ROCO222: Intro to sensors and actuators

Lecture 1

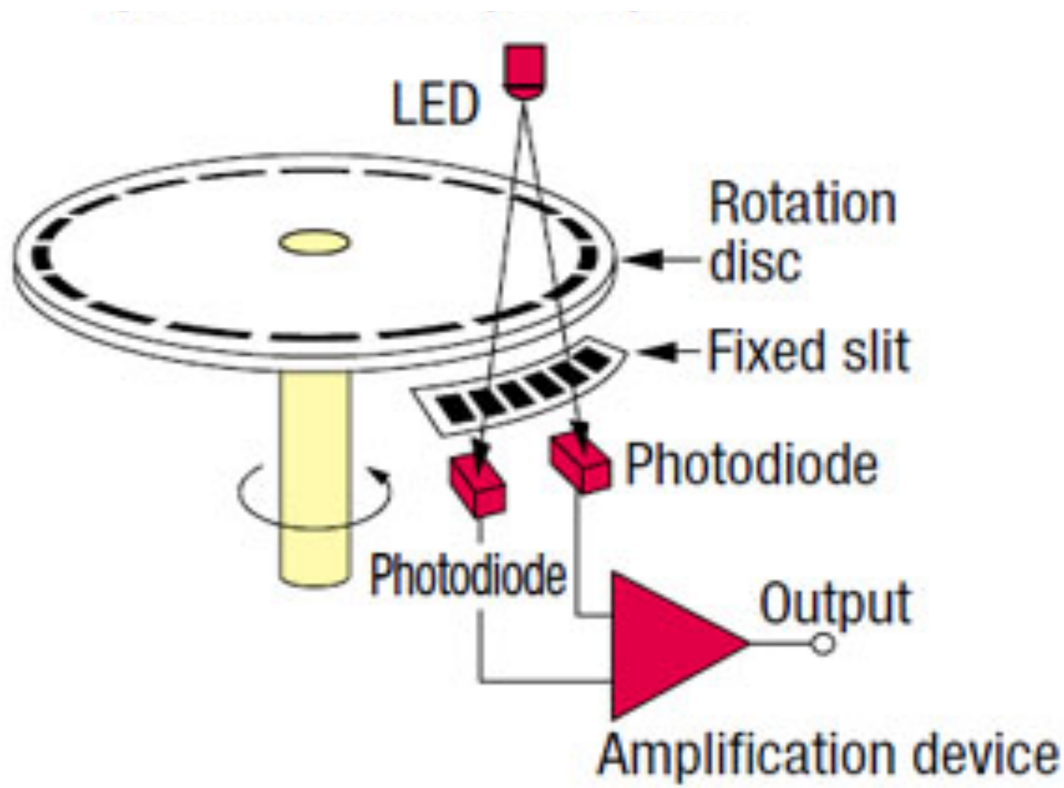
Measuring position

Digital incremental encoder

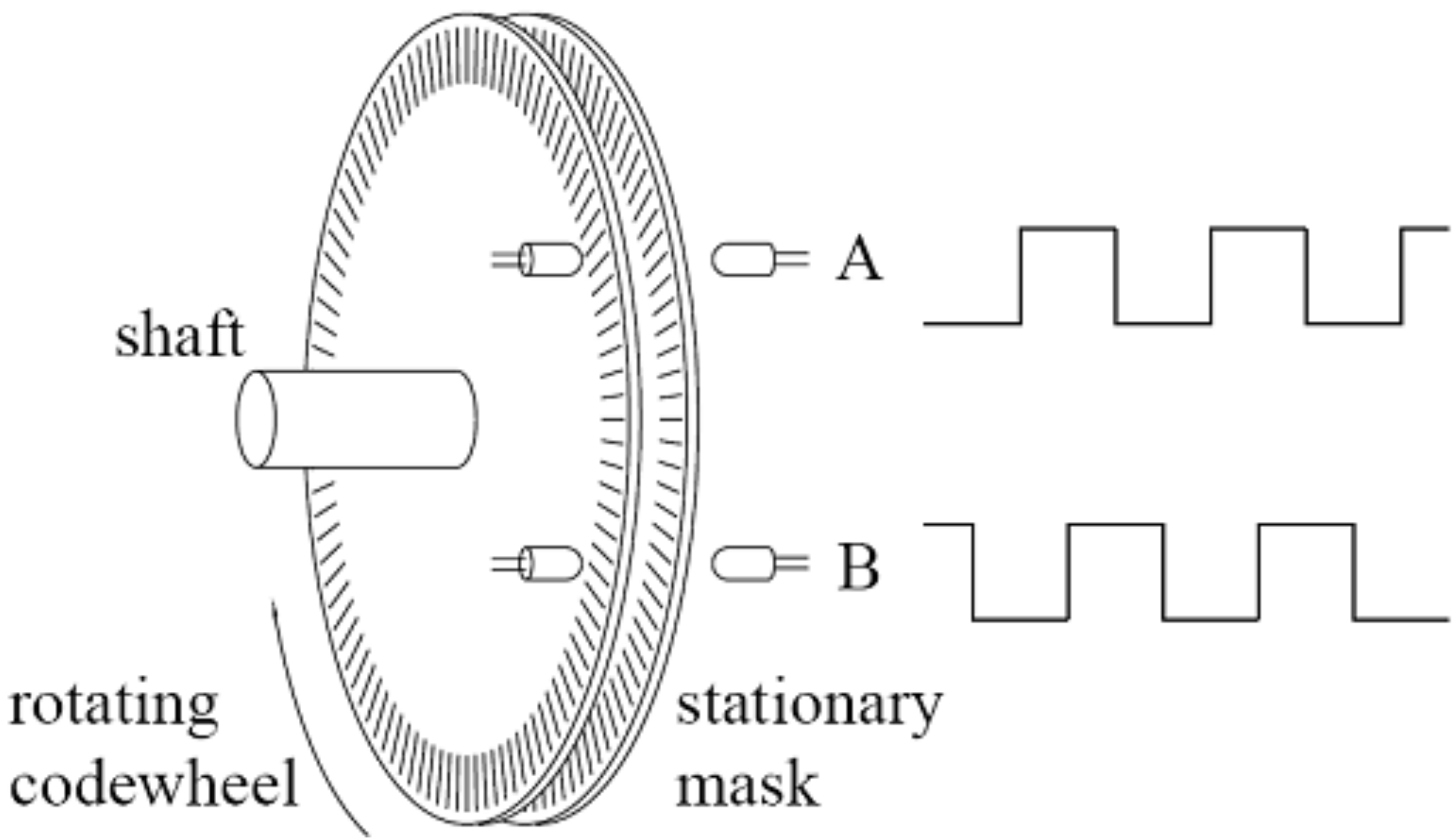
- Generates a relative position signal suitable for positioning tasks
- Rotation direction recognition
- Speed information from number of pulses per time unit
- Standard solution for many applications
- Single output types only used to determining the speed

Optical incremental encoder

- Slotted discs interrupt the light beam
- Photo emitter-detector pair detect pulses of light
- Amplifier then generates output pulses as slot passes light path
- Pulses counted to provide a position estimate
- Secondary LED photo emitter-detector pair provide direction of rotation
- Quadrature encoder generates two square wave pulses 90 degrees apart

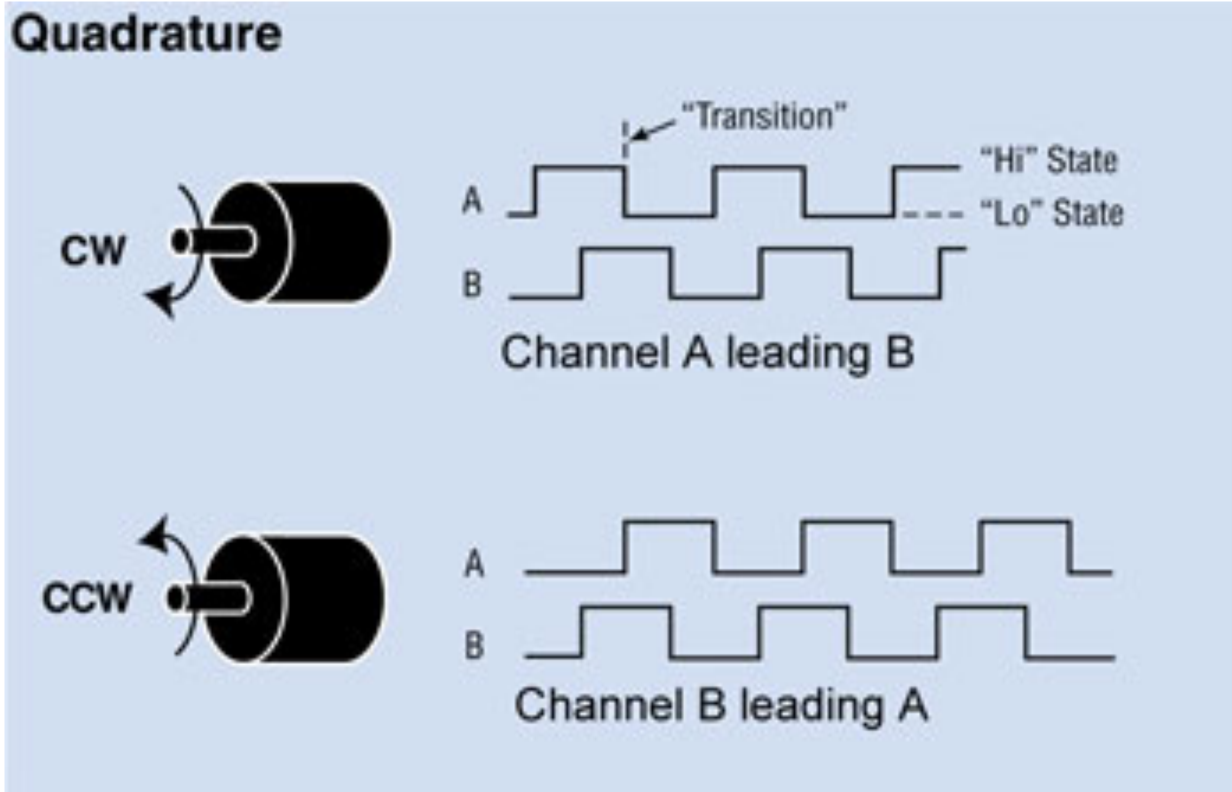


Quadrature output signal generation



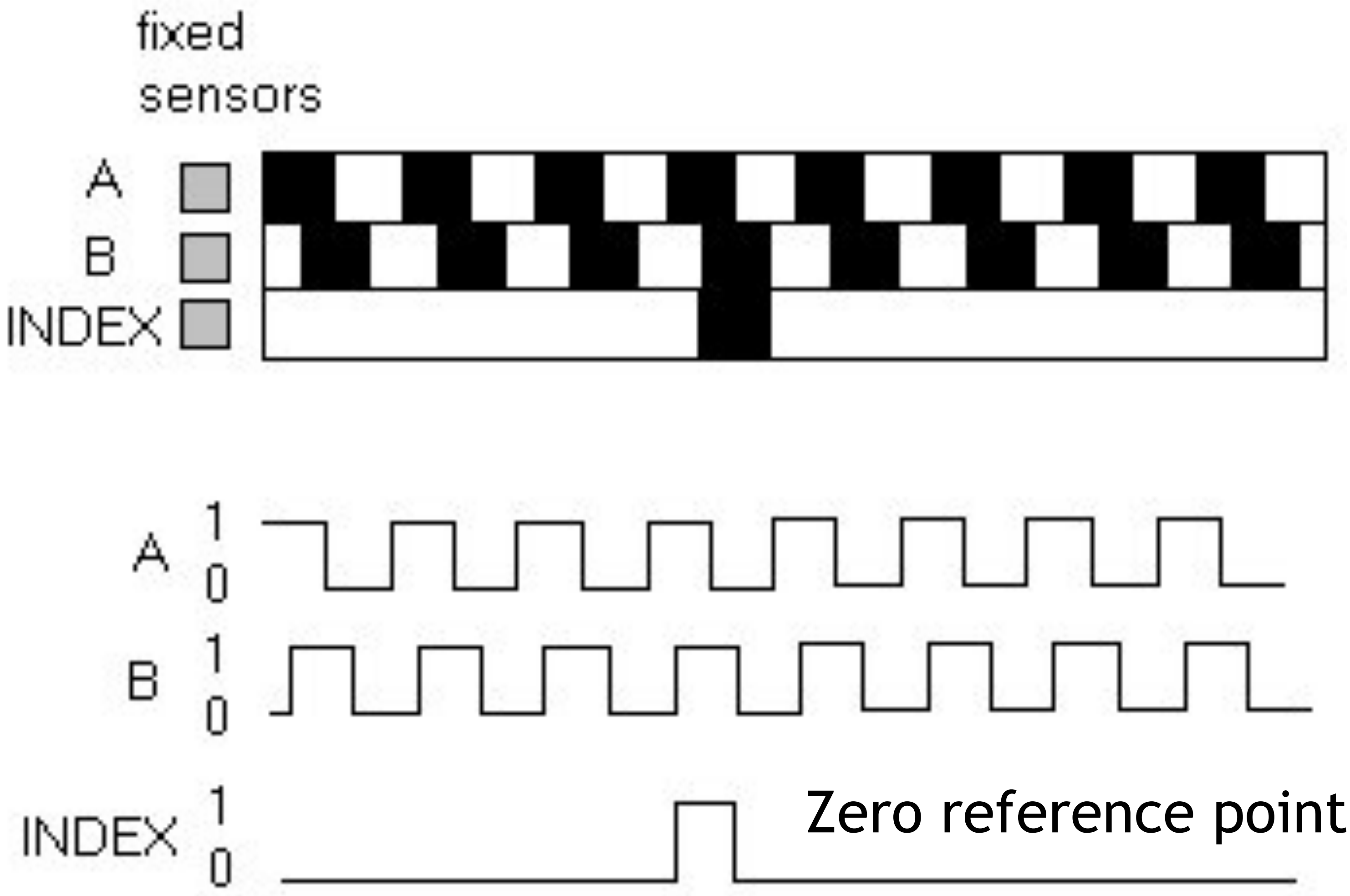
Output of two photo detectors are phase shifted by 90 degrees

