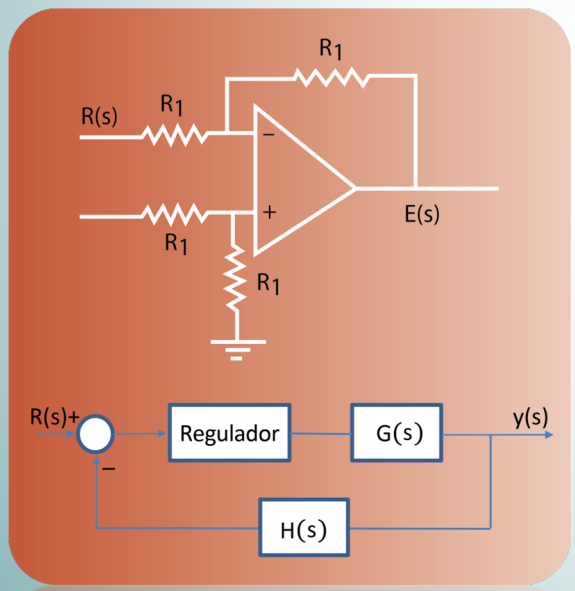
Electrónica Básica, Control e Instrumentación

Bloque II. Sistemas de control

Tema 4. Reguladores



Sandra Robla Gómez

Elena Hoyos Villanueva

José Ángel Miguel Díaz

DPTO. DE TECNOLOGÍA ELECTRÓNICA E INGENIERÍA DE SISTEMAS Y AUTOMÁTICA

Este tema se publica bajo Licencia:

Creative Commons BY-NC-SA 4.0

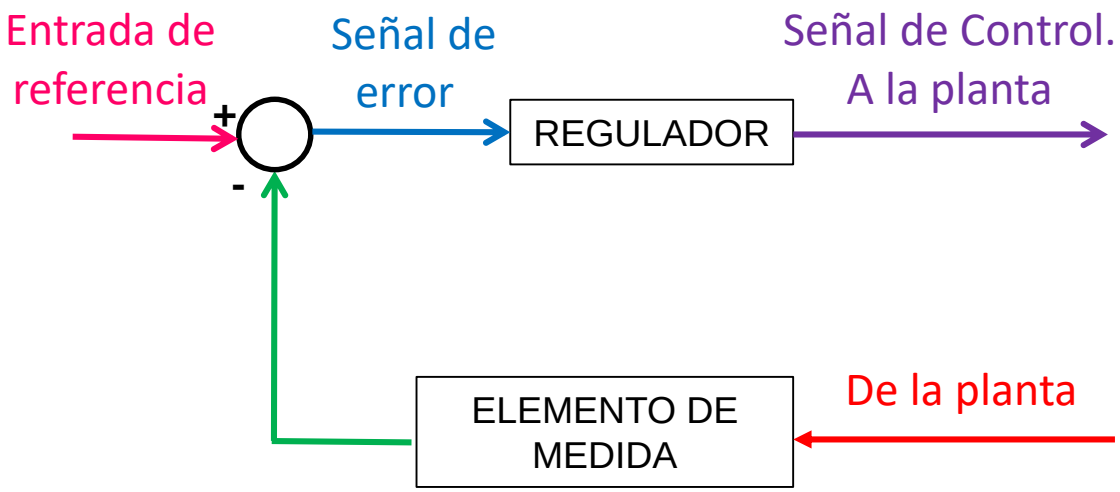
TEMA 4

REGULADORES

1. Acciones de control
2. Control Todo-Nada
3. Control Proporcional (P)
4. Control Integral (I)
5. Control Proporcional e Integral (PI)
6. Control Derivativo (D)
7. Control Proporcional y Derivativo (PD)
8. Control Proporcional, Derivativo e Integral (PID)

1. ACCIONES DE CONTROL

REGULADORES ELECTRÓNICOS



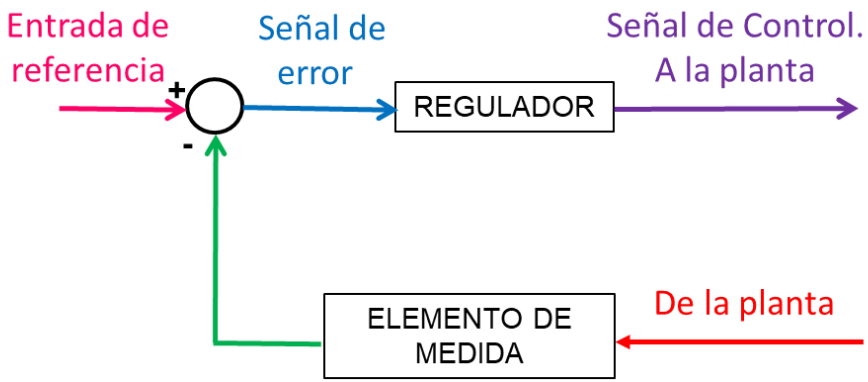
CLASIFICACIÓN:

Según la energía utilizada:

- ❑ Neumáticos
- ❑ Hidráulicos
- ❑ Electrónicos

1. ACCIONES DE CONTROL

REGULADORES ELECTRÓNICOS



Según el tipo de acción:

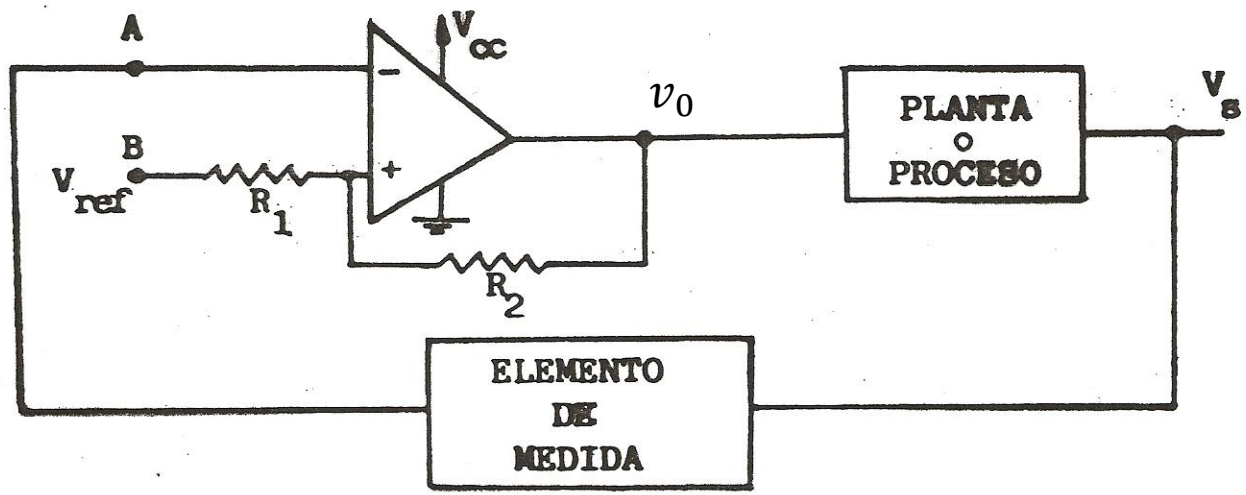
1. Control Todo-nada
2. Control Proporcional (P)
3. Control Proporcional de tiempo variable
4. Control Integral (I)
5. Control Proporcional e Integral
6. Control Derivativo (D)
7. Control Proporcional y Derivativo (PD)
8. Control Proporcional, Integral y Derivativo (PID)

2. CONTROL TODO - NADA

Características principales:

- Sencillo y económico
- No lineal
- Dos únicos posibles valores de salida
- Sin/Con histéresis
- Oscilación de la salida

