Controllers

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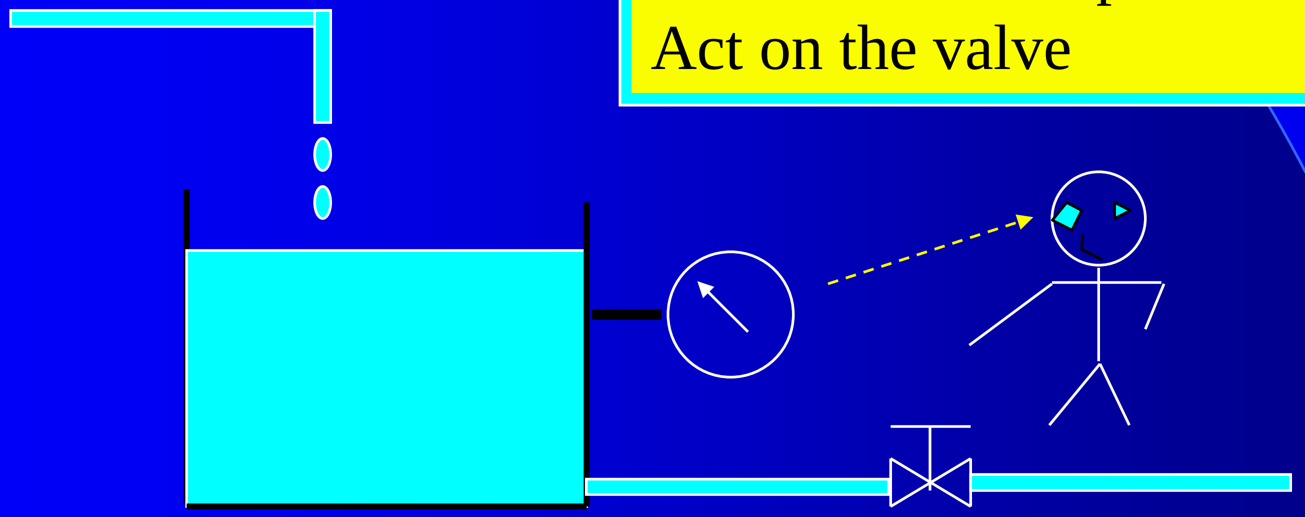
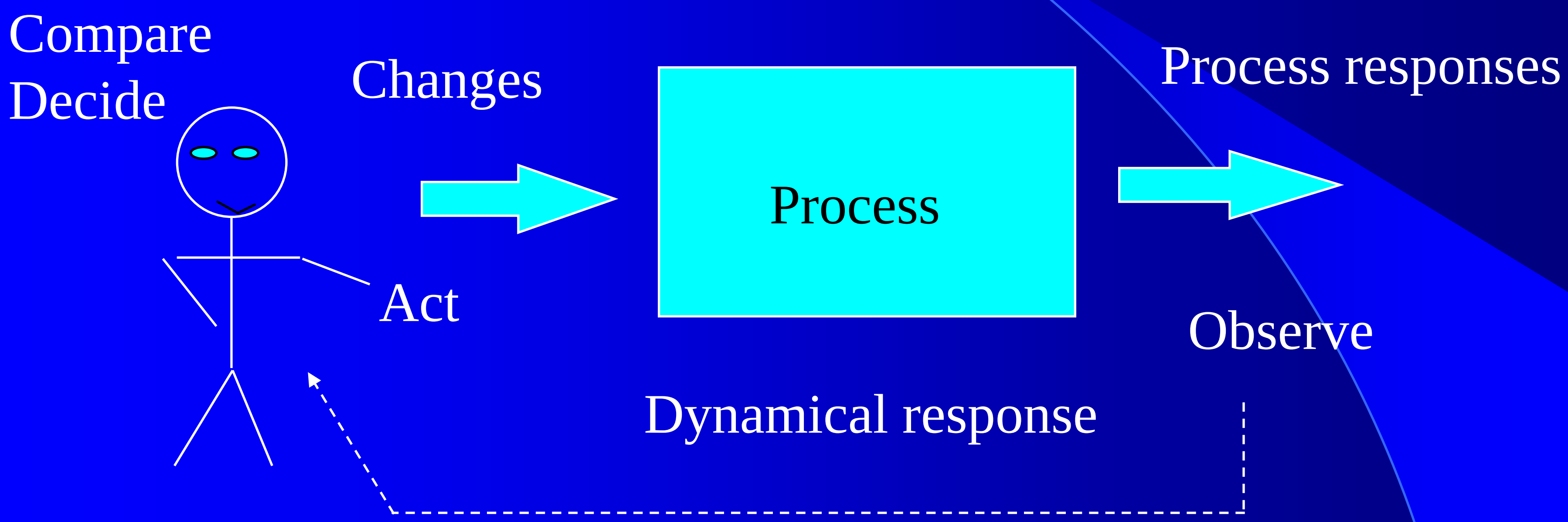
Manual operation of a process

Observe the level
Compare with desired value
Decide the valve position
Act on the valve

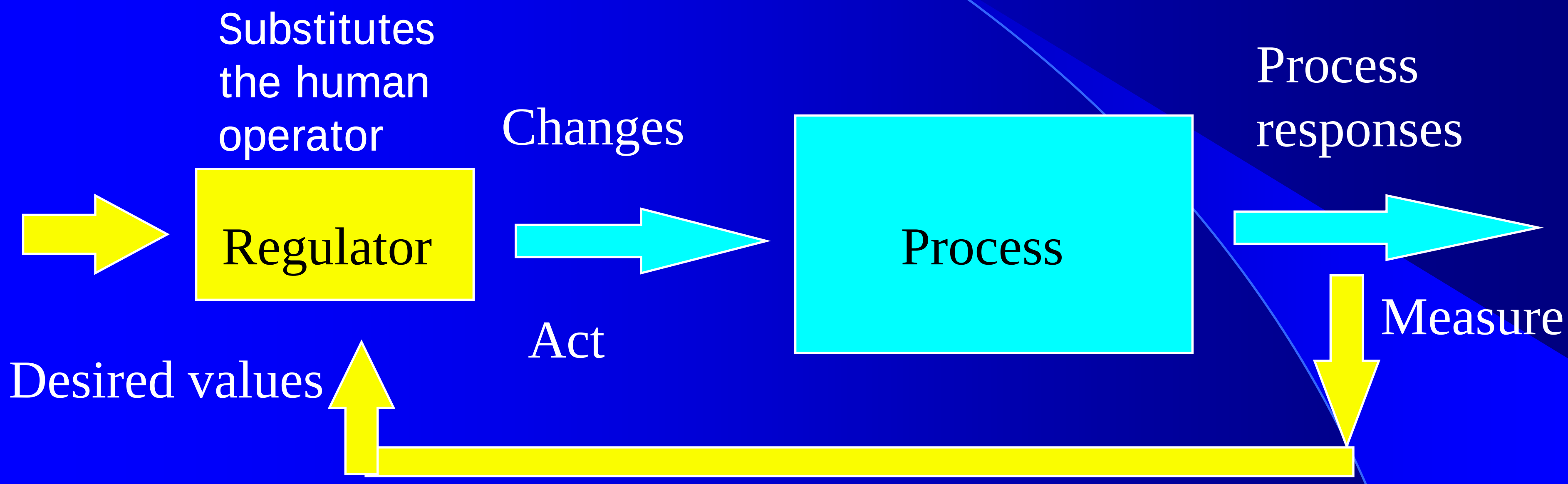


Process operation



Open loop or manual operation

Automatic operation

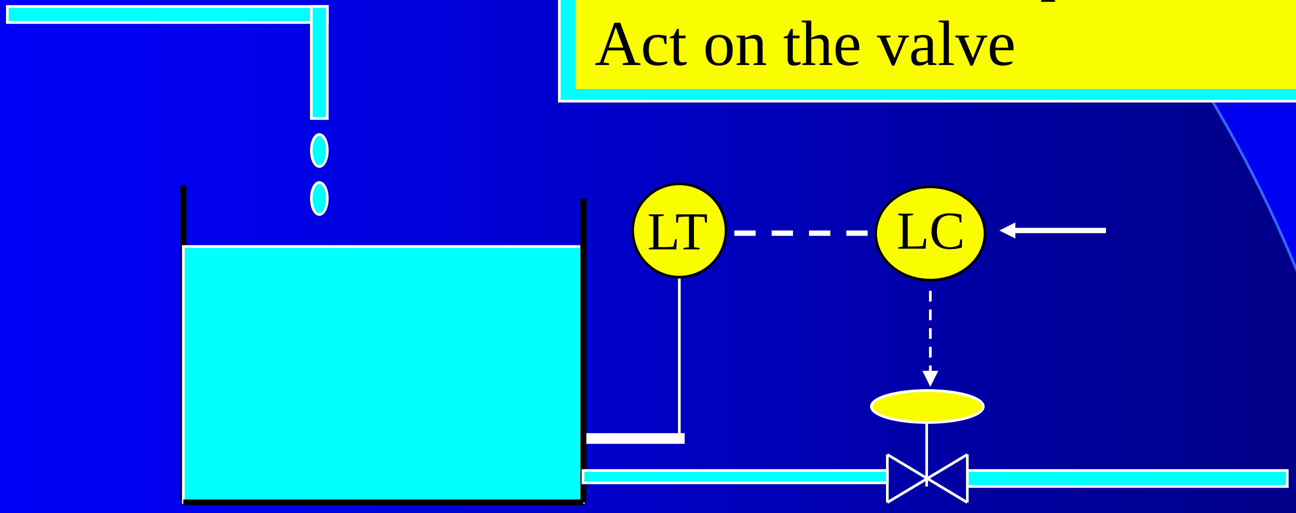


Closed loop or automatic operation

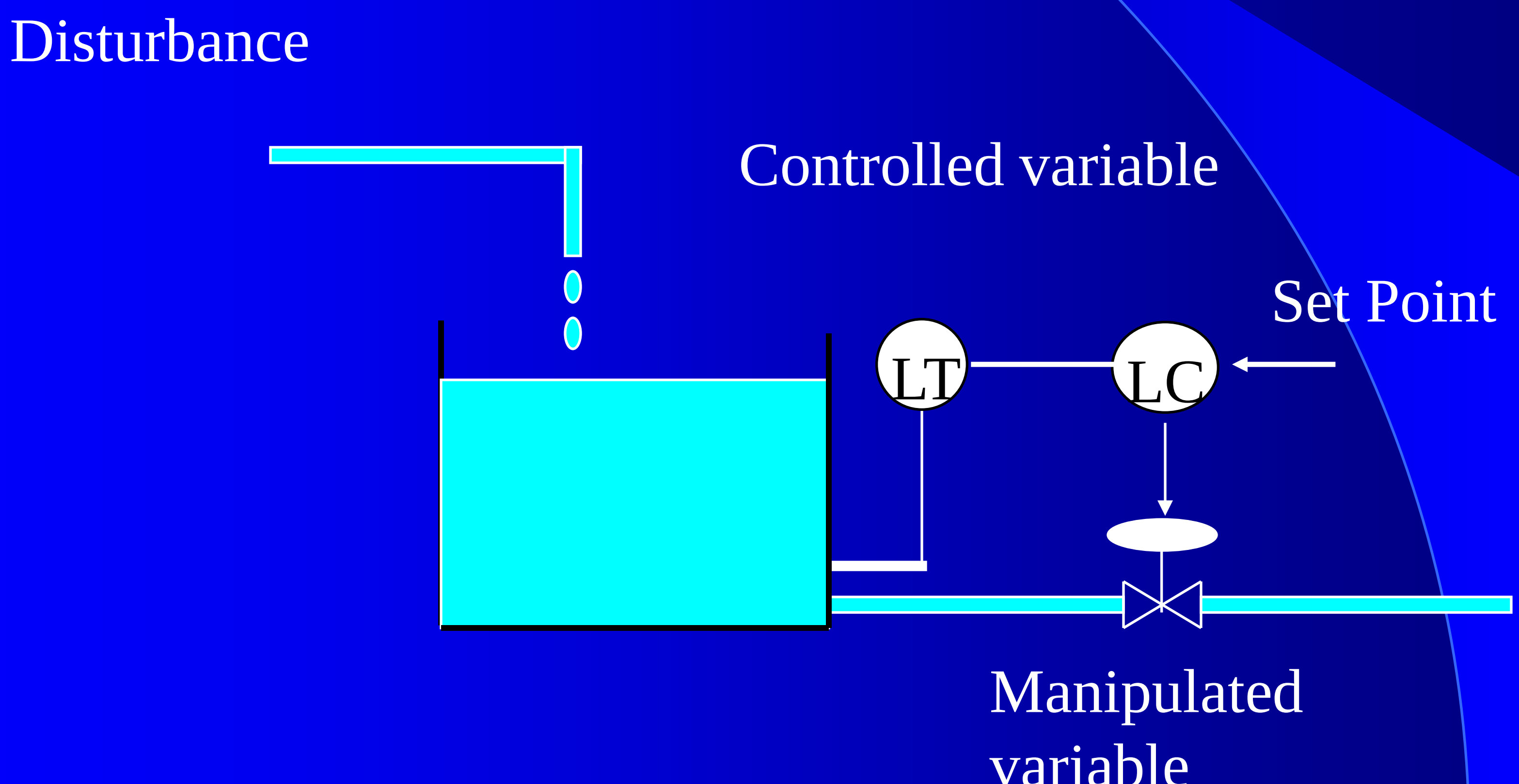
Feedback

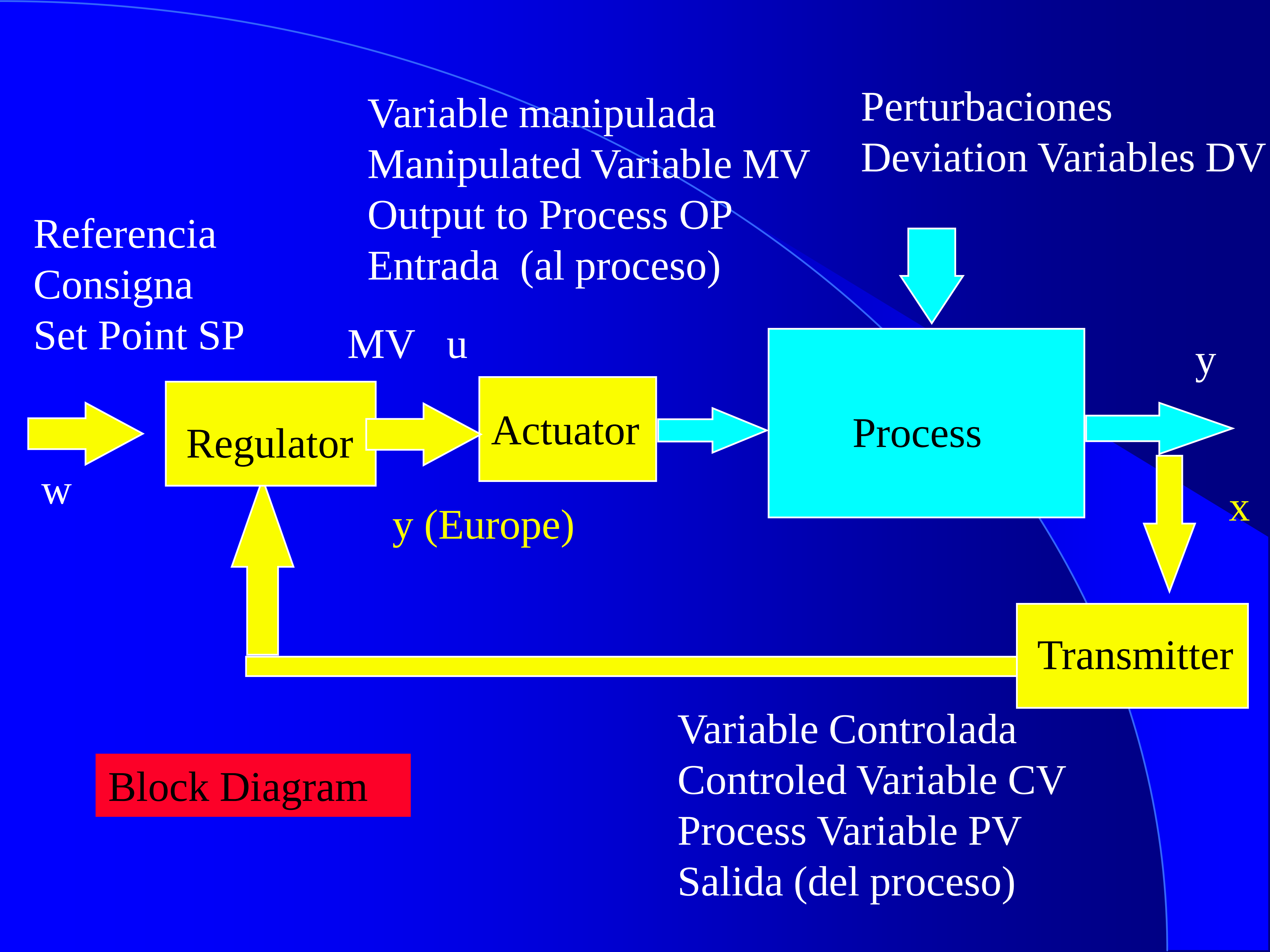
Automatic operation

Measure the level
Compare with desired value
Decide the valve position
Act on the valve

