Sensors

- converts a physical quantity to be measured into voltage.

- Examples of physical quantity

  position, sound, temperature, pressure, vibration, acceleration

- Transducer is the active element of the sensor.

① Position and speed measurement

Position measurement

(i) Proximity sensor / Limit switch: Detect if something has reached close enough

(ii) Potentiometer: Linear or rotary position

(iii) Linear variable differential Transformer

LVDT

Linear displacement

(iv) Encoder: Measure angles (usually on motors)

Speed measurement

Use finite difference on position data.

$$\frac{dp}{dt} = \frac{p_2 - p_1}{t_2 - t_1}$$

noisy + filter → smooth data

software

hardware

butterworth filter

Kalman filter

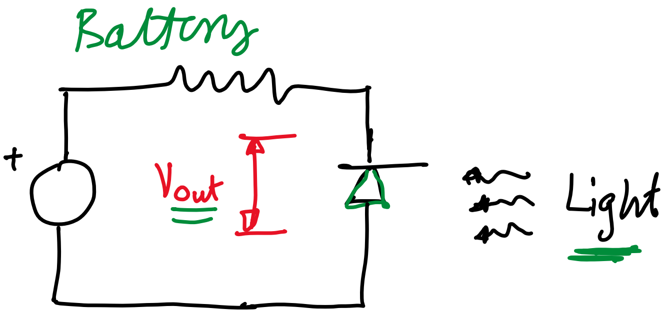
R-C

Photo-emitter detection pair

Principle: Light-sensitive element

(i) photo-diode, (ii) photo cell

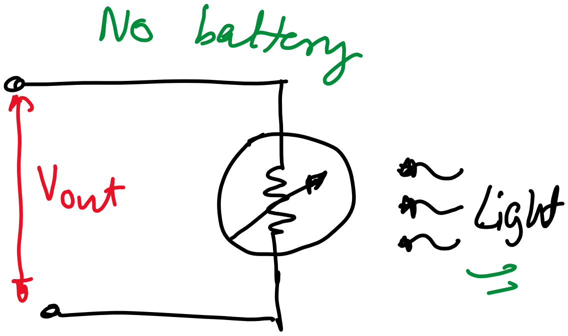
→ Photo diode



No light $V_{out} \simeq 0$

Light $V_{out} = V_{diode} = 2V$

→ Photo cell

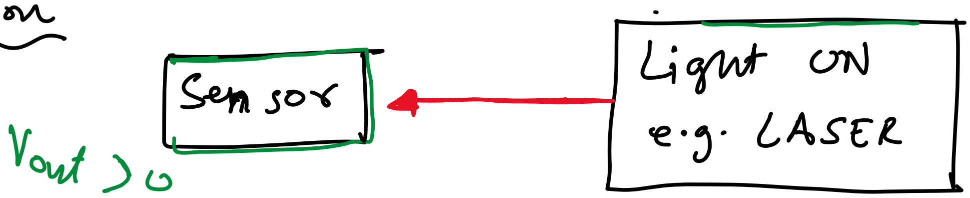


No Light, High Resistance, $V_{out} \simeq 0$

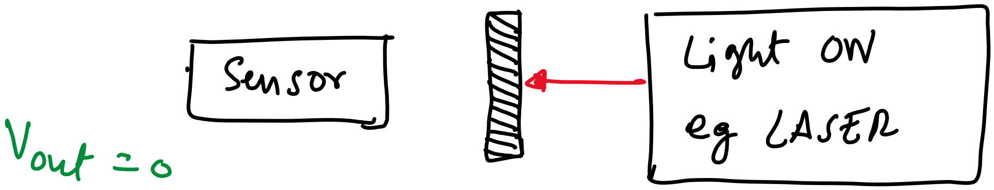
Light, Low Resistance, $V_{out} > 0$

Implementation

Normal



Object detection

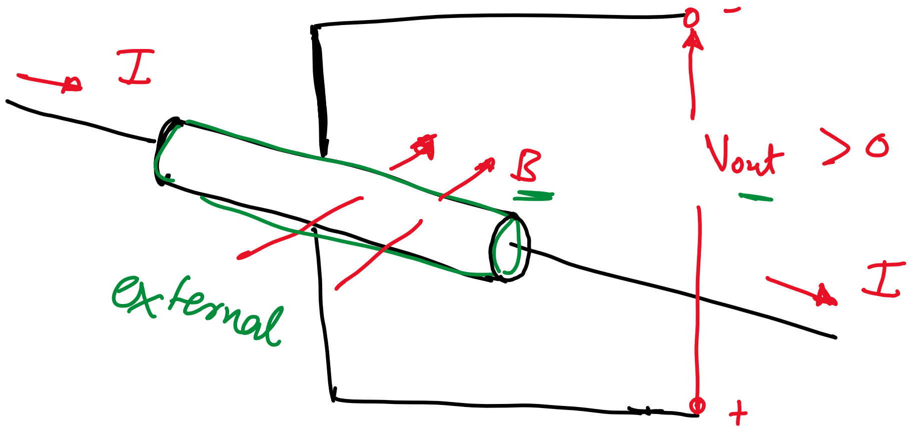


Object blocks Light

Hall-effect sensor

Principle: current carrying conductor that is exposed to magnetic field produces a voltage difference across the end of the conductor (Hall effect)