Quadrature output signal usage



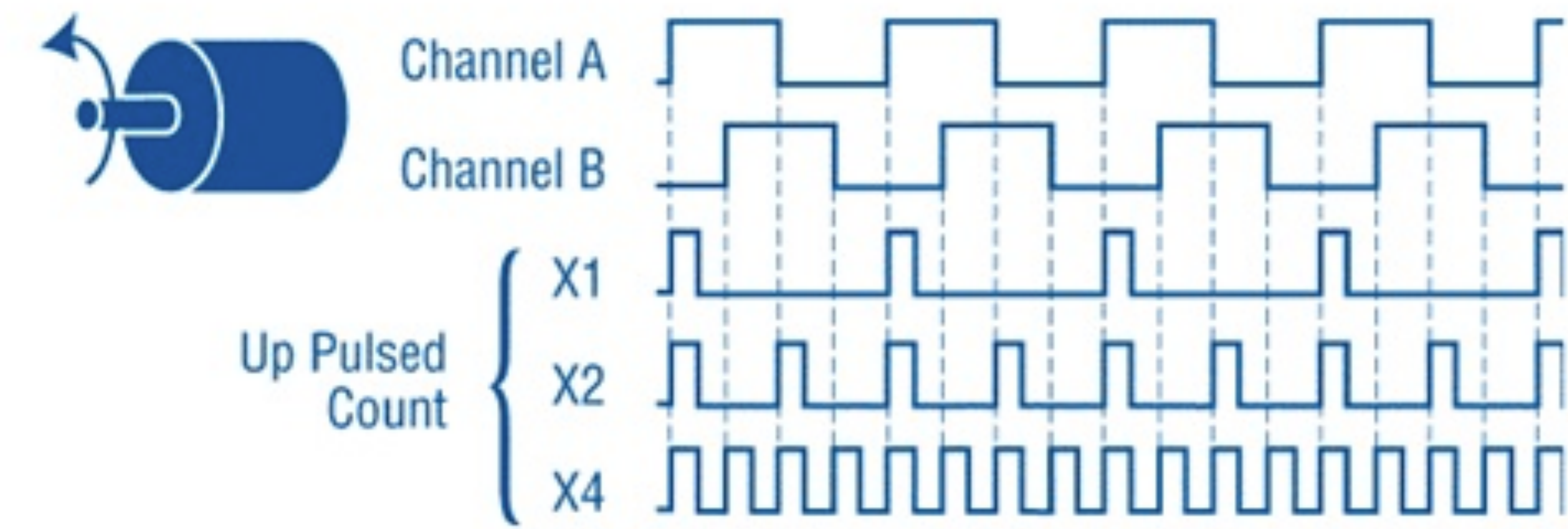
- A quadrature encoder generates two pulse streams that are 90° out of phase with one another
- The possible to determine directionality by monitoring which channel leads in phase

Incremental encoder index signal



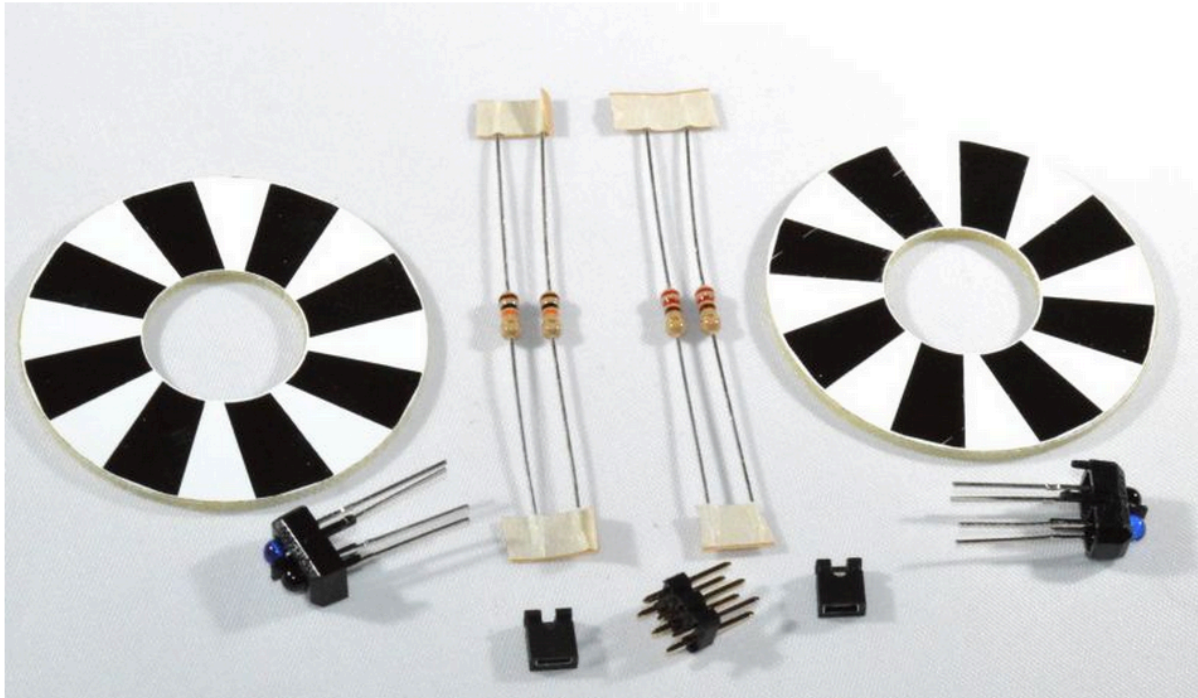
- Gives an absolute position signal at a single reference location
- Can be use to assist calibration

Using all edges can increase resolution



- Triggering off of the leading and or trailing edges of the pulses can increase resolution by up to four times
- More transition to count if use all edges!
- But more sensitive to noise

Budget wheel encoders/sensors



- 2 wheel encoder discs for fitting inside the wheel drive
- 2 optical reflectance sensors
- Count 16 pulses per revolution
- very cheap - £5
- Use with Arduino systems

Typical datasheet for encoder

C O N N E C T I O N S

FUNCTION	CABLE	PLUG
0 Volts	Black	Pin 1
+ Volts	Red	Pin 2
A Channel	White	Pin 3
B Channel	Blue	Pin 4
Z Channel	Yellow	Pin 5
$\overline{A}$ Channel	Green	Pin 6
$\overline{B}$ Channel	Violet	Pin 7
$\overline{Z}$ Channel	Brown	Pin 8

A C C E S S O R I E S A V A I L A B L E

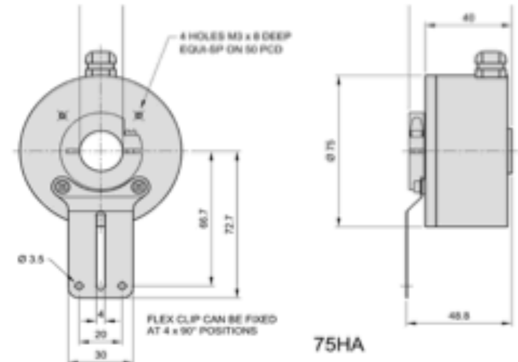
- COUPLINGS
- BRACKETS & FLANGES
- MEASURING WHEELS

S E R I E S

75HA LUMINIUM

ROTARY INCREMENTAL SHAFT ENCODER

The *75HA Series* is a precision, yet versitile hollow shaft encoder, machined from solid aluminium. Its choice of versatile spring mounting clip or front face mounting holes, makes the encoder compatible with many industrial formats.



75HA

S P E C I F I C A T I O N S

Body:
Precision Machined Aluminium

Cover:
Precision Machined Aluminium (Powder Coated)

Shaft:
Stainless Steel

Bearings:
Ballraces

Shaft Sealing:
Front: Sealed bearing
Rear: Single lip seal on rear of cover

Protection:
IP65

Operating Temp:
-20 to +60°C (higher on request)

Maximum Speed:
3000 RPM (Higher on request)

Torque:
2Ncm (typical)

Inertia:
$100 gcm^2$ (typical)

Shaft Loading:
Designed to support its own weight

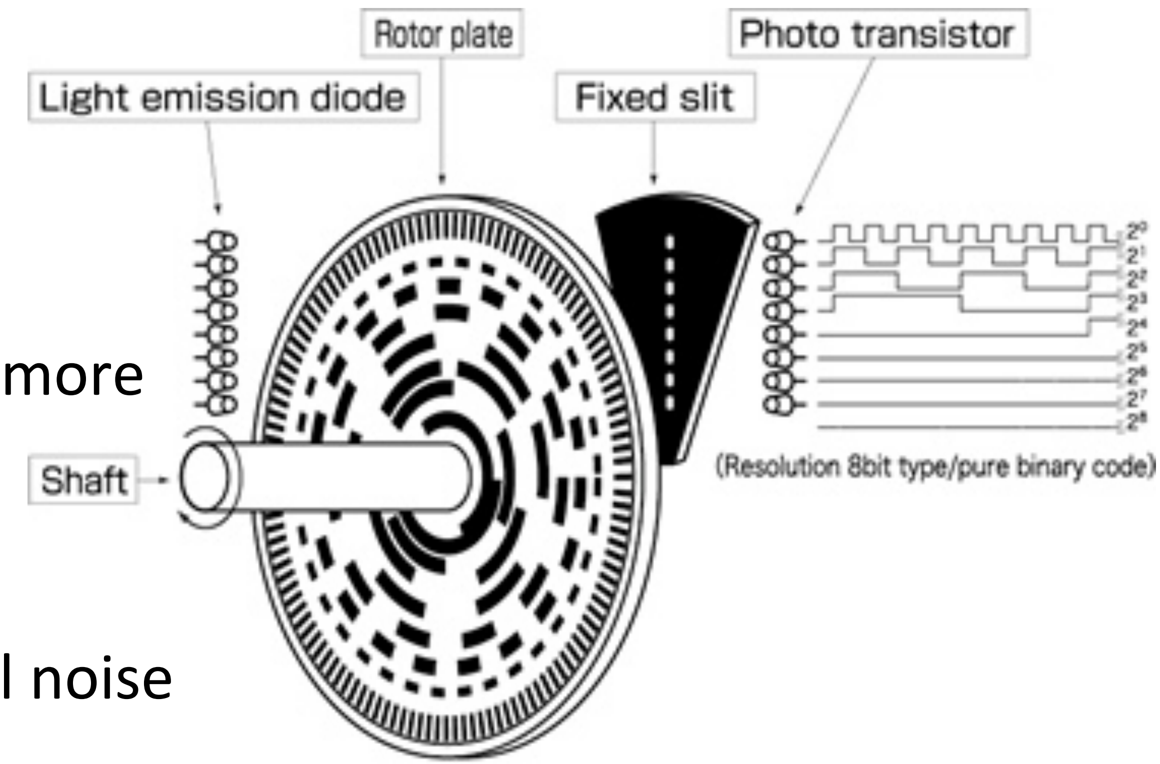
Cable:
Screened, oil and salt water proof

Impulse Frequency:
Up to 300KHz (depending on model)

Current Consumption:
60mA (typical - without load)

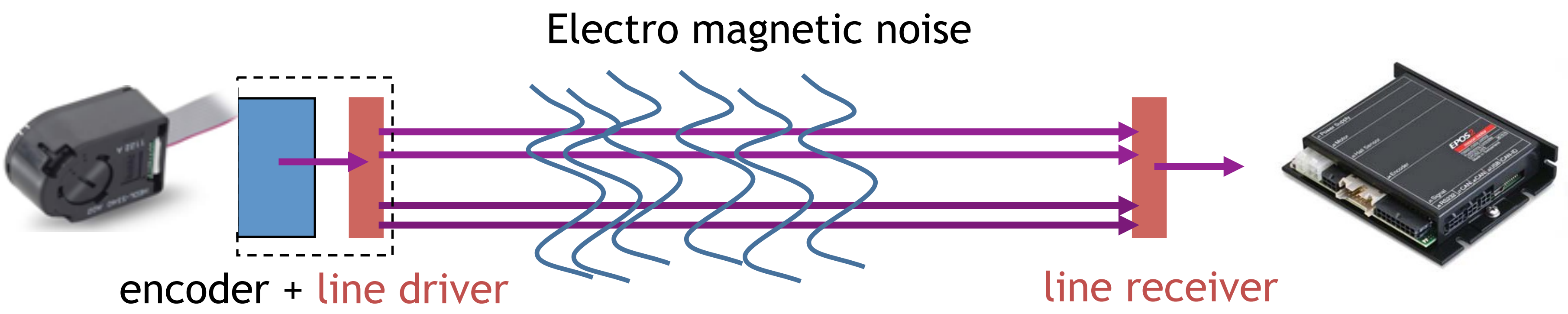
Absolute Optical Encoders

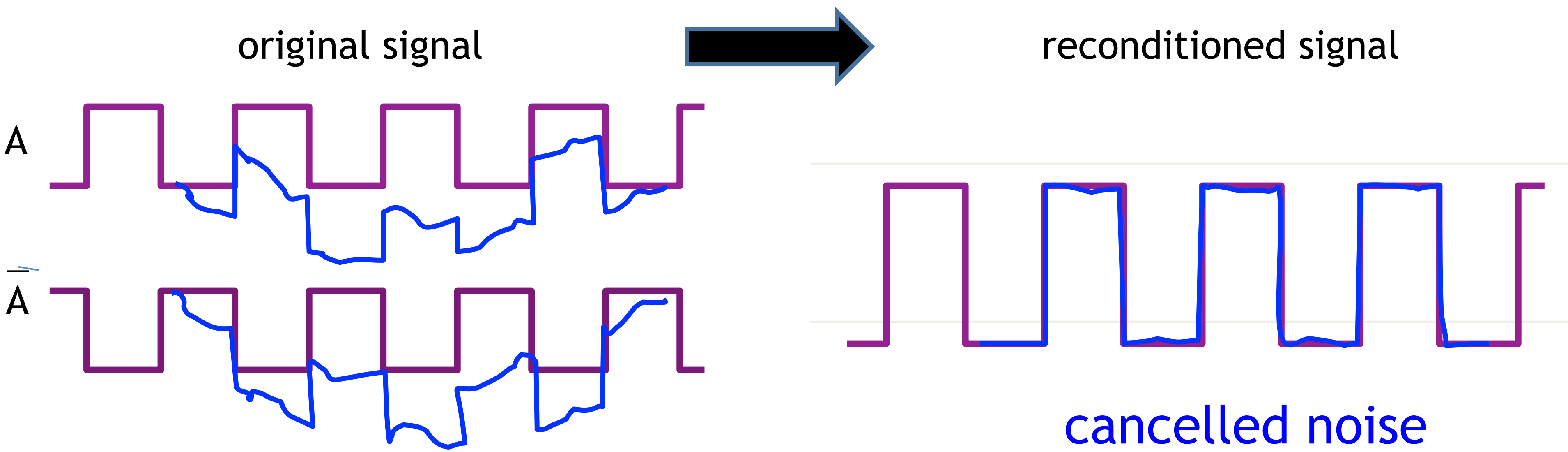
- Absolute encoders record the unique values of each shaft position
- Especially important in the event of a power failure
- Gray and binary codes most common



