Process Control

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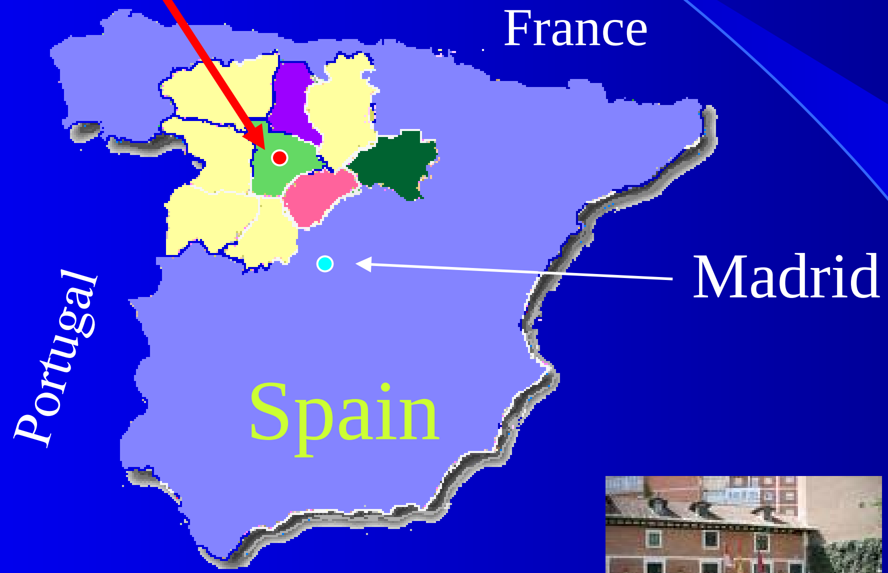
Valladolid

Valladolid-
Madrid
55min.



Miguel de
Cervantes

“El Quijote”

Cristobal
Colombus

- Capital of Castilla-León
- Medium size town
- Car industry, Renault

University of Valladolid

- Second oldest in Spain (XIII century)
- All branches: Humanities, Law, Engineering, Medicine, …
- 26000 students

Santa Cruz Palace
XV century

Vice-Chancellor offices

Dpt. of Systems Engineering and Automatic Control

- Founded in 1973
- School of Industrial Engineering

  Three locations:
  - Mergelina Building
  - Paseo del Cauce
  - Mendizabal
- Two Technology Centres
  - CARTIF (Automation and Robotics)
  - CTA (Centre for Sugar Technology)
- Master/PhD Course: Process and Systems Engineering

  (in cooperation with the Chemical Eng. Dpt.)

  Award of Excellence of the MEC

“Process control and supervision” Research group

- The group

2 Professors
5 lecturers
3 doctoral contracts
12 research grants
2 technicians

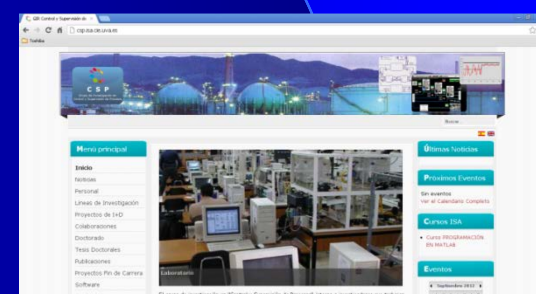
Develop new ideas and theory

Develop software tools

Industrial applications

- Research topics:

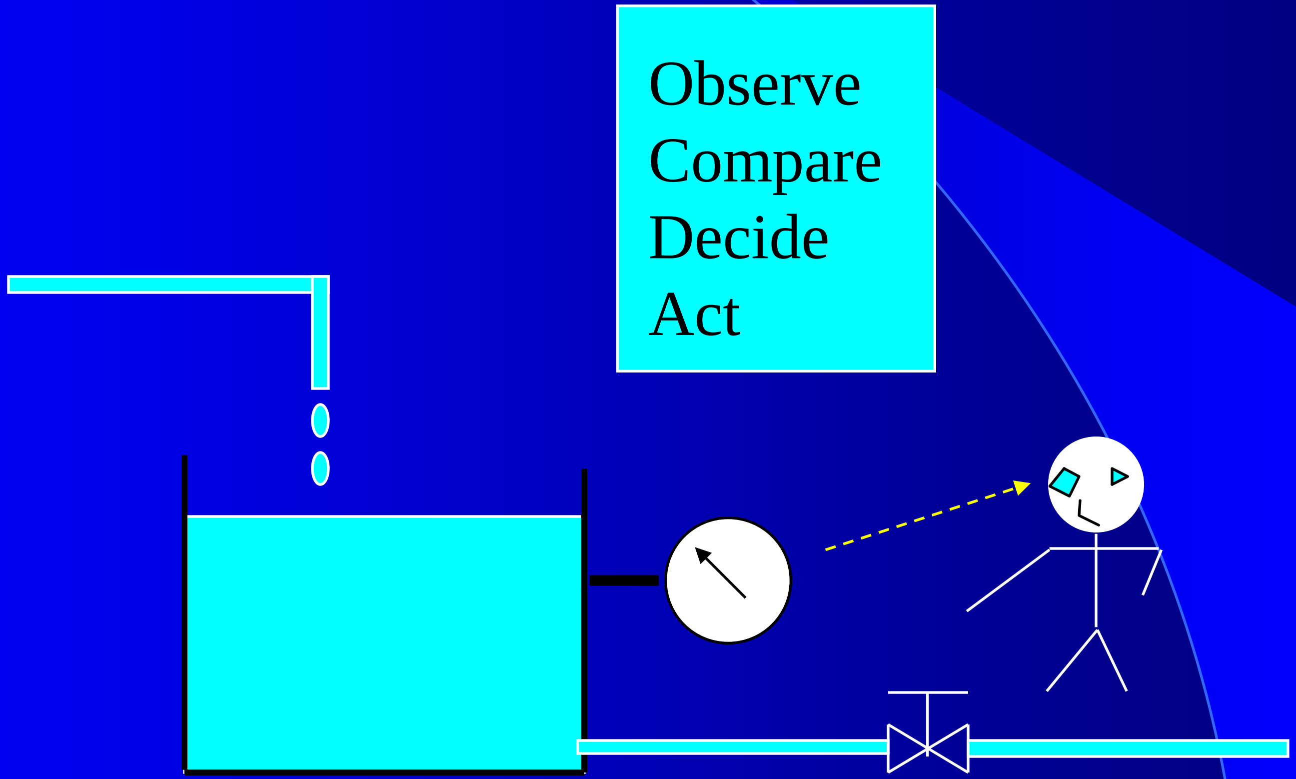
Advanced Control, MPC
Process Optimization
Modelling and Simulation
Fault detection and diagnosis



Web: www.isa.cie.uva.es

Process control deals with the problem of maintaining the main process variables close to its desired values, in spite of disturbances, by means of an automatic system

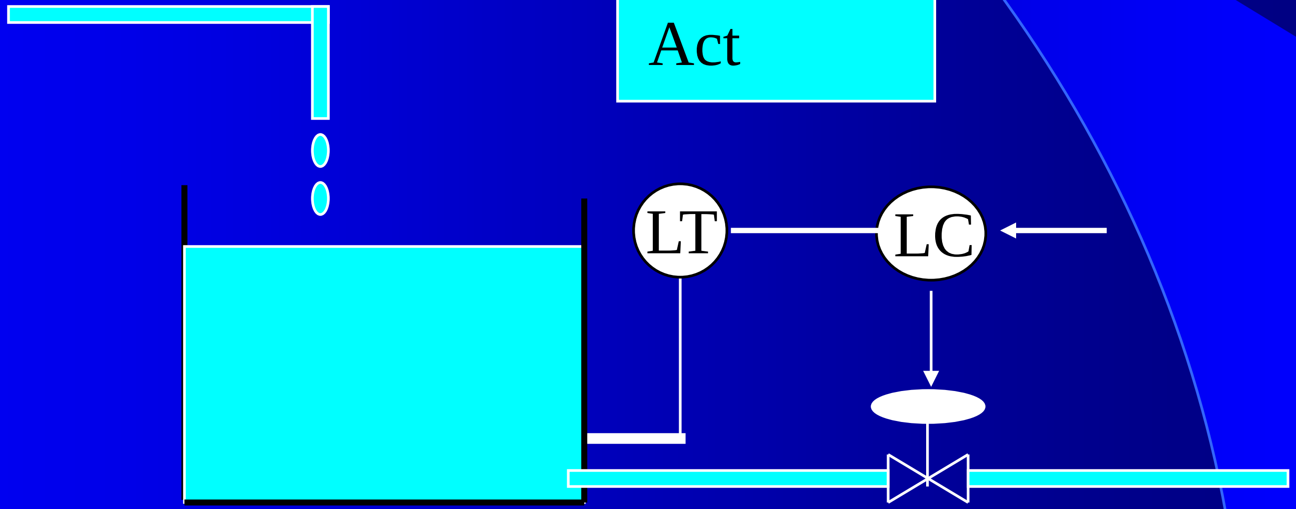
Process Operation
Manual operation



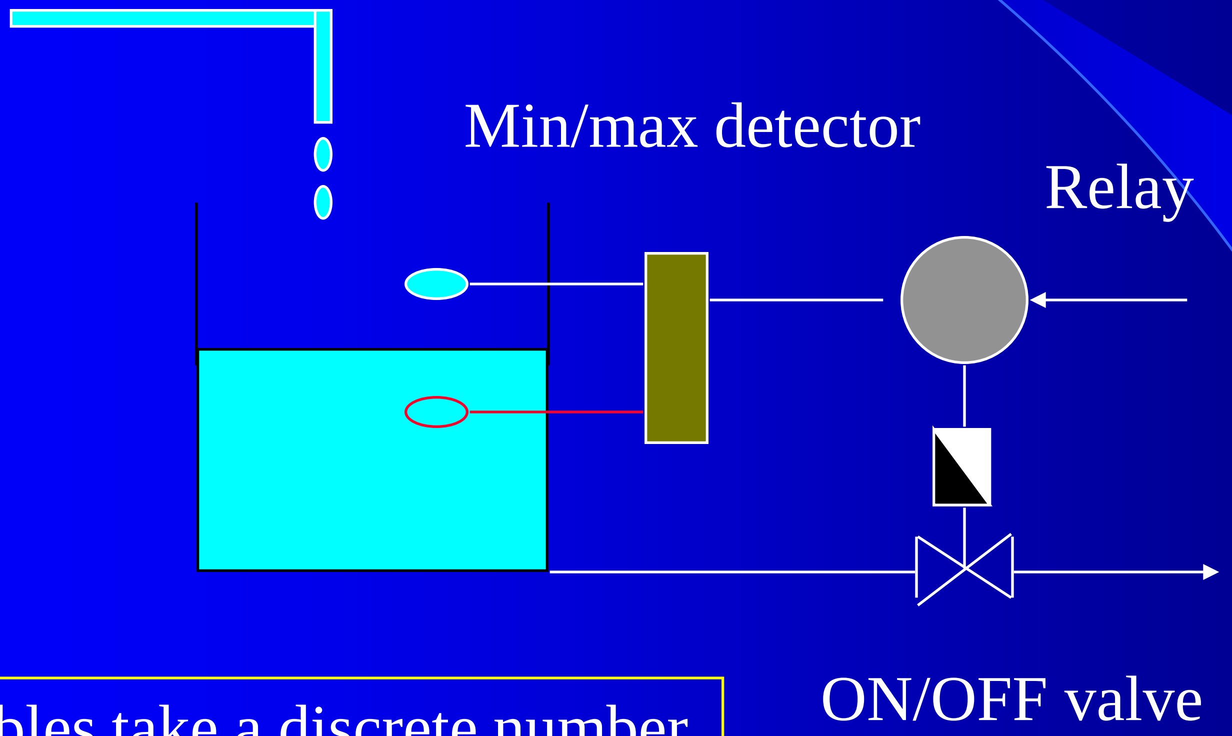
Automatic operation

Continuous Control

Measure
Compare
Decide
Act

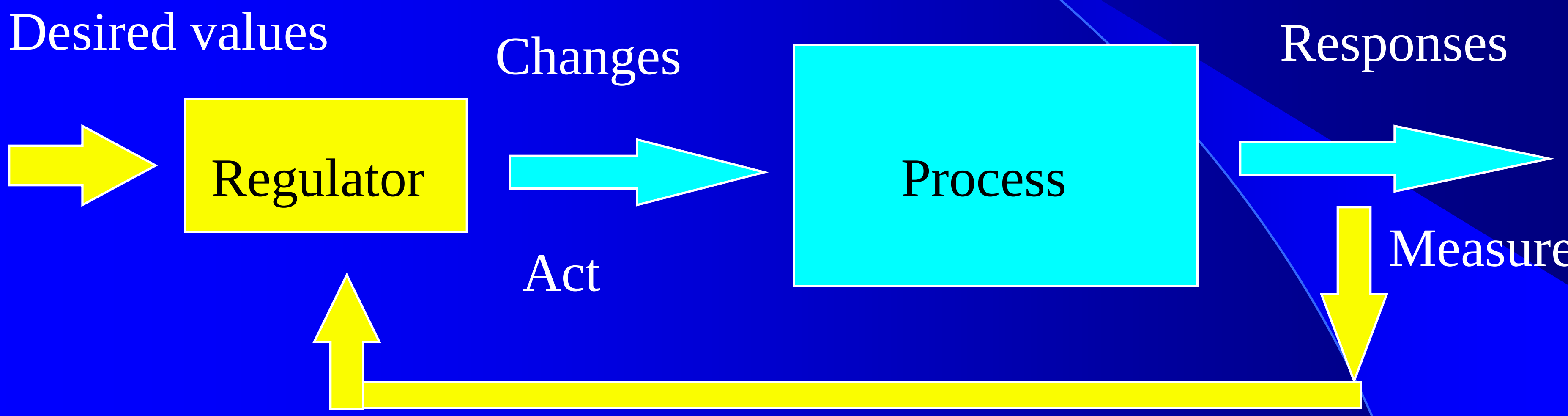


On/Off Control



Variables take a discrete number of values or states and change only at certain time instants

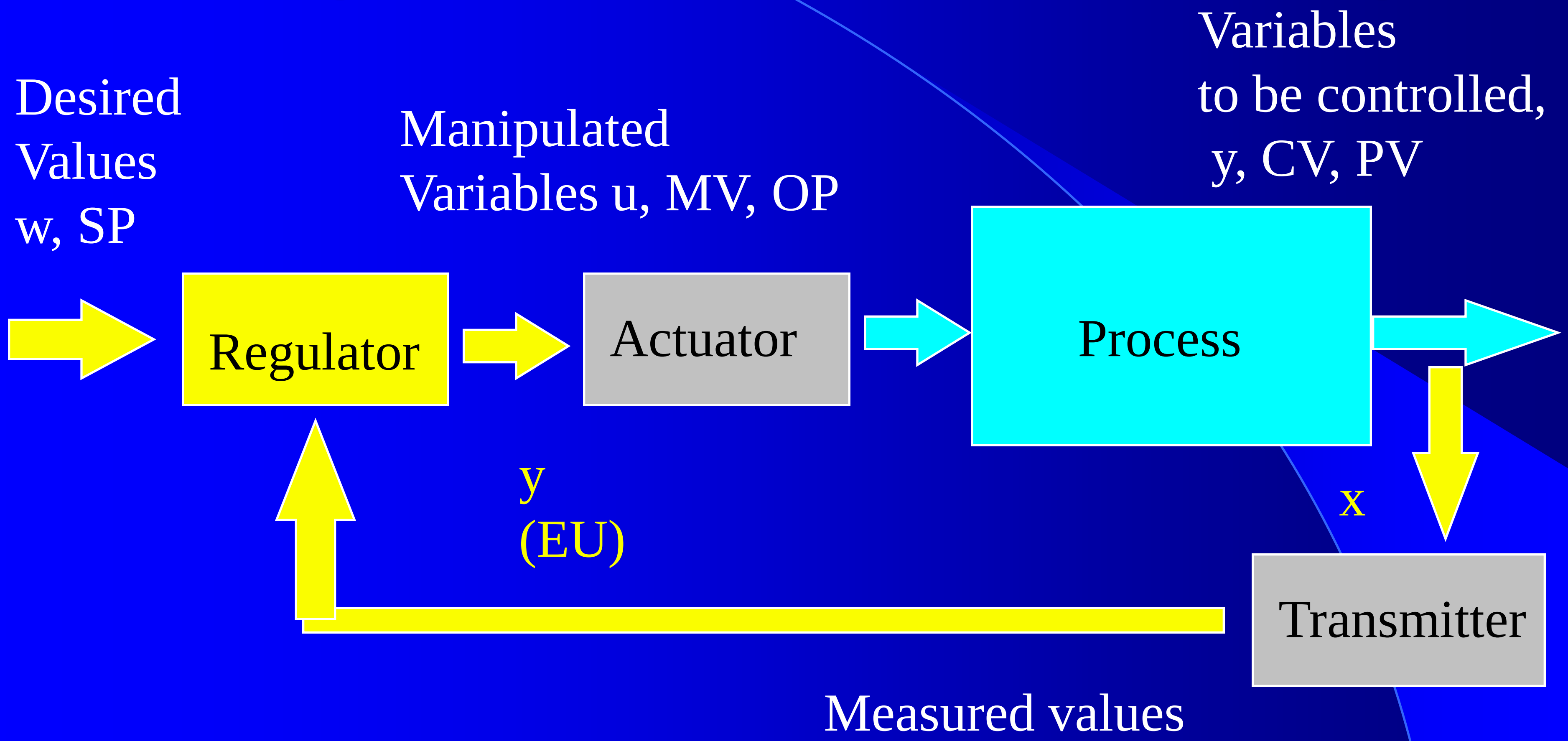
Automatic operation



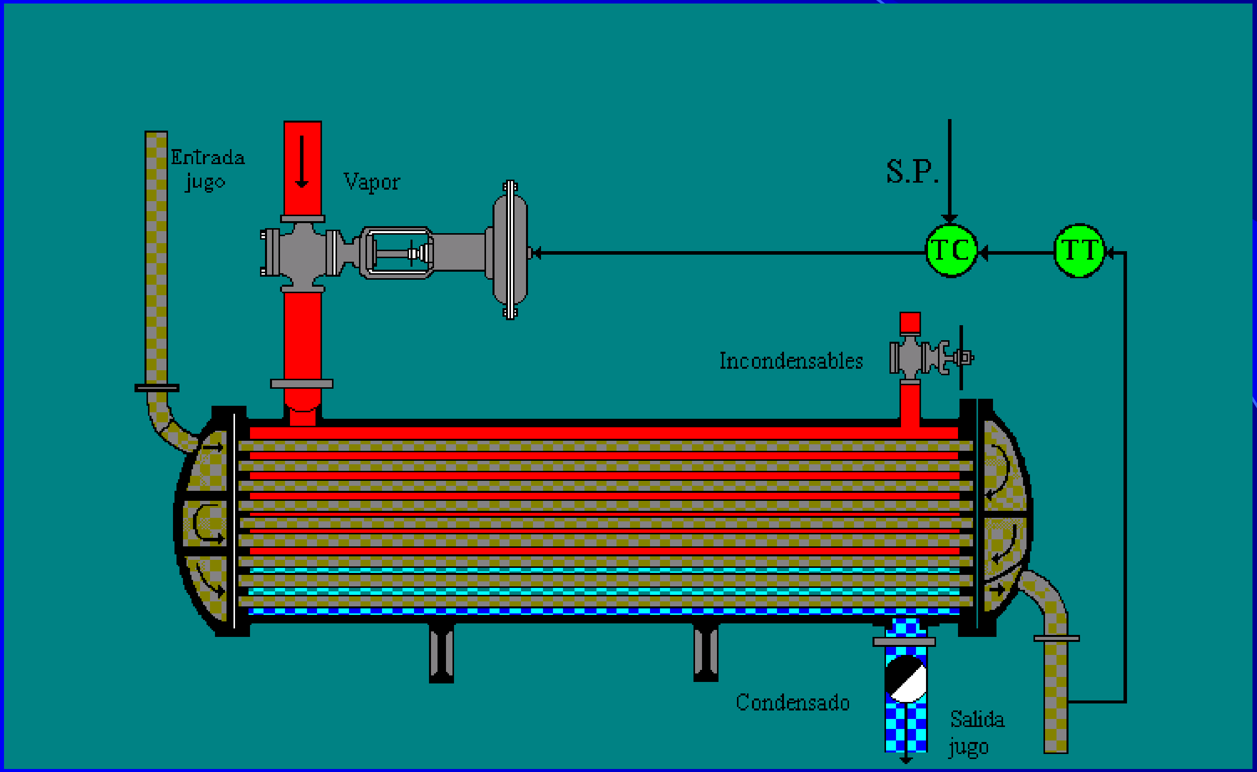
Closed loop operation

Block diagram

Components of a Control loop



Temperature Control



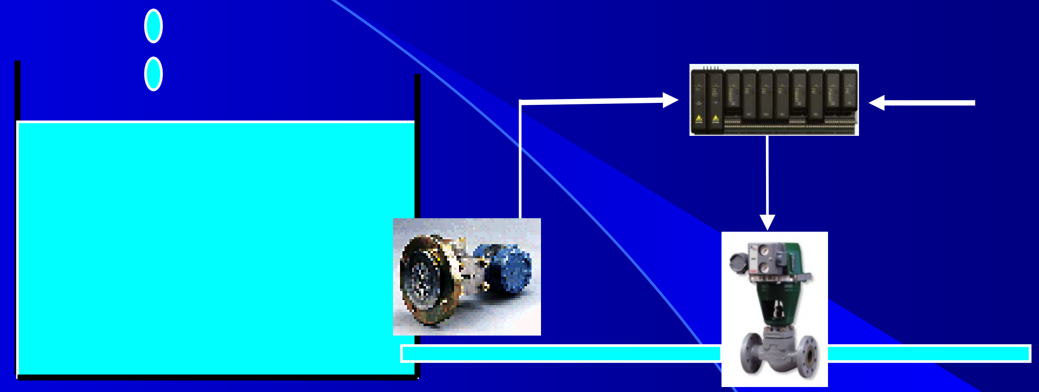
We will focus on continuous control

Index: Instrumentation

- Control Systems: Terminology
- Continuous / Discrete Control
- Transmiters
  - Definitions
  - Level, Pressure, Flow, Temperature...
- Actuators:
  - Valves
  - Pumps, compressors

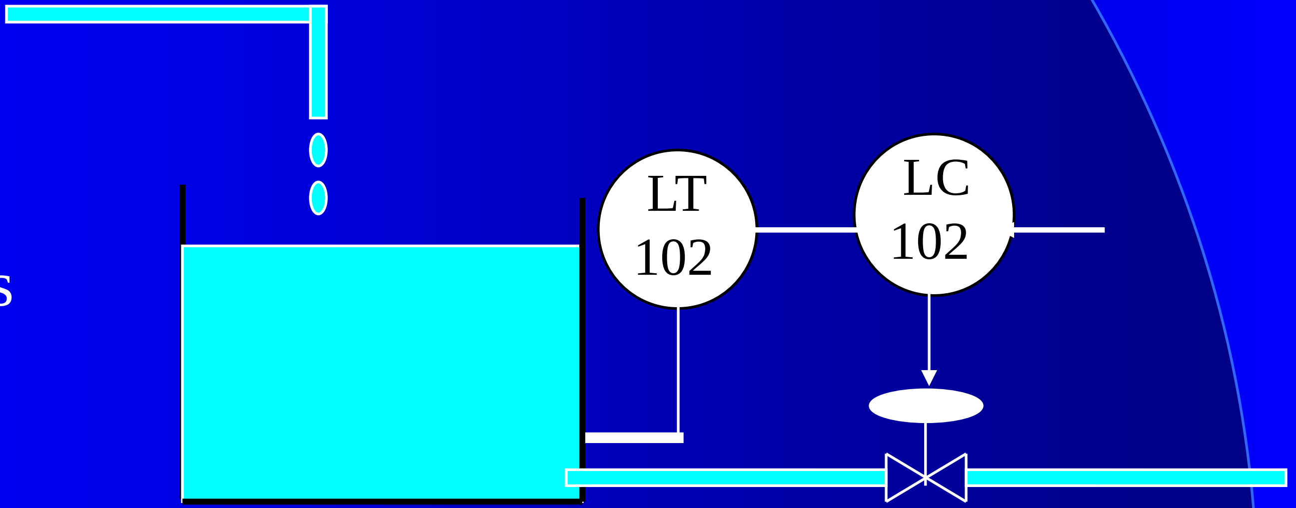
P&I Diagrams

Schematics where process units and instruments are represented using special symbols



Control and measurement instruments are represented by circles with letters and figures

Connection lines

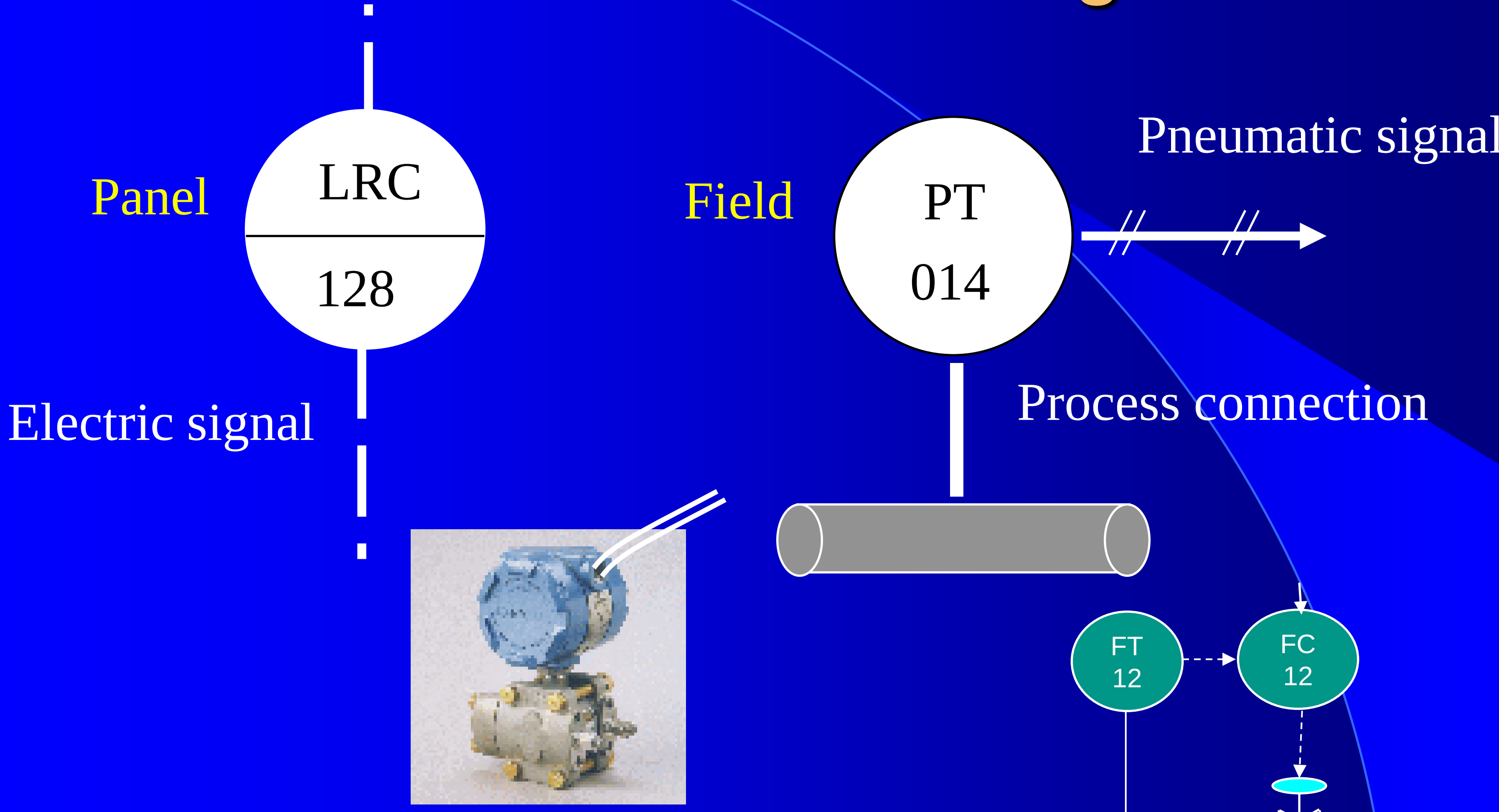


Instruments

- Indicators
- Transmitters
- Registers
- Converters
- Controllers
- Actuators
- Transducers

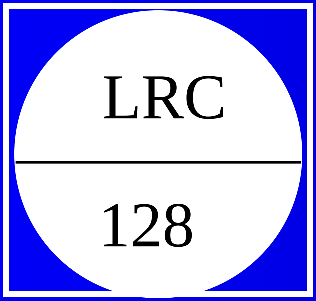
Connected by :
- Pneumatic
- Electric
- Digital
  lines

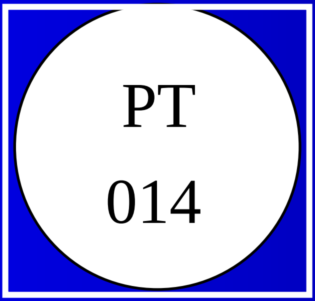
Instruments in P&I Diagrams



Same number in all instruments of a control loop

Digital Instruments

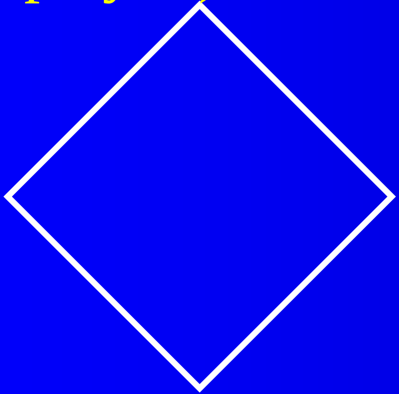


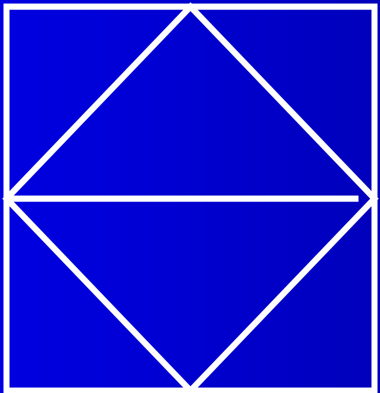


DCS controller, microprocessor,...

