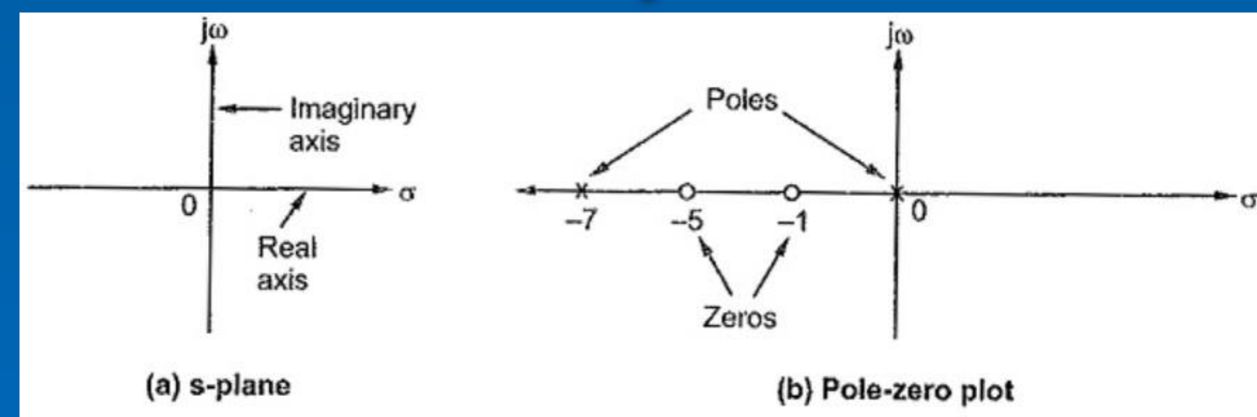
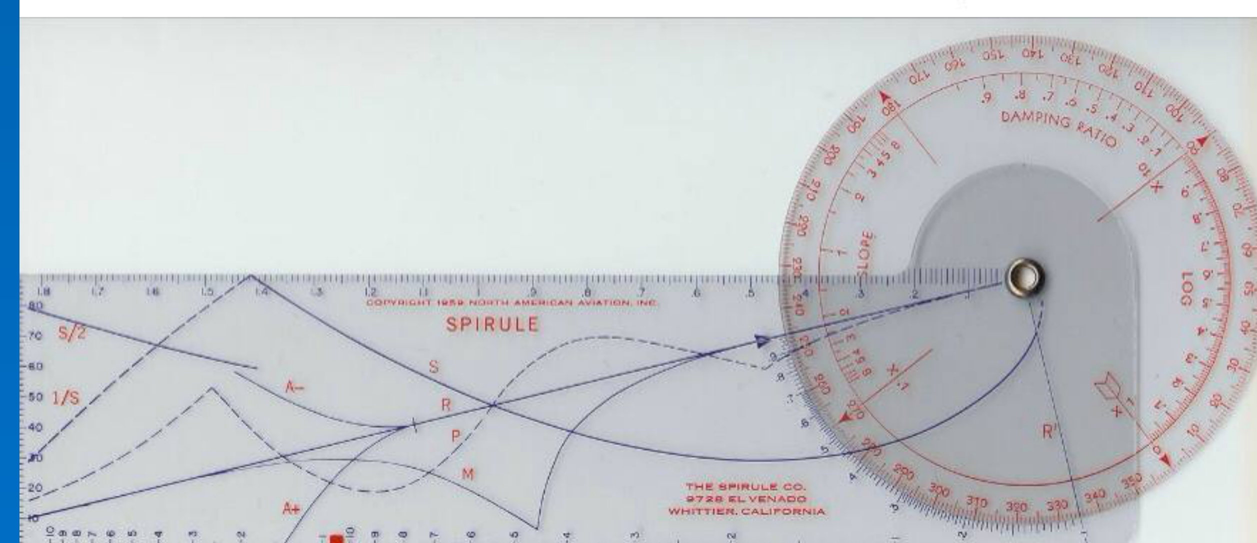
216D4122
DASAR SISTEM KENDALI
MODUL 3 ISTILAH-ISTILAH KHUSUS
Sub-Modul 3C: Order, Pole dan Zero





(versi kuliah DARLING = semi-DARing semi-LurING)

