1. Overview

2. Description of System.

3. PWM & ADC

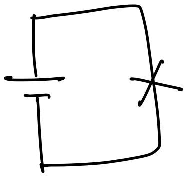
4. Basic Control System.

TA Office Hour : Mon 2-3pm.

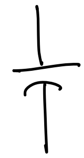
Prajakta Mon, Wed → before 130pm, after 330pm,

Turn off sound effects for ppl entering & leaving

Voltage Sources



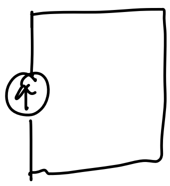
never short ≡



capacitors

store energy
in electrostatic field

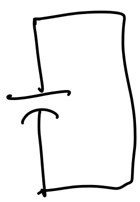
Current Sources



never open ≡

inductors

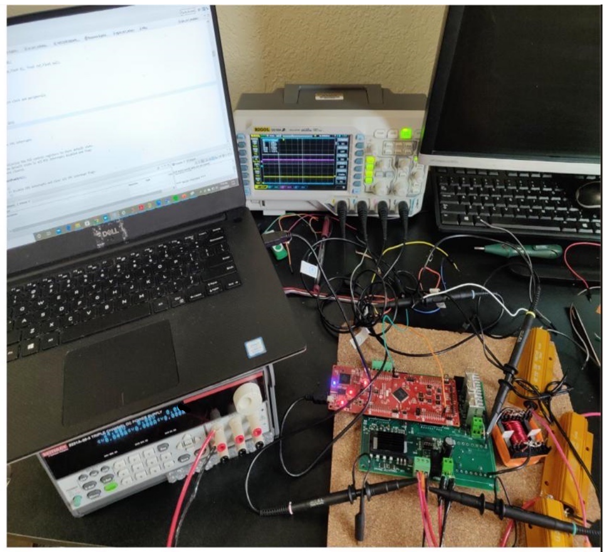
electromagnetic fields



Overview 1.1 Why Real Time System

ckt

PLECS Real-Time Simulator



48 V, 250 W E-Bike Drive Hardware

Hardware in loop + control codes.

Simulations | Real time Simulators | Hardware

Hardware in loop

- PLECS } PE
- SIMULINK
- LTSPICE } AE
- PSCAD } PS

Power system

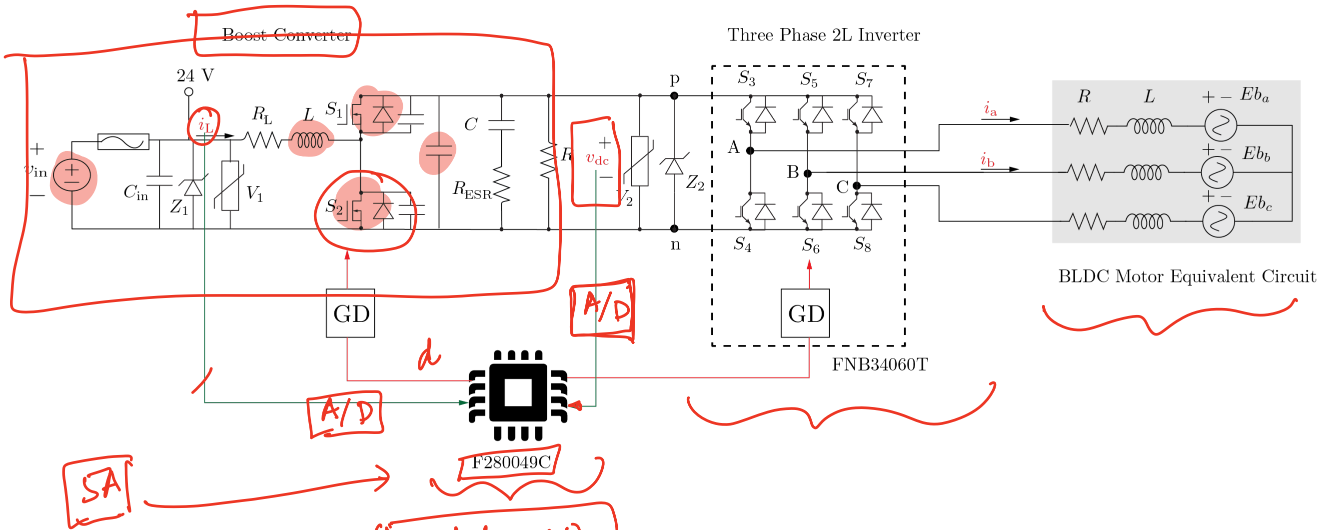
relay

A

differential & algebraic eq.