Accessible to the operator (Configuration, display…)

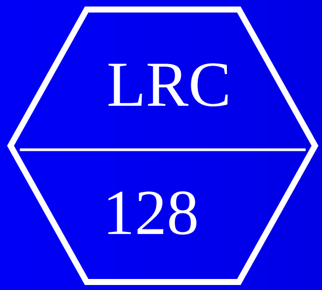
Not accessible to the operator





PLC, logic or secuential control represented by rhombus

Digital Instruments



Computer
Different from a DCS controller
Several functions: DDC, register, alarms,etc.
Access by network

Software or digital network connection

1ª letter

A	analysis
D	density
E	voltage
F	flow
I	current
J	power
L	level
M	moisture
P	pressure
S	speed
T	temperature
V	viscosity
W	weight
Z	position

1ª letter: measured variable

2ª letter: may qualify the first one

- D differential
- F proportion
- S safety
- Q integration

3ª y sig: Function of the Instrument

- I indicator
- R register
  - C control
  - T transmitter
  - V valve
  - Y computation
    - H high
    - L low

Instruments

PDT

LRC

PIC

DT

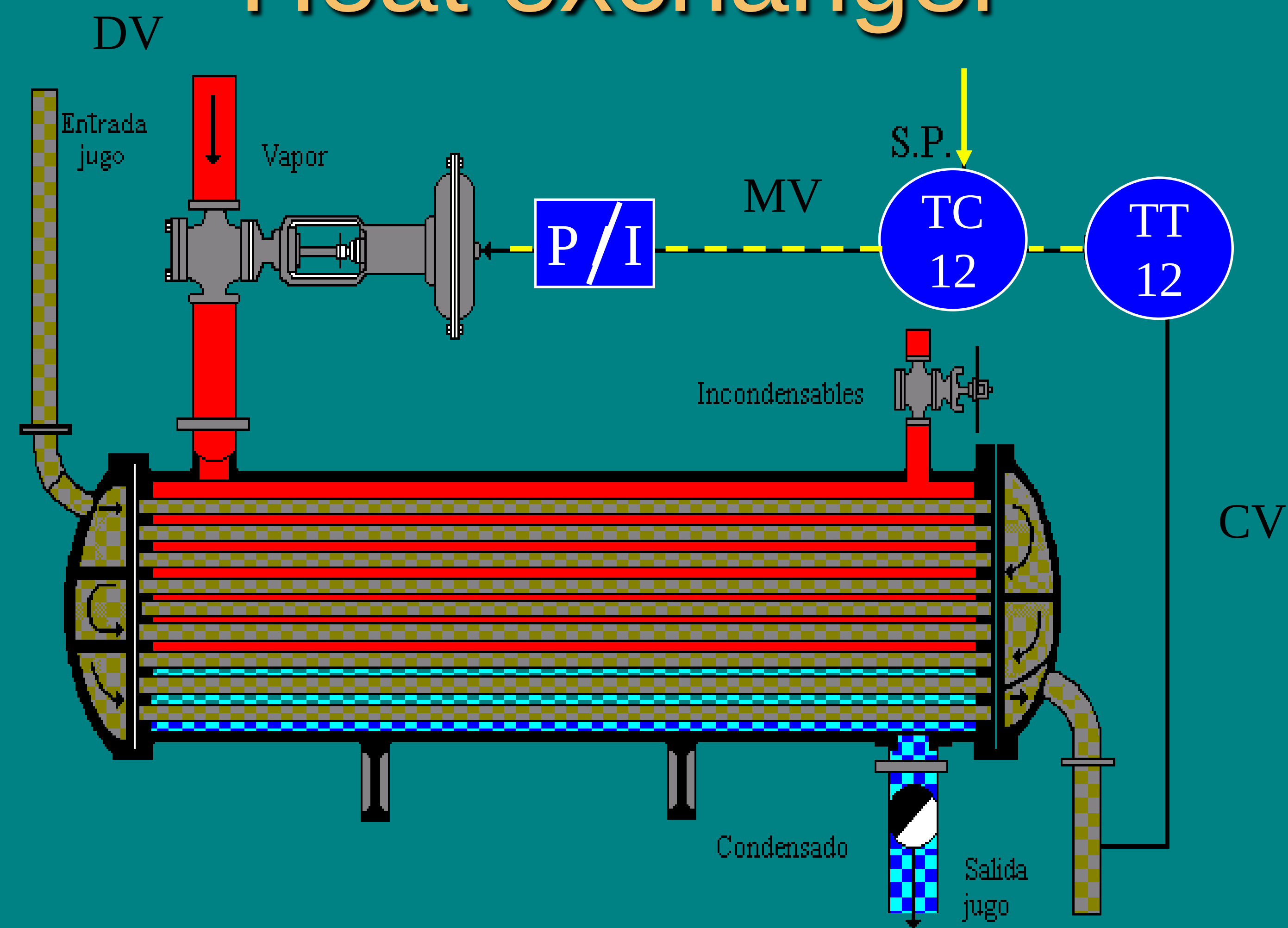
FY

FFC

ST

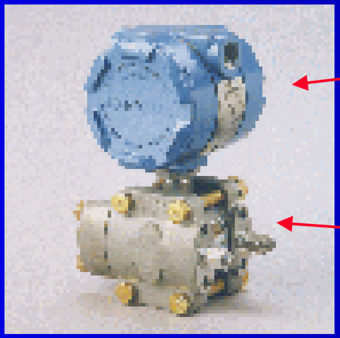
TDT

Heat exchanger

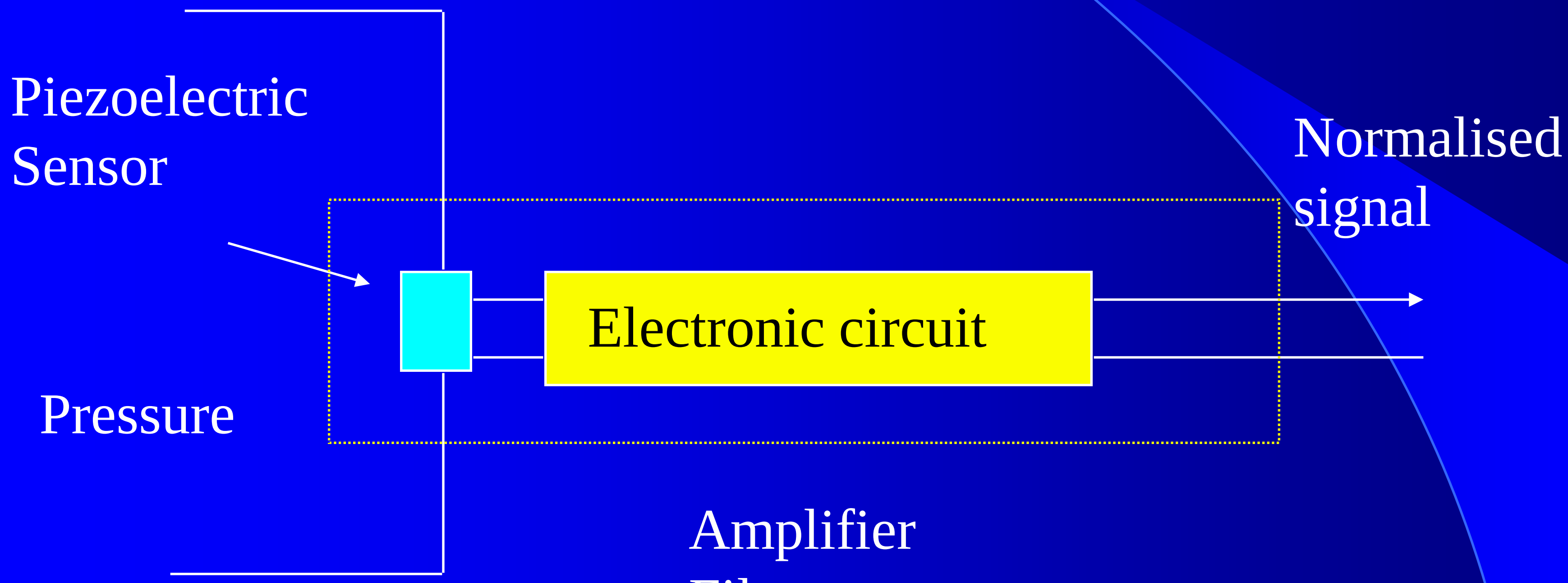


Transmitters

- Sensor: Primary element with properties sensitive to the physical variable
- Transmitter: Converts, amplifies, conditions and normalise the sensor signal in order to send it to other instruments
- Indicator: Shows the measured variable



Pressure transmitter

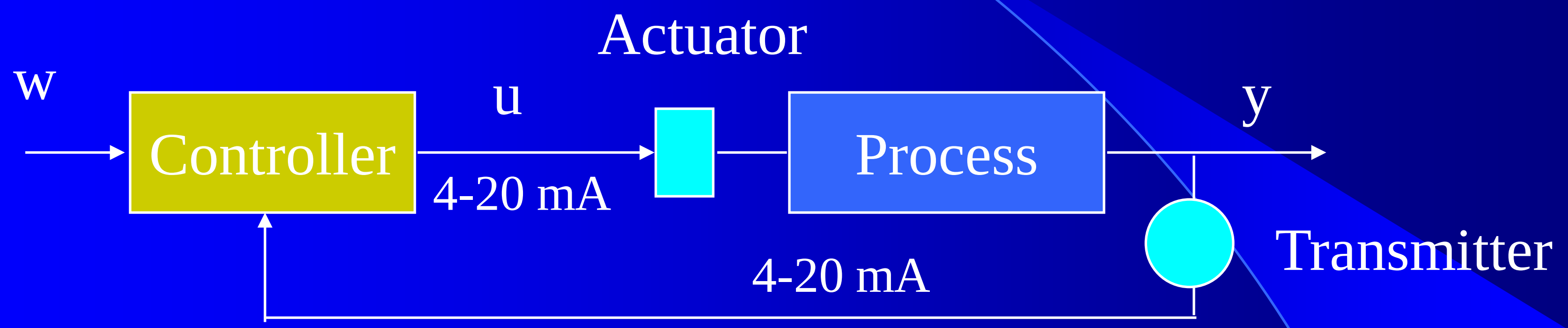


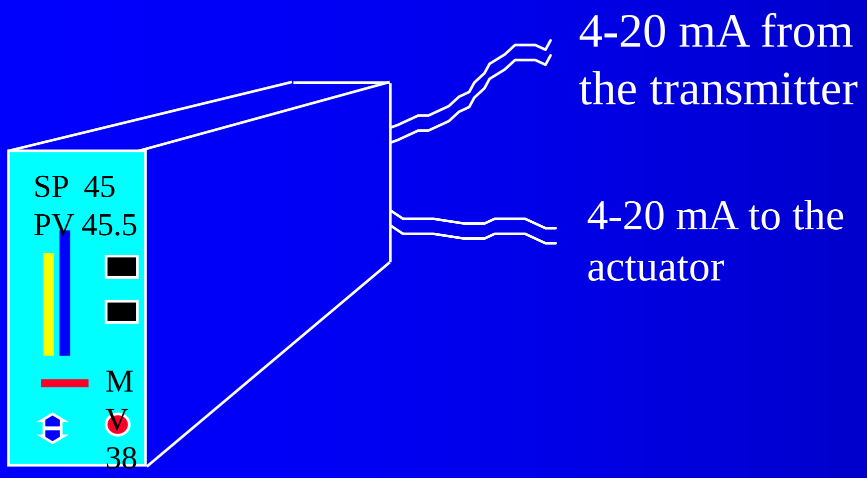
Amplifier
Filter
Calibration
Power
Normalisation

Transmitters (Signals)

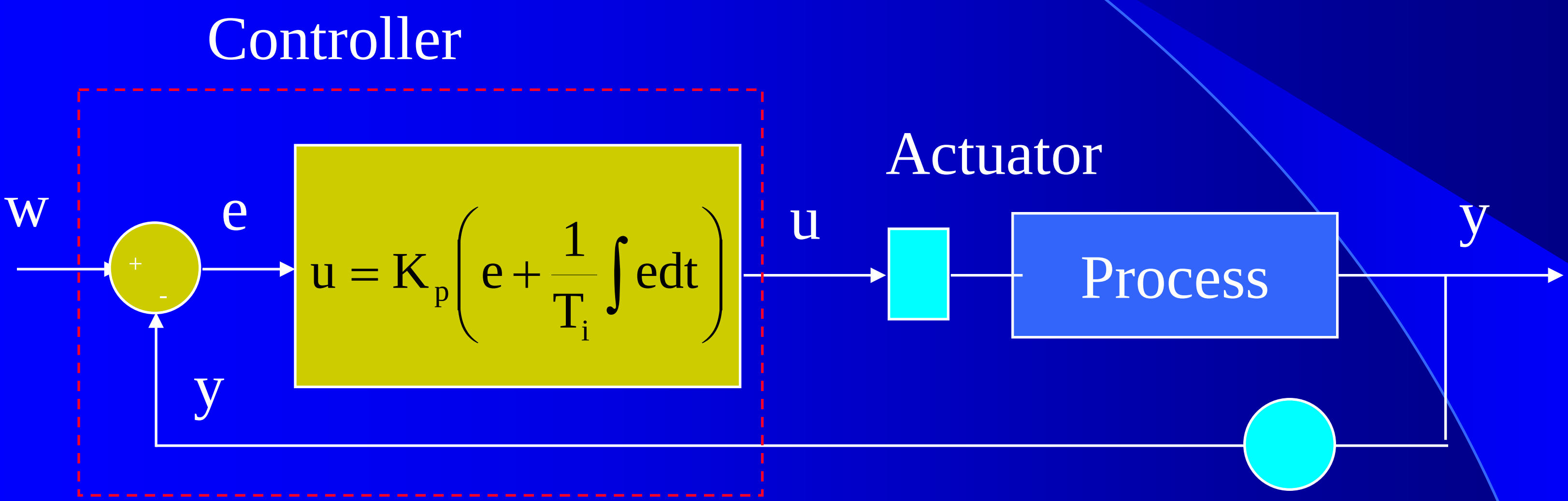
• Pneumatic:	0.2	-	1	Kg/cm^2
	3	-	15	psi
• Electric:	4	-	20	mA
	1	-	5	V cc, ...
• Frecuency:	pulses/time			
• Others:	RTD, Contacts,...			
• Digital:	HART, Fieldbus, RS-232...			

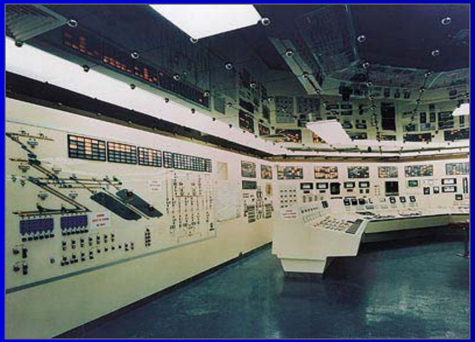
Normalised signals





Controller

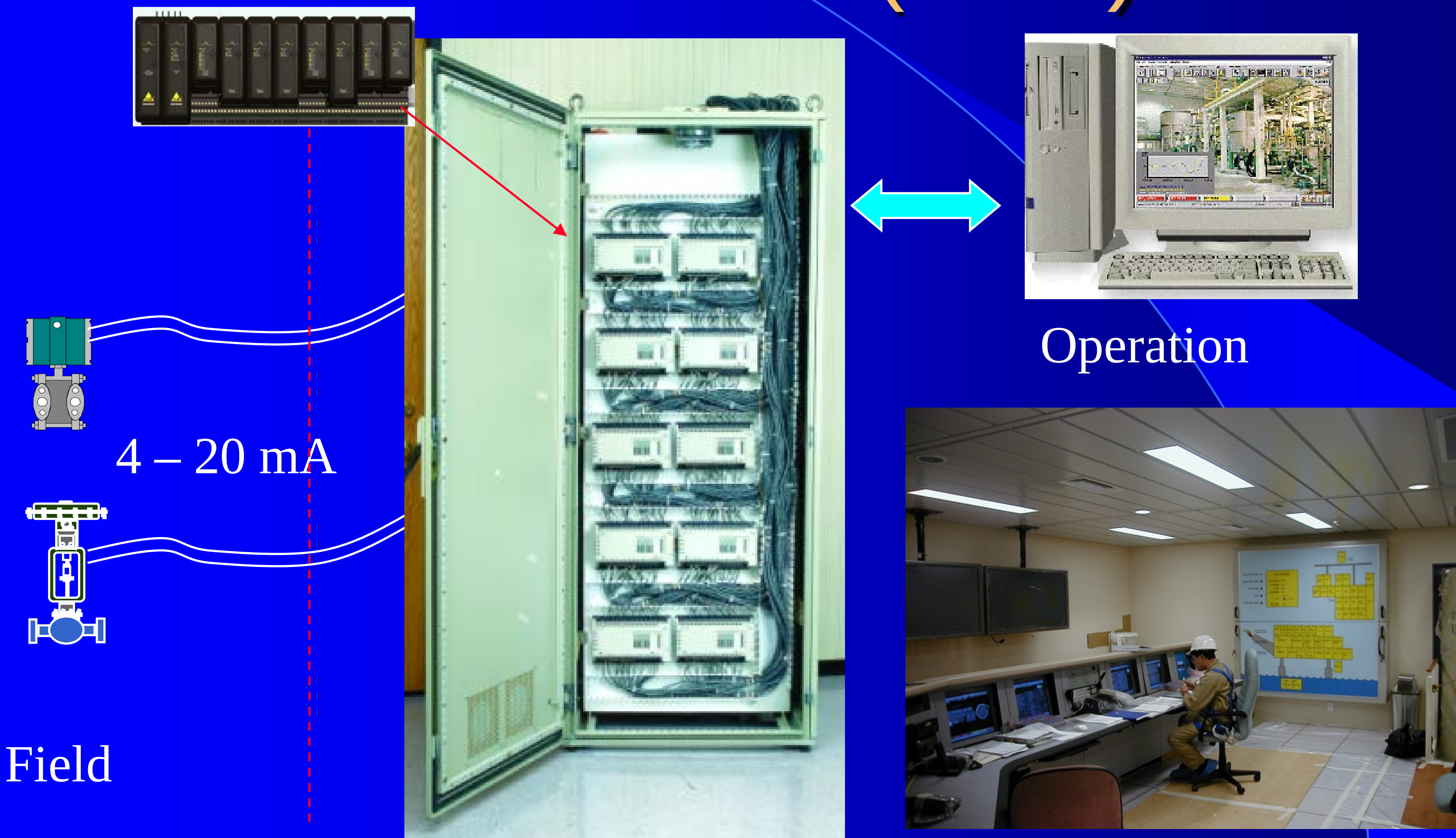




Transmitter

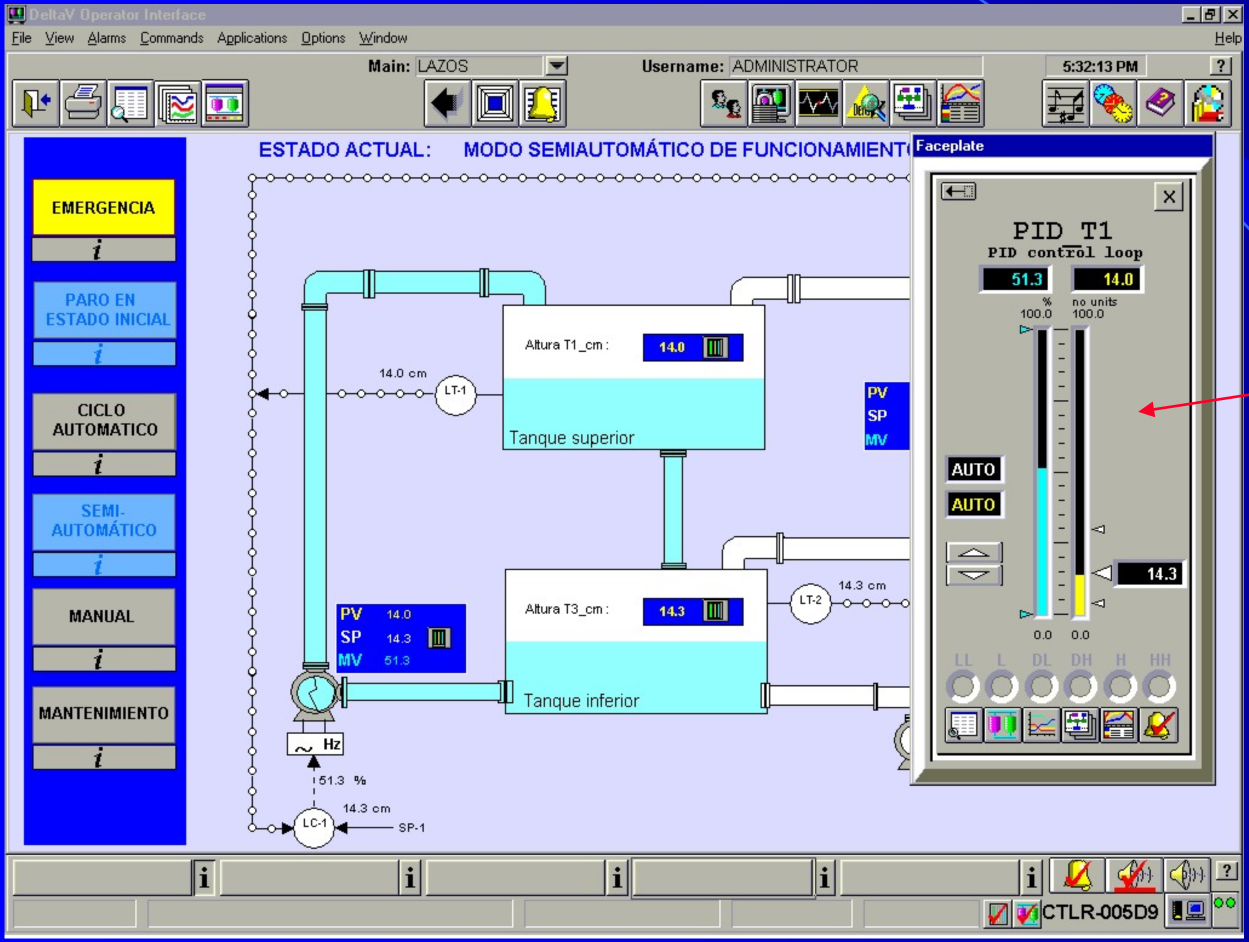
Panel mounting

Control room (DCS)



Control cabinet, Enclosure

Operation

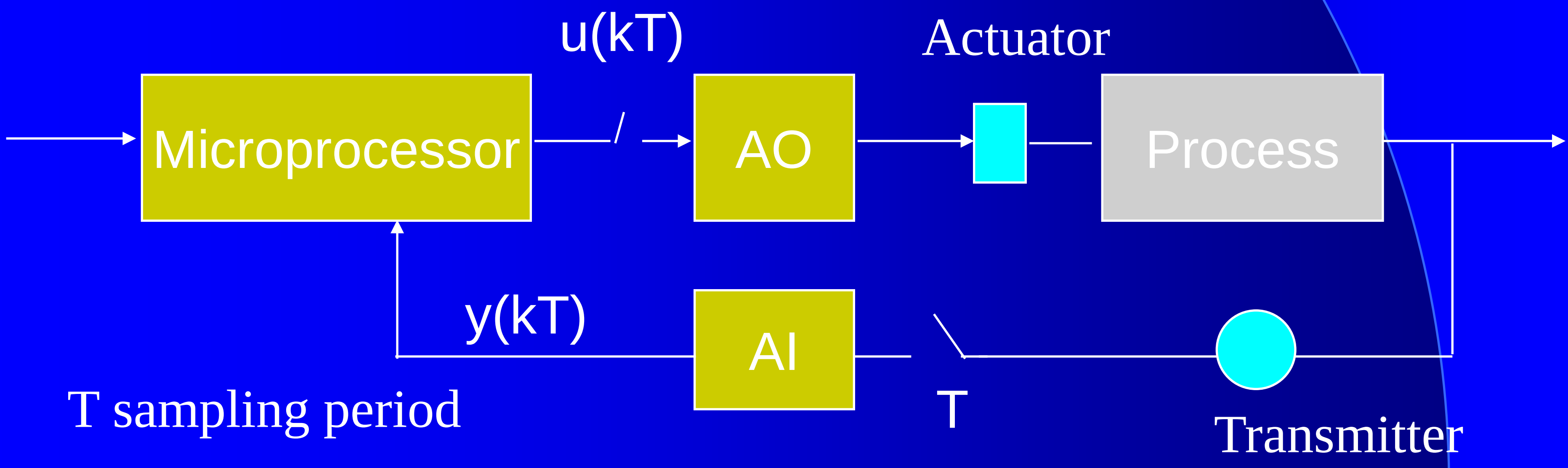


Typical PID face

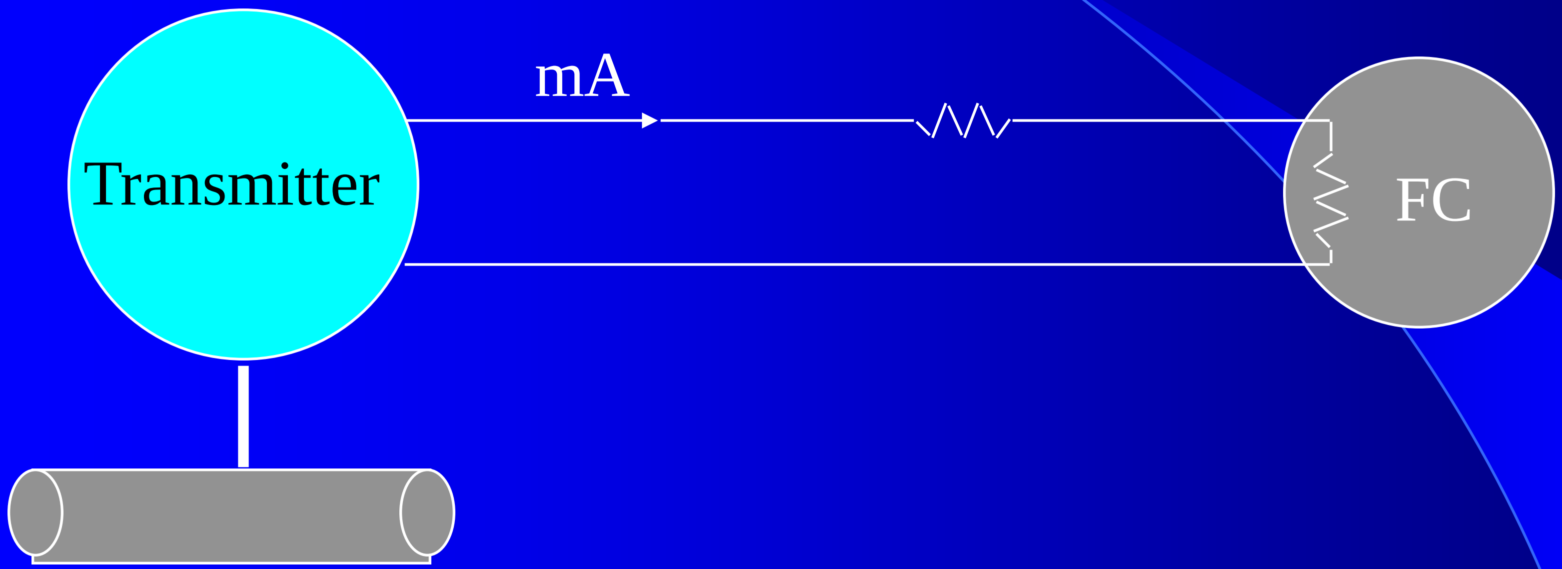
Typical operator screen

Computer control

Power supply, Ethernet AI AO Controller DI DO

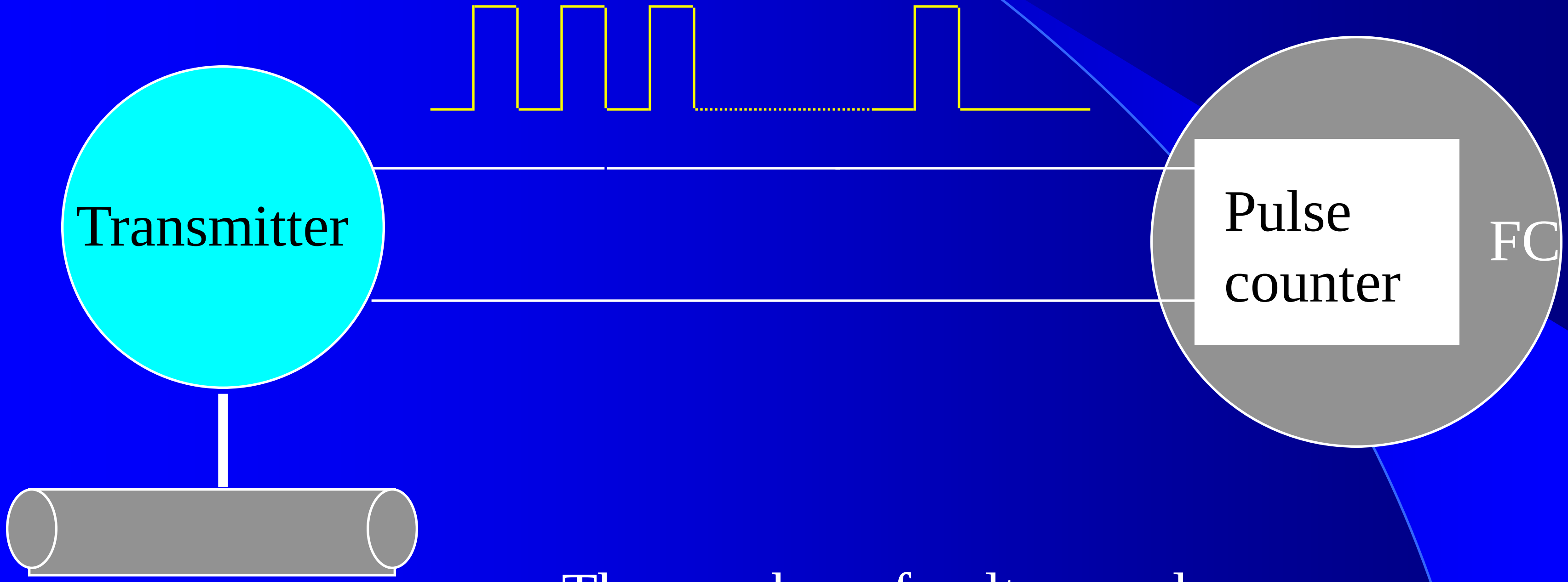


4-20 mA



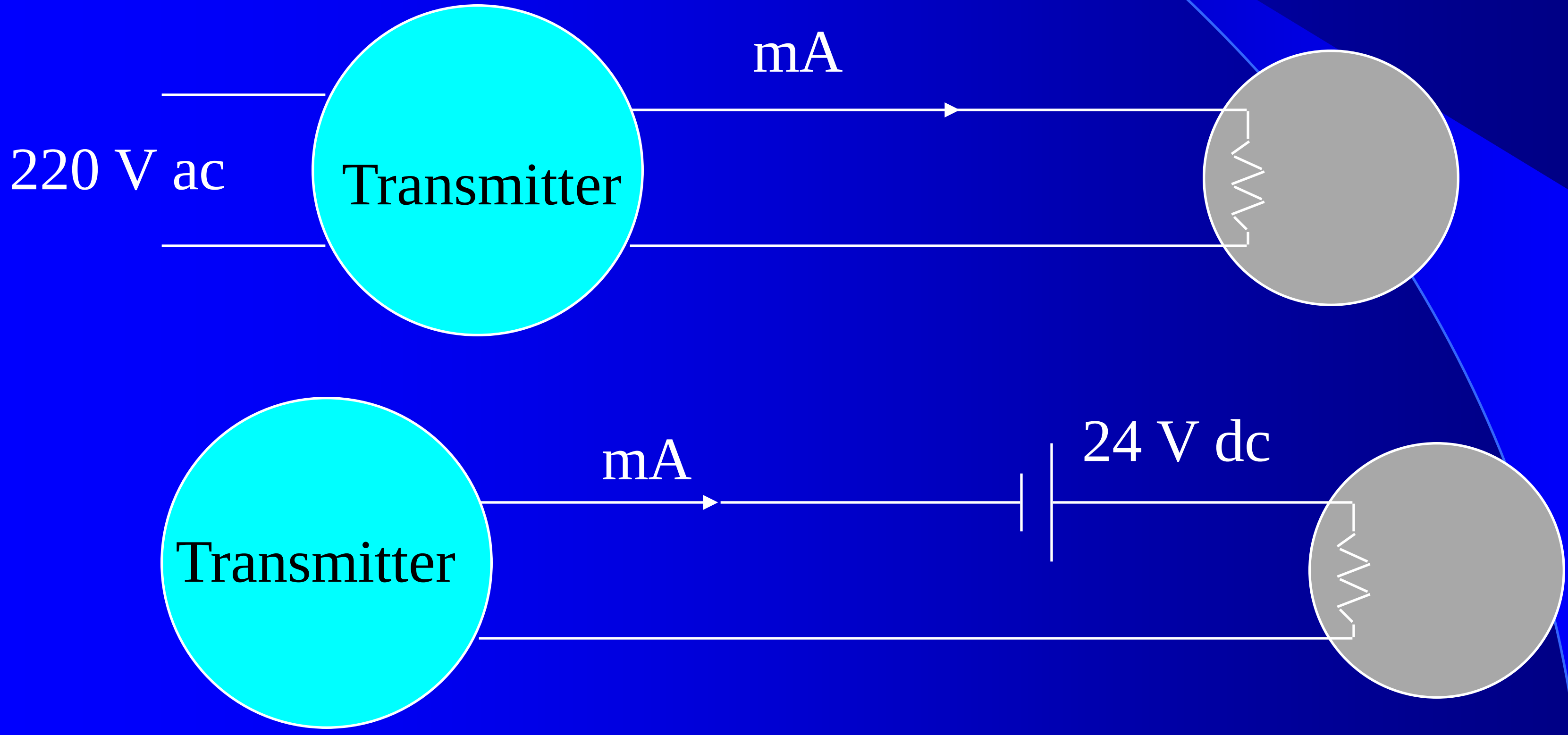
•Current is the same at any point of the line
•A broken line can be identified as different from a measurement in the bottom of the range
• A limited number of devices are allowed in the line