2. CONTROL TODO - NADA

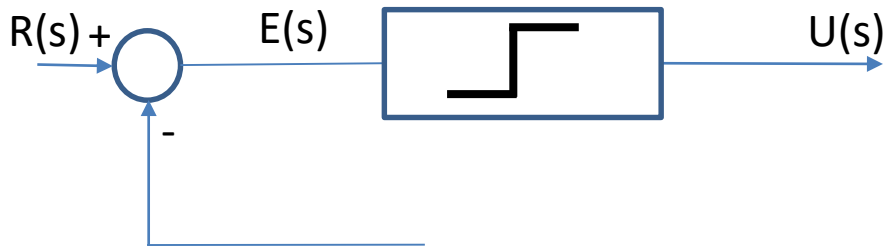


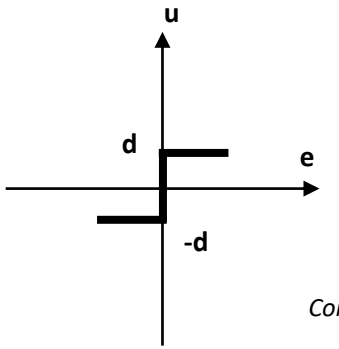
$$V_+ = \frac{V_{ref}R_2}{R_1 + R_2} + \frac{V_0 R_1}{R_1 + R_2}$$

$$V_+ = \frac{V_{ref}R_2}{R_1 + R_2}$$

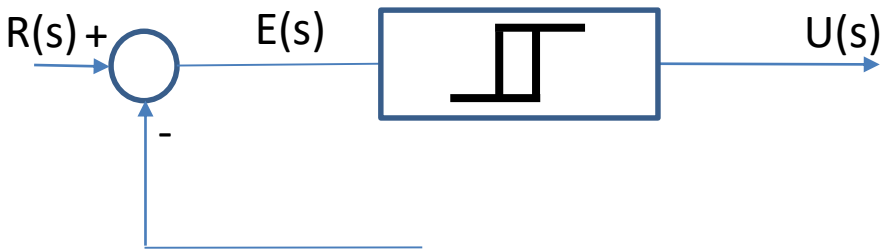
Valor de la histéresis $$V_H = \frac{V_0 R_1}{R_1 + R_2}$$

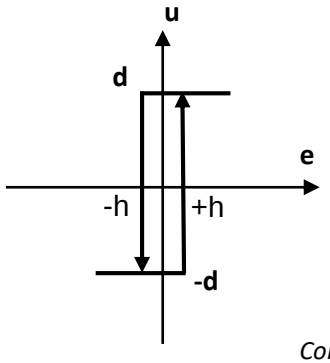
2. CONTROL TODO - NADA



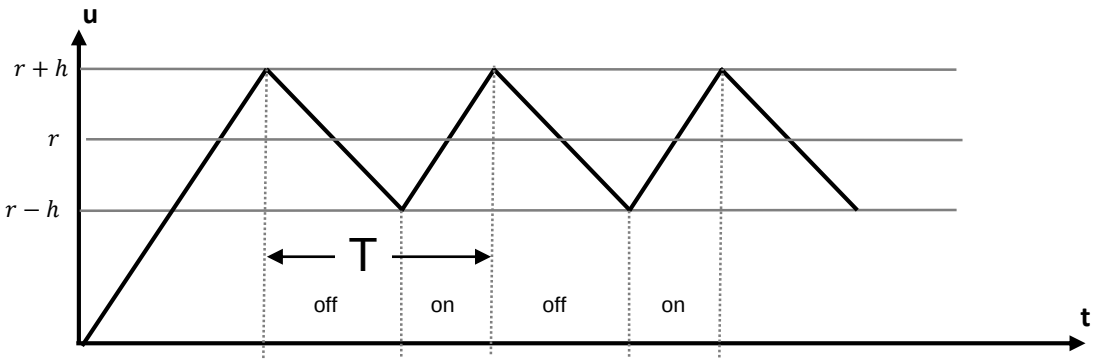


Control todo-nada sin histéresis





Control todo-nada con histéresis



3. CONTROL PROPORCIONAL (P)

Características principales del **regulador proporcional K_p:**

Para **sistemas de primer orden**:

- Mejora τ.
- Disminuye el error estacionario.

Para **sistemas de segundo orden**:

- Disminuye la τ (sistema más rápido).
- Disminuye el error estacionario.
- Afecta al amortiguamiento.

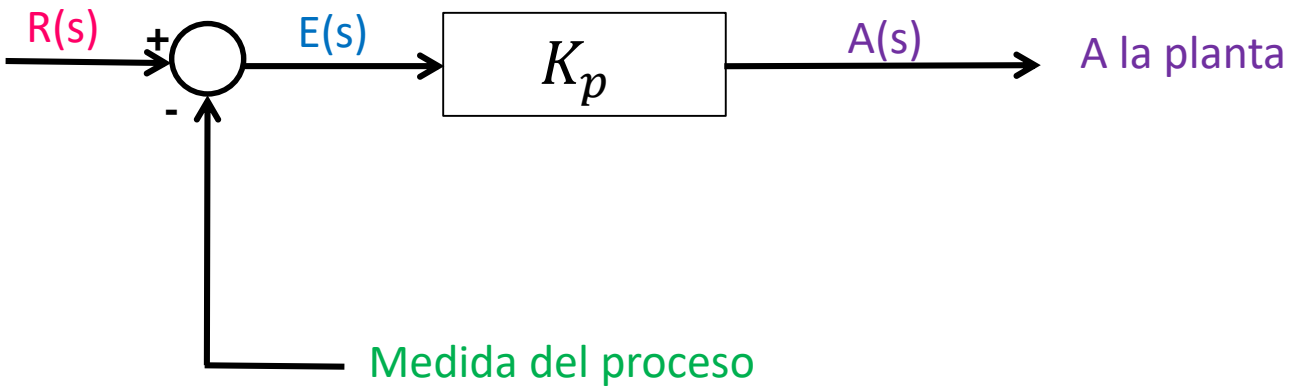
En general:

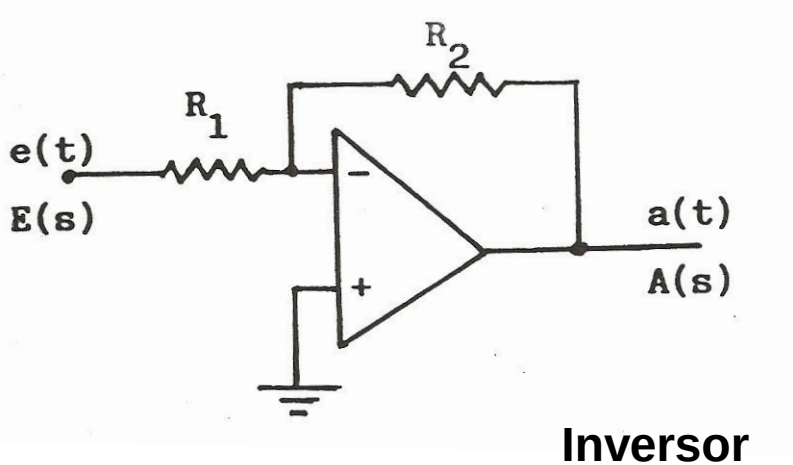
- Sistema más rápido.
- Disminuye el error estacionario.
- Limitación máxima de $\mathbf{K_p}$.

