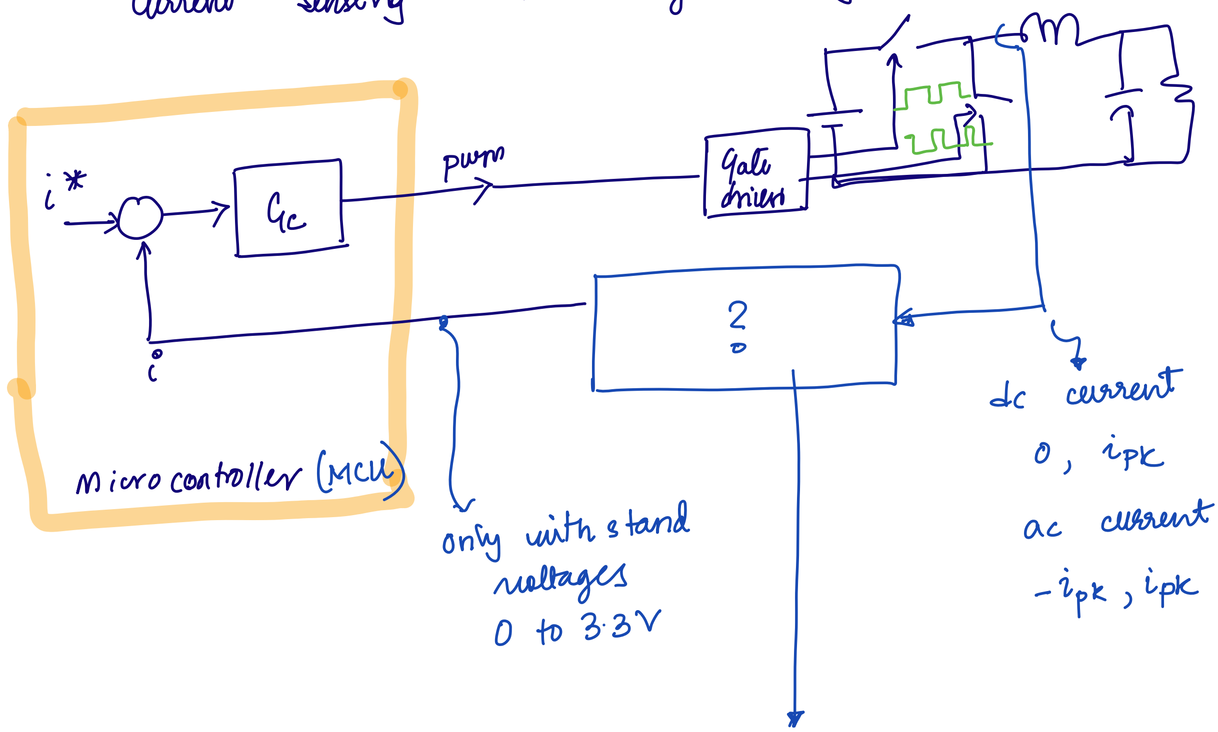
Lecture 18 (March 3)

- HW 5 due now (submission open till midnight today)
- HW 6 due 10th March.

Current Sensing & Voltage Sensing.



current (circuit) ⟶ voltage conversion (for microcontroller)

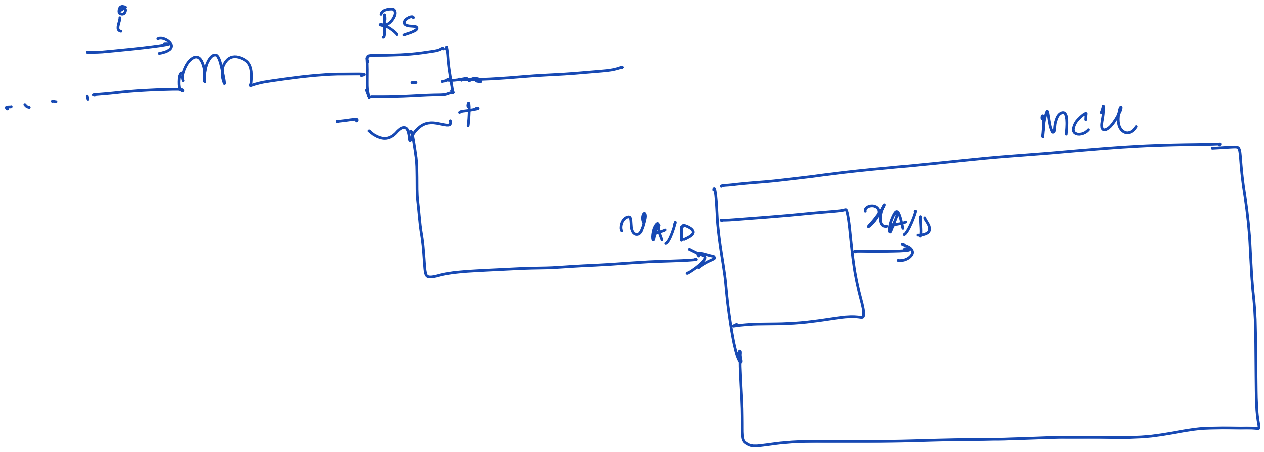
① Sense resistor. (R_s)

'i' – inductor current.

$i \cdot R_s = v_s$ = drop across the sense resistor.

If $0 < v_s < 3.3V$, you can directly feed this to MCU.