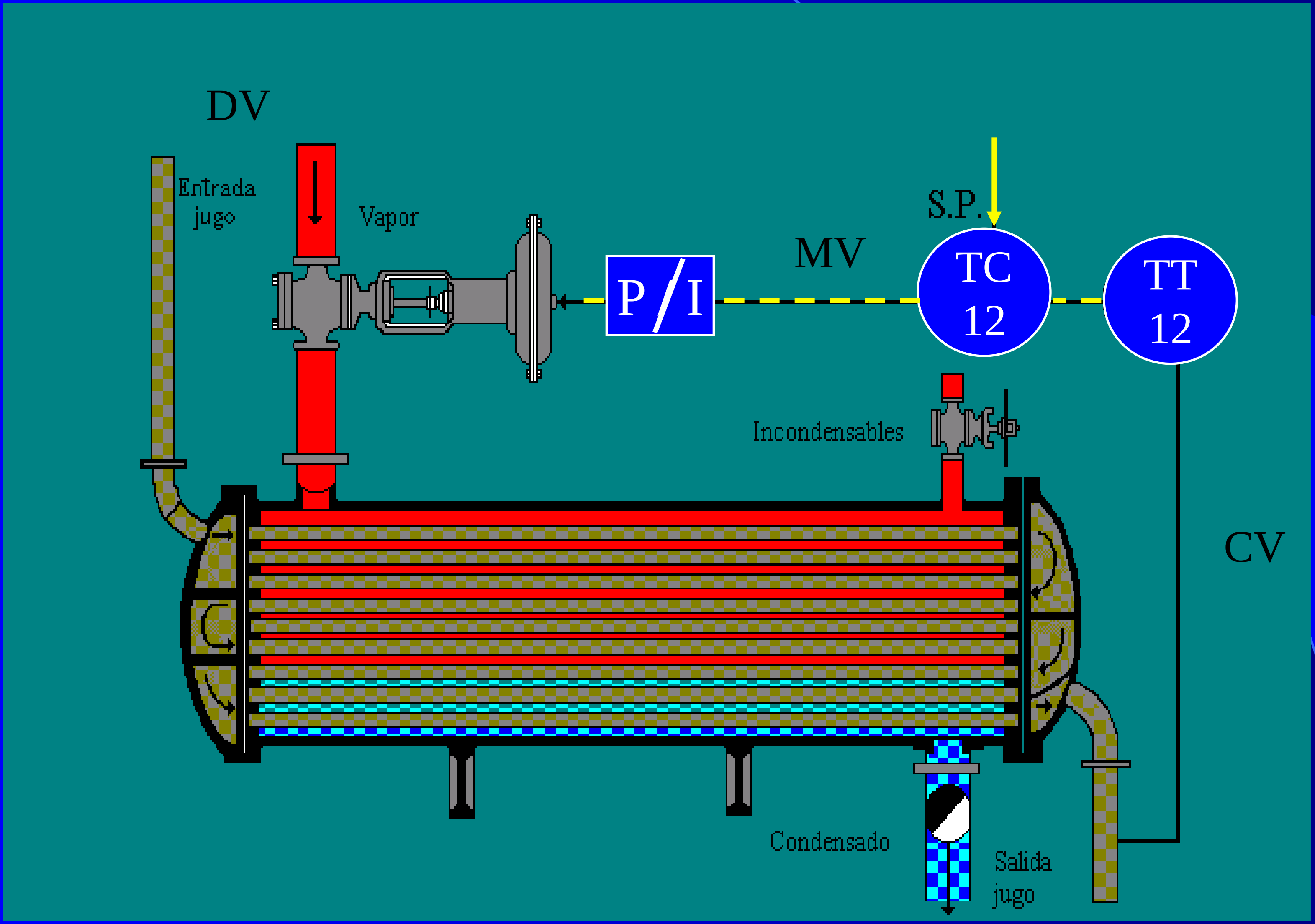


Terminology



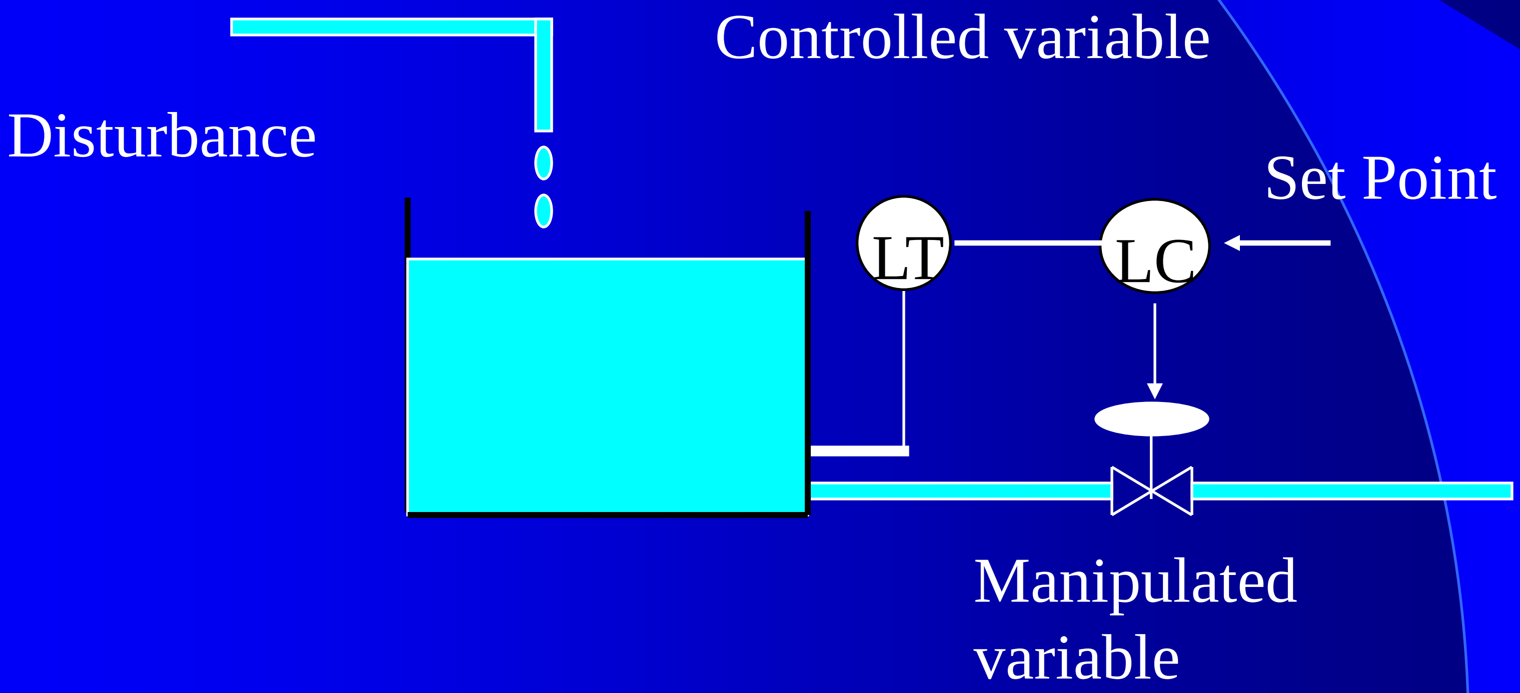

Variable manipulada
Manipulated Variable MV
Output to Process OP
Entrada (al proceso)
Perturbaciones
Deviation Variables DV
Referencia
Consigna
Set Point SP
MV u
Regulator
Actuator
Process
y
w
x
y (Europe)
Transmitter
Variable Controlada
Controled Variable CV
Process Variable PV
Salida (del proceso)
Block Diagram

Heat exchanger

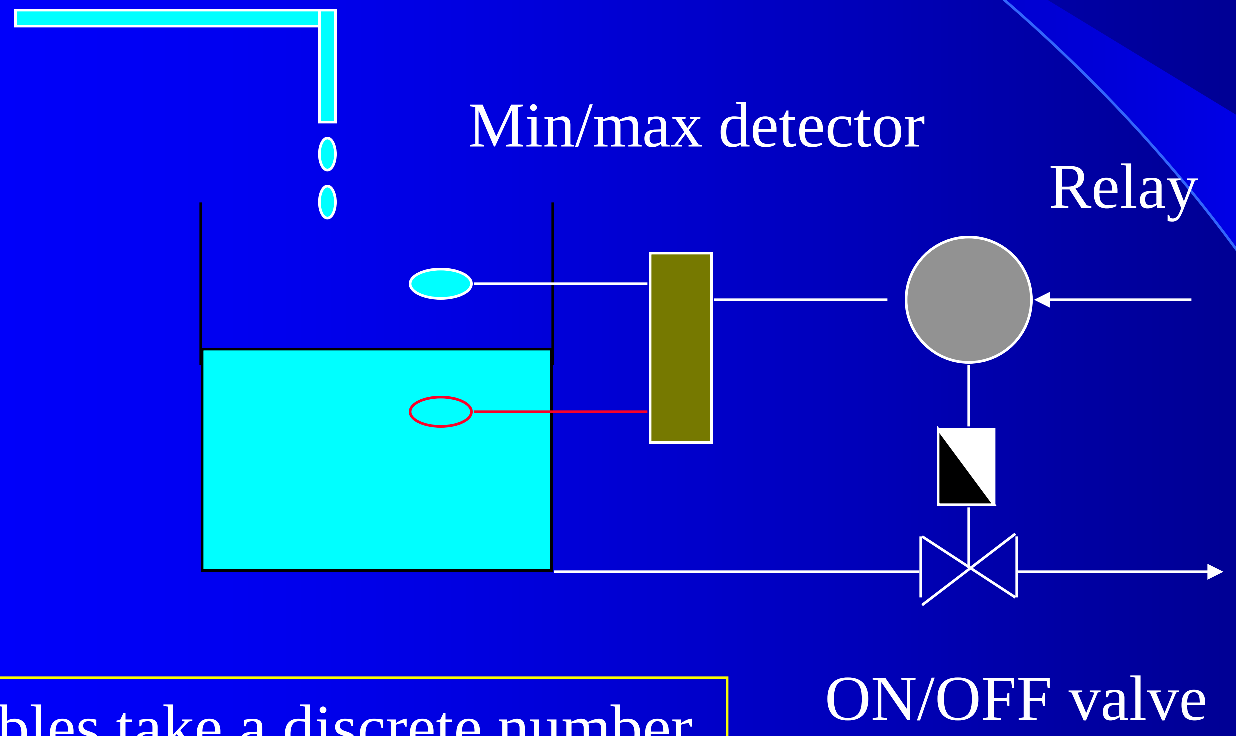


Continuous Control

The controlled variable takes continuous values within a range and the manipulated variable can have any value within a continuous range



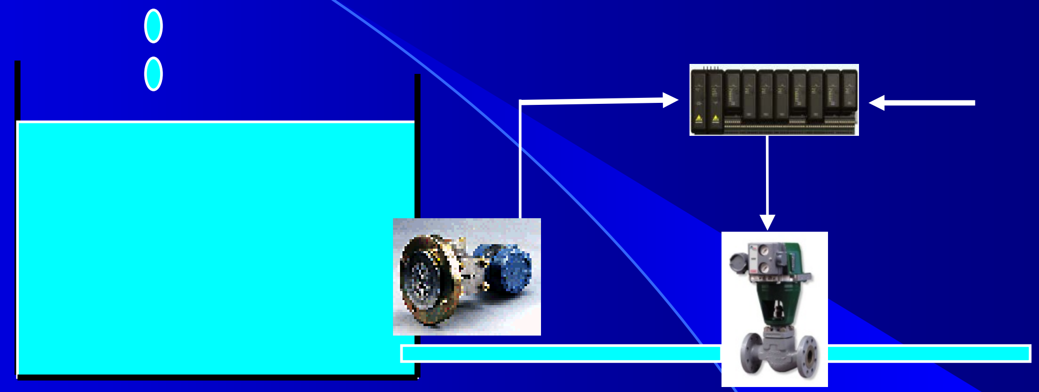
On/Off (Logic / Discrete) Control



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

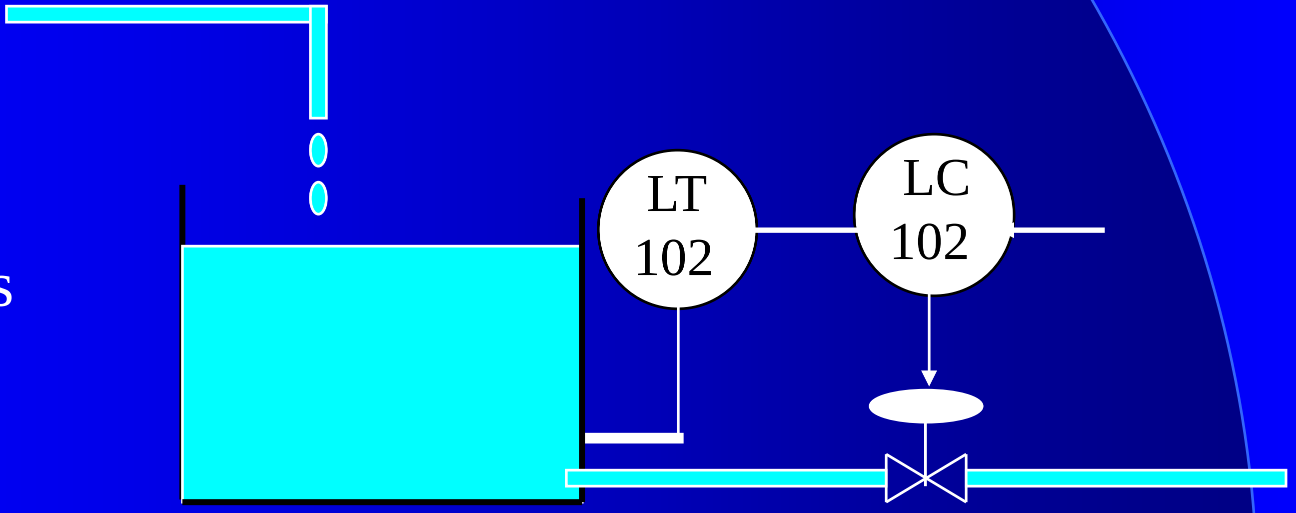
P&I Diagrams

Schematics where process units and instruments are represented using special symbols

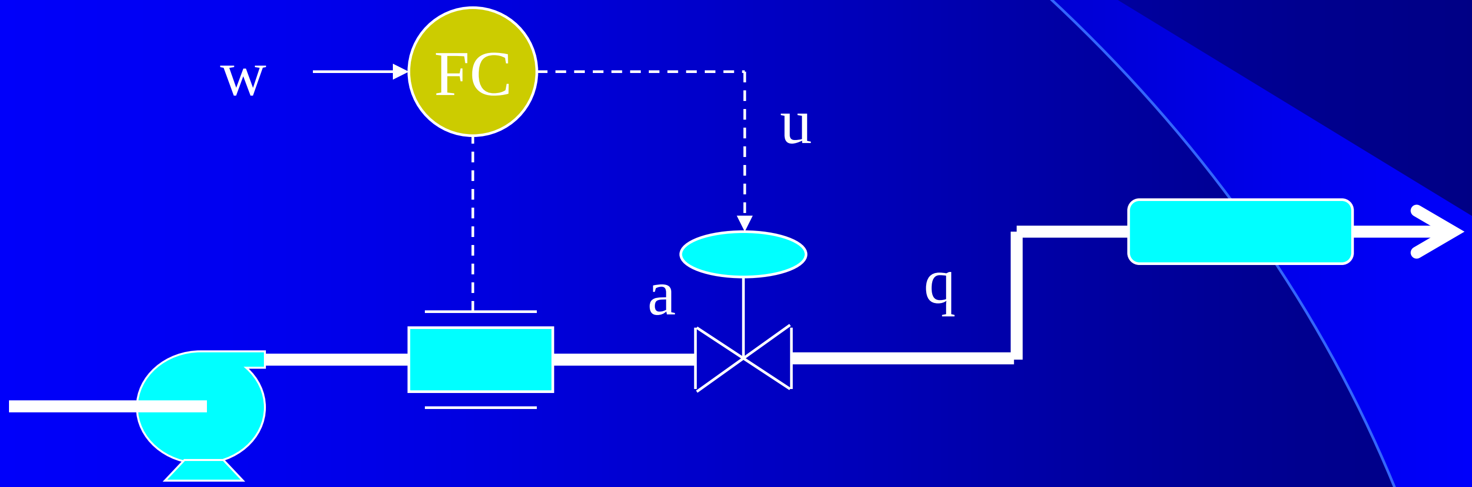


Control and measurement instruments are represented by circles with letters and figures

