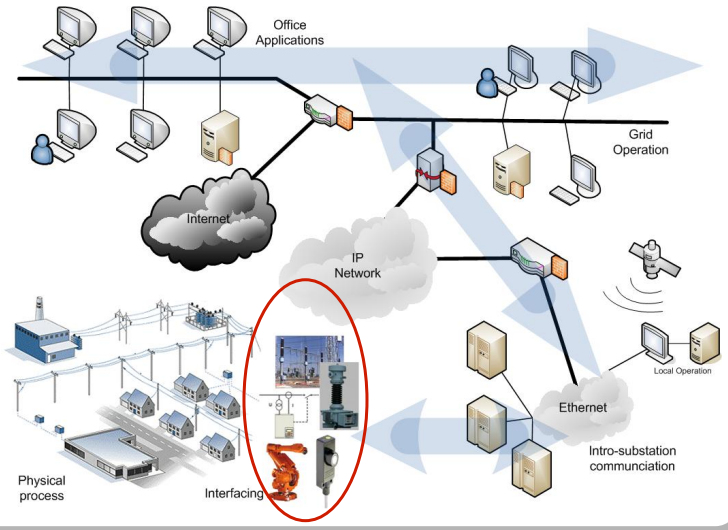
Lecture 4
Power System Instrumentation

Course map



Outline of the Lecture

- Instrument Transformers
  - Voltage Transformer
  - Current Transformers
- Measurement Setups
- Instrumentation

The Current Transformer (CT)

High Voltage

Bushing type
Medium Voltage

Medium Voltage

CT – General Types

- Wound primary
  - Traditional transformer with secondary and primary windings
- Bar primary
  - The primary winding is a single bar, that passes through a core with the secondary winding.

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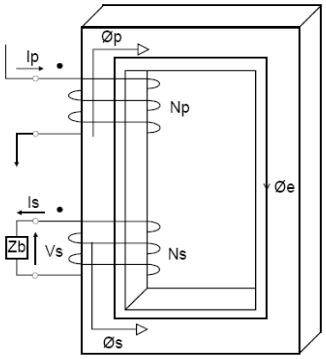
CT – Principle of Operation

- Traditional Electromagnetic transformer
- Is = Ip*Np/Ns
- Normally Bar type CTs are used



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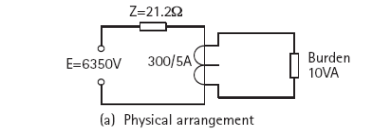
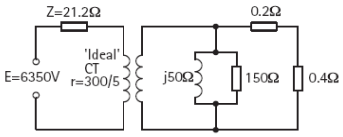
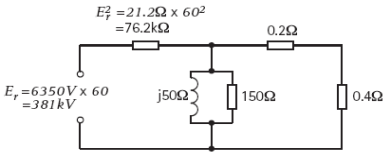
CT – Equivalent Model



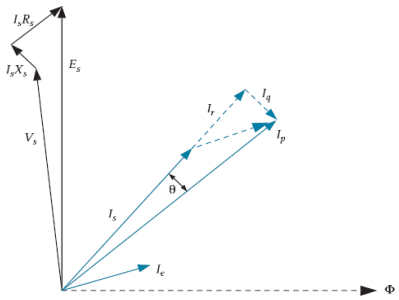
(a) Physical arrangement



(b) Equivalent circuit of (a)



(c) Equivalent circuit, all quantities referred to secondary side



E_s = Secondary induced e.m.f.
V_s = Secondary output voltage
I_p = Primary current
I_s = Secondary current
θ = Phase angle error
Φ = Flux
I_sR_s = Secondary resistance voltage drop
I_sX_s = Secondary reactance voltage drop
I_e = Exciting current
I_r = Component of I_e in phase with I_s
I_q = Component of I_e in quadrature with I_s

CTs Accuracy

Accuracy class		+/- Percentage current (ratio) error				+/- Phase displacement (minutes)			
	% current	5	20	100	120	5	20	100	120
0.1		0.4	0.2	0.1	0.1	15	8	5	5
0.2		0.75	0.35	0.2	0.2	30	15	10	10
0.5		1.5	0.75	0.5	0.5	90	45	30	30
1		3	1.5	1.0	1.0	180	90	60	60