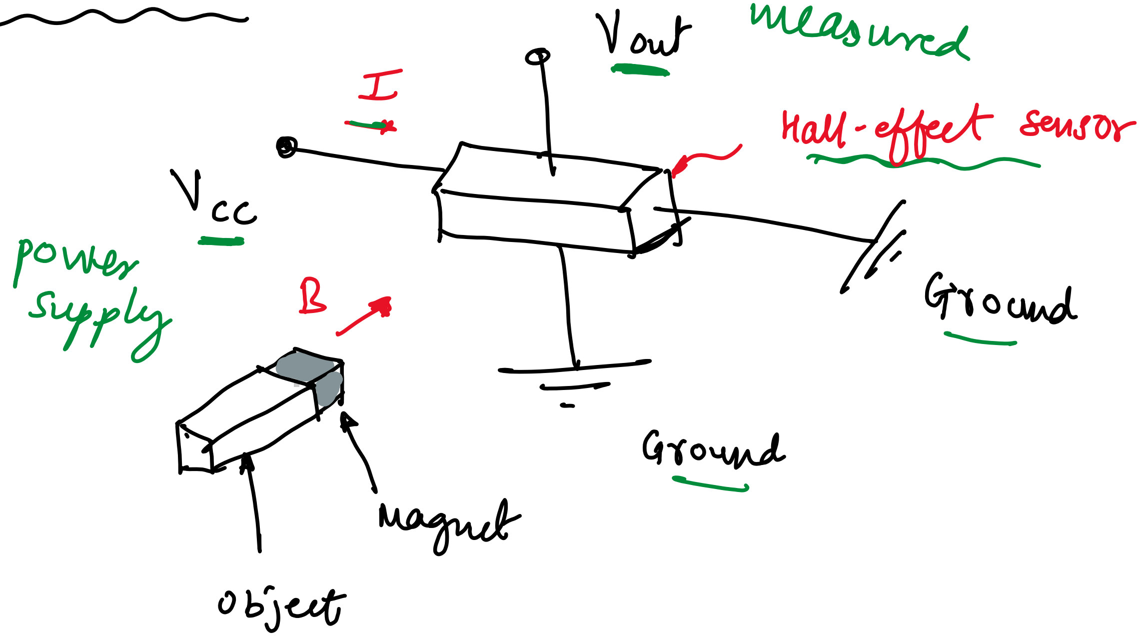
Illustration



$$\vec{V}_{out} = \vec{I} \times \vec{B}$$

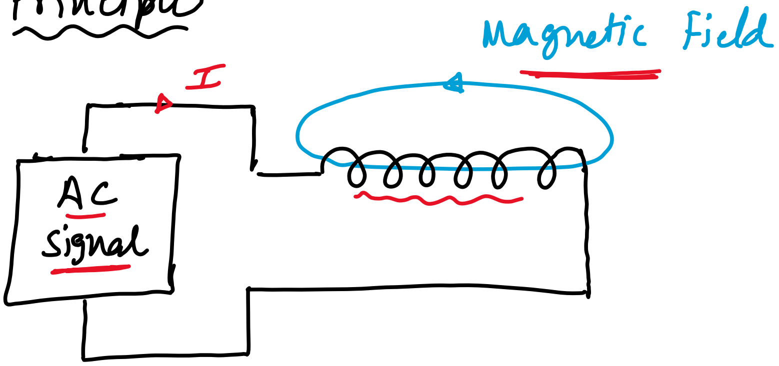
cross-product

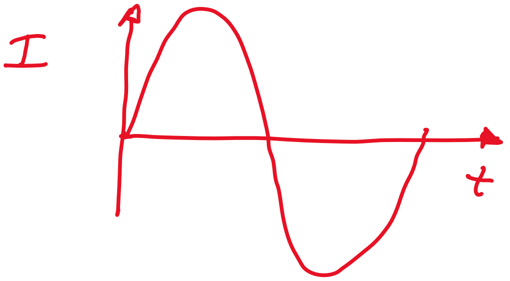
Implementation

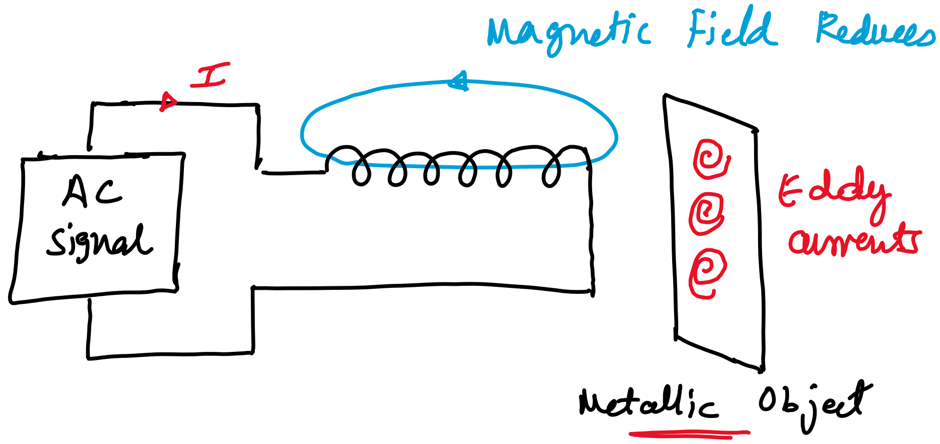


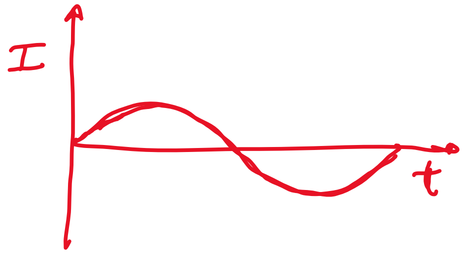
Inductive / Eddy Current Sensor

Principle



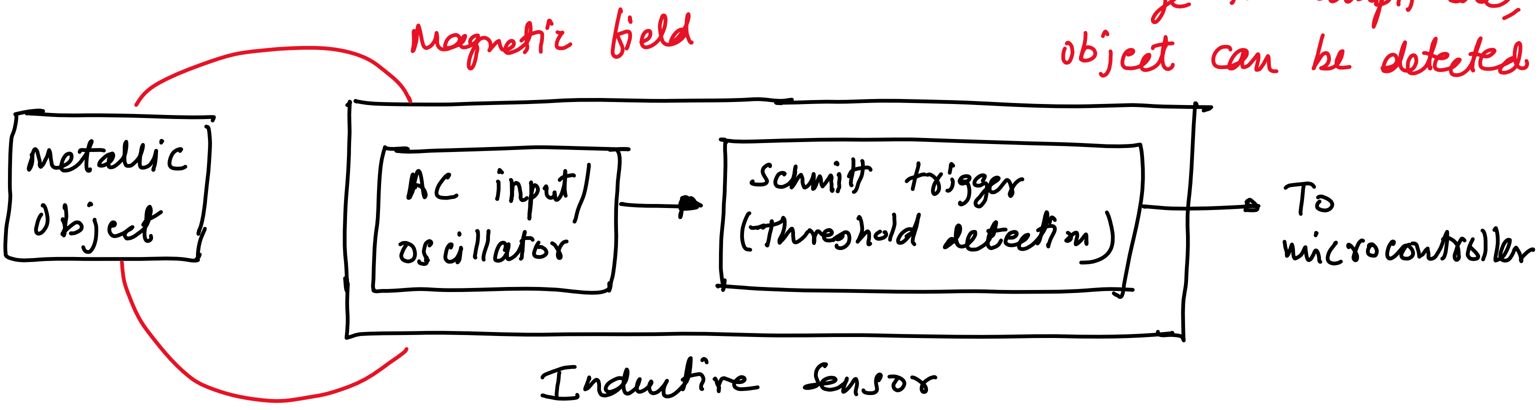






The amplitude of current decreases due to Eddy currents. By detecting change in amplitude, object can be detected.

Implementation

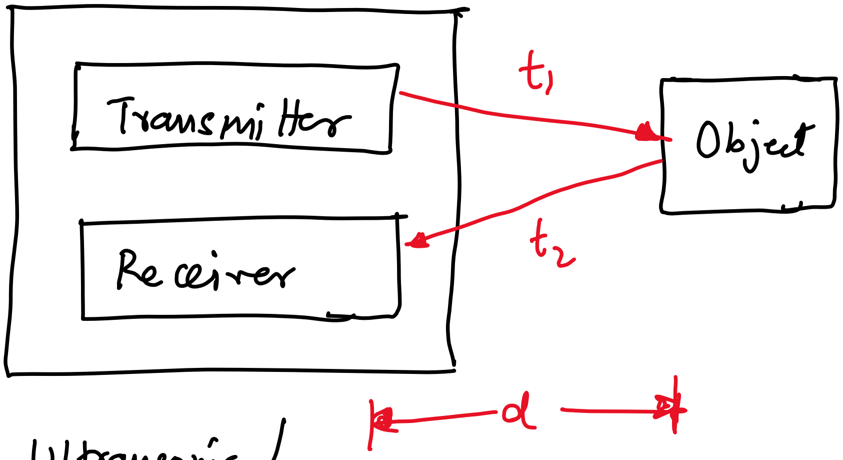


Application ① Car exit in gated communities
② Traffic Lights.

Ultrasonic / Infra red sensor

Principle: Send a high frequency sound wave and measure time to receive the sound wave (time of flight sensor)

Implementation



Ultrasonic/ Infra-red sensor

$$2d \approx \underset{\uparrow}{s} \underbrace{(t_1 + t_2)}_{\text{Produces Voltage } (V_{out}) \propto (t_1+t_2)} \qquad s = \text{speed of sound}$$

1) Calibrate the sensor by putting an object at known distance (d_0) & measure V_0 (Voltage)

2) For a new measurement V_1, $\underset{?}{d_1} = \left(\frac{d_0}{V_0}\right) V_1$ ← measured

