

Averaging

Volt-second balance Lf

$$\langle N_{Lf} \rangle = \phi = \langle N_{sw} \rangle - V$$

$$V = \langle N_{sw} \rangle = V_g - \langle N_{cr} \rangle - \phi$$

$$\rightarrow V = V_g - \langle N_{cr} \rangle$$

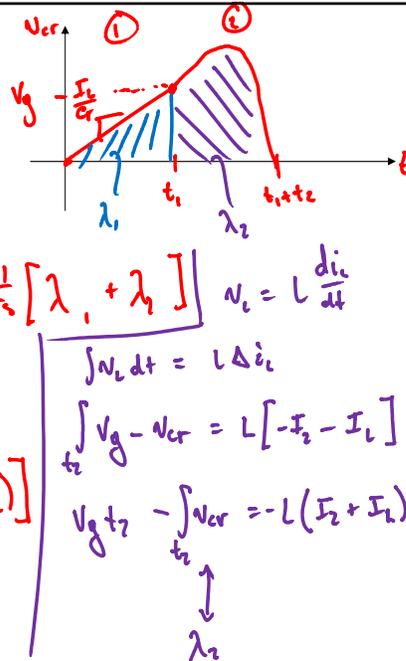
$$\langle N_{cr} \rangle = \frac{1}{T_s} \int_0^{T_s} N_{cr} dt = \frac{1}{T_s} [\lambda_1 + \lambda_2] \quad N_c = L \frac{di_c}{dt}$$

$$\lambda_1 = \frac{1}{2} t_1 V_g$$

$$\lambda_2 = V_g t_2 + L(I_2 + I_c)$$

$$\langle N_{cr} \rangle = \frac{1}{T_s} \left[\frac{1}{2} t_1 V_g + V_g t_2 + L(I_2 + I_c) \right]$$

$$M_{cr} = \frac{F}{2\pi} \left[\frac{\theta_1}{2} + \beta + J_2 + J_c \right]$$



Complete Solution

(half-wave)

$$M_{cr} = \frac{F}{2\pi} \left[\frac{\theta_1}{2} + \beta + J_c + J_2 \right]$$

$$M = \frac{V}{V_g} = \frac{V_g - \langle N_{cr} \rangle}{V_g} = 1 - M_{cr}$$

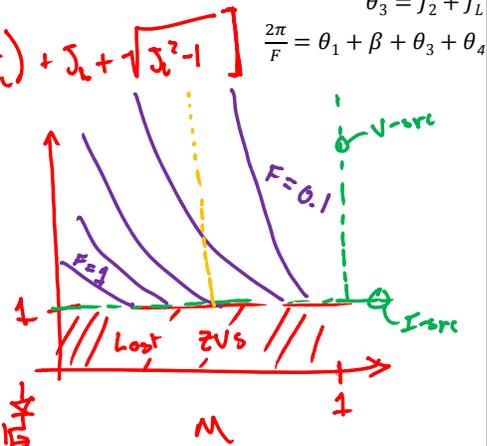
$$M = 1 - \frac{F}{2\pi} \left[\frac{1}{2J_c} + \pi + \sin^{-1}\left(\frac{1}{J_c}\right) + J_c + \sqrt{J_c^2 - 1} \right]$$

$$M = f(F, J_c)$$

FP 1/2 in book (20.61) \rightarrow (20.46)

Note: Full wave ZVS-QR switch:

- Has V-src
- Requires bidirectional voltage implementation of Q



MOSFET Voltage Stresses

$$M_{ds,pt} = 1 + \zeta_c$$

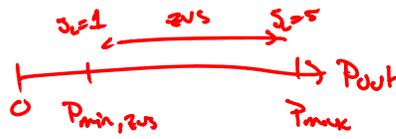
$$V_{ds,pt} = V_g + V_g \zeta_c$$

if ZVS over 80% of load range

$V_{ds,pt}$ @ full power $\approx 6V_g$

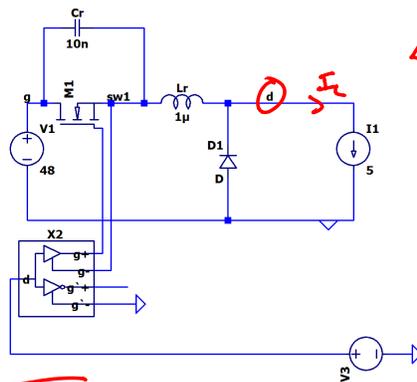
ZVS condition:

$$\zeta_c \geq 1$$



Test Circuit

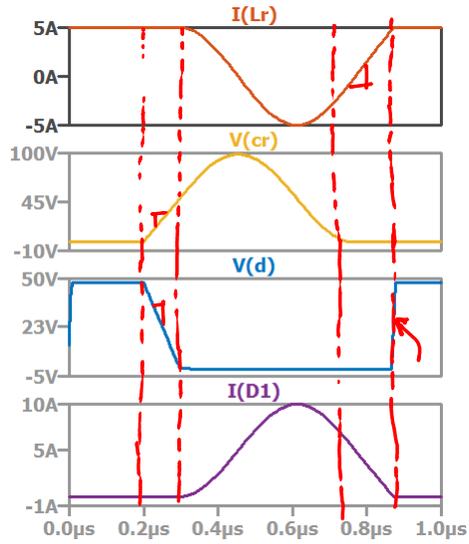
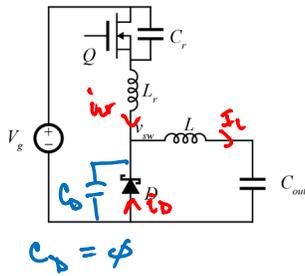
$$f_s = 1 \text{ MHz}$$