- Incremental rotary encoders more common
- Low cost
- Provides easy to use signals
- More susceptible to electrical noise

Encoder signal conditioning





- Use differential output drivers
- Twisted pairs suppress interference better than single wires

Interface to encoders

- E.g. Sensoray 626
- Interfacing encoder signals e.g. to a PC

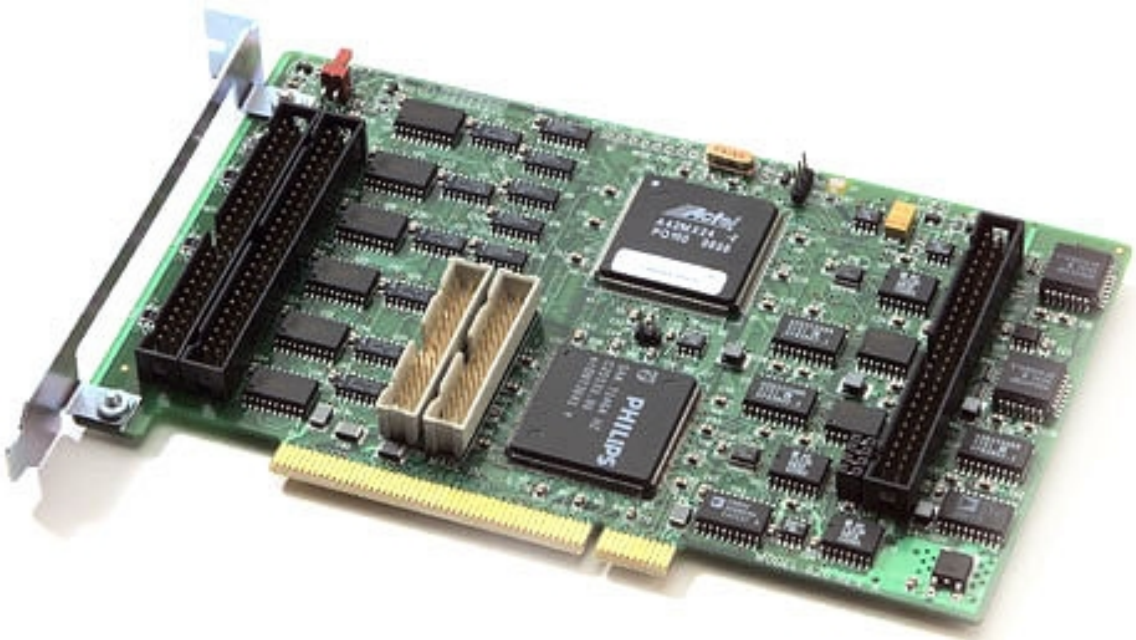
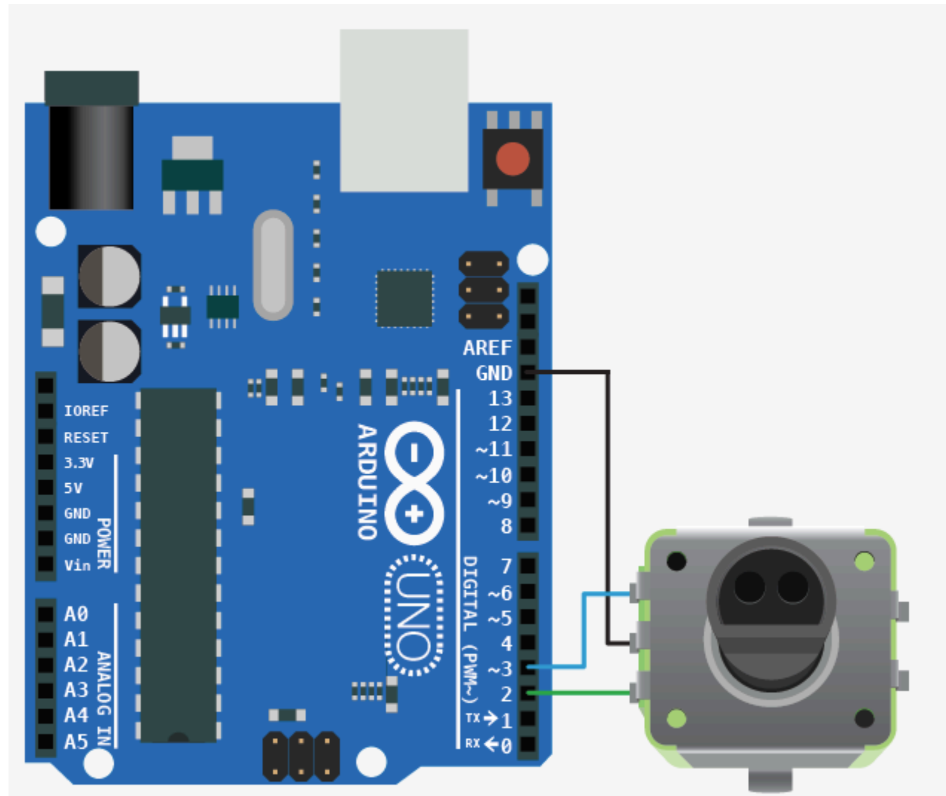


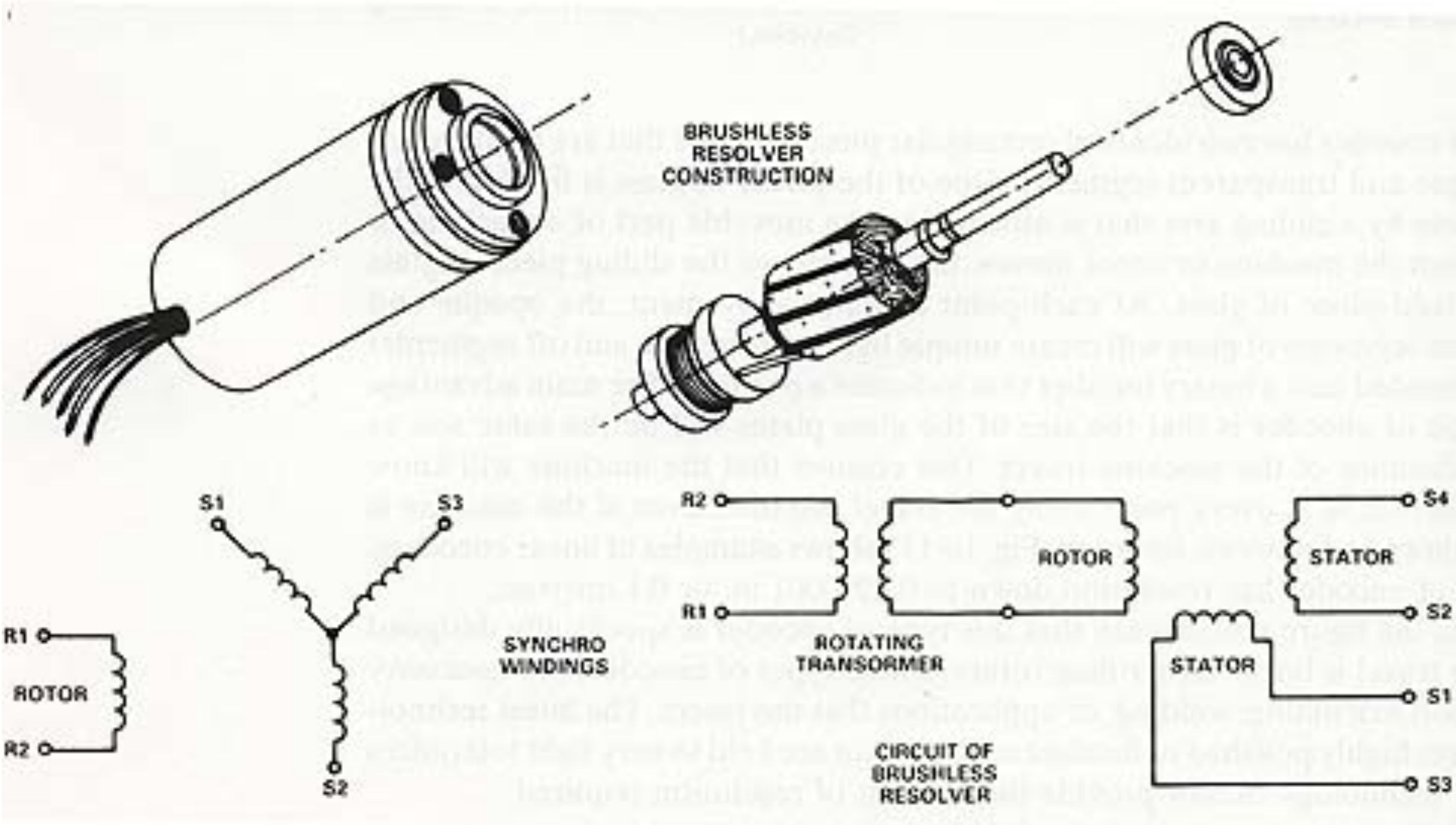
Table 24 Encoder Connectors					
J5					
26 pin IDC ribbon connector					
Encoder 1A – 3A					
Pin	Function	User Designation	Pin	Function	User Designation
1	Encoder (0A) A-		2	Encoder (0A) A+	
3	GND		4	Encoder (0A) B-	
5	Encoder (0A) B+		6	5V	
7	Encoder (0A) I-		8	Encoder (0A) I+	
9	GND		10	Encoder (1A) A-	
11	Encoder (1A) A+		12	5V	
13	Encoder (1A) B-		14	Encoder (1A) B+	
15	GND		16	Encoder (1A) I-	
17	Encoder (1A) I+		18	5V	
19	Encoder (2A) A-		20	Encoder (2A) A+	
21	GND		22	Encoder (2A) B-	
23	Encoder (2A) B+		24	5V	
25	Encoder (2A) I-		26	Encoder (2A) I+	

Can easily interface encoder to Arduino

- Use interrupt inputs
- Count the pulses



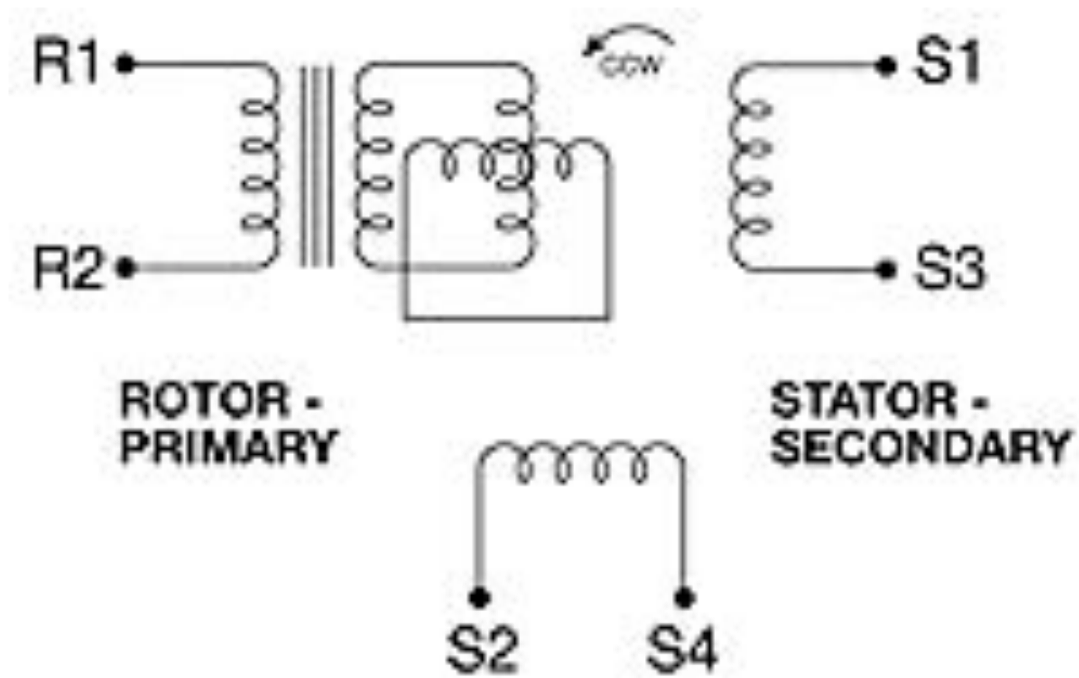
Resolver position measurement



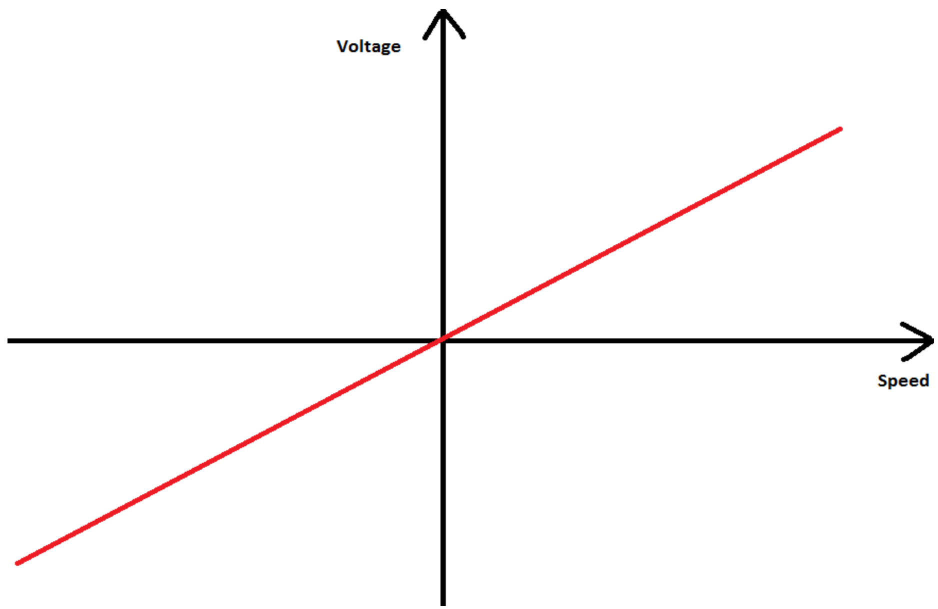
- Electromechanical device with a mechanical design similar to a motor