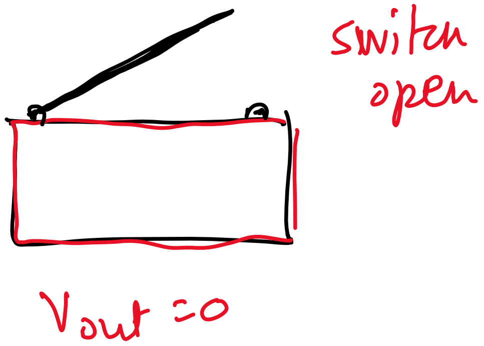
calibration

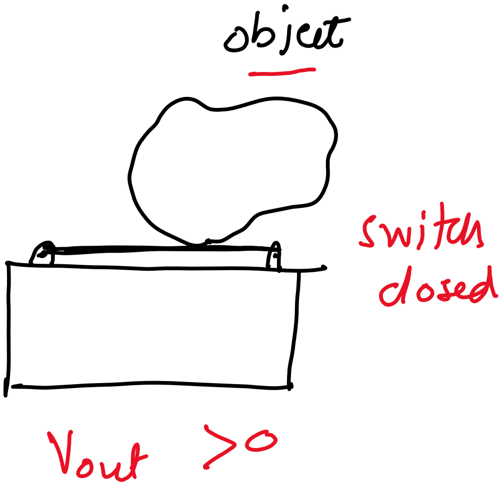
Contact Sensor / Bump sensor

Principle :

Contact leads to closing a circuit which leads to a non zero current in the circuit.

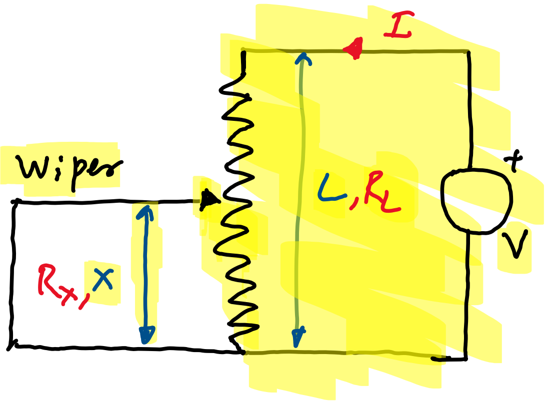
Implementation





Potentiometer

a) Linear potentiometer



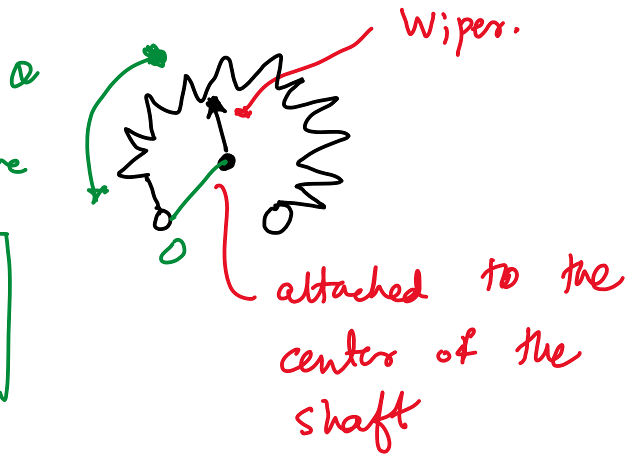
Resistance $R = \frac{\rho l}{A} \Rightarrow R \propto l$

Thus $R_x = \frac{x}{L} R_L$

But $V \propto R$. $\Rightarrow V_x = \frac{x}{L} V \Rightarrow \boxed{\overset{\text{unknown}}{x} = L \frac{\overset{\text{measured}}{V_x}}{V}}$

Here L, V are known apriori, V_x is measured, x is the unknown (distance) that is inferred.

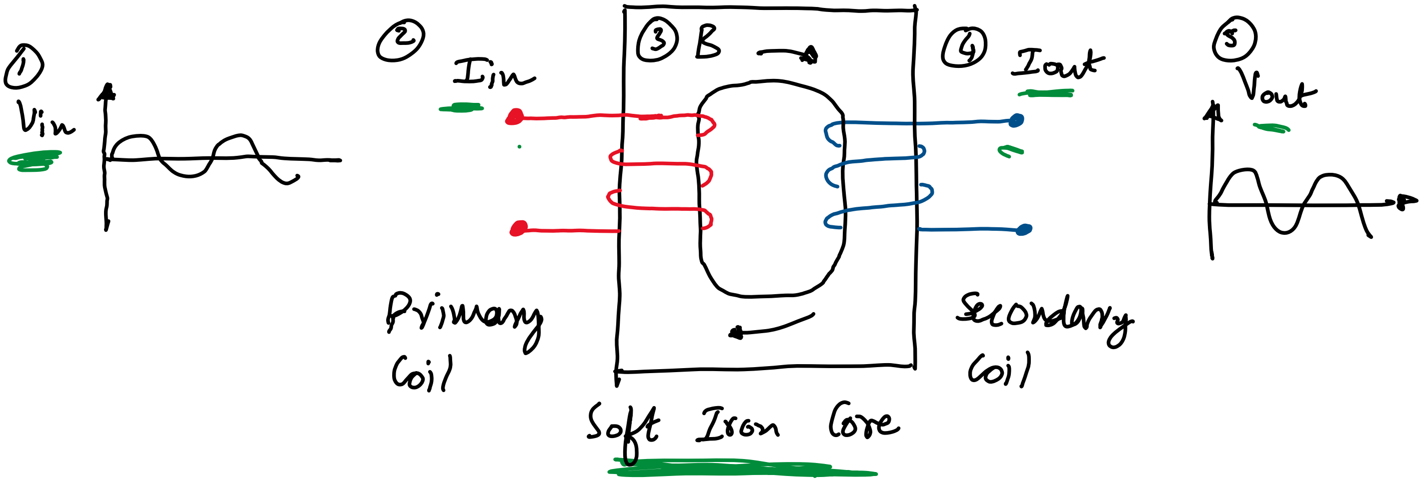
Rotary Potentiometer



$$\boxed{\overset{?}{\theta} = \frac{2\pi}{V_u} \overset{\text{measure}}{V_\theta}}$$