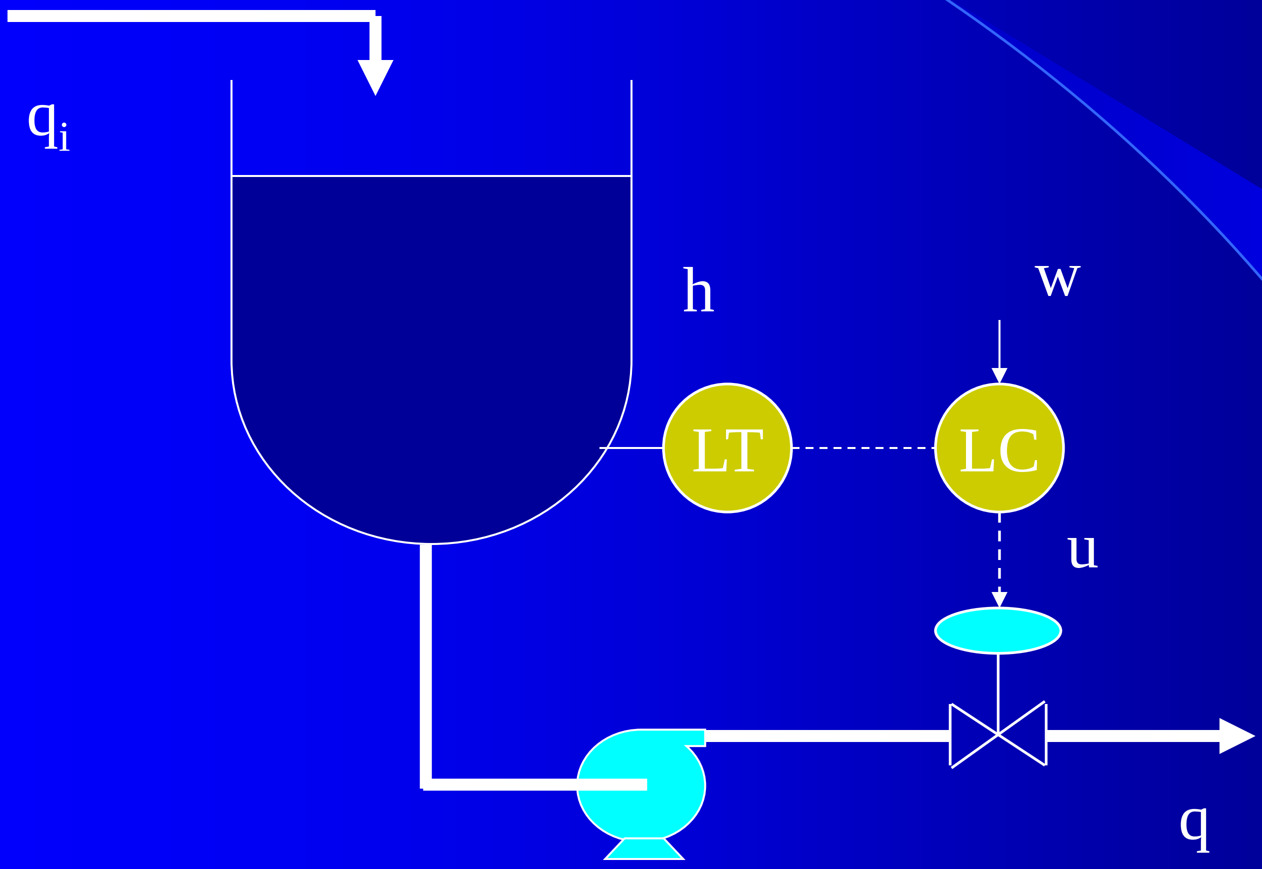
Connection lines



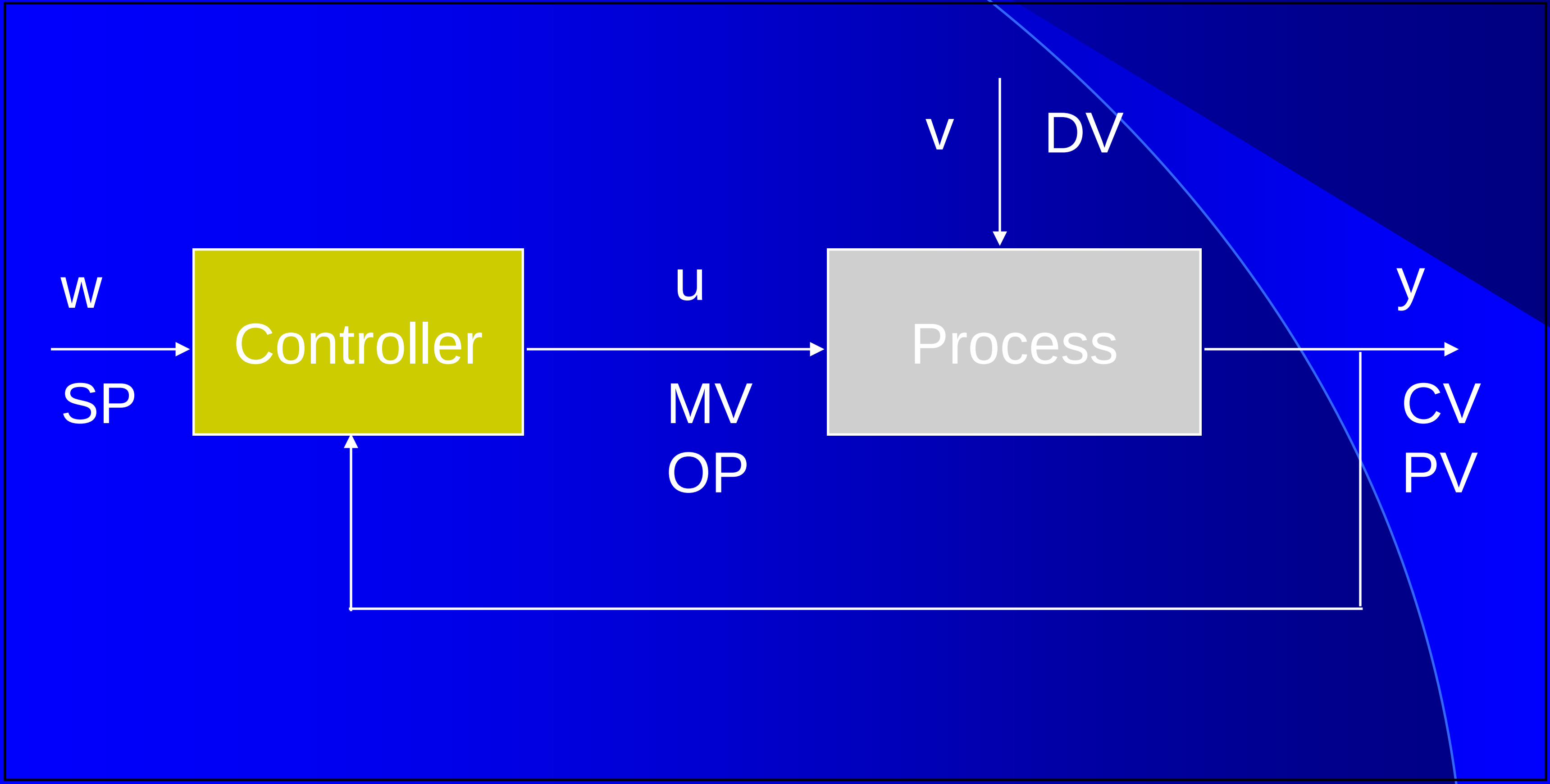
Flow control



Level control

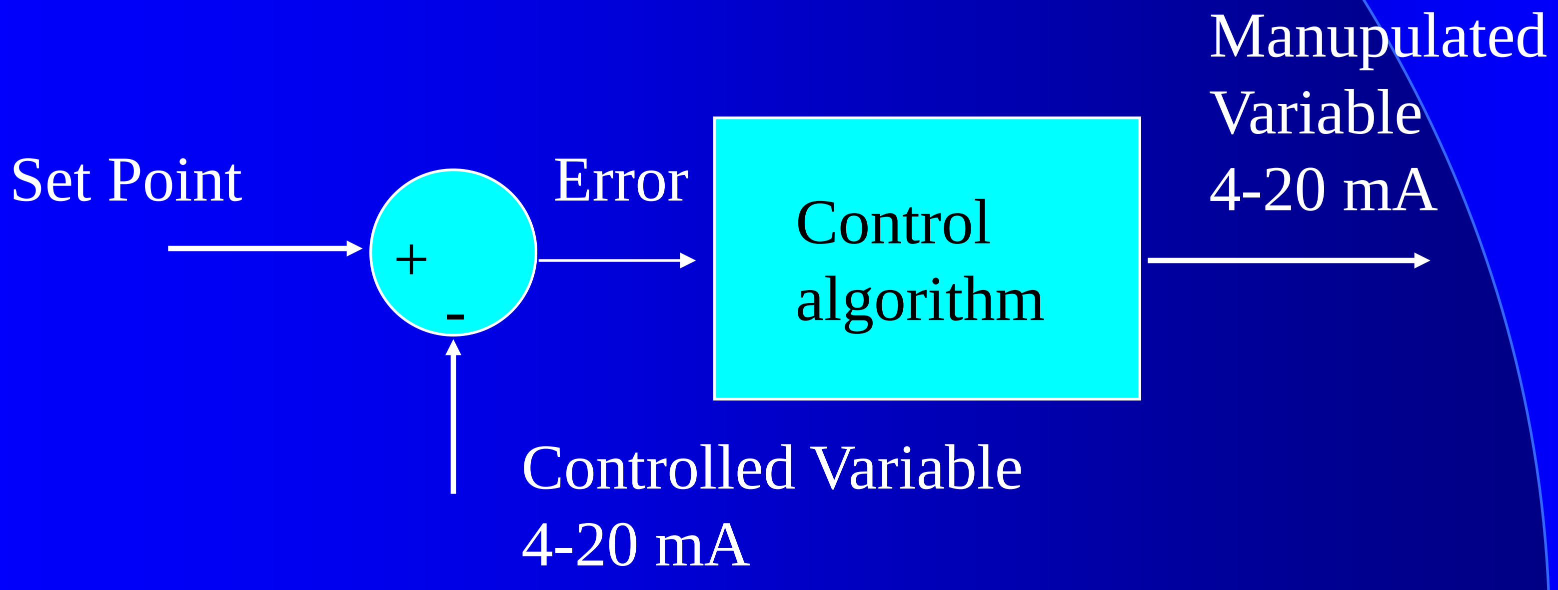


Block Diagram



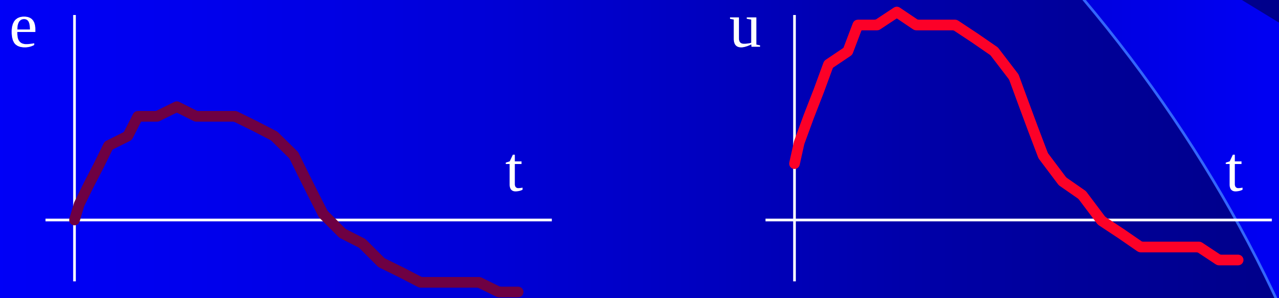
Controllers

- Generate a normalised signal to the actuator as a function of the values of the controlled variable and its desired value (SP)
- Most used: PID



Proportional controller P

$$u(t) = K_p e(t) + bias$$



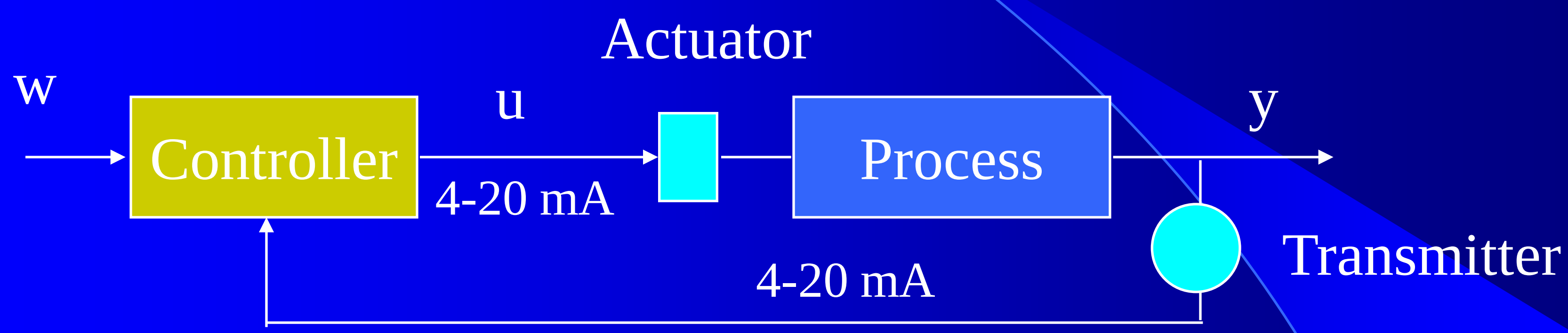
An error of x % creates an action of K_p x % on the actuator

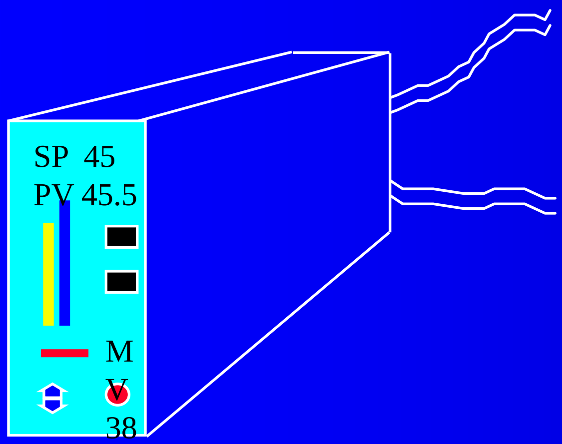
bias = manual reset (CV = SP)

Implementation

- Technologies:
  - Pneumatic
  - Electronics
  - Digital
- Loop controllers (PID)
- Within PLC
- Distributed Control Systems (DCS)
- Embedded systems