Resolver position measurement

- Analog rotor position signal
- Indicating absolute position within a single revolution
- Very rugged
- Need for interfacing electronics
- Resolvers are "excited" by an AC reference sine wave



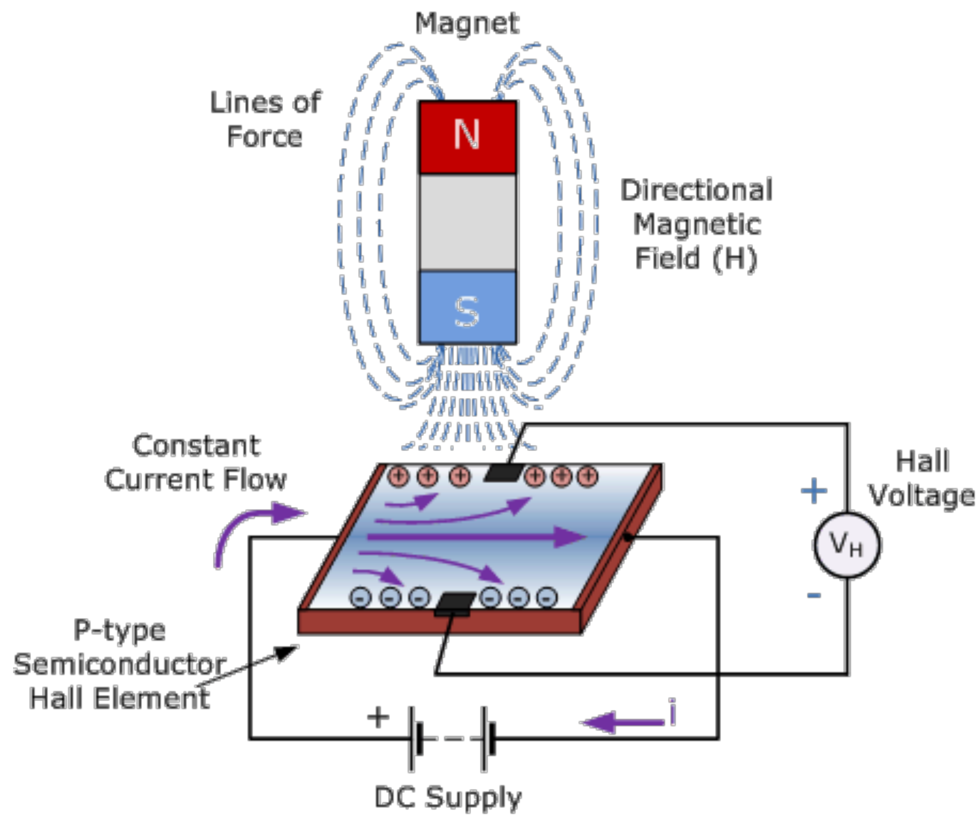
Tachometer velocity measurement



- A tacho is a small generator
- A coil that revolves about a magnet.
- Much like the motor it too has an speed constant
- Measures velocity not position and there for not an encoder
- Analog speed signal
- Rotation direction recognition
- Not suitable for positioning tasks

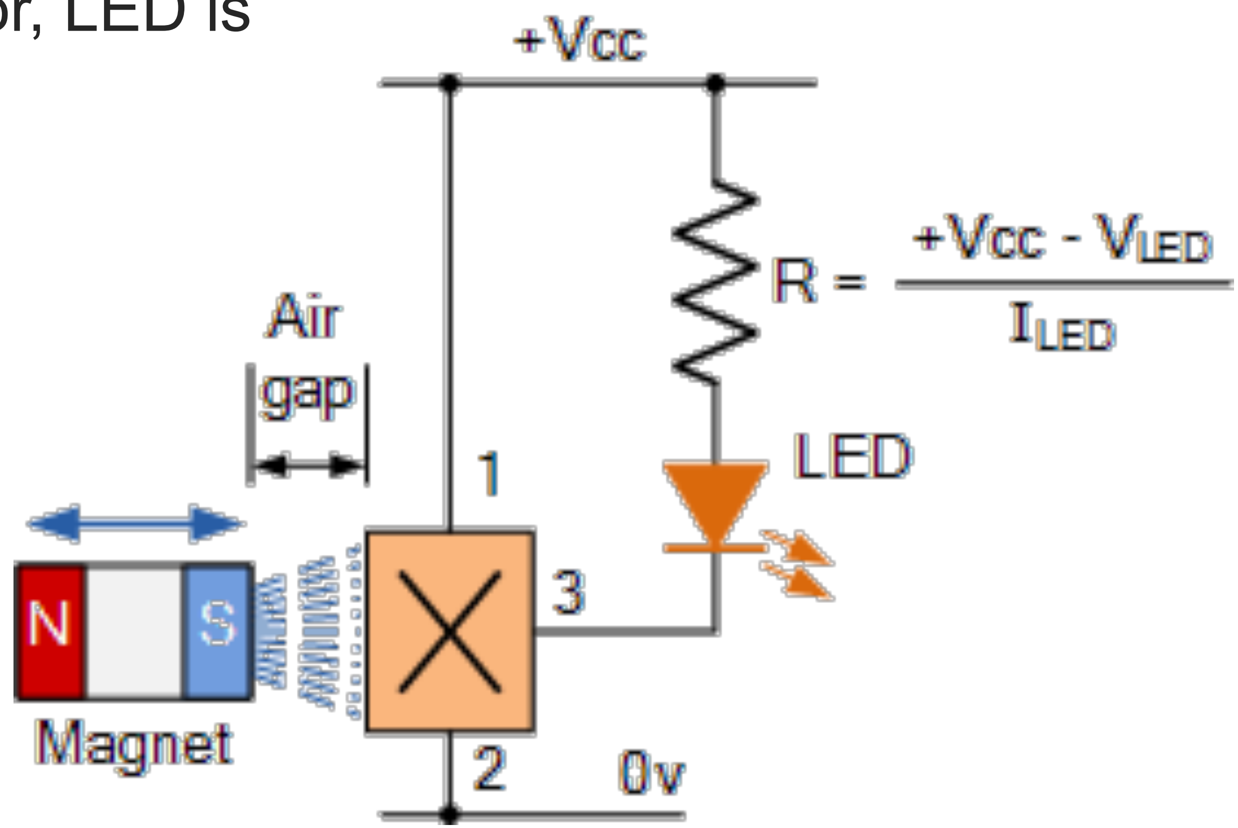
Hall effect magnetic sensor

- The Hall effect is the production of a potential difference across an electrical conductor when a magnetic field is applied in a direction perpendicular to that of the flow of current
- Can be taken advantage of in semiconductor devices to implement a switch activated by the application of a magnetic field
- Hall effect sensors can be used for proximity switching

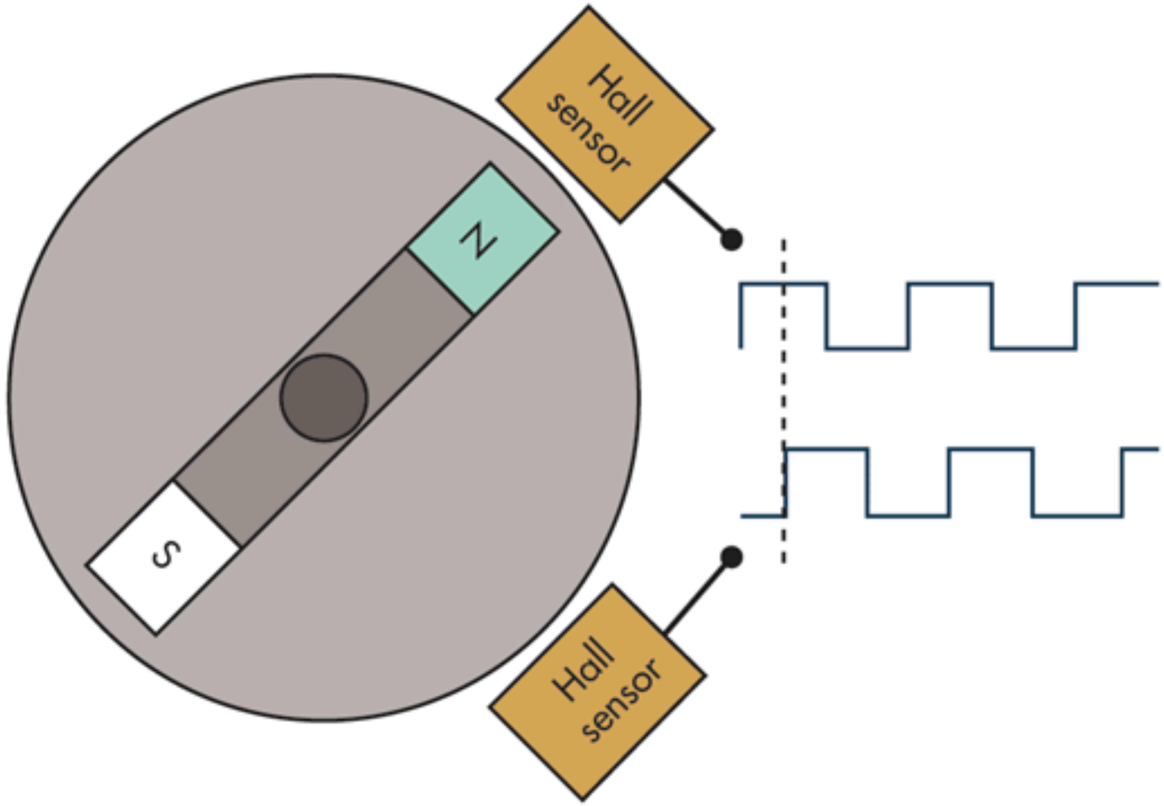


Hall effect magnetic sensor circuit

- Simple switch activated by the application of a magnetic field
- When south pole of magnet brought up to this sensor, LED is switched on

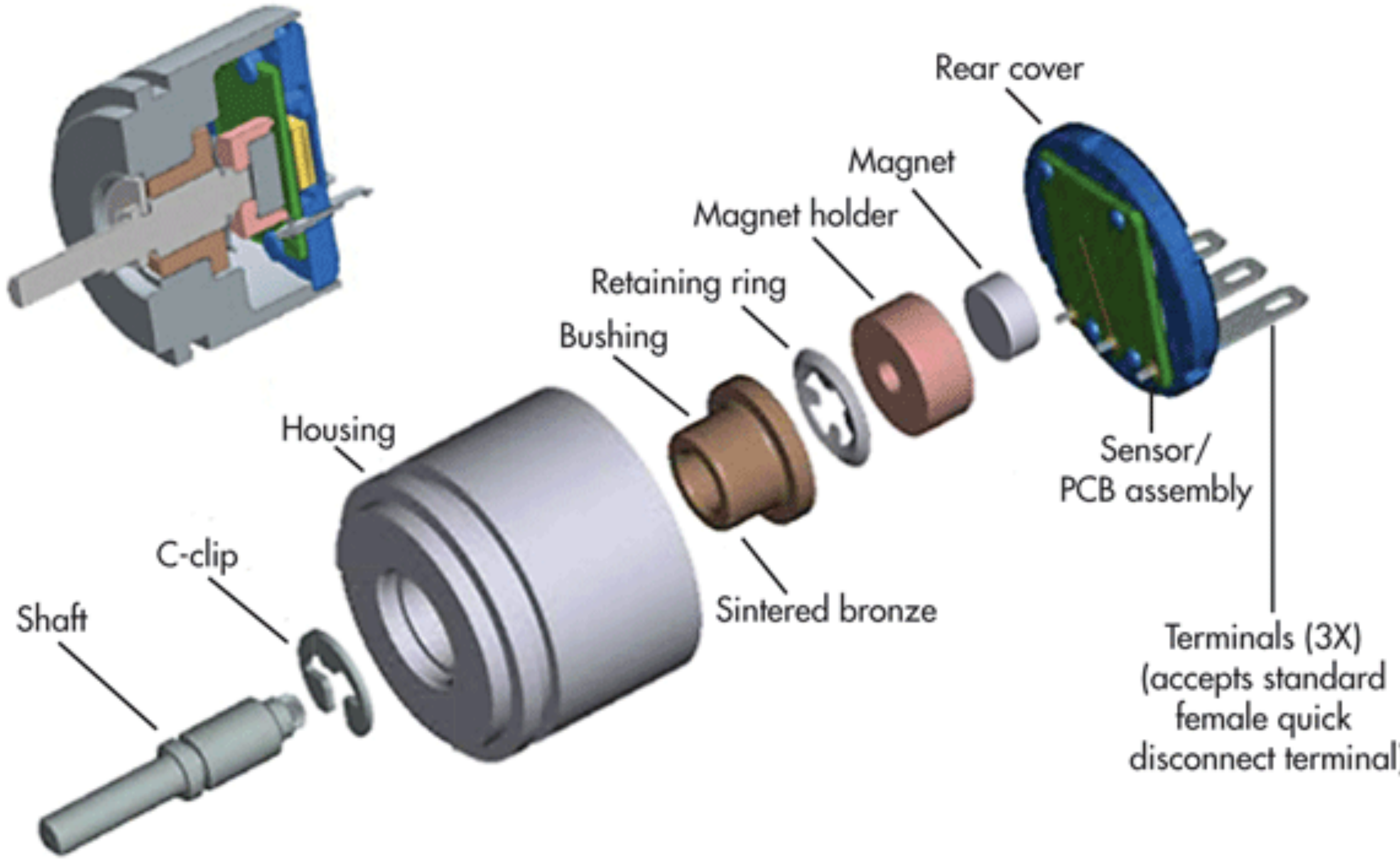


Hall effect magnetic rotary encoder



- Magnetic rotary encoder that comprises two poles and two sensors
- The second sensor makes it possible to not only detect the direction of rotation but also to interpolate the absolute position of the shaft