Linear Variable Differential Transformer (LVDT)

Principle : Electromagnetic induction

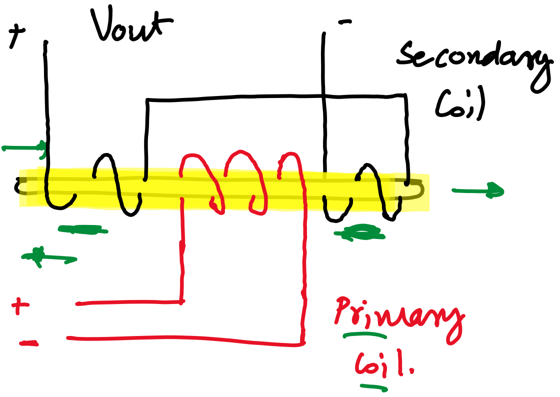


① Vin is the input → ② This causes Iin in primary coil. → ③ Iin magnetizes the soft iron core (B). → ④ B causes Iout ⑤ Iout causes voltage Vout.

$$\frac{V_{out}}{V_{in}} = \frac{\text{No. of coils in secondary}}{\text{No. of coils in primary}}$$

Implementation

Want to measure displacement of the soft iron core



Case 1: Soft iron core is in the middle. The 2 coils produce equal and opposite voltages : $V_{out} = 0$

Case 2 : Soft iron core moves to the right. This causes more coils on the right than the left. This results in a Vout ∝ distance moved by the soft iron core

↳($V \propto x$)

Radio Frequency IDentification (RFID) sensor.

This is a wireless proximity sensor

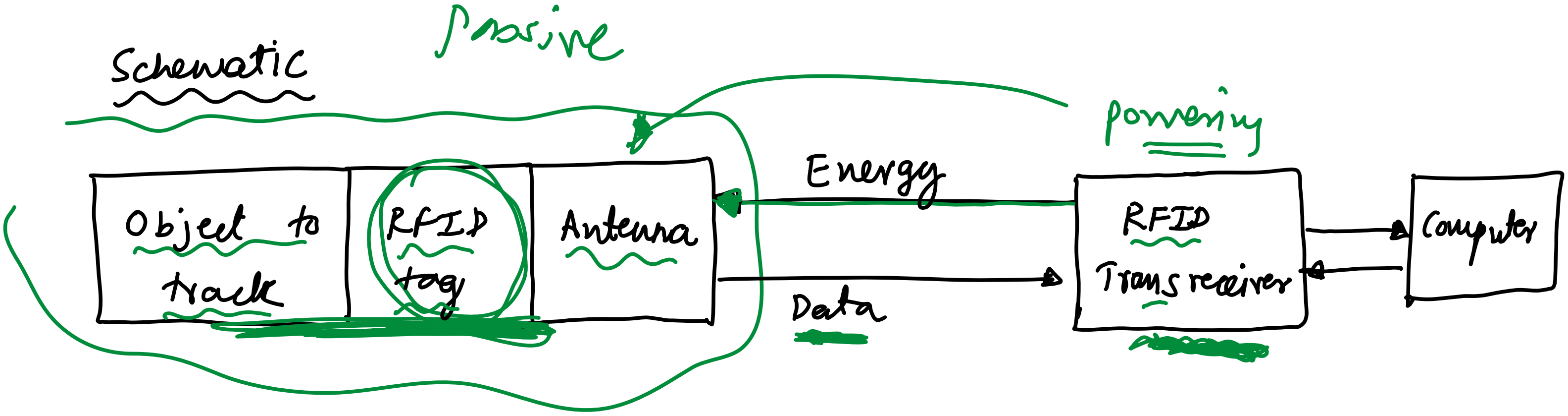
It has 3 elements

① A RFID tag attached to the object to be tracked

② A RFID transreceiver to collect data

③ An antenna on the RFID tag to send radio frequency data to the RFID transreceiver.

Schematic



- RFID tag is passive (no batteries)
- RFID transreceiver is active (powered). It energizes the RFID tag
- Each RFID tag transmits a unique code to the RFID transreceiver. By using different codes on different tags, it is possible to track multiple objects.
- Example, Highway toll collection such as EZ-Pass uses RFID technology.

