Advanced Automotive Engineering

MUNER MOTORVEHICLE UNIVERSITY OF EMILIA-ROMAGNA

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Electric Drives -
Electric Propulsion Systems

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V1.2

Transducers for electric drives

Transducers
Overview

Practical feedback for control loops

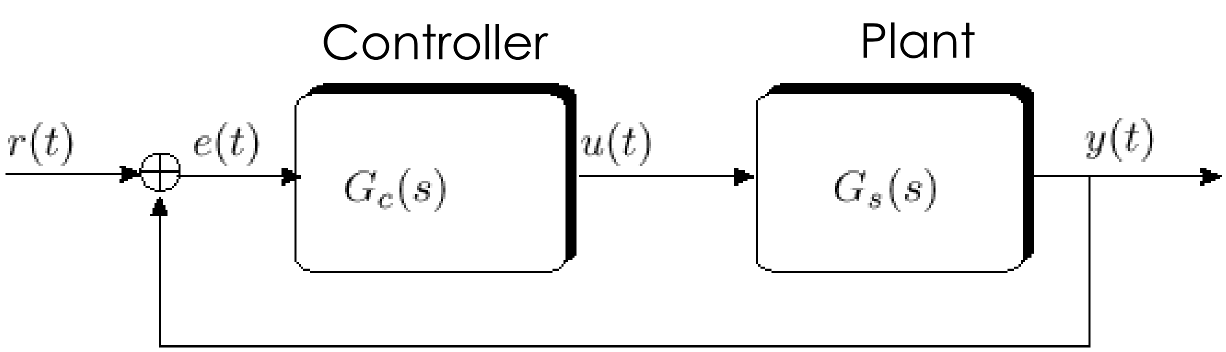
Position transducers
- Absolute / Incremental
- Optical / Magnetic

Current transducers
- Shunt
- Hall-Effect

Feedback transducers

Transducers

- Measure physical quantities (usually converting them into electrical ones)
- Enable closed control loops implementation



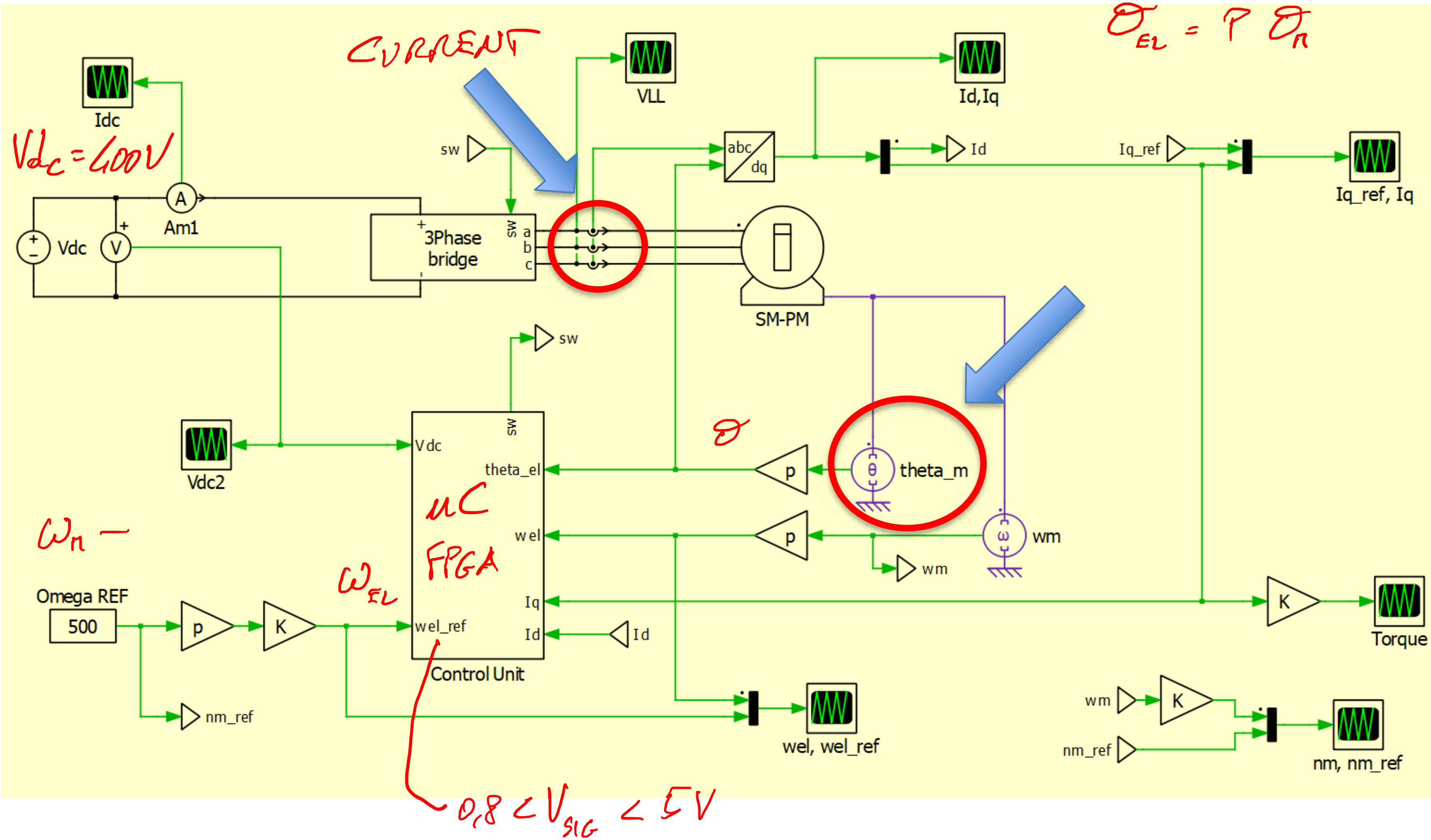
Feedback measurements

Position (speed) and Current

$\theta = \omega t$

$\omega_{EL} = \omega_m \cdot P$

$\theta_{EL} = P\,\theta_m$



Position Feedback

Position transducers

Overview

Type of measure:
- Absolute
- Incremental

Pinciple of operation:
- Magnetic
- Optical

Output signal:
- Analogic
- Digital
- Digital (communication bus)

SSI: Synchronous serial interface

EnDAT

HYPERFACE

Angular position measurement
Useful in AC brushless control

Resolver:

Postion information retrived by time

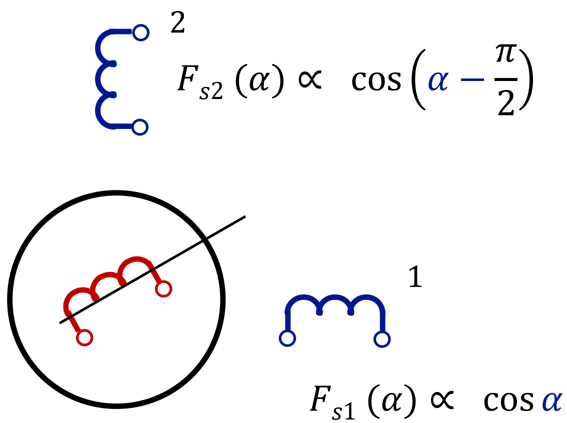
Encoder:

Postion information retrived by space

Two encoder types: relative or absolute

Resolver

Construction



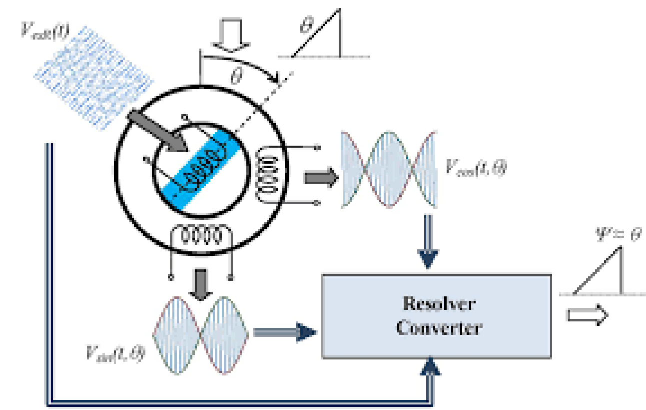
- **Stator**: two sinusoidally-distributed, mutually-orthogonal windings
- **Rotor**: a single sinusoidally distributed winding

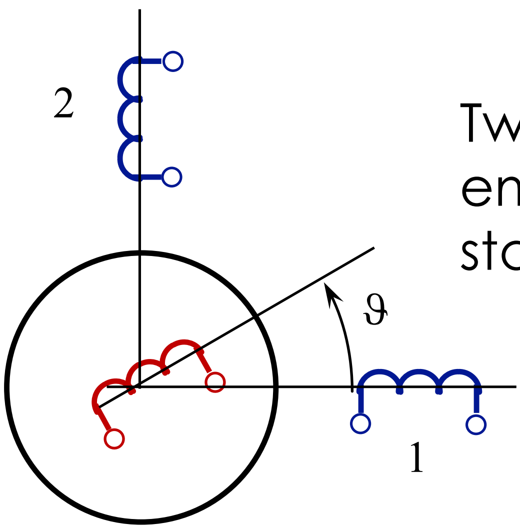
In a resolver, the mutual coupling between stator and rotor windings depends on rotor angular position.

Resolver

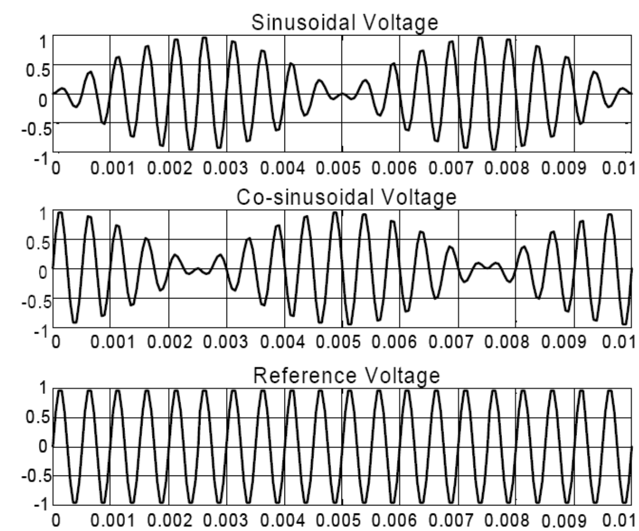
In use

Supply the rotor with a sinusoidal voltage at a relatively high frequency (2÷10 kHz): $V_r \propto \sin(\omega_e t)$





Two amplitude modulated emf are induced at the stator windings



$$V_1 \propto \cos(\vartheta)\sin(\omega_e t)$$

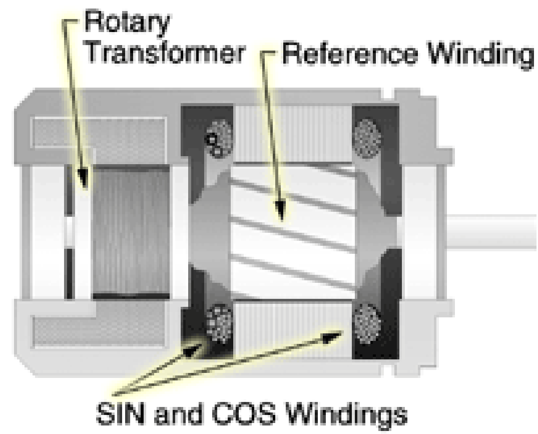
$$V_2 \propto \cos\left(\vartheta - \frac{\pi}{2}\right)\sin(\omega_e t) = \sin(\vartheta)\sin(\omega_e t)$$

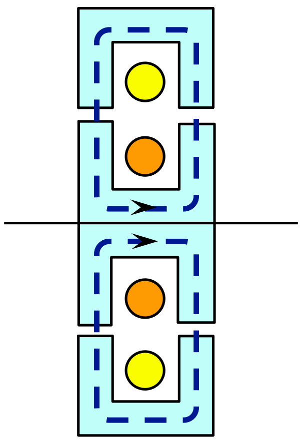
Via amplitude demodulation, the values of $\sin(\vartheta)$, $\cos(\vartheta)$ are obtained

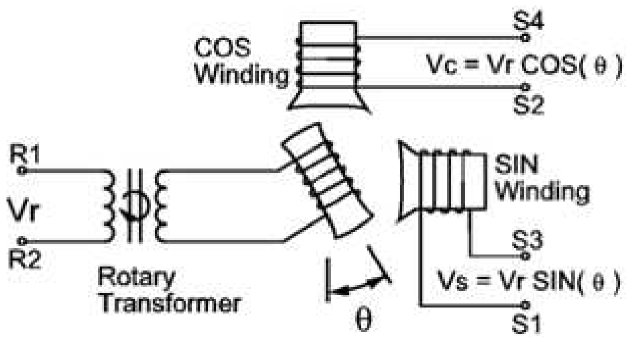
Directional/Direction COSINES

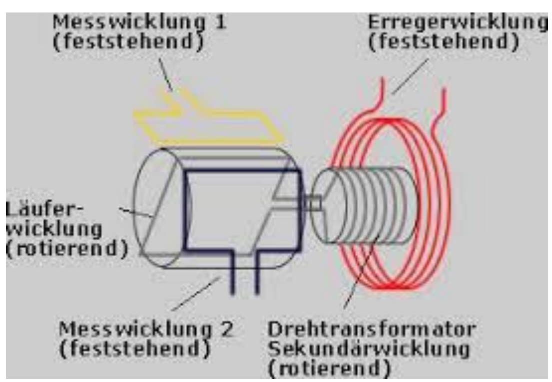
Brushless Resolver
Practical construction

To minimize wear, a toroidal rotary transformer architecture is used to excite the rotor winding