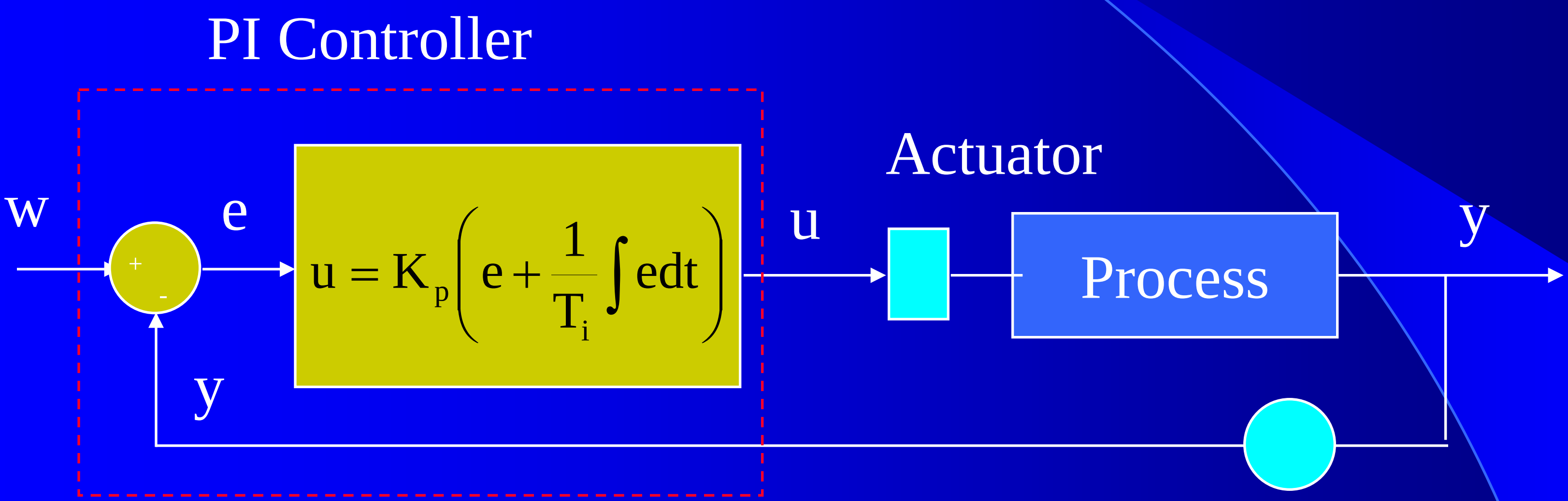
Normalised signals

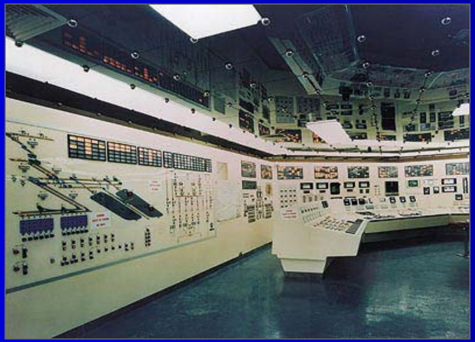




Loop controller

Controllers

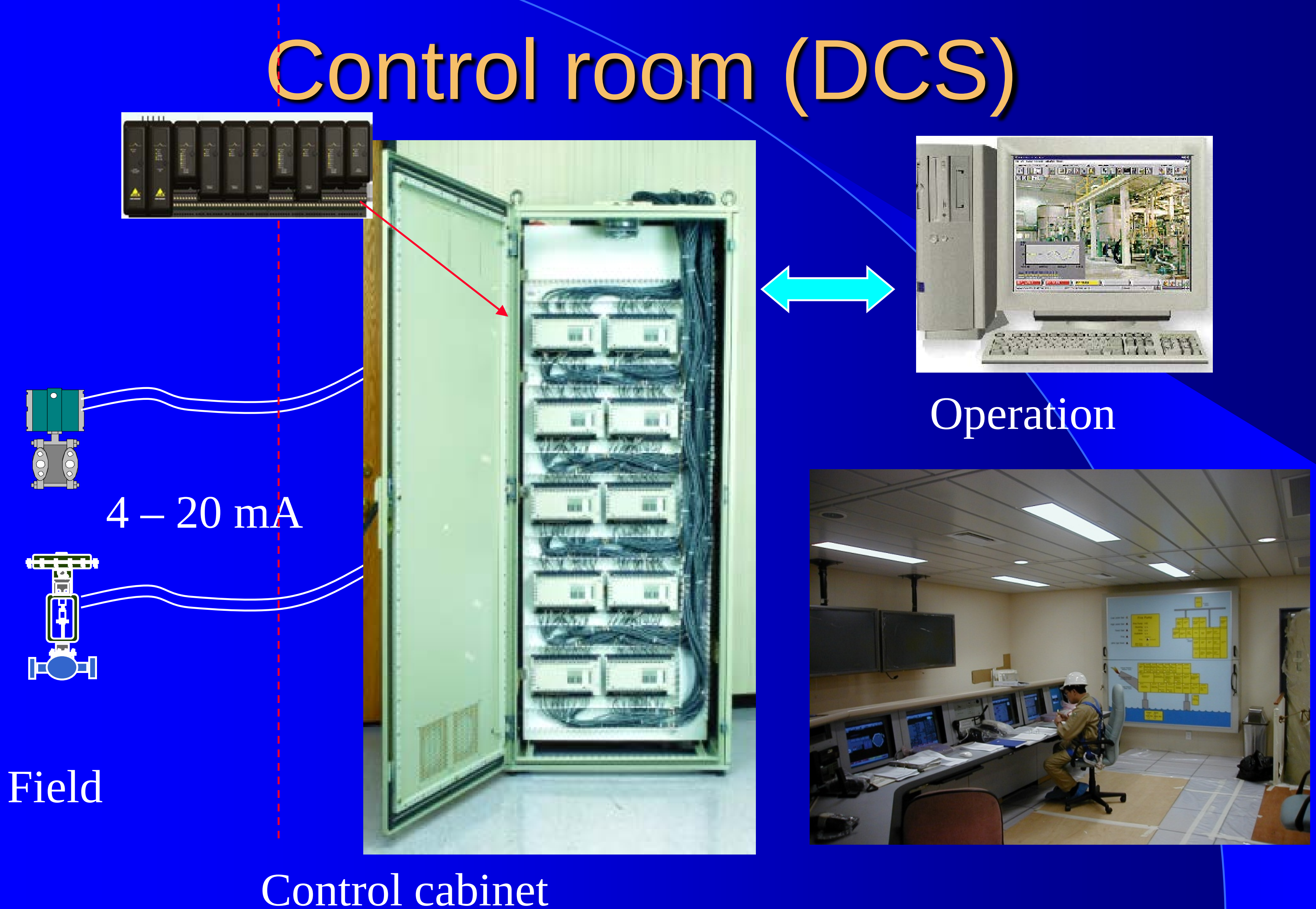




Transmitter

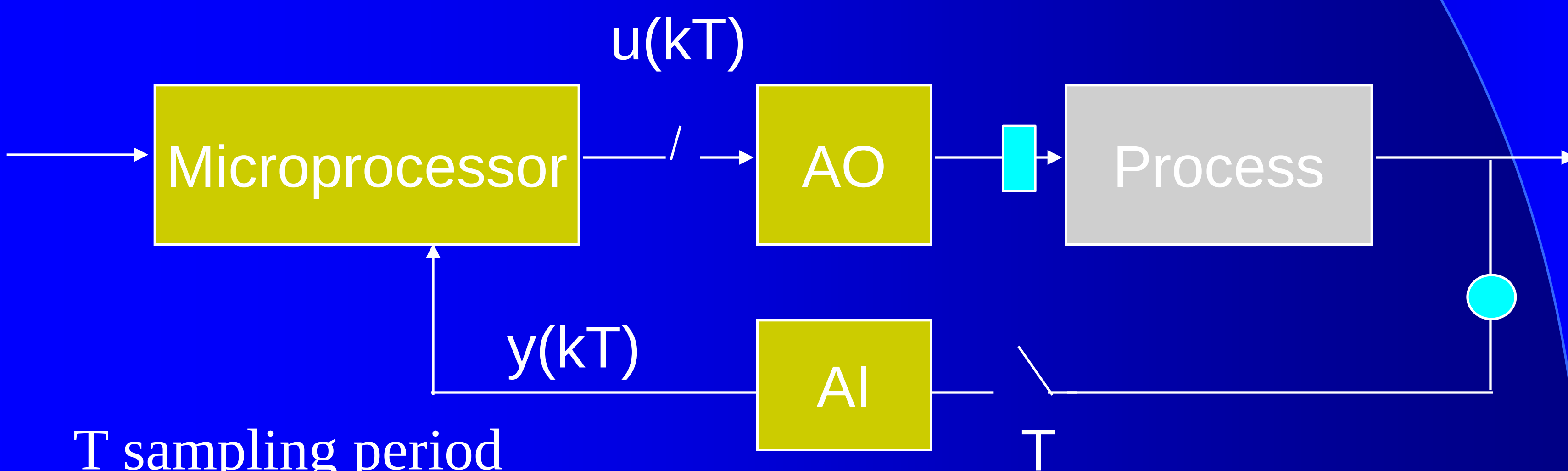
Panel mounting

Control room (DCS)



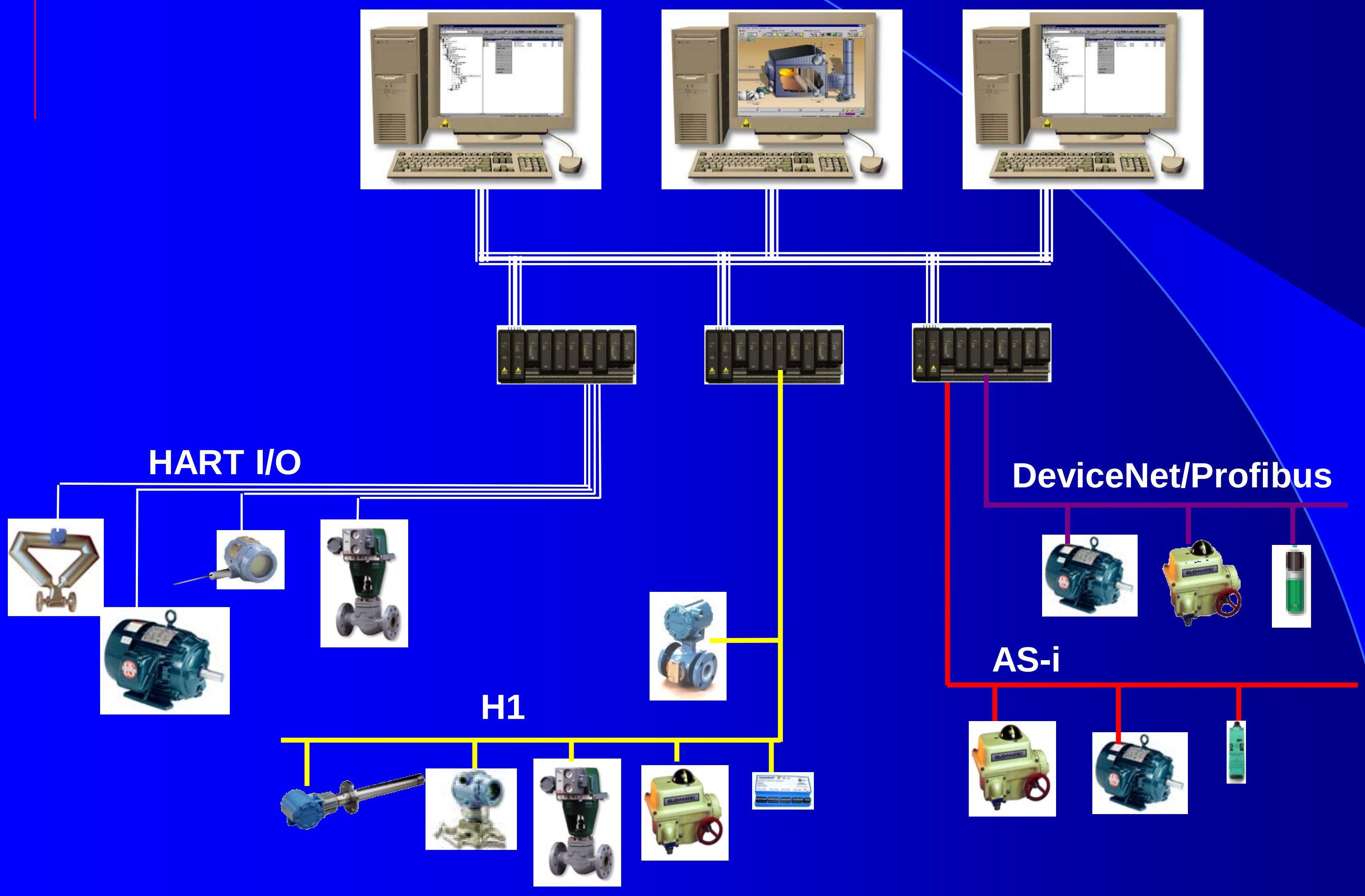
Computer control

Power supply, Ethernet AI AO Controller DI DO

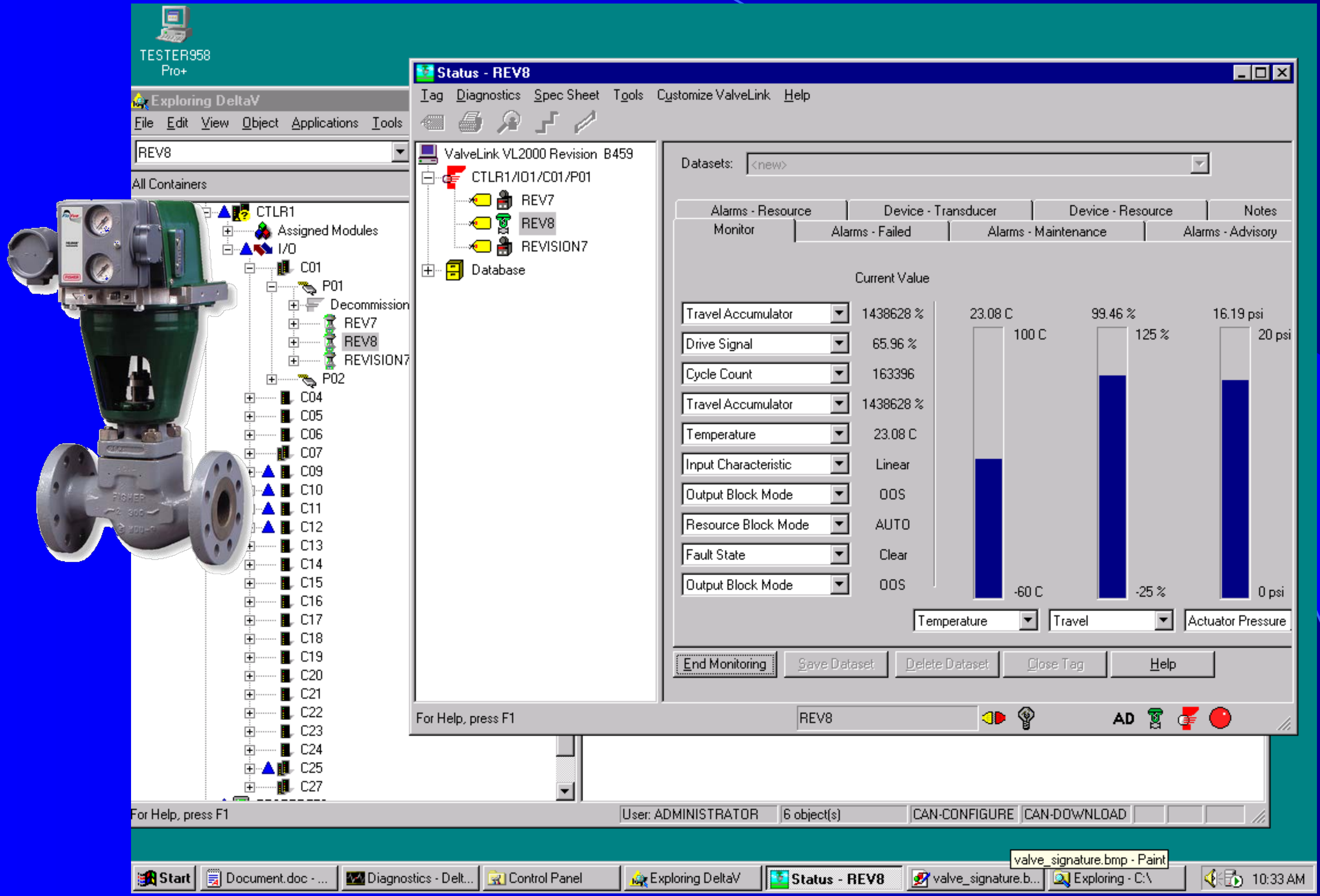


T sampling period

Architectures



Diagnosis, configuration



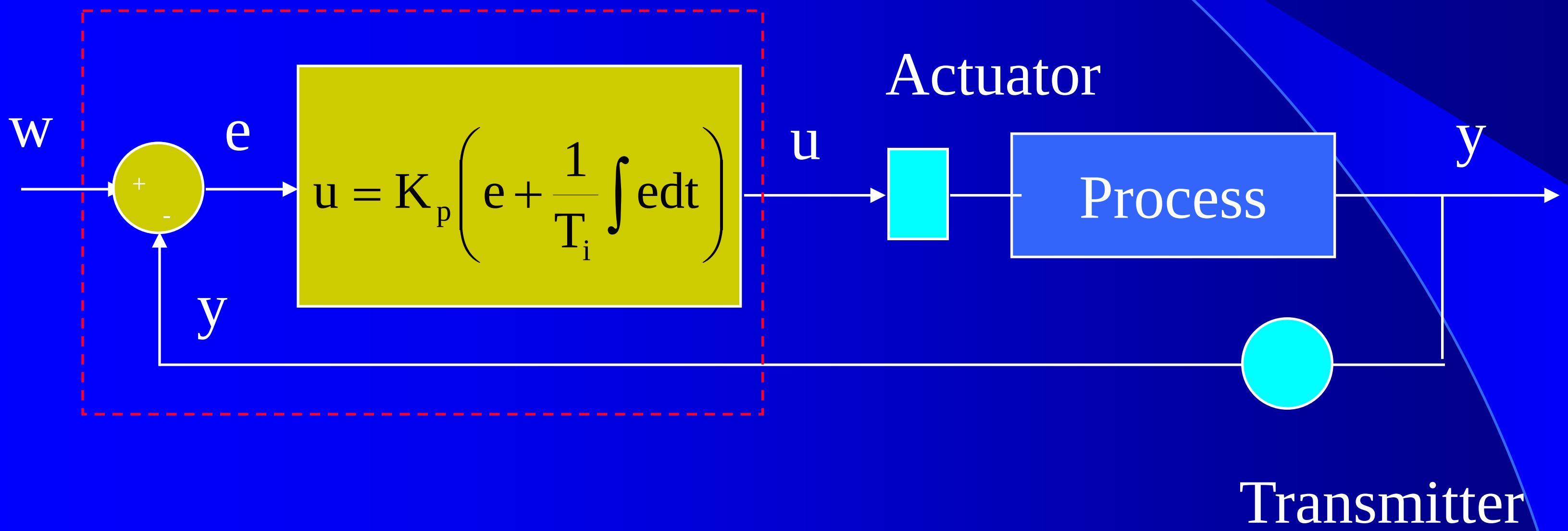
The PID controller

$$e(t) = w(t) - y(t)$$

$$u(t) = K_p\left(e(t) + \frac{1}{T_i}\int e(\tau)d\tau + T_d\frac{de}{dt} \right)$$

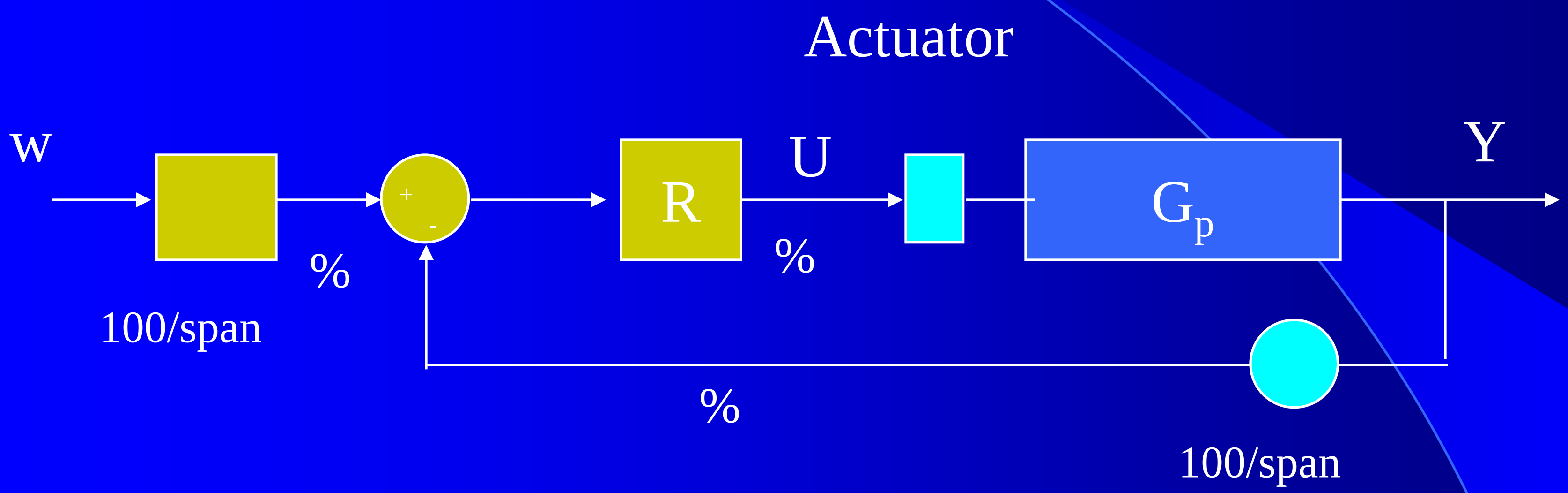
- **Signal based controller,** no explicit knowledge of the model is used
- 3 main tuning parameters K_p, T_i, T_d
- Several versions

PI



w
e
$u = K_p\left(e + \frac{1}{T_i}\int e\,dt\right)$
+
-
y
u
Actuator
Process
y
Transmitter

Units



Input and output regulator signals usually are expressed in terms of % of transmitter and actuator respectively

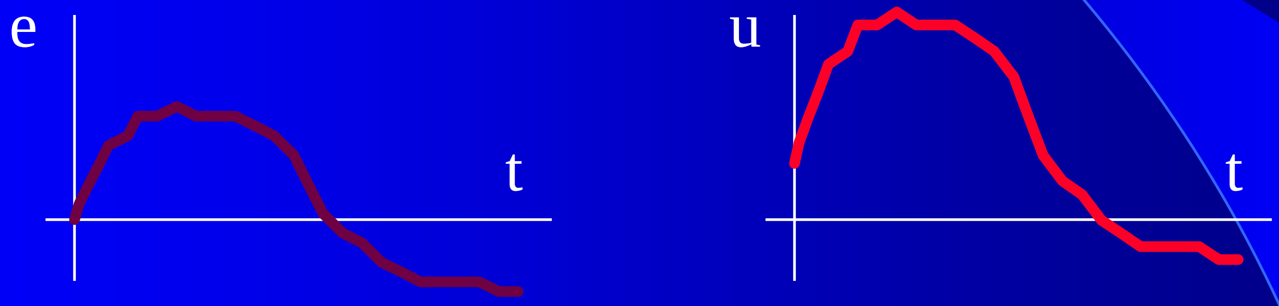
Conversion factors in the controller should correspond to the calibration of the instruments

PID parameters

- K_p gain / Proportional term
  - % span control / % span controlled variable
  - Proportional band PB=100/ K_p
- T_i integral time / Integral term
  - minutes o sg. (per repetition) (reset time)
  - repetitions per min = 1/ T_i
- T_d derivative time / Derivative term
  - minutes o sg.