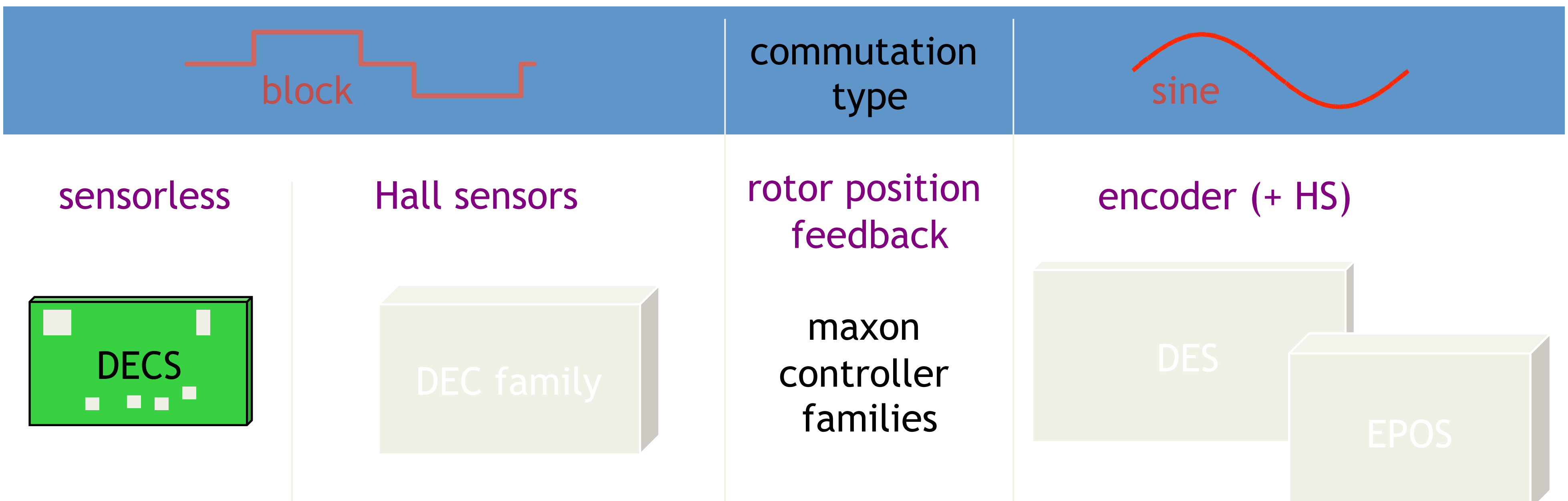
Magnetic rotary encoder



- Construction of a typical magnetic rotary encoder
- This types of encoder is often more robust than an optical encoder

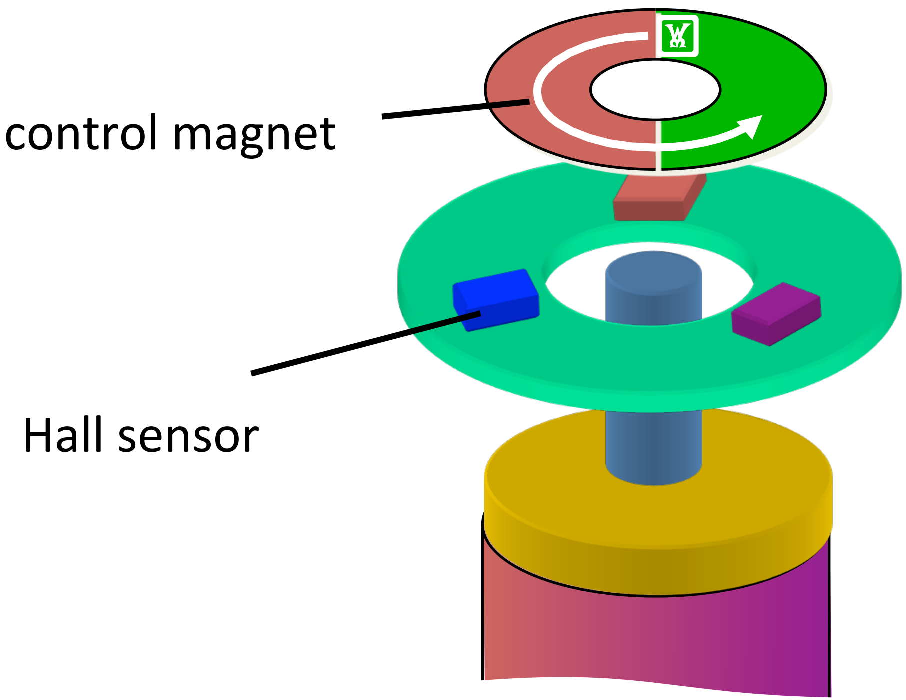
Electronic commutation systems

- Goal of commutation: applying the current to get the maximum torque
- Optimize perpendicular magnetic field orientation of rotor (permanent magnet) and stator (winding)
- Need knowledge of rotor position with respect to winding

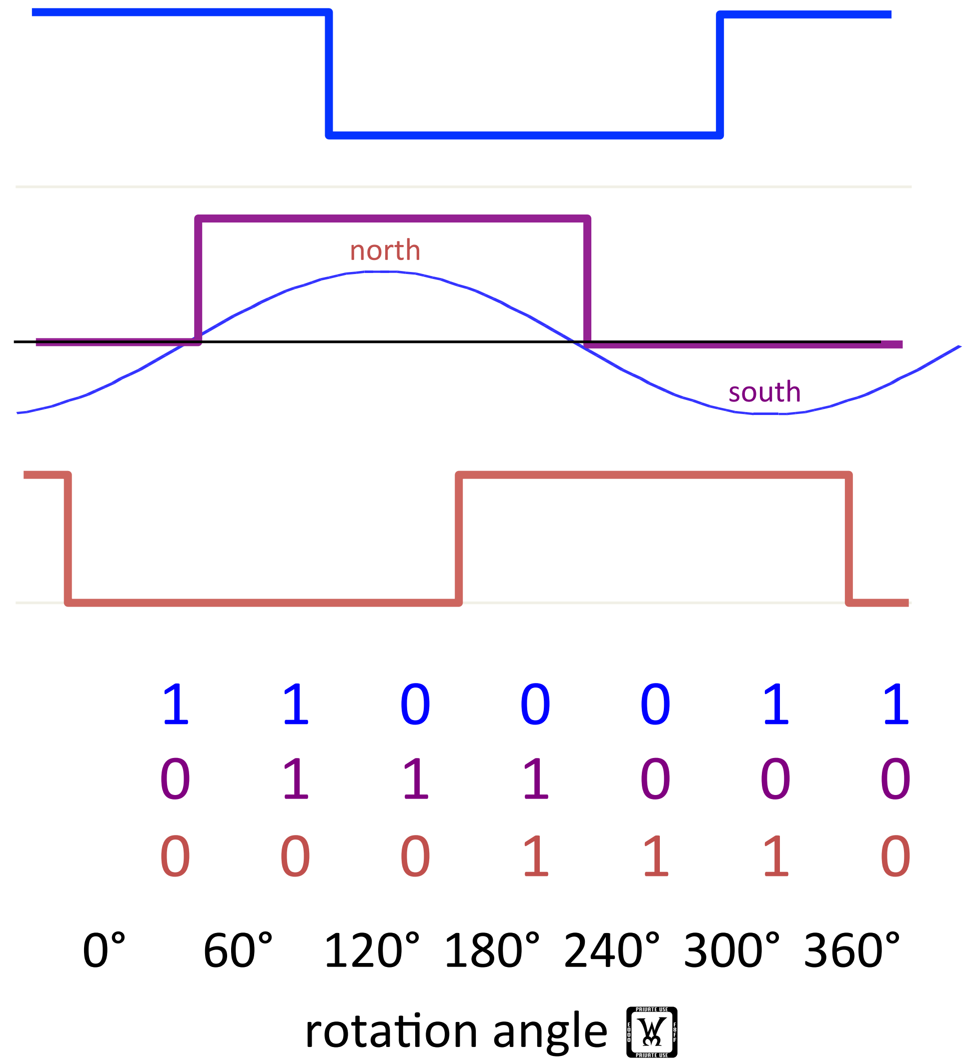


Block commutation

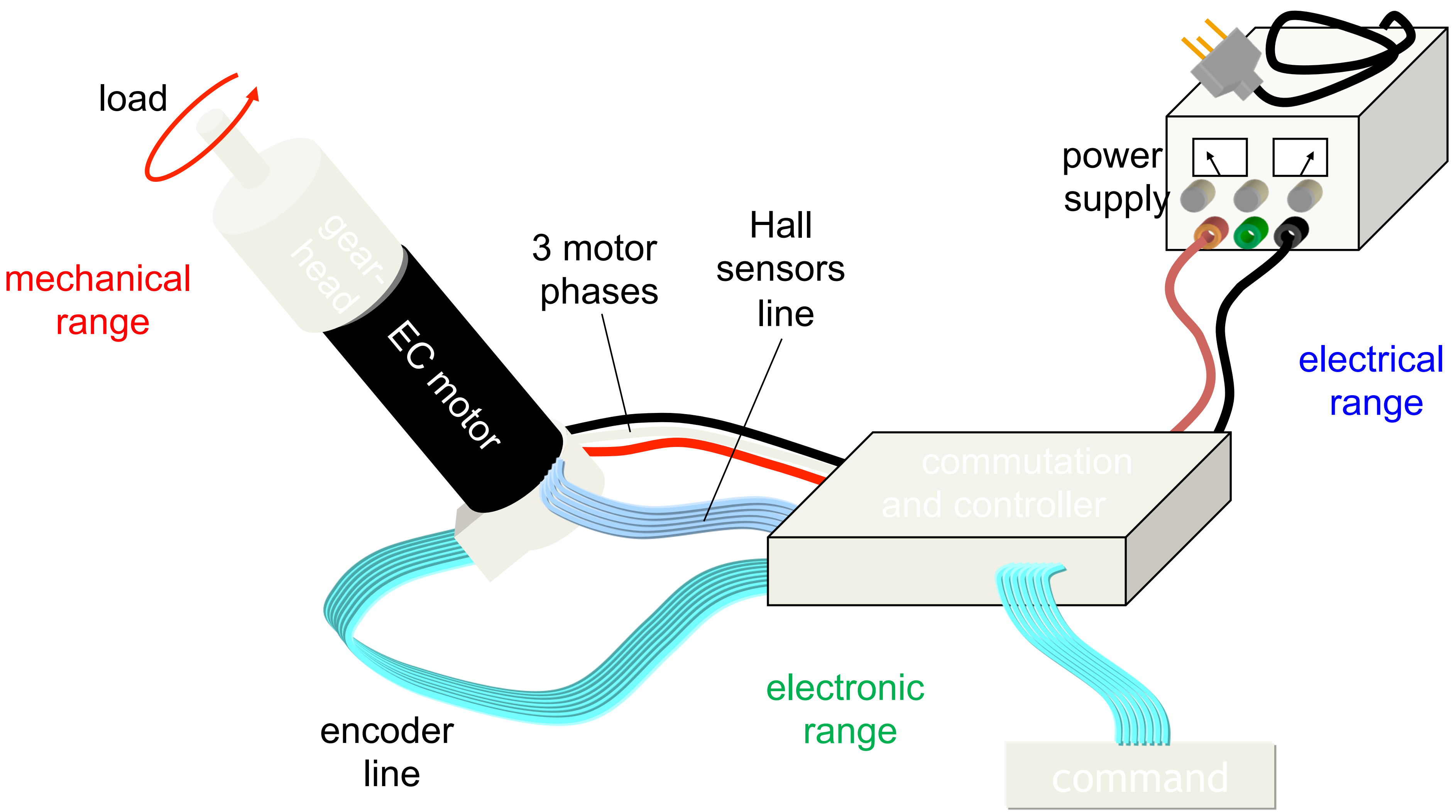
Rotor position from Hall sensor signals



EC-max and EC flat:
Power magnet is probed directly



Components of an EC drive system



ROCO222: Intro to sensors and actuators

Lecture 1

Measuring force

Definition of force

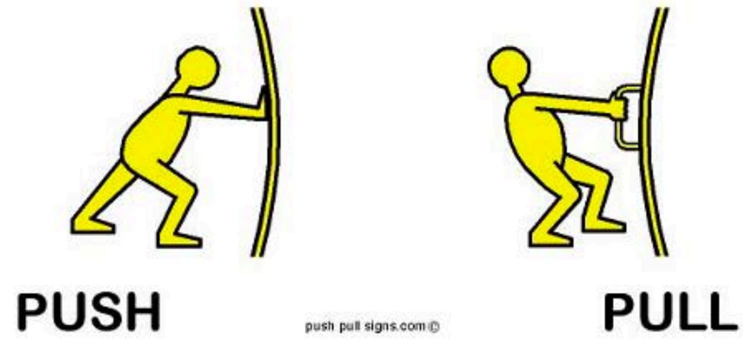
- A push or a pull
- The ability to do work

- Is is a vector quantity
- Has magnitude and direction

- Measured in Newtons (N)

- **Newton's Second Law**
- A force acting on a mass will accelerate or decelerate it
- $F = ma$

where F is Force (N), m is mass (Kg), a is acceleration (ms^{-2})

