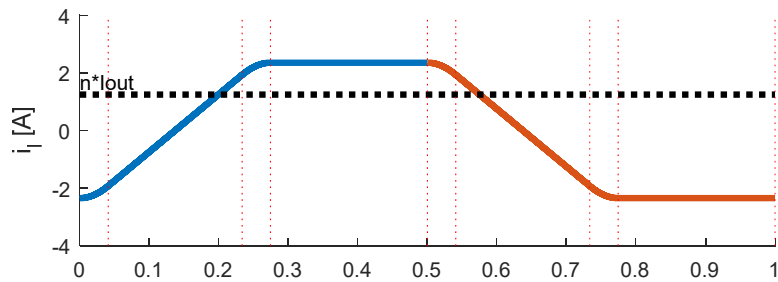
Example Waveforms
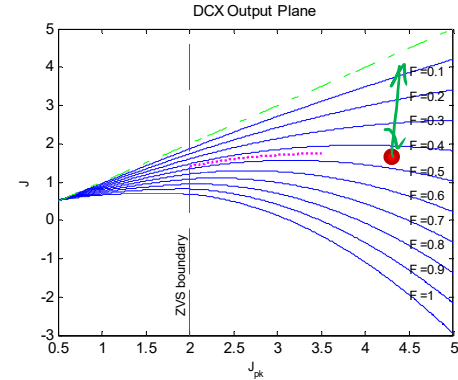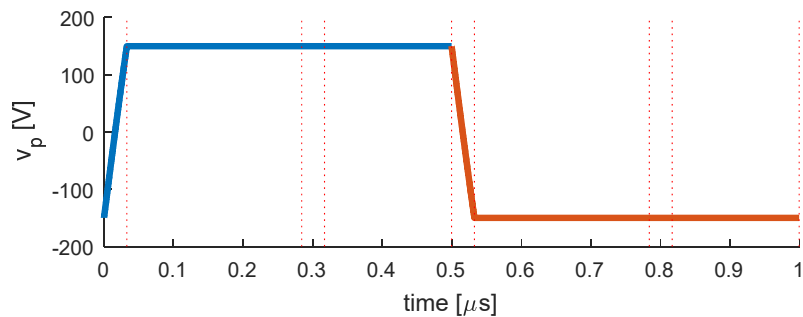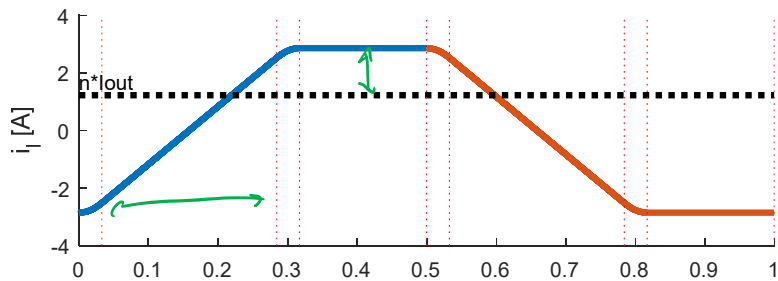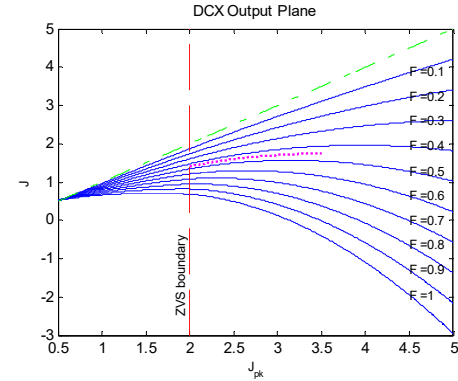