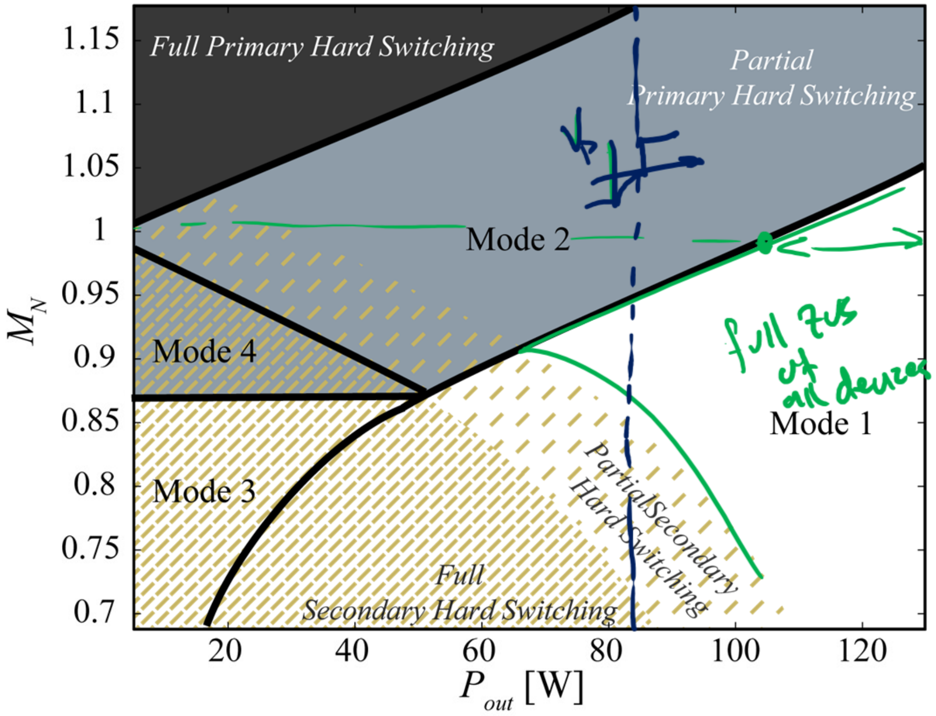
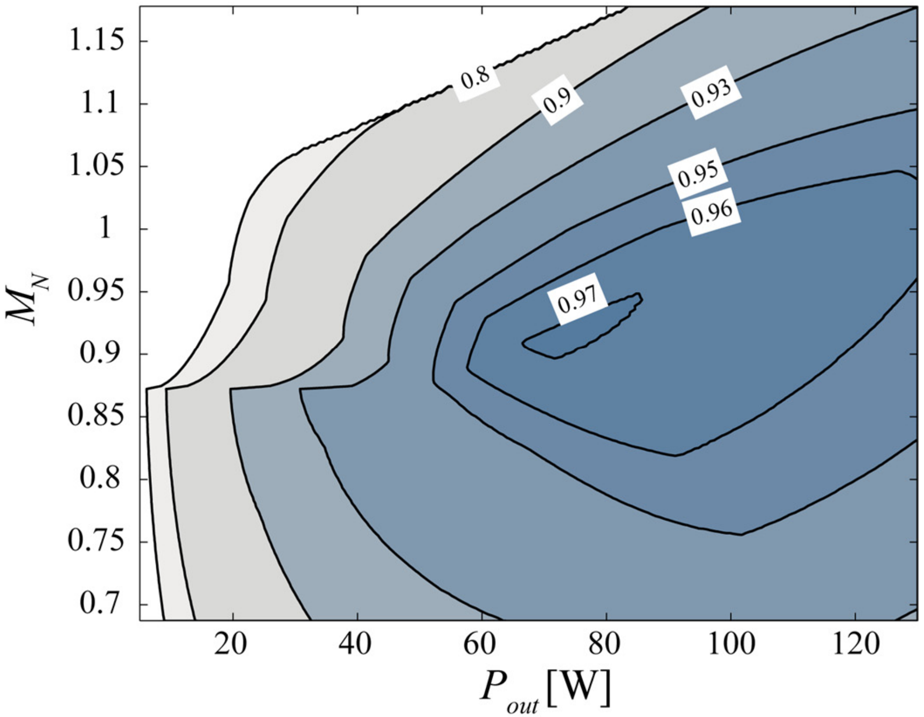
Soft Switching Range with Varying V_{out}