Proportional controller P

$$u(t) = K_p e(t) + \text{bias}$$

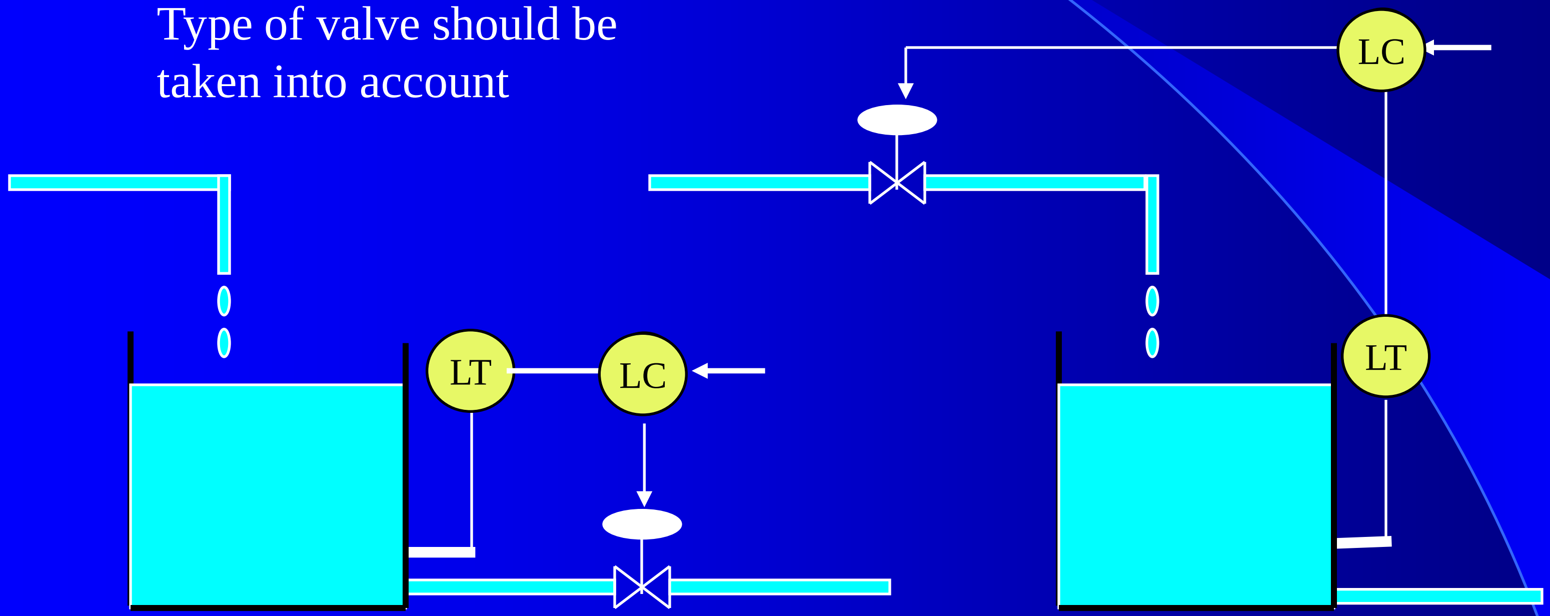


An error of x % creates an action of K_p x % on the actuator

bias = manual reset (CV = SP)

Direct / Reverse Acting

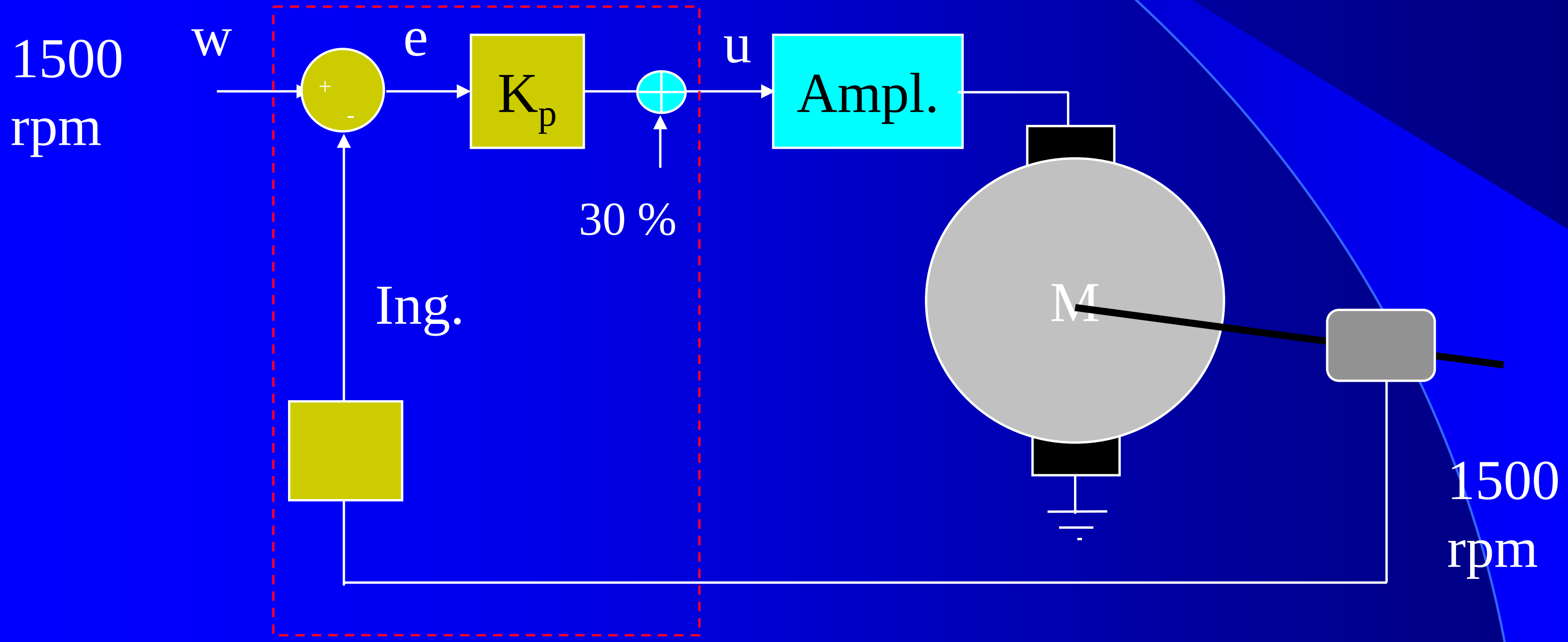
Type of valve should be taken into account



