ZVS-QR Switch Cell SSM

$\mu = 1 - F P_{1/2}\left(\frac{1}{J_L}\right)$

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

$F = \frac{f_s}{f_0}$ $\qquad$ $J_L = \frac{I_L}{V_g}R_0$

μ depends on f_s, i_L, and v_g

$\hat{\mu} = k_i \hat{i}_L + k_c \hat{f}_s + k_v \hat{v}_g$,

$$\begin{cases} k_i = \left.\frac{\partial \mu}{\partial i_L}\right|_{DC} = -F \frac{\partial P_{1/2}\left(\frac{1}{J_L}\right)}{\partial J_L}\frac{R_0}{V_g} \\ k_c = \left.\frac{\partial \mu}{\partial f_s}\right|_{DC} = -\frac{1}{f_0} P_{1/2}\left(\frac{1}{J_L}\right) \\ k_v = \left.\frac{\partial \mu}{\partial v_g}\right|_{DC} = -F \frac{\partial P_{1/2}\left(\frac{1}{J_L}\right)}{\partial J_L}\left(\frac{-I_L R_0}{V_g^2}\right) \end{cases}$$

$$P_{1/2}\left(\frac{1}{J_L}\right) = \frac{1}{2\pi}\left[\frac{1}{2J_L} + \pi + \sin^{-1}\left(\frac{1}{J_L}\right) + J_L + \sqrt{J_L^2-1}\right]$$

$$\frac{\partial P_{1/2}\left(\frac{1}{J_L}\right)}{\partial J_L} = \frac{1}{2\pi}\left[\frac{-1}{2J_L^2} + \frac{\frac{-1}{J_L^2}}{\sqrt{1-\left(\frac{1}{J_L}\right)^2}} + 1 + \frac{J_L}{\sqrt{J_L^2-1}}\right] \checkmark$$

this isn't right

Incorrect

$$\cancel{=} \frac{1}{2\pi}\left[\frac{-1}{2J_L^2} + \frac{-J_L^2}{\sqrt{J_L^2-1}} + 1 + \frac{J_L}{\sqrt{J_L^2-1}}\right]$$

$$\cancel{=} \frac{1}{2\pi}\left[\frac{-1}{2J_L^2} + \frac{J_L^2-1}{\sqrt{J_L^2-1}} + 1\right]$$

$$\cancel{=} \frac{1}{2\pi}\left[1 - \frac{1}{2J_L^2} + \sqrt{J_L^2-1}\right]$$

See next page for correct derivation

$$\frac{\frac{-1}{J_L^2}}{\sqrt{1-\frac{1}{J_L^2}}} \rightarrow \frac{-1/J_L}{J_L\sqrt{1-\frac{1}{J_L^2}}}$$

Check

$$\frac{\partial P_{1/2}\left(\frac{1}{J_L}\right)}{\partial J_L} = f(J_L) \qquad \frac{-1/J_L}{\sqrt{J_L^2-1}} \neq \frac{-J_L^2}{\sqrt{J_L^2-1}}$$

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Corrected Derivation from Previous Page

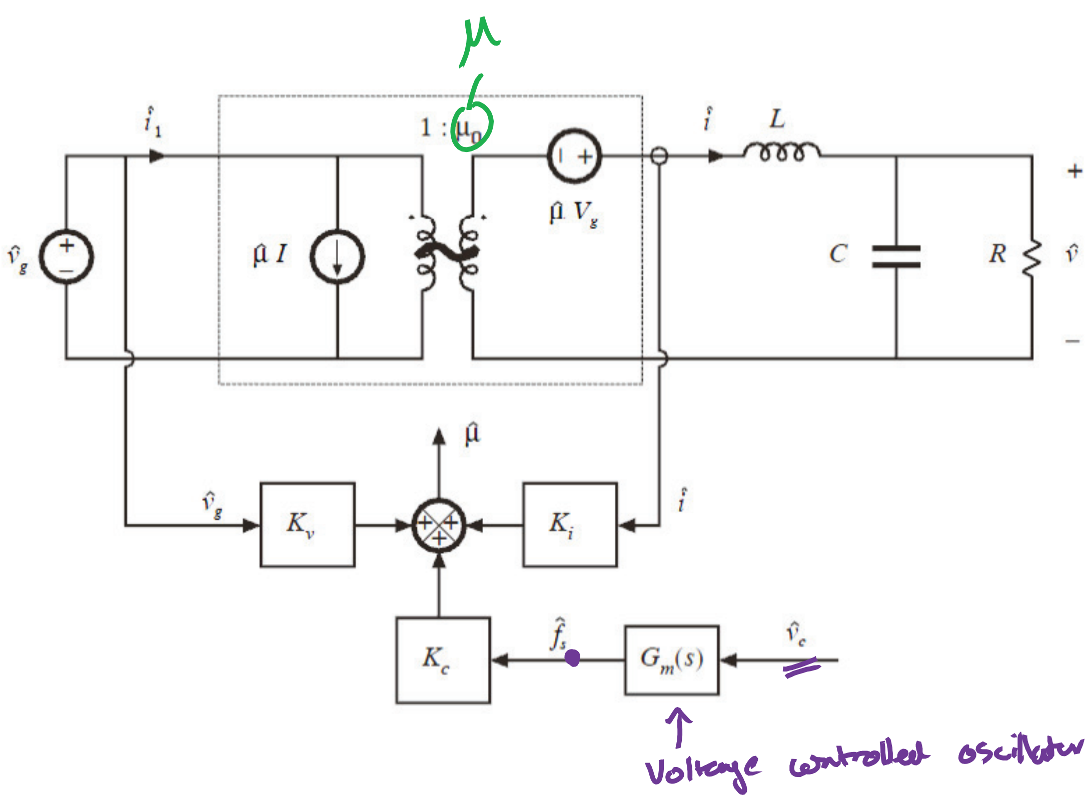
$$\frac{\partial P_{v_2}\left(\frac{1}{J_L}\right)}{\partial J_L} = \frac{1}{2\pi}\left[\frac{-1}{2J_L^2} + \frac{1}{\sqrt{1-\left(\frac{1}{J_L}\right)^2}}\left(\frac{-1}{J_L^2}\right) + 1 + \frac{1/2}{\sqrt{J_L^2-1}}\left(2J_L\right)\right]$$