3. CONTROL PROPORCIONAL (P)

$$a(t) = K_p e(t)$$

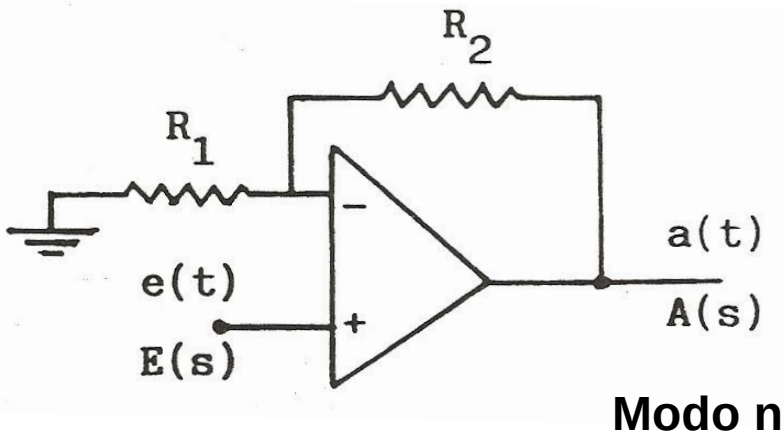
$$\boxed{\frac{A(s)}{E(s)} = K_p}$$





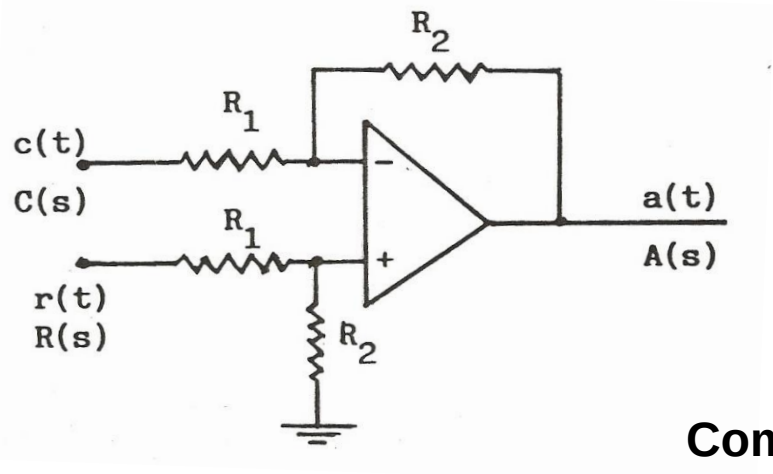
Inversor

$K_p = -R2/R_1$



Modo no Inversor

$K_p = 1 + R_2/R_1$



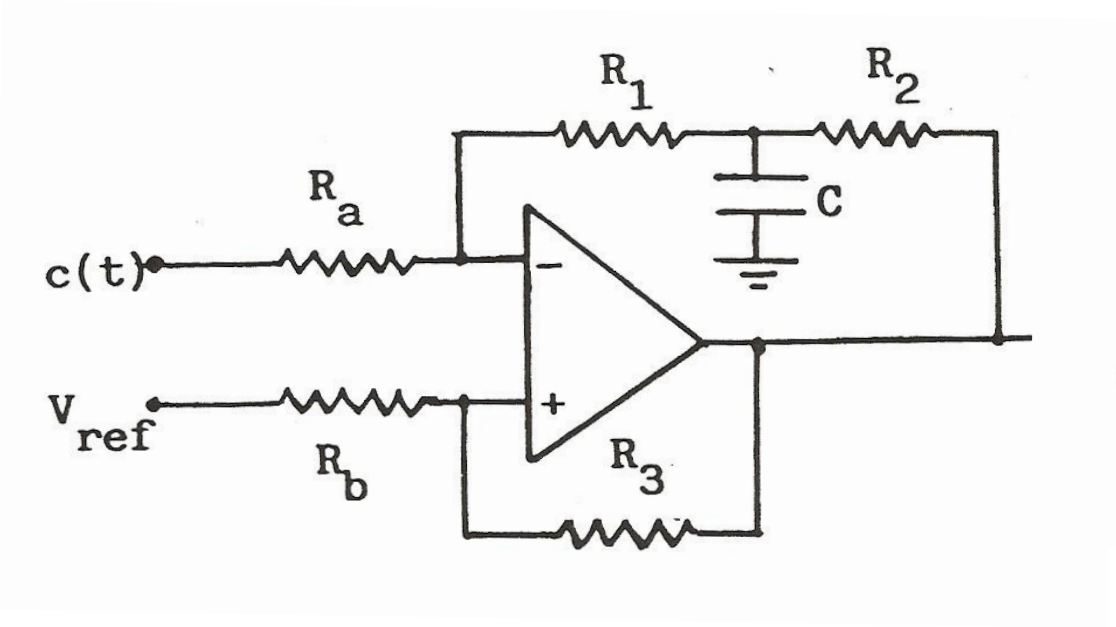
$$a(t) = -\frac{R_2}{R_1}\,c(t) + \frac{R_2}{R_1+R_2}\,r(t)\left(1+\frac{R_2}{R_1}\right) =$$

$$= \frac{R_2}{R_1}\,[r(t) - c(t)] = K_p\,e(t)$$

Comparador

3.1 CONTROL PROPORCIONAL DE TIEMPO VARIABLE

- Se añade un circuito RC entre la salida y la realimentación del inversor.
- Con ello se consigue un retardo en dicha realimentación y el circuito entra en oscilación.



4. CONTROL INTEGRAL (I)

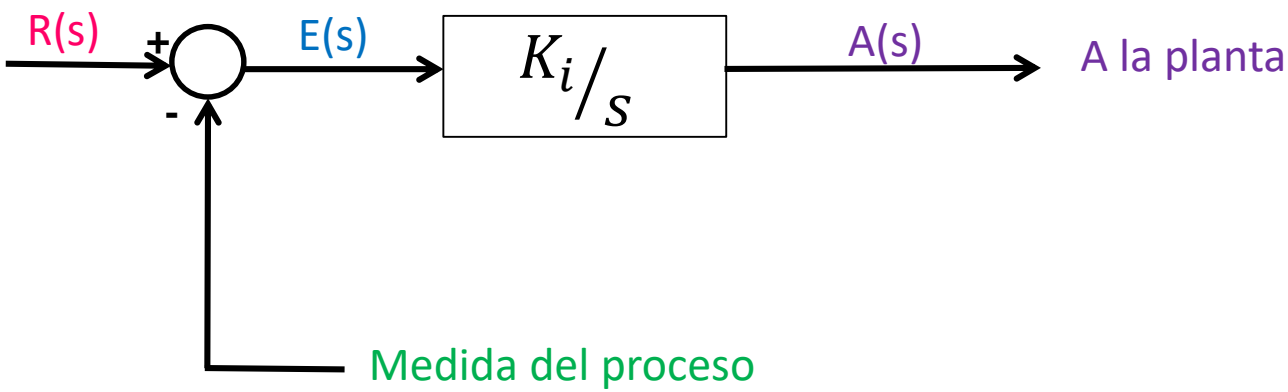
Características principales del **regulador integral** $\frac{1}{T_i s}$**:**

- ❑ Disminuye el error estacionario.

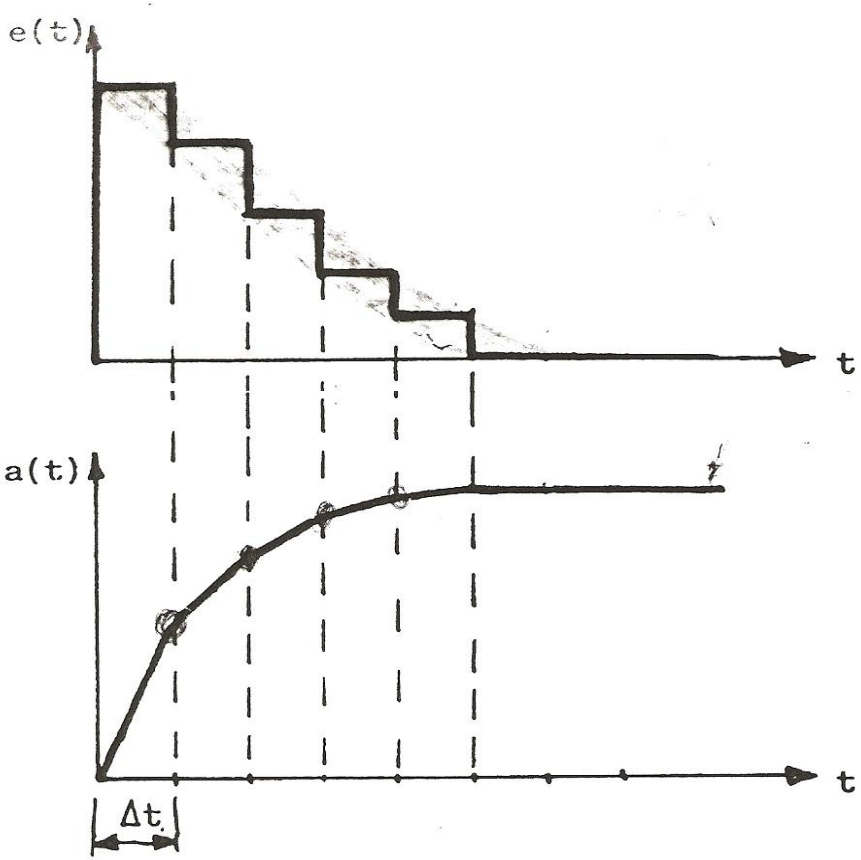
4. CONTROL INTEGRAL (I)