Inside MCU,



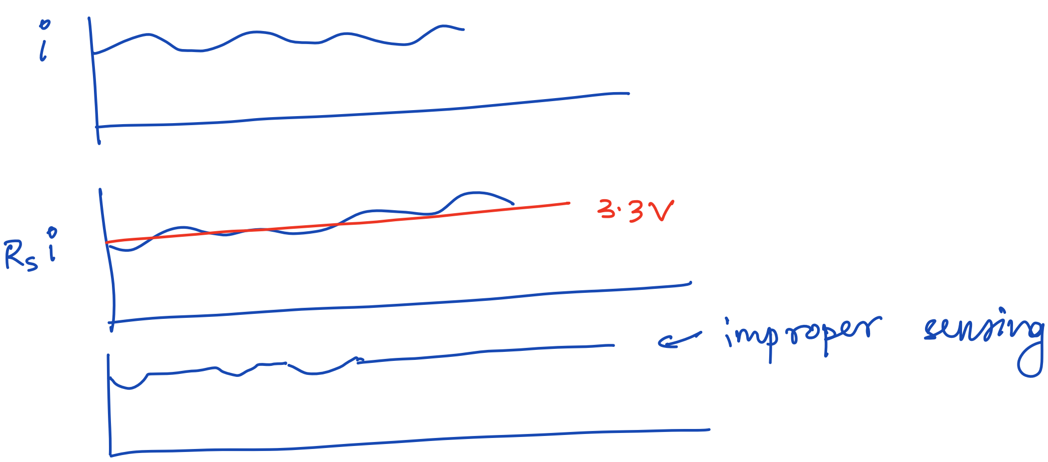
$$x_{A/D}[k] = \text{round}\left(\frac{v_{A/D}}{\underbrace{V_{FS}}_{3.3}} \cdot 2^{\overbrace{n_{ADC}}^{12 \text{ bits}}} \right)$$

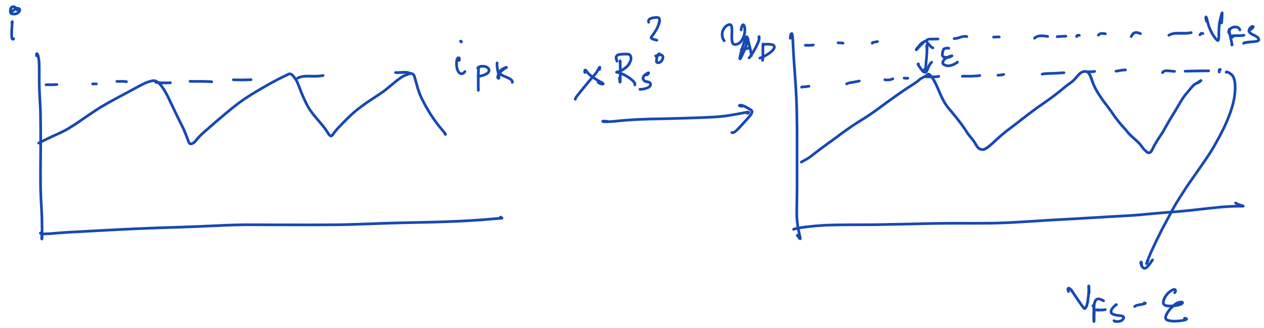
$$x_{A/D} \xrightarrow{?} \text{'}i\text{'}$$

$i[k]$ = inductor current at the k-th sample

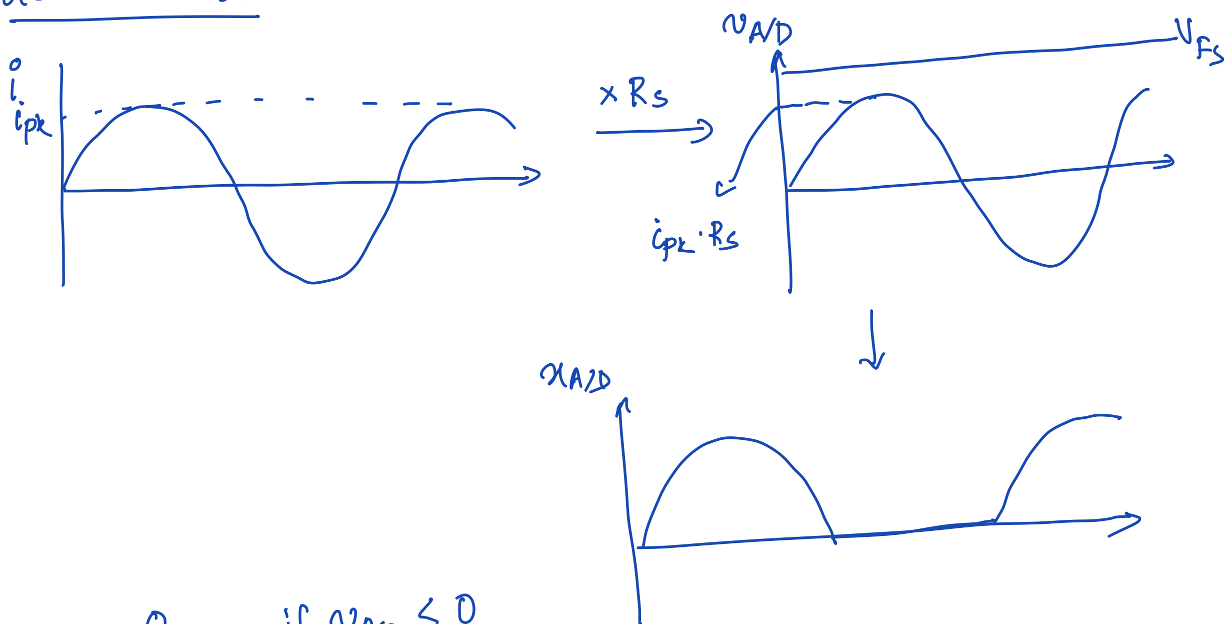
$$i[k] = \left[x_{A/D}[k] \cdot \frac{V_{FS}}{2^{n_{ADC}}} \right] \frac{1}{R_s}$$