Pulses/Frecuency

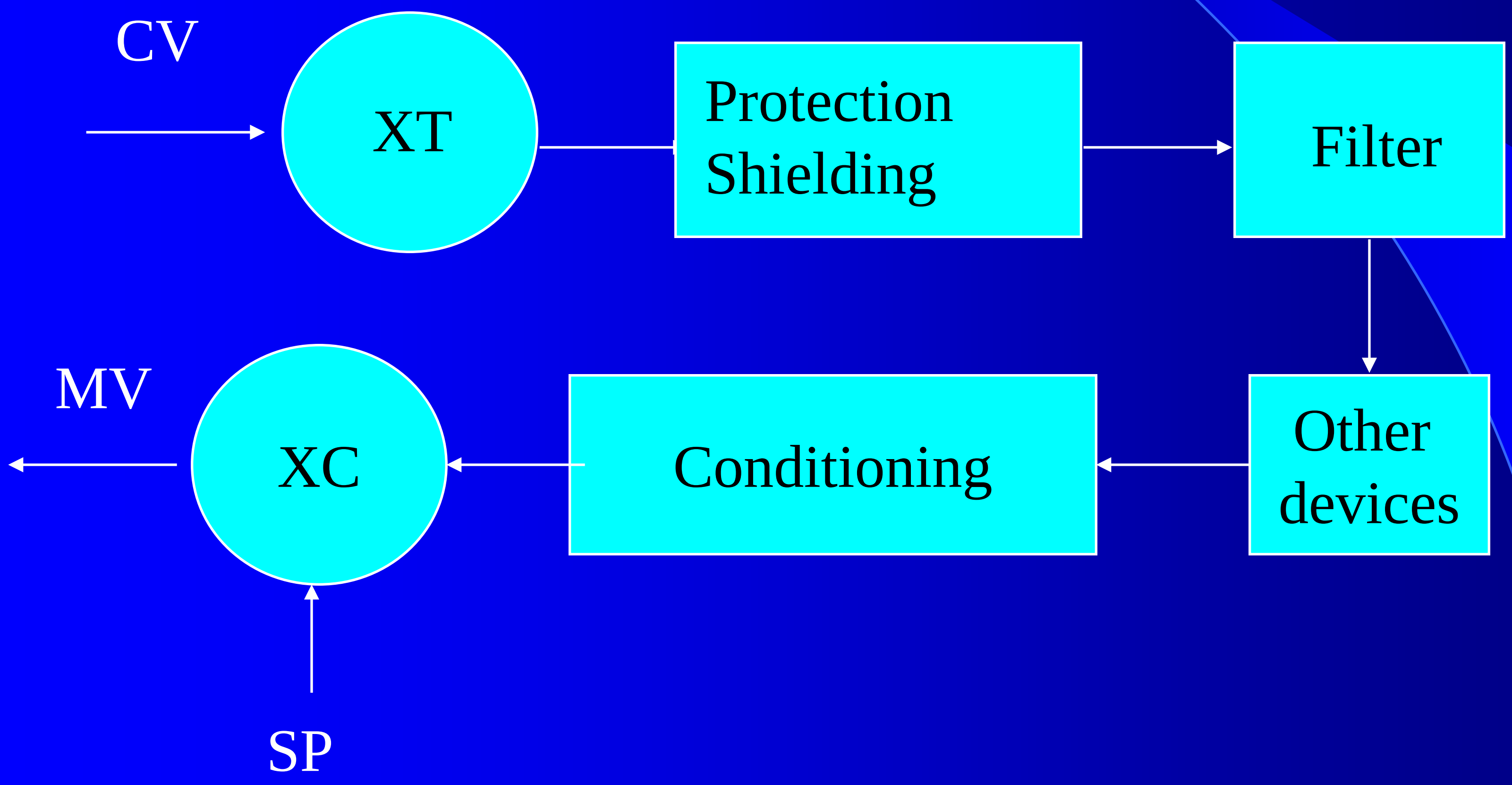


The number of voltage pulses per time unit is proportional to the value of the variable

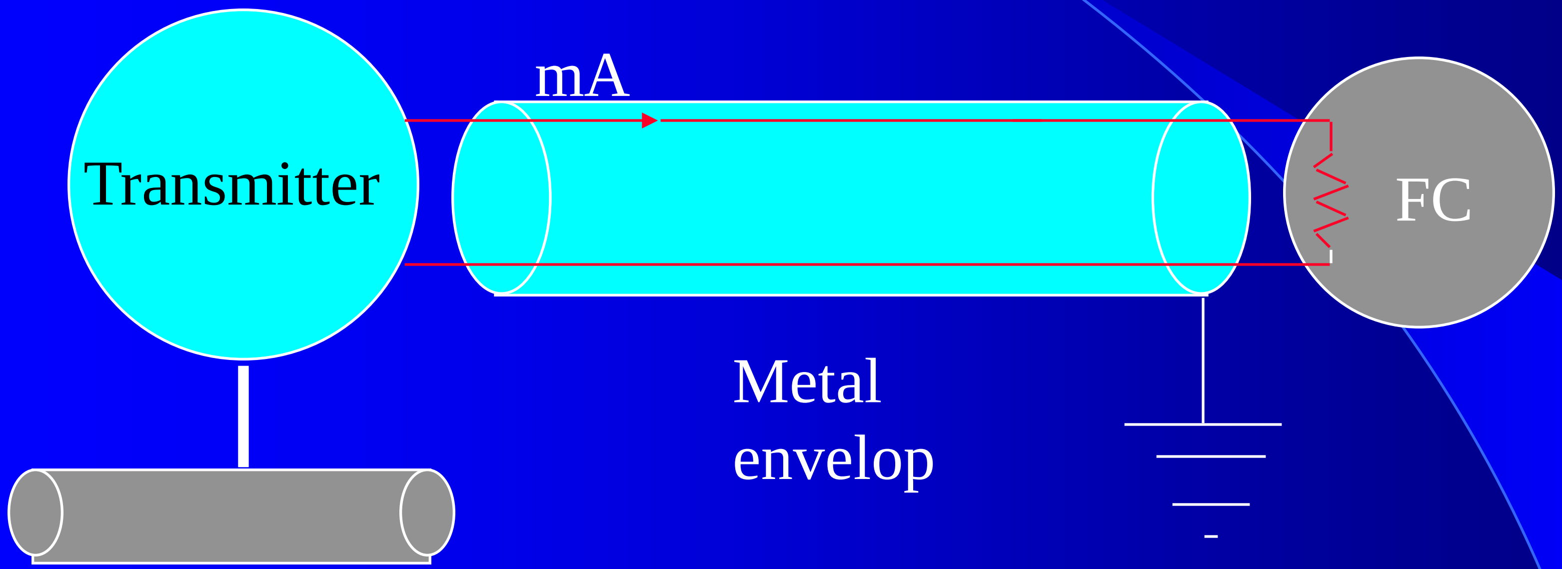
Power supply



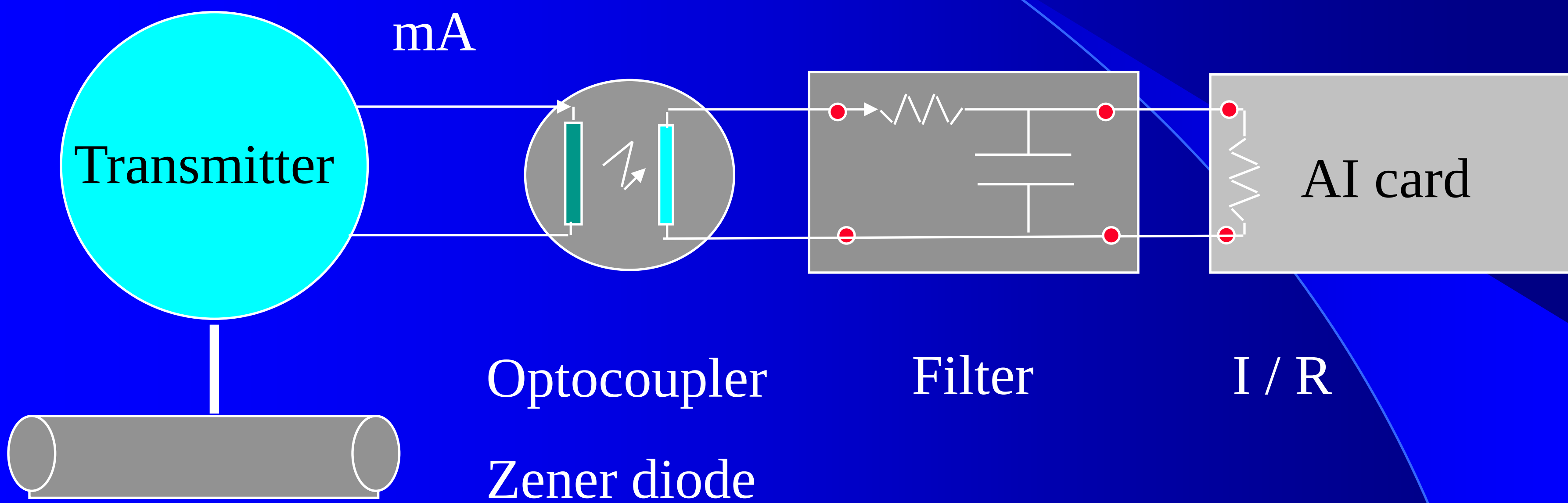
Conecting instruments



Shields



Conditioning / protecting



Optocoupler

Zener diode

Breaker

Filter

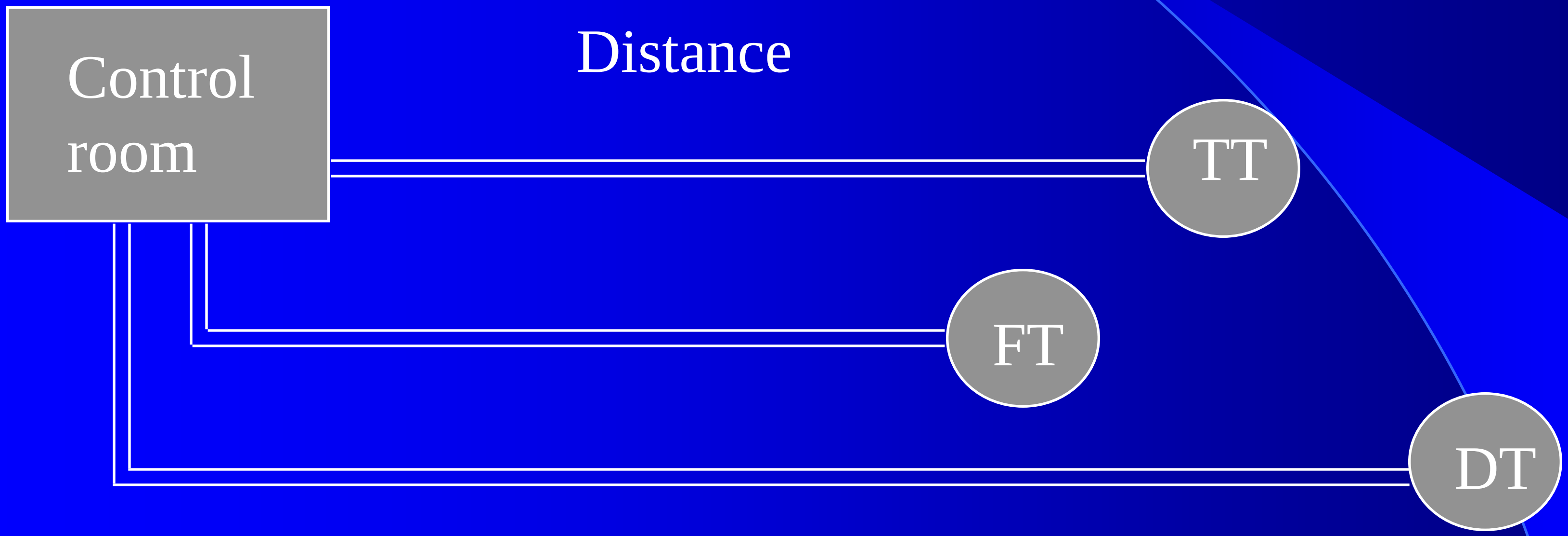
I / R

Safety

Noise

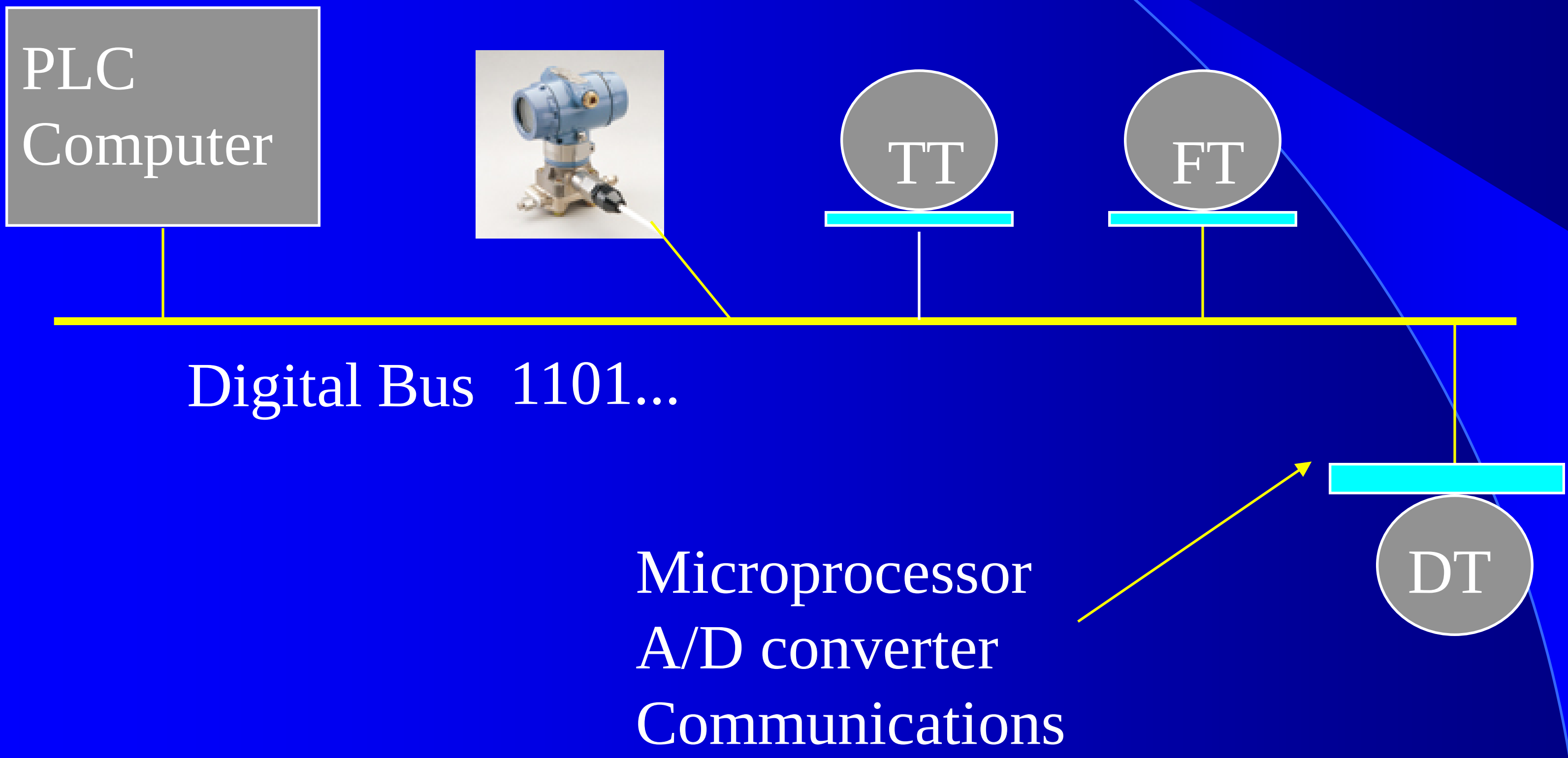
Conversion

Wiring,...

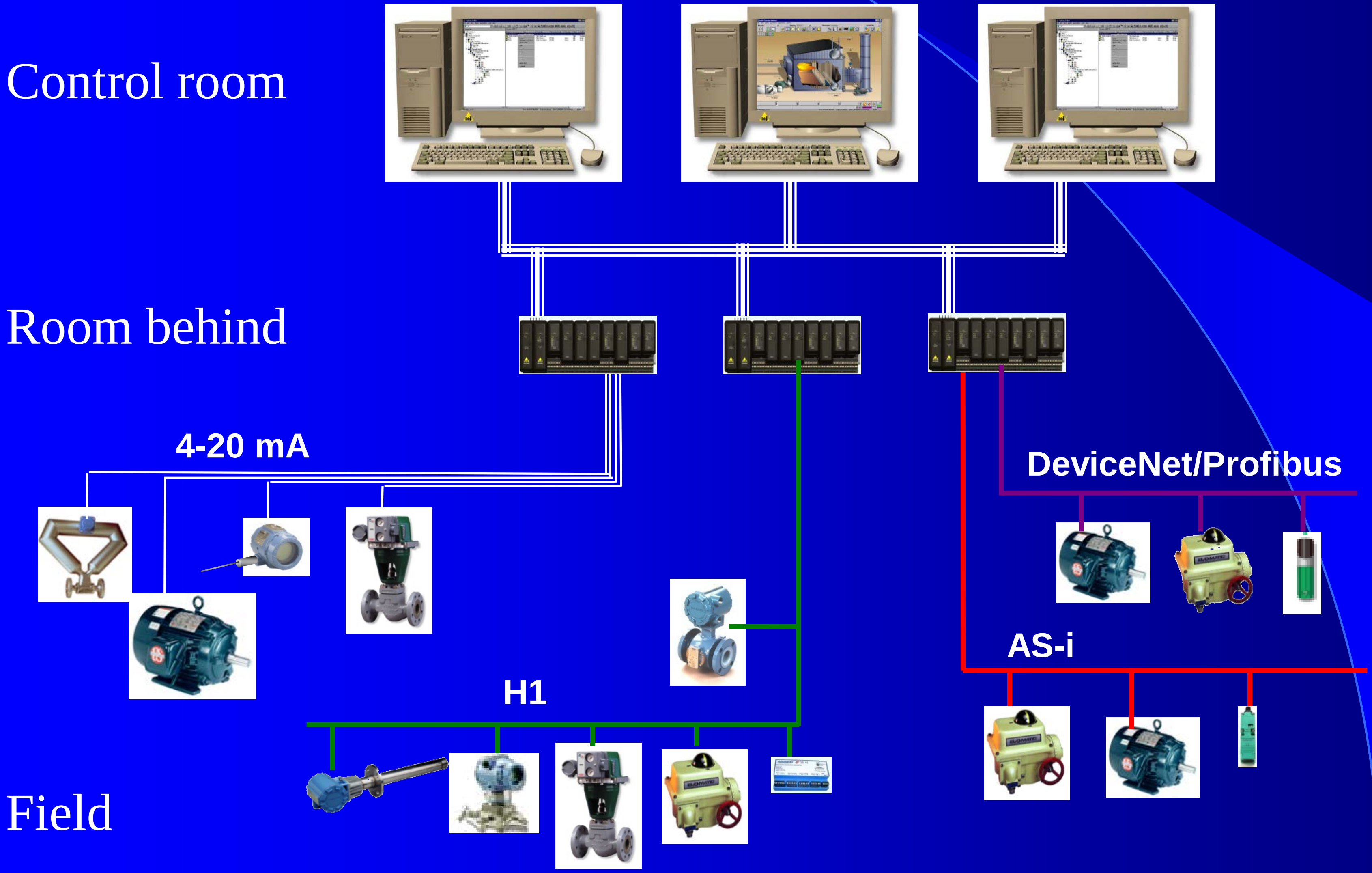


Wiring costs
Noises
Calibration
Maintenance,...

Field buses


PLC
Computer
TT
FT
Digital Bus 1101...
DT
Microprocessor
A/D converter
Communications

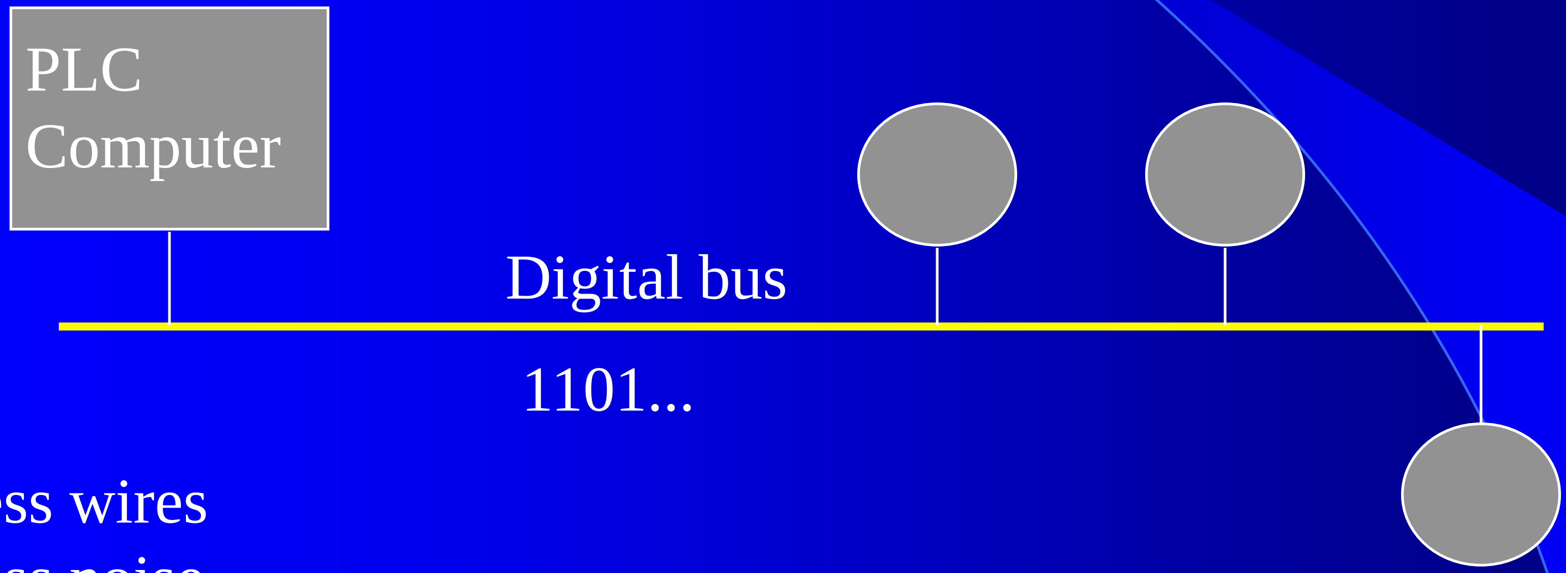
DCS


Control room
Room behind
4-20 mA
DeviceNet/Profibus
AS-i
H1
Field

Smart Instrumentation

- Incorporates a microprocessor and digital communications
- This provides computer power and data storage capability:
  - Data of the instrument
  - Dynamic data
- It is based in a two-way digital communication system
- Gives new functionalities

Fieldbus



- Less wires
- Less noise
- New functions: range adjustment, self-test, documentation,....
- Better information
- Different architectures and protocols

Fieldbuses

- Fieldbus Foundation (H1 and H2 levels)
- Profibus DP, PA
- WorldFIP
- CAN
- DeviceNet
- .....

