RF Amplifiers

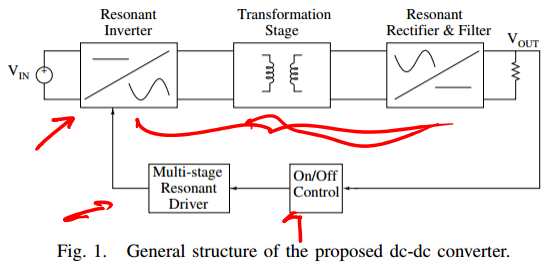

Fig. 1. General structure of the proposed dc-dc converter.

J. M. Rivas, O. Leitermann, Y. Han , D. J. Perreault, " A Very High Frequency dc-dc Converter Based on a Class Φ_2 Resonant Inverter"

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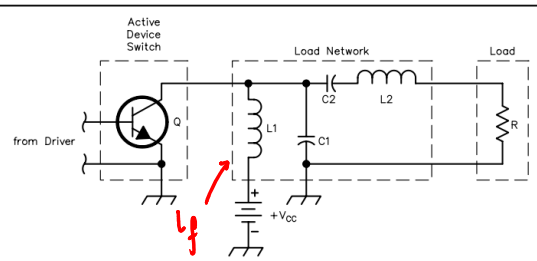
Class-E Amplifier



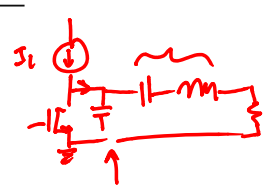


Fig 2—Schematic of a low-order Class-E amplifier.

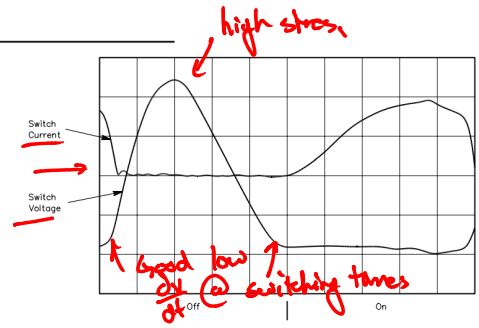


Fig 3—Actual transistor voltage and current waveforms in a low-order Class-E amplifier.

N. O. Sokal, "Class-E RF Power Amplifiers," 2001

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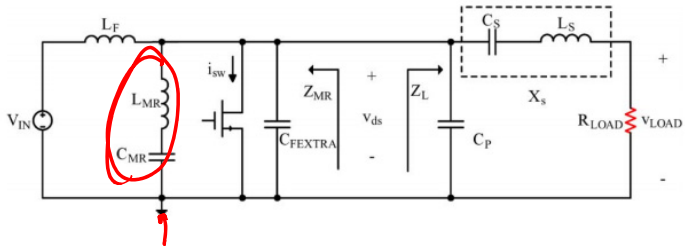
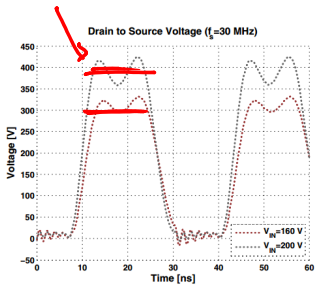
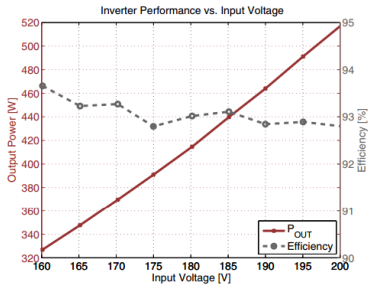
Class Φ_2 Inverter







J. M. Rivas, O. Leitermann, Y. Han , A. D. Sagneri, and D. J. Perreault, " A High-Frequency Resonant Inverter Topology With Low-Voltage Stress", 2008

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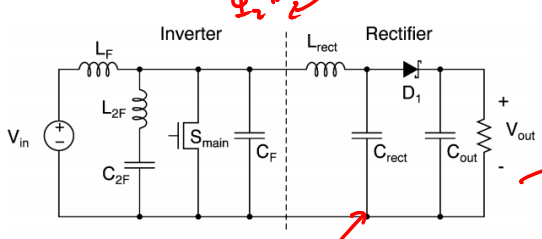
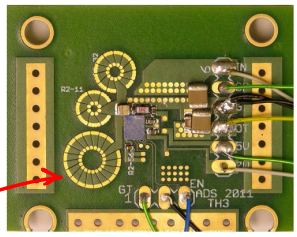
VHF DC-DC Converter