If $R_s i > 3.3V$,





ac currents

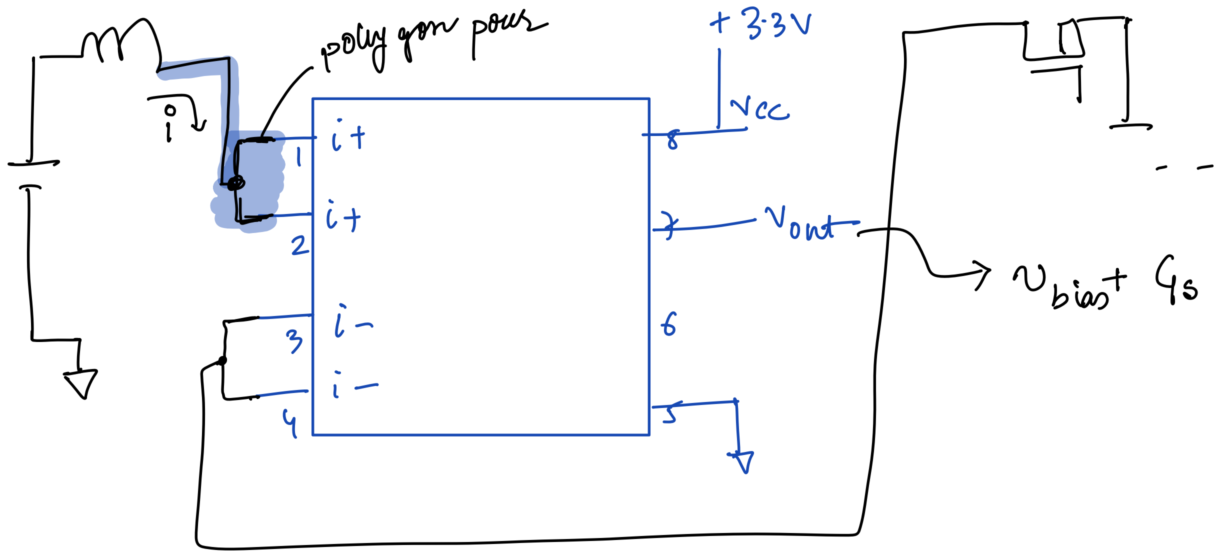


$$x_{A/D} = 0 \quad \text{if } v_{A/D} < 0$$

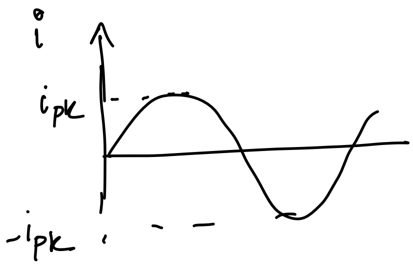
$$= \frac{v_{A/D}}{V_{FS}} 2^{n_{ADC}} \quad \text{if } 0 \leq v_{A/D} \leq V_{FS}$$

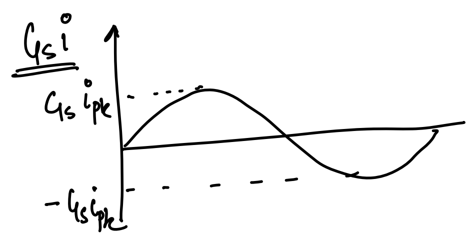
$$= 2^{n_{ADC}} - 1 \quad \text{if } v_{A/D} > V_{FS}$$

ACS730

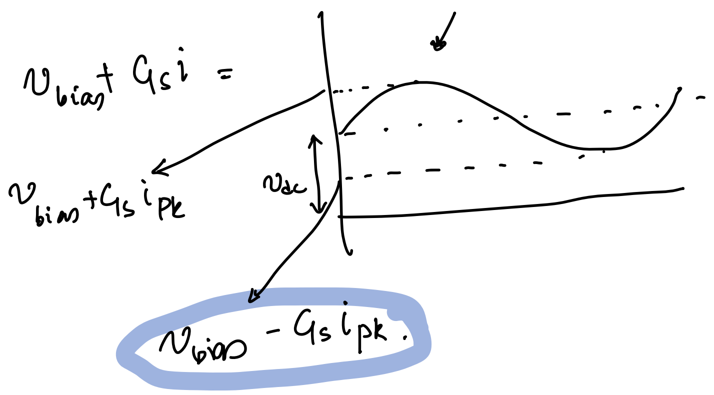


$\to v_{bias} + G_s i = v_{out}$





$v_{out} = v_{bias} + G_s i =$



Q o/p has to be strictly positive : because $0 < v_{A/D} < 3.3$.

