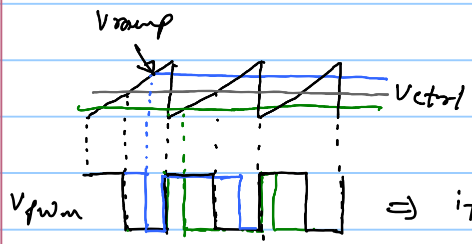
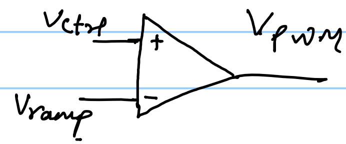
PWM Modulator

- Single edge Modulation
  - Trailing edge
  - Leading edge
- Dual edge Modulation

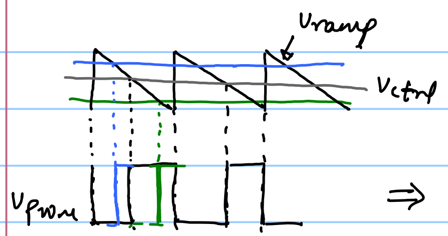
Trailing Edge Modulation





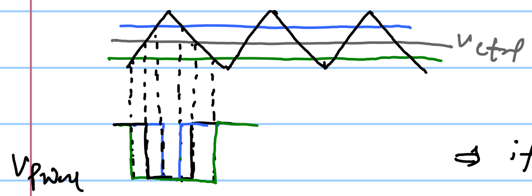
⇒ if duty cycle is changed then only trailing edge moves while leading edge is fixed

Leading Edge Modulation



⇒ if duty cycle is changed then leading edge moves while trailing edge is fixed.

Dual Edge Modulation



⇒ if duty cycle is changed then both edges move.

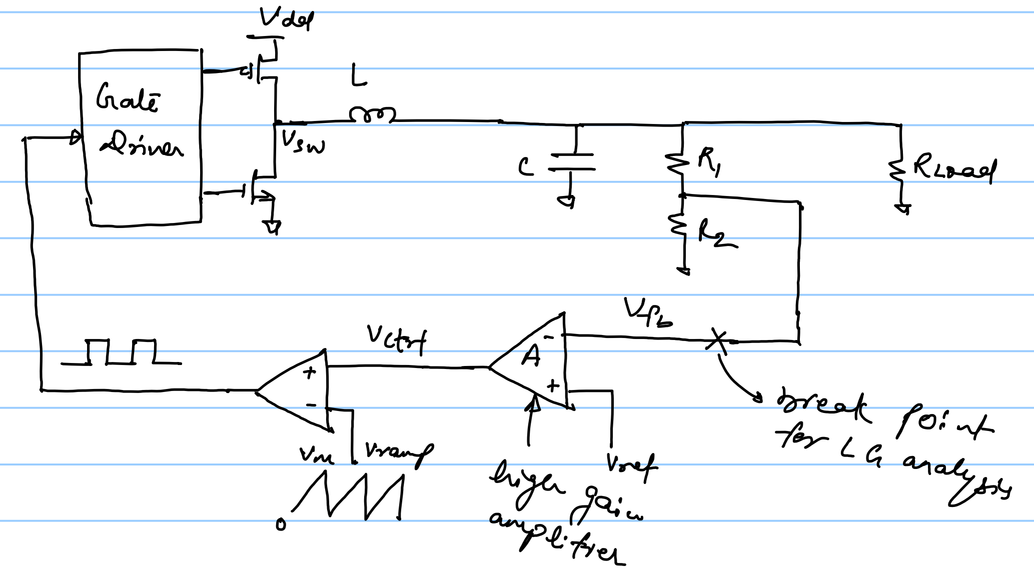
DC-DC control Techniques

- Linear control
  - Voltage mode
  - Current mode

  (Fixed frequency)
- Non-linear control (ripple control)
  - Hysteretic
  - constant ON/OFF time

  (Variable frequency)

Voltage Mode control



Loop gain analysis is required for stability.

Step-1 Break the loop

Step-2 Find the transfer function of each stage in the loop.

① feedback factor

$$H_{FB}(s) = \beta = \frac{R_2}{R_1 + R_2}$$

② Amplifier

$$H_{amp}(s) = A$$

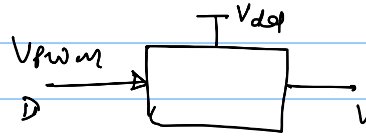
③ PWM modulation

$$Gain = \frac{\partial D}{\partial V_{ctrl}}$$

$$D = \frac{V_{ctrl}}{V_m} \Rightarrow \frac{\partial D}{\partial V_{ctrl}} = \frac{1}{V_m}$$

$$G_{PWM} = \frac{1}{V_m}$$

④ Gate driver + switches



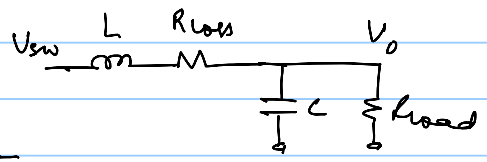
$= D \cdot V_{dd}$

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

$$\frac{\partial V_{sw}}{\partial D} = V_{dd}$$

$$G_{power\_stage} = V_{dd}.$$

⑤ LC filter.



$$H_{LC}(s) = \frac{V_o(s)}{V_{sw}(s)}$$

$$\frac{V_o}{V_{sw}} = \frac{Z_2}{Z_1 + Z_2} = \frac{1}{Y_2 Z_1 + 1} = \frac{1}{\left(sC + \frac{1}{R_{load}}\right)\left(sL + R_{loss}\right) + 1}$$

$$= \frac{1}{s^2LC + R_{loss}Cs + \frac{L}{R_{load}}s + \frac{R_{loss}}{R_{load}} + 1}$$

$$= \frac{1/LC}{s^2 + s\left(\frac{R_{loss}}{L} + \frac{1}{R_{load}C}\right) + \left(\frac{R_{loss}}{R_{load}} + 1\right)\frac{1}{LC}}$$

$R_{loss} << R_{load}$

$$H_{LC}(s) = \frac{1/LC}{s^2 + s\left(\frac{R_{loss}}{L} + \frac{1}{R_{load}C}\right) + \frac{1}{LC}}$$

$$\omega_0 = \sqrt{\frac{1}{LC}}$$

$$\frac{\omega_0}{Q_0} = \frac{R_{loss}}{L} + \frac{1}{R_{load}C}$$

$$Q_0 = \frac{\omega_0}{\frac{R_{loss}}{L} + \frac{1}{R_{load} C}} = \frac{1/\sqrt{LC}}{\frac{C R_{loss} + L/R_{load}}{LC}}$$

$$= \frac{\sqrt{LC}}{C R_{loss} + L/R_{load}}$$