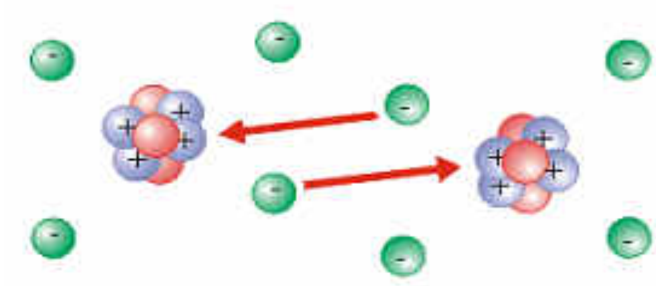


Four fundamental forces in nature

1. Gravity
Dominates at large distances

2. Electromagnetic forces

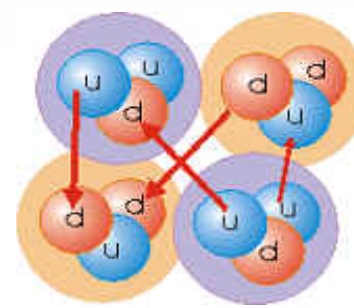
Observed in the interactions between atoms



3 . & 4. Nuclear forces

Strong & weak

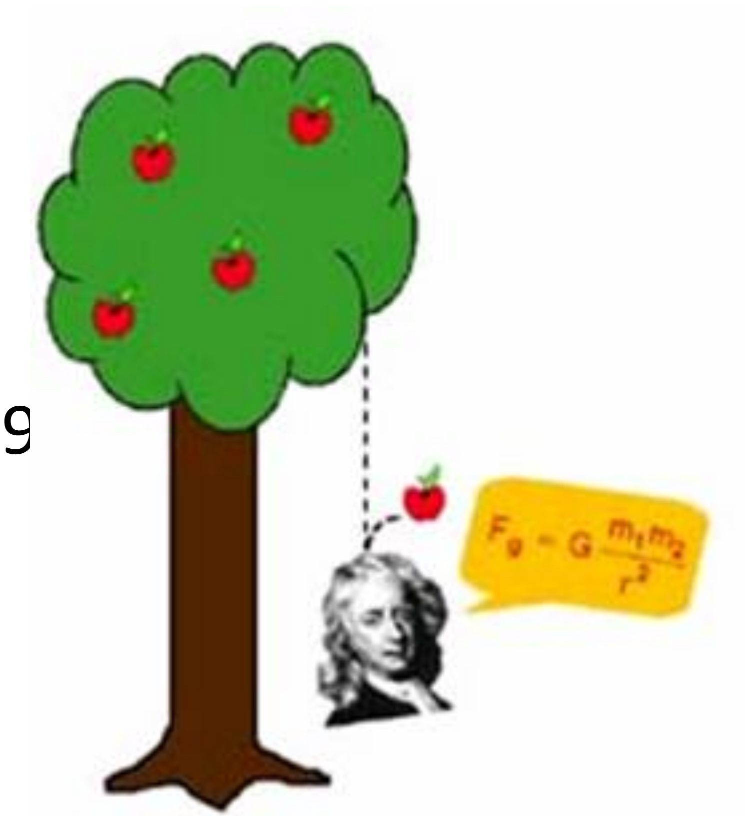
Both very short range



Force arises from gravity acting on a mass

- Force arises from gravity acting on a mass

- F = mg
  - where F is Force (N),
  - m is mass (Kg),
  - g is acceleration due to gravity ≈ 9



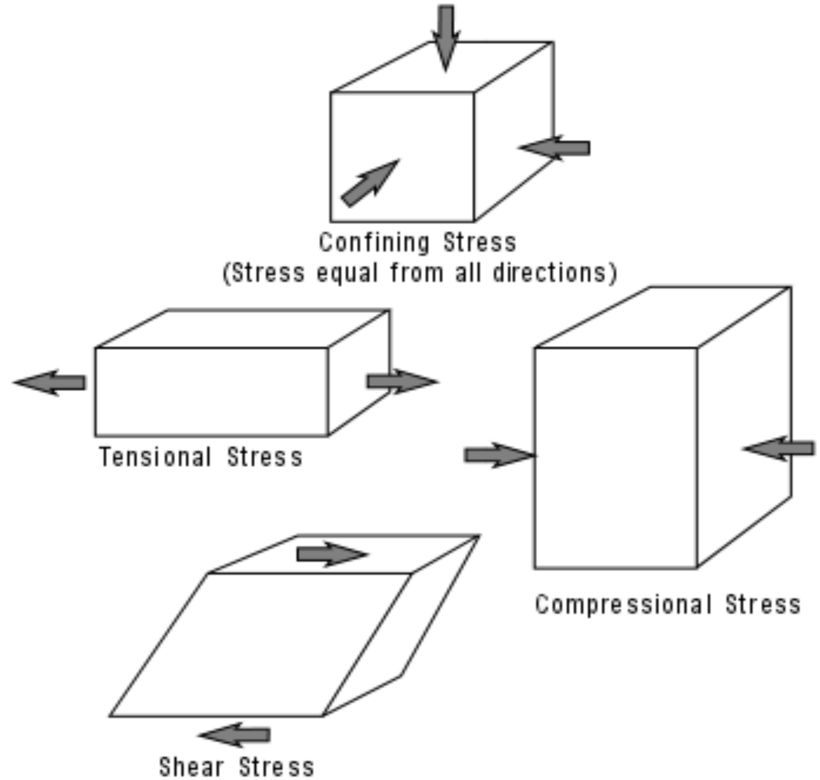
Measuring force by balancing known force

- Use gravity acting on a known mass as source of known force

- Search for equilibrium position to find gravitational mass of test object

Measuring force by measuring strain

- Stress defined as "force per area"
- Strain is defined as: "deformation of a solid due to stress”
- When we apply force
- Induced s**tress** results in a **strain**



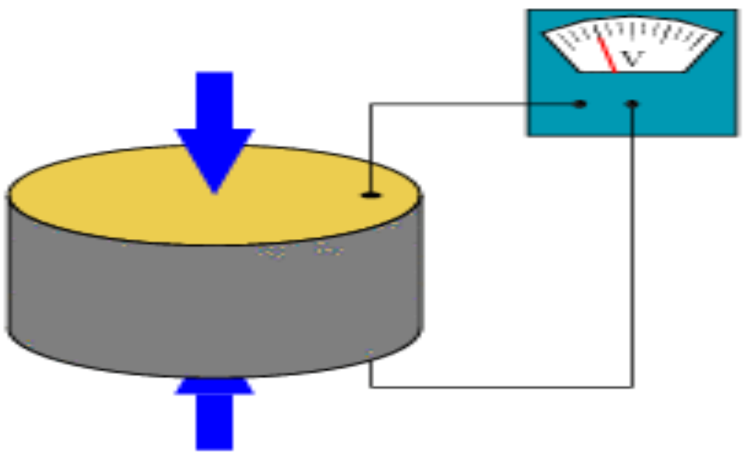
$$E = stress\ /\ strain = (F\ /\ \mathrm{A}_0)\ /\ (\Delta \mathrm{L}\ /\ \mathrm{L}_0)$$

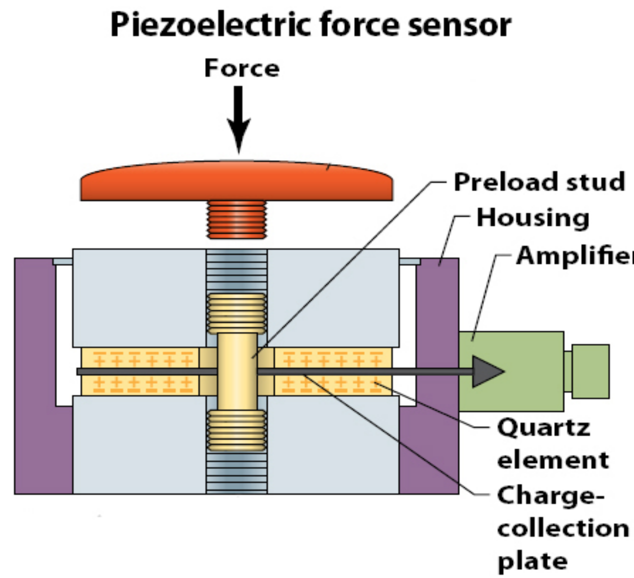
Where
E is the Young's modulus (modulus of elasticity)
F is the force exerted on an object under tension
A_0 is the cross-sectional area
ΔL is the amount by which object length changes
L_0 is the original length of the object

- By measuring strain of a material of known properties can estimate force

Piezo-electric effect

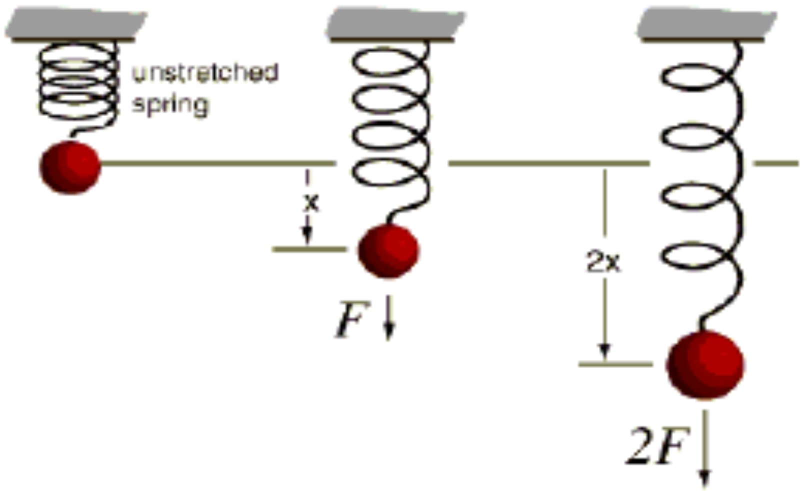
- Some materials generate electric charge under mechanical stress



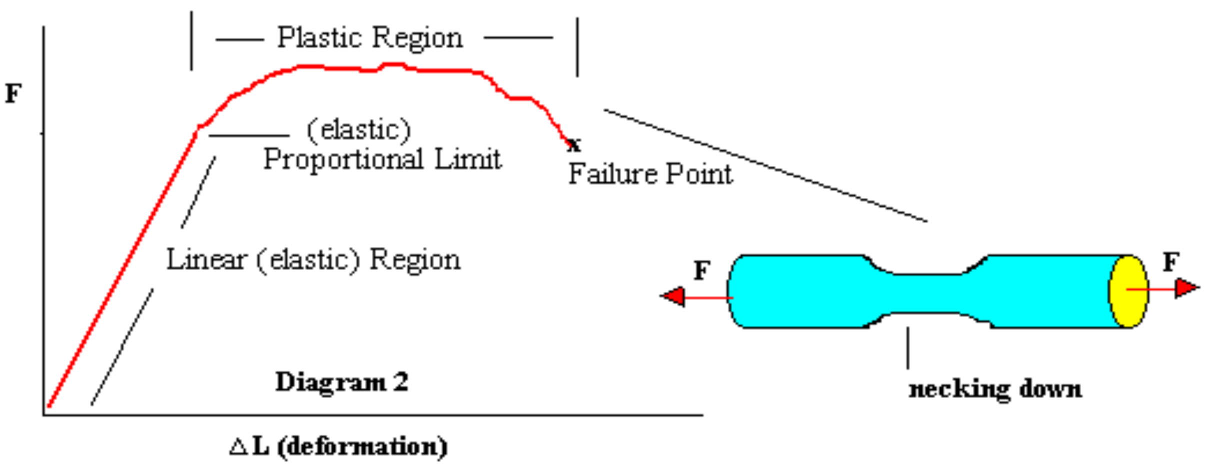


- Force results in a separation of charges with in structure
- Capacitive effect generates output voltage.
- Leakage causes charge dissipation and voltage decay over time
- Suitable for dynamic measurements

Measurement of elastic deformation



Hooke's law: $F = -kx$



Hooke's law only holds over the elastic region

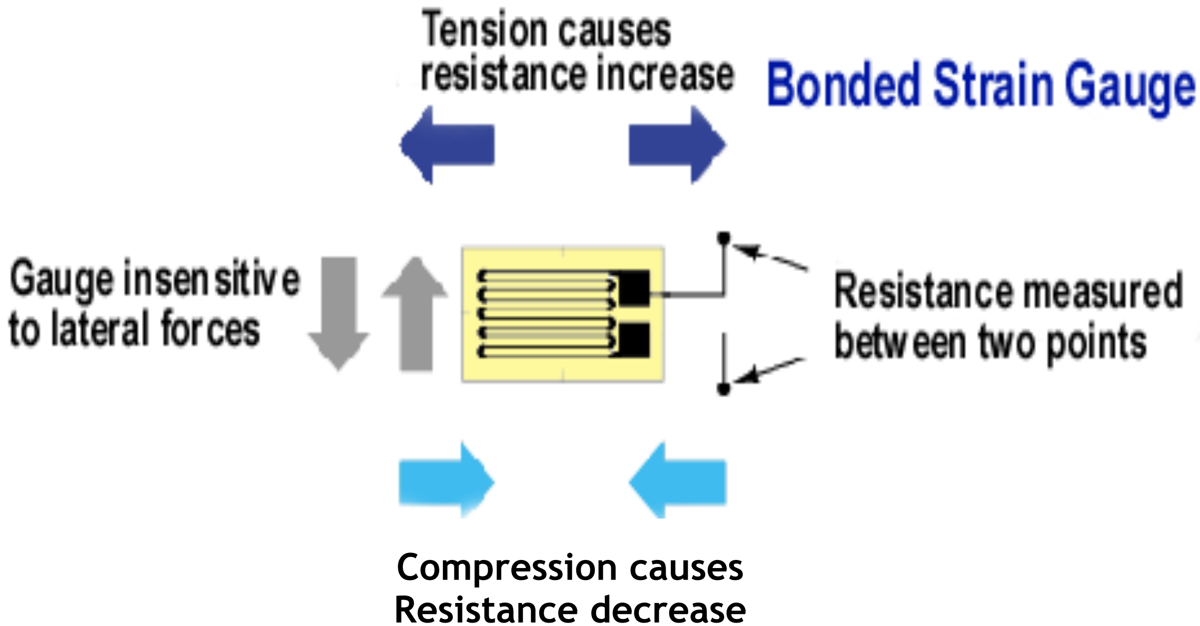
Direct measurement of elastic deformation