$v_{bias} - G_s i_{pk} > 0$

$v_{bias} > G_s i_{pk} \quad \therefore \quad \boxed{i_{pk} < \frac{v_{bias}}{G_s}}$

$$\boxed{v_{bias} + G_s i_{pk} < V_{cc}}$$

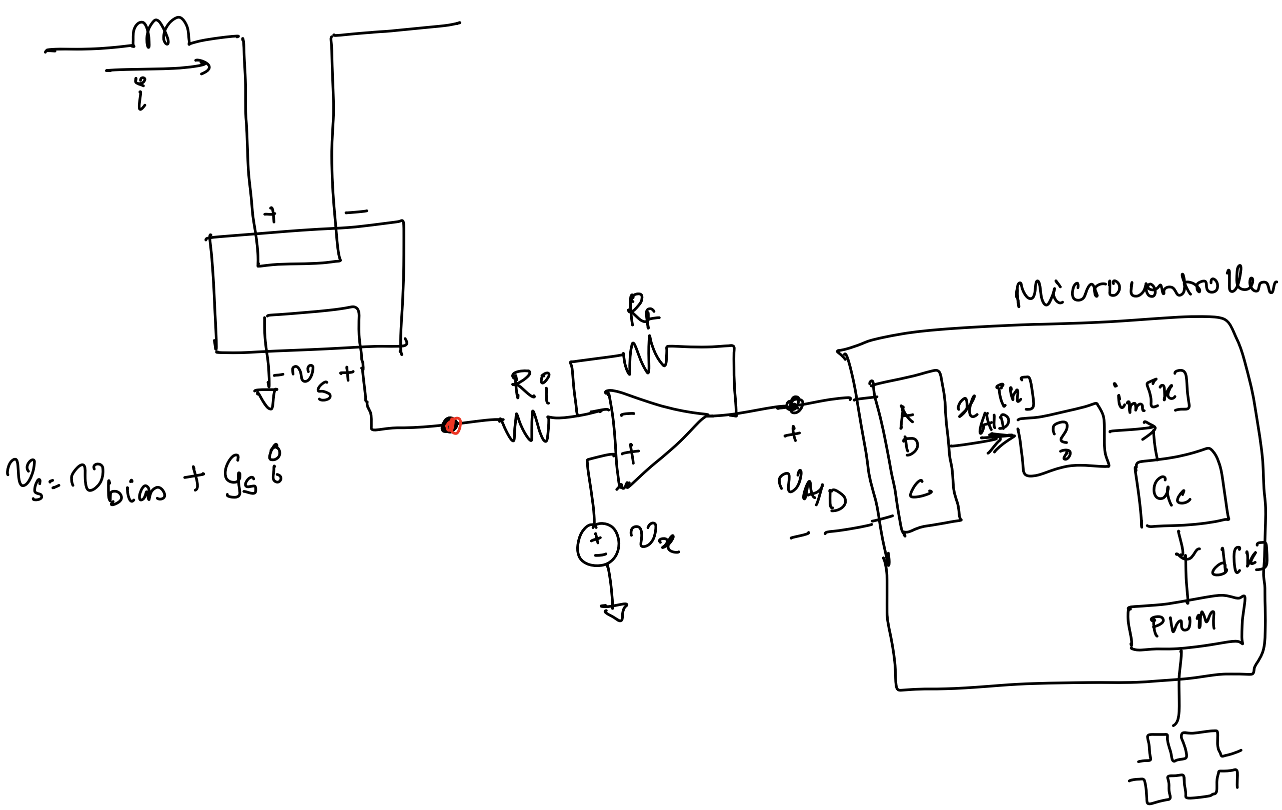
$$v_{bias} = \frac{v_{cc}}{2}$$

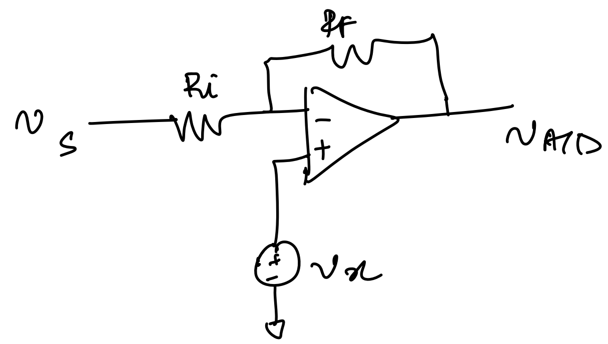
eg. ACS730 $\rightarrow$ $3V = V_{cc}$

& , $v_{bias} = 1.5\ V.$

$G_s = 0.1,\ 0.15,\ 0.2\ \ldots$

<u>Most General current sensing circuit.</u>





Superposition

① $v_x = 0$

$$\left(v_{A/D}\right)\Big|_{v_x=0} = -\frac{R_f}{R_i} v_s$$

② $v_s = 0$

$$\left(v_{A/D}\right)\Big|_{v_s=0} = \left(1+\frac{R_f}{R_i}\right) v_x$$

So, net $v_{A/D}$ obtained by superposition:

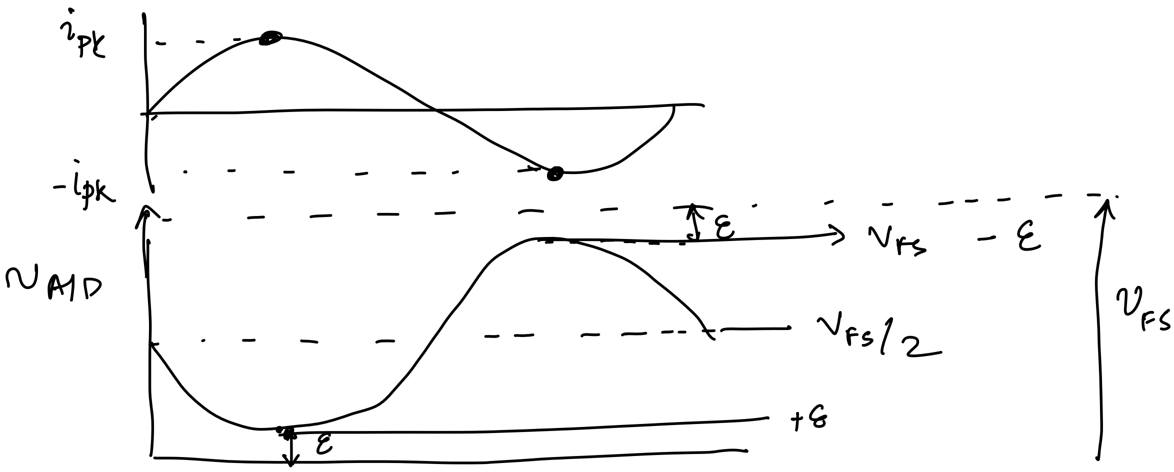
$$v_{A/D} = v_{A/D}\Big|_{v_x=0} + v_{A/D}\Big|_{v_s=0}$$

$$= -\frac{R_f}{R_i} v_s + \left(1+\frac{R_f}{R_i}\right) v_x$$

$$\left[\because v_s = v_{bias} + G_s i\right]$$

$$\underbrace{v_{A/D} = -\frac{R_f}{R_i}\left(v_{bias} + G_s i\right) + \left(1+\frac{R_f}{R_i}\right) v_x}$$ —— ①

$0 < v_{A/D} < v_{FS}.$



① If $i = 0$,

$$v_{A/D} = v_{FS}/2$$

From eq ① we can write

$$v_{A/D} = -\frac{R_f}{R_i}\left(v_{bias} + G_s i\right) + \left(1 + \frac{R_f}{R_i}\right) v_x$$

$$\boxed{\frac{v_{FS}}{2} = -\frac{R_f}{R_i} v_{bias} + \left(1 + \frac{R_f}{R_i}\right) v_x} \quad \text{— ②}$$

Design choices : $\underbrace{R_f/R_i \;,\; v_x}$

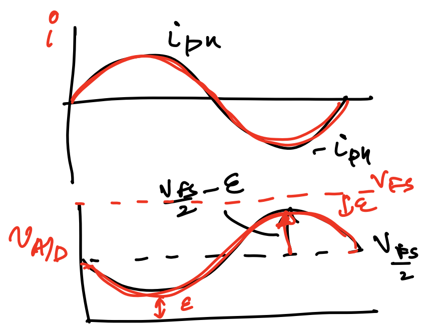
② condition ①

if $i = i_{pk}$, $\quad v_{A/D} > \varepsilon$

$i = -i_{pk}$, $\quad v_{A/D} < v_{FS} - \varepsilon$

$$v_{A/D} = \underbrace{-\frac{R_f}{R_i} v_{bias} + \left(1+\frac{R_f}{R_i}\right) v_x}_{v_{FS}/2} - \frac{R_f}{R_i} \cdot G_s\, i$$

$$v_{A/D} = \underbrace{\frac{v_{FS}}{2} - \frac{R_f}{R_i} G_s\, i}$$



$$\frac{v_{FS}}{2} - \frac{R_f}{R_i} G_s \cdot i_{pk} > \varepsilon$$

or, $$\frac{V_{FS}}{2} - \varepsilon > \frac{R_f}{R_i} G_s\, i_{pk}$$

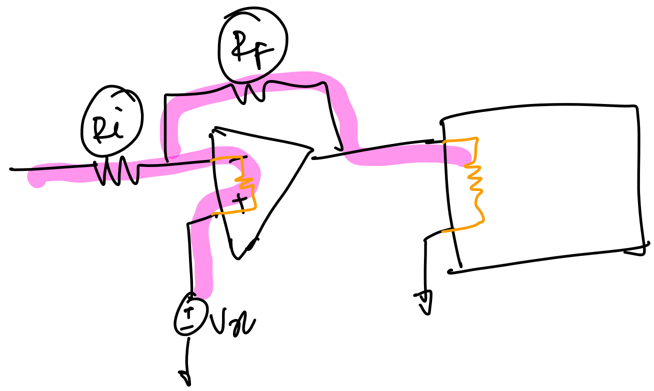
$$\therefore \boxed{\frac{R_f}{R_i} < \frac{1}{G_s\, i_{pk}} \left(\frac{v_{FS}}{2} - \varepsilon\right)} \text{ — ③}$$

$$\frac{R_f}{R_i} = \frac{1}{G_s\, i_{pk}} \left(\frac{v_{FS}}{2} - \varepsilon\right)$$

Ⓐ Choose $\frac{R_f}{R_i}$ by Eq ③

Ⓑ substitute R_f/R_i from Ⓐ in Eq ② to get v_x.

Ⓒ How to get R_f & R_i from R_f/R_i ?



$R_i, R_F \ll R_{leakage}$.