Direct acting controller $K_p < 0$ Reverse acting controller $K_p > 0$

$u(t)=K_p(w-y)$ if y increases, then u decreases if K_p is positive

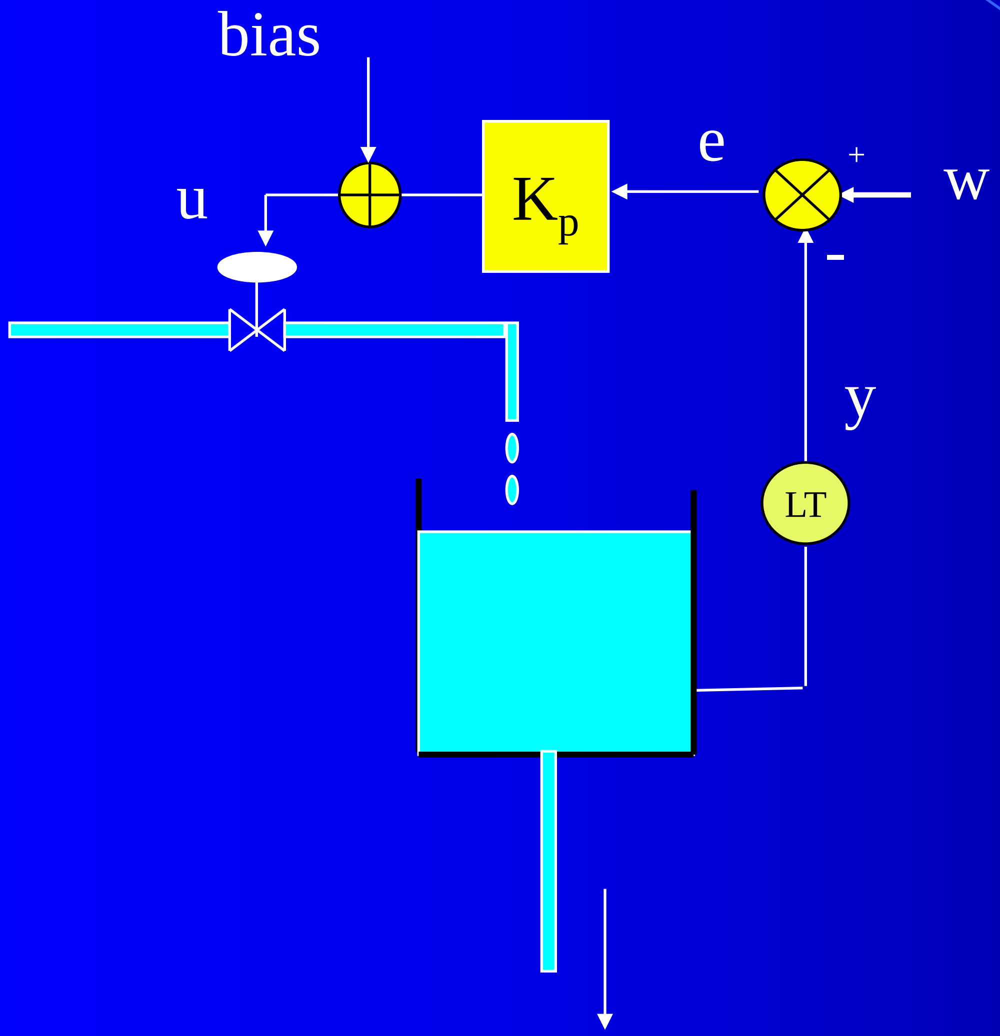
Proportional action



$u(t)=K_p\, e(t) + 30$

There is only an equilibrium point with zero error

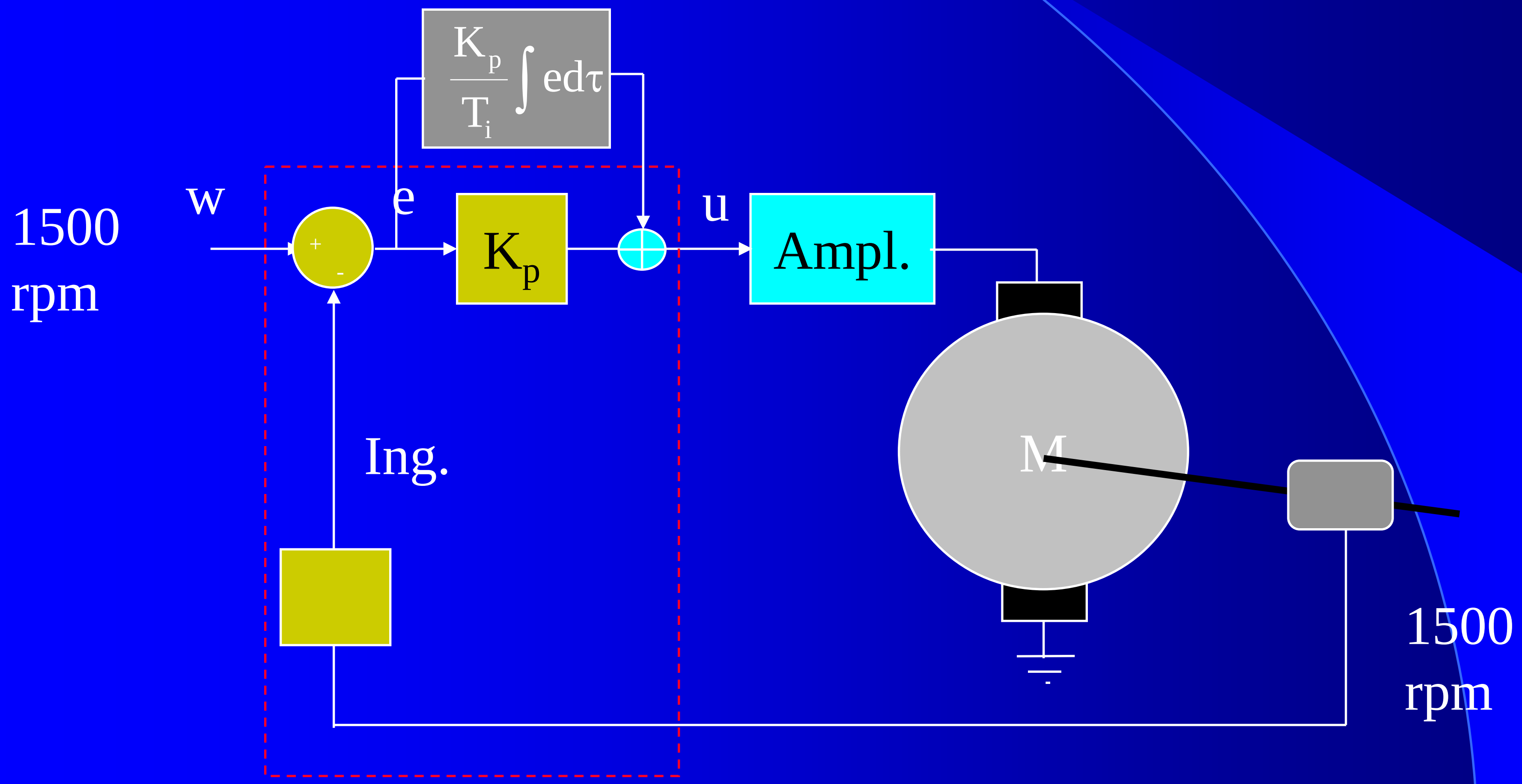
Proportional action



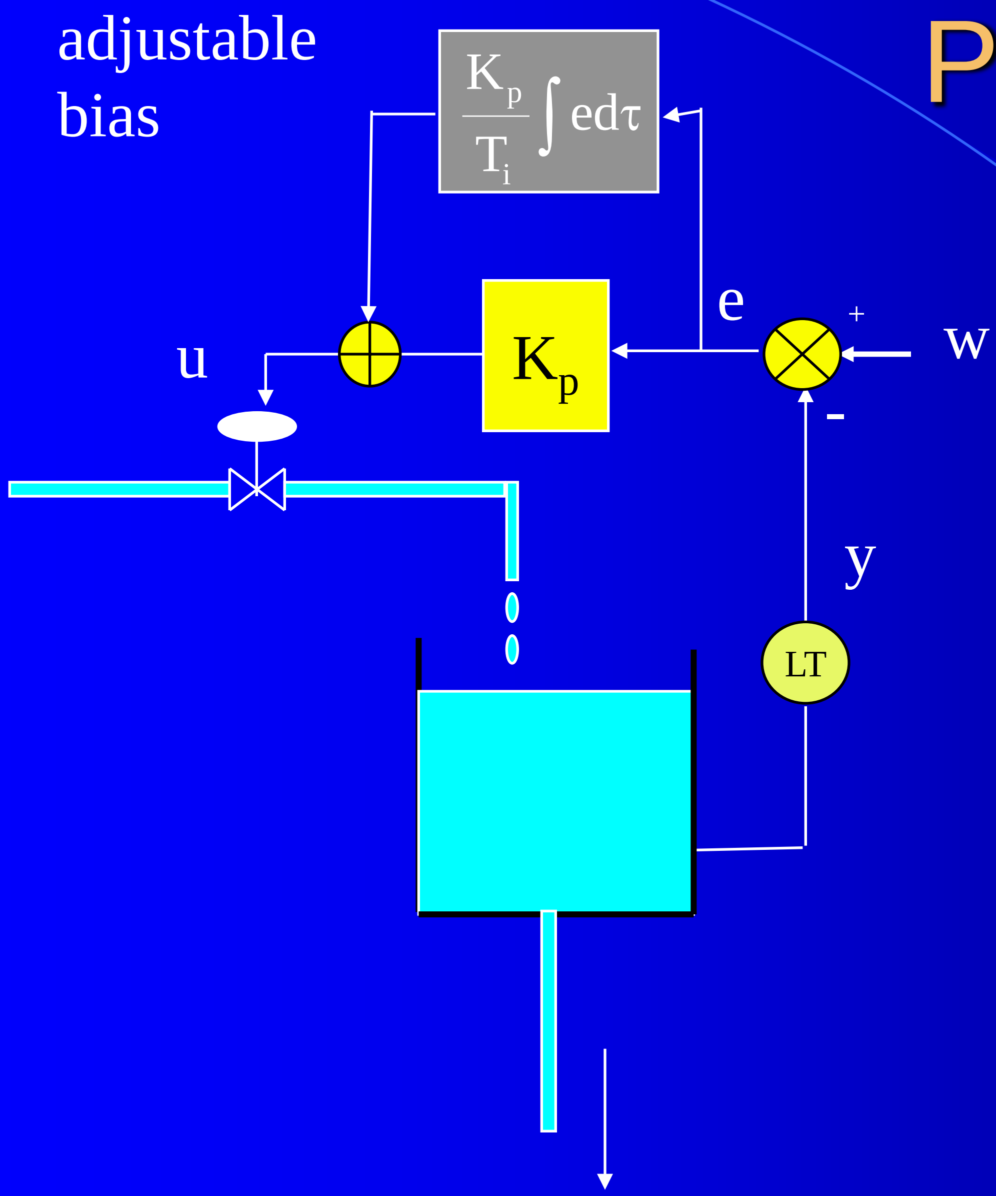
$$e(t) = w - y$$

$$u(t) = K_p\, e(t) + \text{bias}$$

Integral action



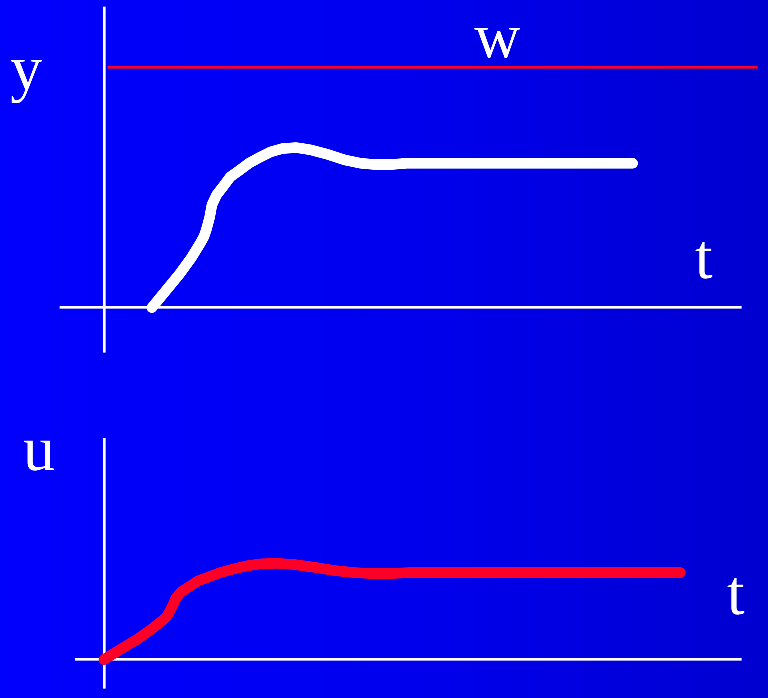
PI



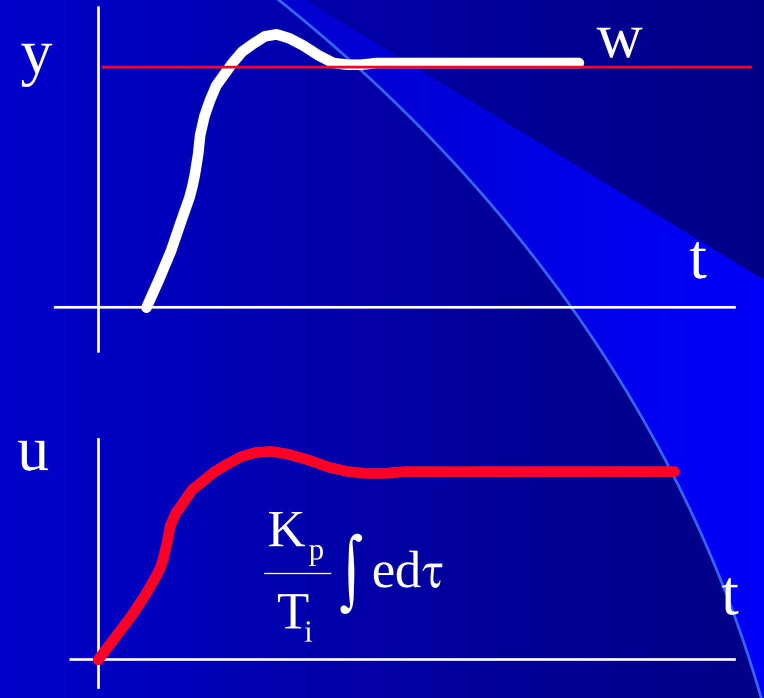
$$e(t) = w - y$$

$$u(t)=K_p\,e(t) + \text{bias}$$

Integral action (automatic reset)



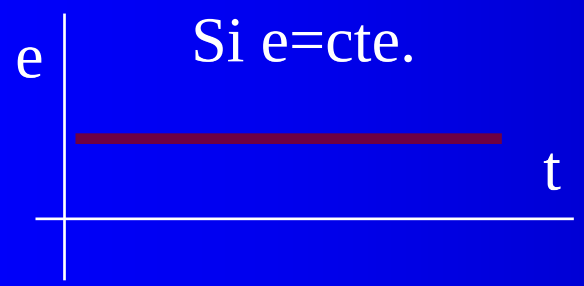
A P controller does not get steady zero error with self-regulated processes



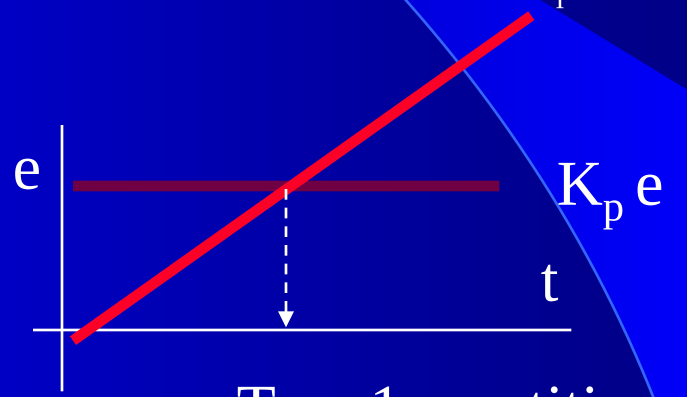
The integral term changes continuously the control signal until the error is zero

Integral action

$$u(t) = \frac{K_p}{T_i}\int_0^t e(\tau)\,d\tau$$



$$\frac{K_p}{T_i}\int e\,d\tau$$

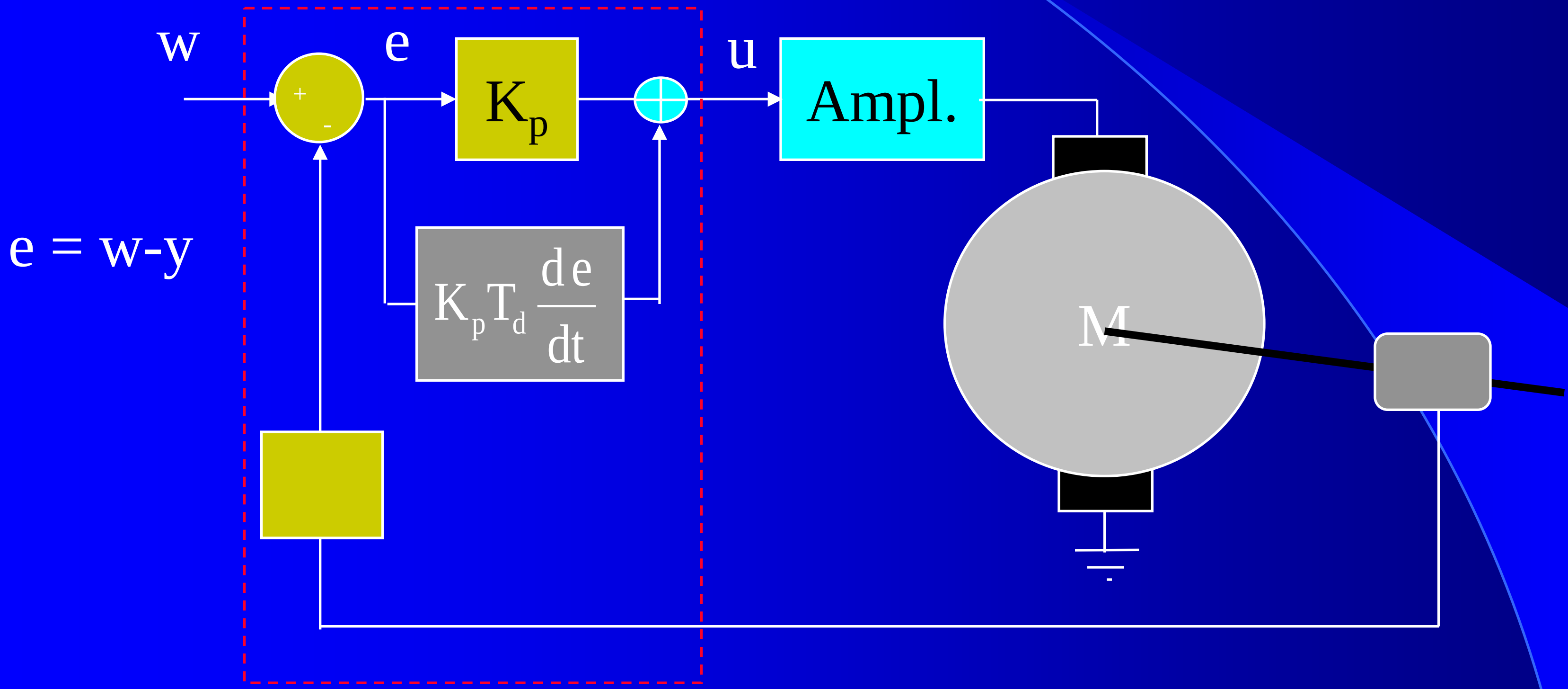


T_i = 1 repetition

The integral action will equate the proportional one in T_i time units if e is constant (one repetition)

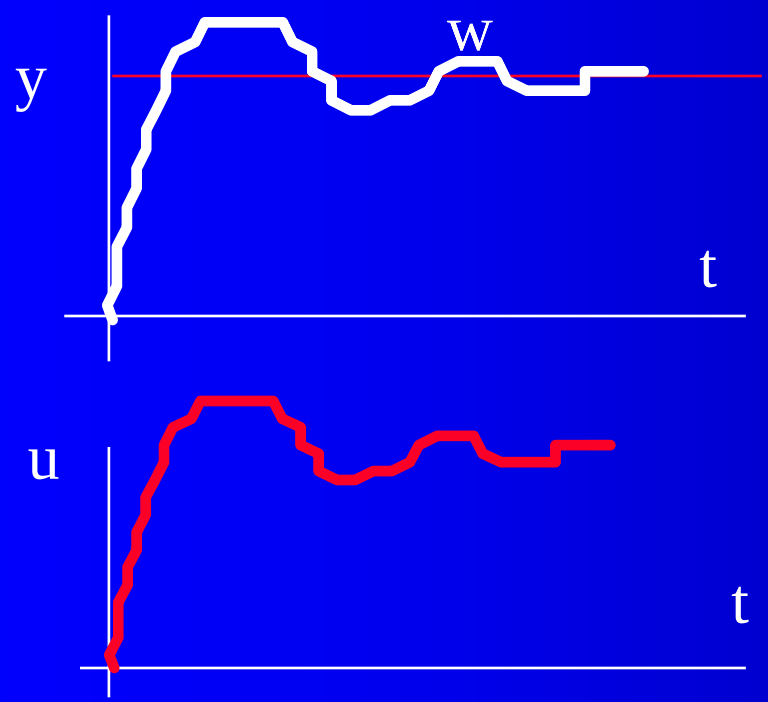
$$\frac{K_p}{T_i}\int e\,d\tau = \frac{K_p}{T_i}et = K_p e \Rightarrow t = T_i$$

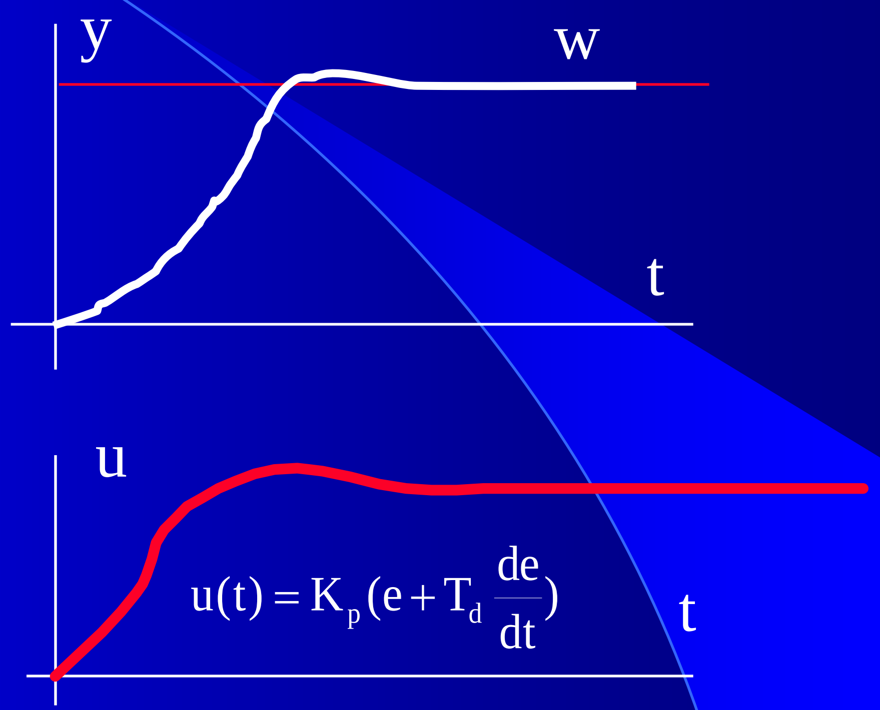
Derivative action



The derivative term will smooth sharp changes in the control signal due to fast changes in the error e = w - y

Derivative action





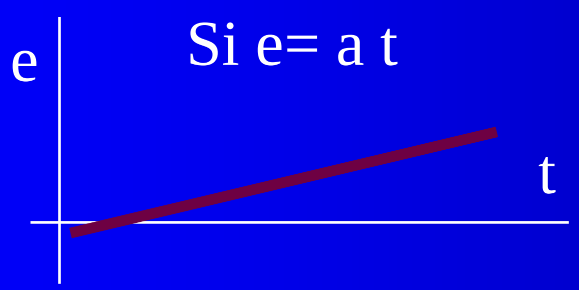
$$u(t) = K_p\left(e + T_d \frac{de}{dt}\right)$$

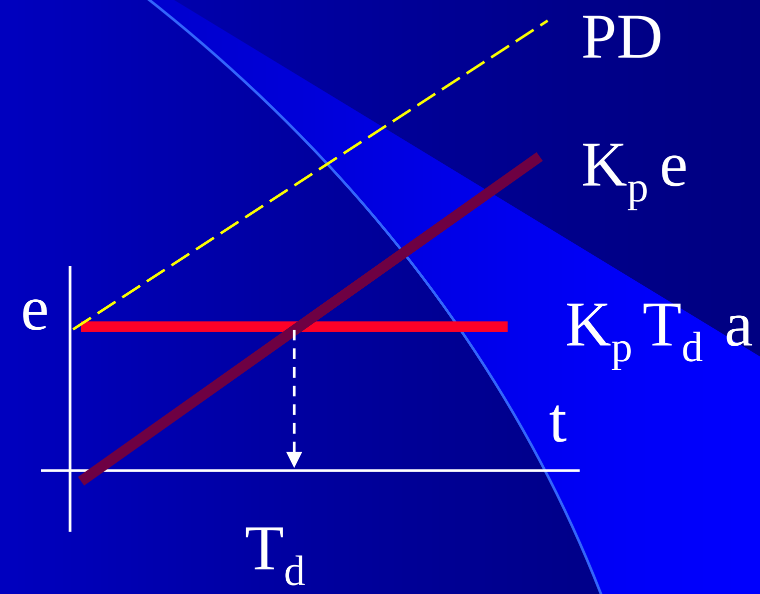
A P controller tuned with high gain in order to get a fast process response can generate too strong u changes and oscillations

If e decreases very fast, the derivative term will decrease u, avoiding oscillations

Derivative action

$$u(t) = K_p T_d \frac{de}{dt}$$



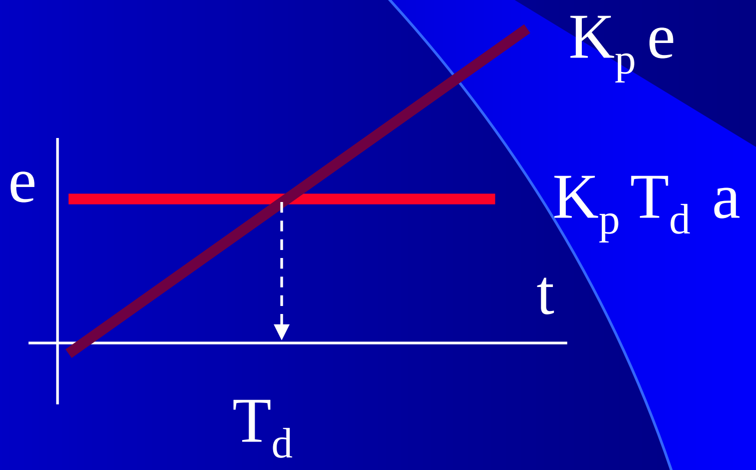


If e changes linearly, the derivative term will equate the proportional one after T_d time units

The derivative action has no influence in the steady state

Derivative action

$$u(t) = K_p T_d \frac{de}{dt}$$



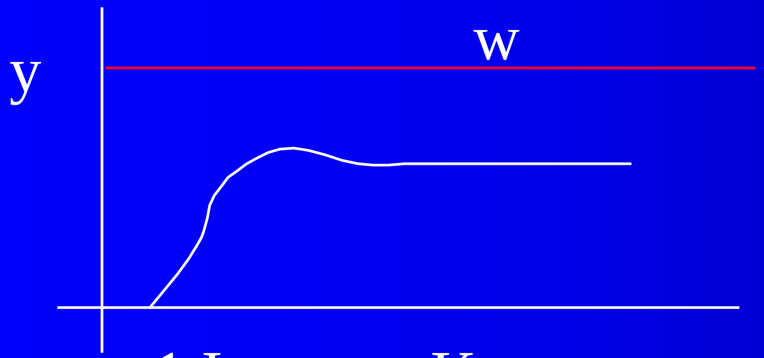
After T_d time units, derivative and proportional terms will be equal if e= a.t.

$$K_p T_d \frac{de}{dt} = K_p T_d a = K_p a t \Rightarrow t = T_d$$

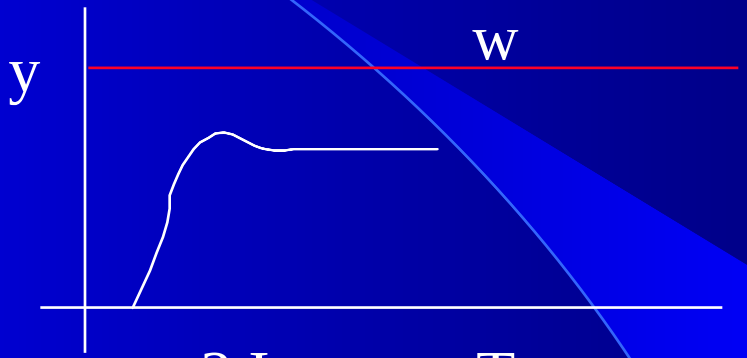
PID tuning methods

- Trial and error
- Experiment based
  - Estimate certain dynamic characteristic of the process
  - Compute the PID parameters using tables and the estimated process dynamics
- Model based
  - Error Index minimization
  - Phase margin,….