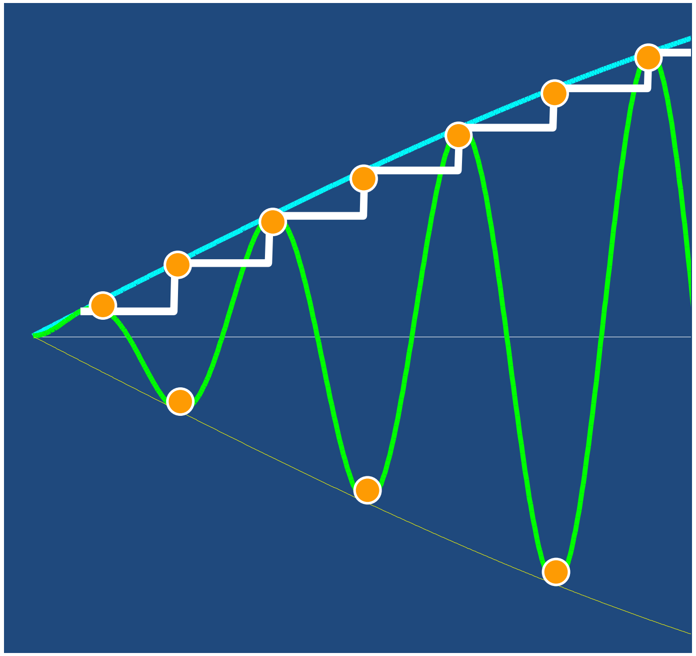








Sampling & Demodulation

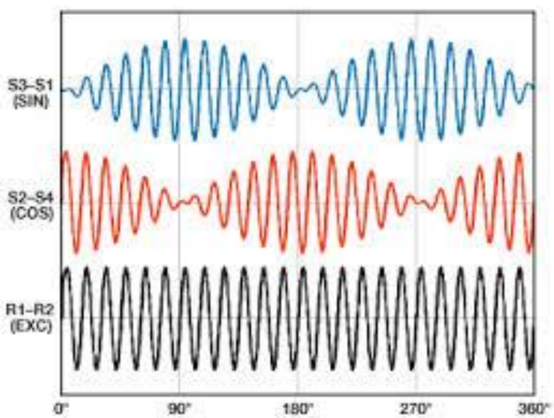


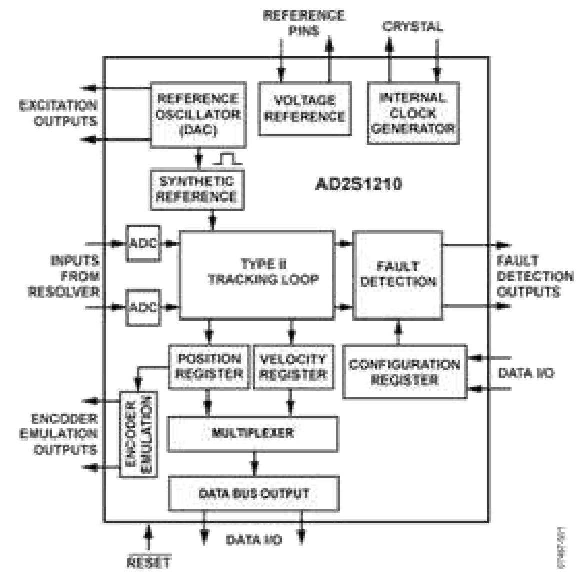
Stator EMF signal is sampled at the peaks:

e.g. $\sin \omega_e t \sin \vartheta$

The sampled signal is at twice the excitation frequency.

Usually all the operations are carried out by Application Specific IC that also provide the excitation and output data digitally on comm. bus (e.g. SPI)

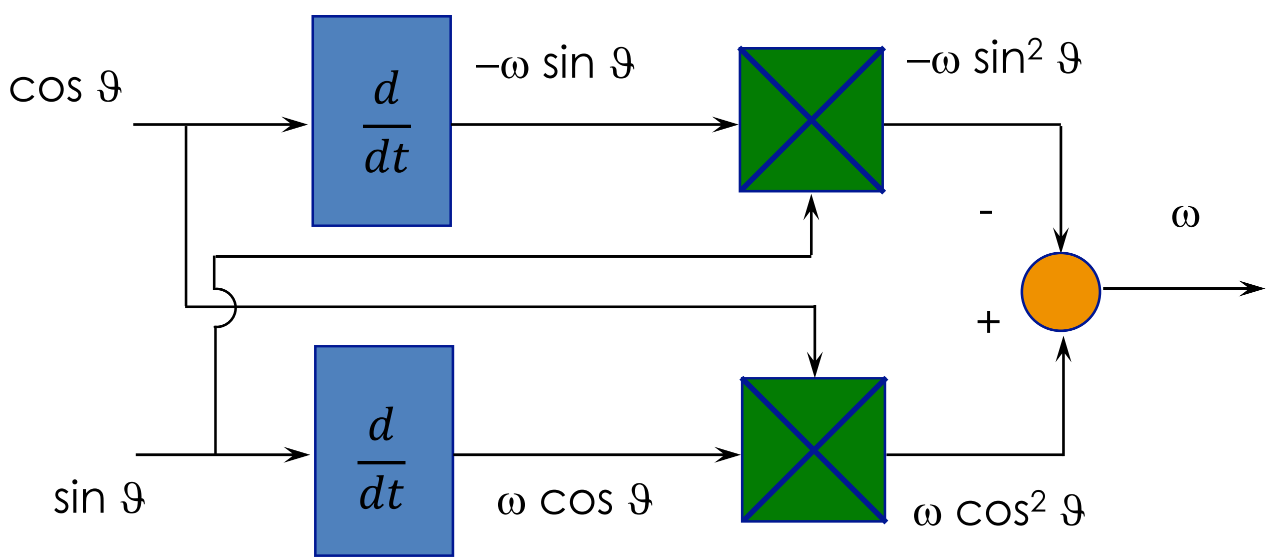




Speed reference signal

Tacho reconstruction

Tacho information (Speed) is obtained as depicted in the following diagram



$$\omega \underbrace{(\cos^2\theta + \sin^2\theta)}_{1}$$

Resolver Wrap Up

Resolvers were the first precise, reliable position feedback devices employed in electric drives

Dedicated IC resolver to digital converter (RDC) are widely used for the sake of convenience

Sampling demodulation might be convenient in high performance digital systems using DSP or FPGA

Accurate demodulation design is mandatory in order to minimize the speed ripple measurement