Networks- Fieldbus

Process Control

Type of Control

Logic Control

Sensor Busses

- **AS-i**
- **LonWorks**
- **Seriplex**

Device Busses

- **CAN**
- **ControlNet**
- **DeviceNet**
- **LonWorks**
- **Profibus DP**
- **Interbus**

FIELDBUS

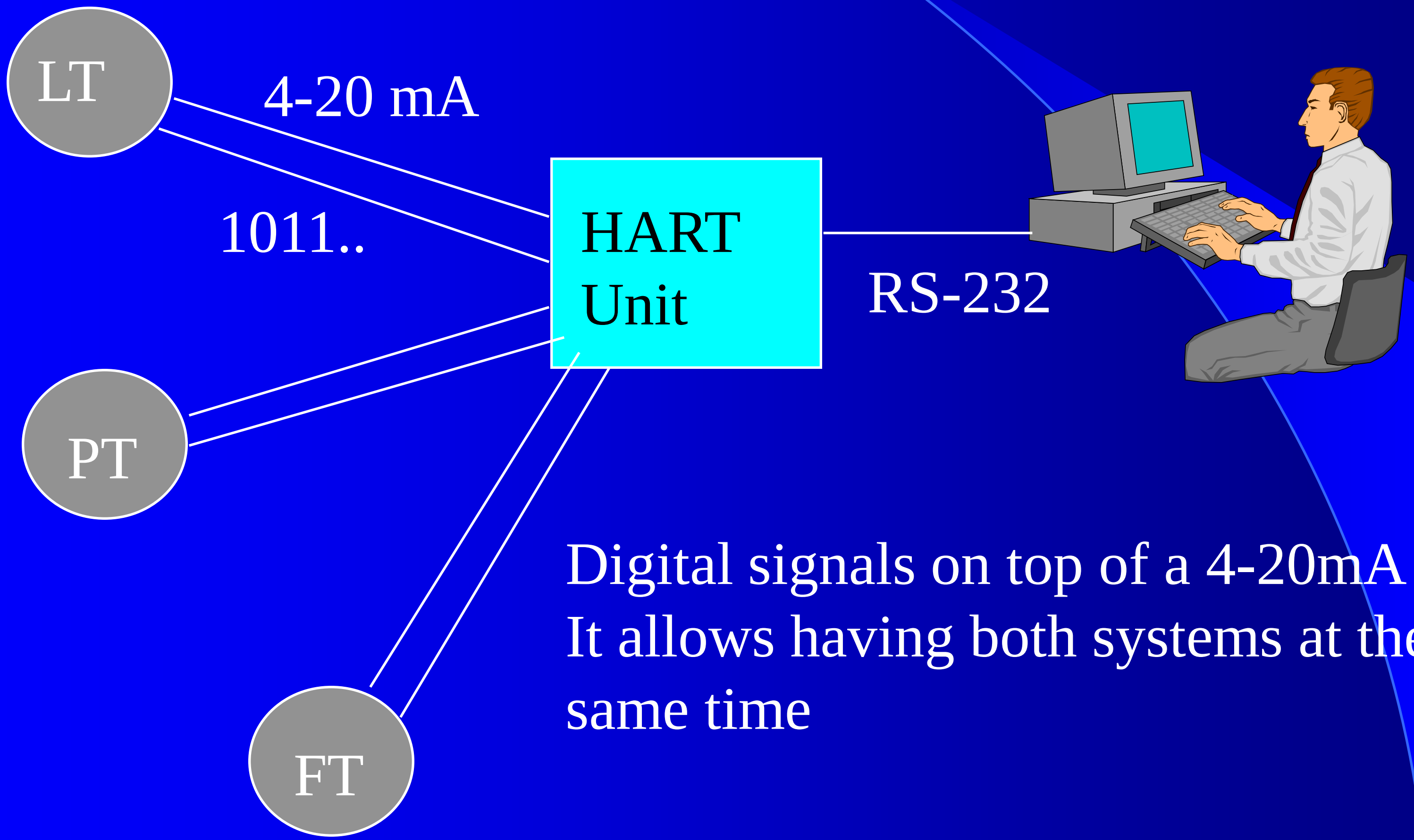
- **Foundation Fieldbus**
- **WorldFIP**
- **Profibus PA**

Simple Devices

Powerful Devices

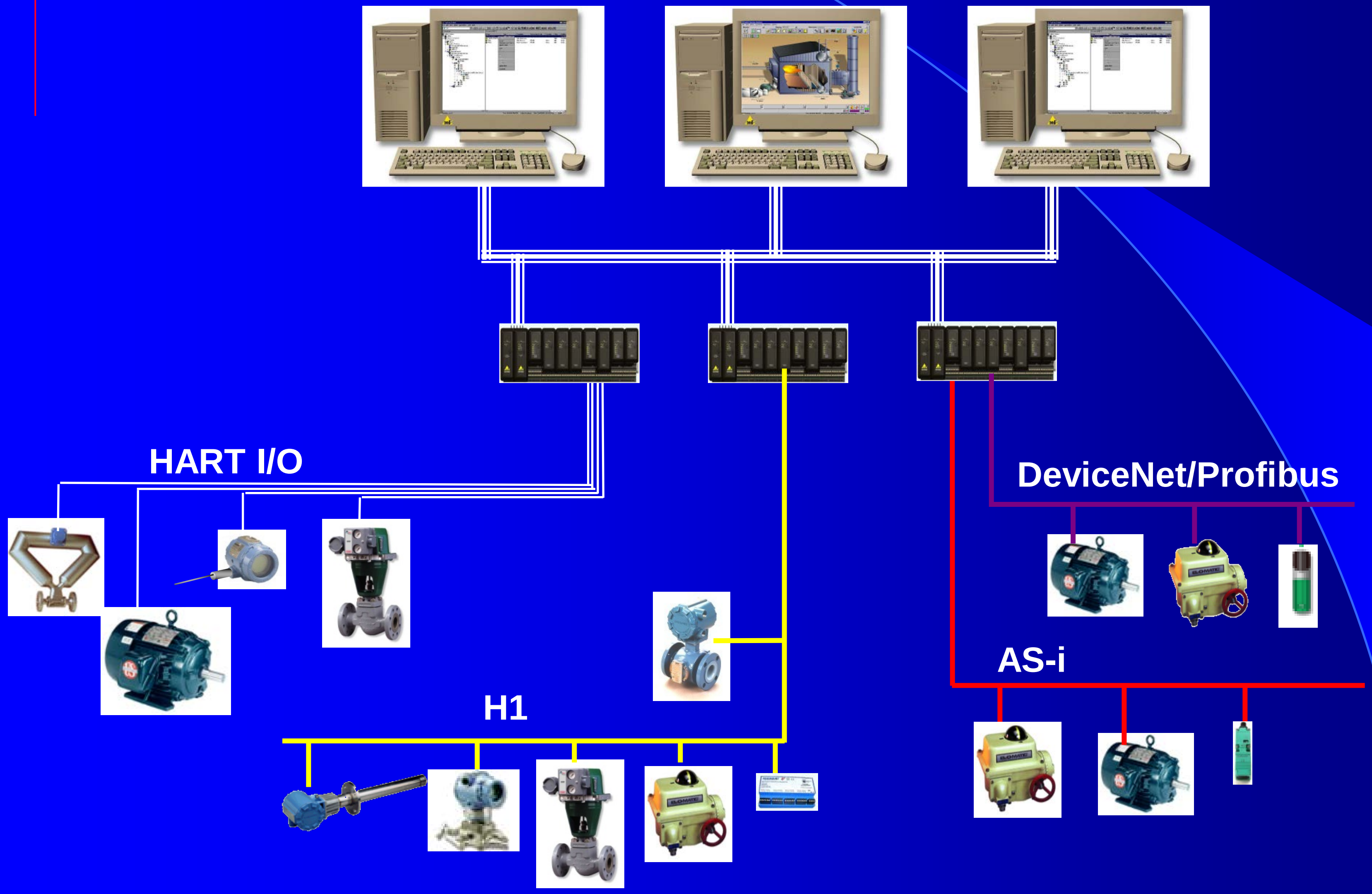
Device Functionality / Cost

HART

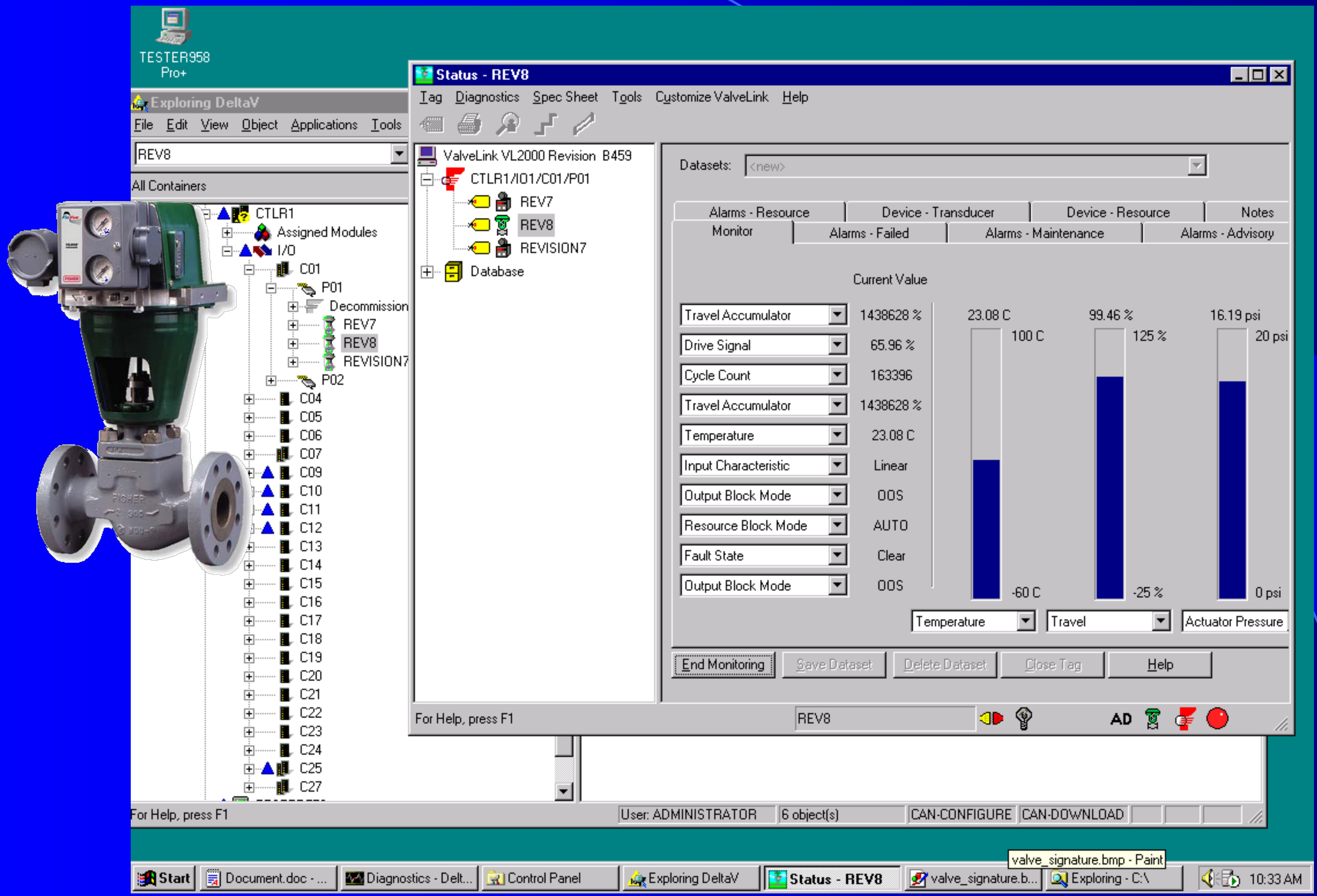


Digital signals on top of a 4-20mA line
It allows having both systems at the same time

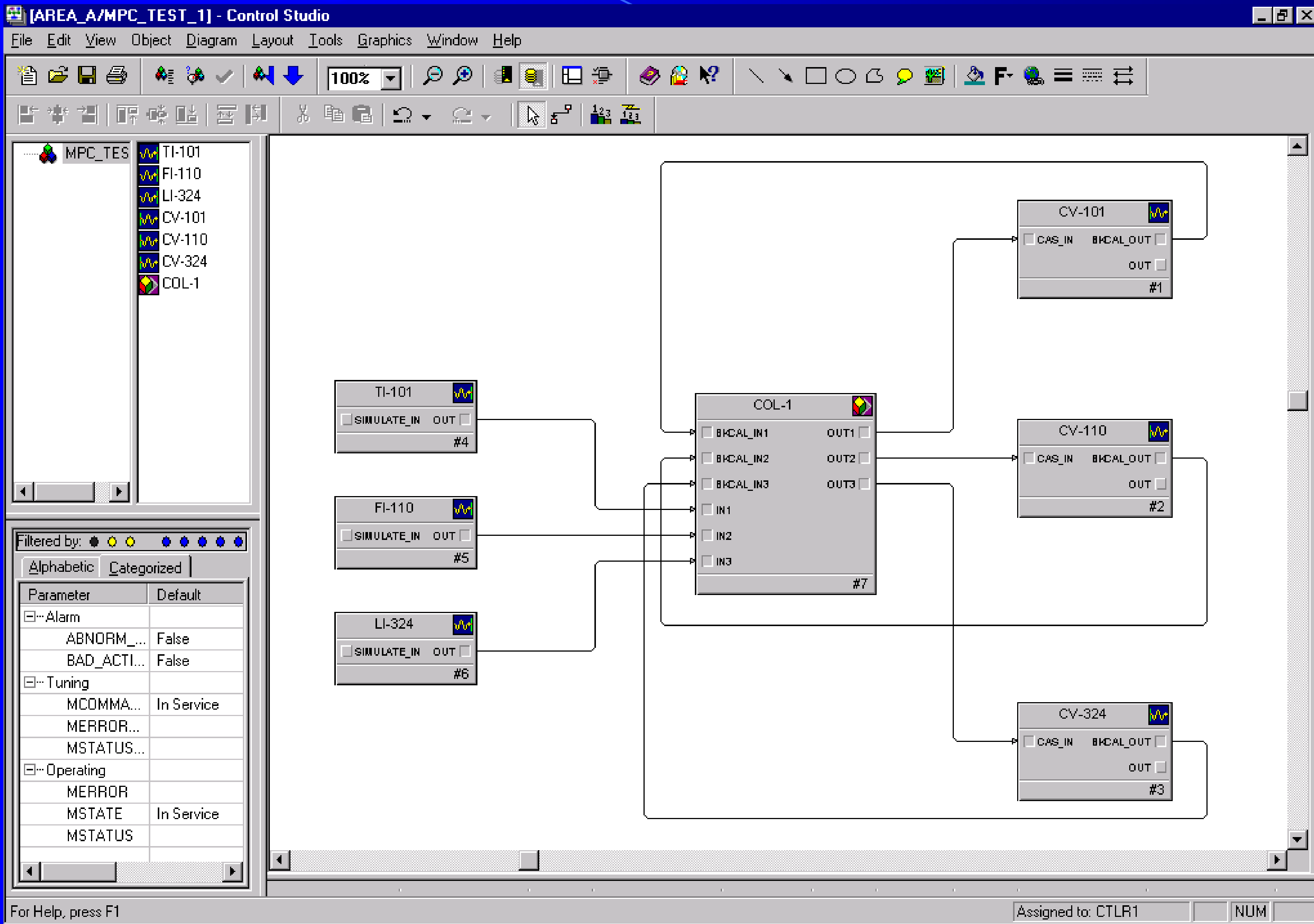
Architectures



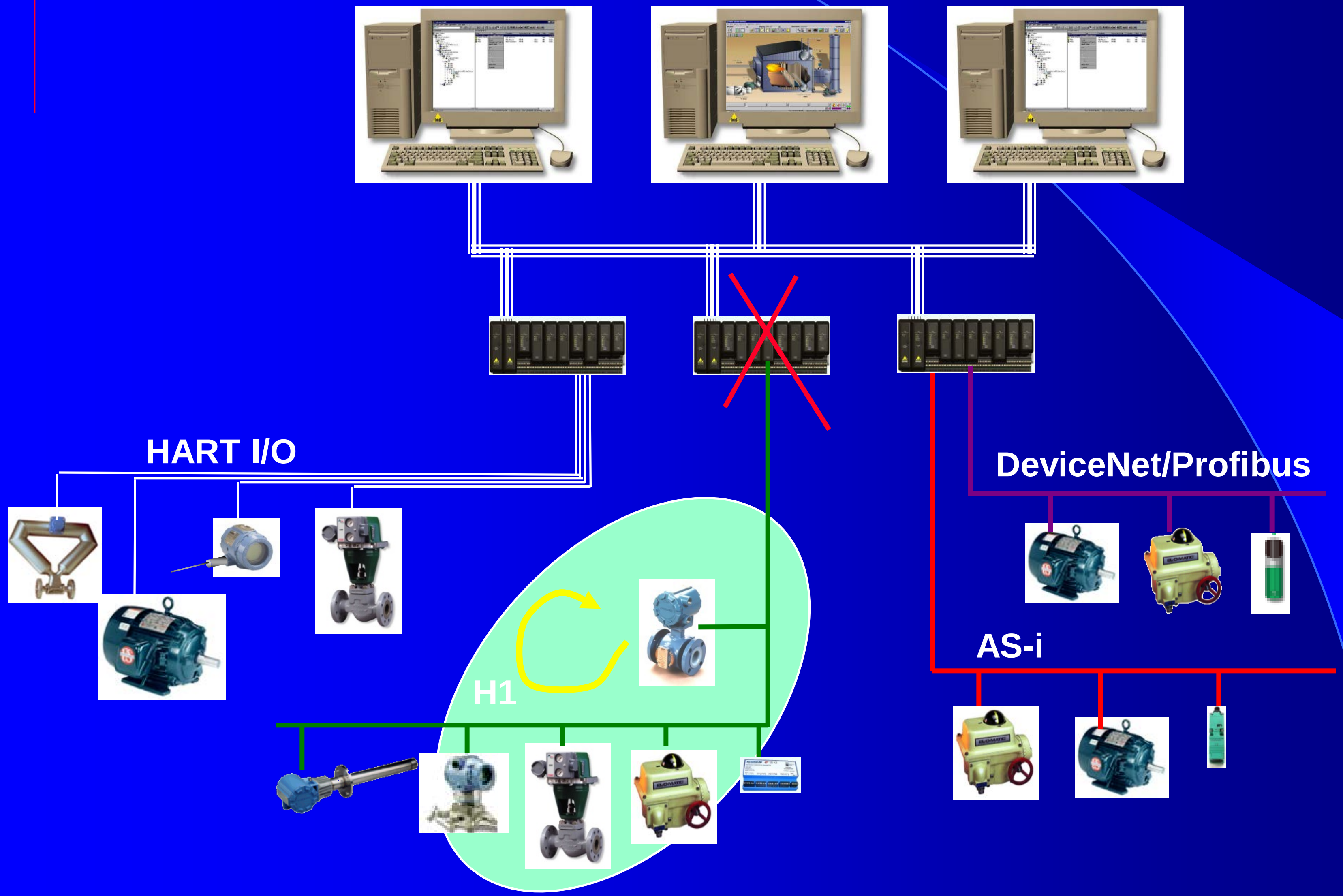
Diagnosis, configuration



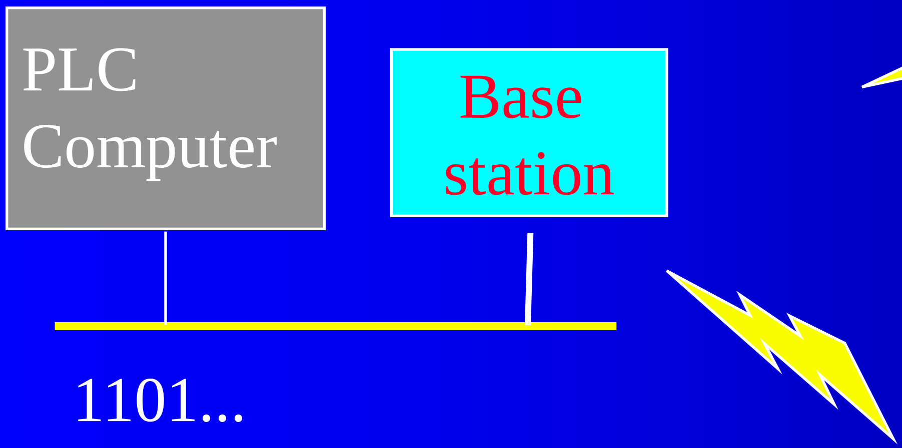
Configuration⇒Download



Control in the instruments



Wireless Instrumentation

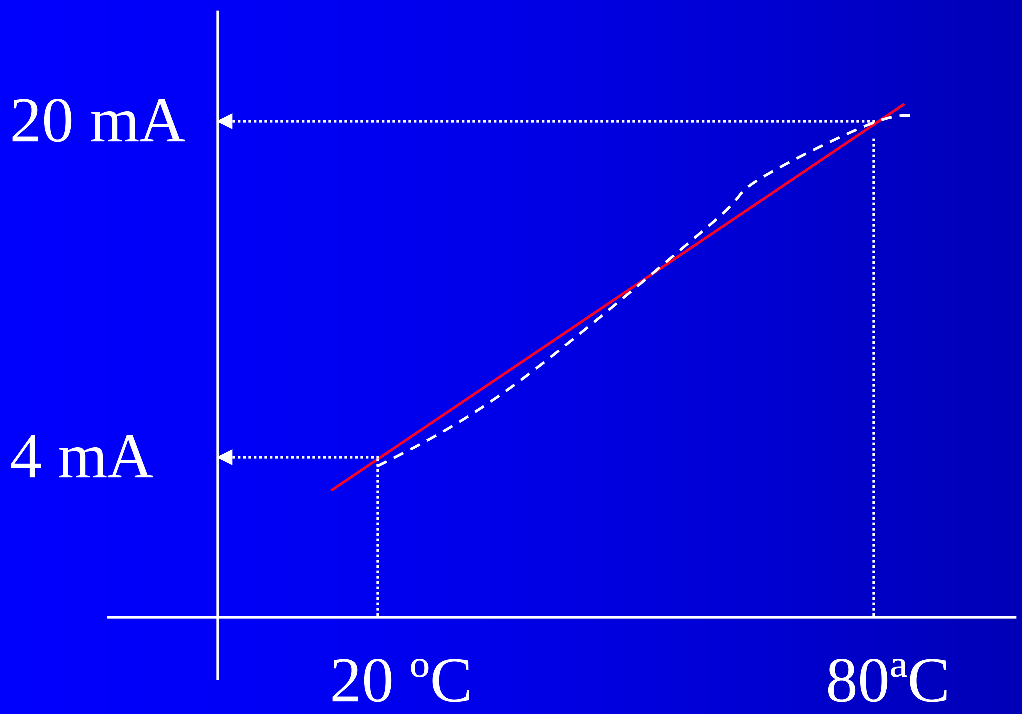


- Less wires
- Automatic routing
- Battery
- Today they are reliable enough

Terminology (SAMA)

- Range
- Span
- Dynamic error
- Precision
- Sensibility
- Repetitiveness
- Dead band / Histeresis

Transmitters



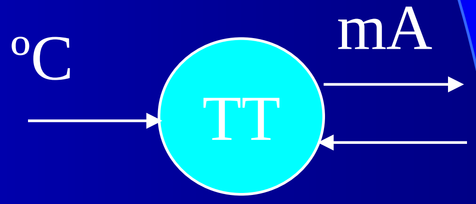
Calibration:

reading = f (real value)

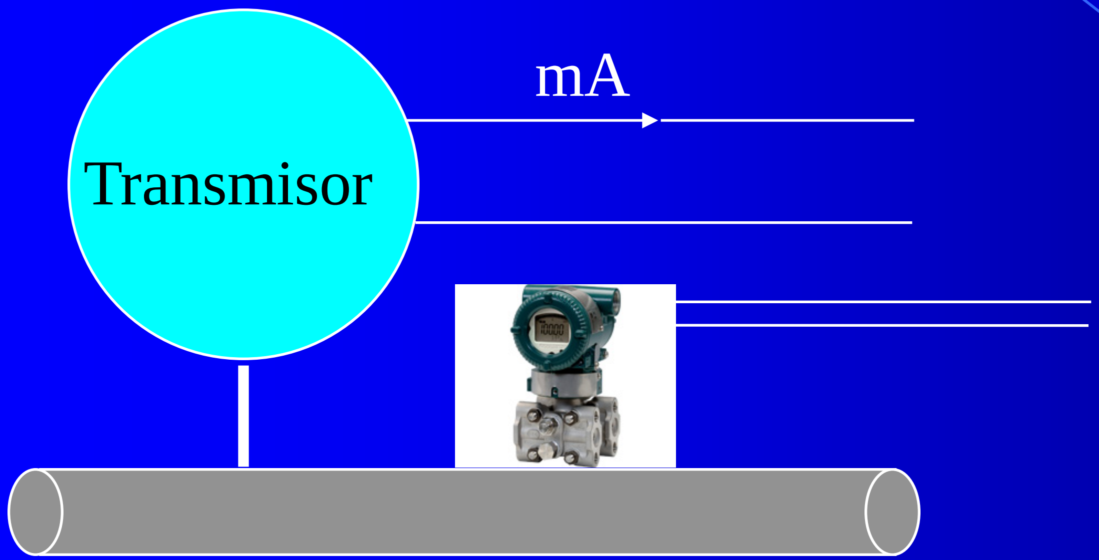
Zero and span

Range: [20 , 80] ºC
Span: 80 - 20 = 60 ºC

mA = 0.2667 ºC - 1.3333



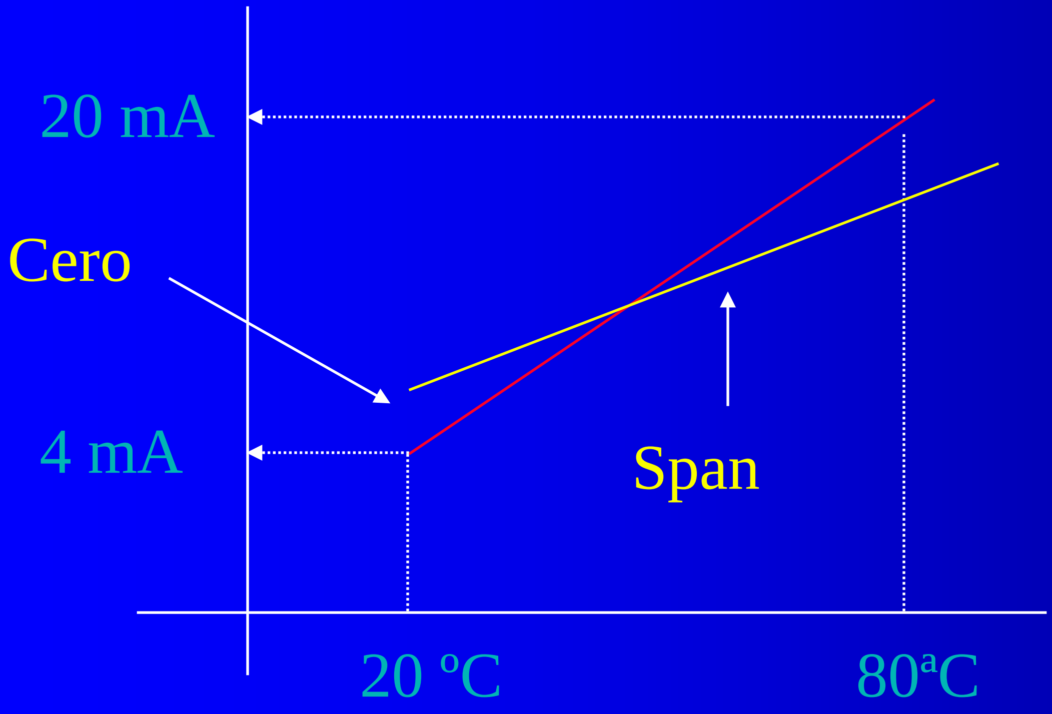
Transmitters / Calibration



In order to calibrate an instrument it is necessary to compare its output signal with the one of a reference instrument under the same conditions

There are instruments (calibrators) that provide measurements with high precision, and are suitable for this task

Calibration



Calibration:

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Zero and span

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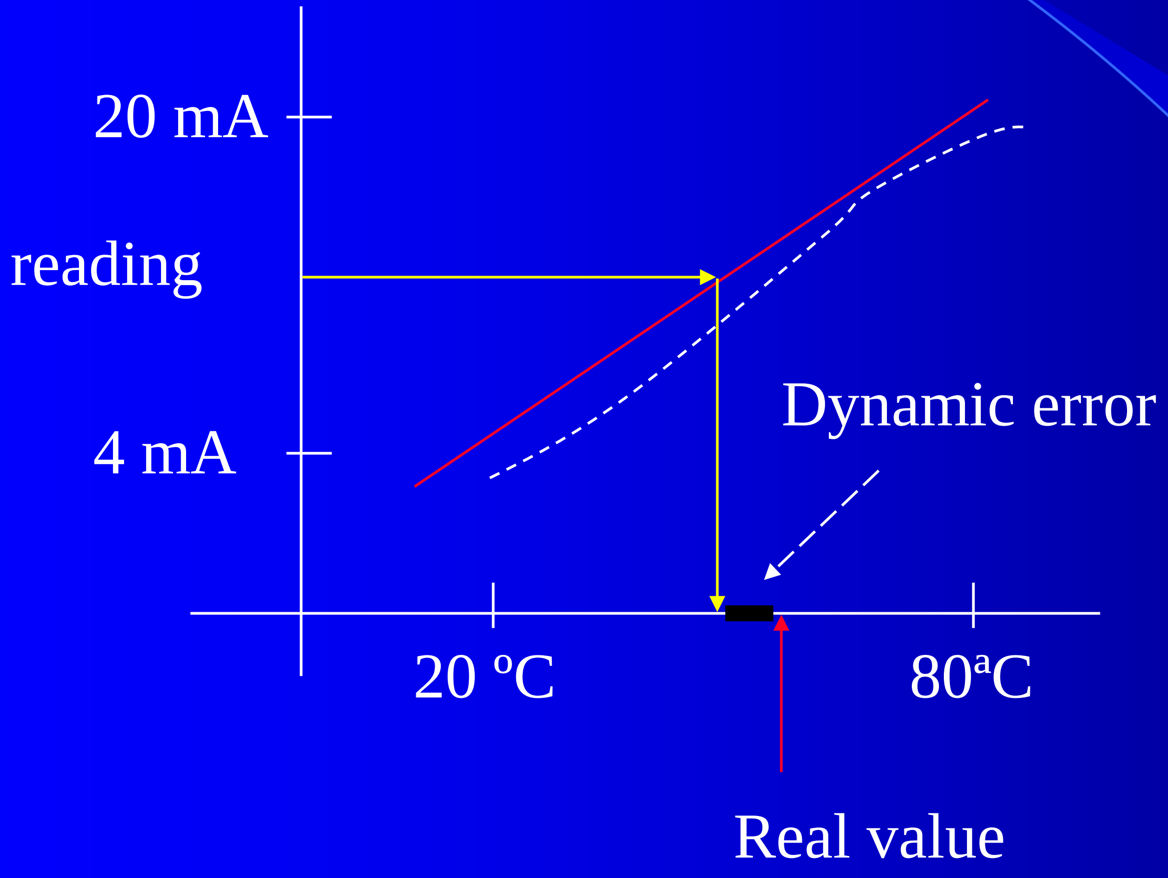
Transmitters

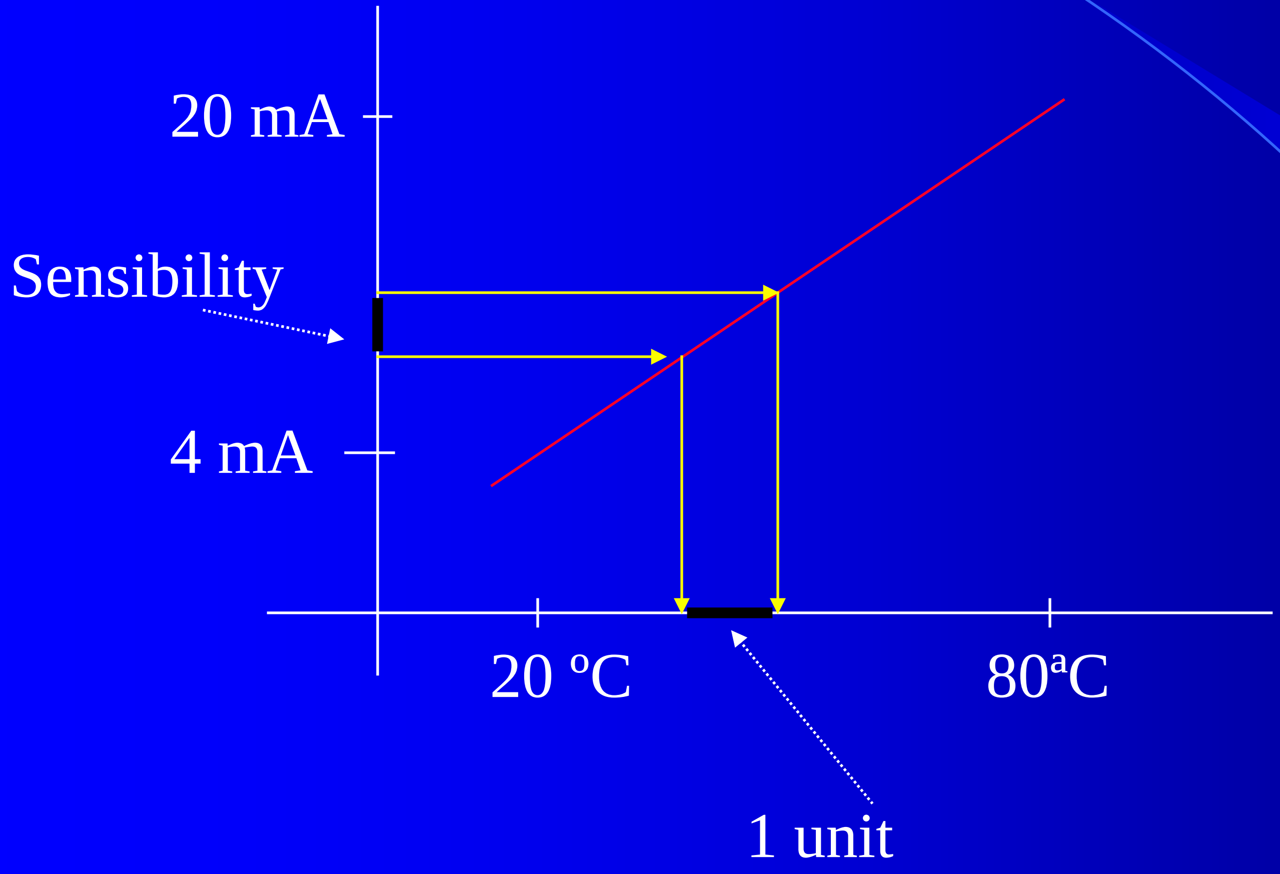


Accuracy:
Maximum error due to non-linearity, hysteresis, etc....