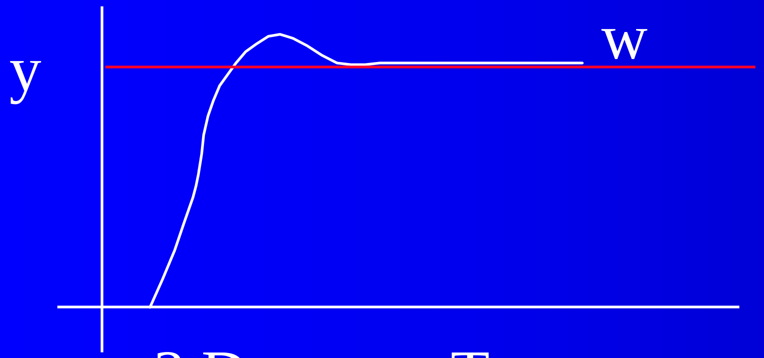
Trial and error



1 Increase K_p



2 Increase T_d



3 Decrease T_i

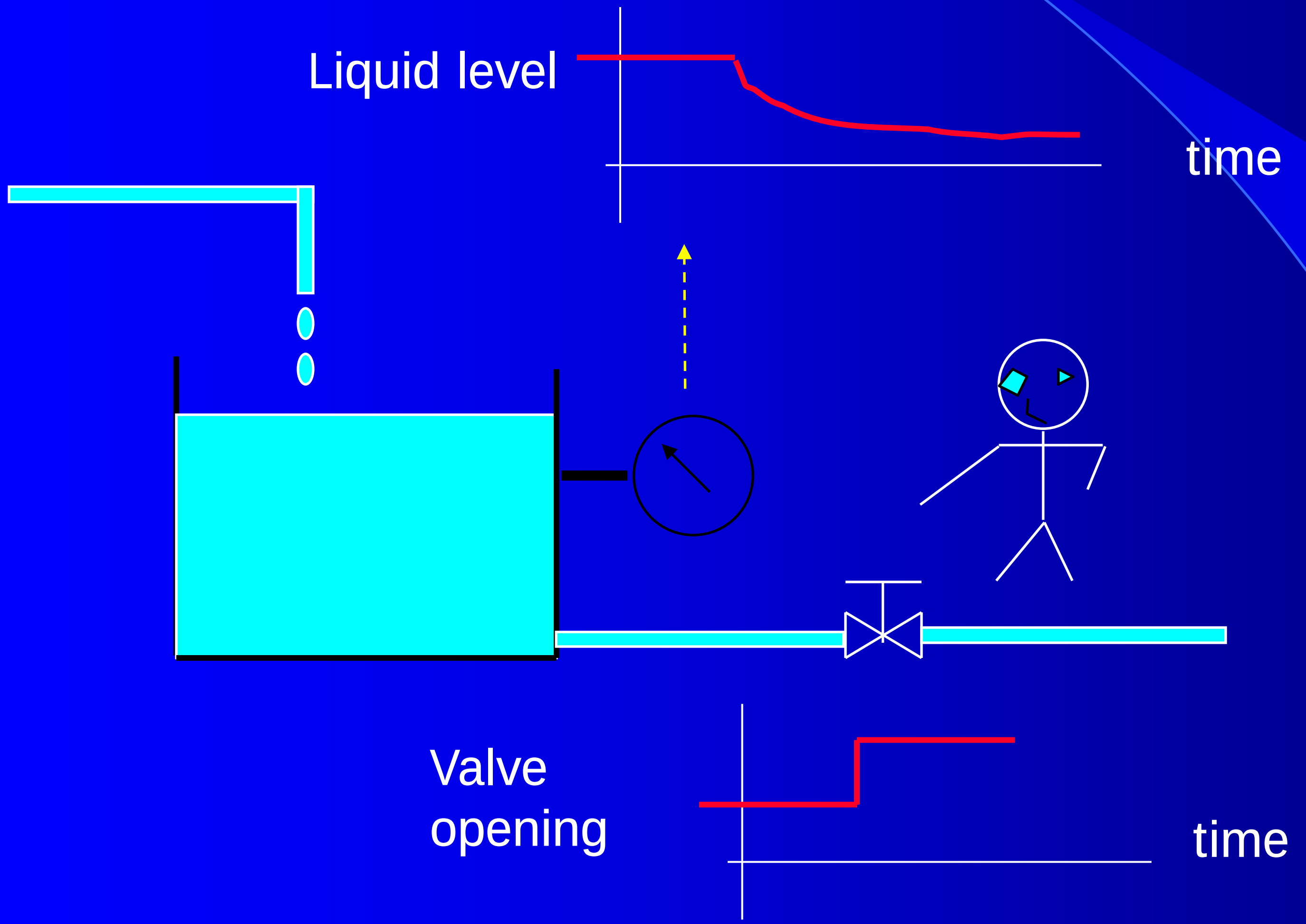
Start with low K_p, and without integral or derivative actions

Increase K_p until a nice response shape is obtained without excessive control action

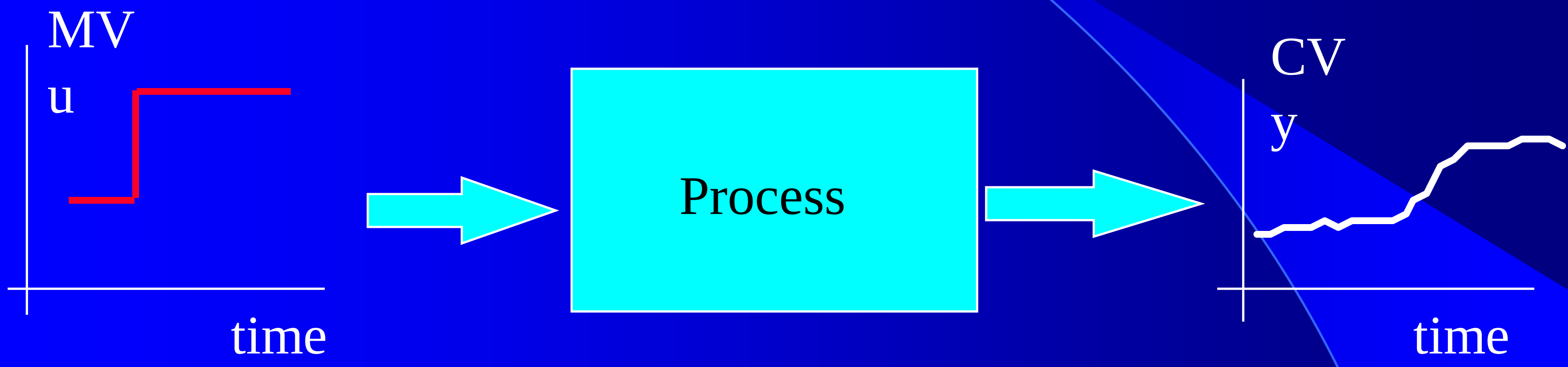
Increase a bit T_d and K_p in order to improve the shape of the response