PS

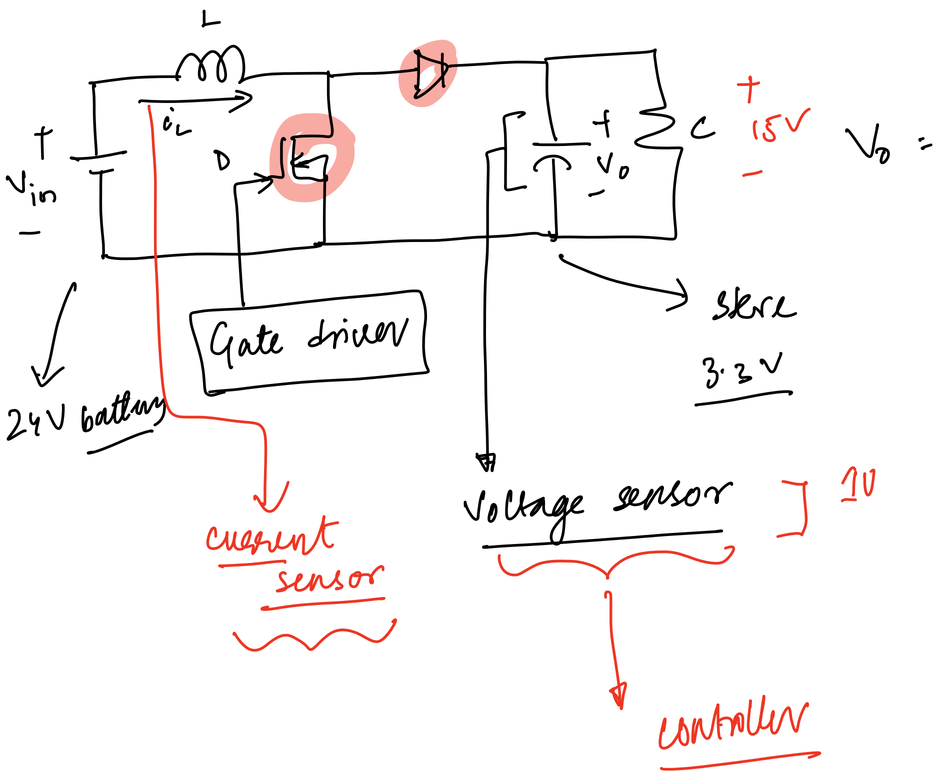
Overview 1.2 System Description



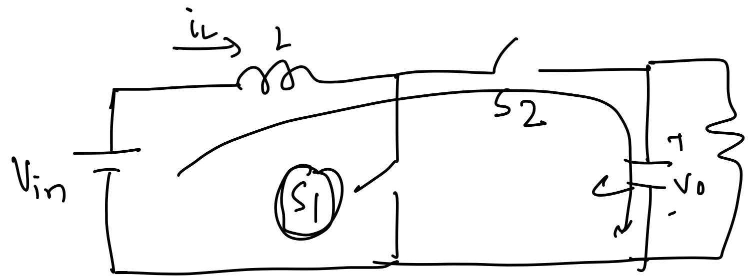
$i_L \rightarrow$ A/D $\rightarrow$ Digital no

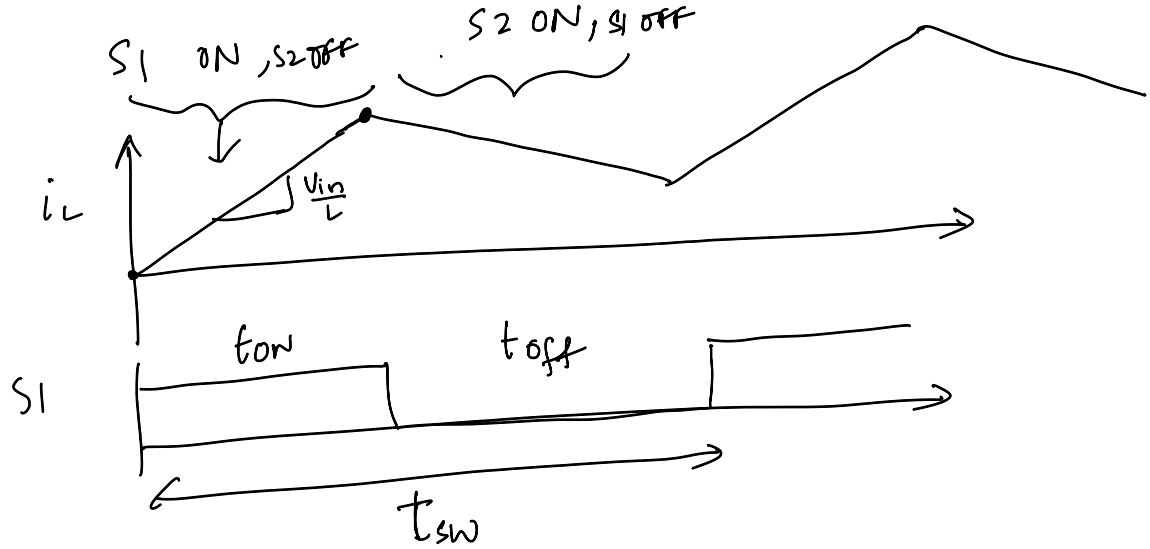
i_L, v_c

Overview 1.3 Basic Diagram of Boost Converter.



$$V_o = \frac{V_{in}}{1-D}$$



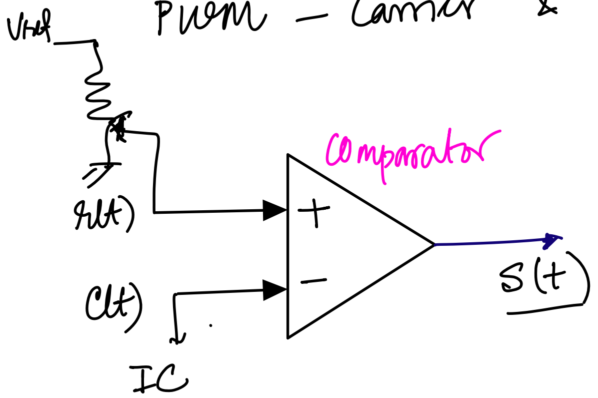


$$D := \text{Duty ratio} = \frac{t_{on}}{t_{sw}} = \frac{T_{on}}{T_{sw}} = T_{on} \cdot f_{sw}$$