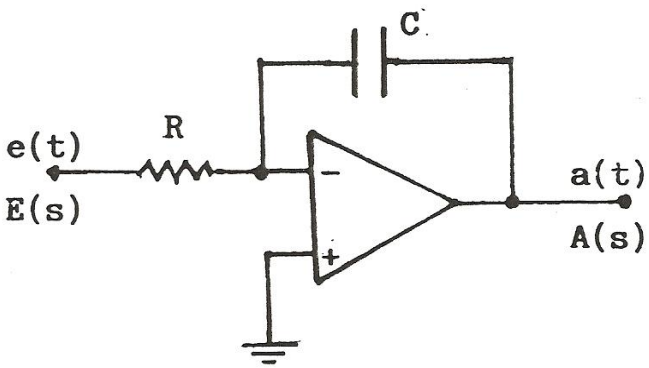
$$\frac{da(t)}{d(t)} = K_i e(t) \qquad a(t) = K_i \int_0^t e(t)dt$$

$$\boxed{\frac{A(s)}{E(s)} = \frac{K_i}{s}}$$



•Cuando la señal de error es una señal decreciente:





$$a(t) = -\frac{1}{RC}\int e(t)\,dt$$

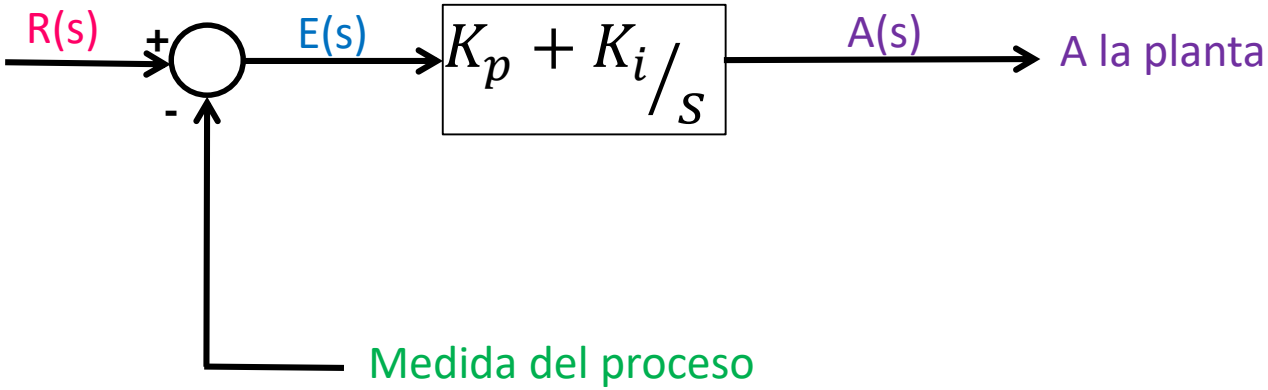
$$\frac{A(s)}{E(s)} = -\frac{1}{sRC} = -\frac{K_i}{s}$$

- El regulador I integra la variable del error e(t).
- Introduce un polo en s=0, lo que elimina el error estacionario. Sin embargo, empeora el transitorio.

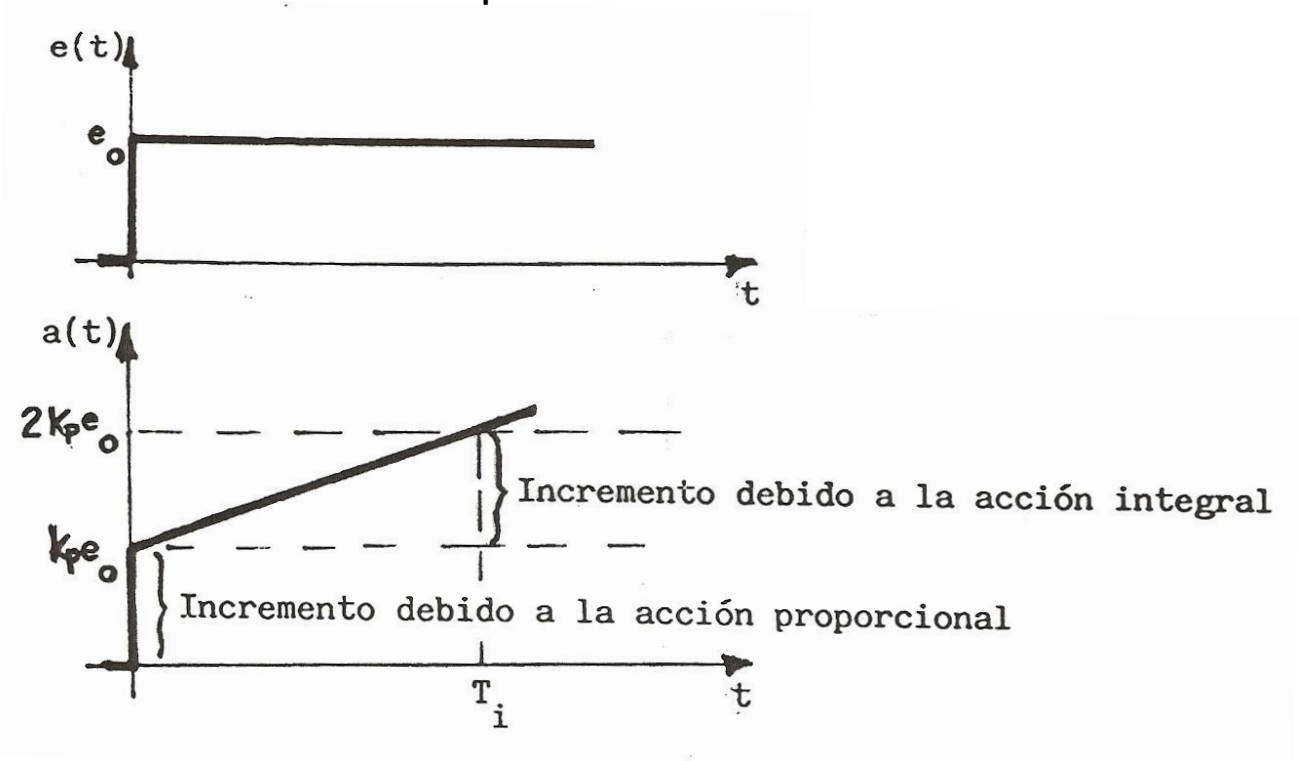
5. CONTROL PROPORCIONAL E INTEGRAL (PI)

$$a(t) = K_p e(t) + K_i \int_0^t e(t)dt$$

$$\boxed{\frac{A(s)}{E(s)} = K_p + \frac{K_i}{s}}$$



•Ante entrada de tipo escalón:

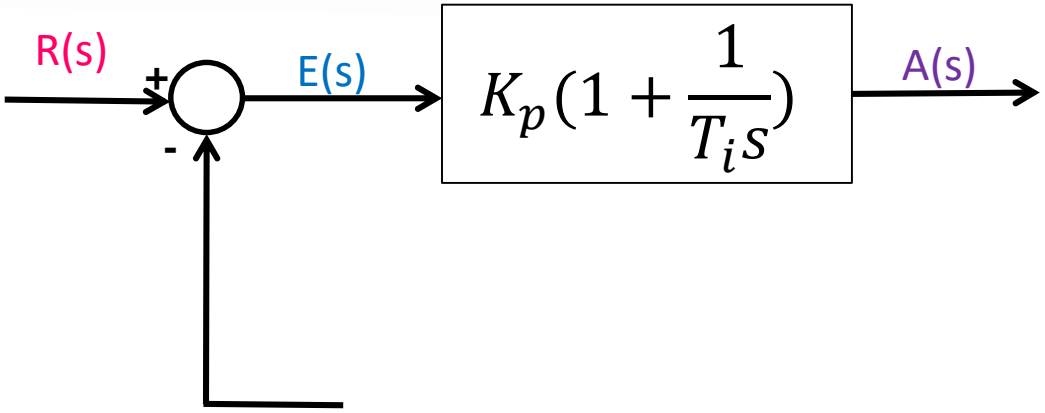


$$2.K_p.e_0 = K_p.e_0 + K_i.e_0T_i$$

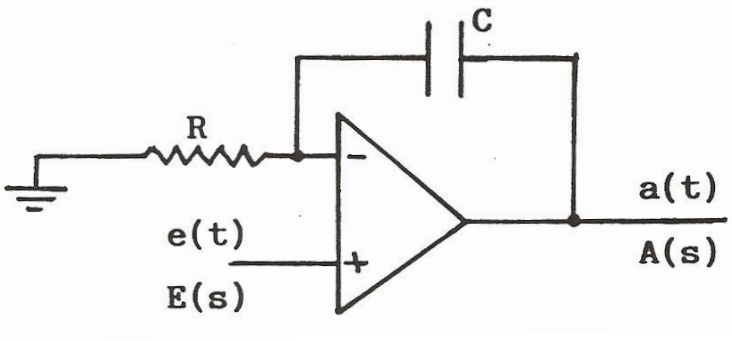
$$\boxed{T_i = \frac{K_p}{K_i}}$$

$T_i \equiv$ minutos por repetición

$1/T_i \equiv$ repeticiones por minuto

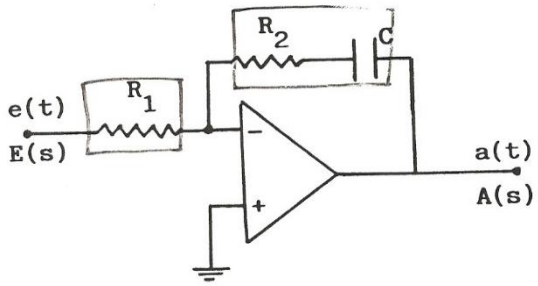


5. CONTROL PROPORCIONAL E INTEGRAL (PI)



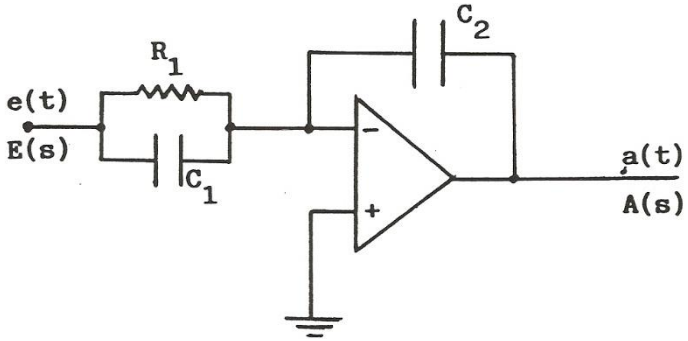
$K_p = 1$

$T_i = RC$



$$A(s) = -\frac{R_2 + \frac{1}{sC}}{R_1} E(s) = -\left(\frac{R_2}{R_1} + \frac{1}{sCR_1}\right) E(s)$$

$$\frac{A(s)}{E(s)} = -K_p\left(1 + \frac{1}{T_i s}\right) \quad \begin{cases} K_p = \frac{R_2}{R_1} \\ T_i = C \cdot R_2 \end{cases}$$

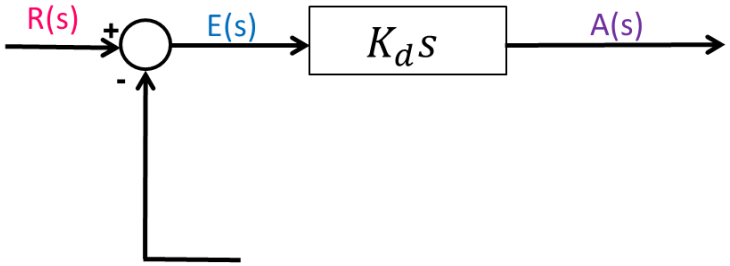


$$\frac{A(s)}{E(s)} = -\frac{\frac{1}{sC_2}}{\frac{R_1}{1+sC_1R_1}} = -K_p\left(1 + \frac{1}{sT_i}\right)$$

$K_p = C_1/C_2$ $\qquad$ $T_i = R_1C_1$

6. CONTROL DERIVATIVO (D)

$$a(t) = K_d \frac{de(t)}{dt}$$



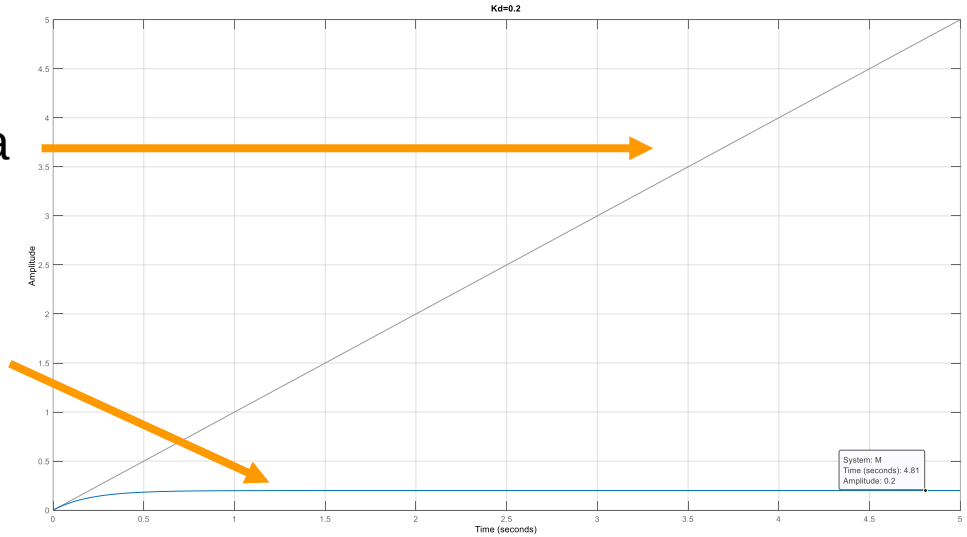
$$\boxed{\frac{A(s)}{E(s)} = K_d s}$$

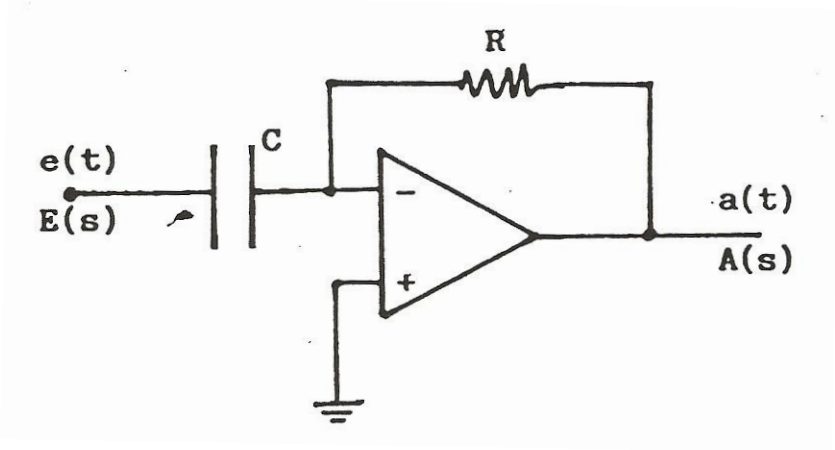
La acción de control derivativo es proporcional a la velocidad de variación del error.