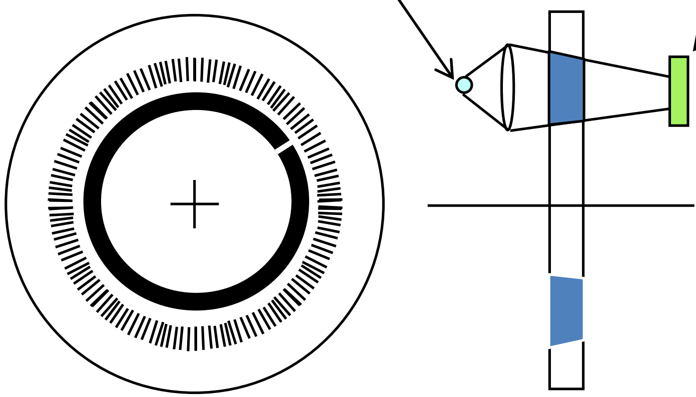
Optical encoders

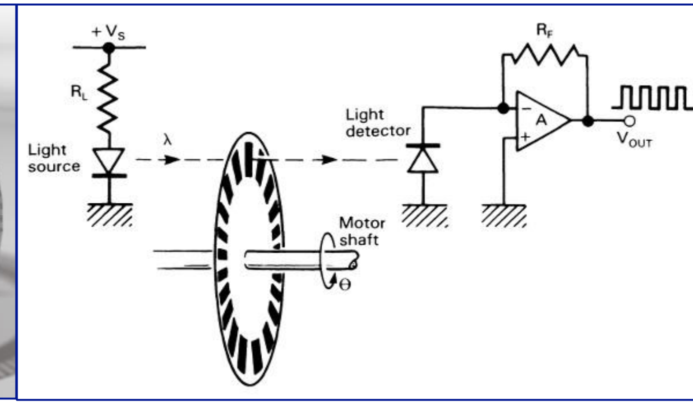
Optical Encoder

Incremental encoder

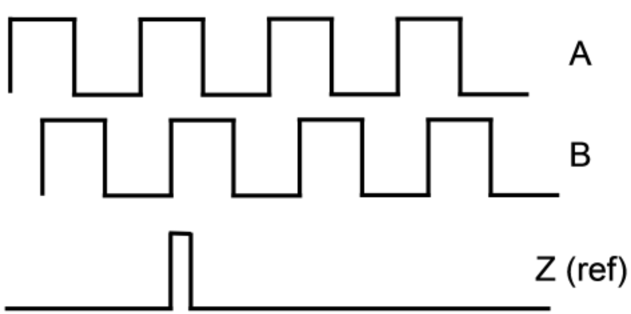
Light source (diode)

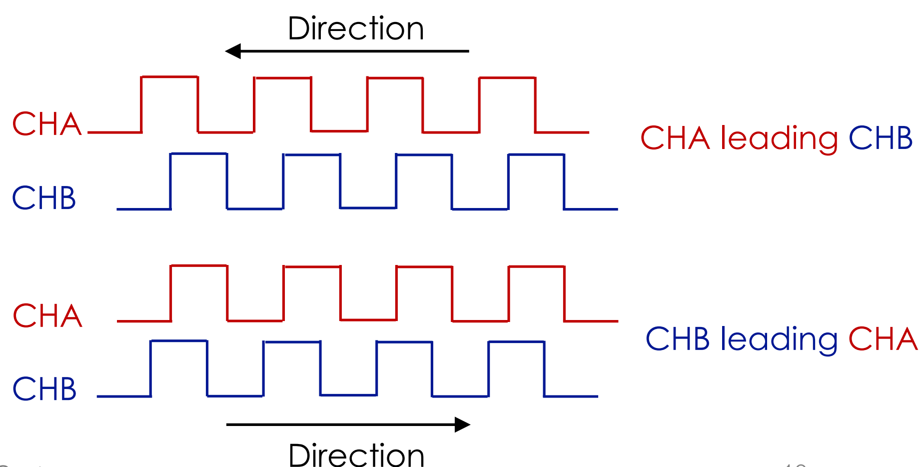
Receiver (phototransistor/photodiode)





Three receivers are usually adopted: channel A,B and channel Z





Optical Encoder
Incremental encoder

The simplest incremental encoder provides two signals (square waves) in quadrature, plus a zero index.

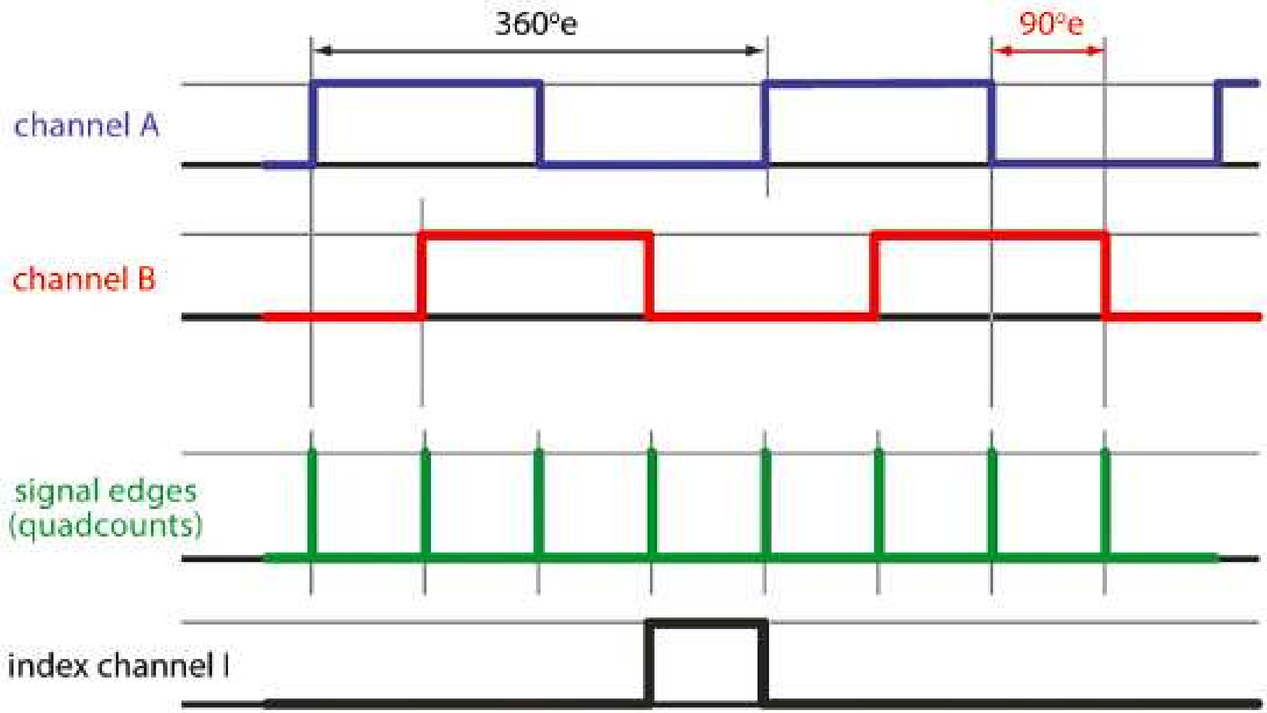
The angular resolution depends on PPR (n° of Pulse Per Revolution) usually in the order of 10^3

1024 – 2048 PPR

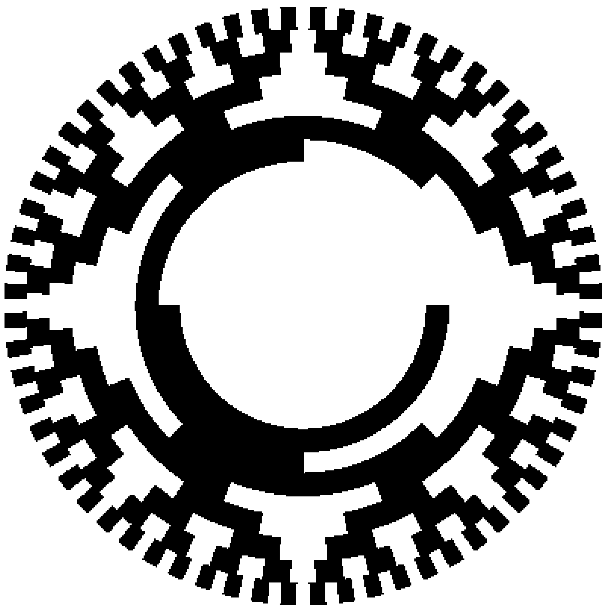
Sampling is strictly spatial, meaning that at low speed no position feedback update for relatively long periods of time.