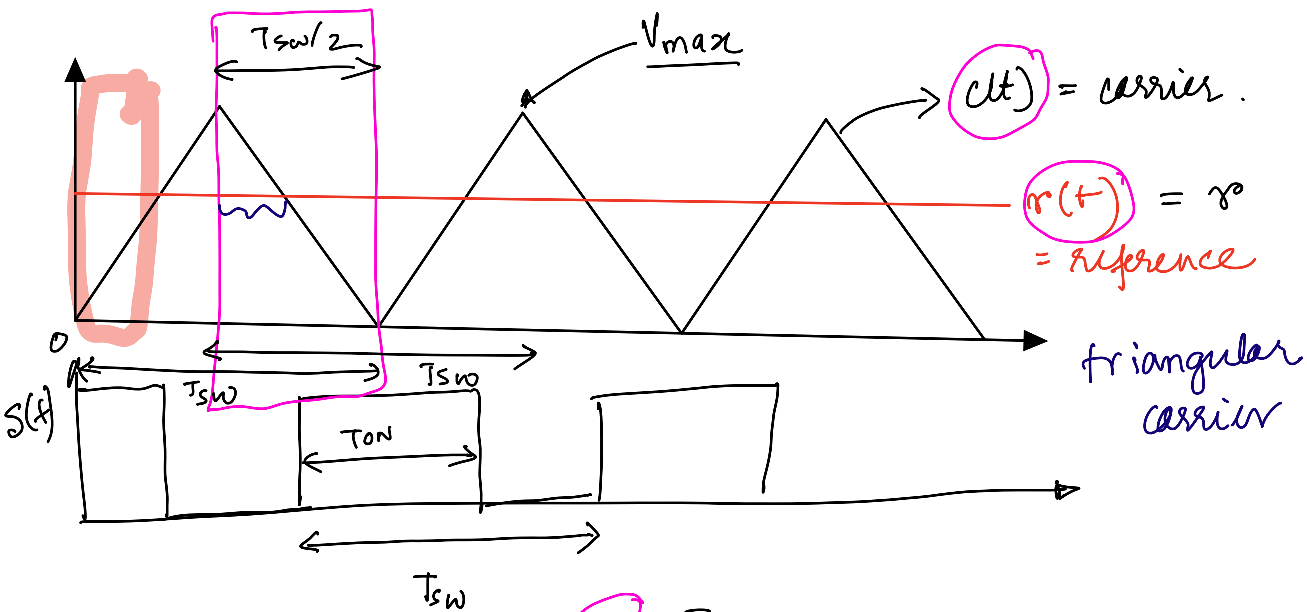
$$V_{in} \overbrace{\left(\frac{t_{on}}{T_{sw}}\right)}^{D} = (V_o - V_{in}) \overbrace{\left(\frac{t_{off}}{T_{sw}}\right)}^{1-D}$$

PWM & ADC 1.1

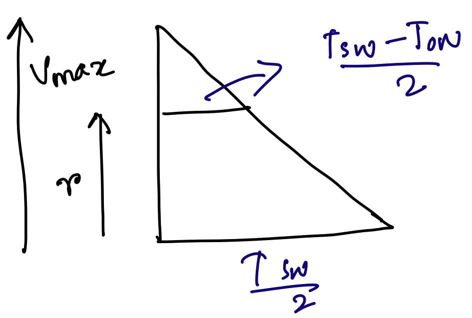
PWM – Carrier & reference → Switching.

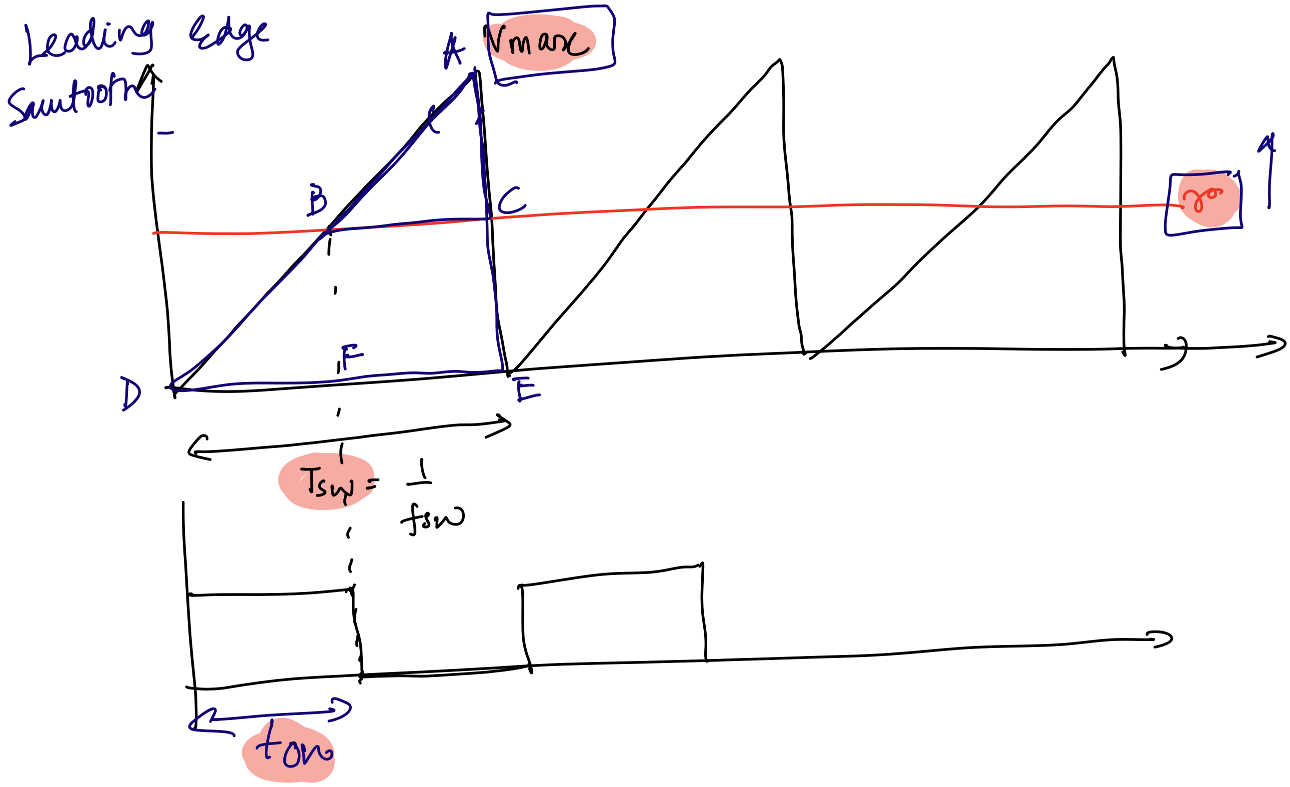


$$s(t) = \begin{cases} 1 & \text{if } r(t) > c(t) \\ 0 & \text{if } r(t) < c(t) \end{cases}$$



$$d = \frac{T_{ON}}{T_{SW}}$$





$$\Delta ABC \sim \Delta ADE$$

$$\frac{V_{max} - r := AC}{T_{sw} - t_{on} := BC} = \frac{AE =: V_{max}}{DE =: T_{sw}}$$