Decrease T_i until the steady state error has disappeared

Process Dynamics

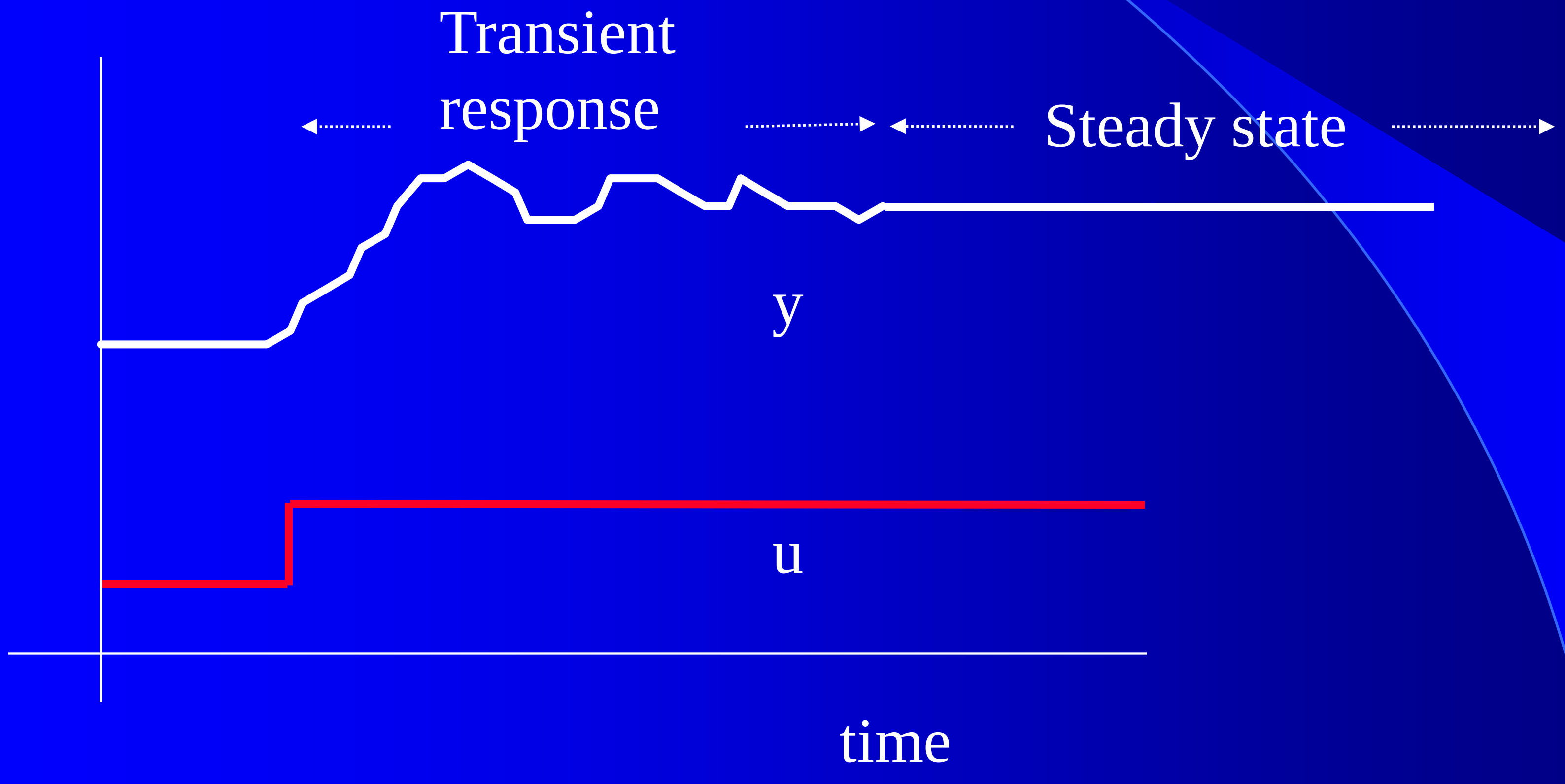


Dynamic response



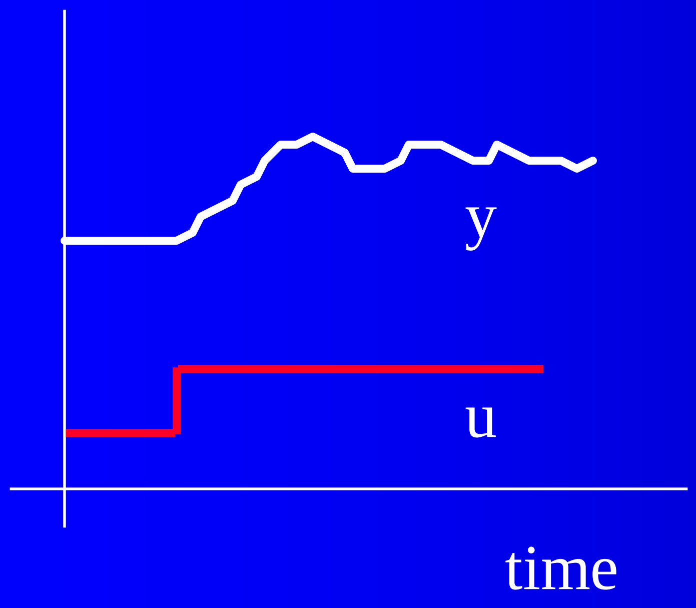
- Experimentation
- Mathematical model

Dynamic response

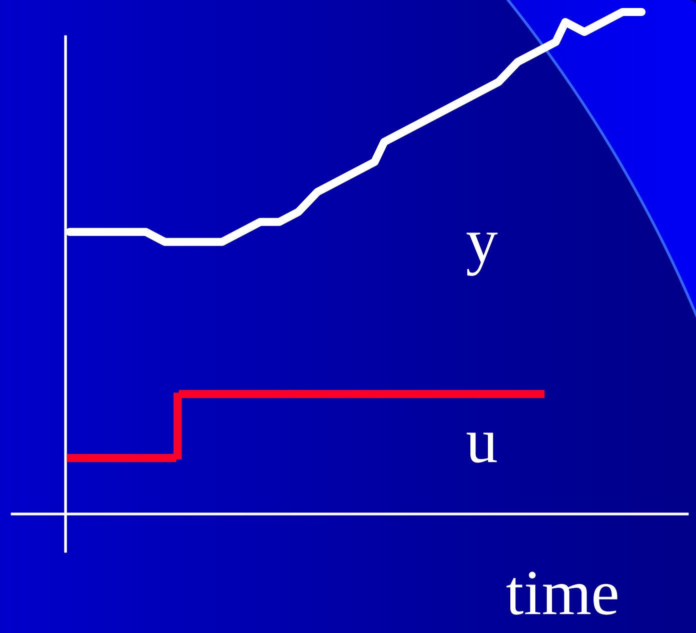


Types of processes

Self- regulated

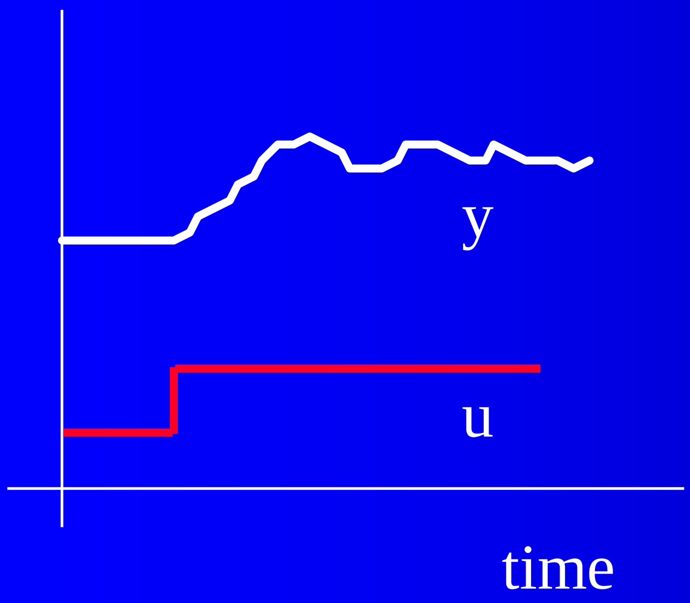


Integrative or non self-regulated

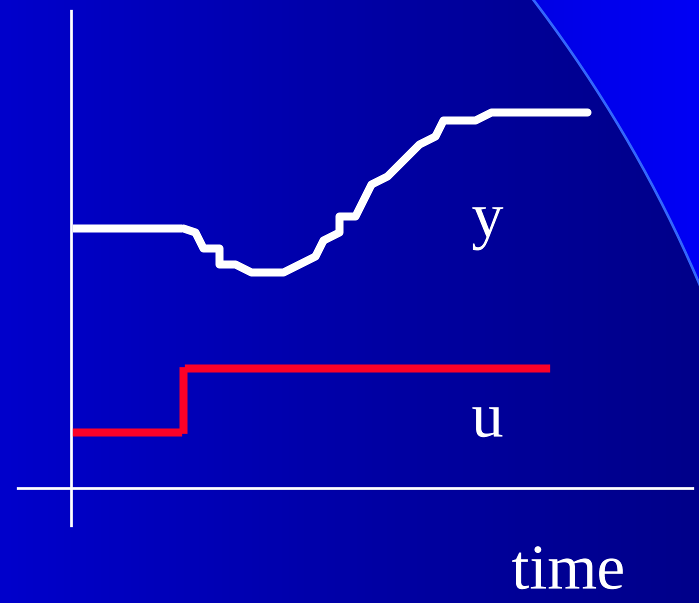


Types of processes

Minimum phase

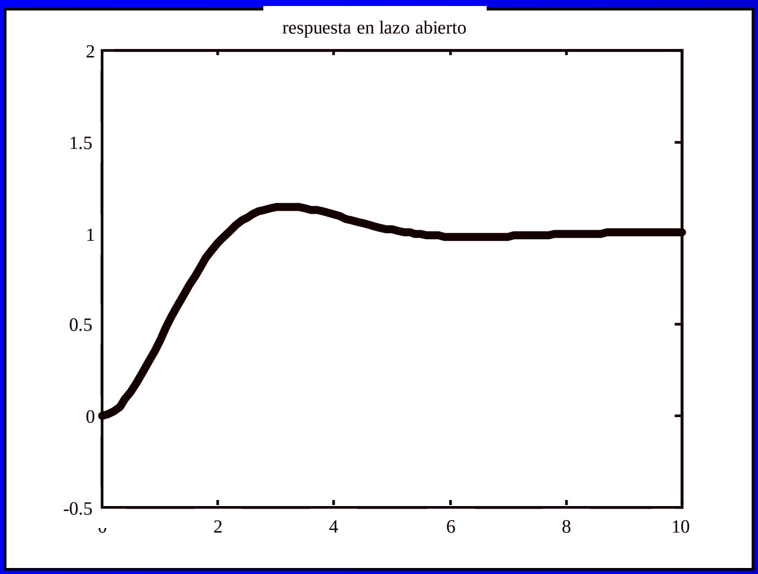


Non-mimimum phase

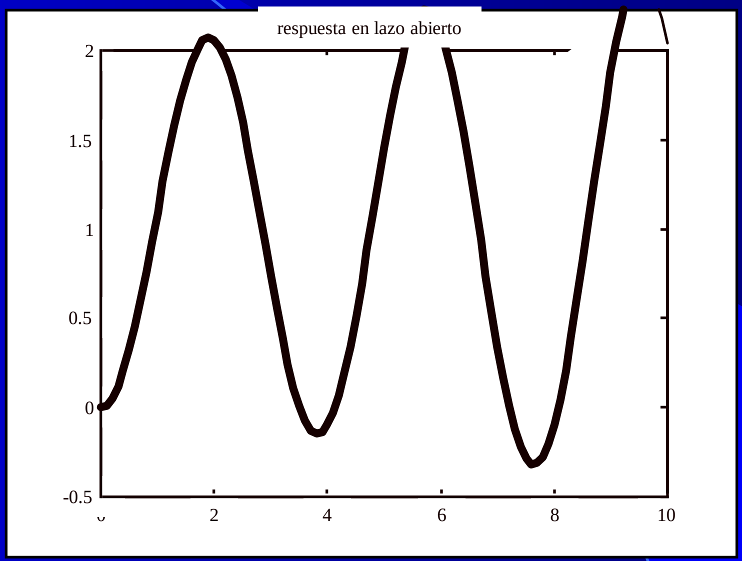


Stability

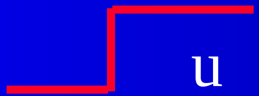
y



y



Stable

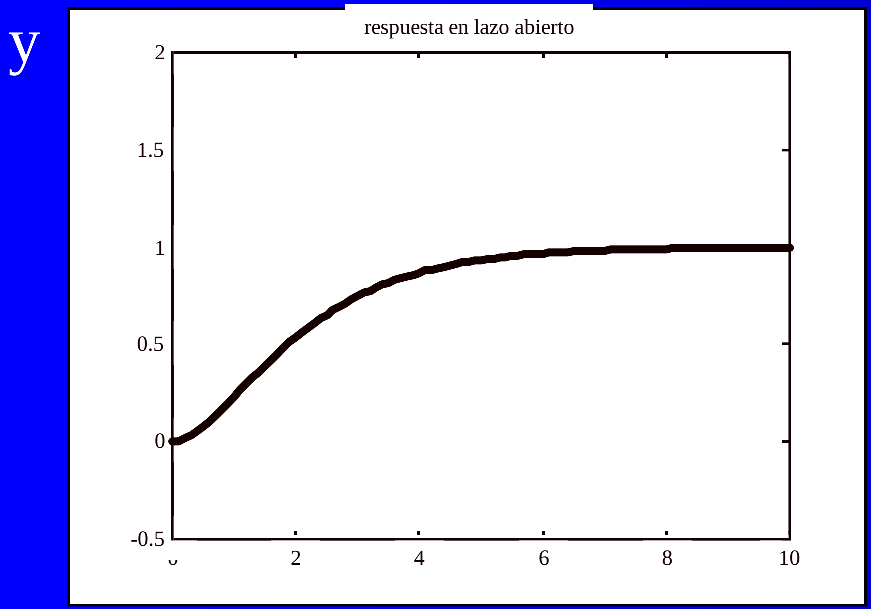


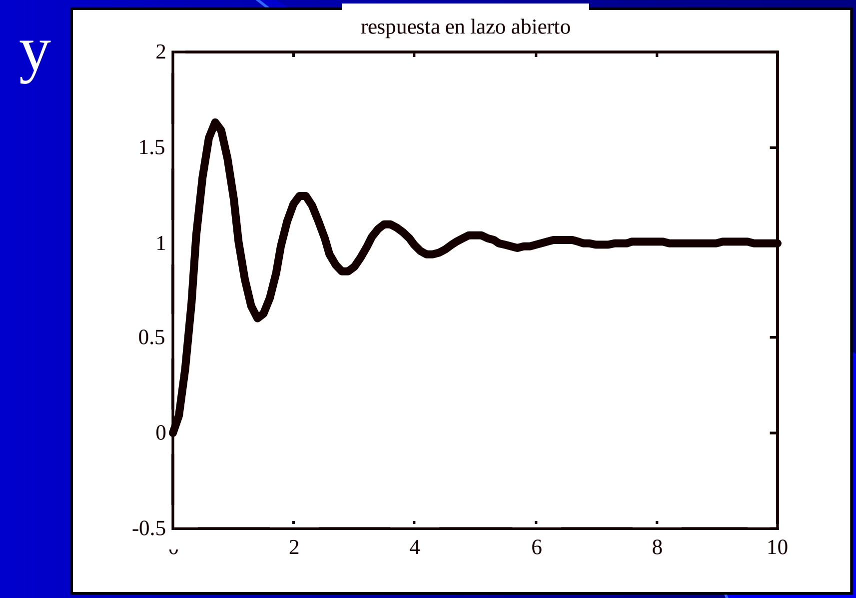
u

Unstable

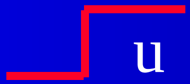
Bounded input ⟹ Bounded output

Damping



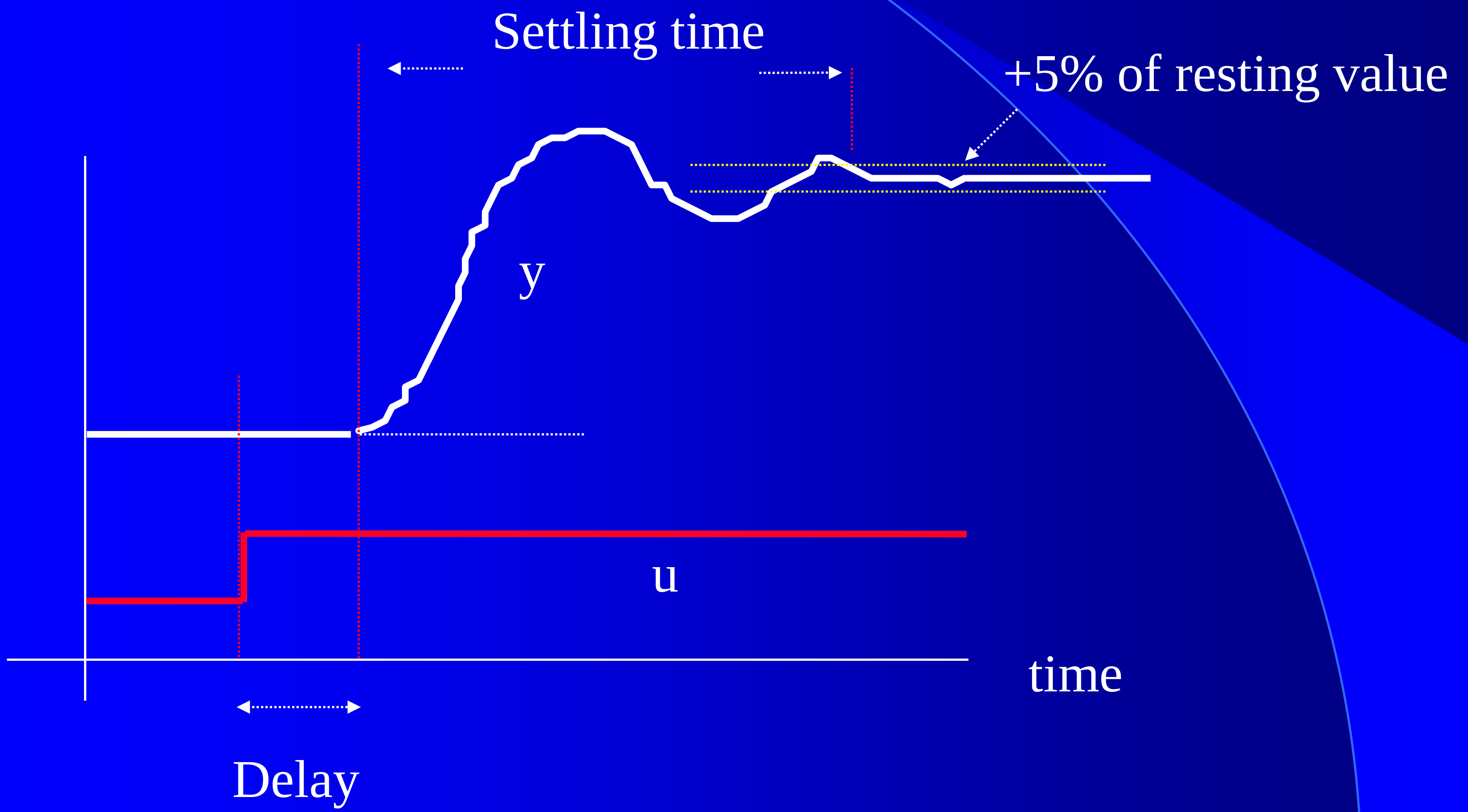


Over-damped



Under-damped

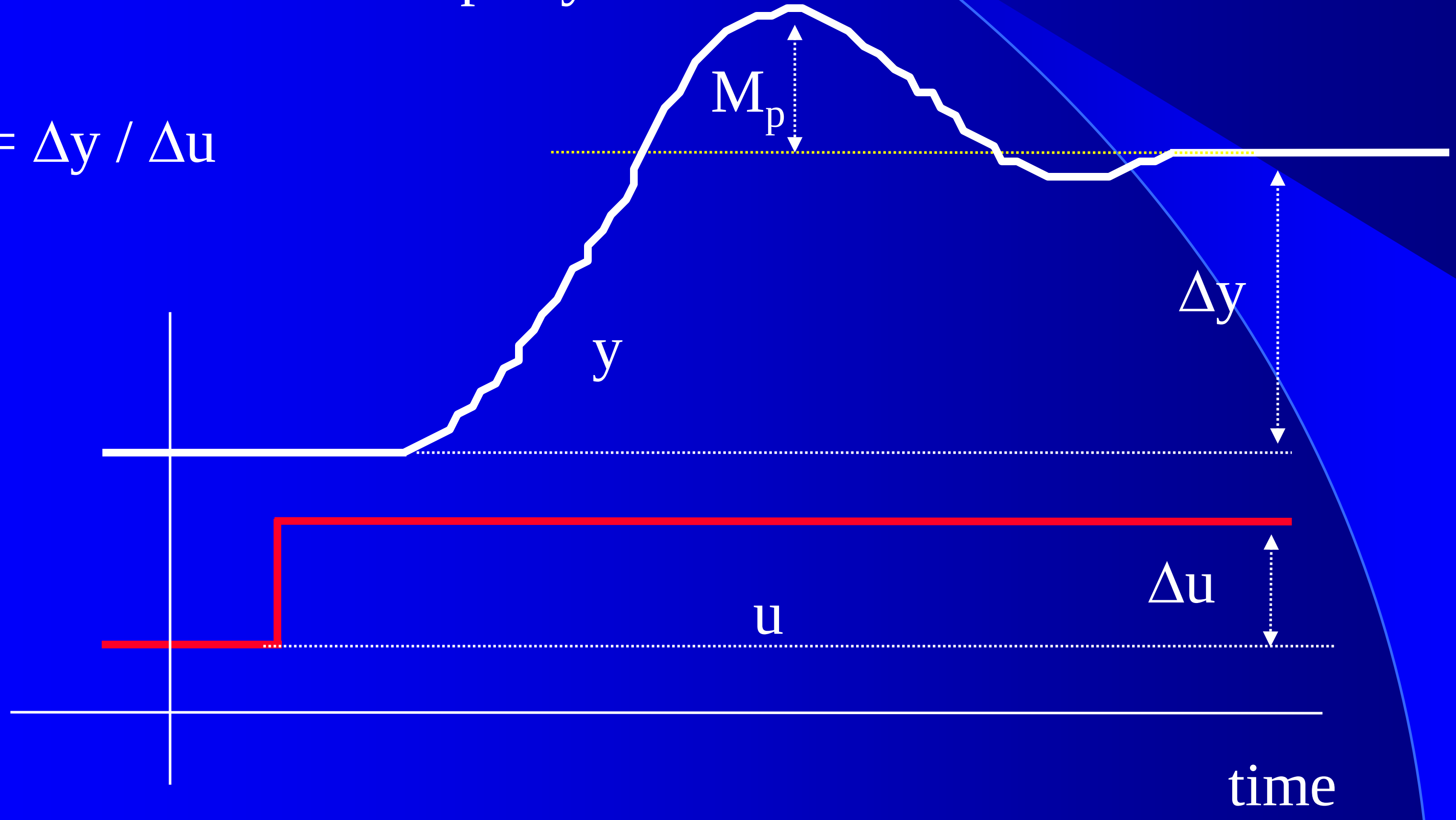
Dynamic response



Dynamic response

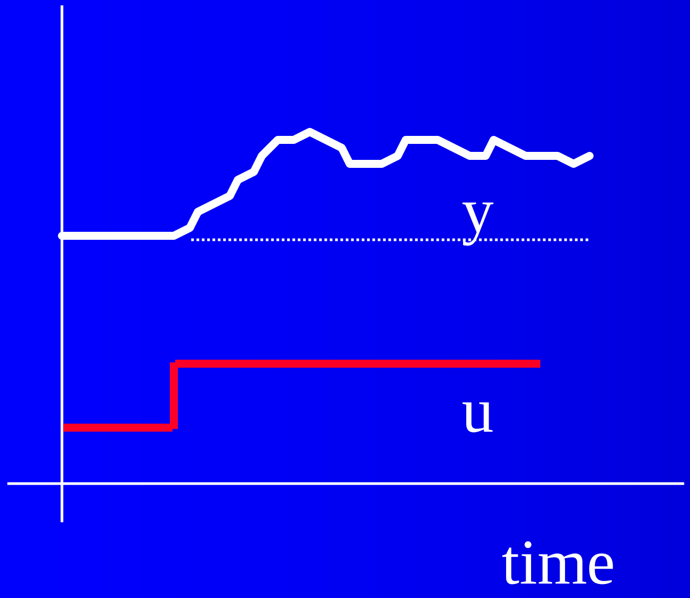
Overshoot in % = 100 Mp/ Δy

Gain = Δy / Δu

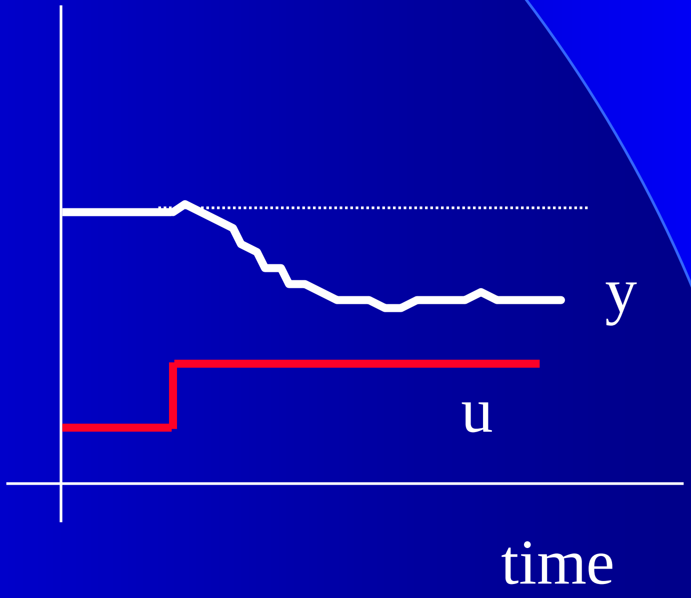


Gain

Positive gain



Negative or inverse gain



Dynamic response