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

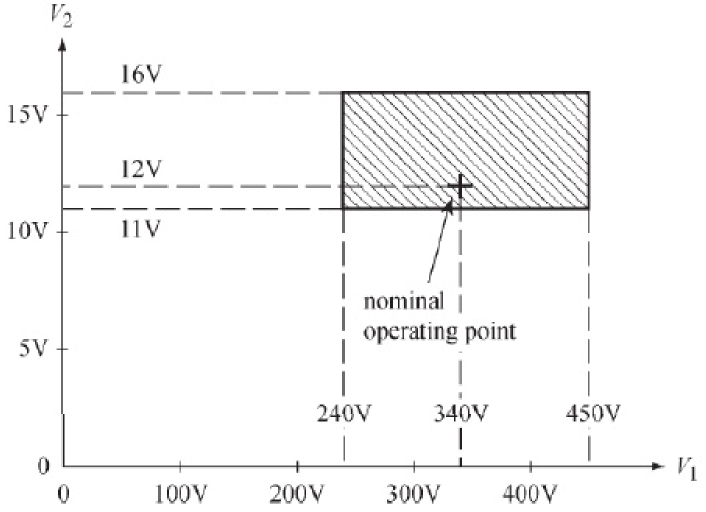
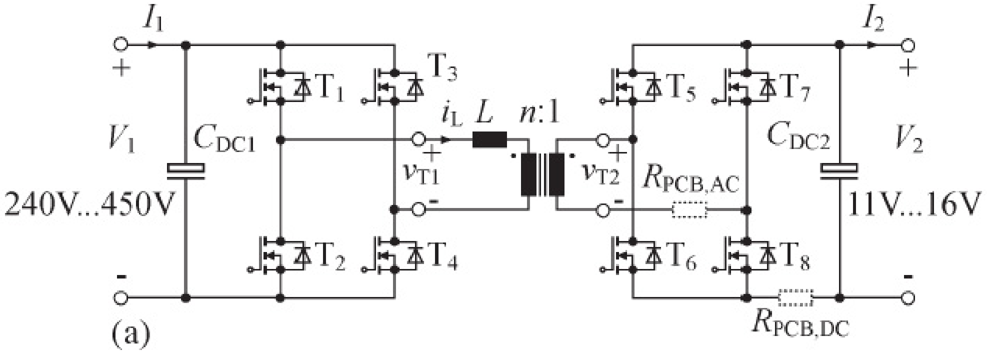


Fig. 1. Converter operating voltage ranges required for automotive application.



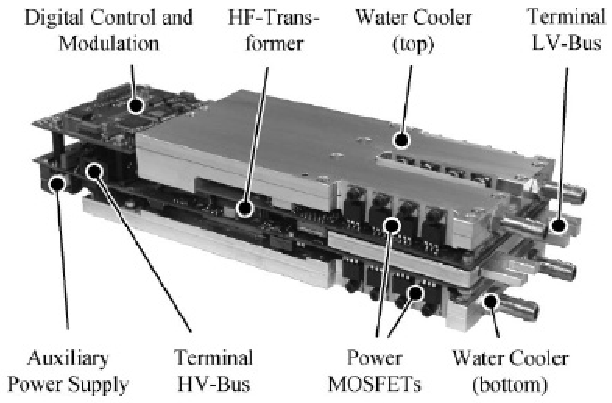


Fig. 3. Automotive DAB converter (273 × 90 × 53 mm).

