## State Plane Solution: Averaging Step

$$\langle i_{out} \rangle \big|_{T_s} = I_{out} = \langle i_L \rangle \big|_{T_s} = \frac{1}{T_s} \int_0^{T_s} i_L \, dt$$

$$I_{out} = \frac{1}{T_s} \left[ \int_0^{t_1} i_L \, dt + \int_{t_1}^{t_2} i_L \, dt + \dots \right]$$

$$\left(\frac{1}{I_{base}}\right) I_{out} = \frac{1}{T_s} \left[ \frac{I_1 - I_4}{2} t_1 + \cancel{-8C} + \frac{I_2 - I_3}{2} t_3 + \cancel{8C} \right] \left(\frac{1}{I_{base}}\right)$$

(1) (2) (3) (4)

$$J_{out} = \left(\frac{1}{\omega_0}\right) \frac{1}{T_s} \left[ \frac{J_1 - J_4}{2} t_1 + \frac{J_2 - J_3}{2} t_3 \right] (\omega_0)$$

$$\boxed{J_{out} = \frac{F}{2\pi} \left[ \frac{J_1 - J_4}{2} \theta_1 + \frac{J_2 - J_3}{2} \theta_3 \right]}$$



## Normalized Period

$$T_s = t_1 + t_2 + t_3 + t_4$$

Define $F = \frac{f_s}{f_0}$

$$\omega_0 T_s = \theta_1 + \alpha + \theta_3 + \beta$$

$$\frac{2\pi f_0}{f_s} = \boxed{\frac{2\pi}{F} = \theta_1 + \alpha + \theta_3 + \beta}$$

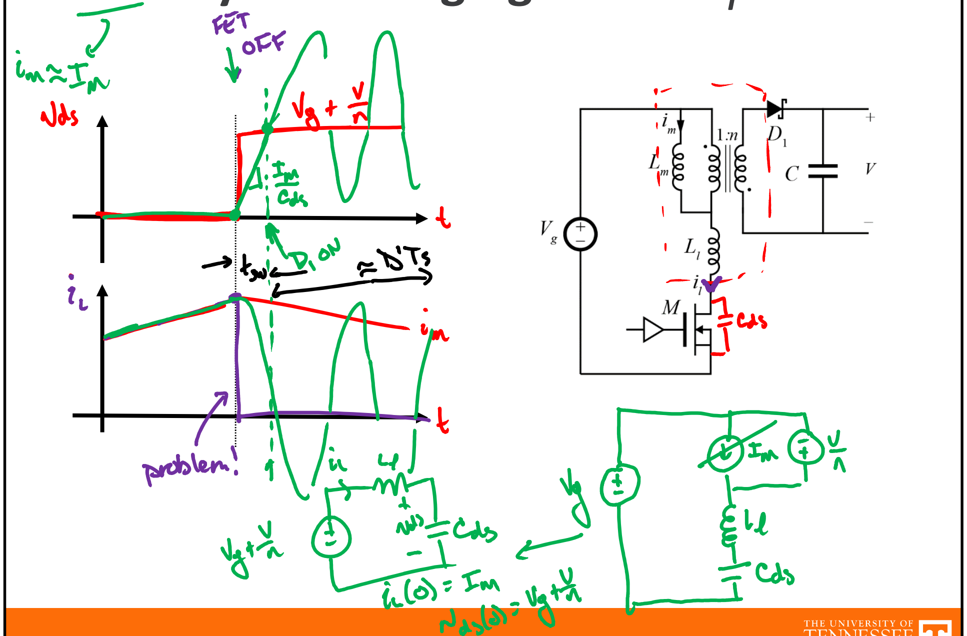
8 total equations

Unknowns:

$\theta_1 \quad \theta_3 \quad \alpha \quad \beta$

$J_1 \quad J_2 \quad J_3 \quad J_4 \quad J_{out}$

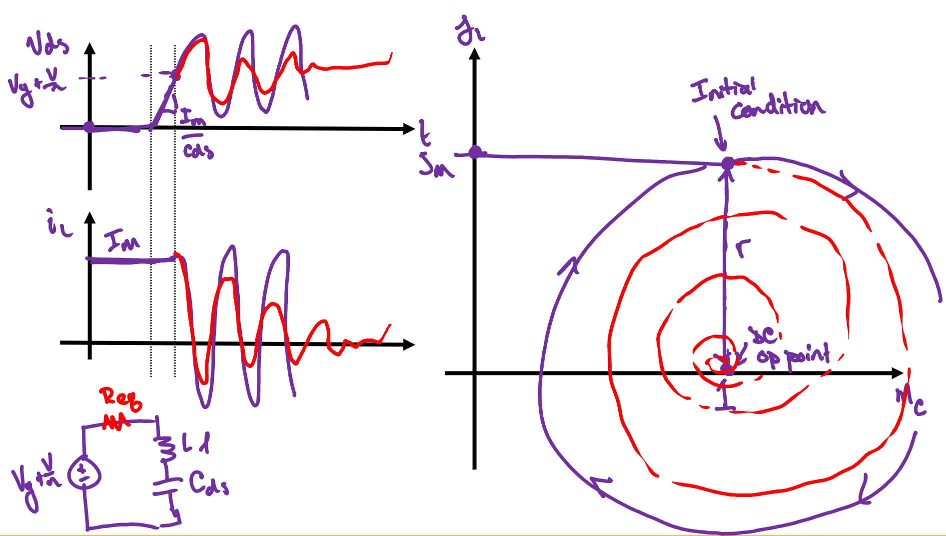
# CCM Flyback: Ringing Due to $L_l$






# MOSFET turn off

$V_{base} = V_g + \frac{V}{n}$



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# Leakage Voltage Stress

$$\left( J_m = \frac{I_m}{I_{base}} = \frac{I_m R_o}{V_{base}} \right)$$

$$m_{c,pk} = 1 + r = 1 + J_m$$

$$V_{c,pk} = V_{base} + J_m V_{base}$$

$$V_{c,pk} = \left(V_g + \frac{V}{n}\right) + I_m R_o$$

example

$V_g = 400V$
$V = 10V$
$P = 100W$
$f_s = 1MHz$
$D = 0.5 \quad n = \frac{1}{40}$

$C_{ds} = 100pF$
$L_m = 1.8mH$
$L_\ell = 35\mu H$
(2% of $L_m$)
$R_o = \sqrt{\frac{L}{C}} = 600\Omega$

$I_m = \frac{n I_{out}}{D'} = 500mA$
$V_{base} = V_g + \frac{V}{n} = 800V$
$V_{c,pk} = 800V + (.5A)\,600\Omega$
$= 1100V$ !

# Leakage Switching Loss

Assume ringing damps out before the end of $D' T_s$

$$E_{start} = \frac{1}{2} L_\ell I_m^2 + \frac{1}{2} C_{ds} \left(V_g + \frac{V}{n}\right)^2$$

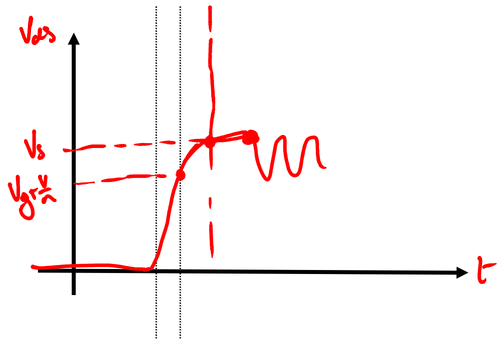
$$E_{end} = \frac{1}{2} C_{ds} \left(V_g + \frac{V}{n}\right)^2$$

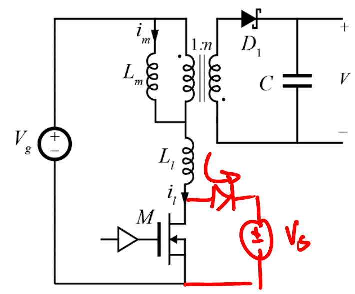
$$E_{loss} = E_{start} - E_{end} = \frac{1}{2} L_\ell I_m^2$$

$$E_{loss} = \frac{1}{2}(35\mu H)(.5A)^2 = 4.4\mu J$$

@ 1MHz $\quad P_{loss} = 4.4W$

# CCM Flyback: Clamping Circuit




$V_g + \frac{V}{n} < V_s < V_{ds,max}$