% of span
% of reading
Direct value,...

Tolerance

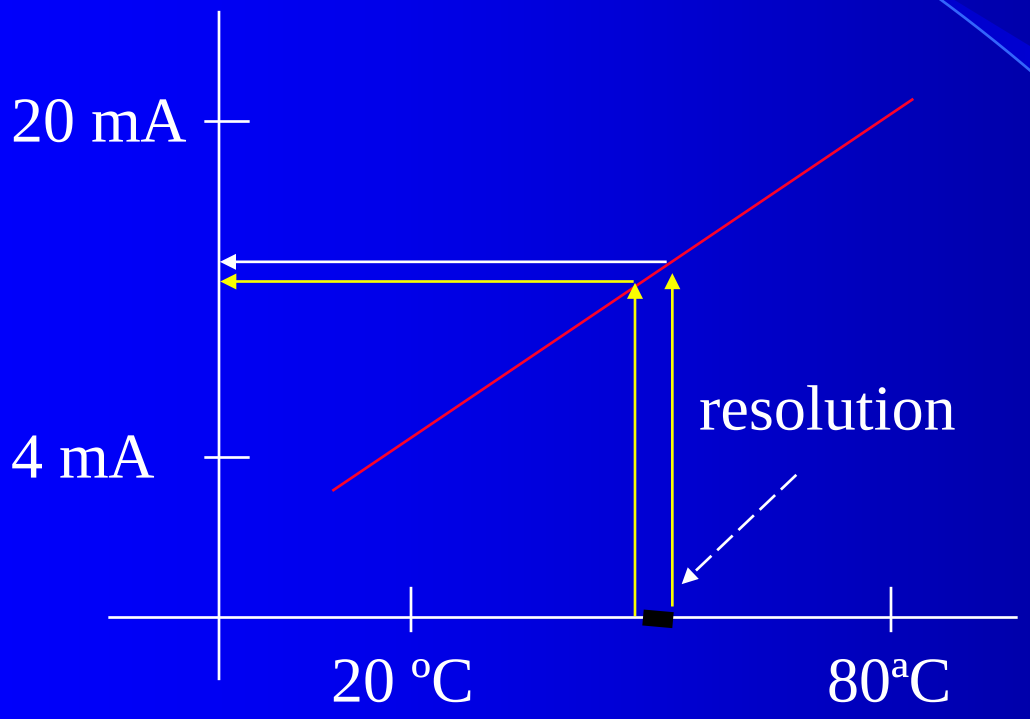
Transmitters



Sensitivity:
Change in the signal corresponding to a unit change in the measured variable

% of span

Transmitters

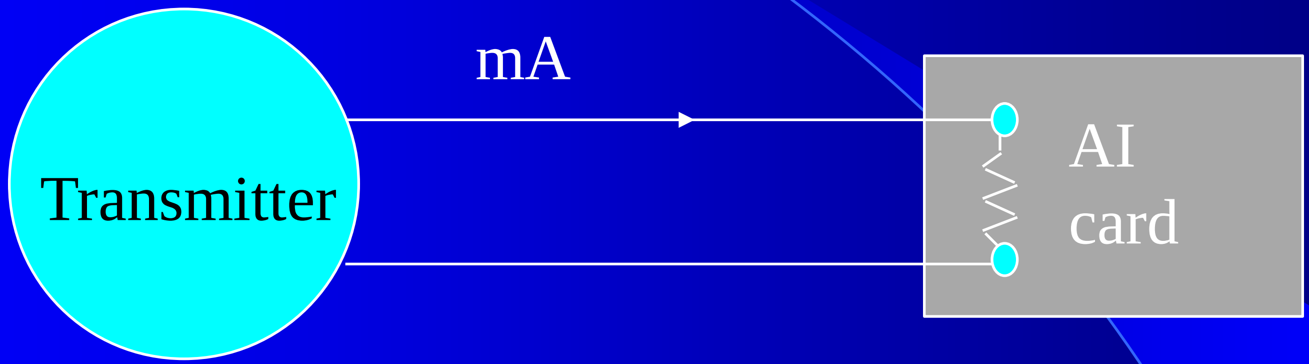


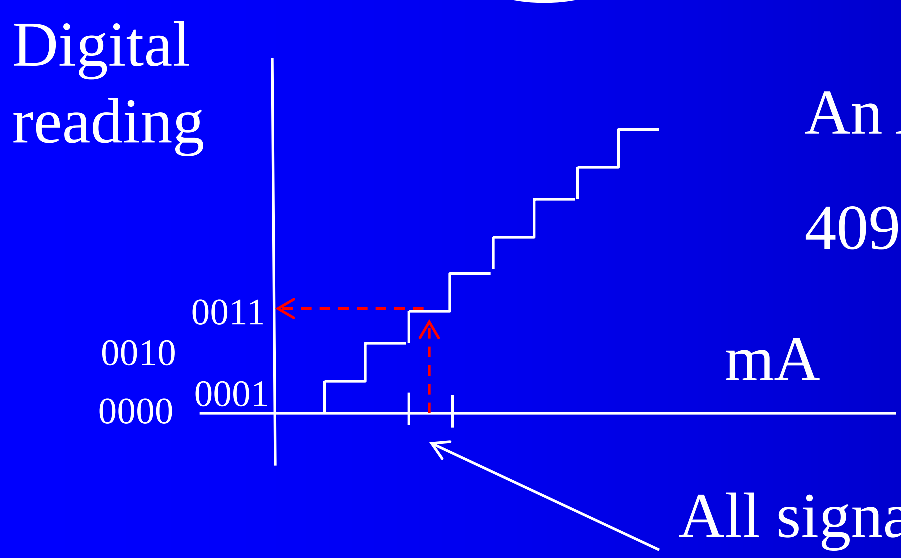
Resolution:
Minimum change in the input required to observe a change in the output

% of span
Direct value,...

The whole measurement chain has to be considered including the AI card of the DCS

Resolution





An AI card with 12 bits can distinguish

$4096 = 2^{12}$ different numbers

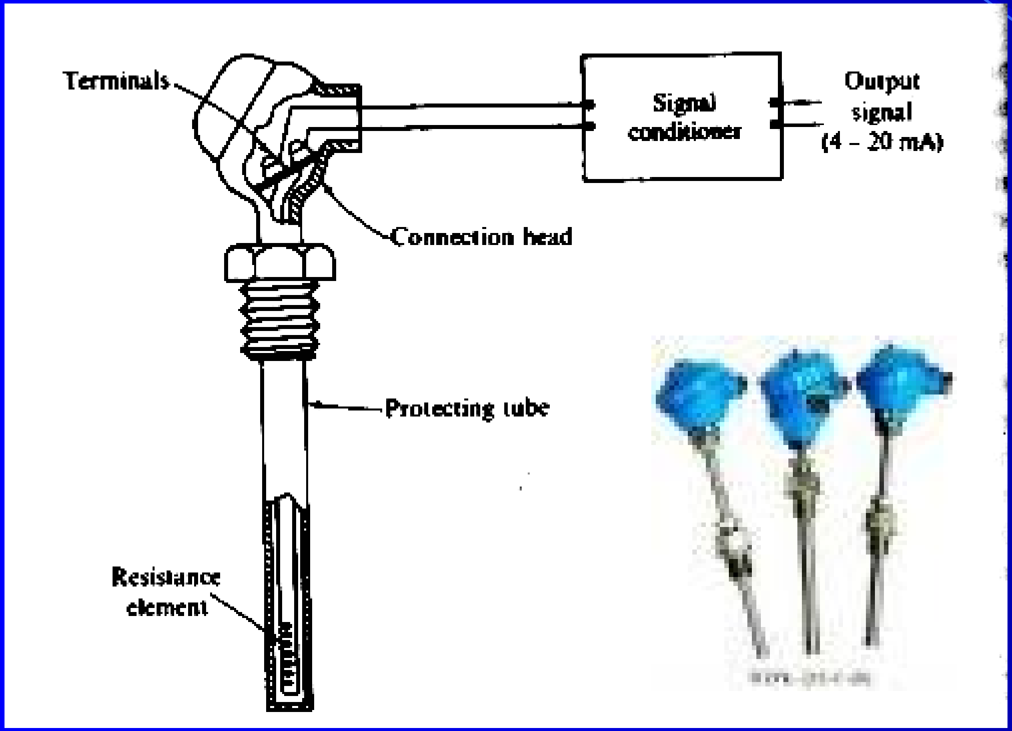
Resolution: 16/4096 mA

All signals in this interval will have the same reading in the DCS

Temperature Transmitters

- Bulb
- RTD (Pt100 0ºC 100 Ω)
- Thermistors (Semiconductors)
- Thermopars E, J, K, RS, T
- Pirometers (High temperature, radiation)

Pt-100



0ºC 100Ω

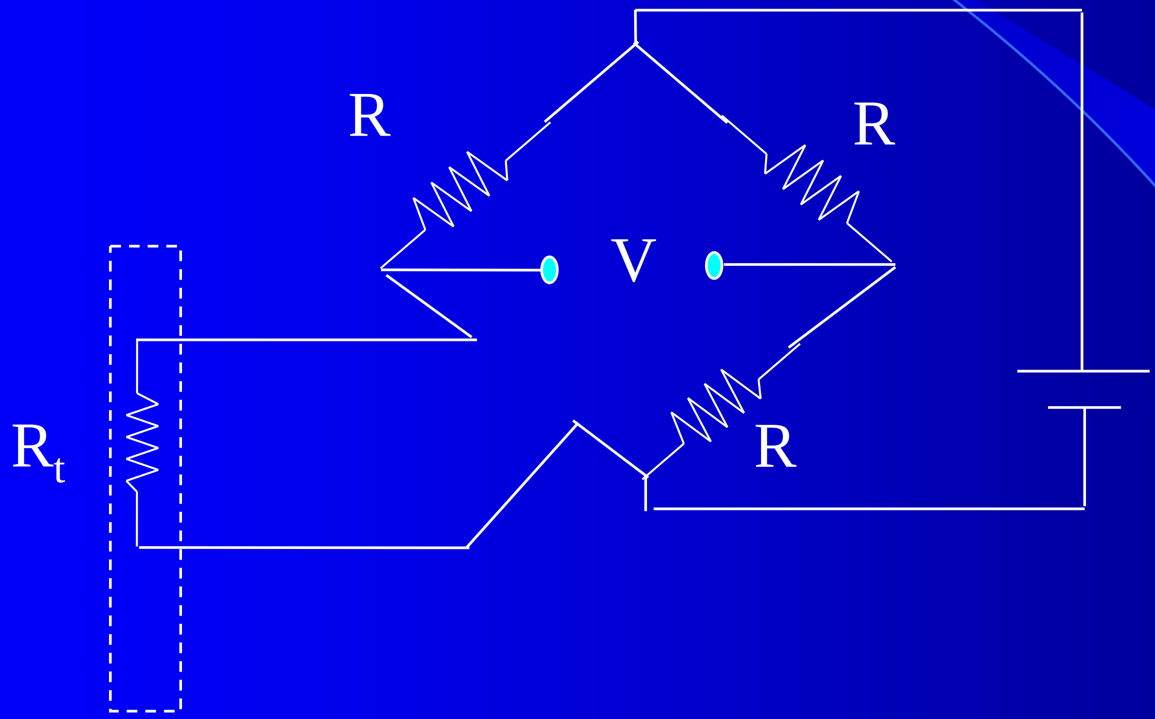
Electrical resistance changes with temperature

An electrical bridge converts changes of resistance in changes of voltage

Range: -200 500ºC Sensitivity: 0.4 Ω/ºC

Accuracy: 0.2%

Bridge



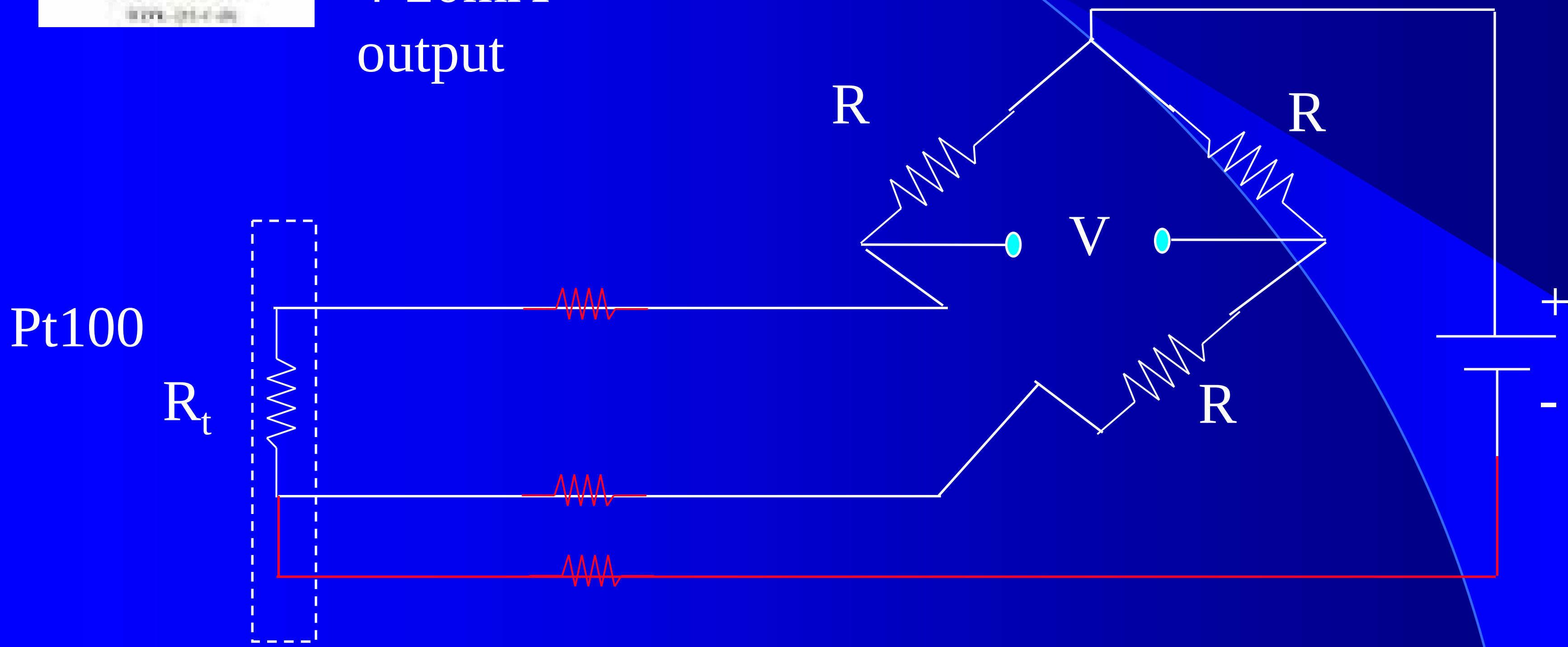
In a balanced bridge left and right branches have the same resistance, so V =0.

If R_t changes, $V \neq 0$

Many TT incorporate a head with 4-20mA output

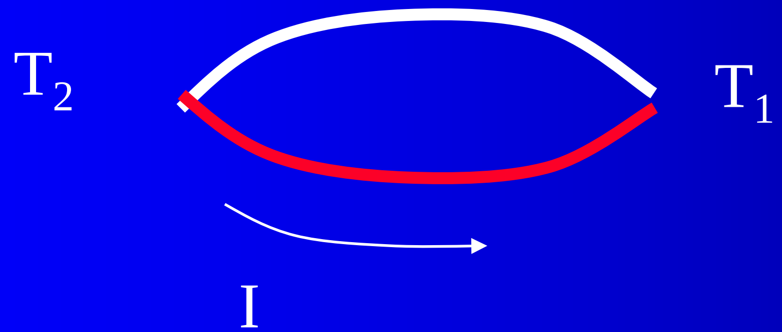
3 wires

From + to – there are two resistors and two wires in the left or right branch on the circuit

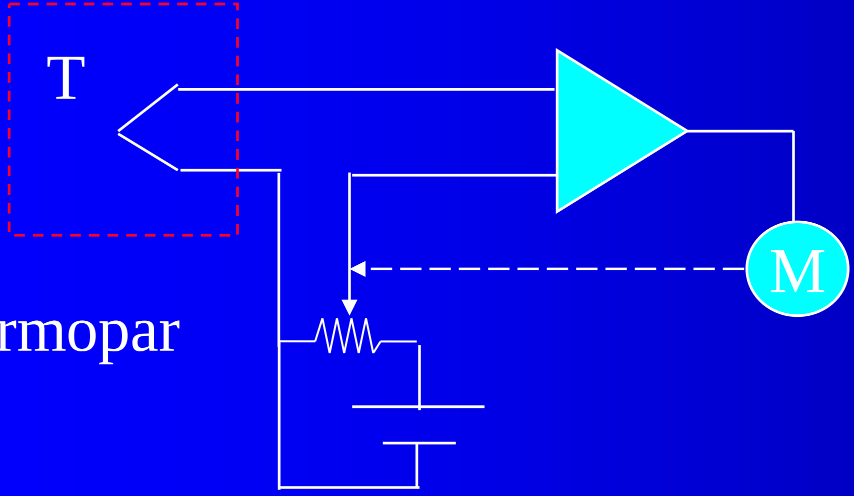


The length of the connecting wires influences the measurement, the third wire introduces the same resistance in each branch, compensating the unbalance due to the wires.

Thermopars



In the junction of certain classes of metals, an e.m.f appears if both ends are at different temperatures. This e.m.f. depends on the temperature difference



Termopar

Measurement: A known voltage is oposed to the one generated by the termopar until a null voltage is obtained at the output of the differential ampliflier.

Thermopars

Kind	Range		Accuracy
T	-200	250ºC	2%
J	0	750ºC	0.5%
K	0	1300ºC	1%
R / S	0	1600ºC	0.5%
W	0	2800ºC	1%

Pressure Transmiters

- Absolute Pressure
- Manometric Pressure
- Differential Pressure

Physical Principles:

•Displacement

•Strain Gauges

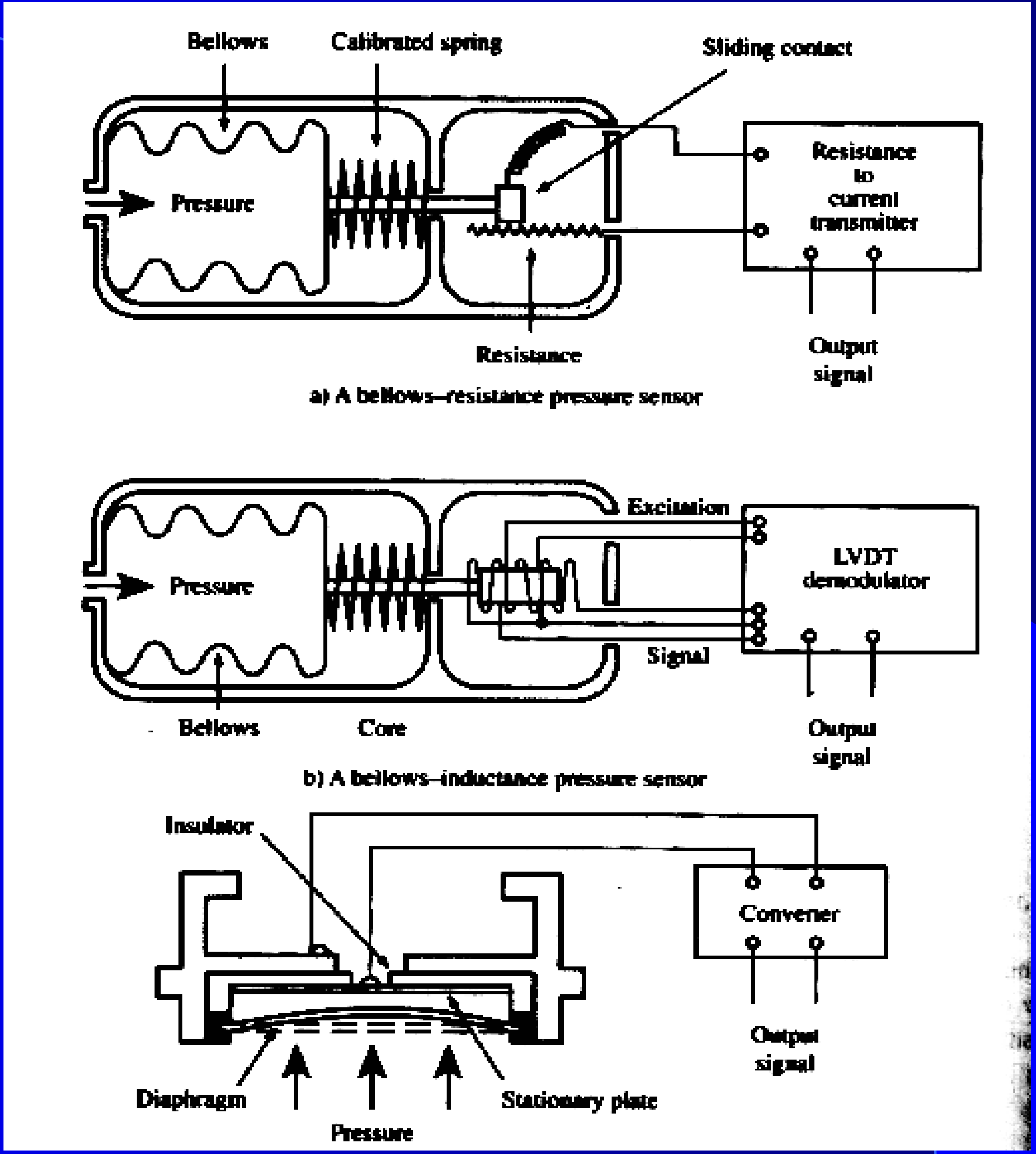
•Piezoelectricity

Potentiometer

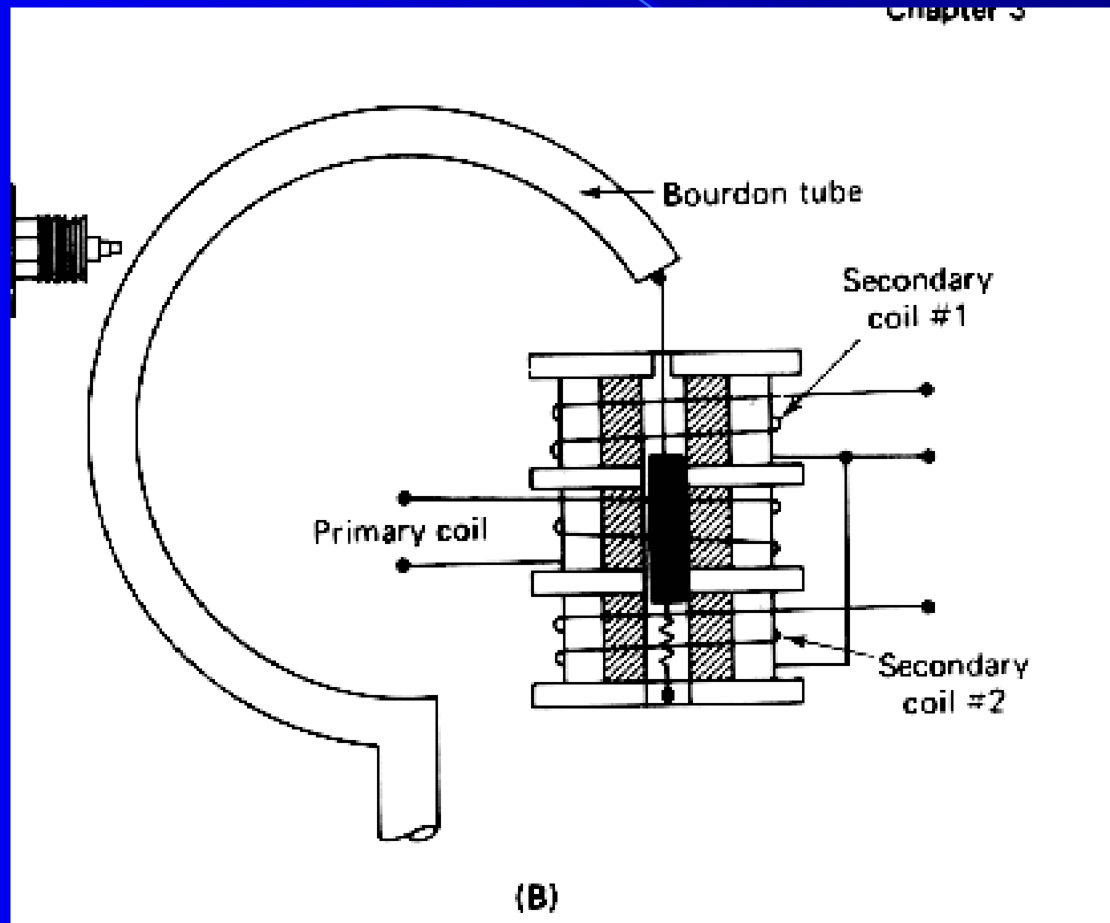
Displacement sensors

Induction

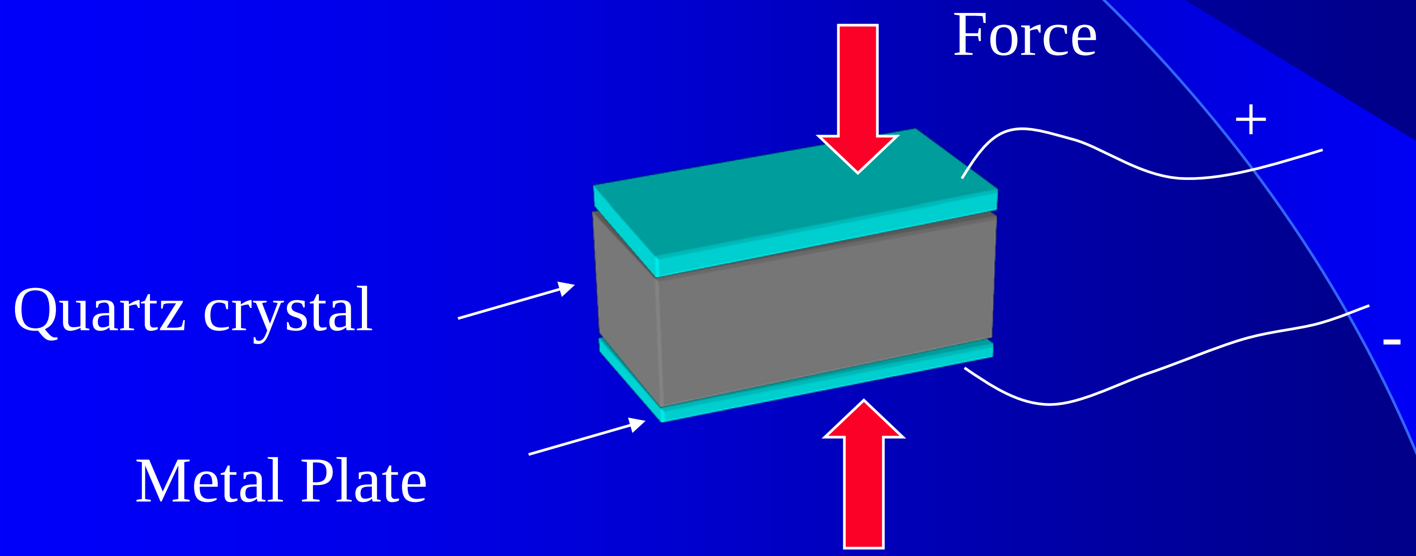
Capacity



Pressure

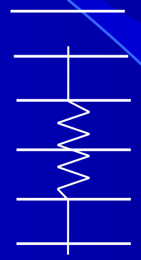

Bourdon tube
Secondary
coil #1
Primary coil
Secondary
coil #2
(B)

Piezoelectric Sensor



Strain Gauges / Hall Effect

Strain gauges

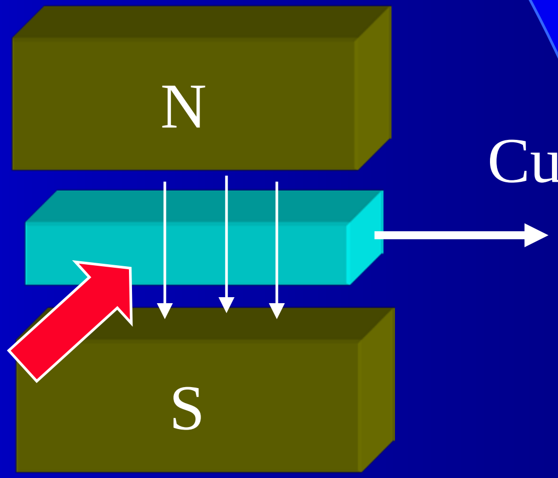


R changes with deformation

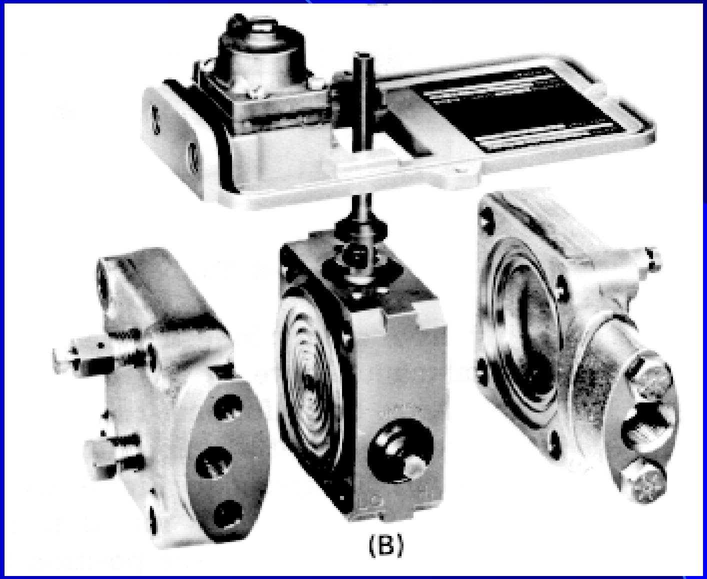
Hall effect

Current

Force



Pressure Transmiters



Level Transmiters

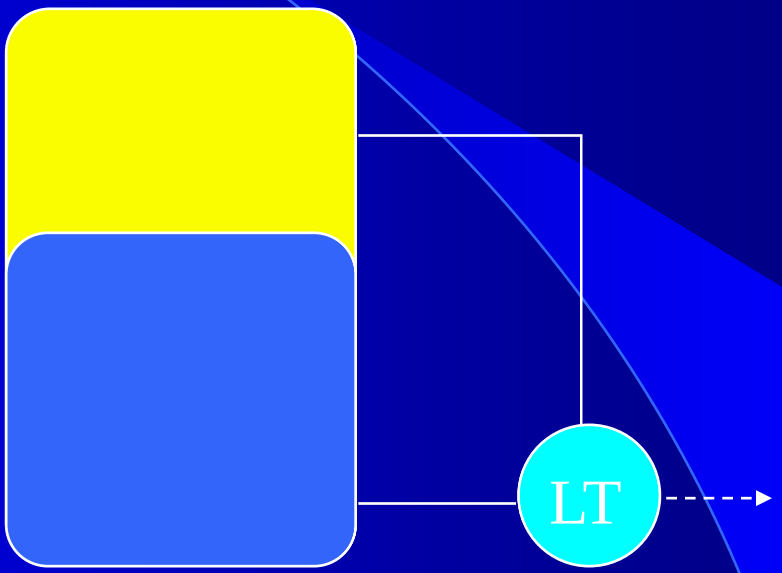
- Displacement
  - Floating devices
  - Force: Archimedes Principle
- Differential Pressure
- Capacitives
- Ultrasounds
- Radar

