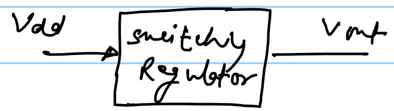
Switching Regulators

→ works on the principle of Pulse Width Modulation (PWM)

→ offers higher efficiency across wide Vout/Vin Range

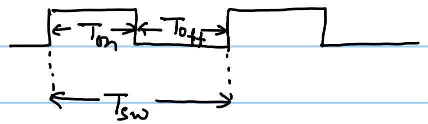
→ Can buck (step down), boost (step-up) or invert input power supply

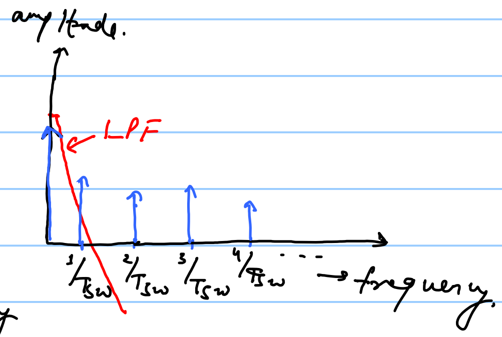


→ $V_{out} < V_{dd}$

→ $V_{out} > V_{dd}$

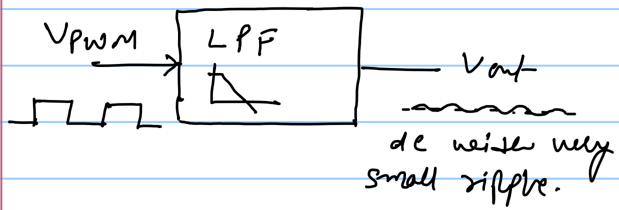
→ $V_{out} < 0$ (negative or inverting)





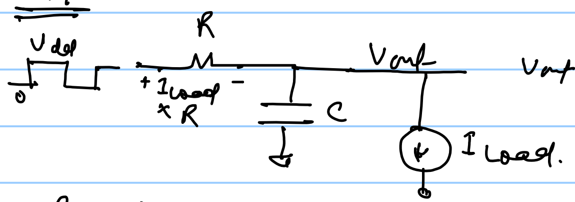
If 3dB cutoff of LPF is $<< \frac{1}{T_{sw}}$

then all harmonics are filtered out and we get only dc component at V_{out}



$$V_{out} = \frac{T_{on}}{T_{sw}} \times V_{dd} = D \cdot V_{dd}$$

LPF



$V_{out} = D \cdot V_{dd} - I_{Load} \cdot R$.

$RC \gg T_{sw}$

$T_{sw} = 1\,\mu s$

R should be much smaller to supply higher load current

$R = 100\,m\Omega$

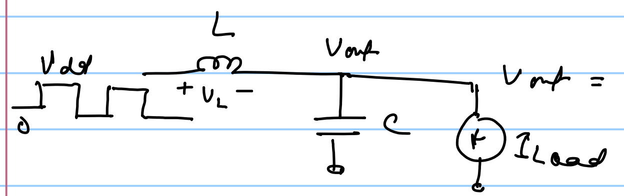
$I_{Load} = 1A$

$RC = 10 \times T_{sw}$

$C = \frac{10 \times 1\mu}{0.1} = 100\,\mu F$

RC filter is not practical due to large C

so we use LC filter



$V_{out} = D \cdot V_{dd}$

ideally L is lossless

$V_L = L \frac{dI_L}{dt}$

$dI_L = \frac{1}{L} V_L \times dt$

$\Delta I_L = \frac{1}{L} V_L dt$

during T_{on}

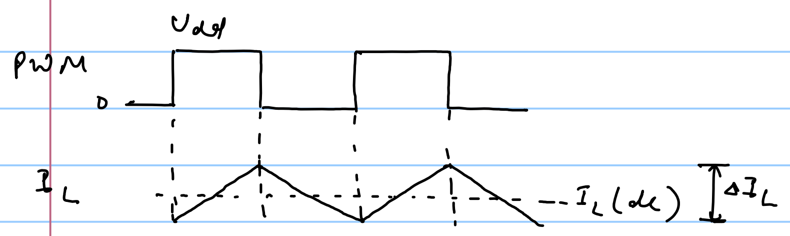
$\Delta I_L = \frac{V_{dd} - V_{out}}{L} \times T_{on}$ $\left(slope = \frac{V_{dd} - V_{out}}{L} \right)$

$$\Delta I_L = \frac{V_{dd}(1-D)\cdot D}{L} \times T_{sw}$$

during off time

$$\Delta I_L = -\frac{V_{out}}{L} T_{off}$$

$$= -\frac{V_{out}}{L}(1-D)\,T_{sw}$$

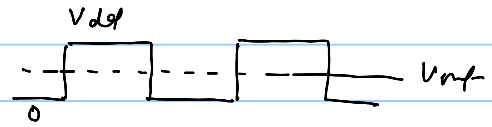


$$I_L = I_L(dc) + \Delta I_L$$

$$I_L(dc) = I_{Load}$$

Volt-Second balance

In steady state average voltage drop across the inductor = 0



Voltage drop across the inductor during ON time.