$$\frac{V_{max} - r}{T_{sw} - t_{on}} = \frac{V_{max}}{T_{sw}}$$

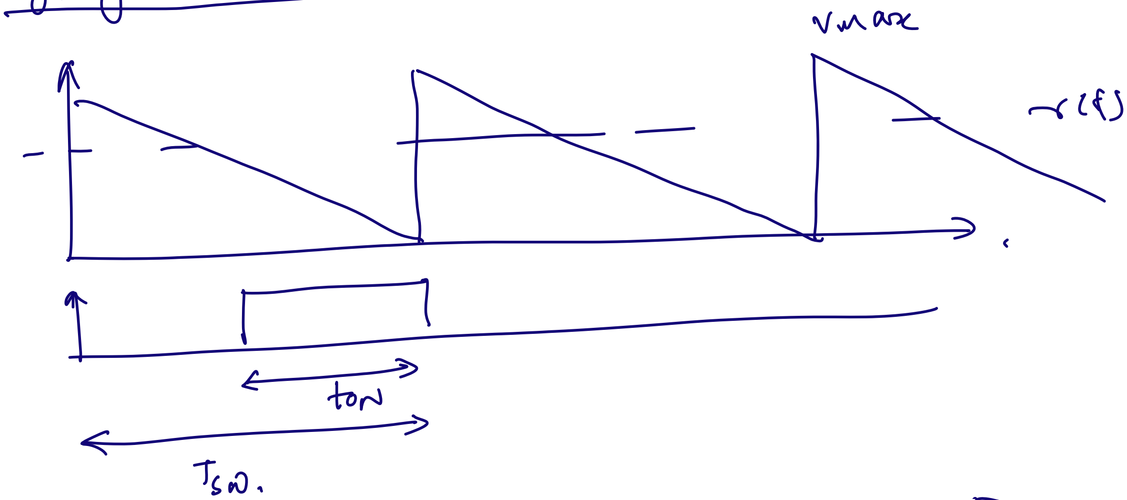
$$D := \frac{t_{on}}{T_{sw}} \Rightarrow \frac{V_{max} - r}{V_{max}} = \frac{T_{sw} - t_{on}}{T_{sw}}$$

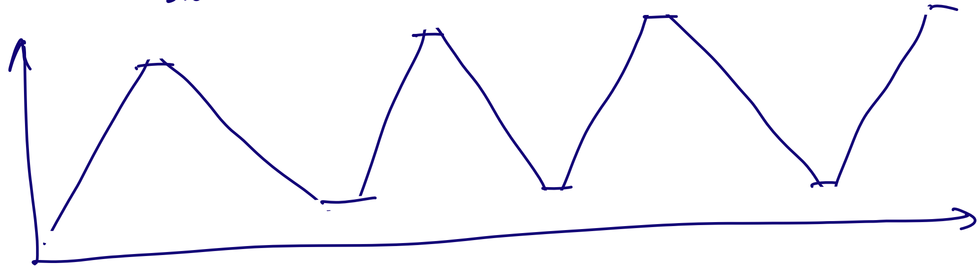
$$\Rightarrow 1 - \frac{r}{V_{max}} = 1 - \frac{t_{on}}{T_{sw}}$$

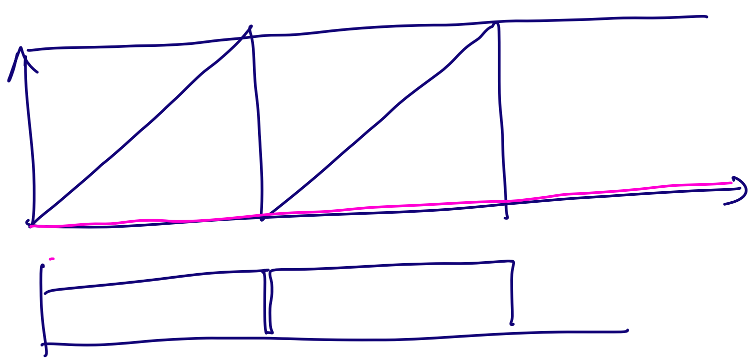
$$\Rightarrow \frac{r}{V_{max}} = \frac{t_{on}}{T_{sw}} = D$$

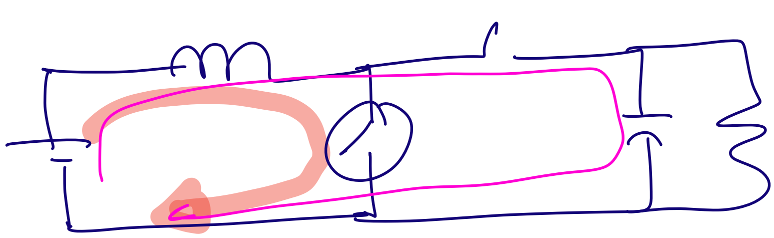
$$\therefore \boxed{D = \frac{r}{V_{max}}}$$

Lagging Edge Sawtooth carrier







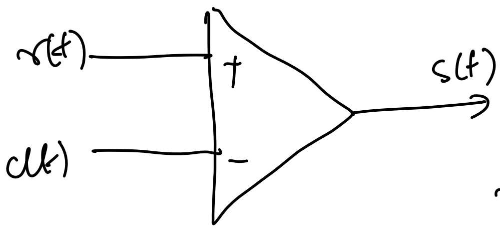


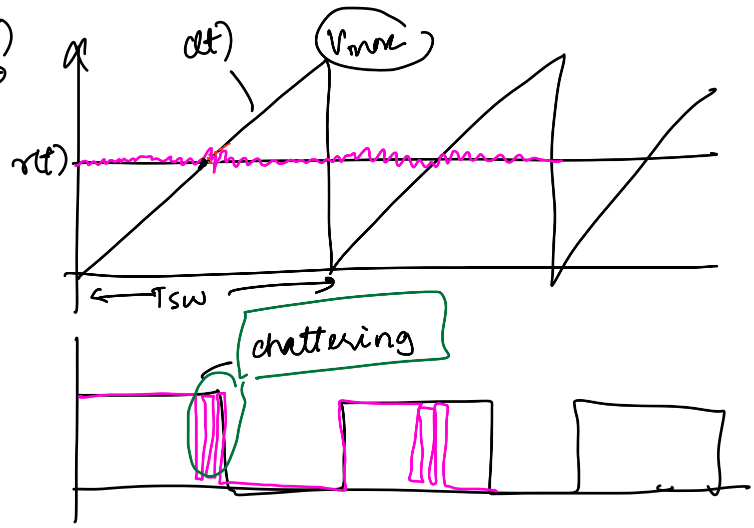
P & A 2.1

Analog PWM v/s Digital PWM

- inf res
- chattering

- no chattering
- finite resolution
- instability due to ADC interaction.