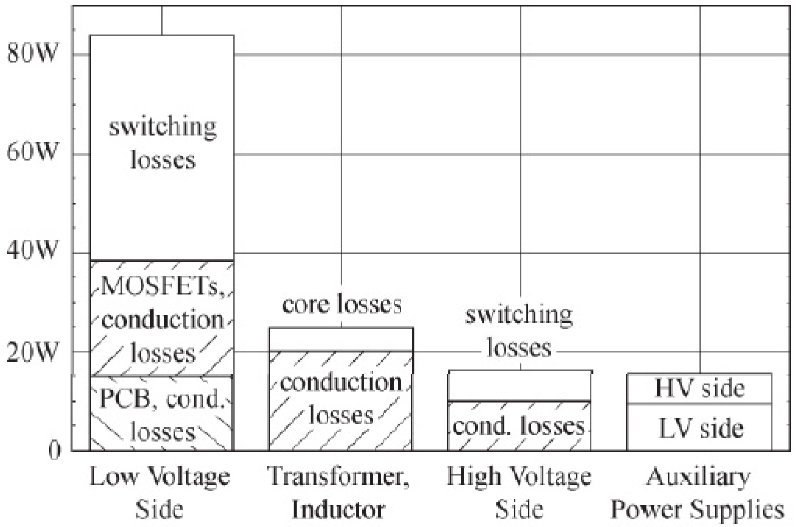
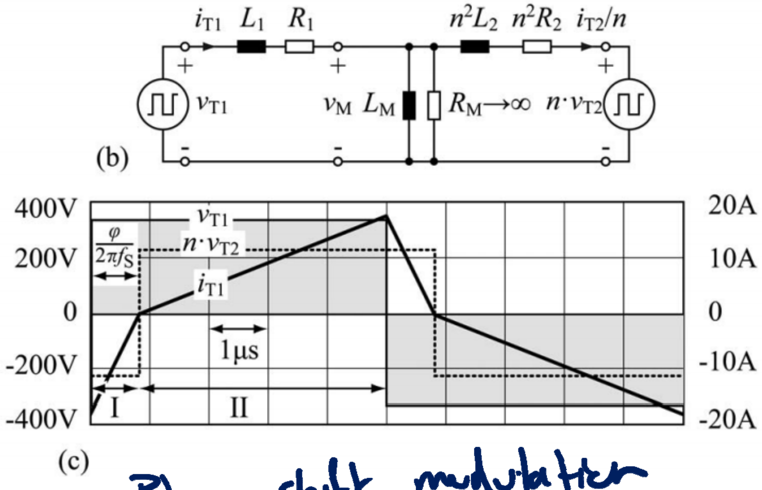


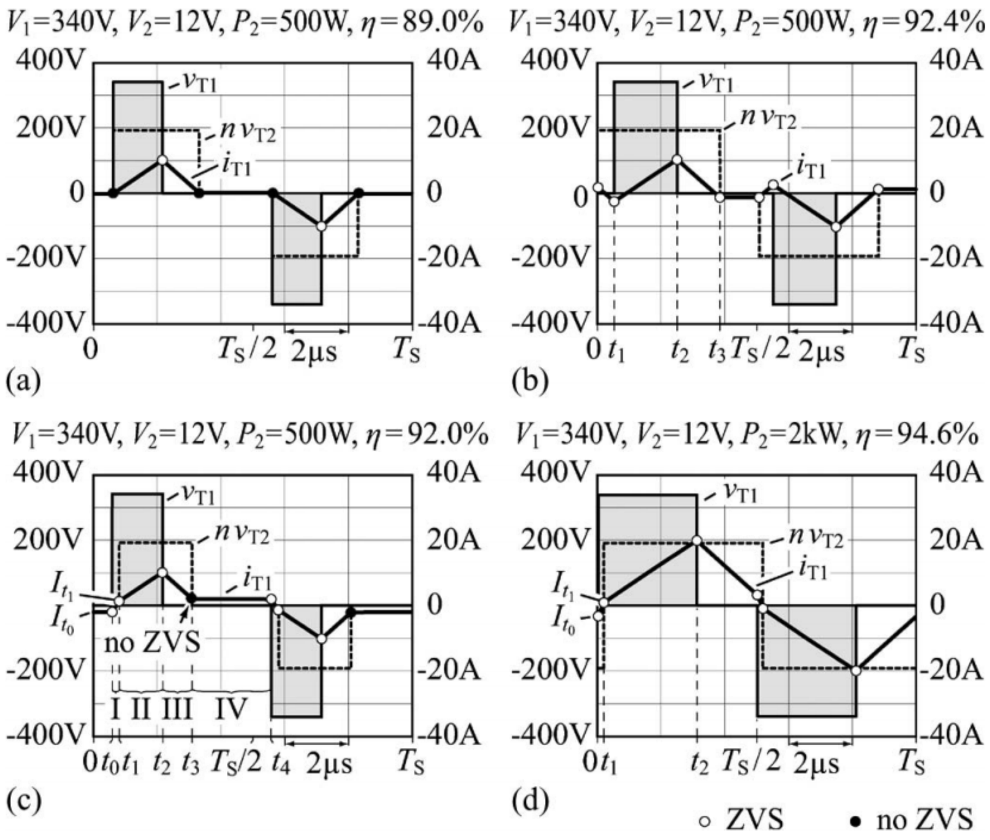
Fig. 13. Calculated distribution of the power losses for operation at $V_1 =$ 340 V, $V_2 = 12$ V, and $P_2 = 2$ kW.