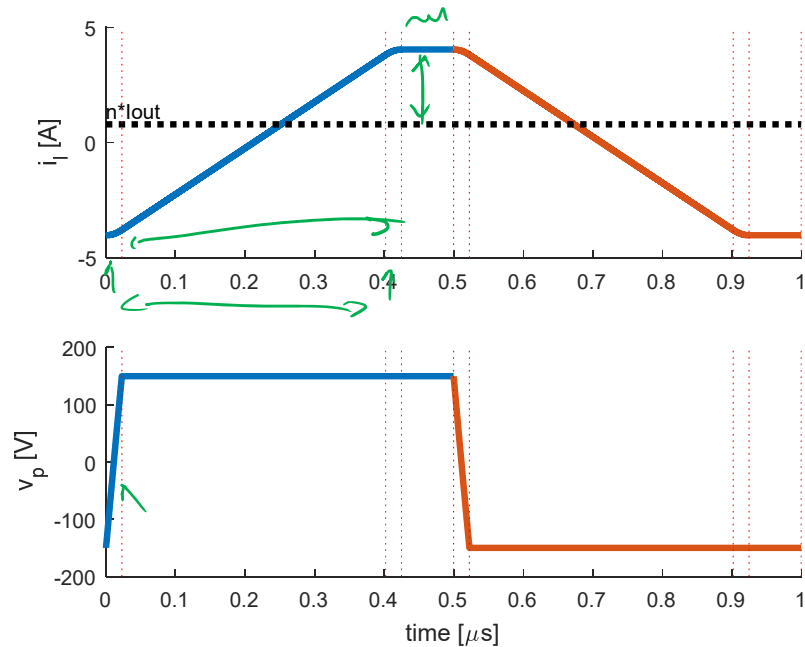
Example Waveforms
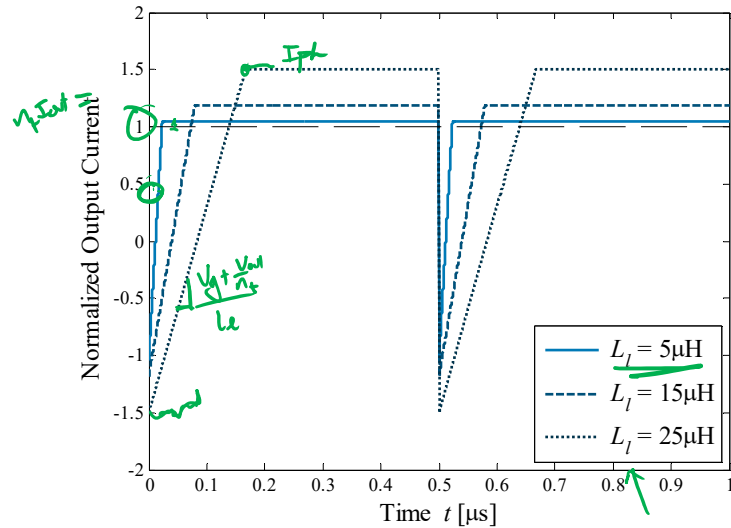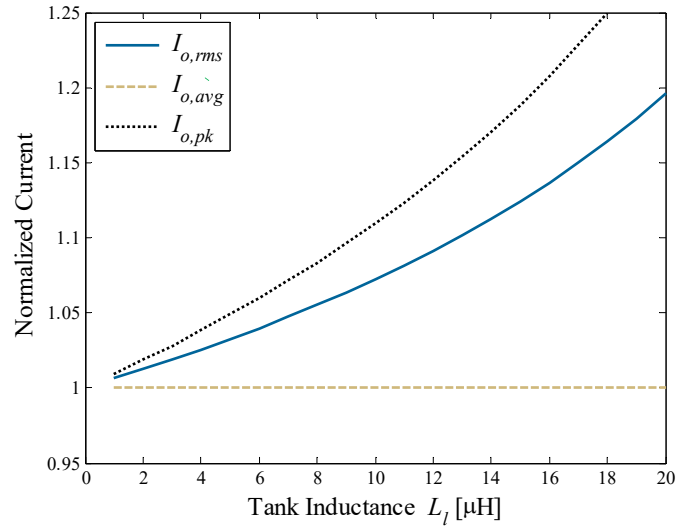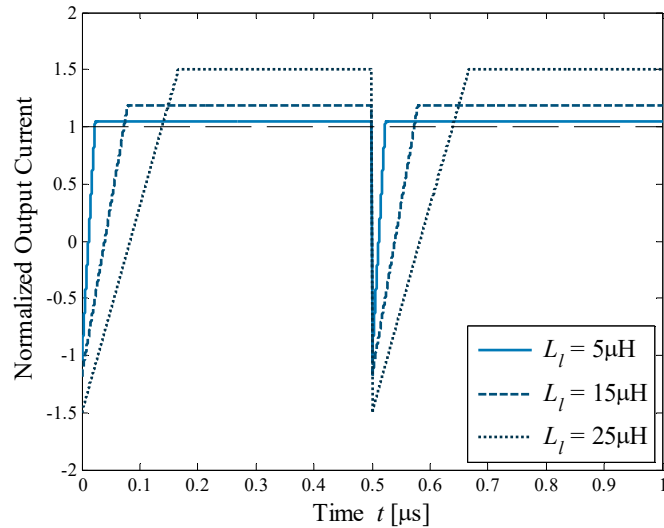