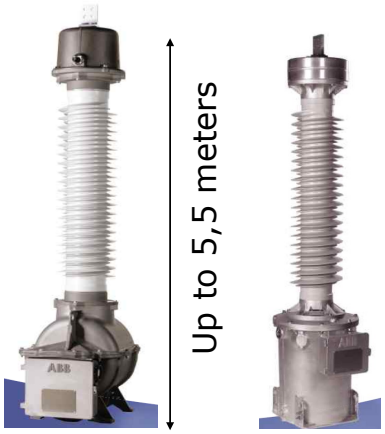
(a) Limits of error accuracy for error classes 0.1 - 1.0

Accuracy class		+/- current (ratio) error, %	
	% current	50	120
3		3	3
5		5	5

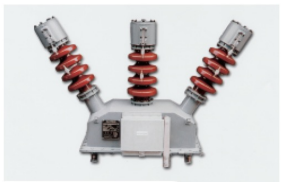
(b) Limits of error for error classes 3 and 5

Table 6.4: CT error classes

Voltage Transformers (VT)



High Voltage



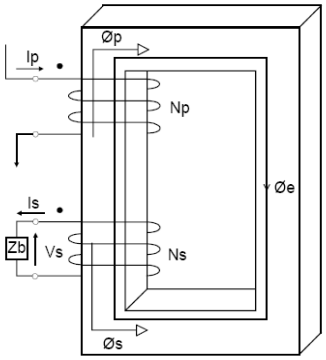
Medium Voltage
< 36kV

VT – General Types

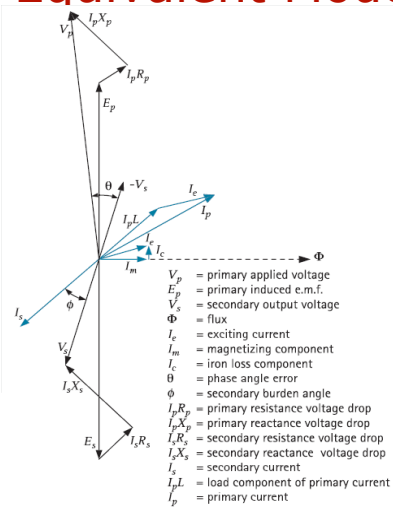
- Electromagnetic type
  - Commonly referred to as VT
  - Traditional Electromagnetic transformer
  - Used up to approx 130kV
    - Thereafter insulation problems arise
- Capacitor Type
  - Commonly referred to as CVT
  - Series coupled capacitors
  - Used up to EHV/UHV levels

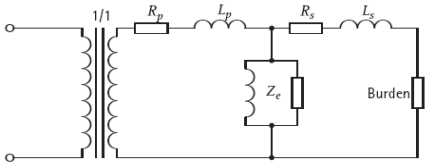
VT – Principle of Operation

- Traditional Electromagnetic transformer
- Vs = Vp*Ns/Np
- Connected either
  - Phase – Earth
  - Phase – Phase
- Single-pole
  - Star coupled



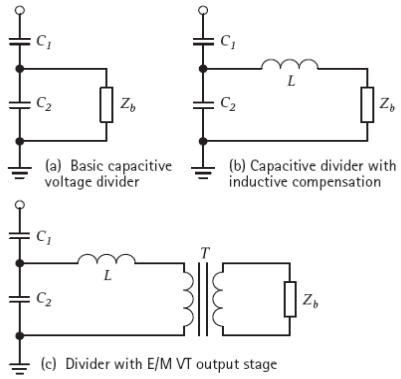
Equivalent Model





CVT – Principle of Operation

- Basic potential divider
- Inductive compensation to cancel effect of capacitive source impedance
- To reduce the size of capacitors, a VT is added on output side.



VT – Design Factors

- Electromagnetic VT
  - Flux density in core well below saturation
  - Output design ranges 200-300 VA
  - Insulation larger volume than windings
- Capacitive VTs
  - More space conserving
  - May include a VT
  - Can be used for overloading High-Frequency signals on Power Line.