$R_i, R_F \sim$ 10 kOhm, 1kOhm

Inside the microcontroller,

$$x_{A/D} = \text{round}\left(\frac{v_{A/D}}{V_{FS}} \cdot 2^{n_{A/D}} \right)$$

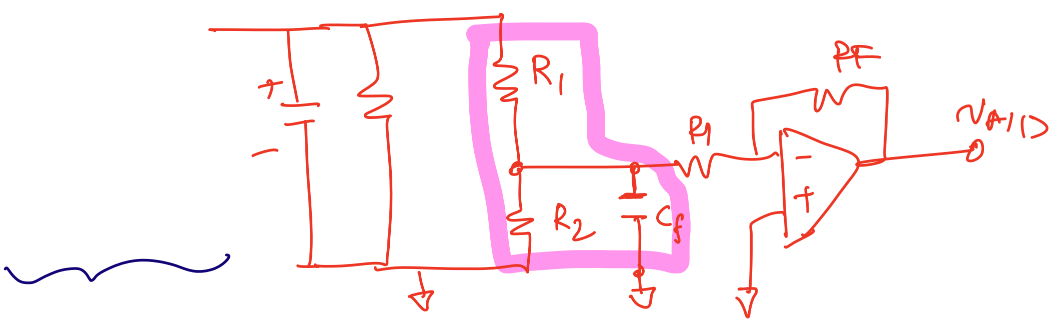
$$x_{A/D} = \text{round}\left(\frac{-\frac{R_F}{R_i}\left(v_{bias} + G_s i\right) + \left(1+\frac{R_F}{R_i}\right) v_x}{V_{FS}} \cdot 2^{n_{AD}} \right)$$

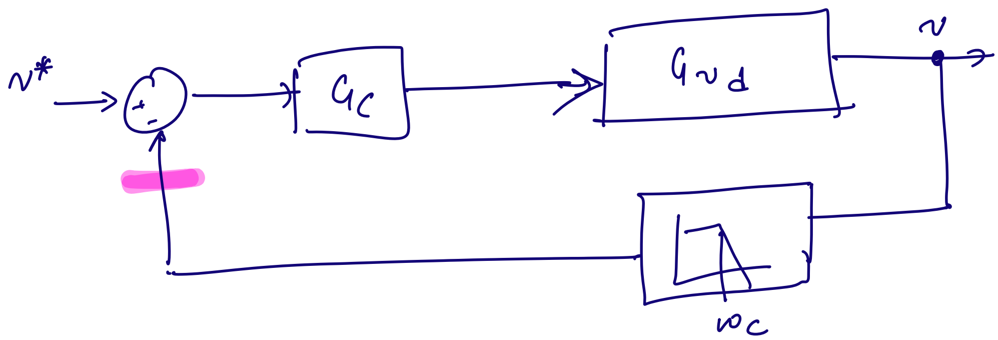
$$= \text{round}\left(\left(\frac{\frac{V_{FS}}{2} - \frac{R_F}{R_i} G_s i}{V_{FS}} \right) 2^{n_{A/D}} \right)$$

$$= \text{round}\underbrace{\left(\left(\frac{1}{2} - \frac{R_F}{R_i} \frac{G_s}{V_{FS}} i \right) 2^{n_{AD}} \right)}_{F}$$

$v_{A/D} \longrightarrow f^{-1} \longrightarrow \underbrace{i[k]}$

5:28 pm





$\omega_c = \dfrac{1}{C_f R_f}$

If $\omega_c \approx \omega_{gv}$ ← voltage control bandwidth.

ω_c = filter cut off frequency >> control bandwith of the inductor current / cap voltage

MHz range cut off frequency.

$v_{A/D} \longrightarrow \underbrace{x_{A/D}[k]}$

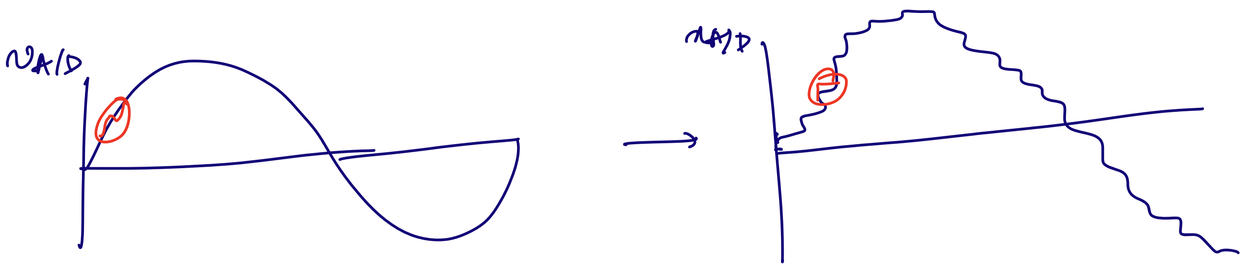
① Low pass filter $x_{A/D}$ digitally.