Digital optical encoder

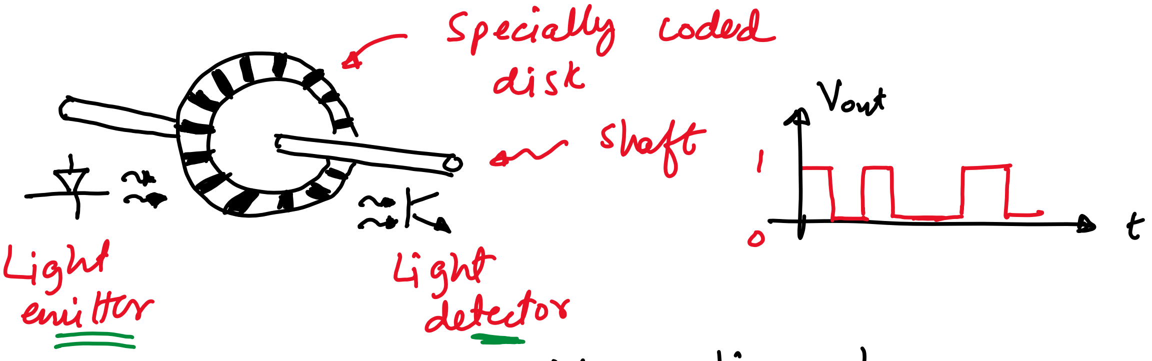
Encoder measures angular position using optics (emitter- detector pair). Encoder produces digital output unlike a potentiometer which produces an analog output.

There are 2 types of encoders

① Incremental encoder: measures relative change in position
② Absolute encoder: measures absolute position

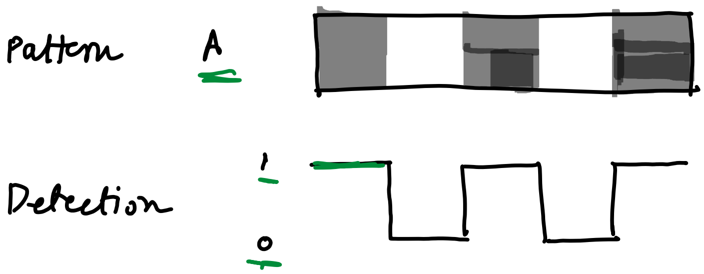
② is more expensive than ①. ① need an initialization routine. If encoders are used for velocity measurements using finite difference then ① or ② are equally good.

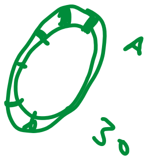
Basic principle of an encoder



① Light emitter : Emits light continuously
② Light detector: Detects light
③ Coded Disk: Contains useful pattern that either blocks or lets light pass. Based on the detected light / pattern it is possible to measure position.

① Incremental encoders





30 slots

$360/30 = 120$

The angle turned can be computed by knowing degrees turned per change in pulse and counting the number of pulses.

EXAMPLE:

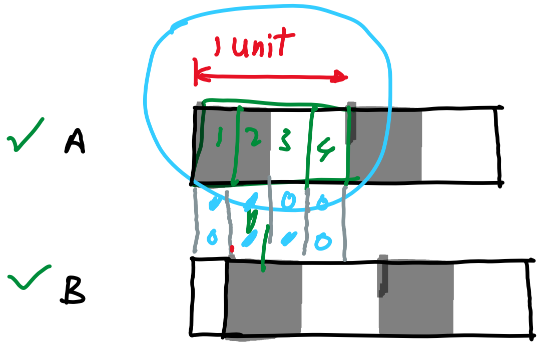
There are 30 slots in the disk. If we count 14 high signals then compute the angle turned.

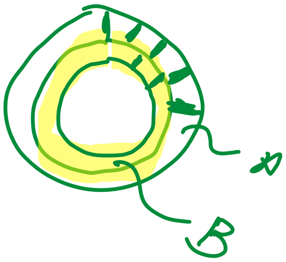
Each slot corresponds to $360^\circ/30 = 12^\circ$ /slot.

Since the count is 15, the angle turned is $14\ (12^\circ) = 168^\circ$.

A single track can only give the angle turned, it cannot provide the direction of motion.

To get magnitude and direction, one needs two tracks





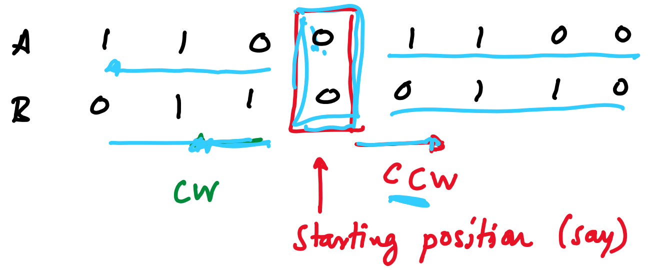
- A/B are 1/4 cycle out of phase, hence called quadrature
- Consider the repeating unit. It has the following code