Optical Encoder
Quad count (x1 x2 or x4)

Line count (index) vs Incremental count



Absolute optical encoder
Single-turn

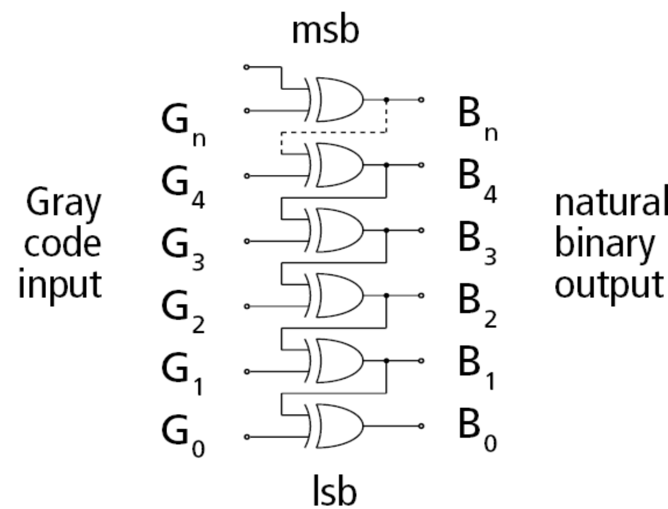


Resolution = 360° /2^{Nbit}

Expensive and delicate for high resolution: 1 bit per individual trace

Parallel output

Grey coding of the position
Two adjacent configurations can only differ by one single bit.



Optical Encoder Wrap-up

Incremental encoder

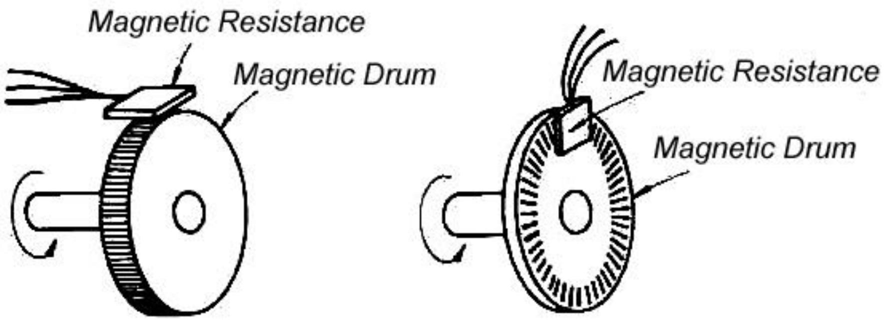
Incremental encoder requires alignment and system initialization (homing) at startup

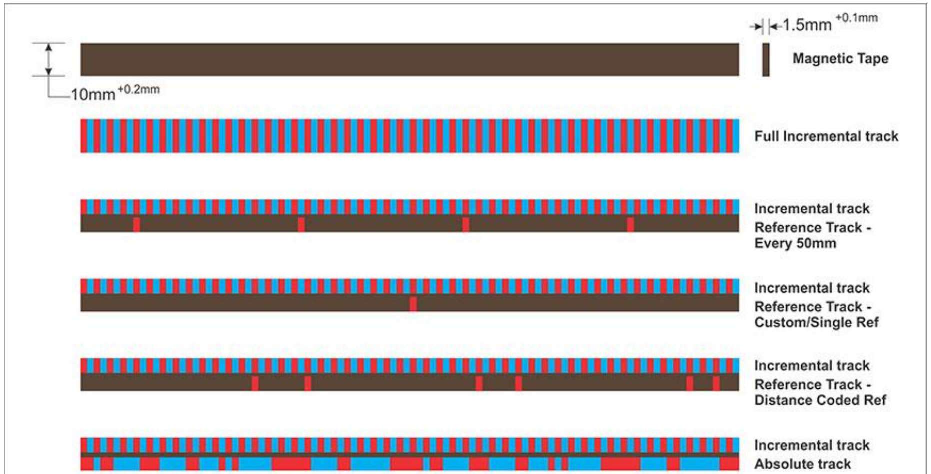
Useful to store last known position in memory, in case of fault or emergency stop

Absolute encoders are an alternative, but more expensive

Magnetic encoders

Magnetic Encoder
Incremental





Magnetic tape Grating variety

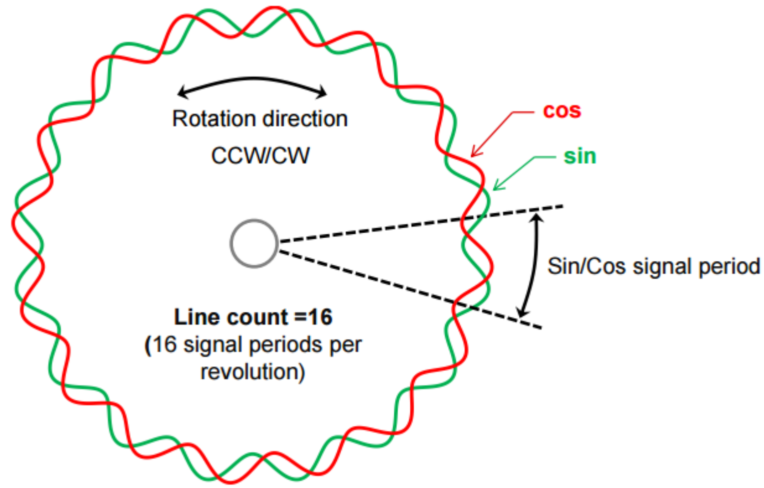
Same principle of operation.

- Scanning head
- Track with alternatively magnetized stripes

Can be pure incremental or mixed (incremental + absolute)

Magnetic Encoder

Incremental Sin Cos



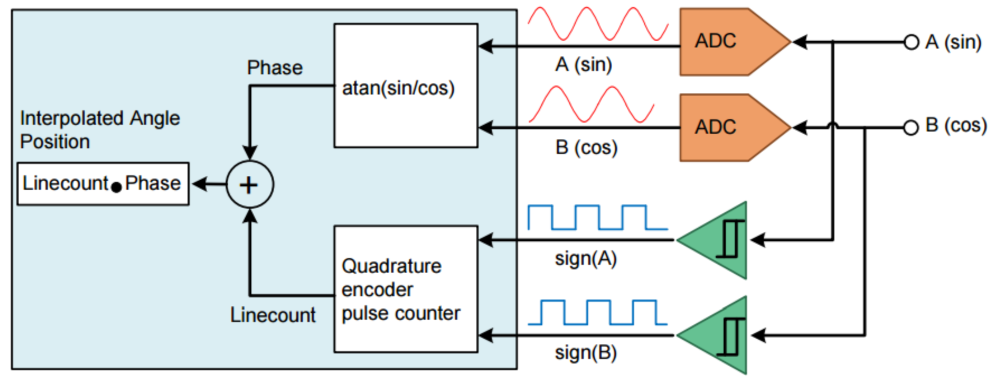
The scanning head houses a permanent magnet for excitation, the saliency on the position wheel modulate the readout of the transducer.

