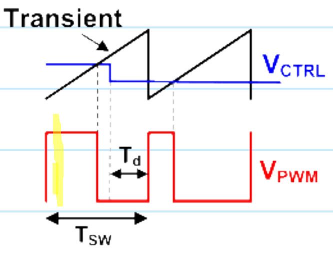
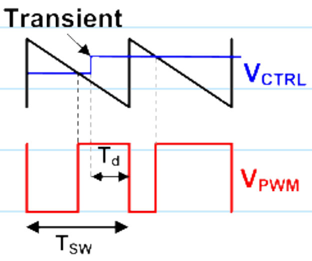
Single Edge vs. Dual Edge PWM



Trailing-Edge PWM

$$T_{d(\max)} = T_{OFF} = (1-D)\cdot T_{SW}$$

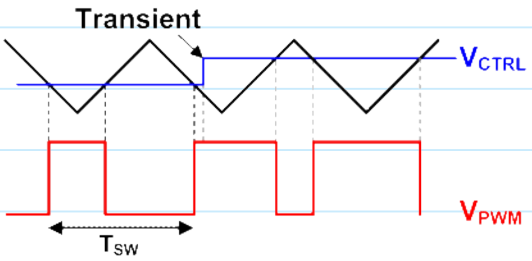
$$T_{d(\max)} \approx T_{SW} \ \ for\ D \approx 0$$



Leading-Edge PWM

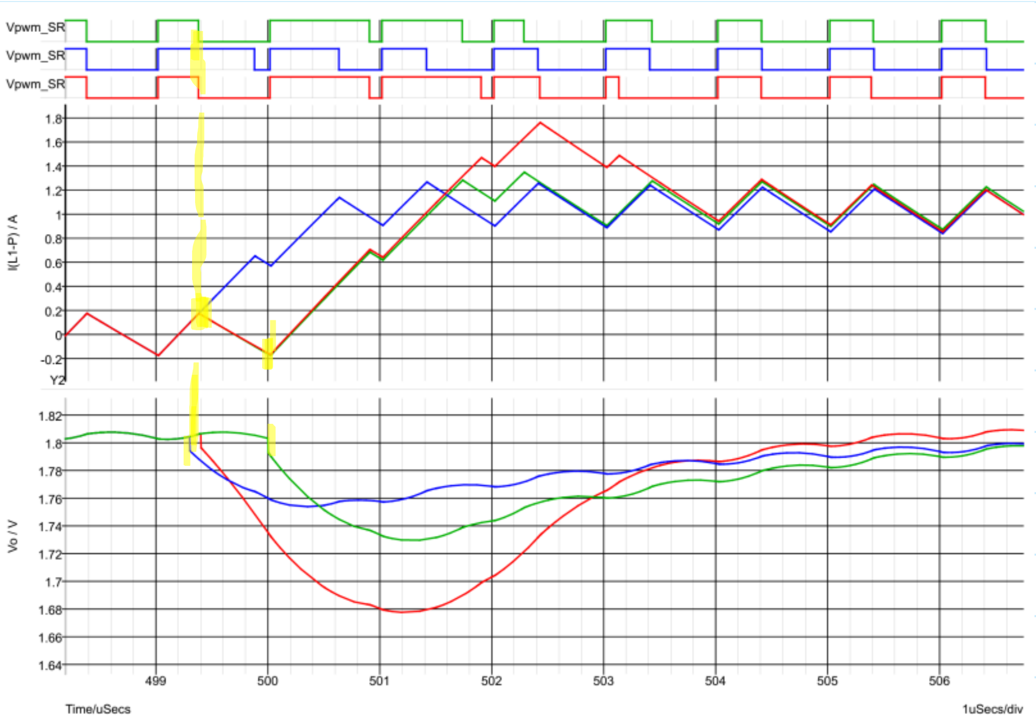
$$T_{d(\max)} = T_{ON} = D\cdot T_{SW}$$