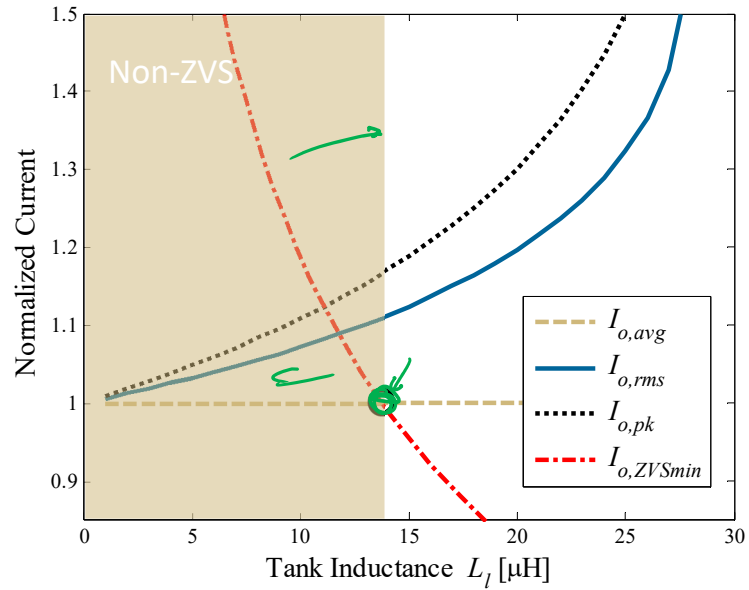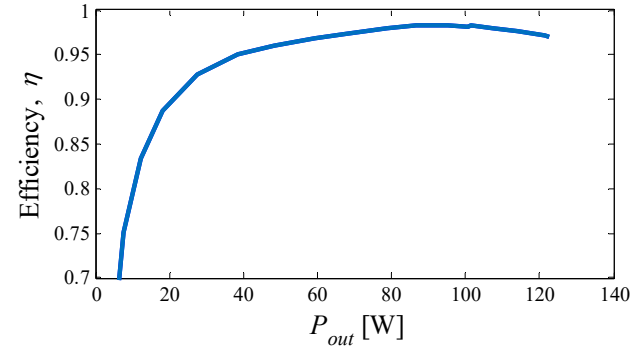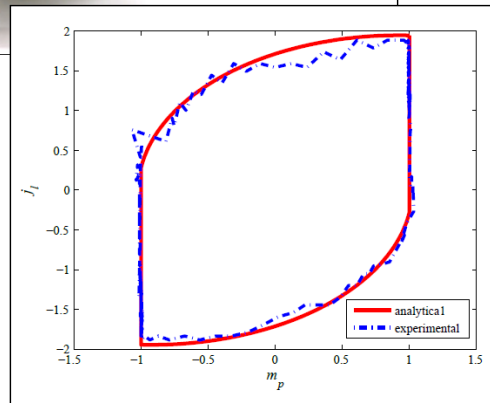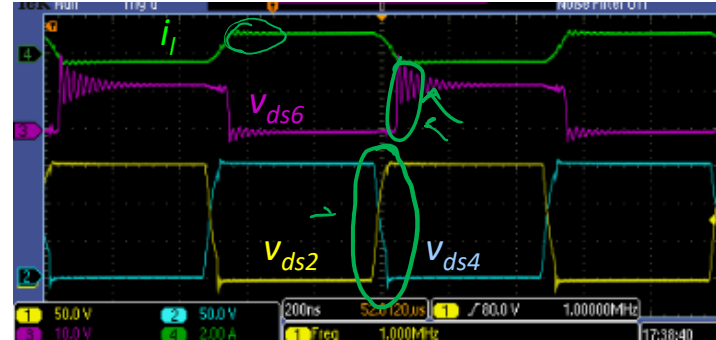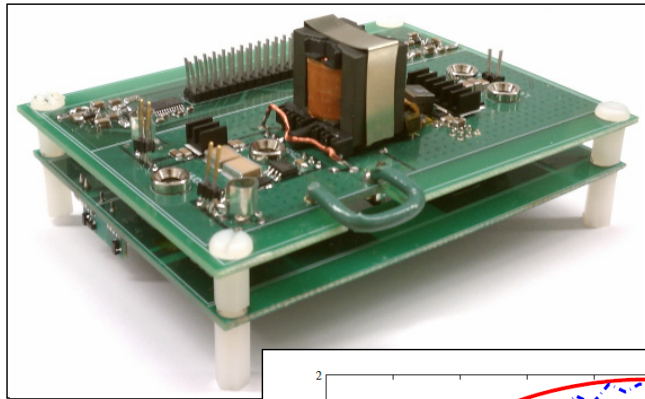
Example Waveforms