Φ_2 inv



Φ_2 Boost Converter



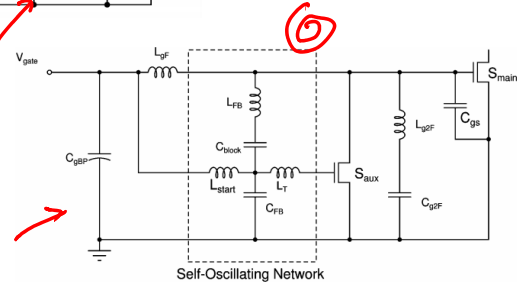


Fig. 5. Trapezoidal resonant gate drive circuit with self-oscillating network. The converter is enabled by applying the voltage V_{gate}, and disabled by setting V_{gate} to zero. This gate driver is employed in the 110-MHz converter (Fig. 9).

R. C. N. Pilawa-Podgurski, A. D. Sagneri, J. M. Rivas, D. I. Anderson and D. J. Perreault, "Very-High-Frequency Resonant Boost Converters," 2009

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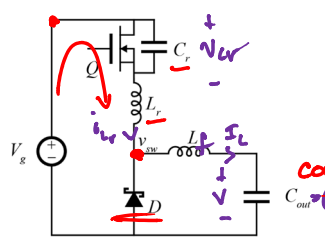
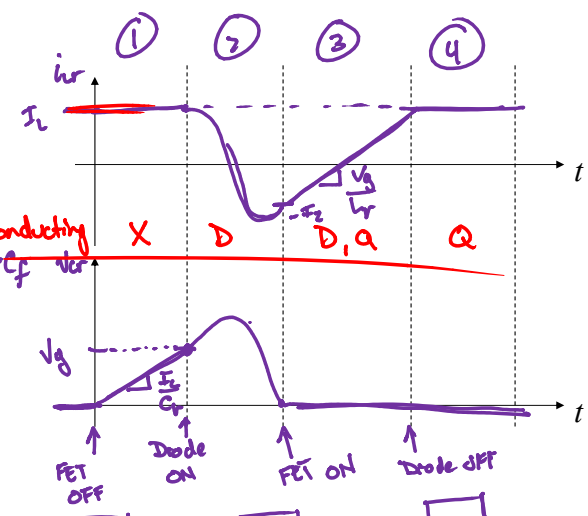
DYNAMIC MODELING

ZVS-QR Buck



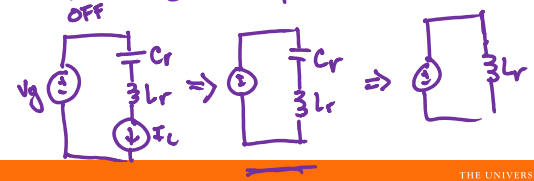


Merits:

1. L & C parasitics of Q FET incorporated
2. $i_{pk} = I_L$

Issues:

1. No diode parasitics integrated
2. $V_{ds,pk} >> $ PWM case



Complete Solution

(half-wave)

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

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

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

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

$FP_{1/2}$ in book (20.61) & (20.46)

Note:
Full wave ZVS-QR switch:
- Has V-src
- Requires bidirectional voltage implementation of Q

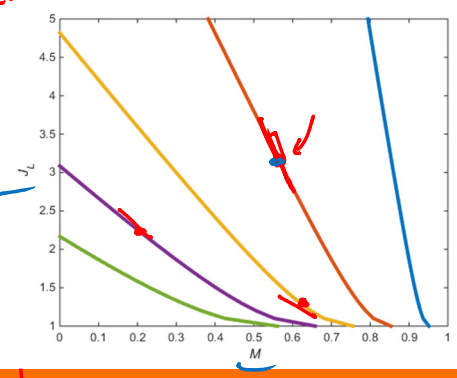
$$\rightarrow \theta_1 = \frac{1}{J_L}$$