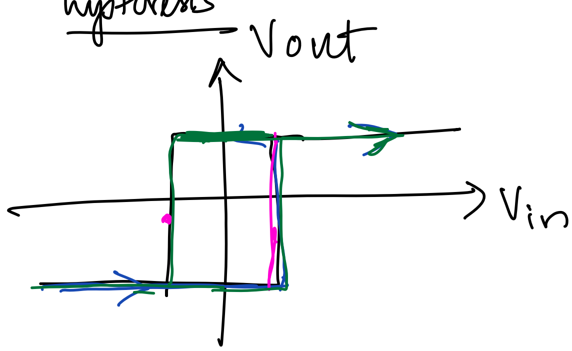


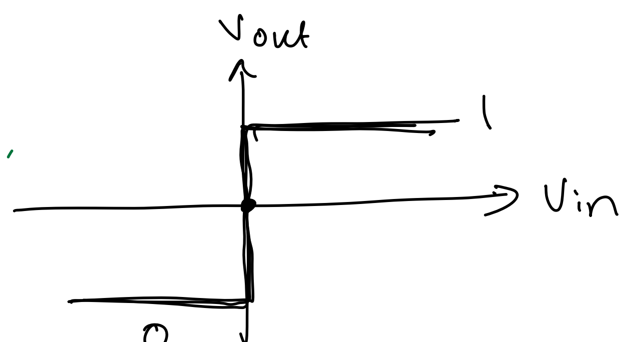
advantage
= infinite resolution

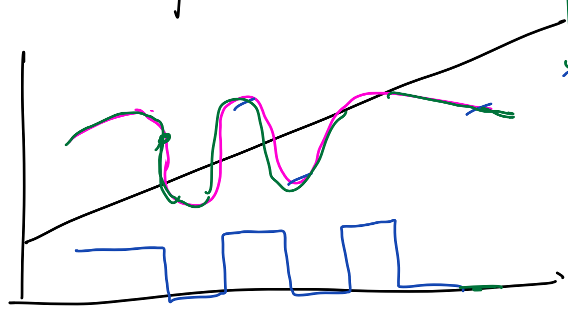
$d = \frac{r}{V_{max}}$ ← analog signal

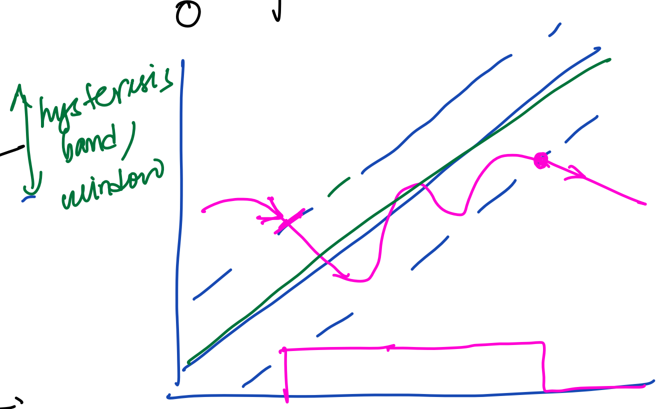
$0 < r < V_{max}$

hysteresis





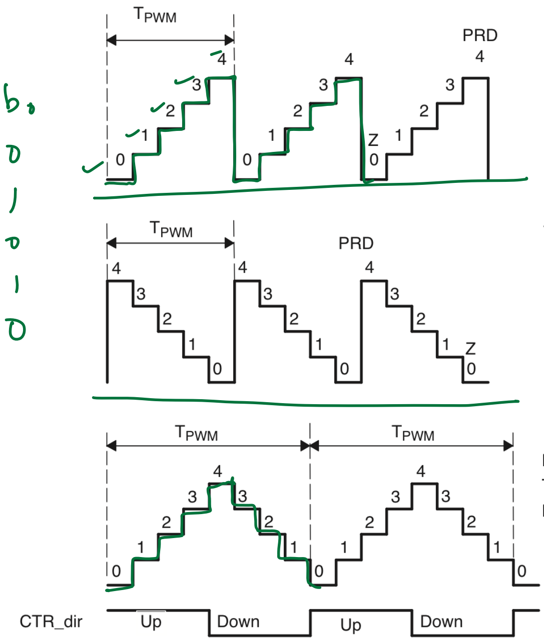




P & A 2.2

3 bits

	b_2	b_1	b_0
0 =	0	0	0
1 =	0	0	1
2 =	0	1	0
3 =	0	1	1
4 =	1	0	0



For Up Count and Down Count
$T_{PWM} = (TBPRD + 1) \times T_{TBCLK}$
$F_{PWM} = 1/(T_{PWM})$

For Up and Down Count
$T_{PWM} = 2 \times TBPRD \times T_{TBCLK}$
$F_{PWM} = 1/(T_{PWM})$