Level: Differential Pressure

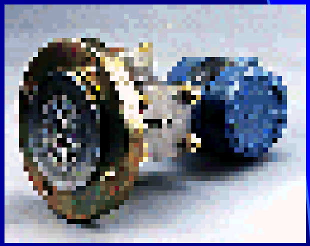
Level is proportional to the differential pressure

Density is assumed constant

Condensation in pipes

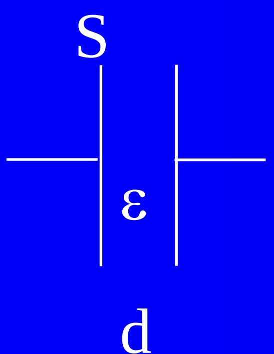


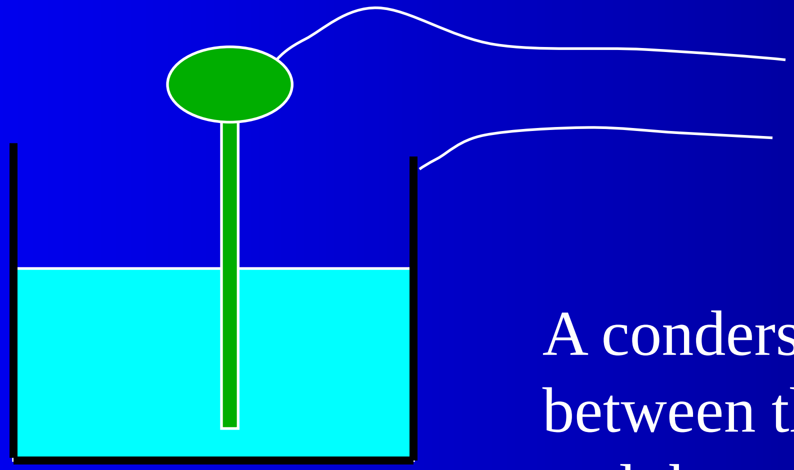
$(p_0 + \rho g h) - p_0$



Electrical Capacity

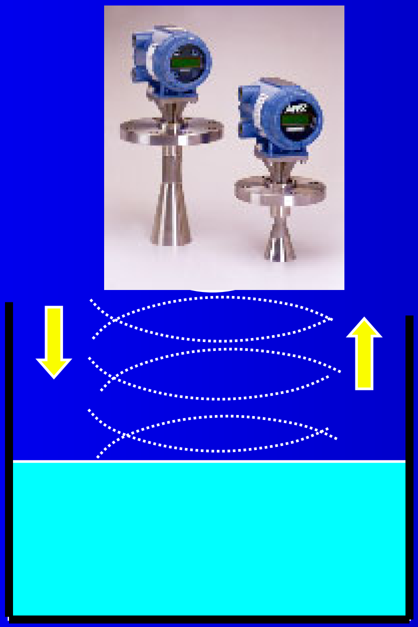
$$C = \frac{\varepsilon S}{d}$$





A conderser is formed between the electrode and the tank wall. Its capacity depends on the fluid level

Level: Ultrasounds, radar



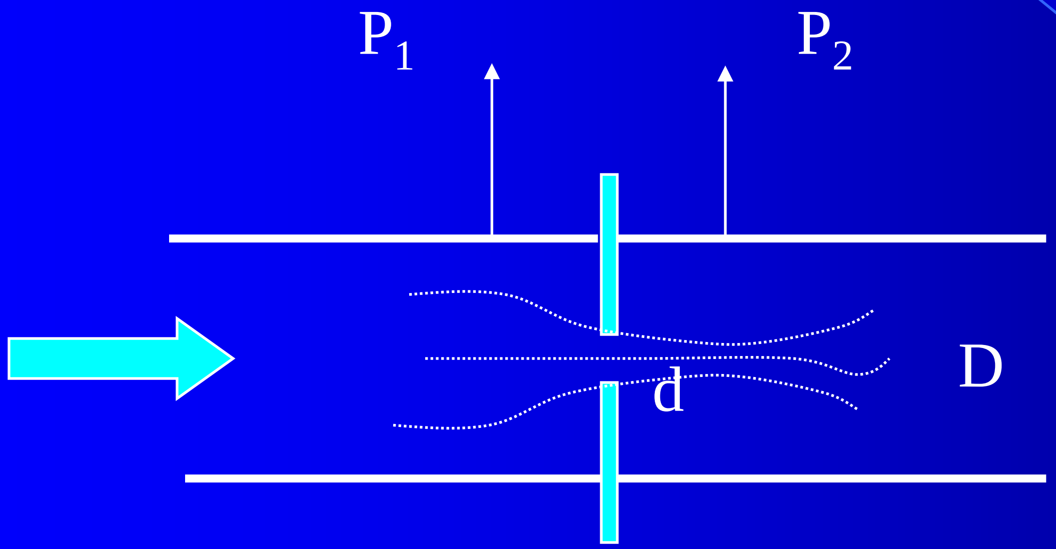
The elapsed time between the emission of the wave and its reception is proportional to the fluid level.

Flow Transmiters

- Differential Pressure
- Electromagnetic
- Turbine
- Vortex
- Doppler
- Mass Flow (Coriolis) …..

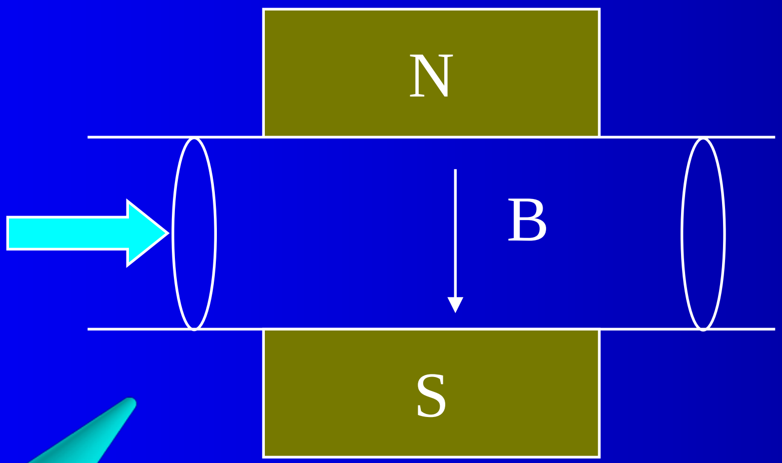
Plates

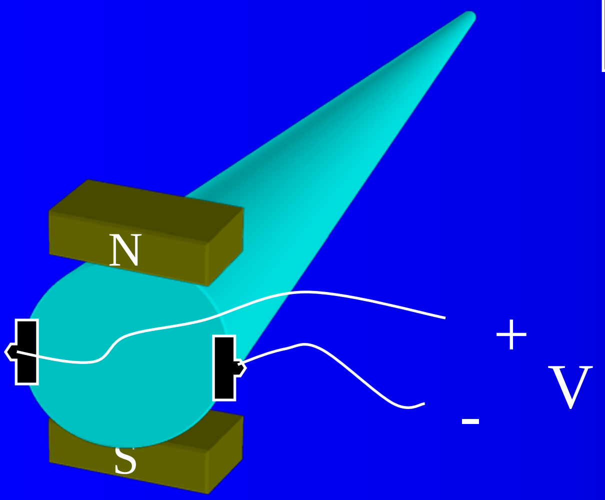
Based on differential Pressure



$$q = C\frac{\beta^2}{\sqrt{1-\beta^4}}\frac{\pi D^2}{4}\sqrt{\frac{2g(P_1 - P_2)}{\rho}} \qquad \beta = \frac{d}{D}$$

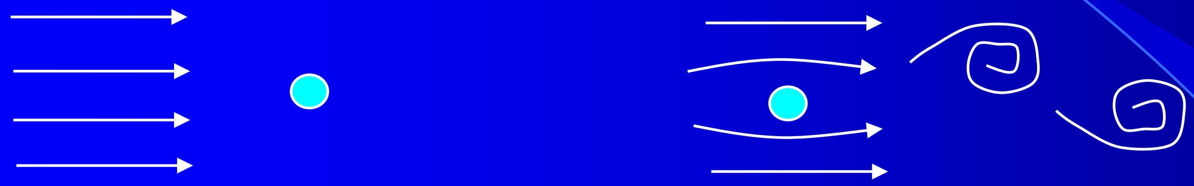
Electromagnetic Flowmeters





In a conductor (liquid) flowing at a speed v within a magnetic field B, an e.m.f. appears that it is proportional to the velocity

Vortex Flowmeters



When a fluid stream passes an obstacle, vortices are alternatively shed on each side

The frequency at which vortices are shed is directly proportional to the fluid velocity

v = 4.167 d frequency   d = diameter of the obstacle

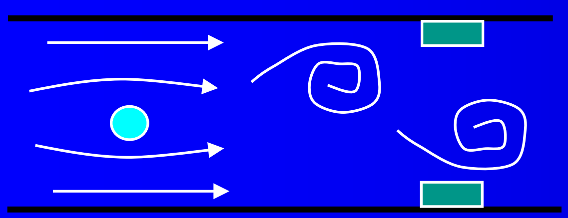
Vortex flowmeters

Industrial vortex flowmeters have a bluff body (obstacle) that generates vortices.

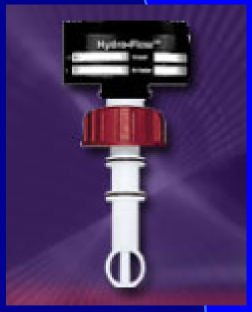
Counting the number of vortices per unit time: disturbances in pressure sensors, capacitance, ultra sonic, etc.

$v = 4.167\ d$ frequency

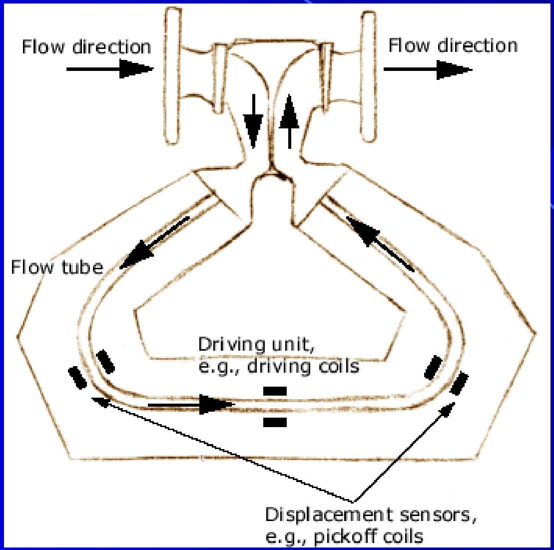
Valid for gases and liquids in a wide range of conditions

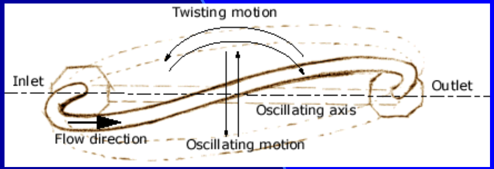


Not valid for very low flows

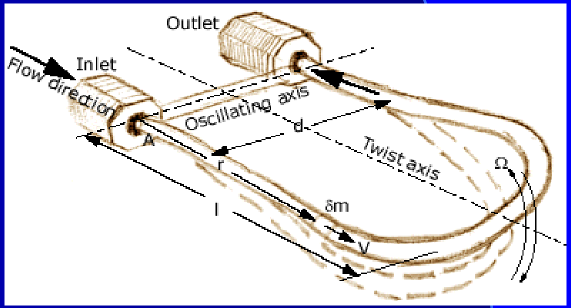


Coriolis Flowmeters





The pipe is forced to oscillate, but the U-shape design induces (Coriolis) opposite forces in both sides. There is a phase shift between input and output sides that depends on the mass flow. Magnetic sensors measure this phase shift.



http://www.flowexpertpro.com/

Choosing a transmitter

Configuration Data Sheet

* = Default Configuration

HART TRANSMITTER

Customer Information	
Customer	P.O. No.
Model No.	Line Item

Input – Output Information (software selectable)		
Sensor Type	No. of Leads	
☐ Pt100 a = 0.00385*	☐ 2-Wire	☐ NIST Type B T/C
☐ Pt100 a = 0.003916	☐ 3-Wire	☐ NIST Type E T/C
☐ Pt200 a = 0.00385	☐ 4-Wire*	☐ NIST Type J T/C
☐ Pt500 a = 0.00385		☐ NIST Type K T/C
☐ Pt1000 a = 0.00385		☐ NIST Type N T/C
☐ Cu 10		☐ NIST Type R T/C
☐ Ni 120		☐ Type W5Re/W26Re
☐ Transmitter Sensor matching (C2 Option)		☐ NIST Type S T/C
		☐ NIST Type T T/C
		☐ DIN Type L T/C
		☐ DIN Type U T/C
		☐ mV
		☐ Ohms

4–20 mA Points and Damping	4 mA Value	20 mA Value	Damping
	☐ 0 °C*	☐ 100 °C*	☐ 5 Seconds*
	☐ °C	☐ °C	☐ Other (value must be less than 32 seconds)
	☐ °F	☐ °F	
	☐ °R	☐ °R	
	☐ K	☐ K	
	☐ mV	☐ mV	
	☐ Ohms	☐ Ohms	

Configuration Data Sheet
February 2004
Revision JA
Rosemount 644

Tagging
Hardware Tag (13 characters maximum)
Software Tag (8 characters maximum – default is first 8 characters of the hardware tag)

Transmitter Information		
Integral Meter (644H Only-M5 option)	With Meter (choose as many as desired)	
	☐ Engineering Units*	☐ mA*
	☐ Percent Range	
NOTE: If an integral meter is ordered with the transmitter, the default configuration alternates between "Engineering Units" and "mA".		
Descriptor (C1 Option)	☐ (16 characters maximum)	
Message (C1 Option)	☐	
	☐ (2 Lines x 16 characters max)	
Date (C1 Option)	☐ Day (numeric)	☐ Month (alphabetic)
	☐ Year (numeric)	

Failure Mode and Software Security
Failure Mode High*
Software Security Off
Continued on Next Page

http://www.emersonprocess.com/rosemount/

http://www.yokogawa.com/fld/fld-top-en.htm

Actuators

- Final control elements. They change the manipulated variable according to the signal from the controller.
  - Valves
  - Motors
  - Variable speed pumps
  - Power amplifiers
  - ....

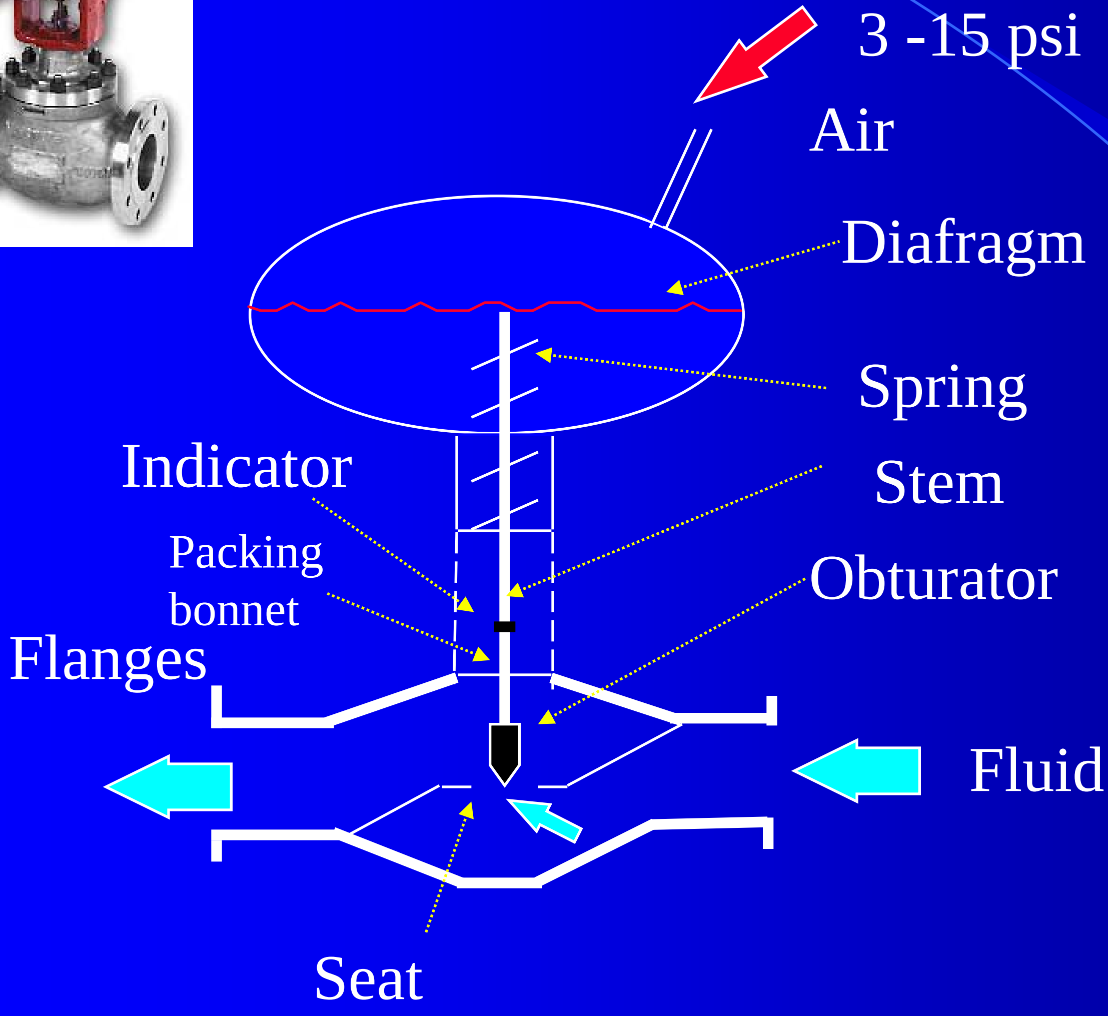
Valves

- Devices that allow modifying the flow of the fluid by means of a change in the pressure drop in the line. Several types:
  - Manual valves
  - One way
  - Safety
  - On/Off
  - Control

Automatic control valves

- Structure and operation
- Types
- Formulas
- Static characteristics
- Cavitation
- Installed Characteristics
- Valve dynamics

Pneumatic valve (Globe)



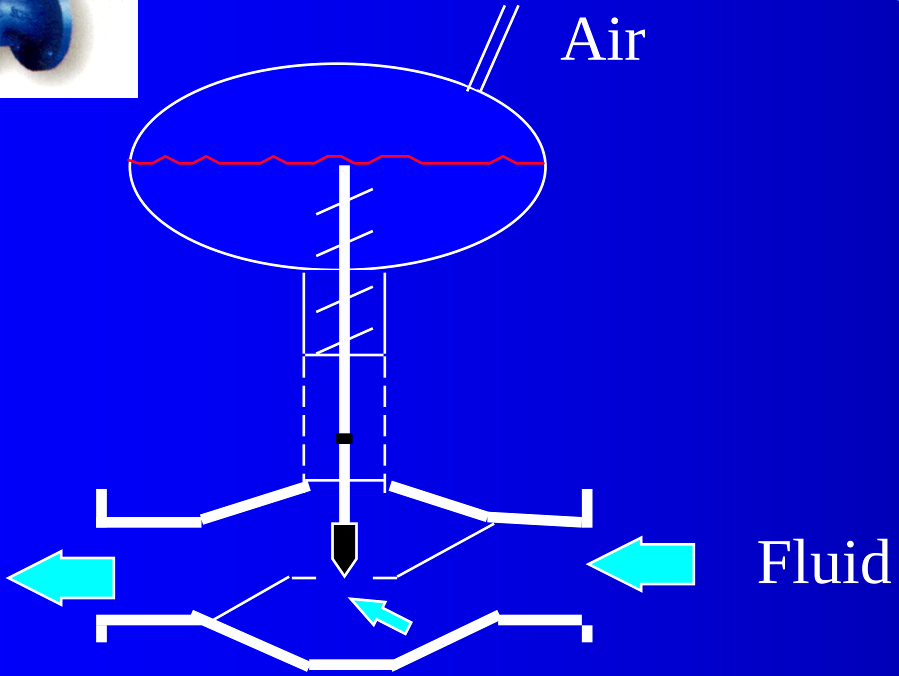
Servomotor

Pneumatic

Electric

Body

Automatic valves



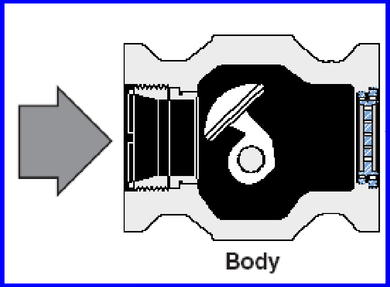
Globe
Double seated
Needle
Saunders
Ball
Butterfly
Camflex II