*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

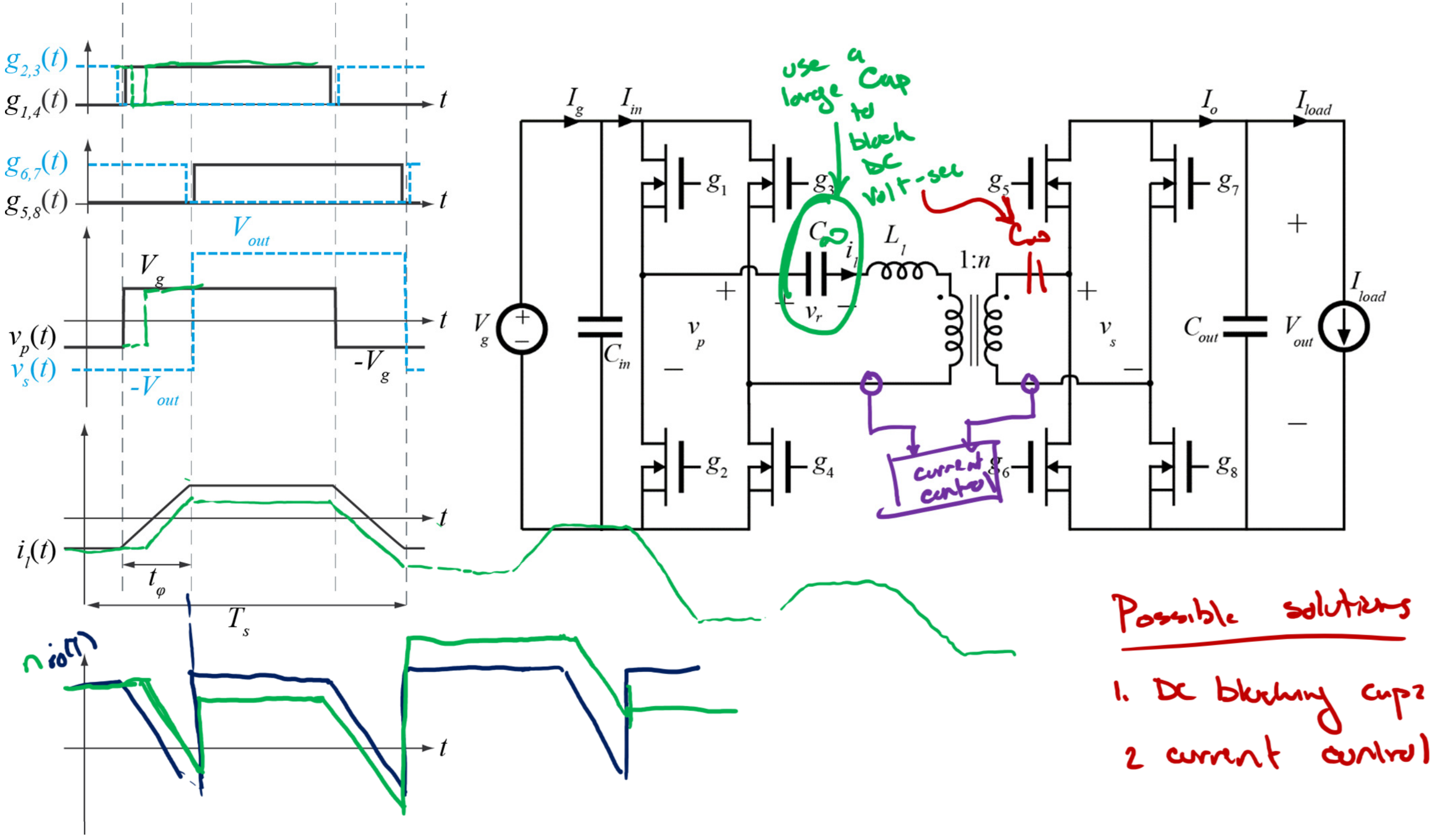


Phase shift modulation



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

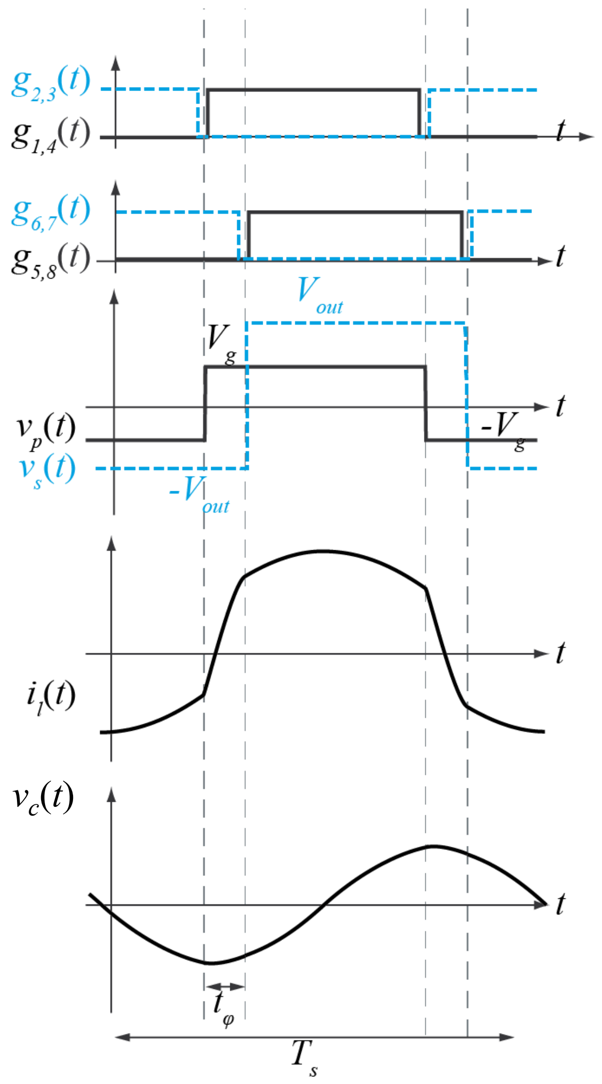
DAB: Transformer Saturation