Can simply observe extension to estimate force

+

Other mechanical methods
Proving ring - Displacement measured directly using micrometer or dial gauge

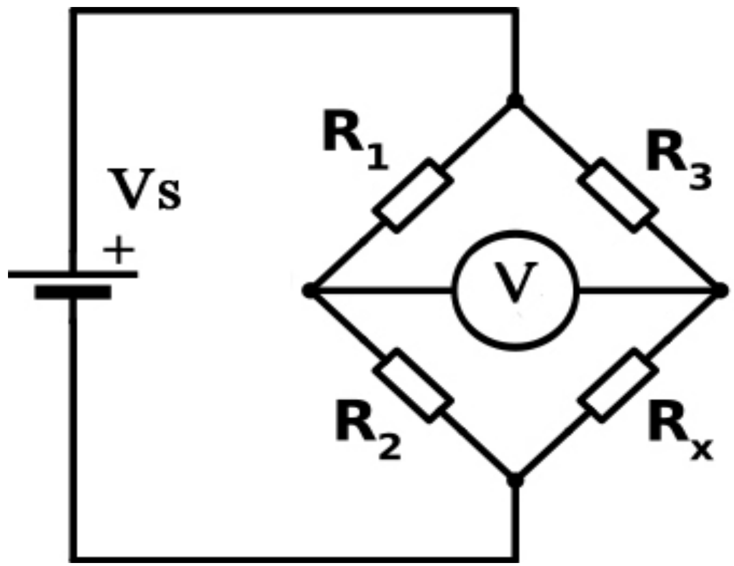
Strain gauge



- This is an electrical method of force measurement
- The gauge measures strain of substrate to which it is attached
- Provided substrate load operated in elastic region of the material, this is linearly relates to the applied force by Young's modulus

- Strain gauge measures strain because when film stretches it becomes narrower and longer and this increases its resistance
- Gauge is much more sensitive to strain is direction along the longer thin regions
- Overall during use such a sensor delivers only a fraction of percent change in resistance
- Resistance change is usually measured using a Wheatstone bridge

Wheatstone bridge circuit



$$I_{LeftBranch} = \frac{V_s}{R_1 + R_2}$$

$$V_{R2} = \frac{V_s R_2}{R_1 + R_2}$$

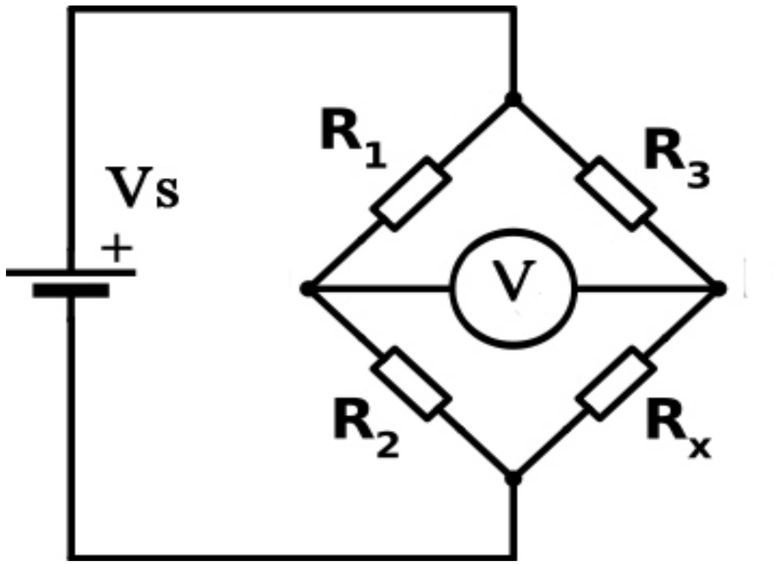
$$I_{RightBranch} = \frac{V_s}{R_3 + R_x}$$

$$V_{Rx} = \frac{V_s R_x}{R_3 + R_x}$$

- Wheatstone bridge converts change in resistance to change in voltage

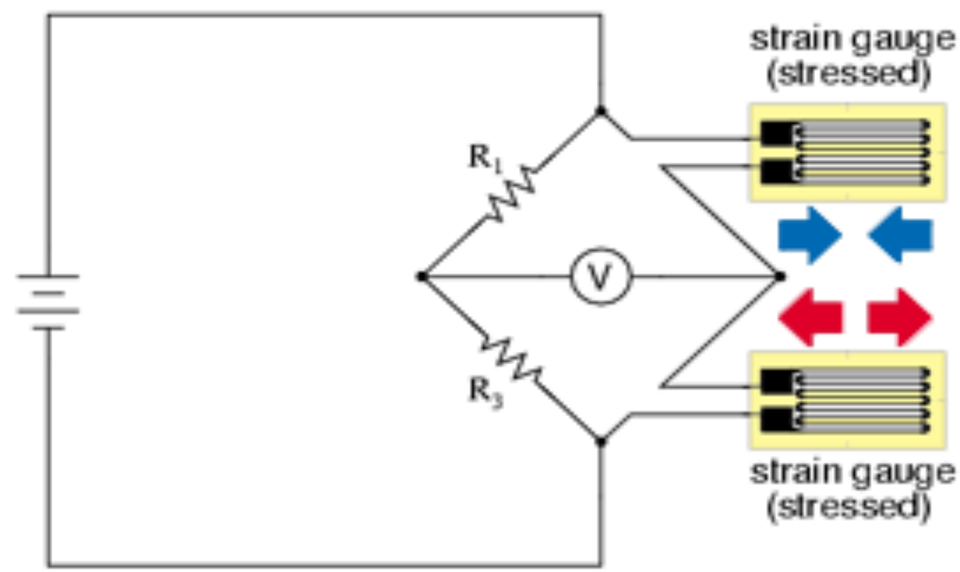
$$V = \left(\frac{R_x}{R_3 + R_x} - \frac{R_2}{R_1 + R_2} \right) V_s$$

Wheatstone bridge circuit



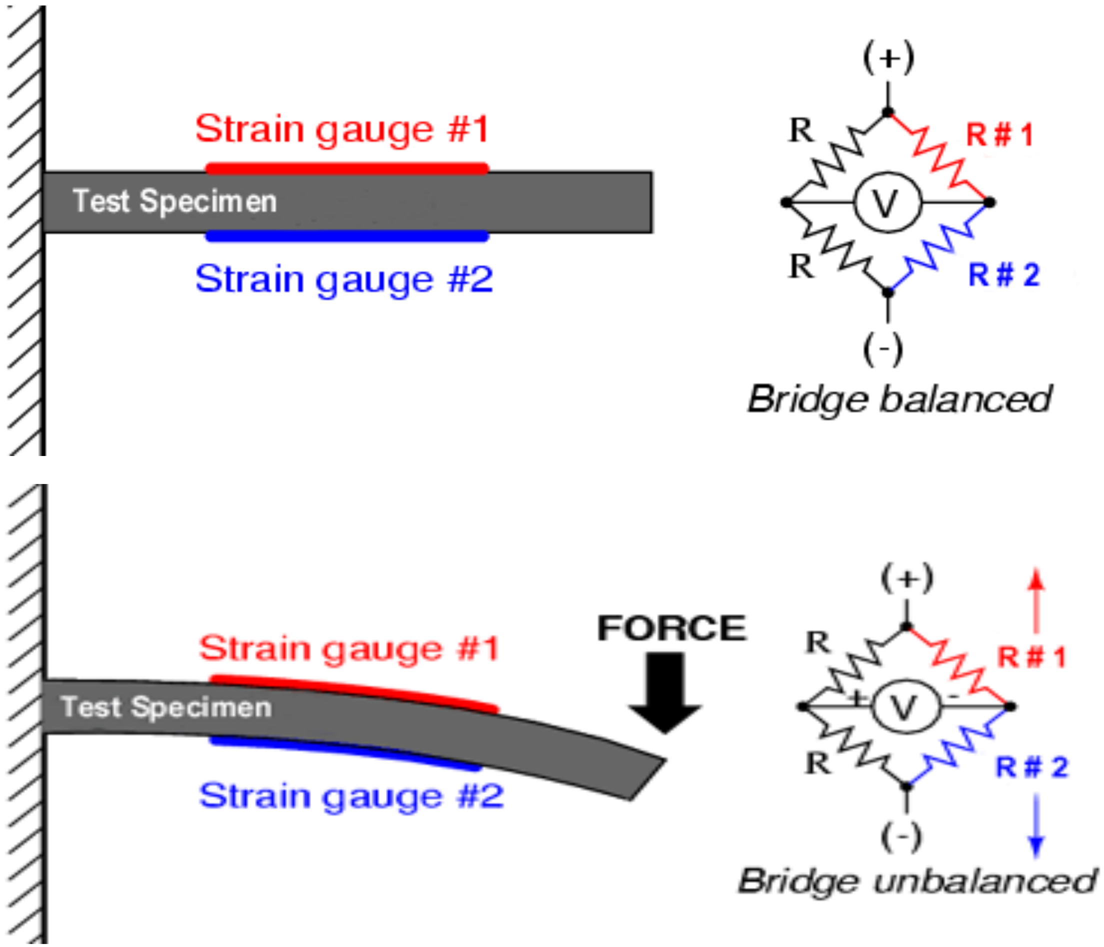
$$V = \left(\frac{R_x}{R_3 + R_x} - \frac{R_2}{R_1 + R_2} \right) V_s$$

- By placing strain gauges into the bridge, changes in their resistance resulting from the strain in the substrate gives rise to changes in voltage that can be measured



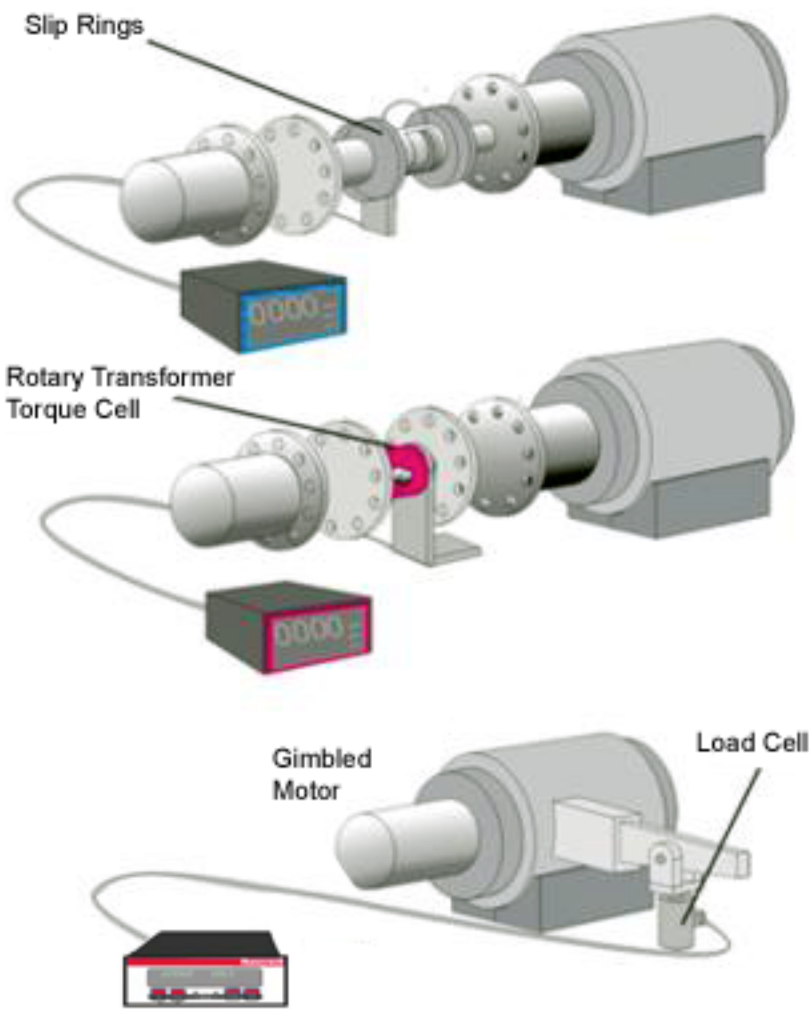
- Bridge arrangement cancels out changes that occur in all the resistive elements
- This compensates for resistance changes due to changes on temperature and also for strains in unwanted directions

Simple cantilever load cell



- If gauges are centrally mounted then
- no change in output voltage due to a side load

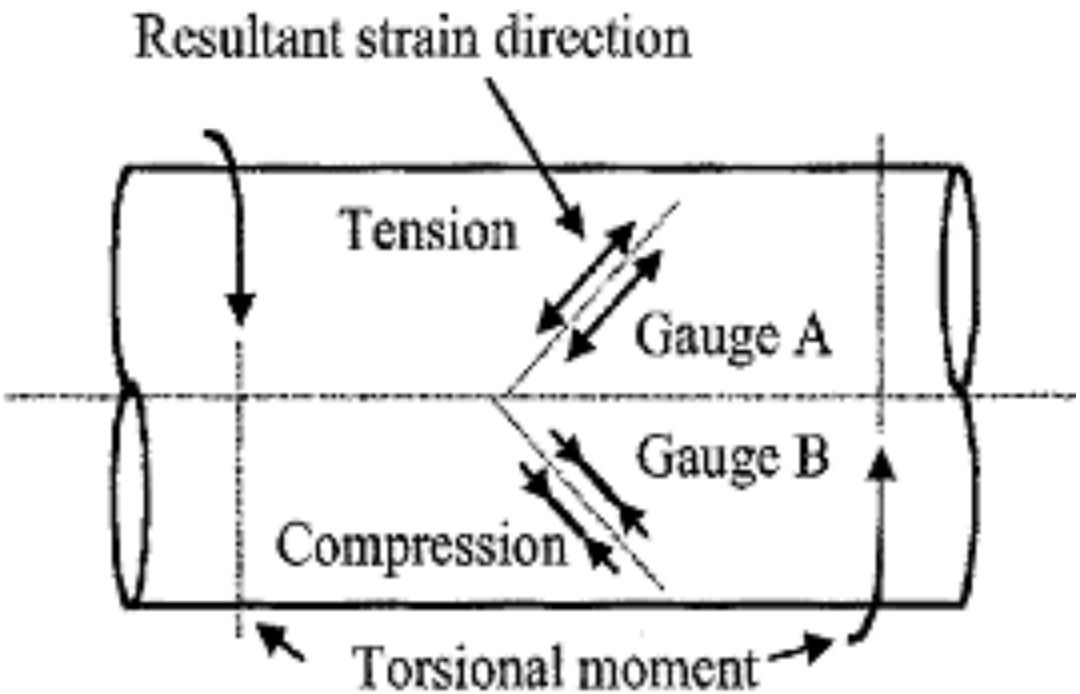
Measuring torque



- Two common ways to obtain torque measurements are by strain-gauging the shaft and by using in-line torque cells.