$V_{L(ON)} = V_{dd} - V_{out}$ — (1)

Voltage drop across the inductor during OFF time

$V_{L(OFF)} = -V_{out}$

Average voltage across the inductor.

$$= \frac{\text{Area of one period}}{T_{sw}} = \frac{(V_{dd} - V_{out})T_{on} + (-V_{out})T_{off}}{T_{sw}} = 0$$

$$(V_{dd} - V_{out}) \cdot T_{on} = V_{out} \cdot T_{off}$$

Volt-second balance. mean
product of Voltage and time during T_{on}
Should be same as product of Voltage and time
during T_{off}.

$$V_{dd} T_{on} = V_{out} (T_{on} + T_{off})$$

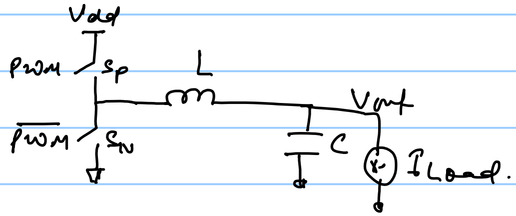
$$V_{out} = \frac{T_{on}}{T_{sw}} \cdot V_{dd} = D \cdot V_{dd}$$

Buck or step-down converter
because $D \leq 1$

Buck converter

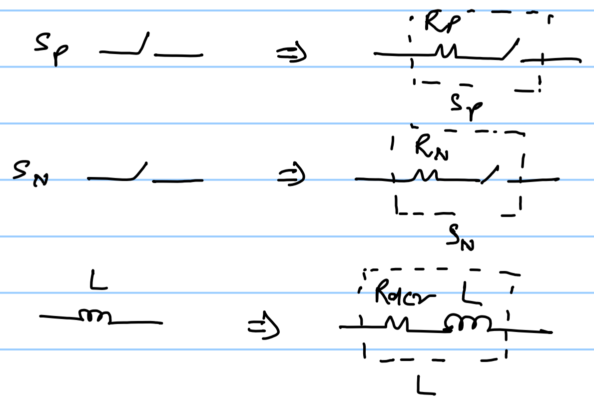
Buck Power stage

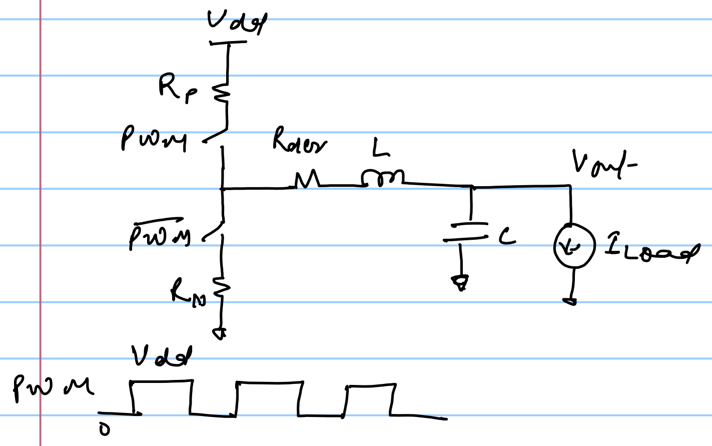
→ Switches + LC filter.



Ideally switches S_P & S_N and L are lossless.

But in reality there is some finite resistance.





$$V_{out} = D \cdot V_{dd} - I_{Load} \underbrace{\left(D \cdot R_p + (1-D) R_N + R_{dcr} \right)}_{R_{loss}}$$

$V_{out} \neq D \cdot V_{dd}$ in reality.

$$V_{out} = \underline{D \cdot V_{dd}} - V_{loss}$$

$$V_{out} = V_{out\text{-}no\,loss} - V_{loss}$$

$$V_{loss} = I_{Load} \times R_{loss},$$

$$D \cdot V_{dd} = V_{out} + V_{loss}.$$

In order to maintain V_{out}, D must be increased to compensate for V_{loss}.

$$V_{out} = D' V_{dd}$$

$$D' = D + \Delta D$$

$$D V_{dd} = \underline{D' \cdot V_{dd}} - V_{loss}.$$

$$\cancel{D V_{dd}} = \cancel{D V_{dd}} + \Delta D V_{dd} - V_{loss}$$

$$\Delta D V_{dd} = V_{loss} \Rightarrow \boxed{\Delta D = \frac{V_{loss}}{V_{dd}}}$$