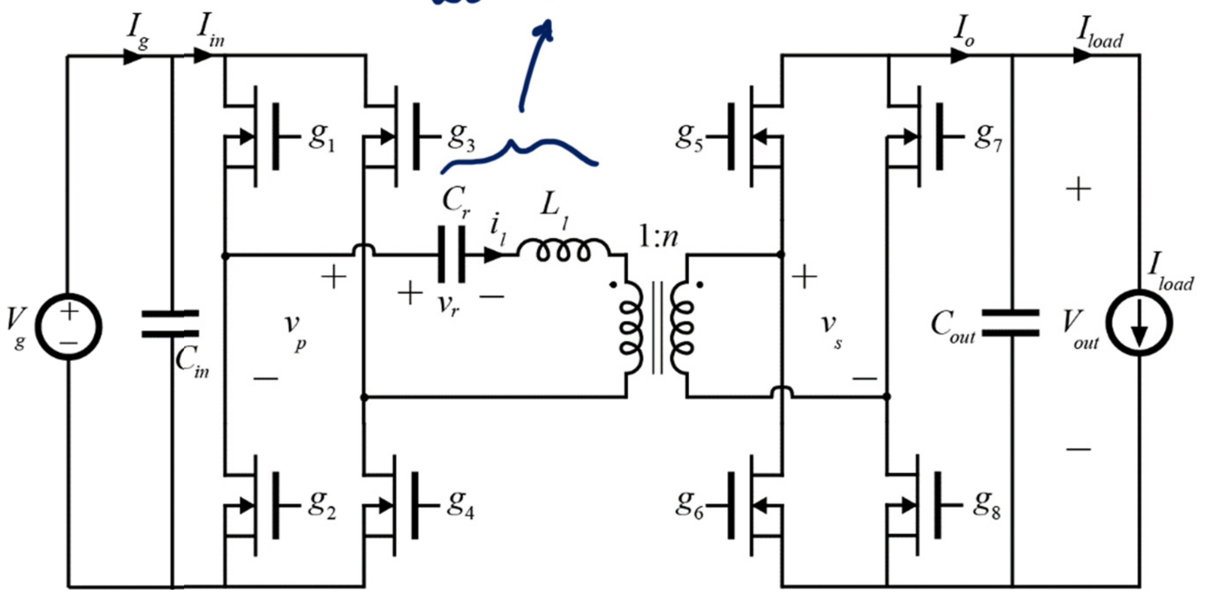
Possible solutions

1. DC blocking caps
2. current control

Series Resonant Converter



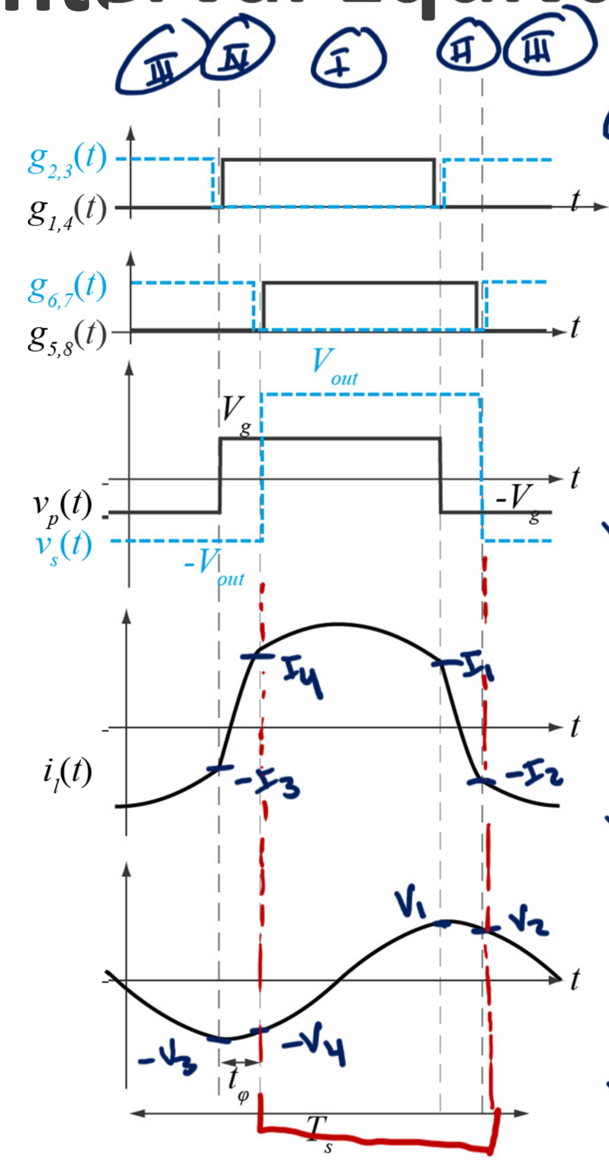
$\omega_0 = \frac{1}{\sqrt{L_r C_r}} \approx 2\pi f_s$