$$= \frac{1}{2\pi}\left[\frac{-1}{2J_L^2} + \frac{-1/J_L}{\sqrt{J_L^2-1}} + 1 + \frac{J_L}{\sqrt{J_L^2-1}}\right]$$

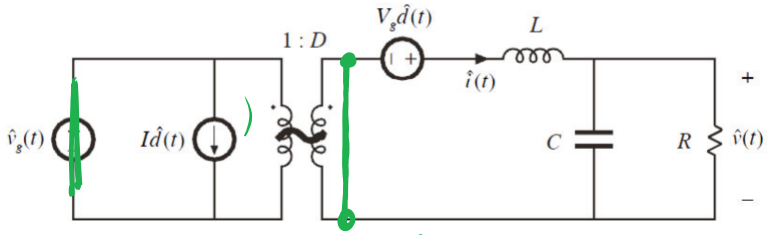
$$= \frac{1}{2\pi}\left[1 - \frac{1}{2J_L^2} + \frac{\frac{1}{J_L}\left(J_L^2-1\right)}{\sqrt{J_L^2-1}}\right]$$

$$\boxed{\frac{\partial P_{v_2}\left(\frac{1}{J_L}\right)}{\partial J_L} = \frac{1}{2\pi}\left[1 - \frac{1}{2J_L^2} + \frac{\sqrt{J_L^2-1}}{J_L}\right]}$$

SSM, Soft-Switching Buck



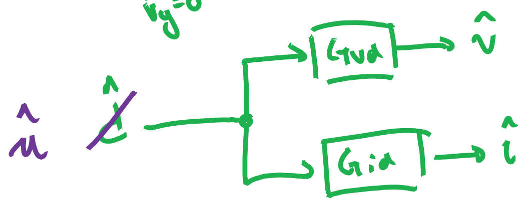
PWM Transfer Functions



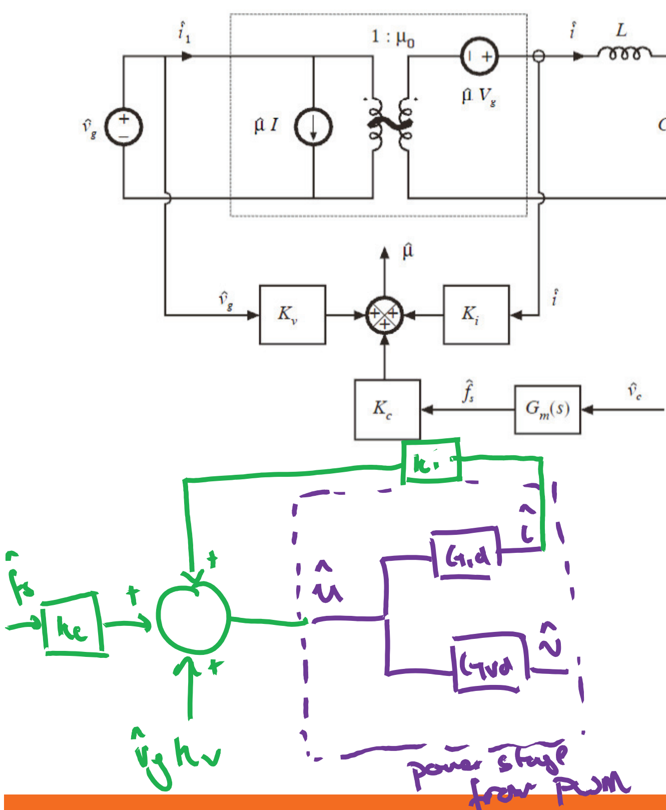
$$R \| \frac{1}{sC} = \frac{R}{1+sCR}$$

$$G_{vd} = \left.\frac{\hat{v}}{\hat{d}}\right|_{\hat{v}_g=0} = V_g \frac{R\|\frac{1}{sC}}{sL + R\|\frac{1}{sC}} = V_g \frac{1}{s^2LC + s\frac{L}{R} + 1}$$

$$G_{id} = \left.\frac{\hat{i}}{\hat{d}}\right|_{\hat{v}_g=0} = V_g \frac{1}{sL + R\|\frac{1}{sC}} = \frac{V_g}{R} \frac{1+sCR}{s^2LC + s\frac{L}{R} + 1}$$