A	1	1	0	0	1	1	0	0
B	0	1	1	0	0	1	1	0

Repeating unit

1 = black 0 = white

Now let us see how to sense the direction



A	1	1	0	0	1	1	0	0
B	0	1	1	0	0	1	1	0

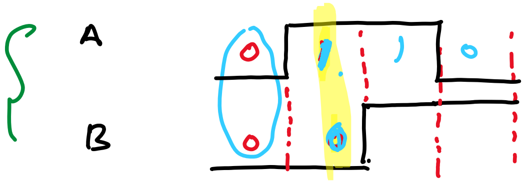
Re-writing

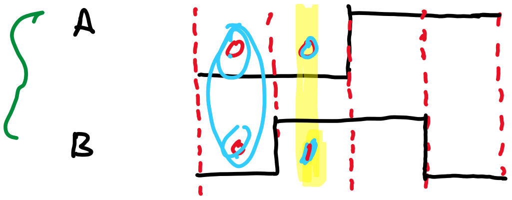
CCW

A	0	1	1	0	0
B	0	0	1	1	0

CW

A	0	0	1	1
B	0	1	1	0





A leads B → 0-1 transition in

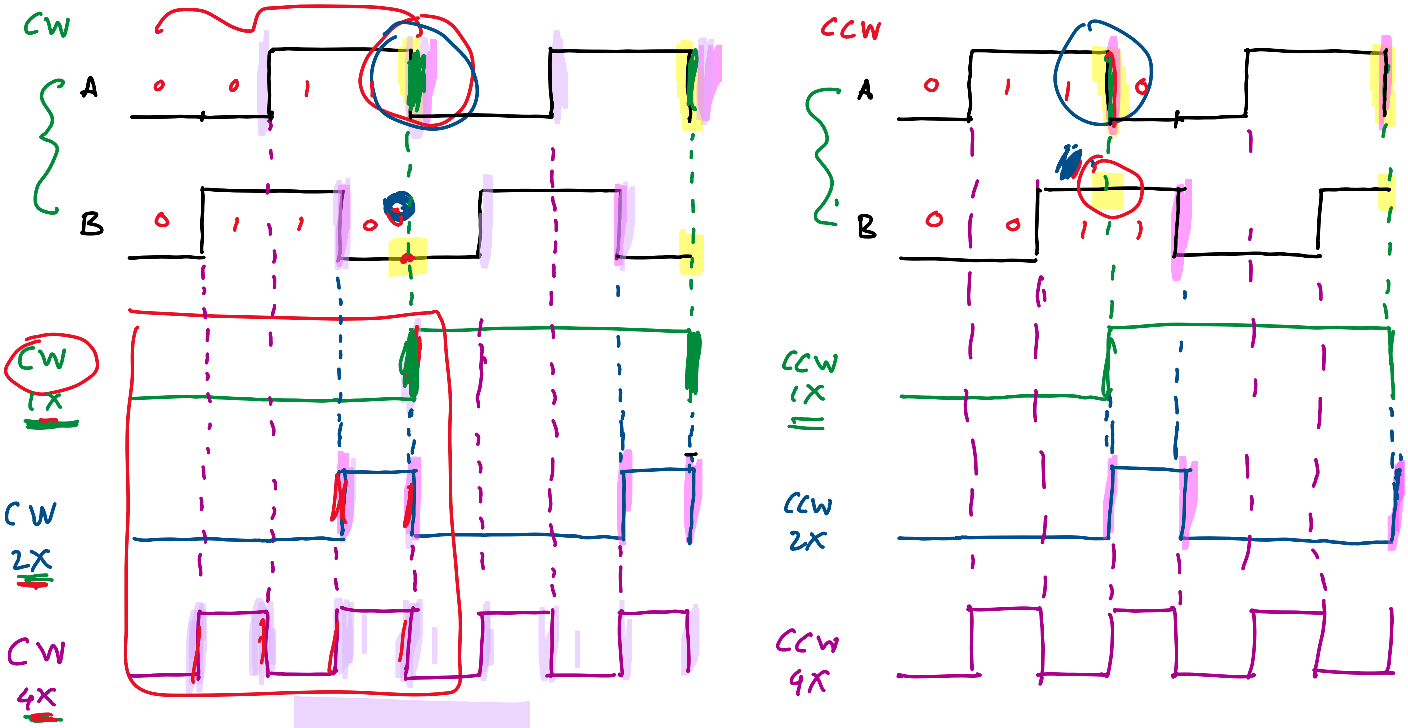
B leads A → 0-1 transition in

A leads B → 0-1 transition in A occurs before B

B leads A → 0-1 transition in B occurs before A

① Direction sensing. This is based on edge detection using Flip Flops

There are 3 resolutions: 1x, 2x, 4x.



These are determined as follows

1) 1X uses negative edge of A OR B

2) 2X uses negative edge of A AND B

3) 4X uses positive AND negative edge of A AND B

How to use these to determine direction

Lets look at 1X:

For CW: A ↓ B = 0

For CCW: A ↓ B = 1

} This is highlighted

— This logic can be used to determine direction.

② Magnitude sensing

A has 500 slots then we have resolution of 2(500) = 1000 (0 & 1). B has 500 slots, hence we would have another 1000. The combination would have a resolution of 4000

Consider a motor spinning at 1000 rpm. The motor has a resolution of 4000 per revolution (A, B channels, each with 500 slots)

$$\text{The encoder count} = \frac{1000 \text{ rev}}{60 \text{ sec}} \times \frac{4000 \text{ counts}}{1 \text{ rev}}$$

$$= 66\,000 \text{ counts per revolution.}$$

A computer cannot keep track of these many counts. Hence specialized counters are used. Example, LS 7166 is 24-bit counter.