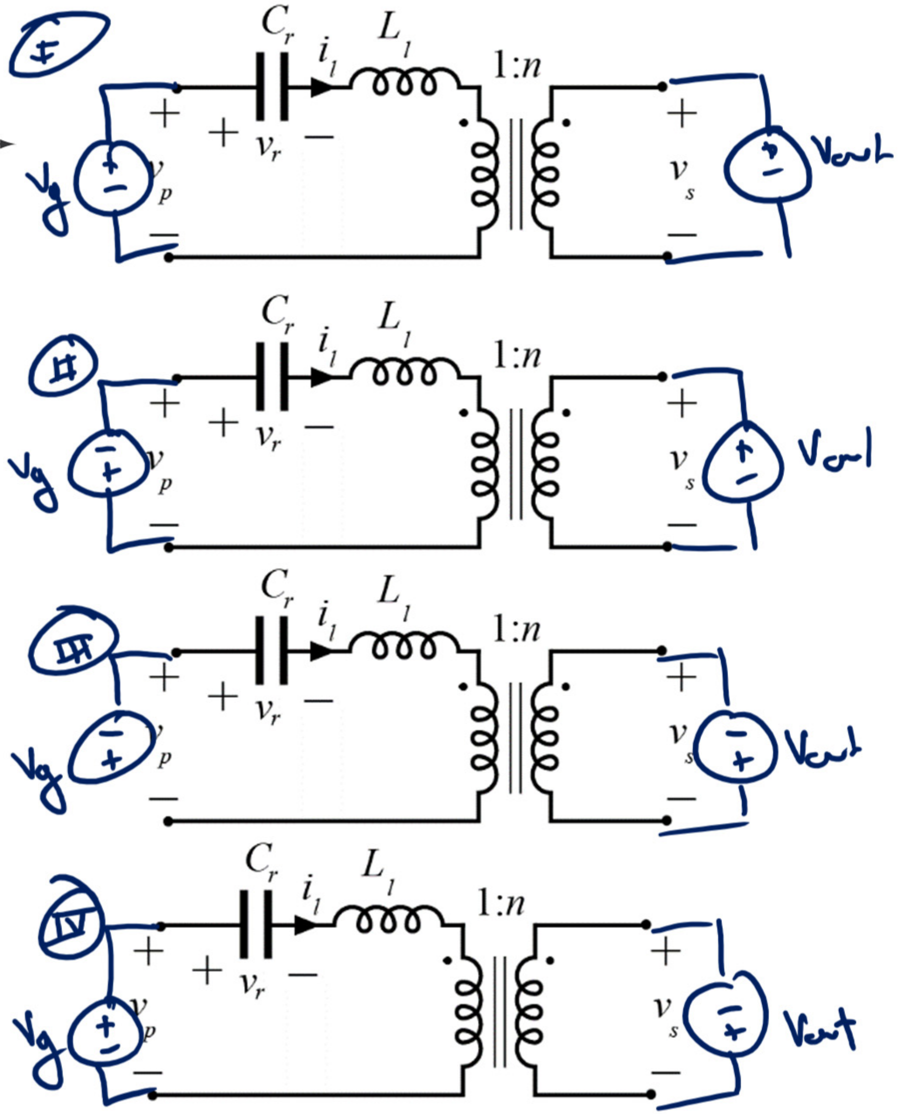


Analyze with $R_0 = \sqrt{\frac{L_r}{C_r}}$ & $\omega_0 = \frac{1}{\sqrt{L_r C_r}}$

(neglect C_p & C_s)

Subinterval Equivalent Circuits