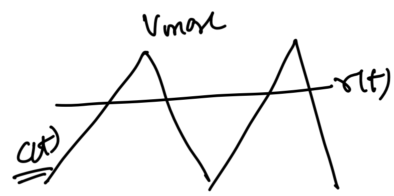
bits

	b_1	b_0
0 =	0	0
1 =	0	1
2 =	1	0
3 =	1	1

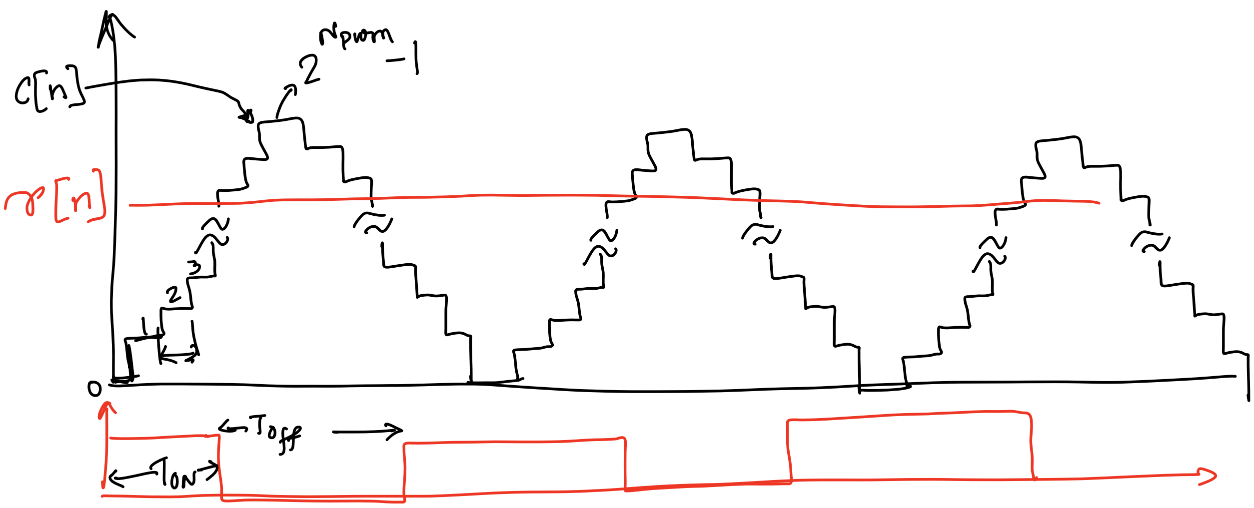
4

N bits

2^N

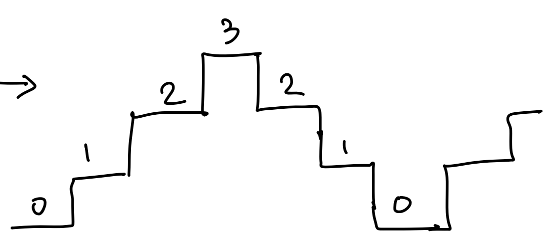


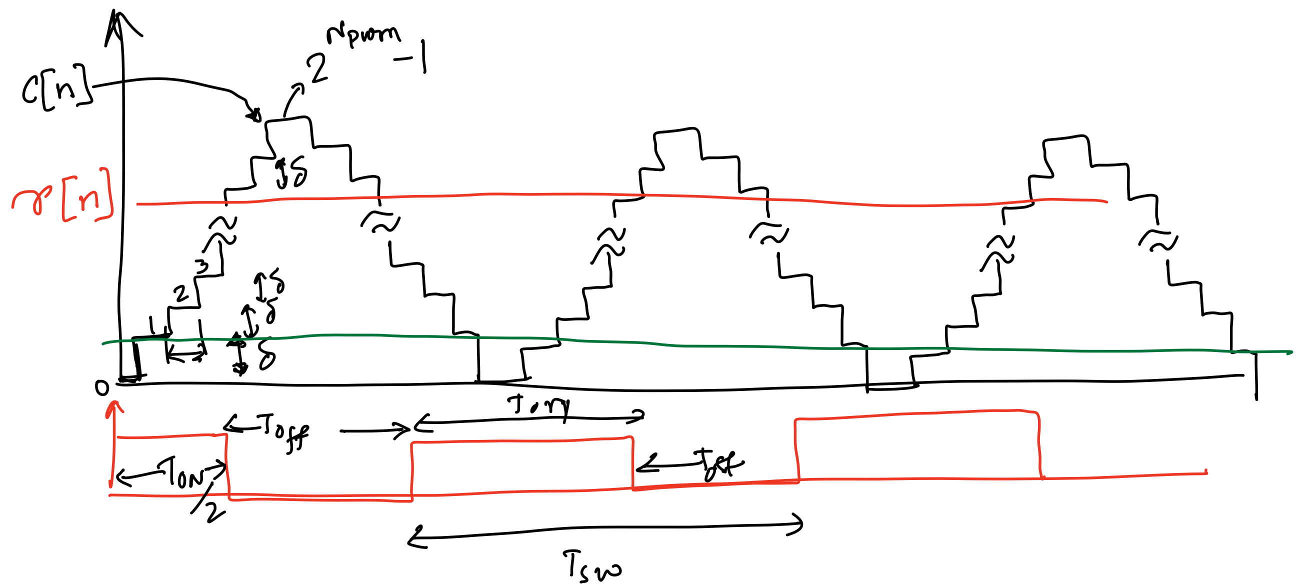
for $\boxed{N_{pwm}}$ bits, $\boxed{2^{N_{pwm}}}$

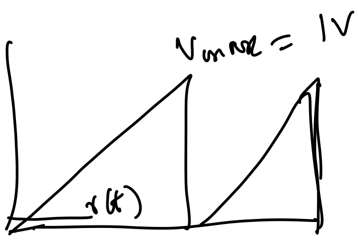


$x[n]$ = at the nth sample ⇒ discrete s/s.