Advantages of incremental encoder

- low cost for high resolution

Disadvantage of incremental encoder

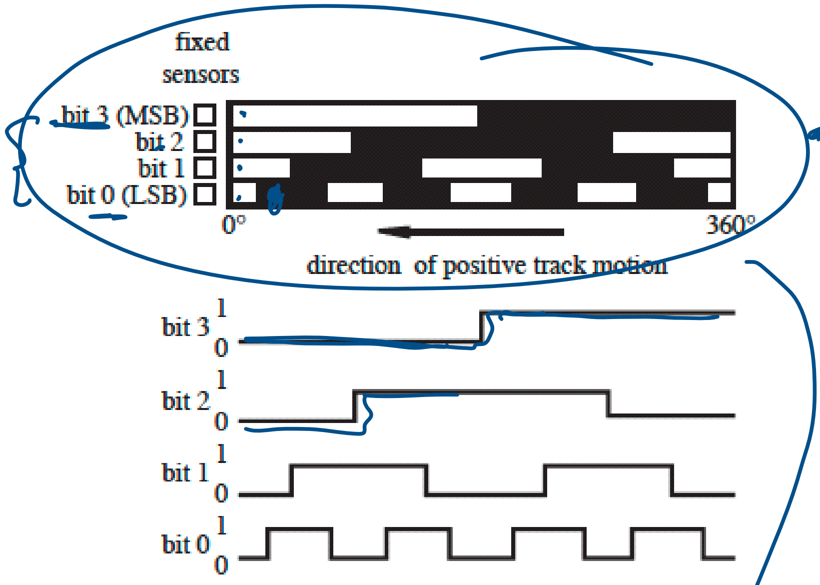
- gives only change in position. Some encoders have a third channel (besides A, B) called the Z-channel. This has a mark that can be used to zero the position. However, this requires one to physically move the shaft.

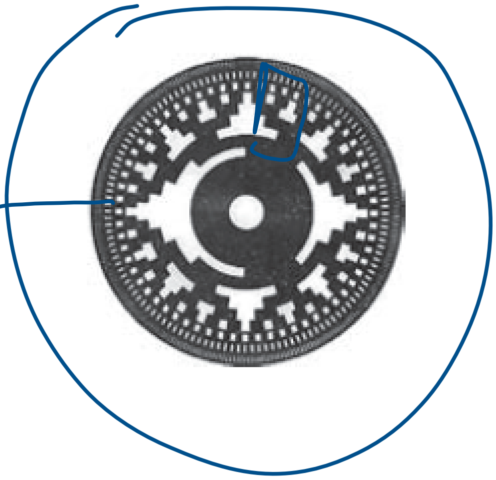
② Absolute encoder

Provides absolute position. If the encoder has N tracks then there are 2^N levels and resolution is $\frac{360^\circ}{2^N}$

e.g. N=4 ; $2^4=16$ levels; Resolution = $\frac{360}{16}$ = 22.5°

Illustration of N=4





Decimal Code	Rotation Range (°)	Natural binary code ($B_3B_2B_1B_0$)	Gray code ($G_3G_2G_1G_0$)
0	0–22.5	0000	0000
1	22.5–45	0001	0001
2	45–67.5	0010	0011
3	67.5–90	0011	0010
4	90–112.5	0100	0110
5	112.5–135	0101	0111
6	135–157.5	0110	0101
7	157.5–180	0111	0100
8	180–202.5	1000	1100
9	202.5–225	1001	1101
10	225–247.5	1010	1111
11	24 7.5–270	1011	1110
12	270–292.5	1100	1010
13	292.5–315	1101	1011
14	315–337.5	1110	1001
15	337.5–360	1111	1000

0

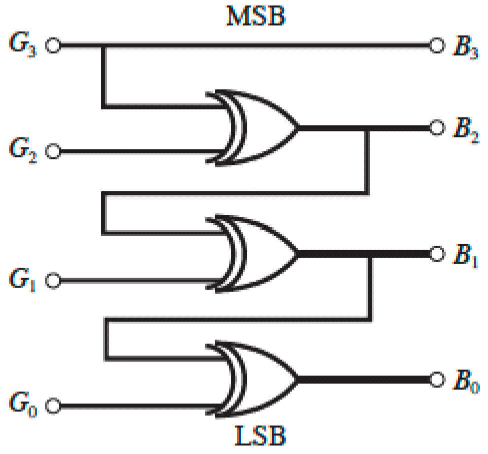
13

binary

Decimal Code	Rotation Range (°)	Natural binary code ($B_3B_2B_1B_0$)	Gray code ($G_3G_2G_1G_0$)
0	0–22.5	0000	0000
1	22.5–45	0001	0001
2	45–67.5	0010	0011
3	67.5–90	0011	0010
4	90–112.5	0100	0110
5	112.5–135	0101	0111
6	135–157.5	0110	0101
7	157.5–180	0111	0100
8	180–202.5	1000	1100
9	202.5–225	1001	1101
10	225–247.5	1010	1111
11	24 7.5–270	1011	1110
12	270–292.5	1100	1010
13	292.5–315	1101	1011
14	315–337.5	1110	1001
15	337.5–360	1111	1000

$N = 12 = 2^{12}$

$14 = 2^{14}$



$$B_3 = G_3$$

$$B_2 = B_3 \oplus G_2$$

$$B_1 = B_2 \oplus G_1$$

$$B_0 = B_1 \oplus G_0$$