$$T_{d(\max)} = T_{SW} \ \ for\ D \approx 1$$



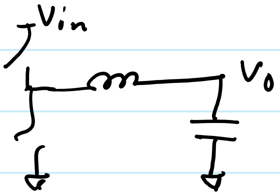
Dual-Edge PWM

$$T_{d(\max)} = \frac{T_{SW}}{2}$$

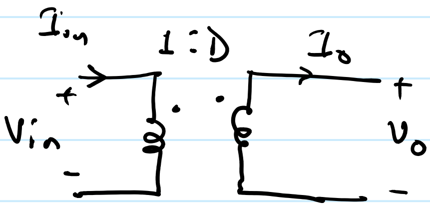


Transformer Model of Buck Converter

$V_o = D \cdot V_{in}$



$P_{out} = P_{in}$ under ideal condition $(\eta = 100\%)$



$$V_o \cdot I_o = V_{in} \cdot I_{in}$$

$$\frac{V_o}{V_{in}} = \frac{I_{in}}{I_o}$$

$$\frac{V_o}{V_{in}} = D \Rightarrow I_{in} = D \cdot I_o$$

$V_{in} = 5V$, $V_o = 2.5V$

$D = 0.5$, $I_o = 1A$

$I_{in} = 0.5A$

Efficiency and Losses

$$\% \eta = \frac{P_{out}}{P_{in}} \times 100$$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{V_0 I_0}{V_{in} \cdot I_{in}} \text{ ——— } ①$$

$$V_0 = D \cdot V_{in}$$

$$\frac{V_0}{V_{in}} = D$$

under conduction loss

$$V_0 = D \cdot V_{in} - V_{loss}$$

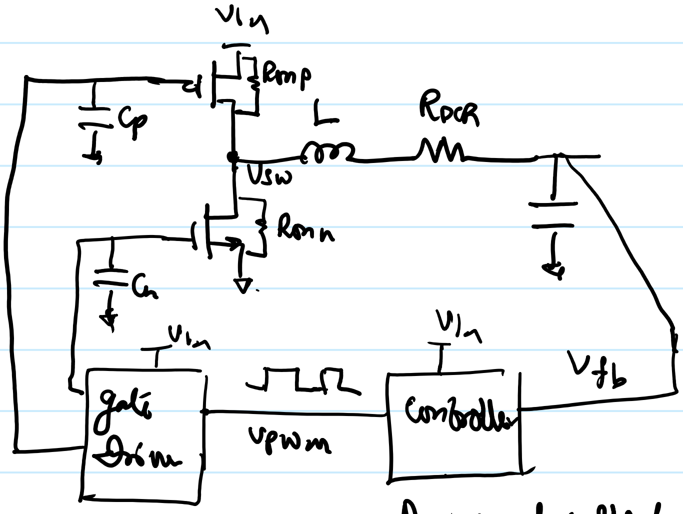
from ①

$$\eta = \frac{(D \cdot V_{in} - V_{0loss}) I_0}{V_{in} \times I_{in}} = \frac{D \cdot V_{in} I_0 - V_{loss} I_0}{V_{in} \times I_{in}}$$

$$I_{in} = D \cdot I_0$$

$$\frac{D \cdot V_{in} I_0 - V_{loss} I_0}{I_0 \times D \times V_{in}} = \boxed{\eta = 1 - \frac{V_{loss}}{D \cdot V_{in}}}$$

Losses



Quiescent current ($I_{load} = 0$)
(I_Q)

P_{loss} = conduction or RMS loss or resistive loss
(P_{cond}) (I^2R)

- → Inductor DCR losses
- → switches Ron losses

+

switching losses

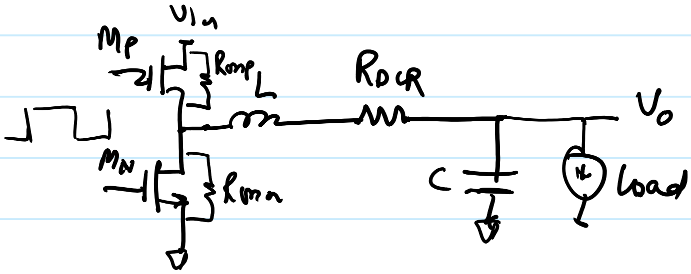
- gate driver losses (CV^2f)
- Powerfet switching losses
- dead time losses
- magnetic losses

+

Quiescent losses (I_Q)