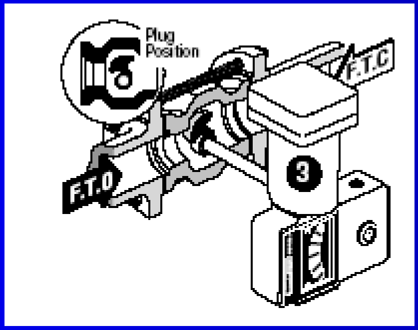
2 -3 ways

- Sealed
- Maximum pressure
- Flow capacity
- Kind of fluid

Butterfly / Ball / Camflex

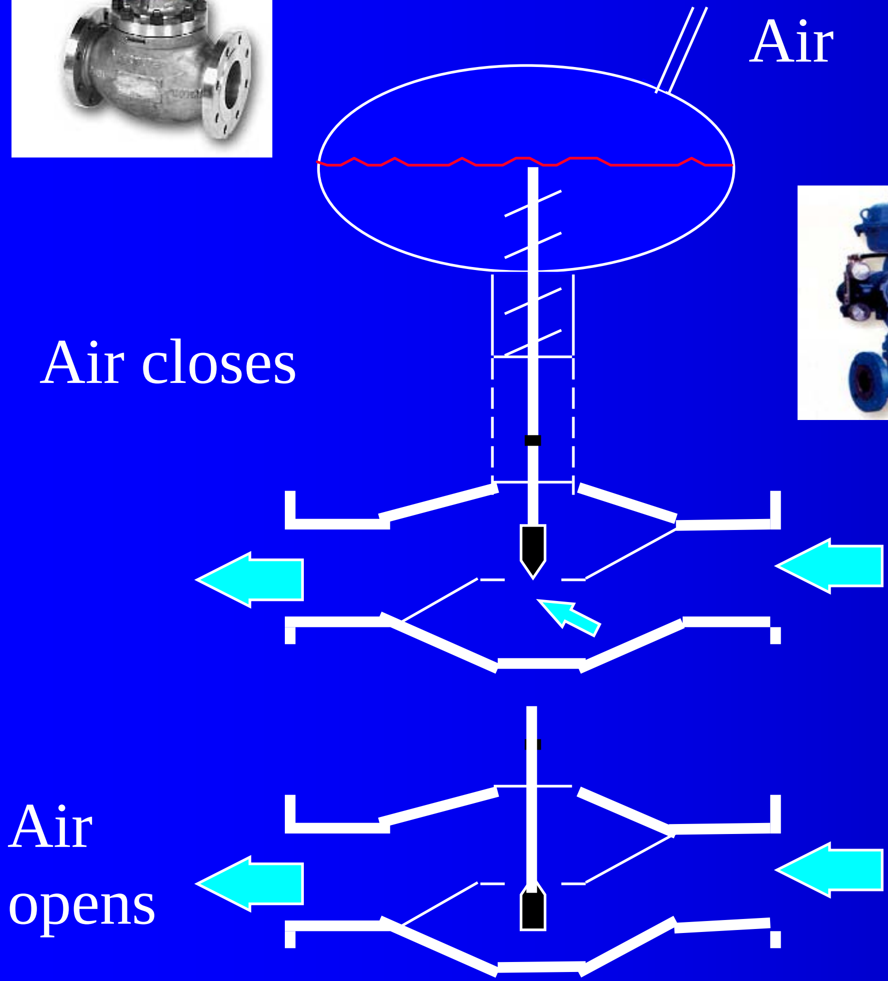

Butterfly

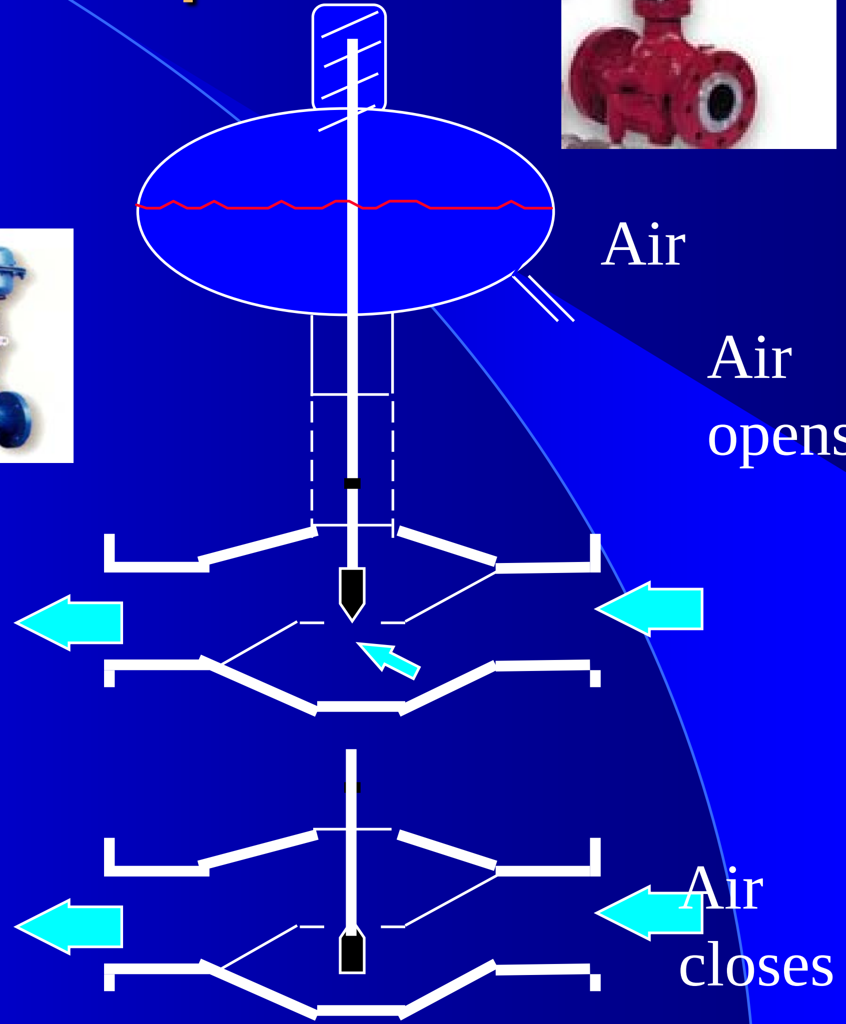




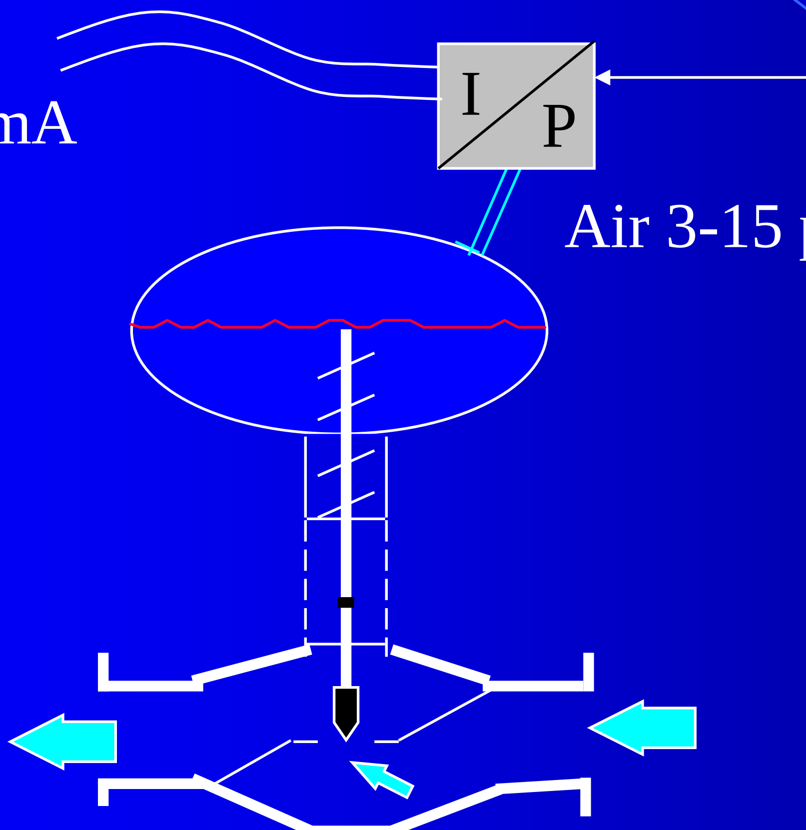
Camflex II

Air open/close
Fail closed/ open



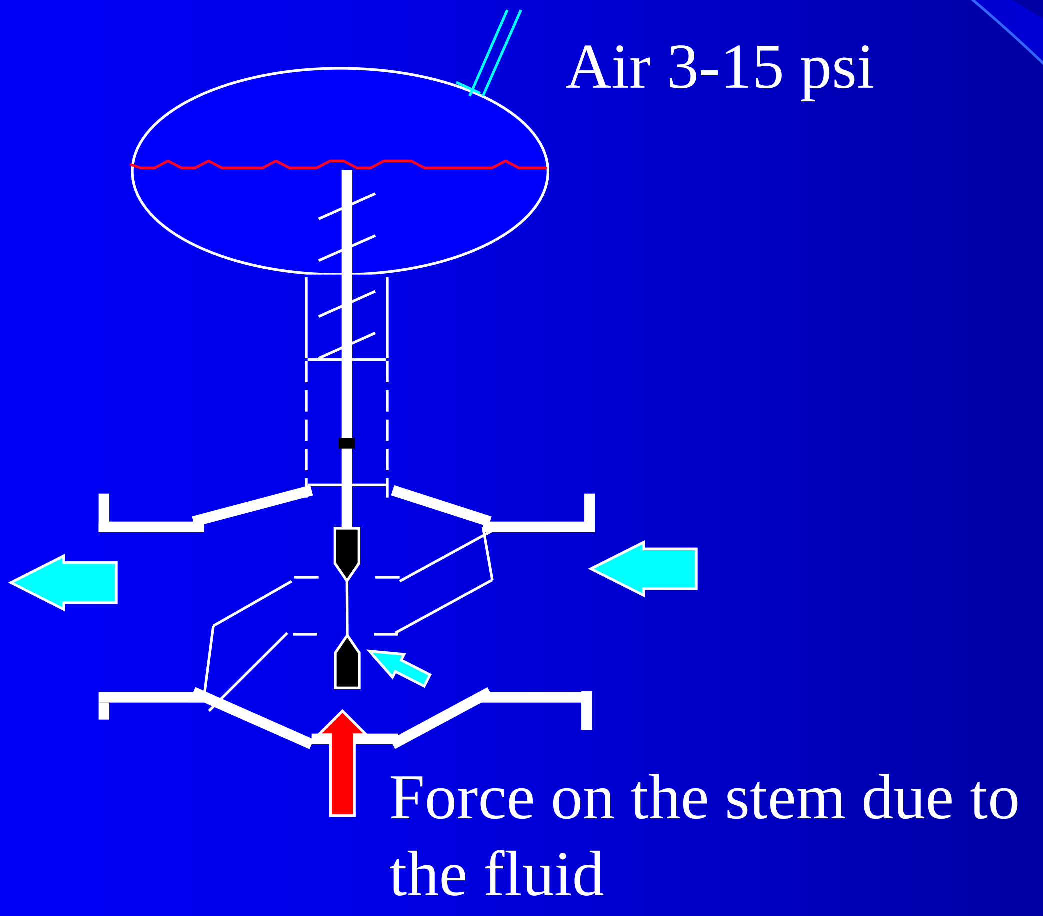


I/P Converter

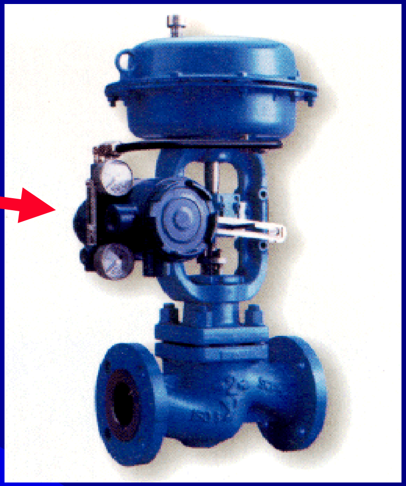


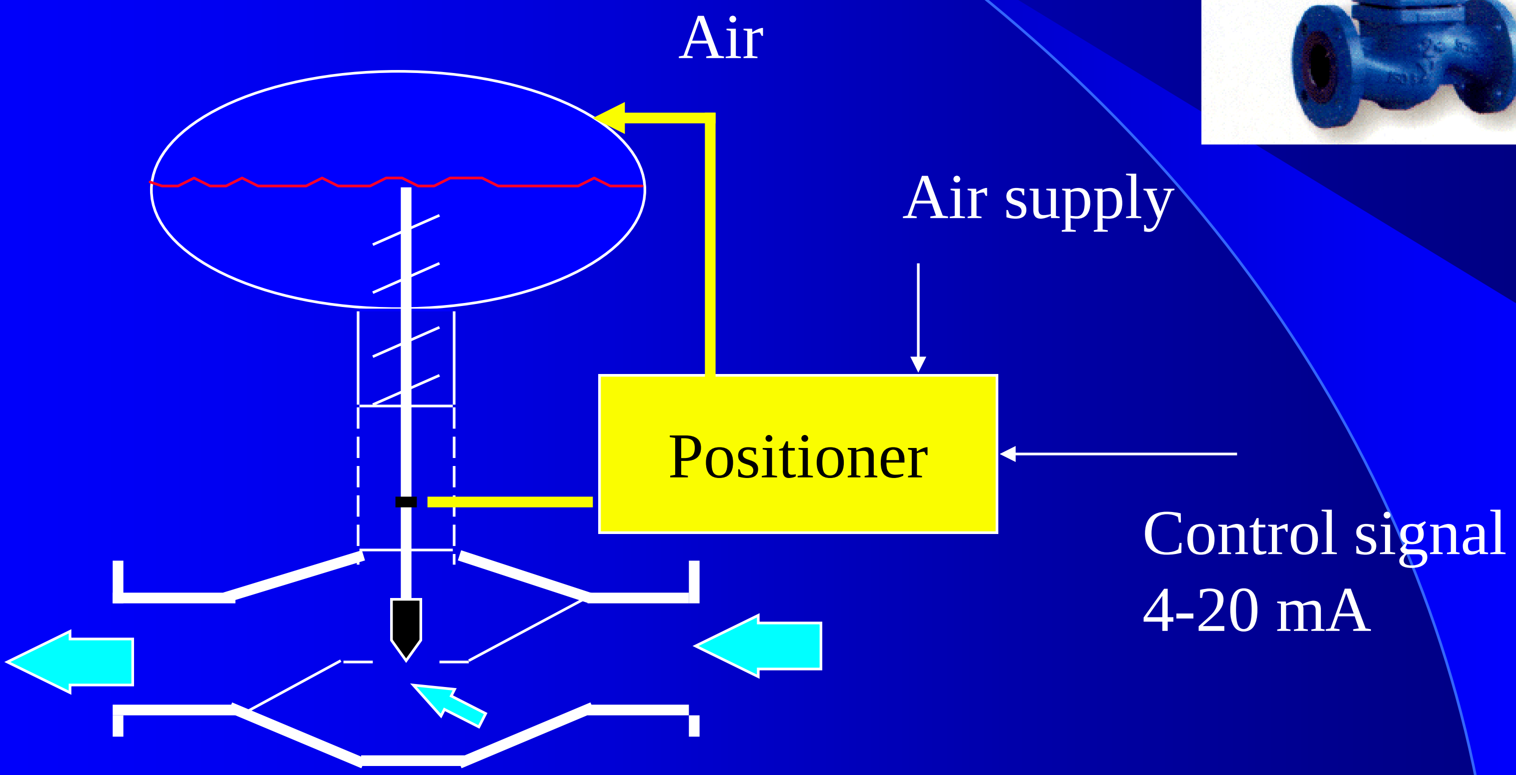
Low accuracy in the position of the stem

Double seated valve



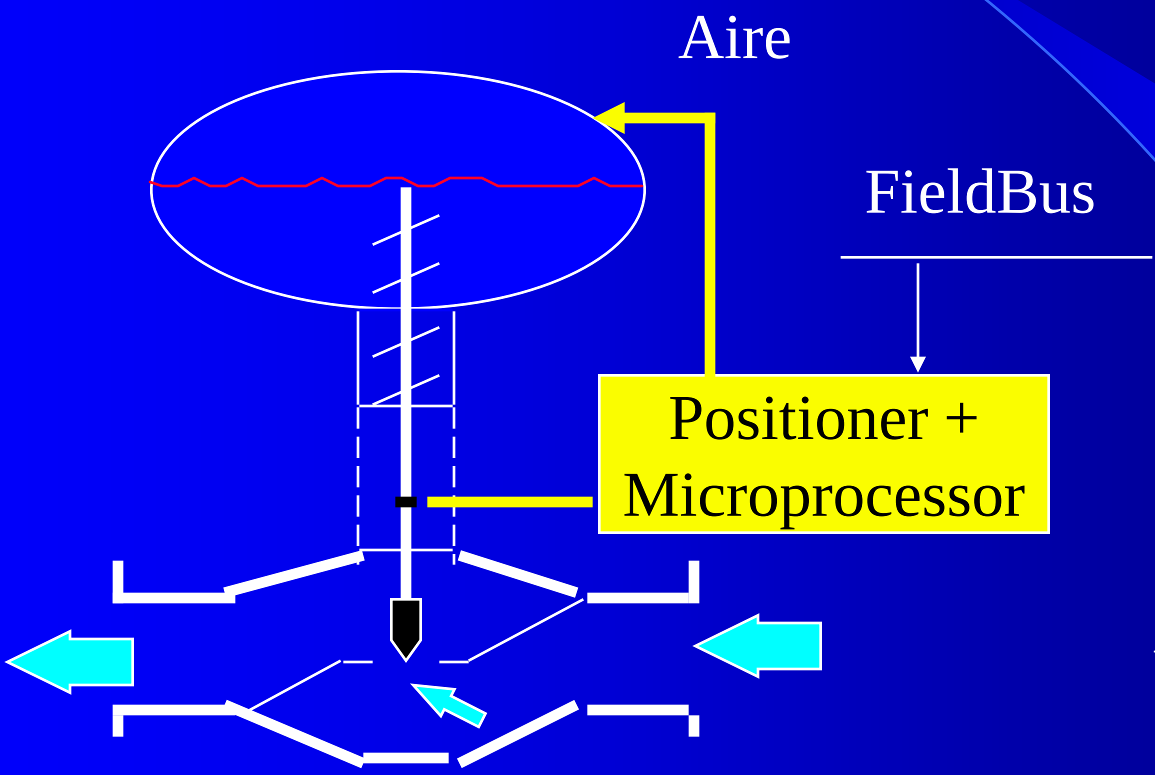
Positioner





Stem position control system

Intelligent valves



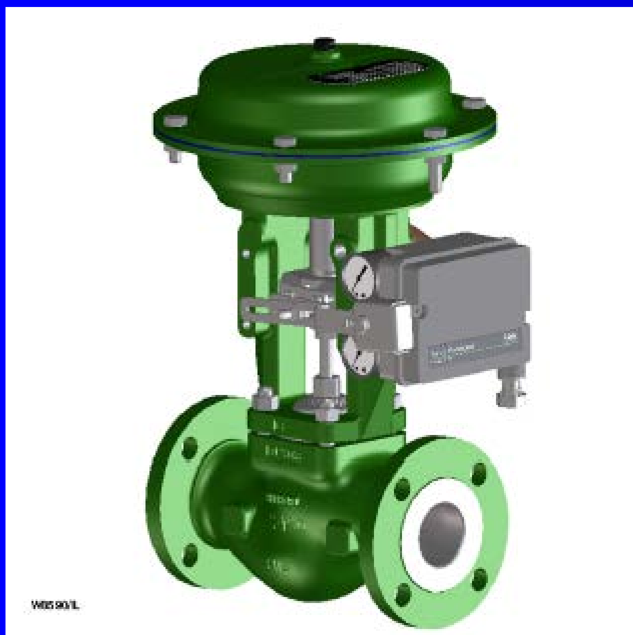
Data

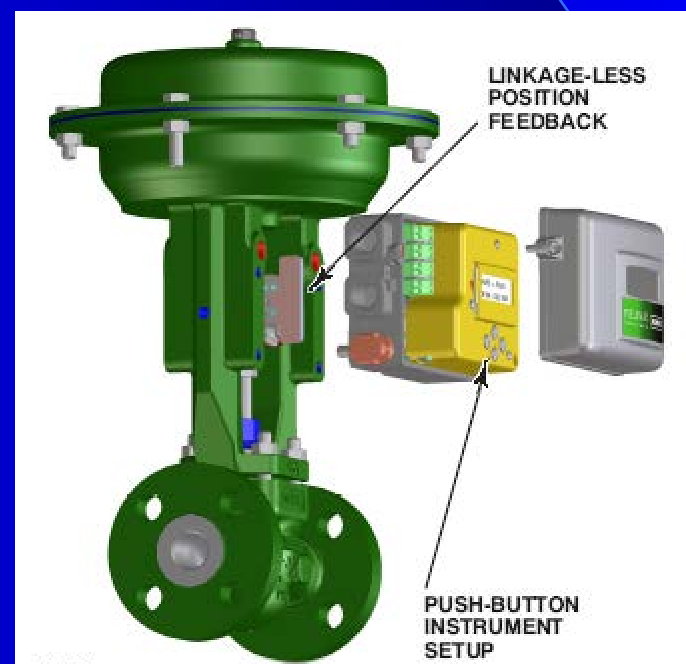
Diagnosis

Alarms

Control blocks, etc.

Digital positioner

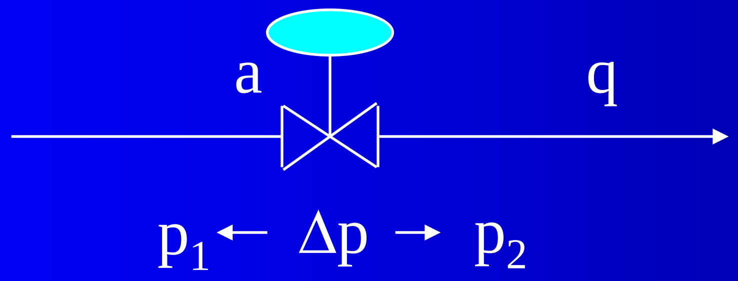




Non contacting

Pressure drop

$$\Delta p_v = \frac{1}{a^2 C^2} q^2 \rho$$



Δp pressure drop
q flow
a opening
C coefficient
ρ density

Formulas

$$q = aC_v \sqrt{\frac{\Delta p_v}{\rho}}$$

q gpm

p psi

Líquids

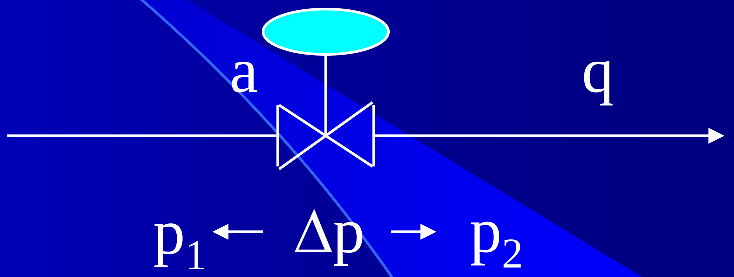
q m3/h

p bars

ρ relative density

a opening fraction

$$q = \frac{aC_v}{1.16} \sqrt{\frac{\Delta p_v}{\rho}}$$



C_v flow coefficient

Saturated steam

q Tm/h

p bars

a opening fraction

$$q = \frac{aC_v}{72.4} \sqrt{\Delta p_v (p_1 + p_2)}$$

Viscosity corrections

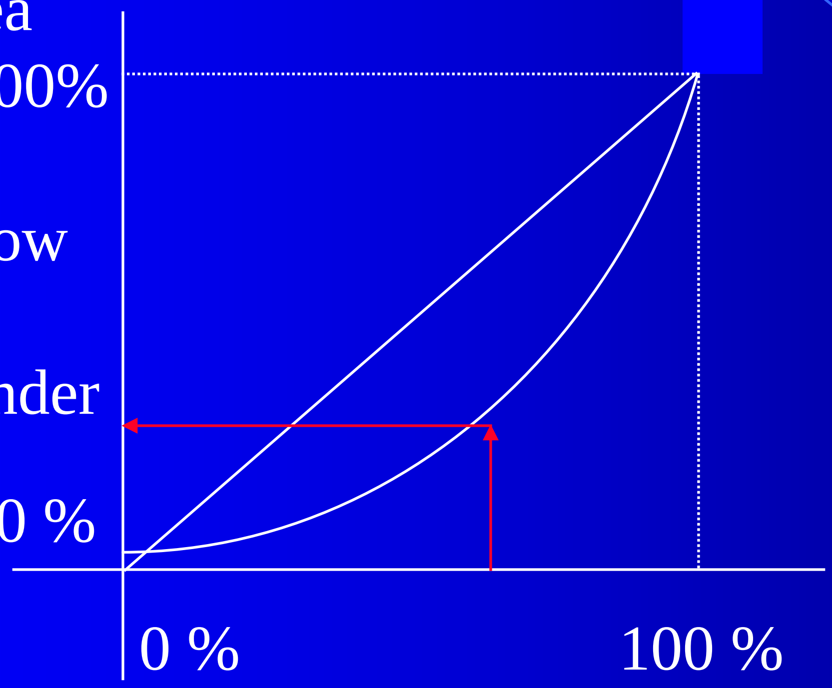
Static Characteristics

% of seat area

100%

% of max Flow
in nominal
conditions under
constant Δp

0 %



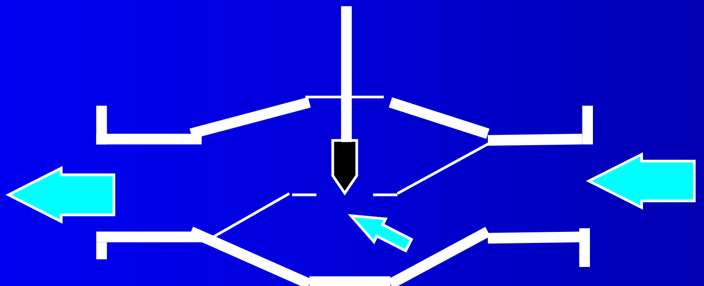
0 %

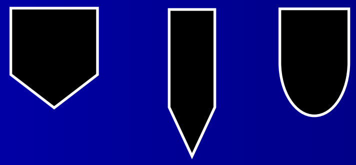
100 %

% stem position

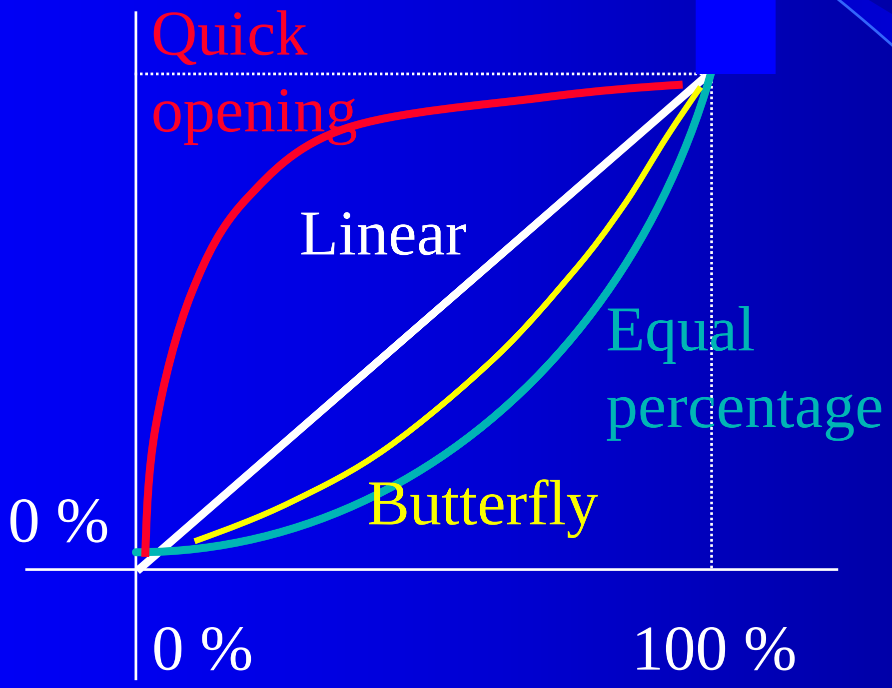
Linear
Equal percentage
Quick opening
Butterfly
Camflex

Different
obturator
shapes

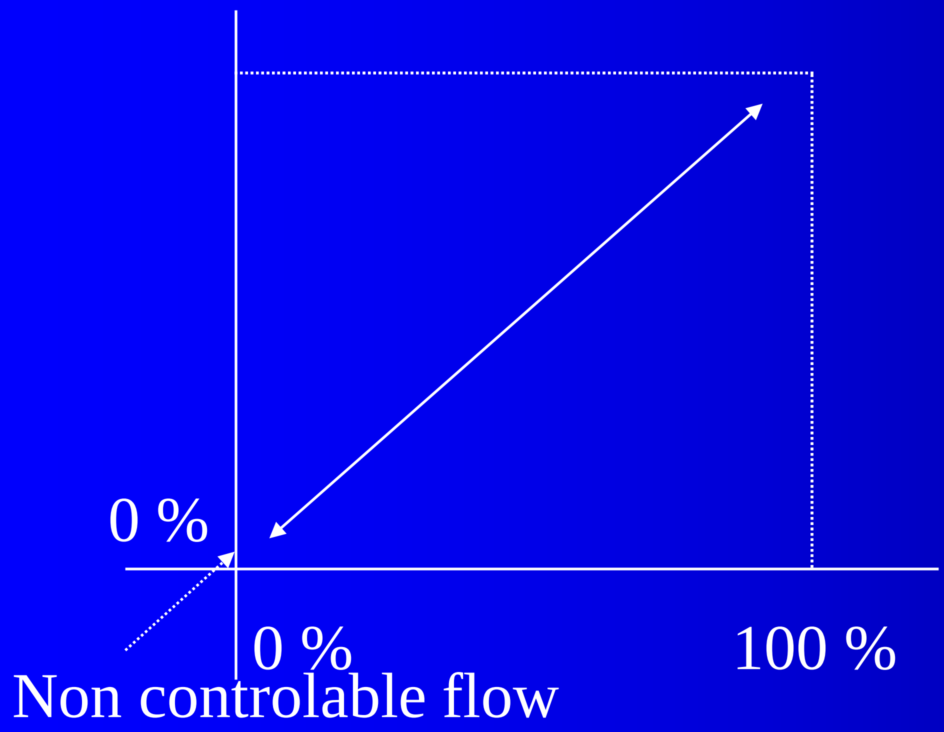




Static Characteristics



Rangeability



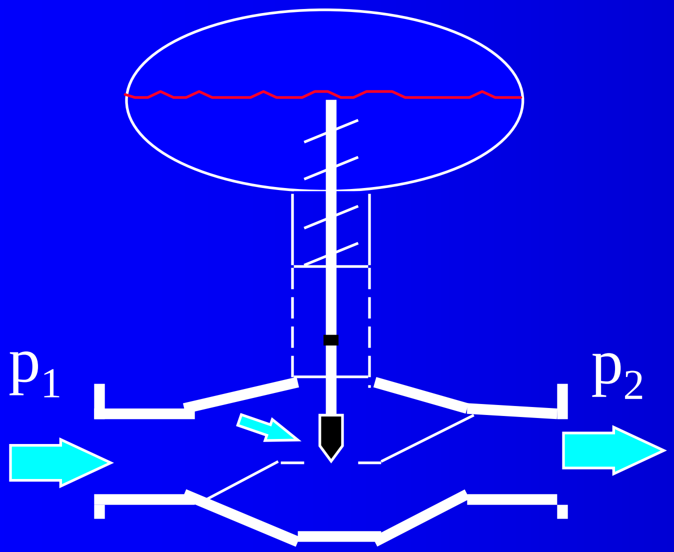
$$R = \frac{\text{máx. controlable flow}}{\text{mín. controlable flow}}$$

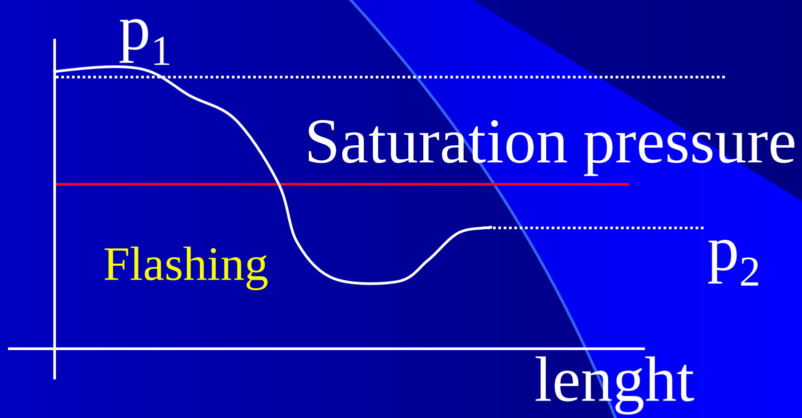
R= 100, 50...20

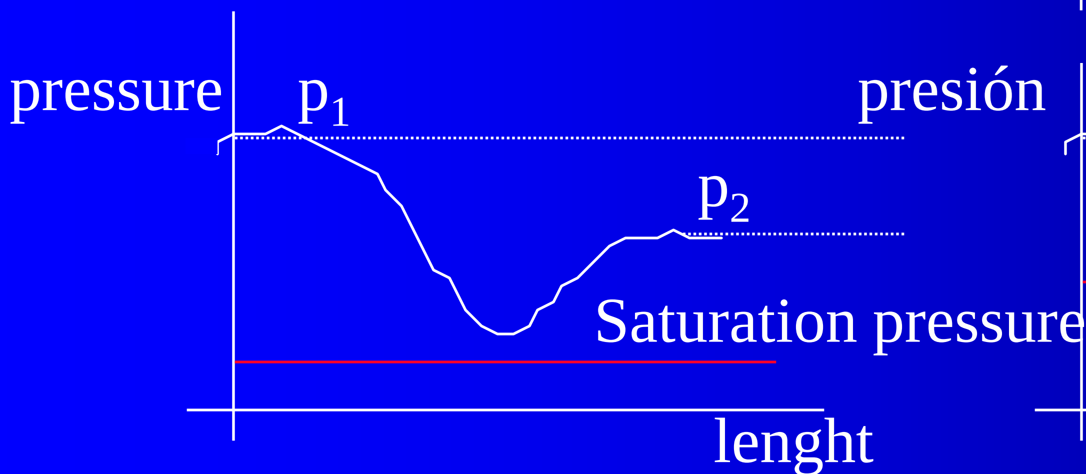
% steam position

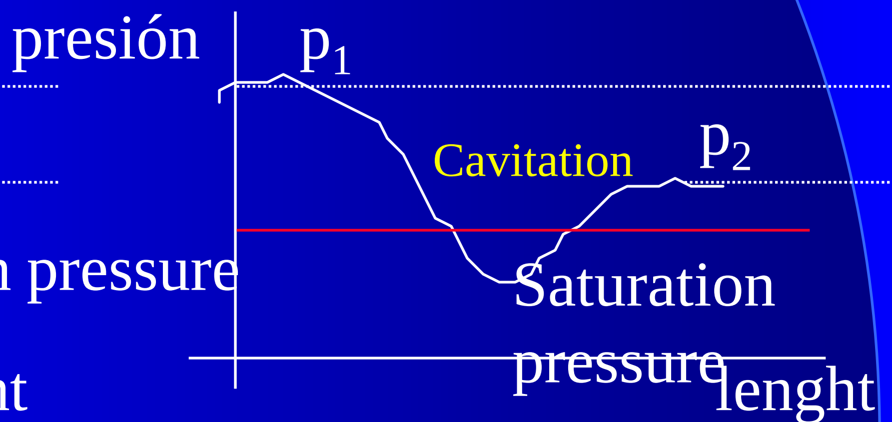
Cavitation / Flashing

The liquid will boil if its pressure is below the saturation one





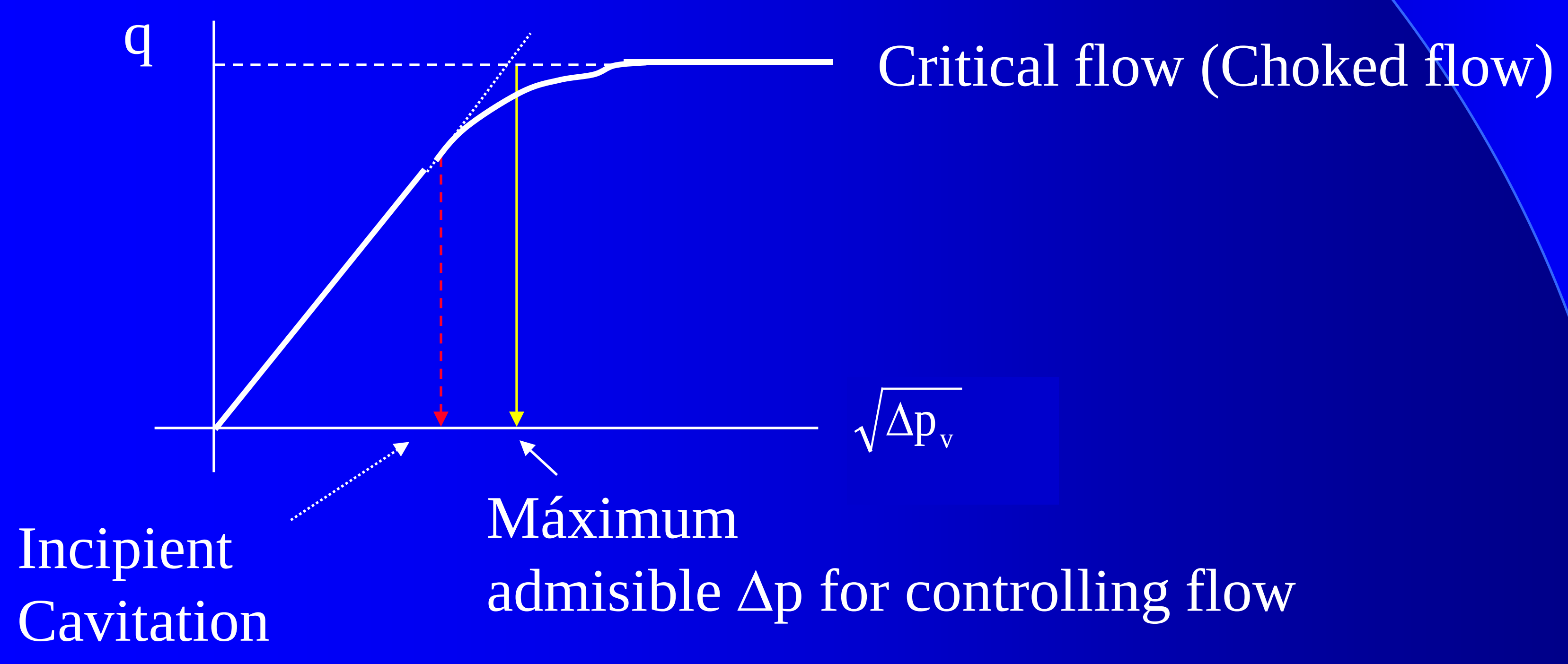




Flashing

$$q = \frac{aC_v}{1.16}\sqrt{\frac{\Delta p_v}{\rho}}$$

As Δp_v increased q increases until flashing appears which will choke the flow

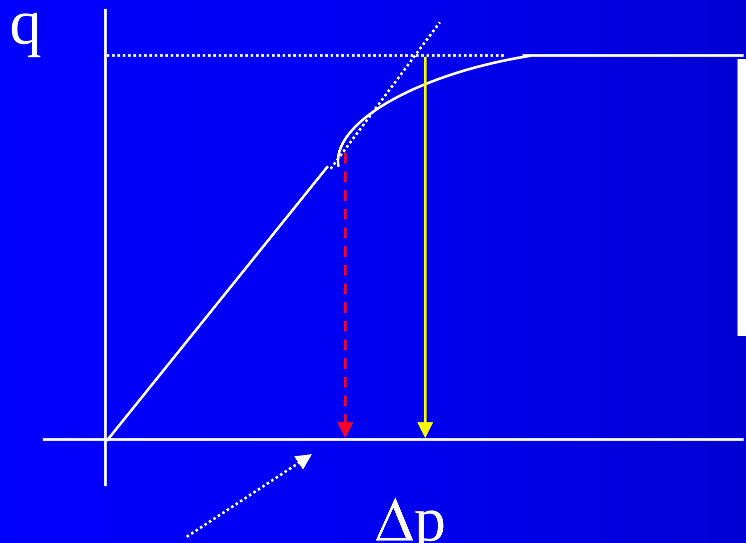


Flashing / Cavitation

$$q = \frac{aC_v}{1.16}\sqrt{\frac{\Delta p_v}{\rho}}$$

K_c incipient cavitation Coefficient

$$\Delta p_v \le K_c(p_1 - p_v)$$



$$\Delta p_M = C_f^2\left[p_1 - p_v\left(0.96 - 0.28\sqrt{\frac{p_v}{p_c}}\right)\right]$$