$$\rightarrow J_2 = \sqrt{J_L^2 - 1}$$

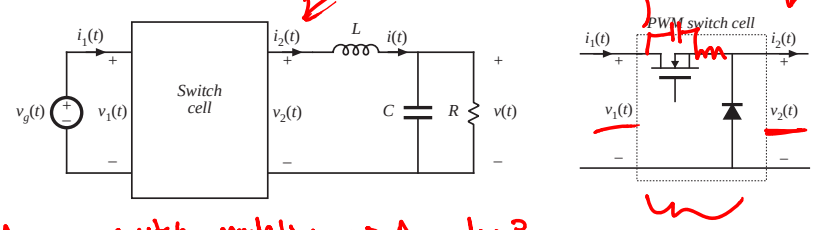
$$\rightarrow \beta = \pi + \sin^{-1}\left(\frac{1}{J_L}\right)$$

$$\theta_3 = J_2 + J_L$$

$$\frac{2\pi}{F} = \theta_1 + \beta + \theta_3 + \theta_4$$



PWM Parent



Average switch modeling → Appendix B

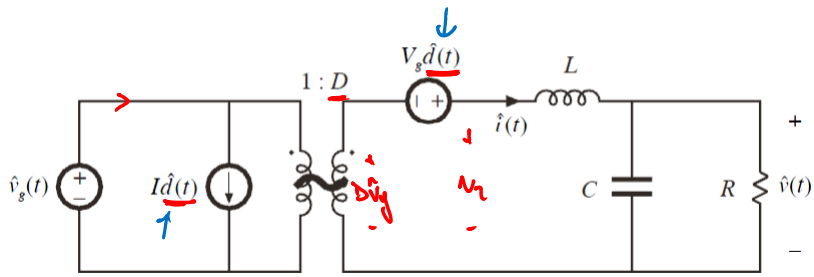
For PWM Buck

Averaged $\langle v_2\rangle = D\langle v_1\rangle$, $\langle i_1\rangle = D\langle i_2\rangle$ $\xrightarrow{\text{Linearize}}$ $\hat{v}_2 = D\hat{v}_1 + V_1\hat{d}$, $\hat{i}_1 = D\hat{i}_2 + \hat{d}I_2$

Buck is special case $\frac{\langle v_2\rangle}{\langle v_1\rangle} = M = \frac{V}{V_g}$

SSM, PWM Case

Textbook, Fig.7.17(a)



To get ZVS-QR model, replace D & $\hat{d}$ w/ M & $\hat{m}$ from before

ZVS-QR SSM

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

$$M = 1 - \frac{F}{2\pi} f(J_L)$$

$$M = 1 - \frac{f_s}{2\pi f_0} f\left(\frac{I_L}{V_g} R_0\right)$$

1. $f_s \rightarrow$ control
2. I_L
3. V_g

$$\rightarrow \hat{m} = \left.\frac{\partial M}{\partial f_s}\right|_{DC} \hat{f}_s + \left.\frac{\partial M}{\partial i_L}\right|_{DC} \hat{i}_L + \left.\frac{\partial M}{\partial v_g}\right|_{DC} \hat{v}_g$$

$$\left.\frac{\partial M}{\partial f_s}\right|_{DC} = \frac{-f\left(\frac{I_L}{V_g} R_0\right)}{2\pi f_0}$$

$$-\frac{\partial M}{\partial i_L} = \frac{F}{2\pi}\frac{\partial f(J_L)}{\partial J_L}\frac{\partial J_L}{\partial i_L} = \frac{F}{2\pi}\frac{R_0}{V_g}\frac{\partial f(J_L)}{\partial J_L}$$

$$-\frac{\partial M}{\partial V_g} = \frac{F}{2\pi}\frac{\partial f(J_L)}{\partial J_L}\frac{\partial J_L}{\partial V_g} = \frac{F}{2\pi}\left(\frac{-I_L R_0}{V_g^2}\right)\frac{\partial f(J_L)}{\partial J_L}$$

$$\frac{\partial f(x_c)}{\partial x_c} = \frac{\partial}{\partial x_c}\left[\frac{1}{2x_c} + \pi + \sin^{-1}\left(\frac{1}{x_c}\right) + x_c + \sqrt{x_c^2-1}\right]$$