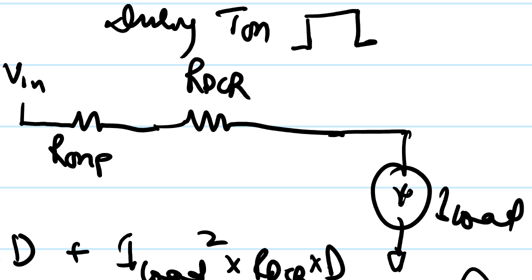
$$P_{loss} = P_{cond} + P_{sw} + P_Q$$

Conduction or RMS Loss



During T_{on} . $M_P \to ON$ & $M_N \to OFF$

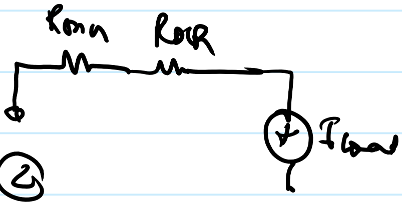
$$I_{MP} = I_{load}$$



$$P_{loss\text{-}T_{on}} = I_{Load}^2 \times R_{onp} \times D + I_{load}^2 \times R_{DCR} \times D \quad — ①$$

$P_{loss\text{-}T_{OFF}}$

$$= I_{load}^2 \times R_{onn}(1-D) + I_{load}^2 \times R_{DCR}(1-D) \quad — ②$$



$P_{loss\text{-}cond}$ = ① + ②

$$= I_{load}^2 R_{onp} \cdot D + I_{load}^2 R_{onn}(1-D) + I_{load}^2 R_{DCR}$$

$$= I_{load}^2 \left(D \cdot R_{onp} + (1-D) R_{onn} + R_{DCR} \right)$$

Assuming $R_{onp} = R_{onn} = R_{on}$

$$V_{loss} = I_{load} \times R_{tot}$$

$$R_{total} = R_{on} + R_{DCR}$$

Conduction Loss

$$V_o = D \cdot V_{in}$$

under losses

$$V_o = D \cdot V_{in} - V_{loss}$$

$\Rightarrow$ D has to be increased to regulate the V_o

$R_{on} = 30\,m\Omega$, $R_{DCR} = 50\,m\Omega$, $I_{load} = 1A$

$$V_{loss} = 100\,mV$$

$V_{in} = 5\,V$, $V_{out} = 2.5\,V$

$$D = 0.5$$

$$V_o = 2.5 - 0.1 = 2.4\,V$$

$$D_{new} = D + \Delta D$$

$$V_o = (D + \Delta D) V_{in} - V_{loss}$$

$$\Rightarrow V_o = D V_{in} + \Delta D \cdot V_{in} - V_{loss}$$

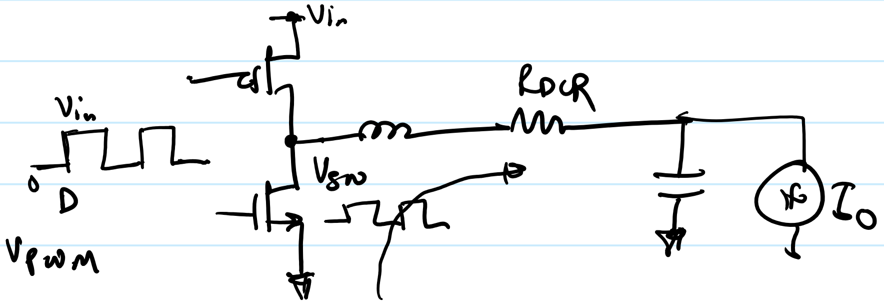
$$D \cdot V_{in} = V_o$$

$$\Rightarrow \boxed{V_{loss} = \Delta D \cdot V_{in}}$$

$$I_{in\_new} = I_o (D + \Delta D) = \underline{I_o \cdot D} + \Delta D I_o$$

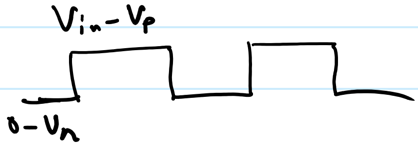
Calculating Ron and Rdcr Losses

Calculating Ron & RDCR losses



$$\mathrm{Avg}(V_{pwm}) = D \cdot V_{in}$$

$$V_p = I_o \cdot R_{onp}$$
$$V_n = I_o \cdot R_{onn}$$



$$\mathrm{Avg}(V_{sw})$$

$$= D \cdot (V_{in} - V_p) + (1-D)(-V_n)$$

$$= D \cdot V_{in} - \underbrace{D \cdot I_o R_{onp} - (1-D) I_o R_{onn}}_{P_{loss\_FET}}$$

$$D \cdot V_{in} = \mathrm{Avg}(V_{pwm})$$

$$P_{loss\_FET} = \mathrm{Avg}(V_{pwm}) - \mathrm{Avg}(V_{sw})$$

$$P_{loss\_dcr} = \mathrm{Avg}(V_{sw}) - V_o$$