$$x^{o}_{A/D} = \frac{s}{s+w_c}\, x_{A/D}$$

② moving average filter:

$$x^{o}_{A/D} = \frac{x_{A/D}[k] + x_{A/D}[k-1]}{2}$$

never try this ③ $x^{o}_{A/D} = \underbrace{x_{A/D}[k]\ \&\ (\overbrace{FFF}0)}$



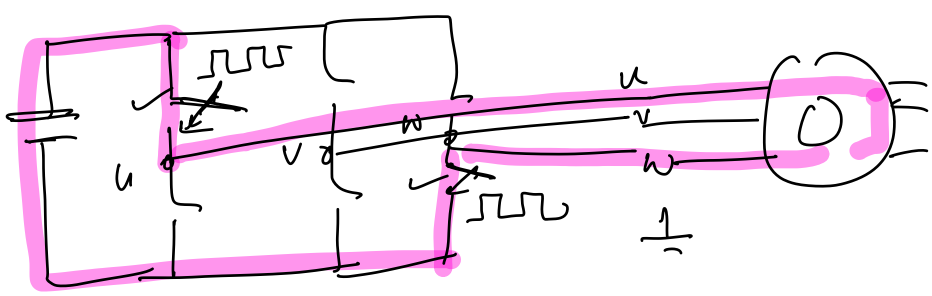
digital 9 $\longrightarrow$ binary 1001

$\overbrace{1111}^{F}\ \overbrace{1111}^{F}\ \overbrace{1111}^{F}\ 0000$

MSB LSB

LSB = lowest significant bit

MS B



6-step driving – Hall sensors feedback

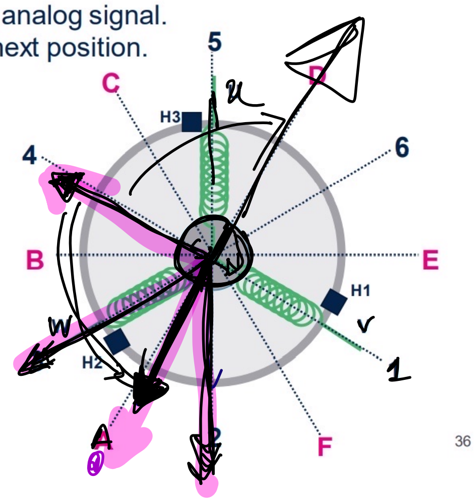
The **Hall sensors** detects the rotor position returning a digital or analog signal. The information is used to move the stator magnetic field in the next position.

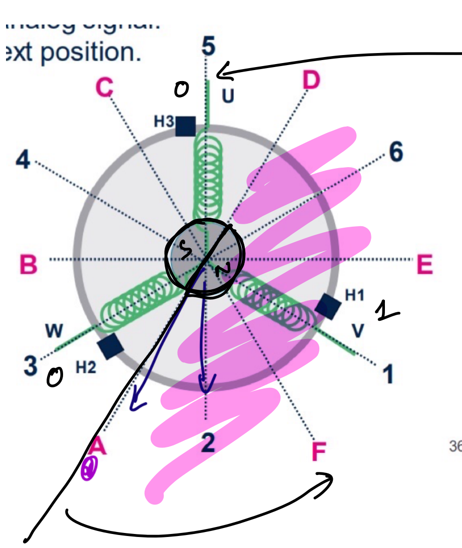
C	b	a
H_3	H_2	H_1
0	0	1
0	1	1
0	1	0
1	1	0
1	0	0
1	0	1

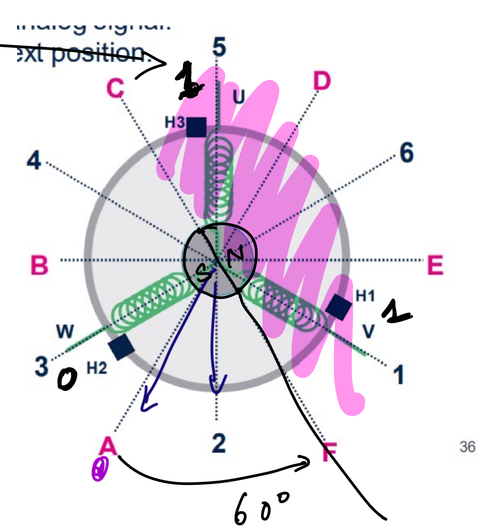
Rotor position	Stator position	Current
1	A	U → W
2	B	V → W
3	C	V → U
4	D	W → U
5	E	W → V
6	F	U → V