QR Transfer Functions



$$\hat{u} = \hat{v}_g k_v + \hat{f}_s k_c + k_i G_{id} \hat{u}$$

$$\hat{u} = \frac{\hat{v}_g k_v + \hat{f}_s k_c}{1 - k_i G_{id}}$$

$$G_{vc} = \left.\frac{\hat{v}}{\hat{f}_s}\right|_{\hat{v}_g=0} = \left(\frac{k_c}{1 - k_i G_{id}}\right) G_{vd}$$

$$G_{vd} = \frac{V_g}{D(s)} \qquad D(s) = s^2LC + s\frac{L}{R} + 1$$

$$G_{vc} = \frac{G_{vd}\, k_c}{1 - k_i G_{id}}$$

$$G_{id} = \frac{\frac{V_g}{R}(1+sCR)}{D(s)}$$

$$G_{vc} = \frac{\frac{V_g}{D(s)}\, k_c}{1 - k_i \frac{V_g}{R}\frac{(1+sCR)}{D(s)}} = \frac{V_g k_c}{s^2LC + s\frac{L}{R} + 1 - k_i\frac{V_g}{R}(1+sCR)}$$

$$= \frac{V_g k_c}{s^2LC + s\left(\frac{L}{R} - V_g C k_i\right) + \left(1 - k_i\frac{V_g}{R}\right)}$$

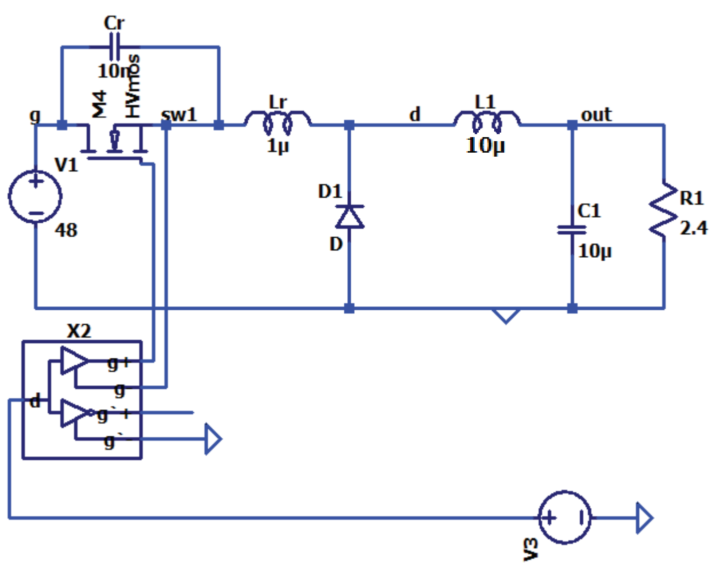
DC gain changed

$$= \frac{\frac{V_g k_c}{1 - k_i\frac{V_g}{R}}}{s^2\frac{LC}{1-k_i\frac{V_g}{R}} + s\,\frac{\frac{L}{R} - V_g K_i C}{1 - k_i\frac{V_g}{R}} + 1}$$

ωo changed

Q change

Example



$f_s = 1\,MHz$

$\zeta_L \approx 1$

$P_o = 60W$

$V = 12V$

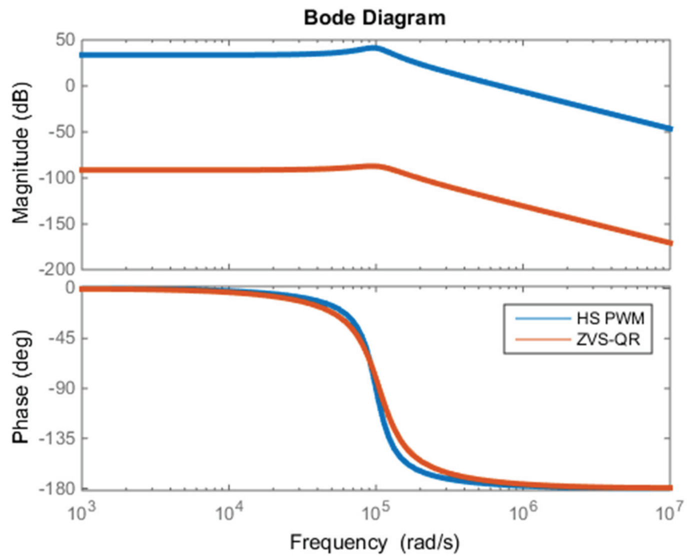
$F = 0.6$

$k_c = 6.24e{-2}$

$k_i = -0.005$

$k_v = 5.6e{-4}$

Control-to-Output Transfer Function



AC Link Converters?