VT Connection

- VTs are single pole above 36 kV
- CVTs
  - Phase to Earth
- VTs
  - Phase to Phase, Phase to Earth
  - Star coupling

VT - Accuracy

- Accuracy classes for measurement & revenue metering
- Accuracy classes for protection

Accuracy class	0.8 – 1.2 x rated voltage 0.25 – 1.0 x rated burden at 0.8pf	
	voltage ratio error (%)	phase displacement (minutes)
0.1	+/- 0.1	+/- 5
0.2	+/- 0.2	+/- 10
0.5	+/- 0.5	+/- 20
1.0	+/- 1.0	+/- 40
3.0	+/- 3.0	not specified

Table 6.1: Measuring voltage transformer error limits

Accuracy class	0.25 – 1.0 x rated burden at 0.8pf 0.05 – V_f x rated primary voltage	
	voltage ratio error (%)	phase displacement (%)
3P	+/- 3.0	+/- 120
6P	+/- 6.0	+/- 240

Table 6.2: Additional limits for protection voltage transformers.

Summary - VTs/CTs

- VTs and CTs are the primary measurement method for medium and high voltage
- Important design characteristics are
  - Accuracy for revenue metering
  - Linearity for protection
  - Size = cost
- The output is further transformed using transducers.

Contents of the Lecture

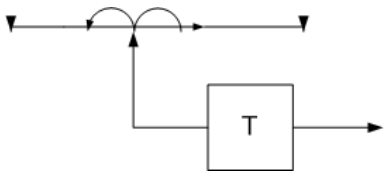
- Instrument Transformers *(NPAG Ch. 6)*
  - Voltage Transformer
  - Current Transformers
- Measurement Setups
- Transducers *(NPAG Ch. 22)*

What do we need to measure?

- Voltage V
- Current I
- Frequency f
- Phase angle φ
- Power Q,P
- Position on/off
- …..

Current Measurement

- Connected to secondary side of CT
- Cannot sense direction
- Measurement types
  - Mean sensing
  - r.m.s. measurement

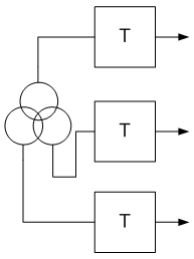


Current measurements

- Instantaneous current per phase
  - $i_A(t)$ $i_B(t)$ $i_C(t)$

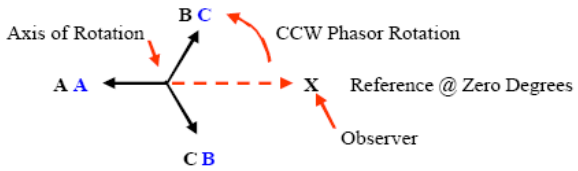
Voltage Measurement

- Connected to secondary of VT/CVT



Phase Angle Measurement

- Implemented using zero-crossing detection
- Sensitive to harmonics
- Connected to phases and quantities (U or I) as needed for measurement



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Frequency Measurement

- Important for system operation
- Analog – Digital conversion
  - Fourier Transform for *f* analysis
- Accuracy up to 0,01% available, +/- 5 mHz
- Connected to VT or CT secondary

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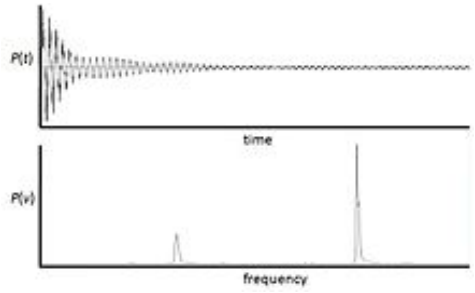
Signal processing

- Analysing Frequceny content
- Fast Fourier Transform FFT

$$X_k = \sum_{n=0}^{N-1} x_n e^{-i 2\pi k \frac{n}{N}} \qquad k = 0, \ldots, N-1.$$