$V_{base} = V_g$

Assume: $M = n$
DC solution

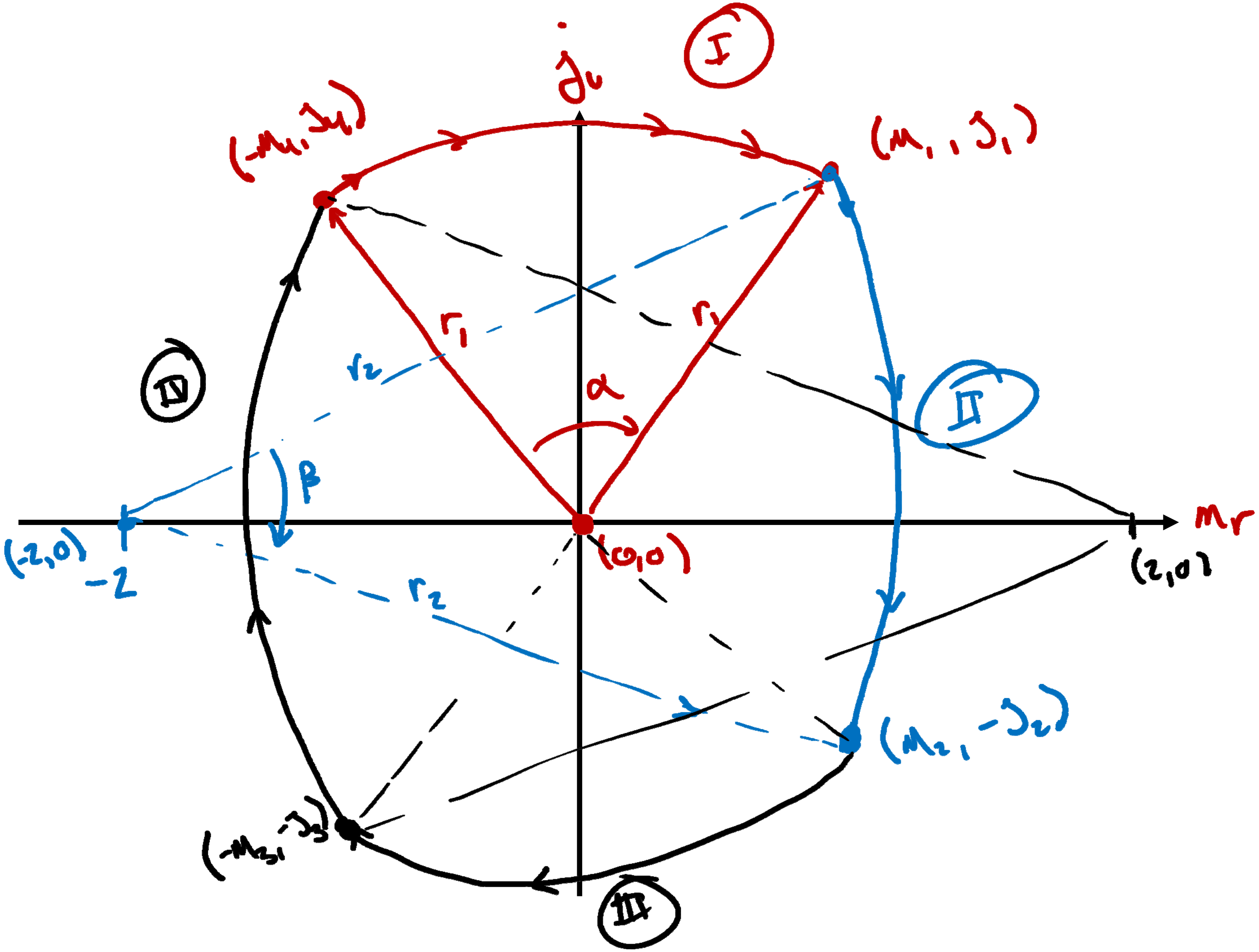
I: $v_r = V_g - \frac{V}{n}$, $i_L = 0$, $m_r = 0$, $j_L = 0$