Δp_M Maximum admisible pressure drop

C_f Critical flow Factor

p_c critical point pressure

More precise formulas for gases

$$q = \frac{a\, C_f C_v p_1 \sqrt{\rho}\,(y - 0.148 y^3)}{54.5} \quad \text{gas}$$

$$y = \frac{1.63}{C_f}\sqrt{\frac{\Delta p_v}{p_1}} \qquad y \le 1.5$$

q Tm/h
p bars

$$q = \frac{a C_f C_v p_1 (y - 0.148 y^3)}{83.7} \quad \text{saturated steam}$$

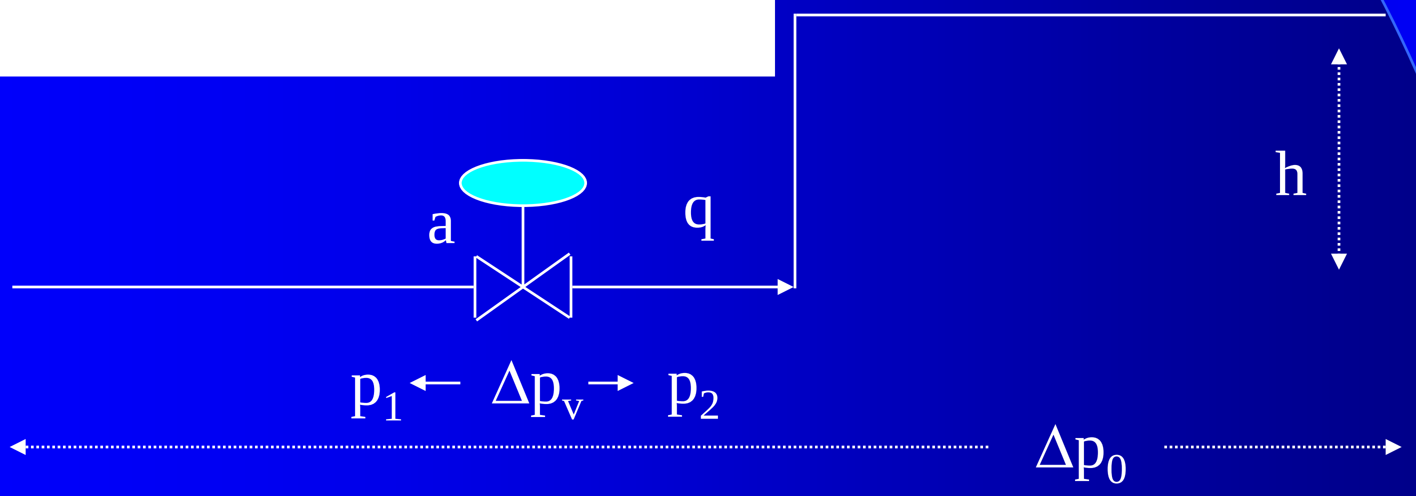
$$q = \frac{a C_f C_v p_1}{83.7} \quad \text{critical flow}$$

Installed Characteristics

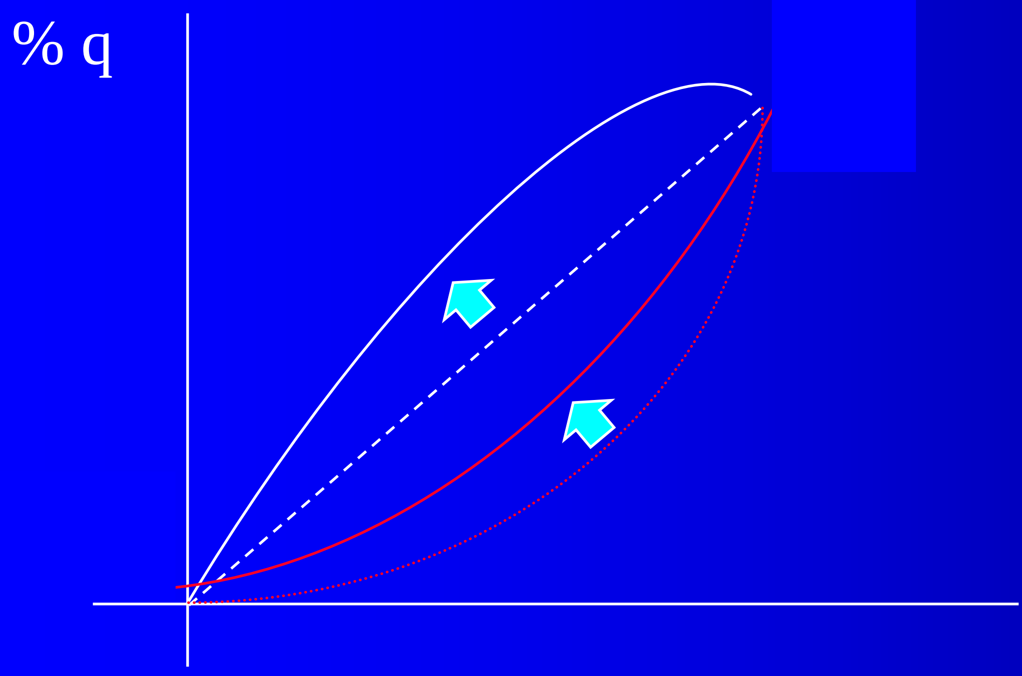
$$q = \frac{aC_v}{1.16}\sqrt{\frac{\Delta p_v}{\rho}}$$

$$q = \frac{1}{1.16}\sqrt{\frac{\Delta p_0 - \rho g h}{\rho\left(K_L + \frac{1}{a^2 C_v^2}\right)}}$$

$$\Delta p_0 = \Delta p_v + K_L \rho q^2 + \rho g h$$



Installed Characteristics



$$q = \frac{1}{1.16}\sqrt{\frac{\Delta p_0 - \rho g h}{\rho\left(K_L + \frac{1}{a^2 C_v^2}\right)}}$$

Valve sizing

- Critical for many control loops
- Find the adequate C_v and type of valve
- Commercial Software available

Fisher

Masoneilan

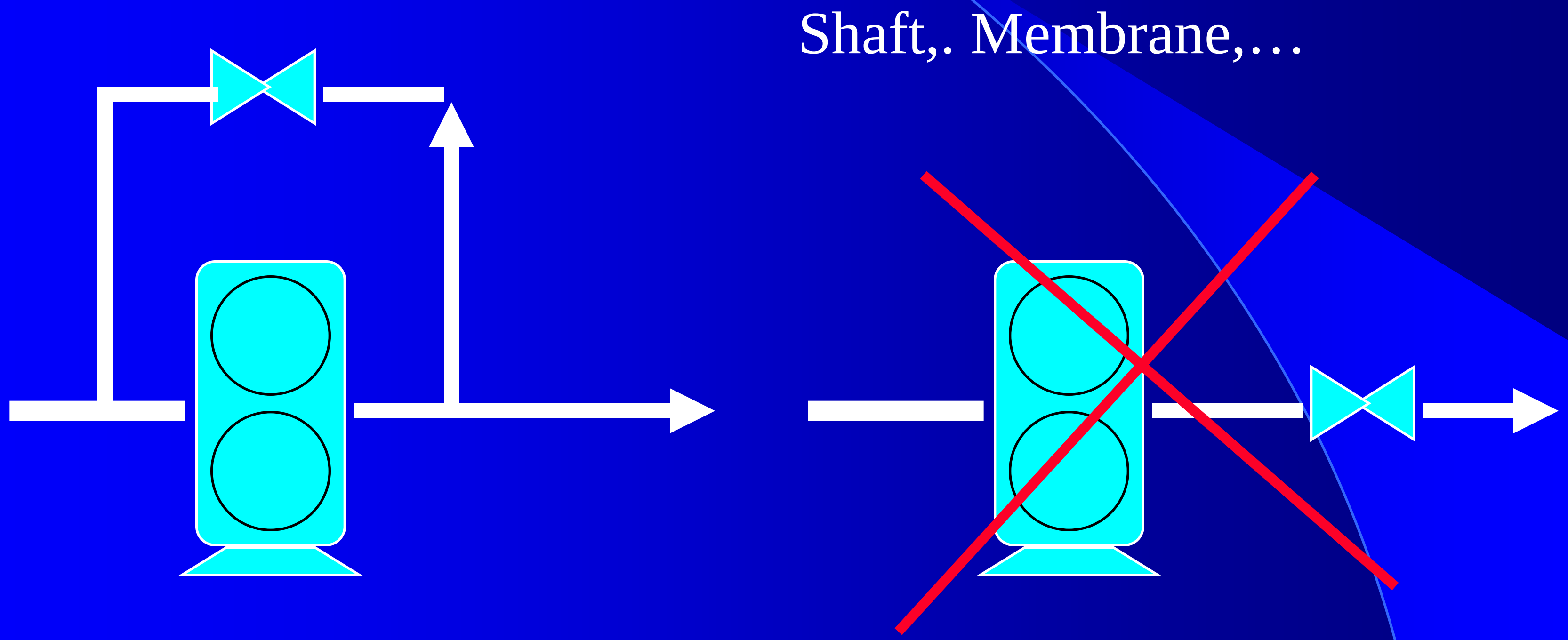
http://www.emersonprocess.com/fisher/

http://www.masoneilan.com/

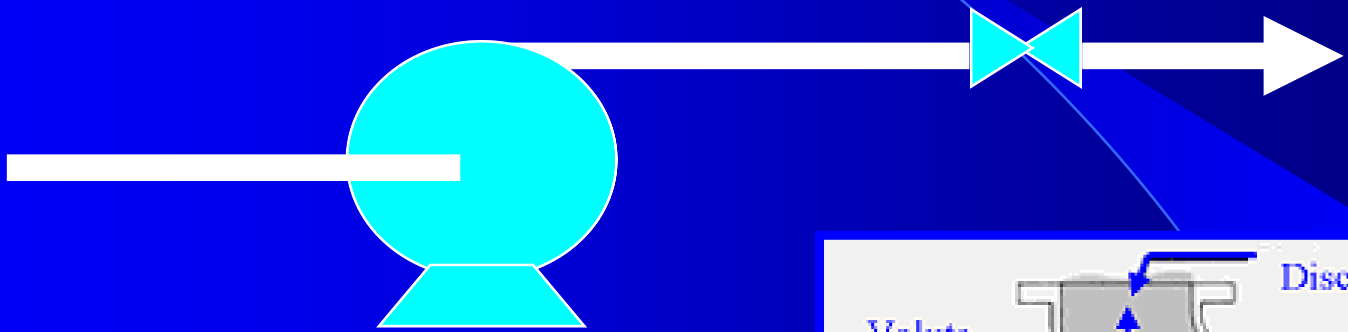
Pumps

- Positive displacement
- Centrifugals
- Installation
- Power and efficiency
- Characteristic curve
- Cavitation

Positive Displacement



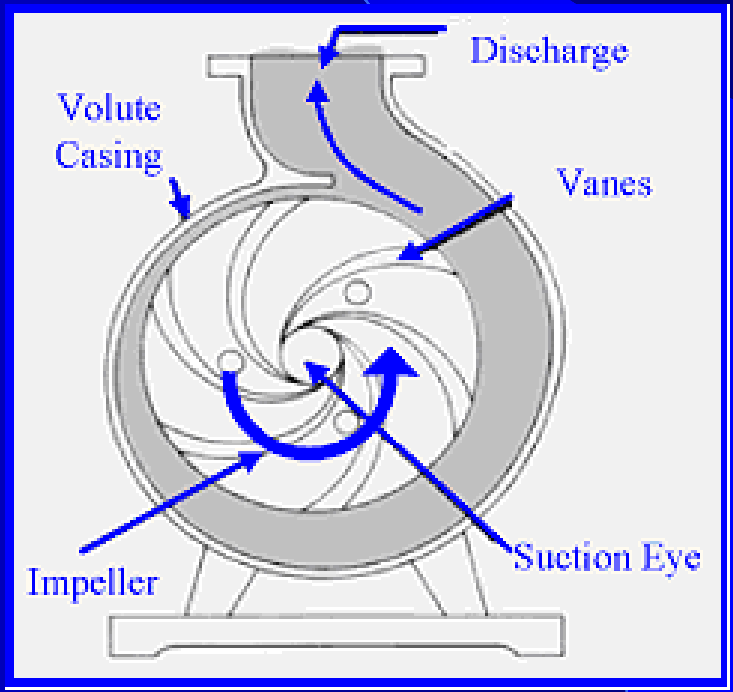
Centrifugal pumps



Mechanical energy

Electrical energy

Impeller



Centrifugal pump

Energy increment = supplied energy - losses

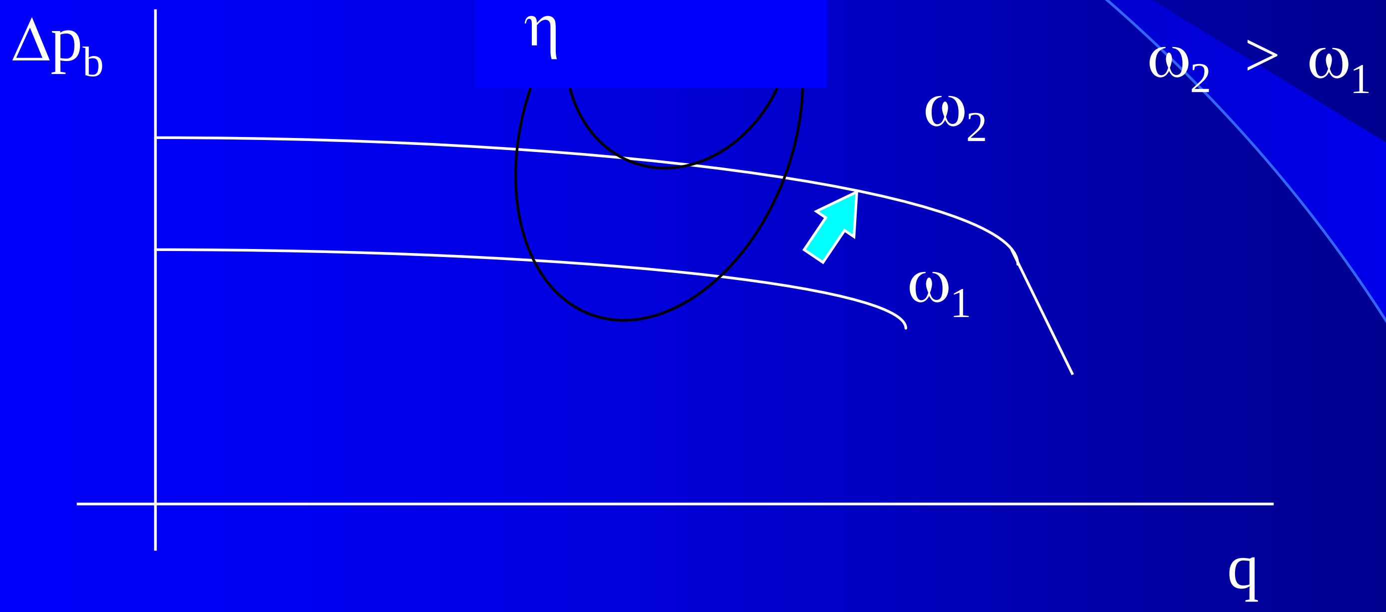
$$\Delta p_b = \rho\left(aw^2 - bq^2\right)$$

$$P = 36.022\Delta p_b q \quad P \text{ Supplied power}$$

$$P = \eta W \quad W \text{ Absorved power}$$

P	kw
q	m^3/h
p	bars

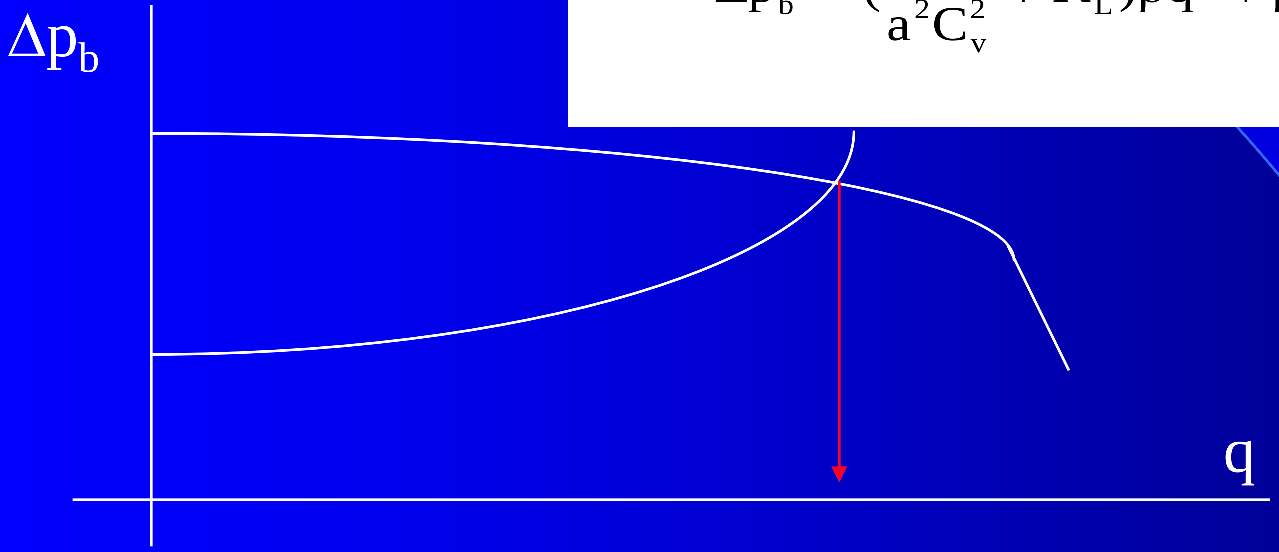
Characteristic curves

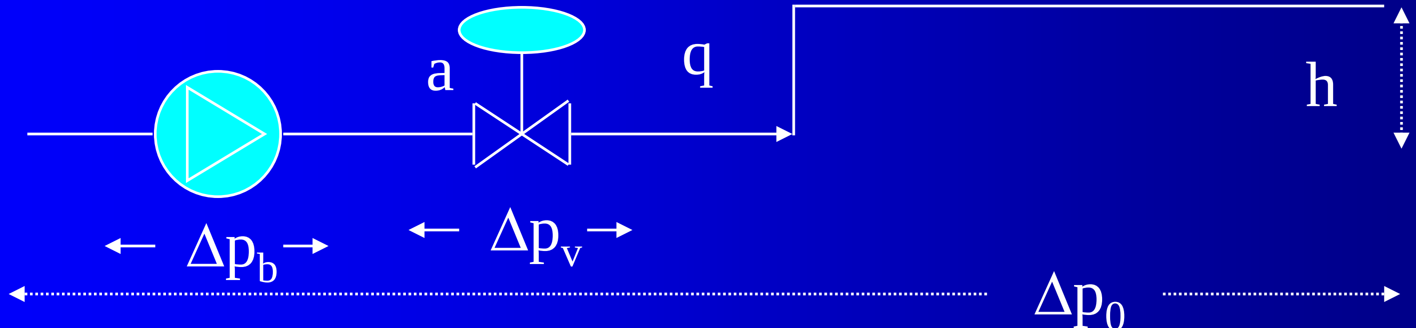


Operating point

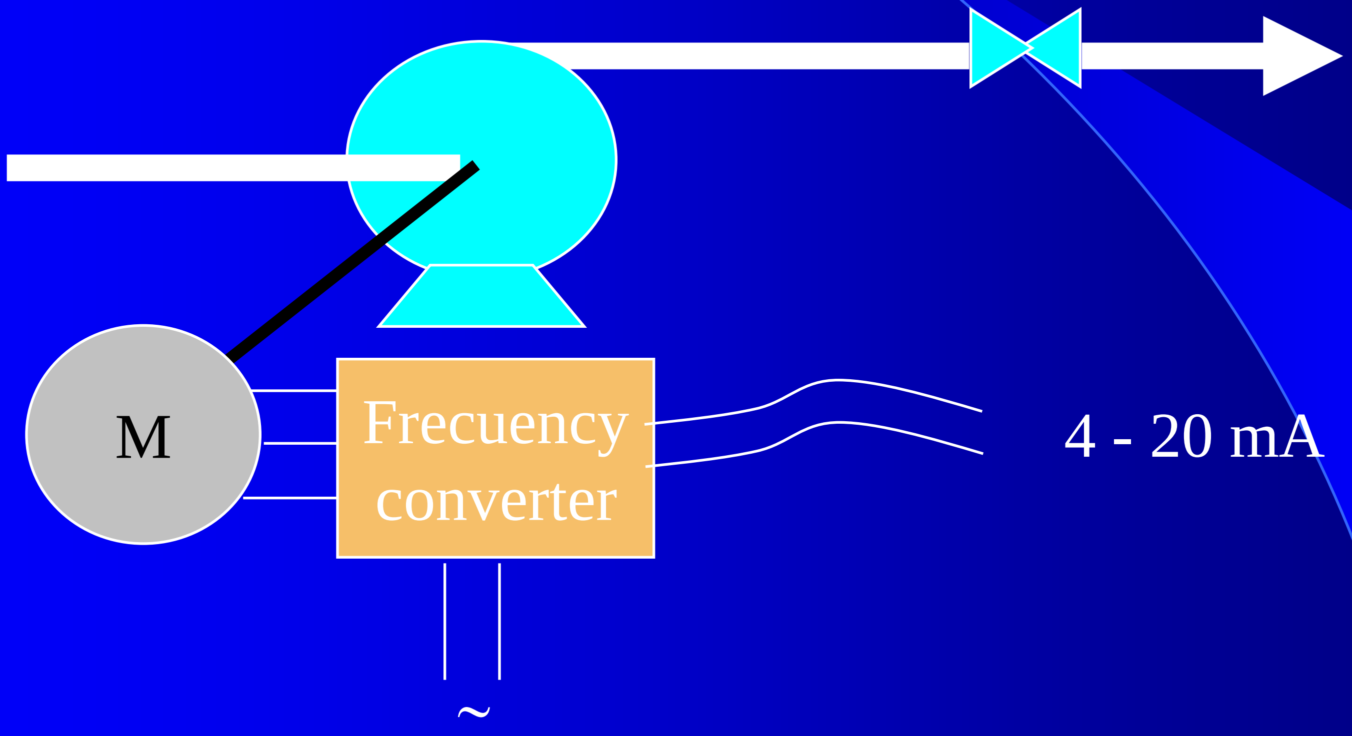
$$\Delta p_0 + \Delta p_b = \Delta p_v + K_L \rho q^2 + \rho g h =$$

$$\Delta p_b = \left(\frac{1}{a^2 C_v^2} + K_L\right)\rho q^2 + \rho g h - \Delta p_0$$

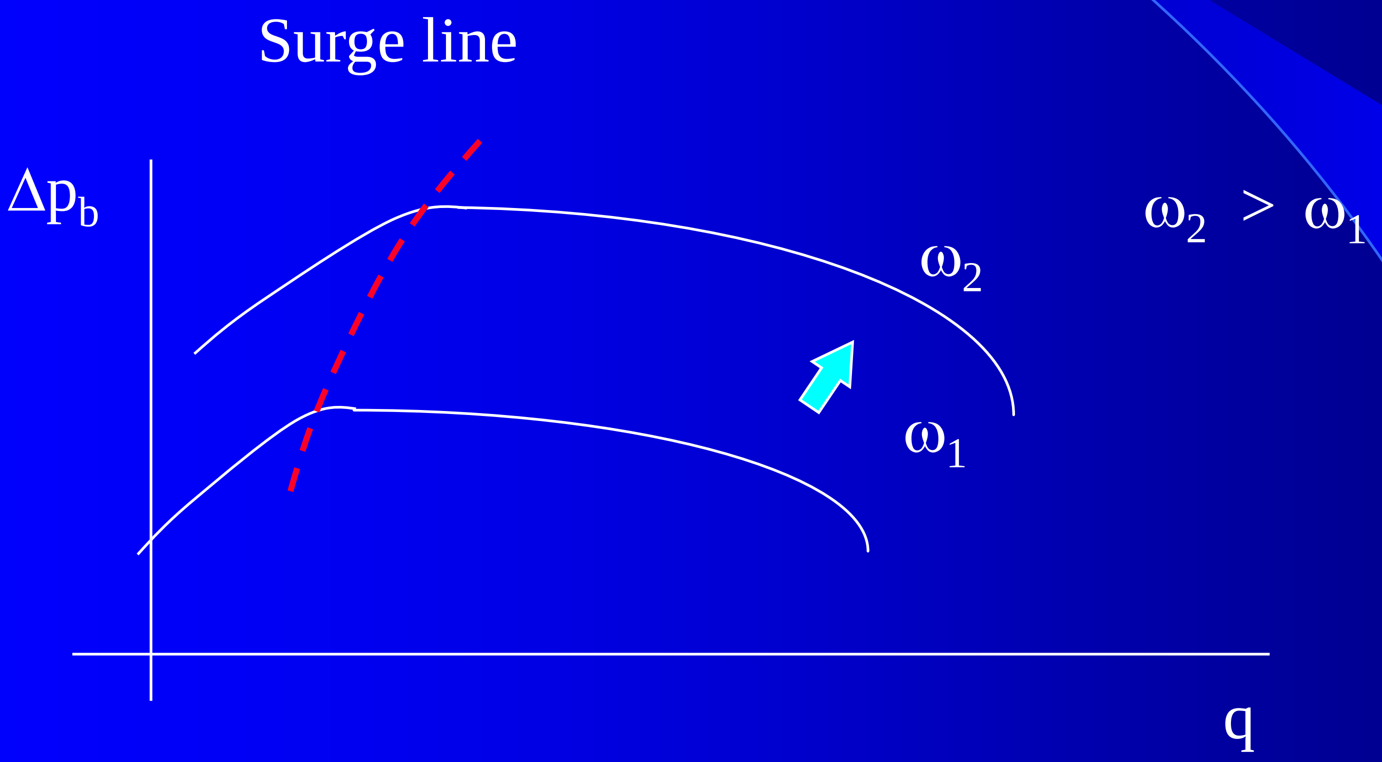




Variable speed pumps



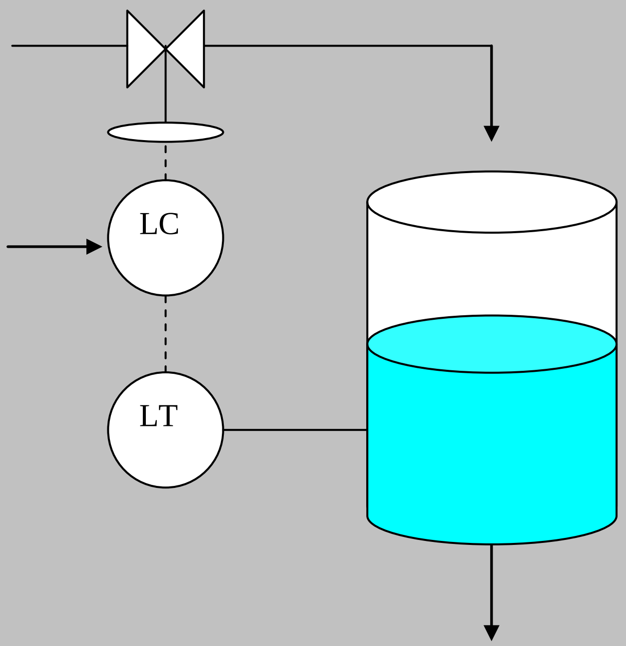
Centrifugal Compressors



Exercise

Select the instrumentation from a commercial supplier and fill in the form.

Select commercial instruments for the implementation of the following control loop:



Maximum flow: 120 m3/h
Nominal flow: 60 m3/h
Max height: 4 m
Max Temperature: 80 ºC
Nominal temperarure: 50 ºC
Pipe diameter: 10 cm.
Pressure in the pipe: 2 bar
Fluid: water

And fill in the following form:

Transmitter		**Valve**	
Type of measurement		Kind of valve	
Output signal		Air open / close	
Range		Cv	
Precision		Diameter	
Sensibility		K_c	
Linearity		Rangeability	
Max. temperature		Max. Pressure	
Process connection		Process Connection	
Manufacturer		Manufacturer	
Reference		Reference	