$N_{pwm} = 2$ →





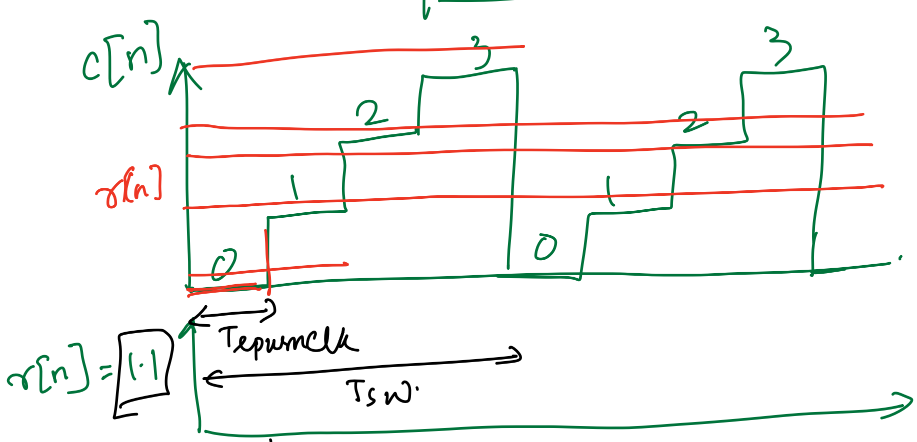


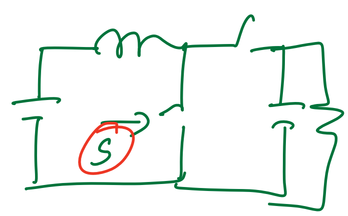
$r(t) = 0.1 \quad \therefore \quad D = \frac{0.1}{1V} = 0.1$

$r(t) = 0.000001 \quad \therefore \quad D = 0.000001$

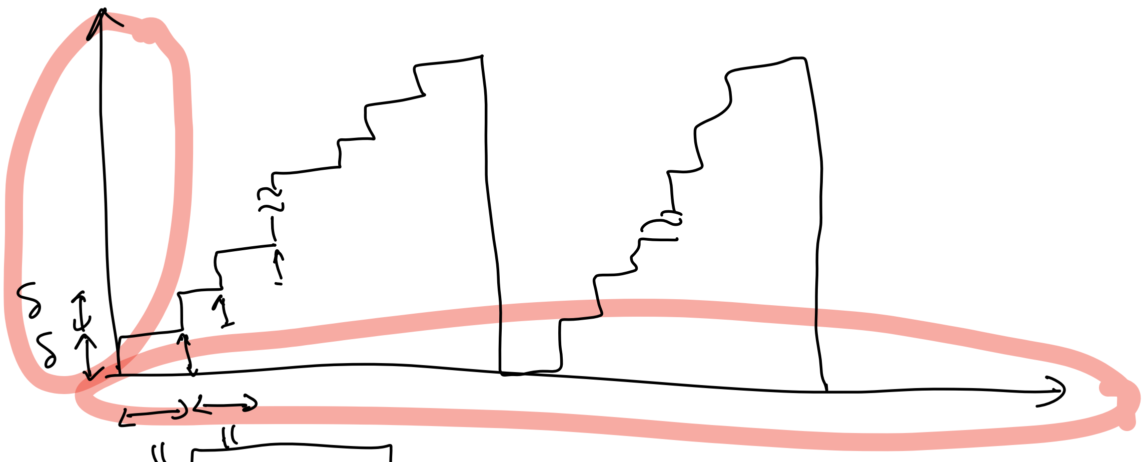
$\delta = \frac{1}{2^{N_{pwm}}}$ = smallest duty ratio

: quantization.





$\delta = \frac{1}{2^2} = \frac{1}{4}$



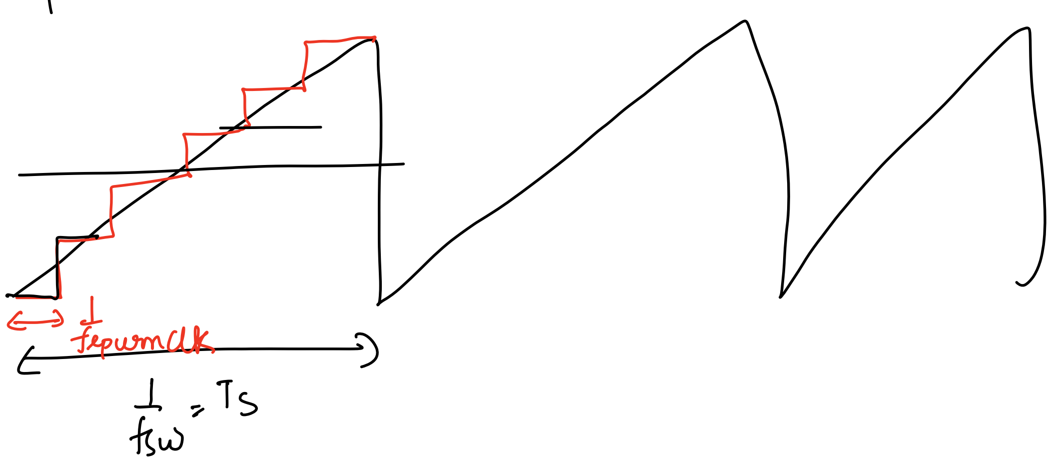
$$D_{min} = \frac{T_{ON}}{T_{SW}} = \frac{T_{epwmclk}}{T_{SW}}$$

$$\boxed{\delta = \frac{1}{2^{N_{pwm}}} = D_{minimum}}$$

$$\boxed{\frac{1}{2^{N_{pwm}}} = \frac{T_{epwm\,clk}}{T_{sw}} = \frac{f_{sw}}{f_{epwmclk}}}$$

Q Boost converter. switching freq = 50kHz.