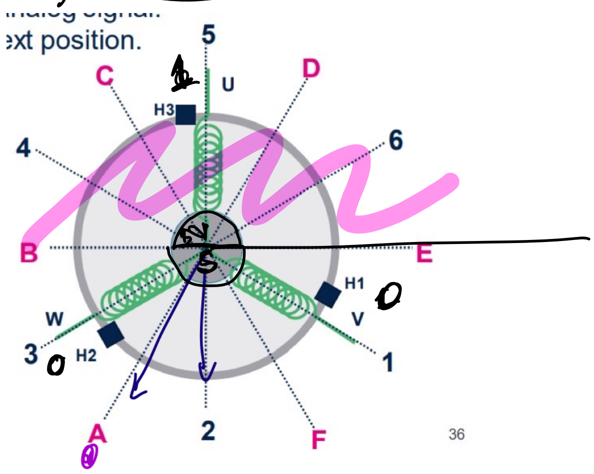
NOTE: Clockwise rotation

life.augmented









counter = 0 when H_1, H_2, H_3 has a change

counter ++

counter stops when any one of H_1, H_2, H_3 changes

$$\text{time} = \text{counter} \times t_{sample}$$

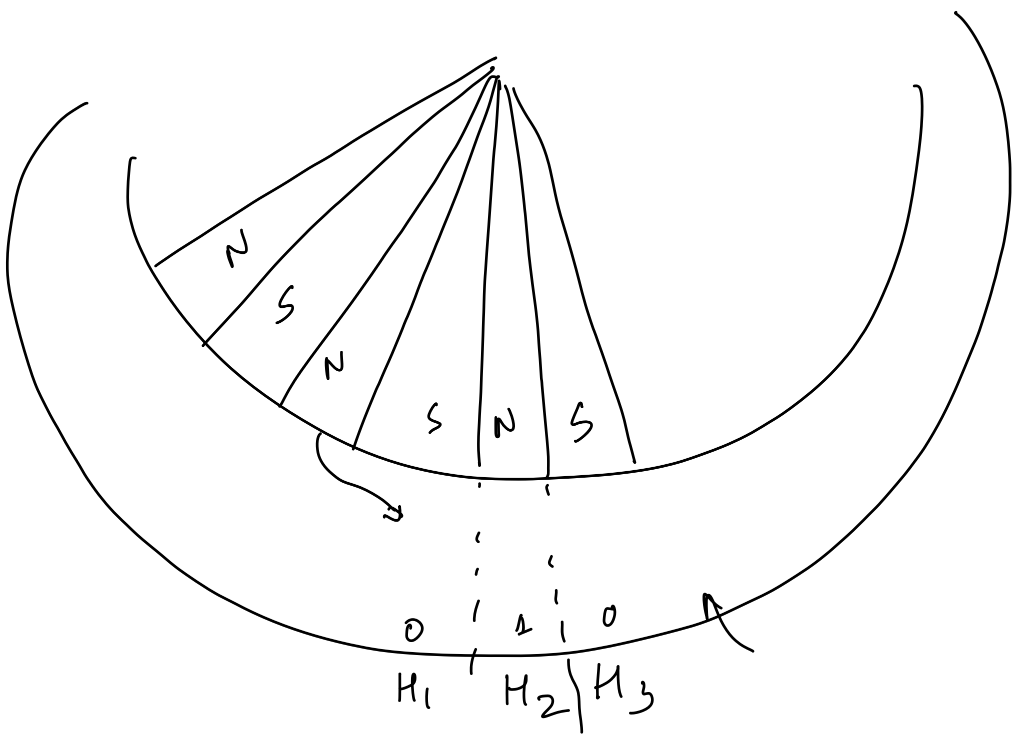
$$= (\text{counter})\left(\frac{1}{2 f_{sw}}\right)$$

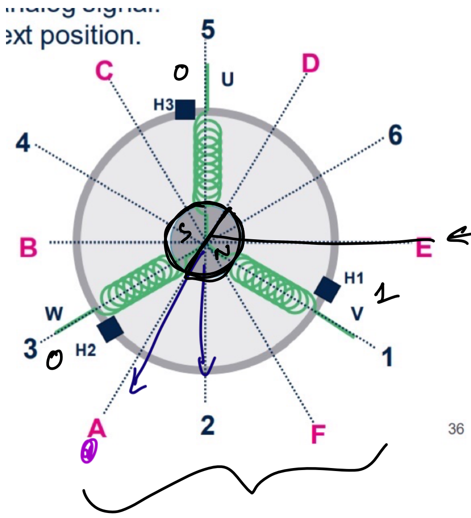
$$= \text{counter} \cdot 50\,\mu s.$$

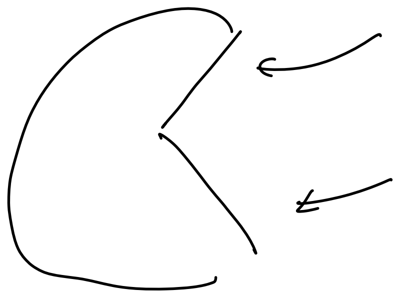
rotation between any 1 hall effect sensor

$$\text{change} = \frac{2\pi}{6} = \frac{\pi}{3}$$

$$\omega^* = \text{electrical speed} = \frac{\pi/3}{(\text{counter})(50\,\mu s)} \text{ rad/s}$$







- Because of the Hall sensors, the angle θ updates every 60°.

So,

H_3 H_2 H_1	θ
0 0 1	0°
0 1 0	60°
1 0 0	120°
1 0 1	⋮
1 1 1	⋮
0	

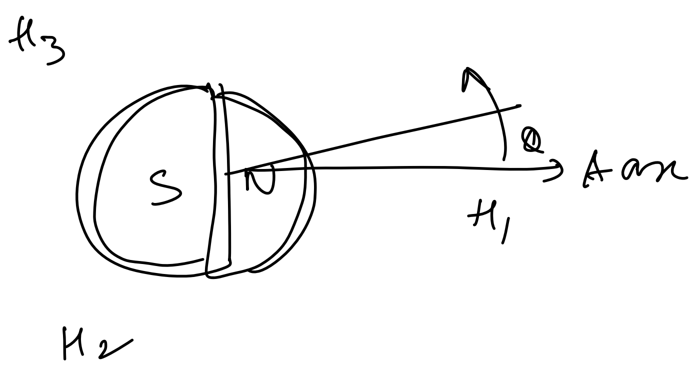
$\theta_i = 0^\circ$ *

$\theta = \theta_i + \int \omega . dt$

$\theta_i = 60^\circ$

$\theta = \theta_i + \int \omega \, dt$

(*) Who said 001 $\longrightarrow$ corresponds to 0°.



(*) At very high speeds,
hall effect sensor outputs can get
missed.

So, your speed & angle estimation might
not work.