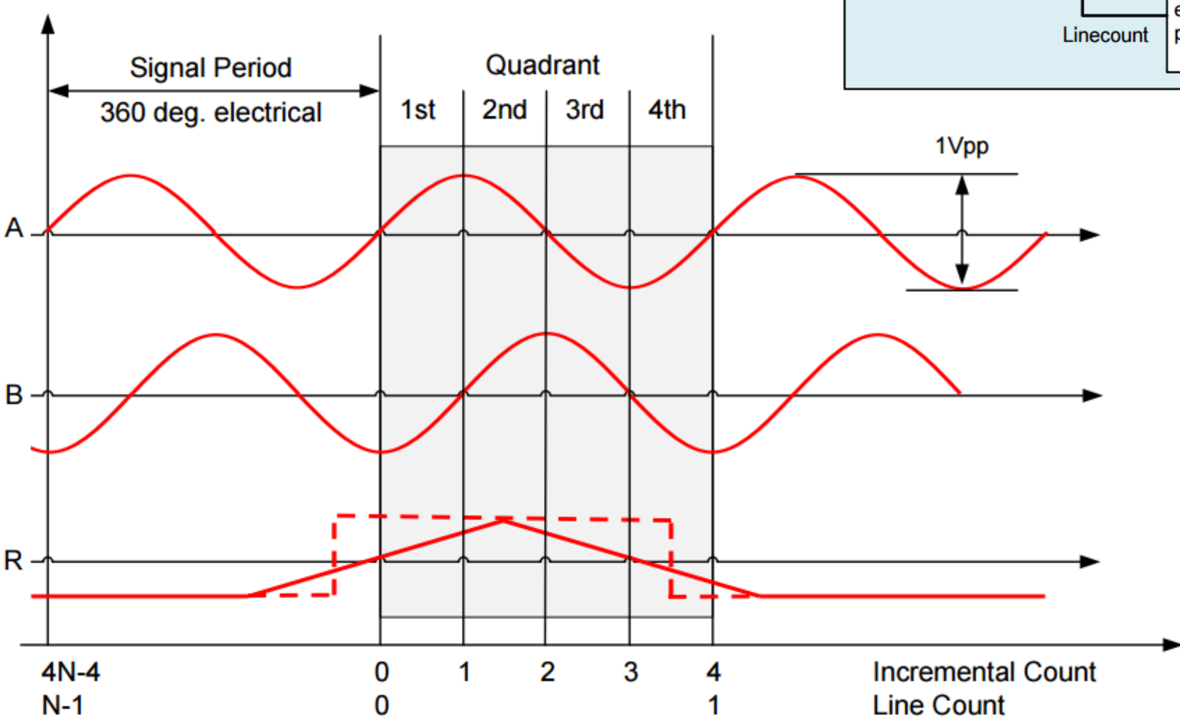
Analog output signals

Extremely rugged construction

Magnetic Encoder
Demodulation of Sin Cos signals

Enhances resolution

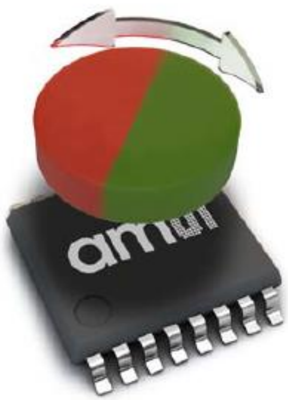




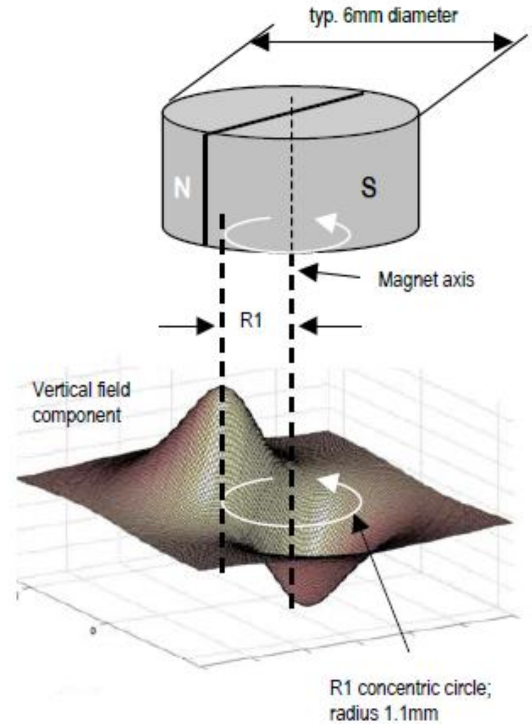
Line count vs Incremental count

Hall effect resolver

Absolute position feedback



Usually available as a System on chip, with minimal accessory component required.



Very useful in small, integrated drives

- Rugged, non-contact operation (+ magnet loss diagnosis)
- Angular resolution up to 12 - 14 bits
- Multiple interfaces: SSI, PWM, quadrature A / B signals
- Readily interfaceable to uControllers

Position Feedback Conclusion

High performance AC Drives, until recently, employed RESOLVERS as the most used position transducer

Optical incremental encoder suffer from vibration and dust presence: not suitable for harsh environment

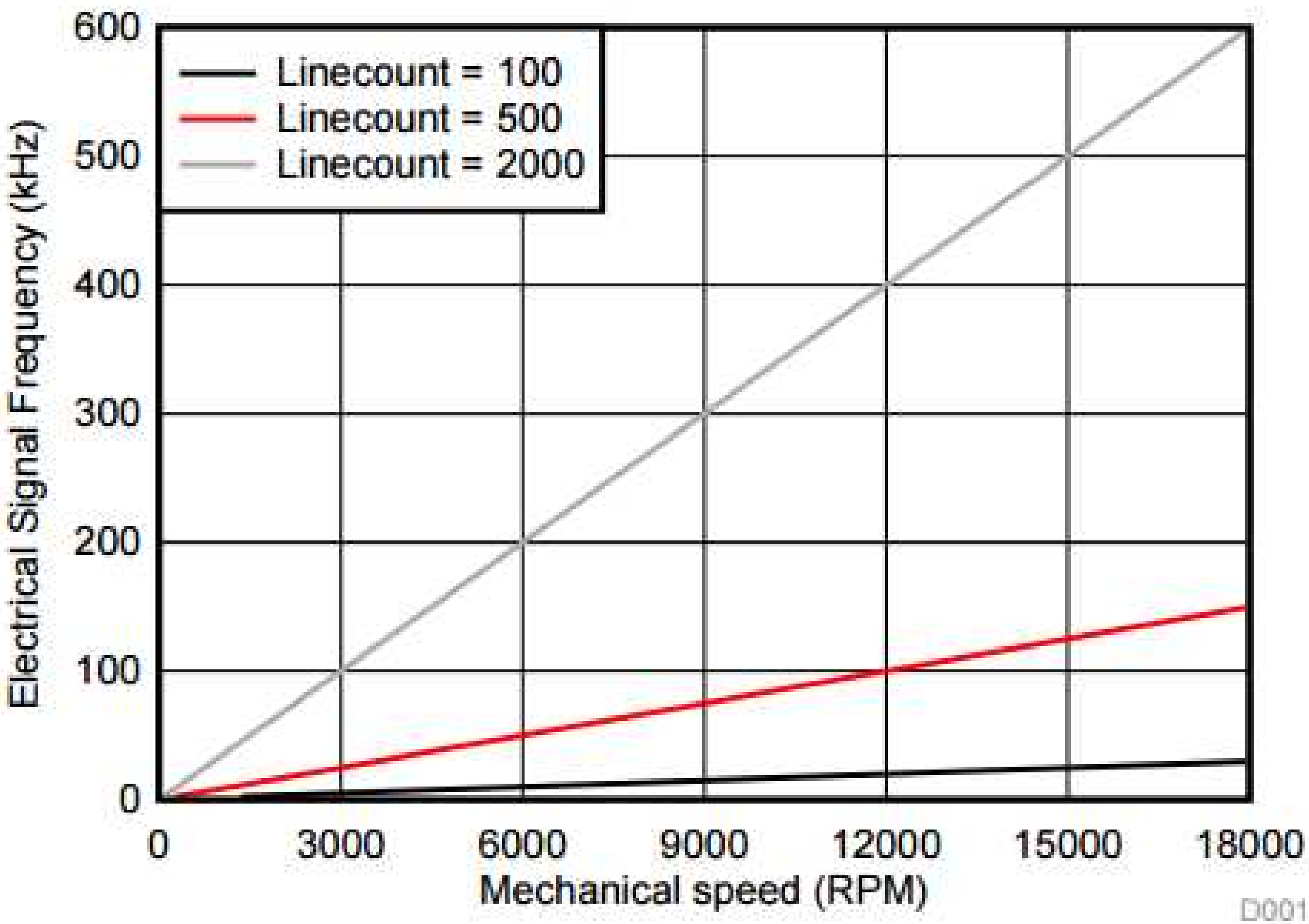
A good remedy: the magnetic incremental or sin/cos encoder