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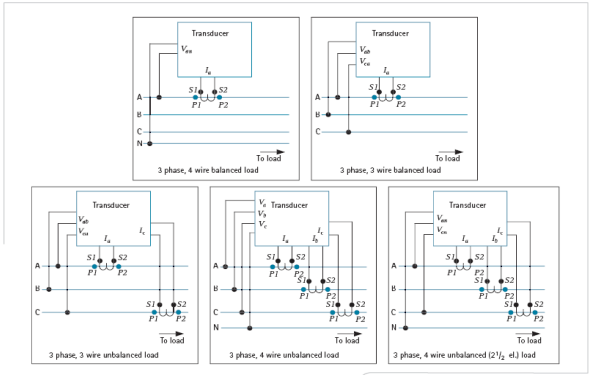
Power Measurement

- Measurement of P & Q
  - Many configurations available
  - Direction of the flow important



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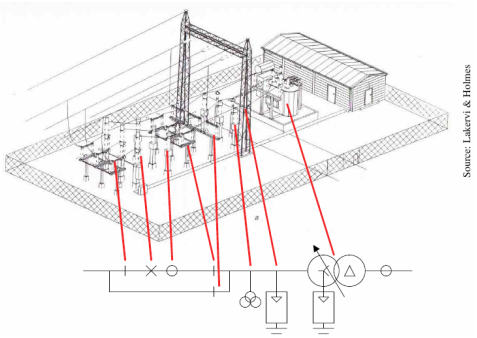
Outline of the Lecture

- Instrument Transformers
  - Voltage Transformer
  - Current Transformers
- Measurement Setups.
- Instrumentation

Wiring & Communication



Transducer types

- Analog or Digital transducers

- Digital transducers (A/D conversion)
  - Benefits
    - Improved long-term stability
    - More accurate r.m.s measurement
    - Improved Communications
    - Programmable scaling
    - Reduced size
    - Wider range of functions
  - Output normally a RS-485 or 232 interface

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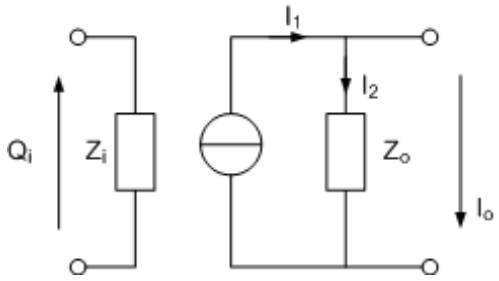
Equivalent Model (analog)

- Output from a transducer normally a current source
- E.g. 4-20 mA as a function of input



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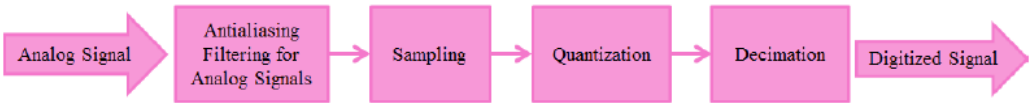
A/D conversion



- Accuracy determined by
  - Bit resolution, Least Significant Bit
  - Non-linearity due to imperfections.
  - Sampling & Aliasing

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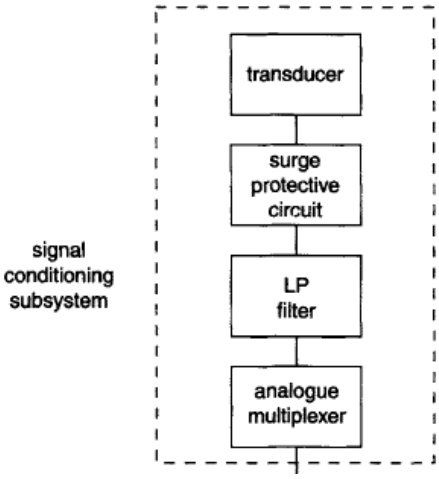
Signal conditionings



- To prepare analog signal for A/D conversion
- To protect circuits
- Enable multiplexing, depending on capability of digital channels