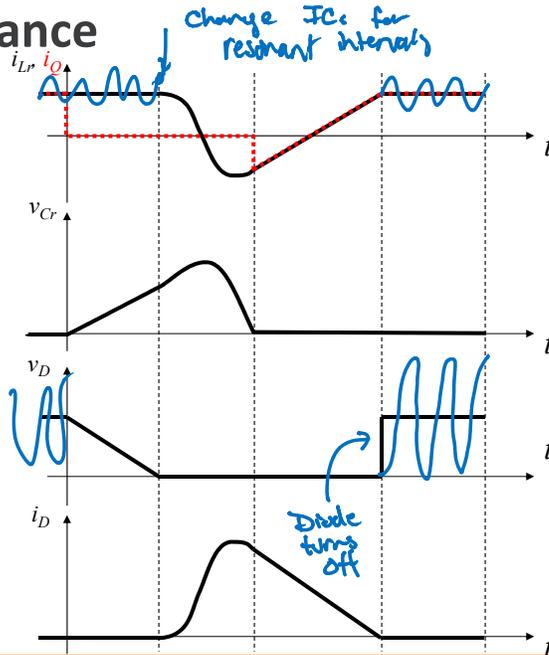
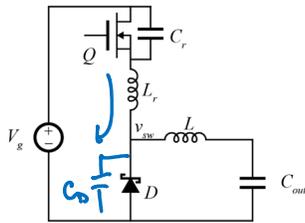
$$\langle V_d \rangle \approx 16V$$

$$\zeta_c = \frac{5A}{48V} \sqrt{\frac{1\mu}{10n}} \approx 1 \rightarrow \text{near ZVS boundary}$$

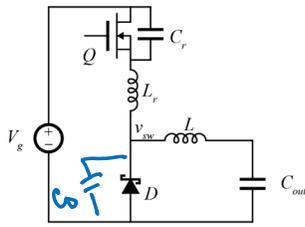
Simulation Results



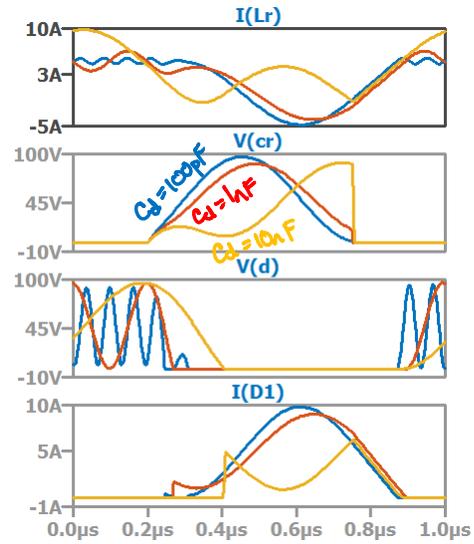
Diode Capacitance



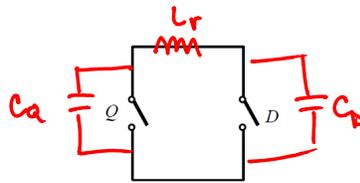
Simulation Results: Diode Capacitance



$$C_g \gg C_p$$



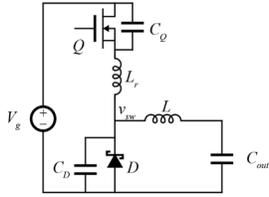
Wishlist: Multi-Resonant



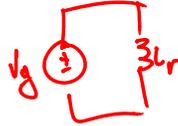
Next: ZVS-MR

ZVS-MR Buck

Devices Conducting Eg. Circ. R_o

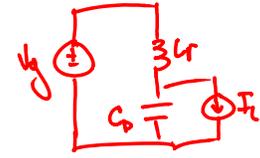


Q, D



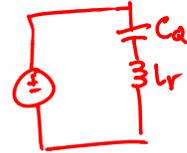
X
Linear

Q



$$R_o = \sqrt{\frac{L_r}{C_o}}$$

D



$$R_o = \sqrt{\frac{L_r}{C_a}}$$

W. A. Tabisz and F. C. Lee, "Zero-voltage-switching multi-resonant technique—a novel approach to improve performance of high frequency quasi-resonant converters," *Power Electronics Specialists Conference, 1988*.



All devices off