Output Current Vs. Inductance
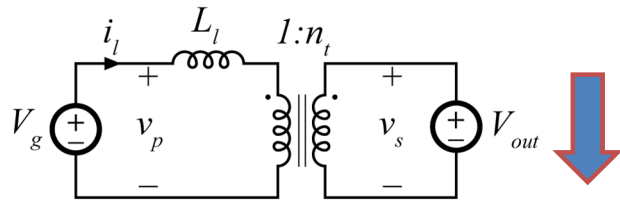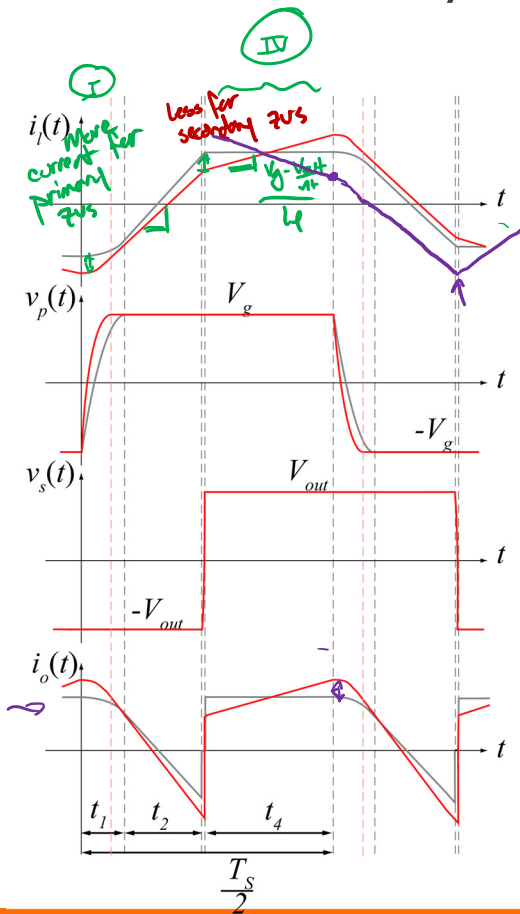
Output Current Vs. Inductance

Constraints on Inductance

DAB: Experimental Results

Operation with $V \neq nV_g$

- E.g. Decrease to $M_N < 1$ by decreasing output voltage

  M < nt

  if M > nt opposite

- Current now ramping, causing more energy available for primary ZVS, but higher RMS currents

- Can use behavior to extend ZVS range of one bridge