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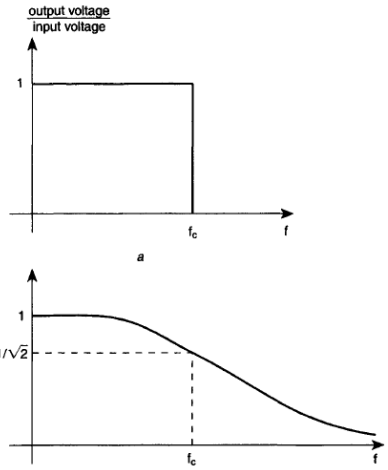
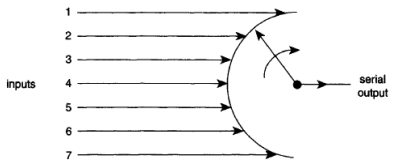
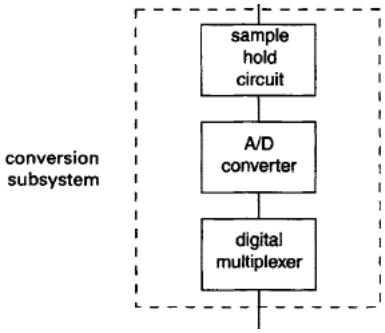
Analogue LP filter

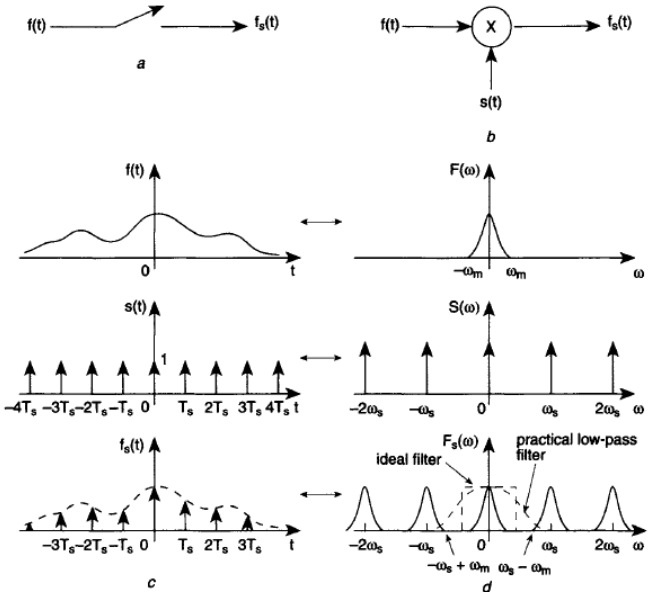


- To limit frequency content of measurement signal
- Multiplexing principle:

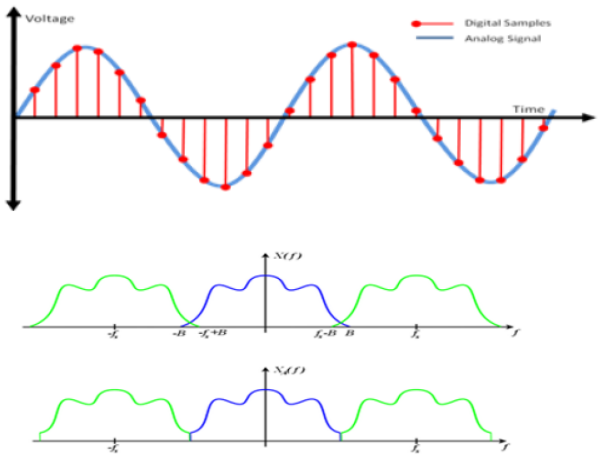


A/D Conversion

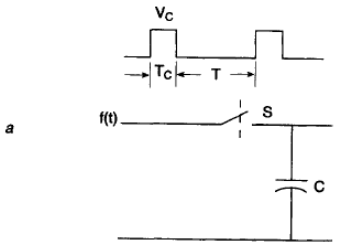


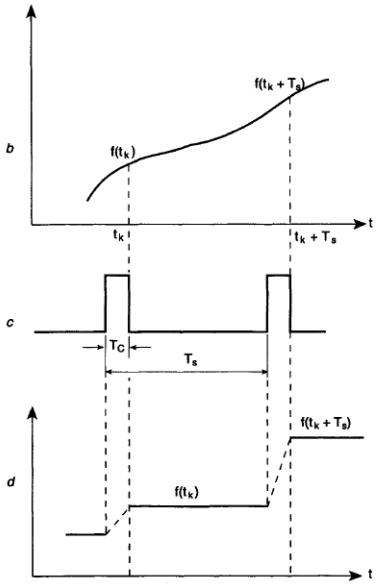


Sampling & Aliasing

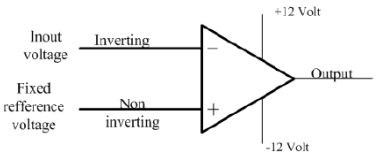


Sample & Hold



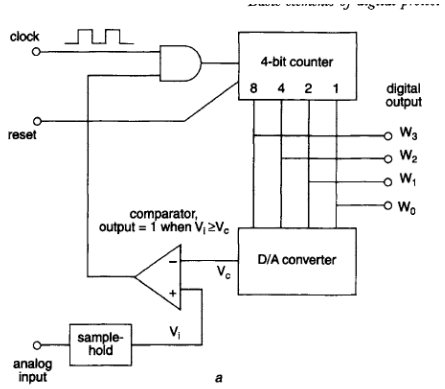


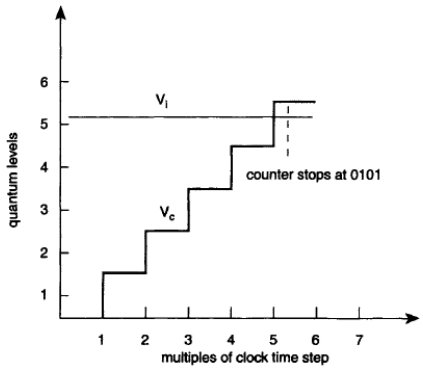
A/D - Quantization



- Base circuit is the comparator
- If Input > Vref output = V+
- If Input < Vref = Output = V-

Counter based A/D





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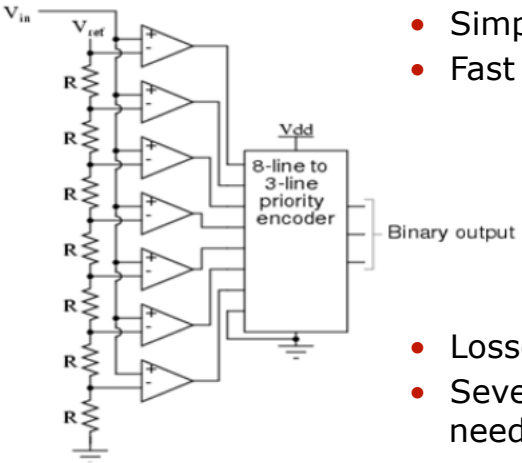
Flash ADC



- Simple concept
- Fast

- Losses increase
- Several comparators needed
- Low resultion

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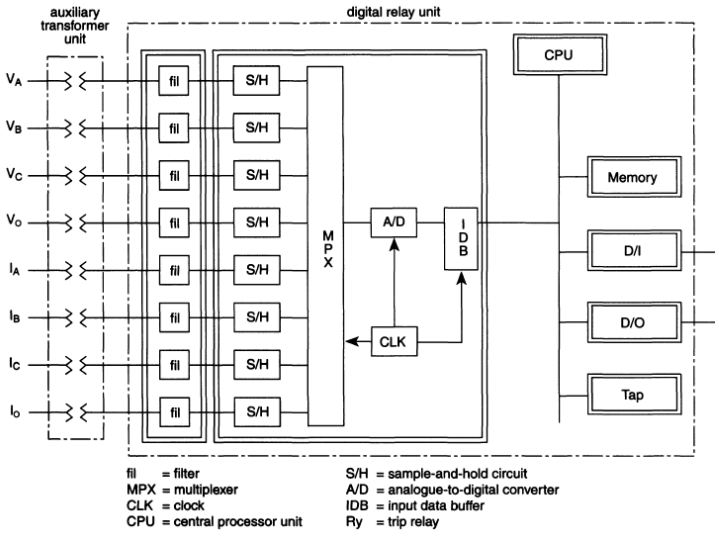
Further AD-Converter types

- Integrator
  - Integrating signal applied to input of comparator and reference
- Sigma Delta
  - Oversampling of the input, and successive stages of comparation and summing.

- Accuracy still determined by
  - Bit resolution, Least Significant Bit
  - Non-linearity due to imperfections.
  - Sampling & Aliasing

Putting it all together



Questions or comments?