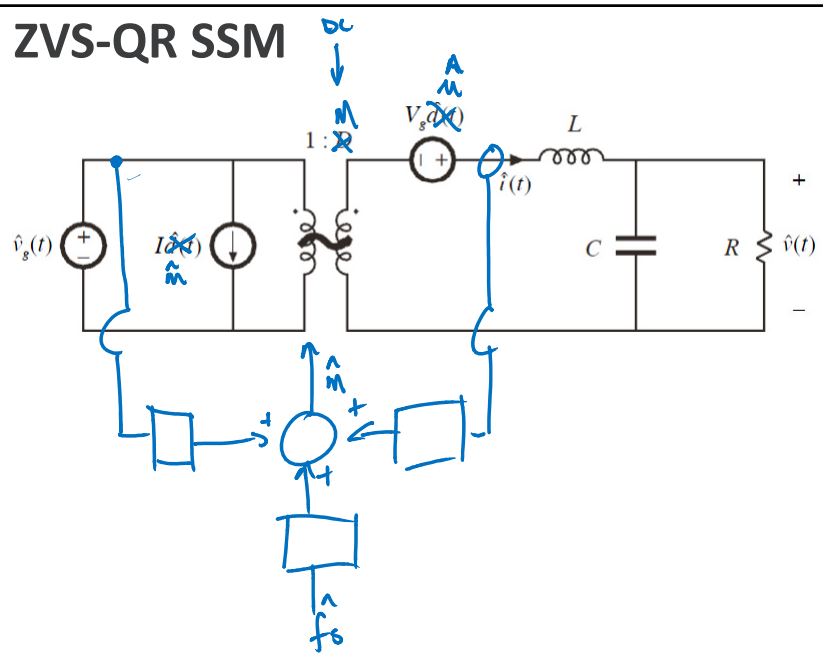
$$= -\frac{1}{2x_c^2} - \frac{1/x_c^2}{\sqrt{1-\frac{1}{x_c^2}}} + 1 + \frac{1}{2}\frac{1}{\sqrt{x_c^2-1}}\,2x_c$$

$$\frac{\partial}{\partial x}\sin^{-1}(x) = \frac{1}{\sqrt{1-x^2}}$$

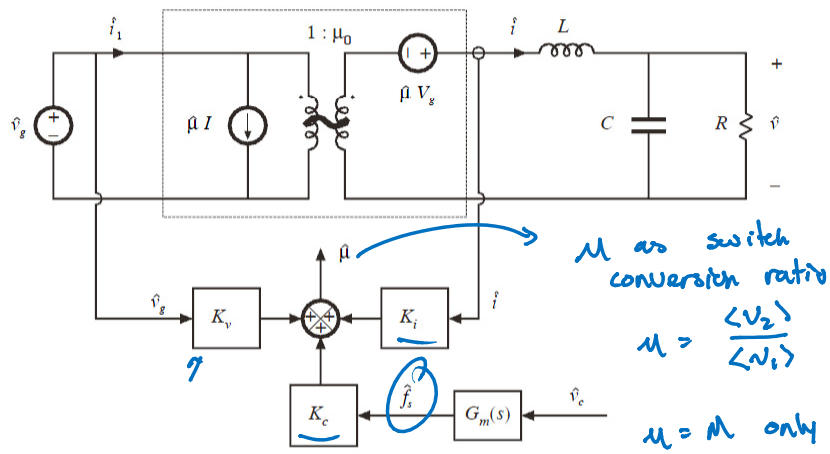
$$= -\frac{1}{2x_c^2} \quad \frac{-1/x_c^2}{\sqrt{1-\frac{1}{x_c^2}}} + 1 + \frac{x_c}{x_c\sqrt{1-\frac{1}{x_c^2}}}$$

$$= 1 - \frac{1}{2x_c^2} + \frac{1-1/x_c^2}{\sqrt{1-\frac{1}{x_c^2}}} = 1 - \frac{1}{2x_c^2} + \frac{\sqrt{x_c^2-1}}{x_c}$$

ZVS-QR SSM



SSM, Soft-Switching Buck



μ as switch conversion ratio

$$\mu = \frac{\langle v_2 \rangle}{\langle v_1 \rangle}$$

$\mu = M$ only for Buck