Epwm clock = 50MHz



q = quantization = smallest duty ratio $= \frac{f_{sw}}{f_{cpuclk}}$

$= \frac{50k}{50M} = \frac{1}{10^3} = \frac{1}{1000}$

$\boxed{= 0.001}$

Boost converter

$V_o = \frac{V_{in}}{1-D}$

Let's say $D = 0.5$ $\quad V_o = \frac{24}{.5} = 48$

0.500001 ✗

$D = 0.501 \longrightarrow V_o = \frac{24}{1-.501} = 48.0961V$

$\Delta V_o = 48.0961V - 48V$

$\boxed{\Delta V_o = 0.0961V}$

48.99996

$$q = \text{quantization} = \text{smallest duty ratio} = \frac{f_{sw}}{f_{epwmclk}}$$

$$= \frac{50k}{50M} = \frac{1}{10^3} = \frac{1}{1000}$$

$$\boxed{= 0.001}$$

Q: How many bits do you need? $N_{pwm} = ?$

$$\boxed{\frac{1}{2^{N_{pwm}}} = \frac{T_{epwm\,clk}}{T_{sw}} = \frac{f_{sw}}{f_{epwmclk}}}$$

$f_{sw} = 50\,kHz$, $f_{epwmclk} = 150\,kHz$.

$$\frac{1}{2^{N_{pwm}}} = \frac{50}{150} = \frac{1}{\boxed{3}}.$$

$$\boxed{0, 1, 2, 3}$$ $N_{pwm} = 2$ bits

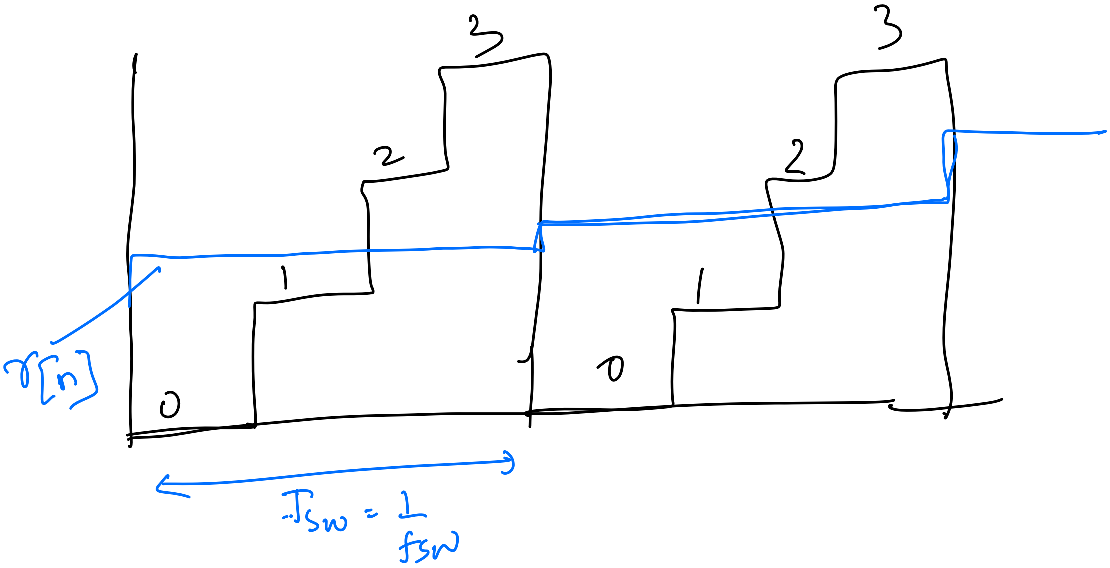
$f_{epwm} = 250\,kHz$

$$\boxed{\frac{1}{2^{N_{pwm}}} = \frac{50}{250} = \frac{1}{5}}$$!! Not an equality

3 bits.

$$\boxed{2^{N_{pwm}}} > \frac{f_{epwmclk}}{f_{sw}} \Rightarrow 2^{?} \geq 1000$$

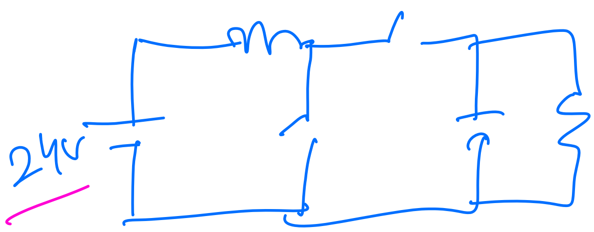
$$\boxed{N_{pwm} = 10}$$

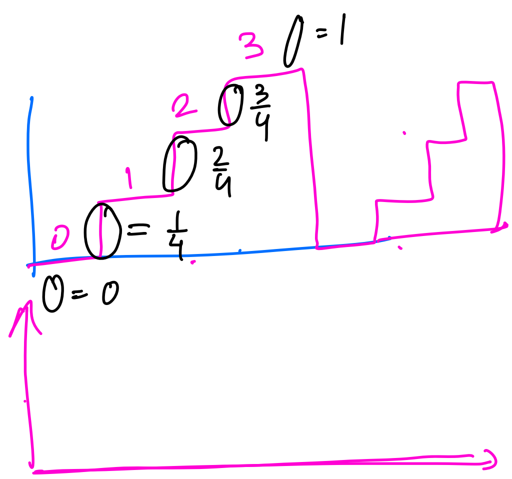


→ No chattering for digitial PWM

→ Problem exists of limited resolution.

Q



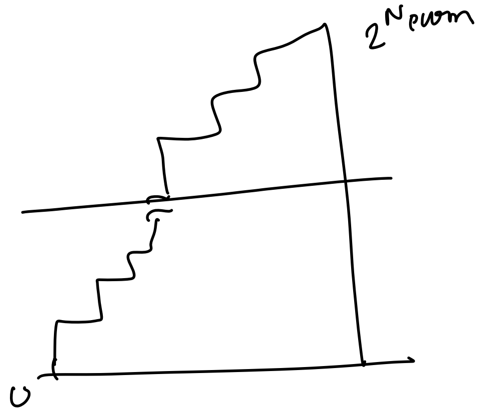


$$\boxed{N_{pwm} = 2}$$

$D_{min} = \frac{1}{2^2} = \frac{1}{4}$

$V_o = ?$ possible $D = \boxed{0, \frac{1}{4}, \frac{1}{2}, \frac{3}{4}, 1}$ ⇒ Vout 24, 48, . .

$0, \frac{1}{4}, \frac{2}{4}, \frac{3}{4}, \frac{4}{4}$



$r = \frac{2^{N_{pwm}}}{2}$

$d = 0.5$

0.25

$d = \frac{r}{V_{max}} = \frac{2^{N_{pwm}} \times d}{2^{N_{pwm}}}$

PWM & ADC 1.1

" Peak- Valley Sampling"