•Ante **entrada** de tipo **rampa**:

Entrada

Salida regulador



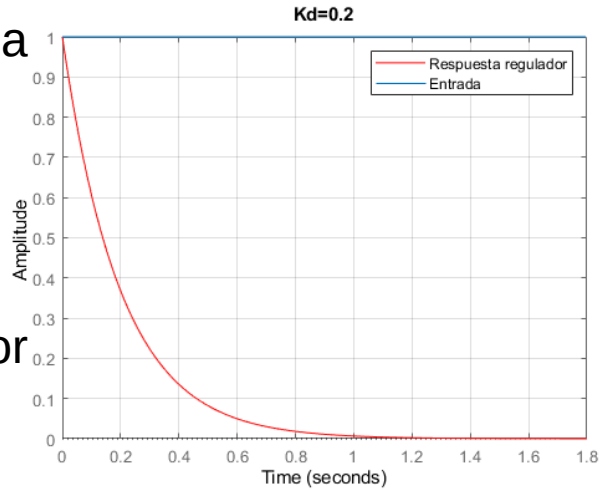


$$\frac{A(s)}{E(s)} = -RC\,s = -K_d\,s$$

•Ante **entrada** tipo **escalón**:

Entrada

Salida regulador

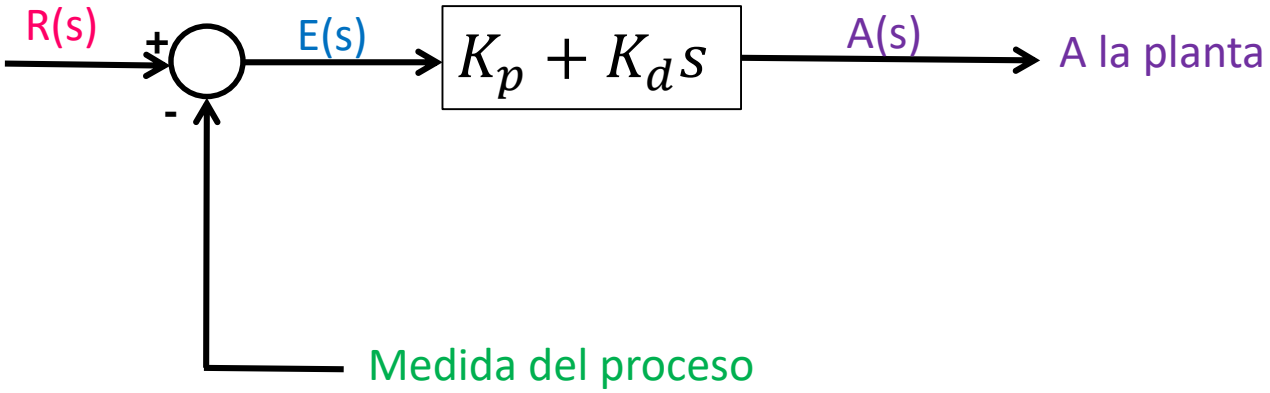


- El regulador D genera una señal de control proporcional a la derivada del error e(t).
- Mejora la estabilidad del transitorio.

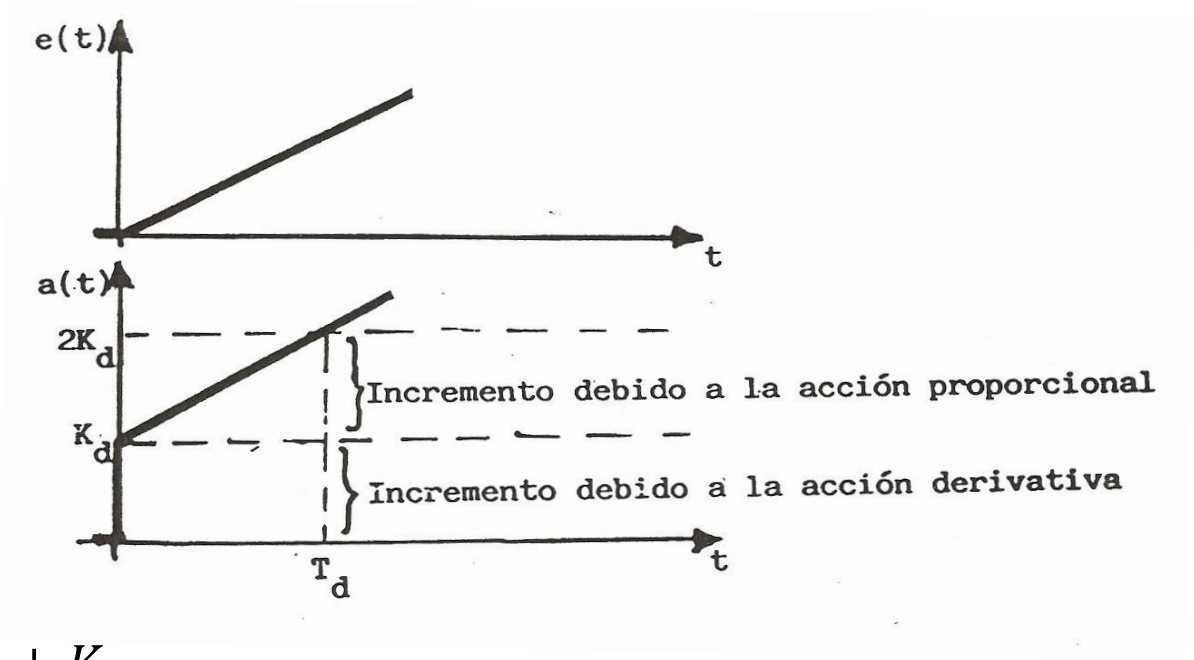
7. CONTROL PROPORCIONAL DERIVATIVO (PD)

$$a(t) = K_p e(t) + K_d \frac{de(t)}{dt}$$

$$\boxed{\frac{A(s)}{E(s)} = K_p + K_d s}$$

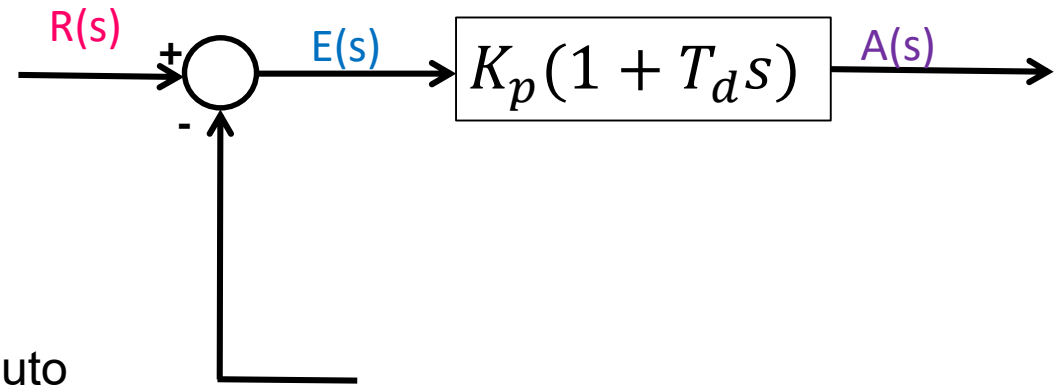


•Si la entrada es de tipo rampa:

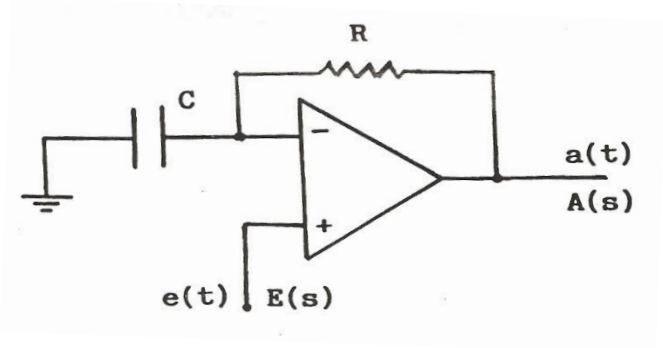


$$2K_d = K_p.T_d + K_d$$

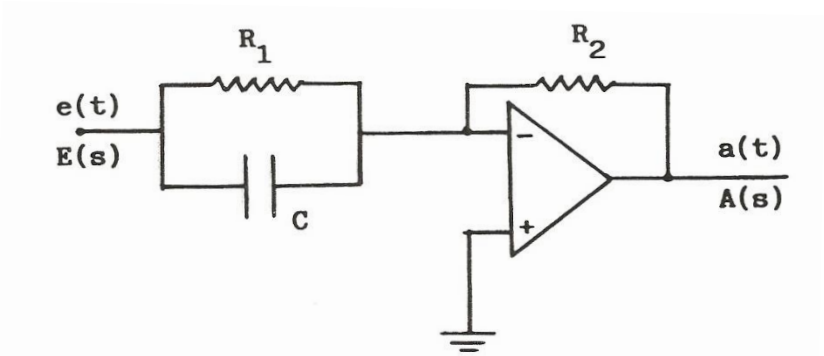
$$\boxed{T_d = \frac{K_d}{K_p}}$$



T_d ≡ minutos de anticipación
1/ T_d ≡ anticipaciones por minuto

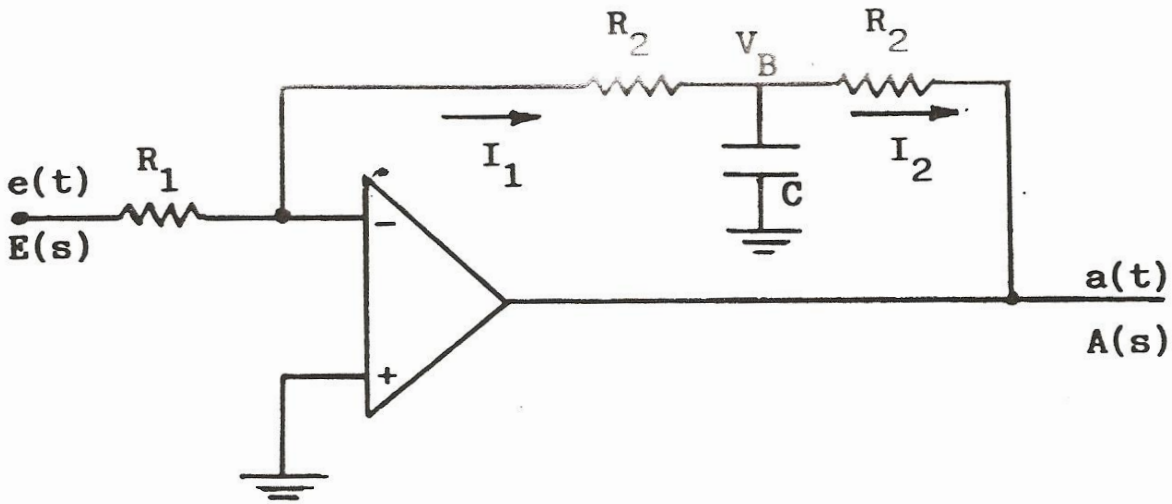


$K_p = 1 \qquad T_d = RC$



$$\frac{A(s)}{E(s)} = -\frac{R_2}{\dfrac{R_1}{1+sCR_1}} = -\frac{R_2}{R_1}(1+sCR_1) = K_p(1+T_d s)$$

$$K_p = -\frac{R_2}{R_1} \qquad Td = CR_1$$



$$A(s) = -(I_1 + I_2)\cdot R_2$$

$$V_B = (I_1 - I_2)\frac{1}{sC}$$

$$V_B = -I_1 R_2$$

$$E(s) = I_1 R_1$$

$$I_2 = I_1(1 + sCR2)$$

$$A(s) = -R_2(2 + sCR_2)I_1 = -\frac{R_2}{R_1}(2 + sCR_2)E(s)$$

$$\frac{A(s)}{E(s)} = -\frac{R_2}{R_1}(2 + sCR_2) = K_p(1 + T_d s)$$

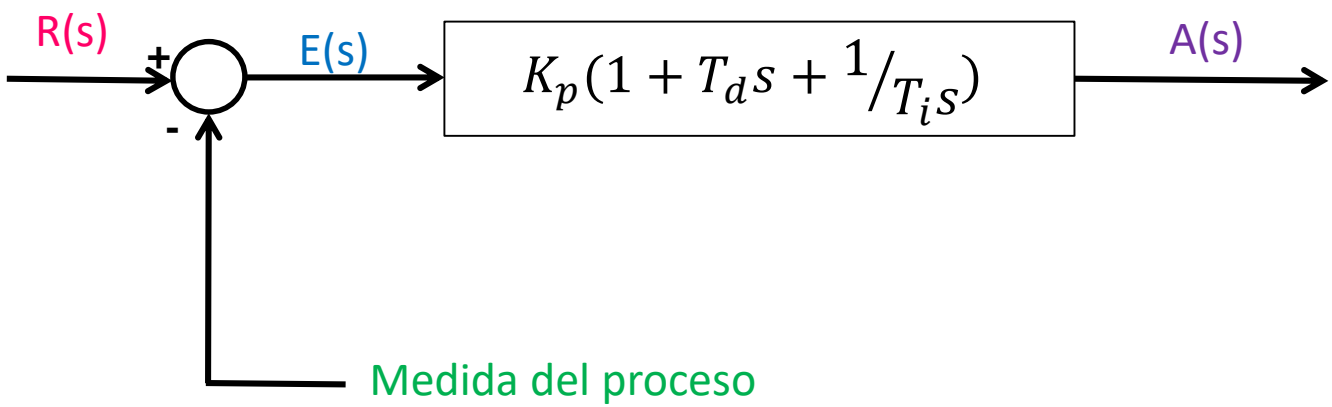
$$\begin{cases} K_p = -\dfrac{2R_2}{R_1} \\ T_d = \dfrac{CR_2}{2} \end{cases}$$

8. CONTROL PROPORCIONAL, DERIVATIVO INTEGRAL (PID)

$$a(t) = K_p e(t) + K_d \frac{de(t)}{dt} + K_i \int_0^t e(t)\,dt =$$

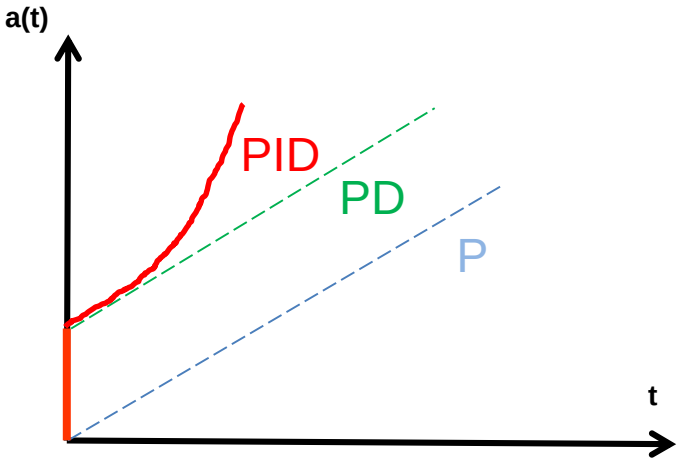
$$= K_p \left[e(t) + \frac{K_d}{K_p} \frac{de(t)}{dt} + \frac{K_i}{K_p} \int_0^t e(t)\,dt \right]$$

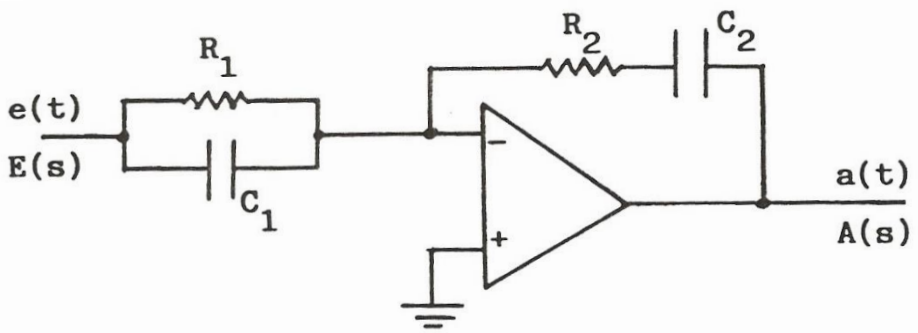
$$\boxed{\frac{A(s)}{E(s)} = K_p \left(1 + T_d s + \frac{1}{T_i s} \right)}$$