Absolute single turn magnetic encoders are readily available as system on chip, especially useful in embedded applications

The widespread use of Digital Control Systems led to the use of fully digital position sensors, with proprietary interfaces

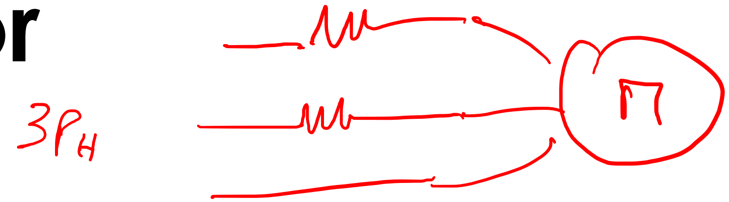
Position feedback limitations

Speed/Resolution tradeoff



Current Feedback

Shunt Resistor

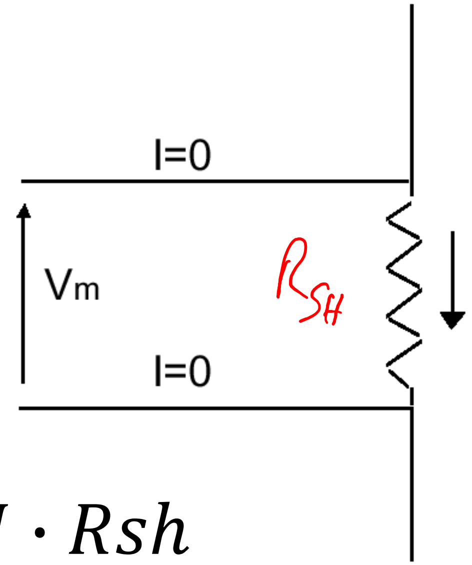


PROS

- Simple and rugged
- Low cost
- Wide bandwidht (100 kHz)