- Both have two technical obstacles: getting power to the gauges over the stationary/rotating gap and getting the signal back.

Measuring torque using gauge on shaft



- The gauges lie perpendicular to one another at 45 deg to the plane about which the tensional moment is applied.

1- 6 DOF load cells

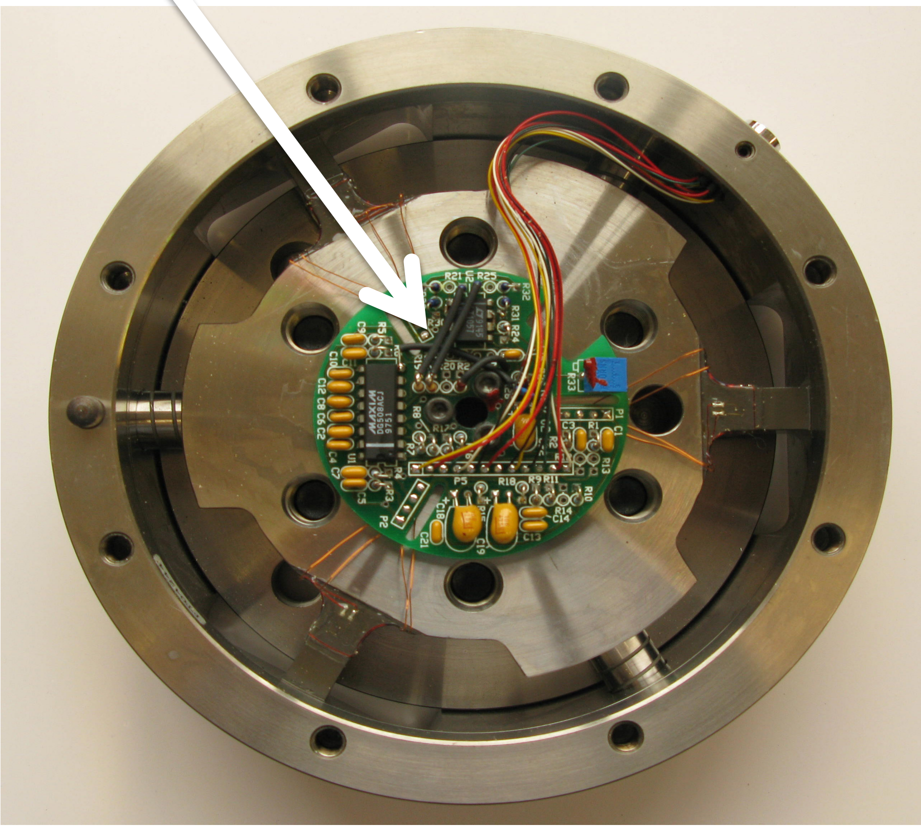
1 translational DOF

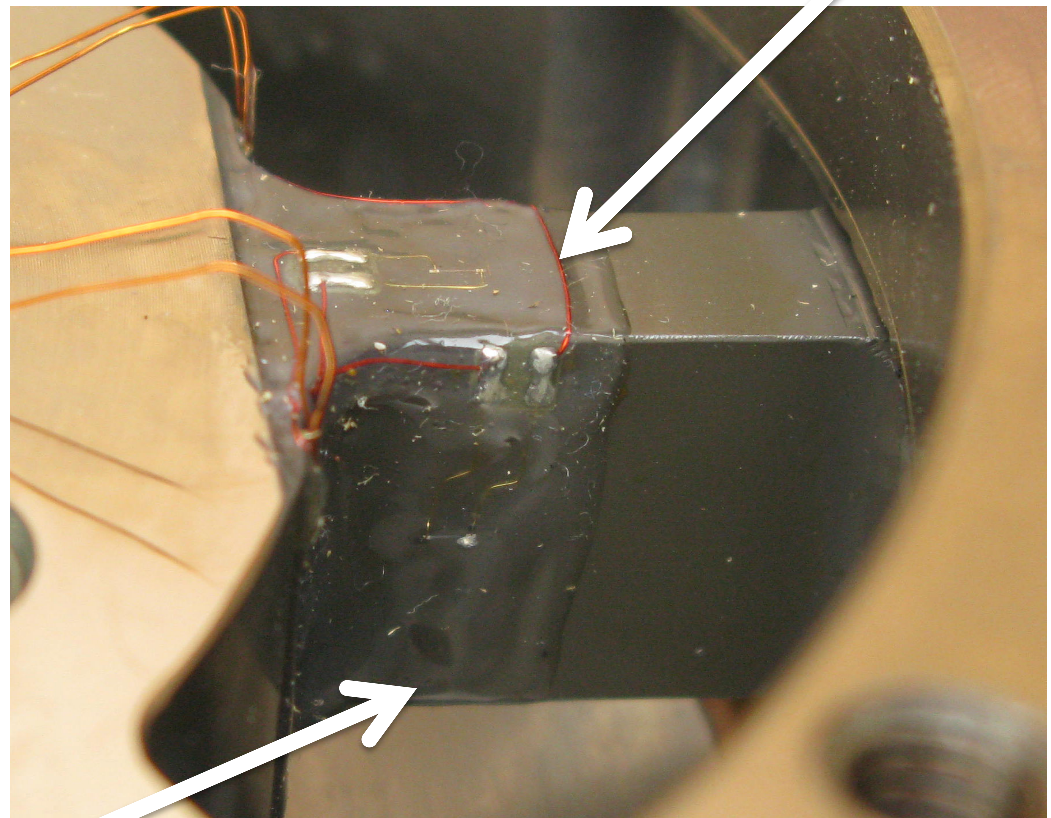
3 translational & 3 rotational DOFs

Inside a large 6DOF FT

Signal conditioning circuitry

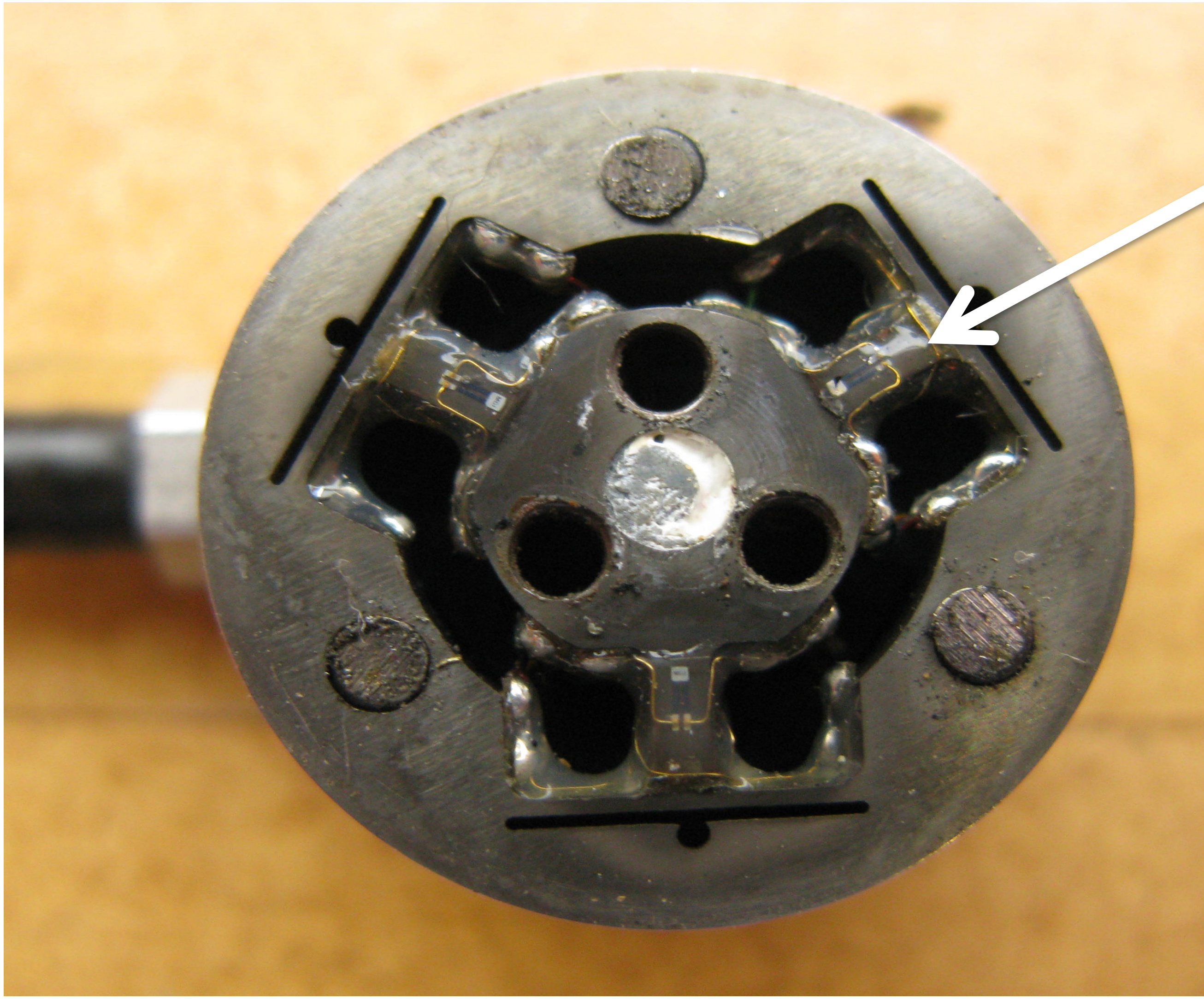
Silicon strain gauges





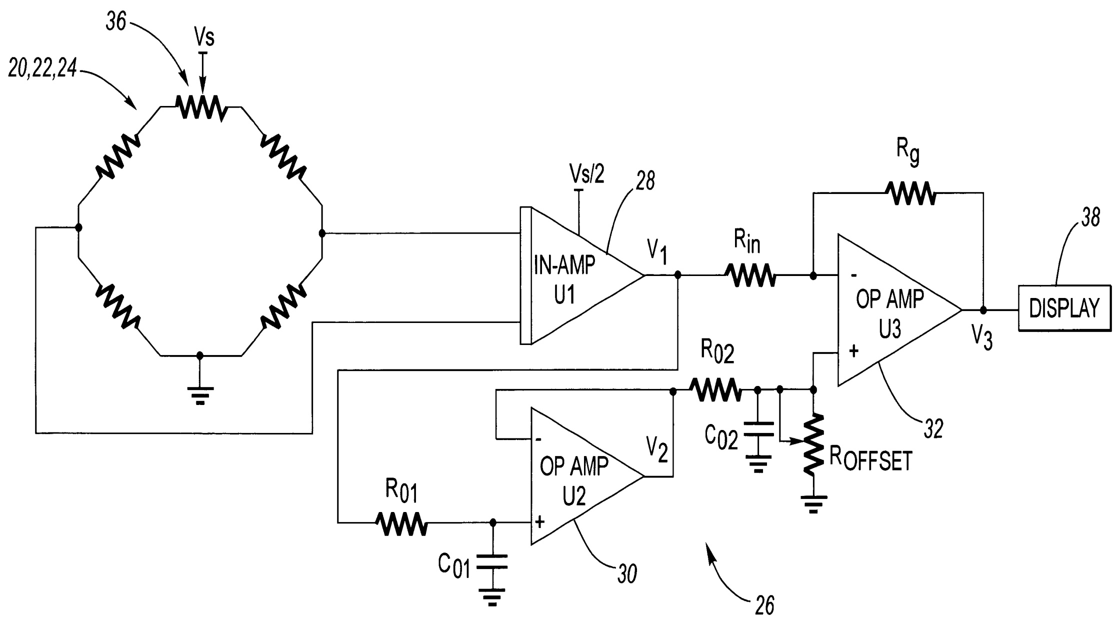
Massive structure which deforms under stress

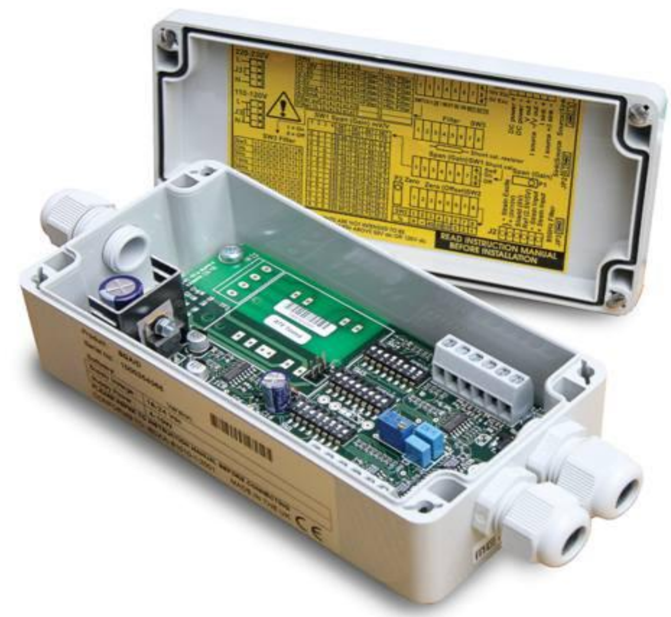
Inside a small 6DOF FT



Silicon strain gauges

A signal conditioning amplifier is needed





- The amplifier needed because voltage changes generates by Wheatstone bridge are small
- Need differential input to cancel interference
- Also it can filter unwanted signal outside the bandwidth of interest