8. CONTROL PROPORCIONAL, DERIVATIVO INTEGRAL (PID)

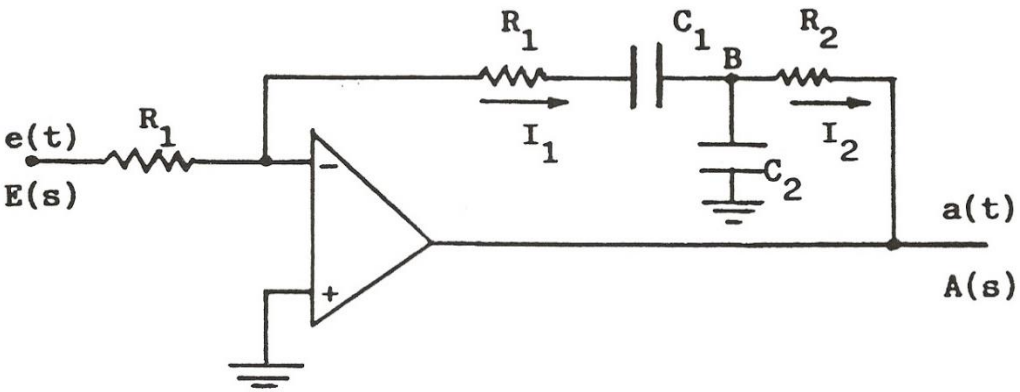
•Cuando el error tiene forma de rampa unitaria:





$$\frac{A(s)}{E(s)} = -\frac{R_2 + \frac{1}{sC_2}}{\frac{R_1}{1+sC_1R_1}} = -\frac{(1+sC_1R_1)(1+sC_2R_2)}{sC_2R_1}$$

$$\frac{A(s)}{E(s)} = \underbrace{-\left(\frac{C_1}{C_2} + \frac{R_2}{R_1}\right)}_{\text{Proporcional}} - \underbrace{\frac{1}{sC_2R_1}}_{\text{Integral}} - \underbrace{sC_1R_2}_{\text{Derivativa}}$$



$$A(s) = -\left(R_1 + \frac{1}{sC_1}\right) I_1 - R_2 I_2$$

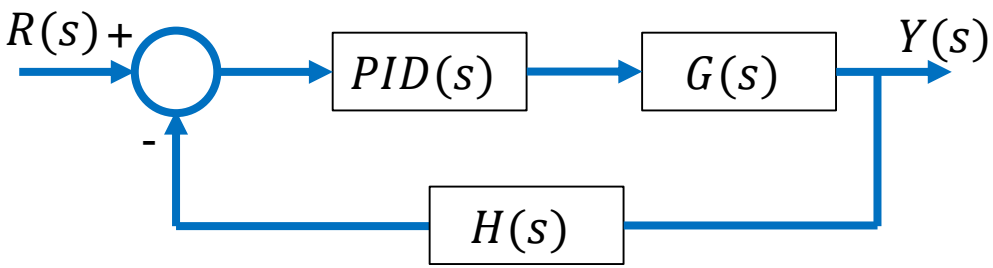
$$V_B = (I_1 - I_2)\frac{1}{sC_2}$$

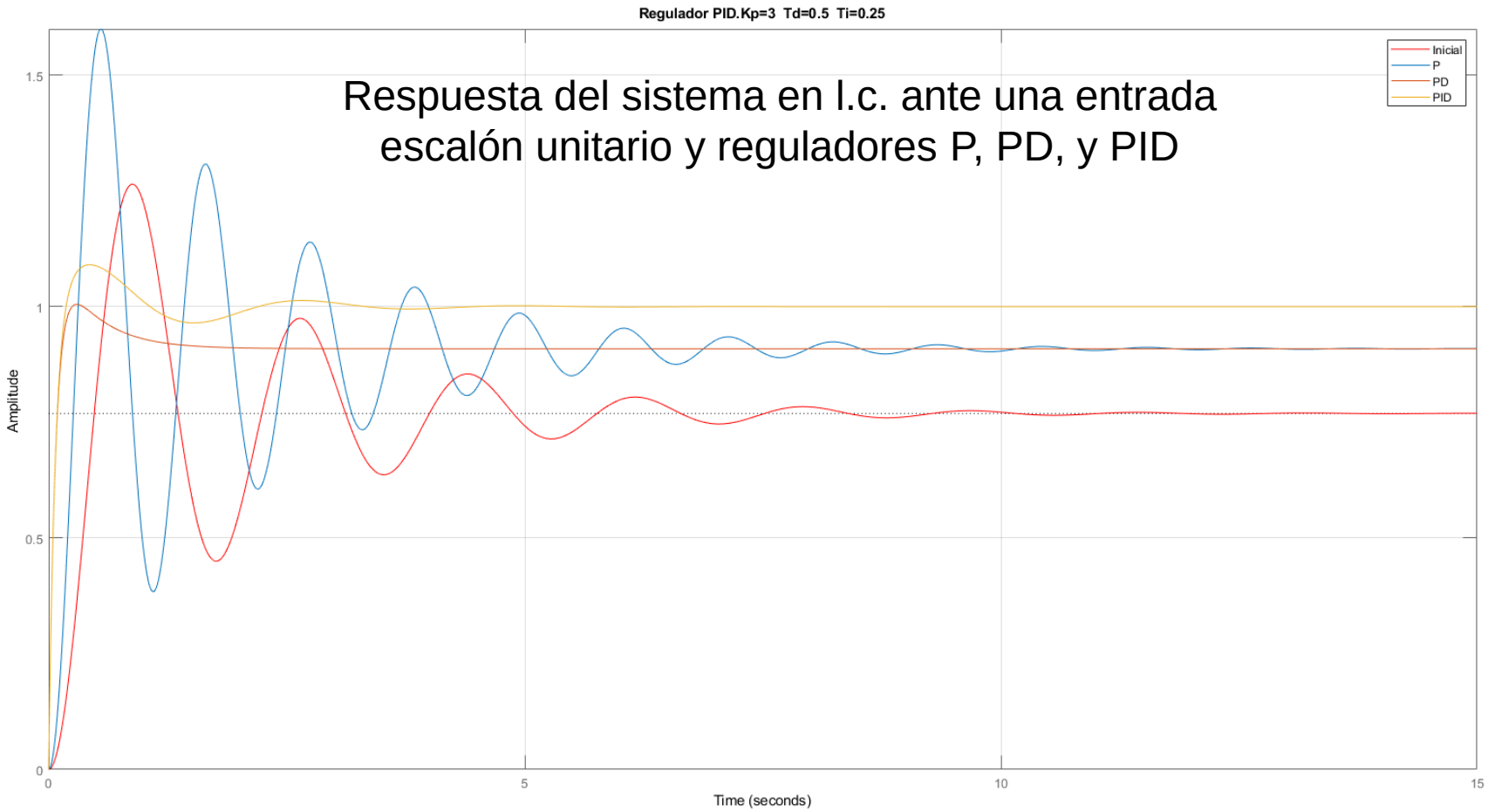
$$V_B = -\left(R_1 + \frac{1}{sC_1}\right) I_1$$

$$I_2 = \left(1 + sC_2 R_1 + \frac{C_2}{C_1}\right) I_1$$

$$A(s) = -\left(R_1 + R_2 + \frac{C_2 R_2}{C_1} + \frac{1}{sC_1} + sC_2 R_1 R_2\right)\frac{E(s)}{R_1}$$

$$\frac{A(s)}{E(s)} = -\left(\underbrace{1 + \frac{R_2}{R_1} + \frac{C_2 R_2}{C_1 R_1}}_{\text{Proporcional}} + \underbrace{\frac{1}{C_1 R_1 s}}_{\text{Integral}} + \underbrace{C_2 R_2 s}_{\text{Derivativa}}\right)$$



$$G(s) = \frac{10}{s^2 + s + 3} \qquad \mathrm{H}(s) = 1$$

$$R(s) = \frac{1}{s}$$