CONS

- Dissipative
- No galvanic insulation



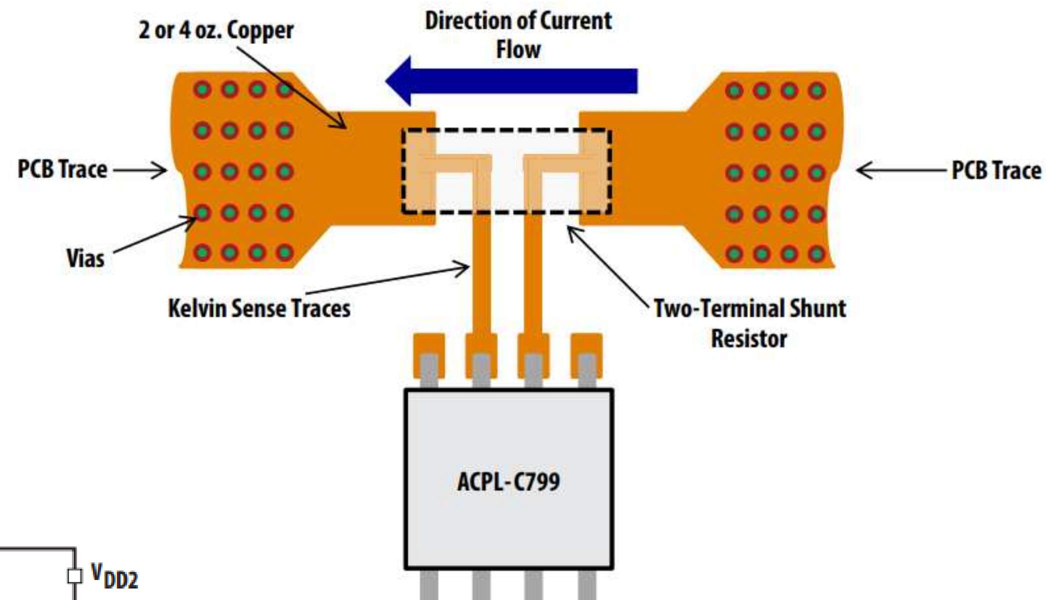
$$Vm = I \cdot Rsh$$

Rsh must be of low value, to limit Joule losses

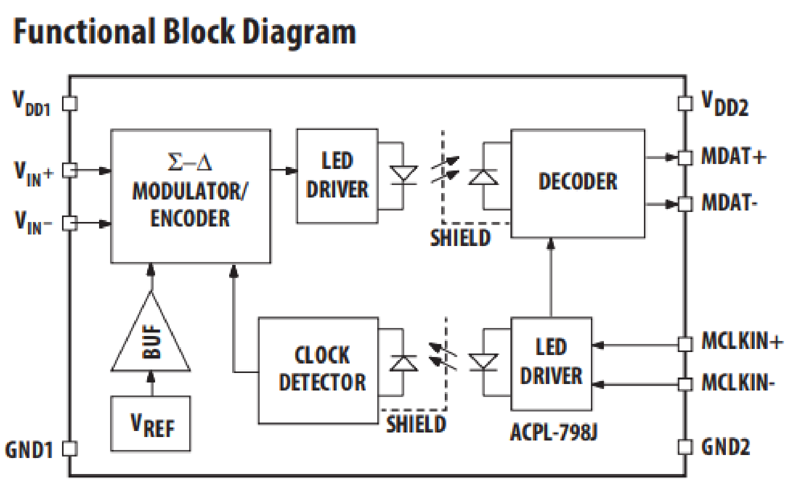
Differental readout required

Shunt resistor readout

With added galvanic insulation



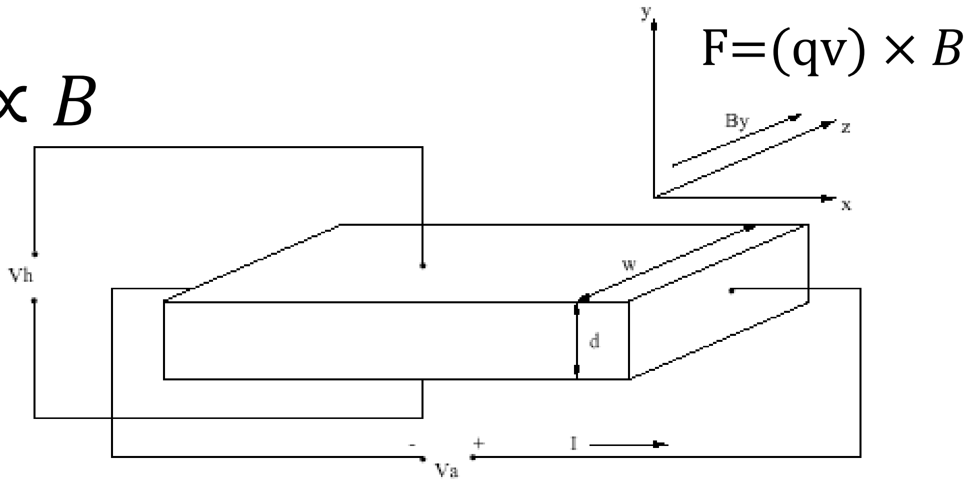
Insulation amplifier or
Sigma-delta modulator



Hall Effect Current transducers

Principle of operation

$$Vh \propto B$$



PROS

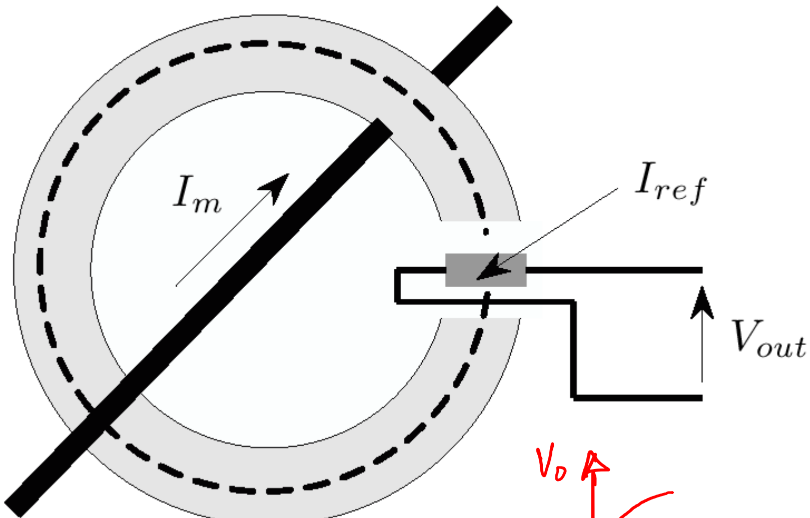
- Rugged
- Inherently insulated
- Not dissipative

CONS

- More expensive
- Require additional power supply
- Offset & drift (open loop)
- Bandwidth limitations (closed loop)

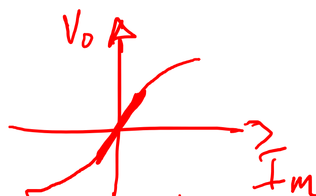
Hall Effect Current transducers

Open loop construction



In the airgap of a toroidal core there is a Hall-effect sensor on which the toroidal core concentrates the magnetic field generated by the unknown electric current Im.

A small reference current Iref is passed on the transducer which, by Hall effect, generates a voltage Vout proportional to the current Im.



$$V_{out} = (K\, I_{ref}) I_m$$

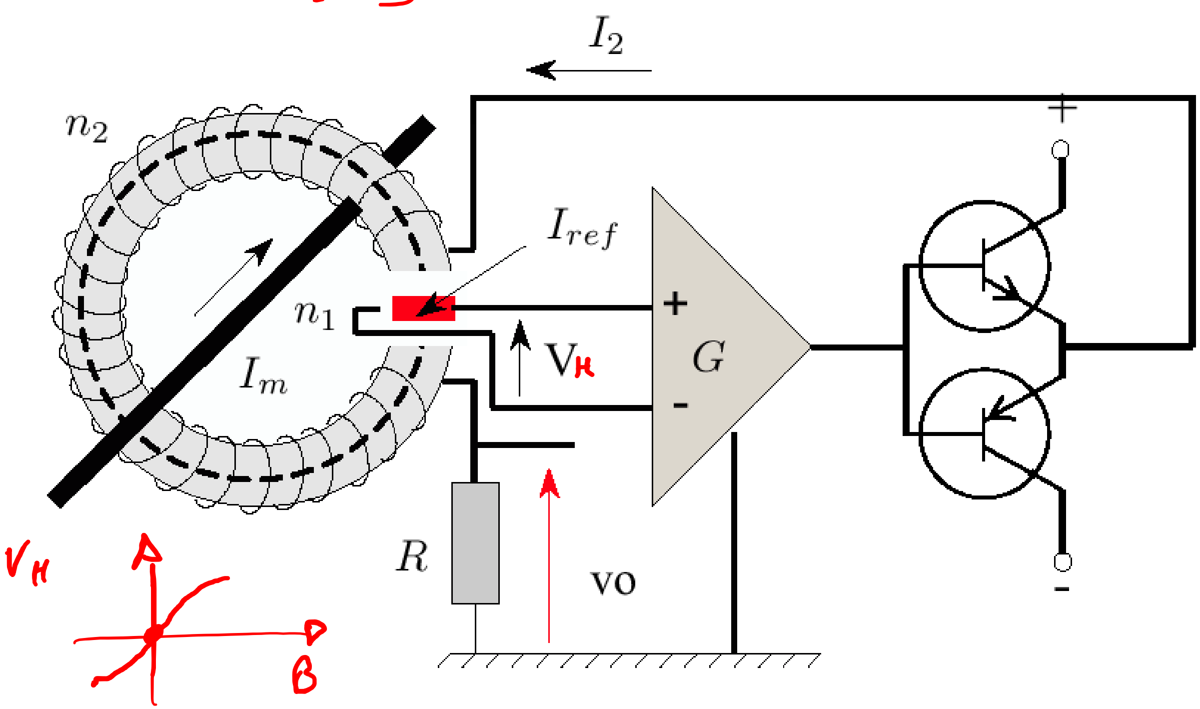
NON LINEARITY

$$V_{OUT} \propto I_m \cdot N_1$$

Hall Effect Current transducers

~~Open~~ loop construction

CLOSED



Hall effect transducers have good linearity only for low magnetic flux values.

With closed loop configuration the Hall effect sensor work around a zero magnetic flux.

Closed loop operation:

$$n_1 I_1 + n_2 I_2 = \mathcal{R}\Phi_B = 0$$

$$V_o = R\, I_2 = R\,\frac{I_m}{n_2}$$