II: $v_r = -V_g - \frac{V}{n}$, $i_L = 0$, $m_r = -2$, $j_L = 0$

III: $v_r = -V_g + \frac{V}{n}$, $i_L = 0$, $m_r = 0$, $j_L = 0$

IV: $v_r = V_g + \frac{V}{n}$, $i_L = 0$, $m_r = +2$, $j_L = 0$

Complete State Plane – Phase Shift Modulation



State Plane Solution

Because of symmetry

$M_1 = M_3 \qquad J_1 = J_3$

$M_2 = M_4 \qquad J_2 = J_4$

I

$r_1^2 = M_4^2 + J_4^2 = M_1^2 + J_1^2 = M_2^2 + J_2^2$

$\alpha = \tan^{-1}\left(\frac{M_4}{J_4}\right) + \tan^{-1}\left(\frac{M_1}{J_1}\right) =$

$\alpha = \tan^{-1}\left(\frac{M_2}{J_2}\right) + \tan^{-1}\left(\frac{M_1}{J_1}\right)$

II

$r_2^2 = (2+J_1)^2 + M_1^2 = (2+J_2)^2 + M_2^2$

$\beta = \tan^{-1}\left(\frac{J_1}{2+M_1}\right) + \tan^{-1}\left(\frac{J_2}{2+M_2}\right)$

$J_1^2 + 4J_1 + 4 + M_1^2 = J_2^2 + 4J_2 + 4 + M_2^2$

$J_1 + 1 = J_2 + 1$

$J_1 = J_2$ & $M_1 = M_2$ } consequence of $M = N$

$M_1 = M_2 = M_3 = M_4$ & $J_1 = J_2 = J_3 = J_4$

Also

$\frac{T_S}{2} = t_\alpha + t_\beta$

$\frac{\pi}{F} = \alpha + \beta$

Averaging Step

$$n\langle i_{out}\rangle = \frac{2}{T_s}\int_0^{T_s/2} i_2(t)\,dt$$

$$= \frac{2}{T_s}\left[q_1 + q_2\right]$$

$$q_1 = C_r\left(V_1 - (-V_4)\right) = C_r 2V_1$$

$$q_2 = C_r = \left(V_2 - V_1\right) = \phi$$

with $M_1 = M_2 = M_3 = M_4$

$$n\langle i_{out}\rangle = \frac{2}{T_s} C_r 2V_1$$

$$J = \frac{2}{T_s} 2C_r R_0 M_1 >$$

$$\boxed{J = \frac{F}{\pi} 2M_1}$$