Semester Akhir 2020-2021

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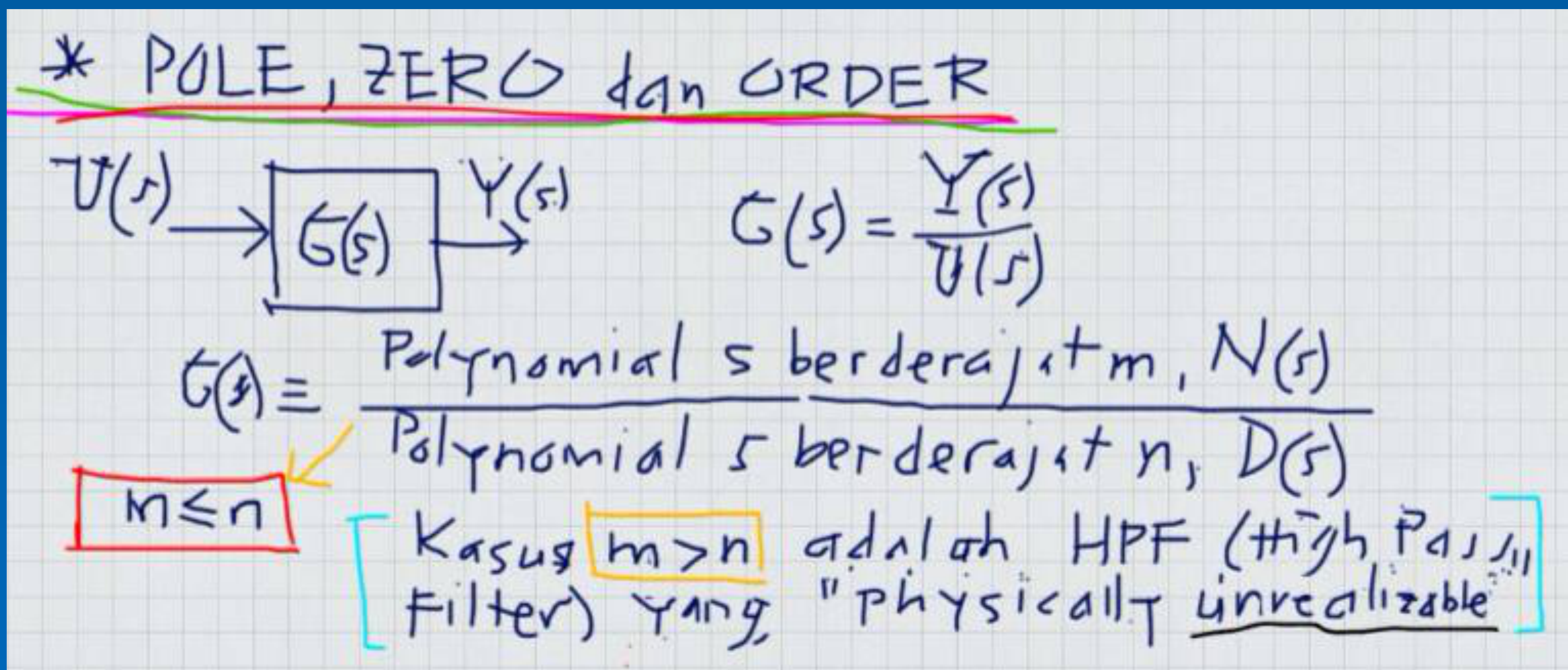

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Order, Pole dan Zero

Tugas MANDIRI (tidak dikumpul), gunakan fasilitas ***Google Search*** untuk melakukan penelusuran dengan kata-kunci istilah-istilah khusus berikut ini.

3 (tiga) ISTILAH-2 KHUSUS yang sering digunakan dalam analisis dan desain **SISTEM KENDALI**, yang sama sekali berbeda artinya jika dilihat dalam KAMUS, yaitu:

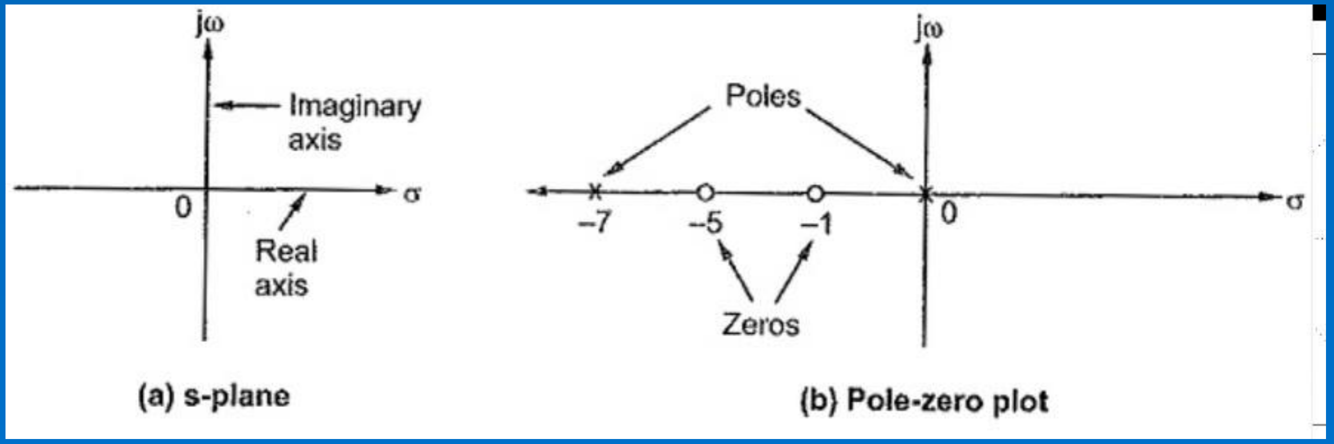
- ***Order*** dari SISTEM
- ***Pole(s)***
- ***Zero(s)***

ketiganya **TERKAIT** dengan Model **NISBAH ALIH** dari **SISTEM**.

Poles and Zeros

$$H(s) = K\frac{\prod_{i=1}^{m}(s-z_i)}{\prod_{i=1}^{n}(s-p_i)}$$

- K is the transfer gain
- The roots of numerator is called zeros of the system. Zeros correspond to signal transmission-blocking properties.
- The roots of denominator are called poles of the system. Poles determine the stability properties and natural or unforced behavior of the system.
- Poles and zeros can be complex quantities.
- $z_i = p_i$, cancellation of pole-zero may lead to undesirable system properties.



Apa itu ORDER dari SISTEM ?

Terkait dengan 2 konfigurasi dasar :

⇒ Order dari sistem kendali sesuai dengan jumlah pole $G(s)$ + jumlah pole $H(s)$ pengendali kendalian

⇒ Pole dan Zero dari OLTF $G(s).H(s)$ adalah pole dan zero dari masing-masing $G(s)$ dan $H(s)$

⇒ Pole dari CLTF $G_T(s)$ adalah akar-akar pers. karakteristik

$$1 + G(s)H(s) = 0$$

* POLE, ZERO dan ORDER

$U(s) \rightarrow$ [$G(s)$] $\rightarrow Y(s)$

$$G(s) = \frac{Y(s)}{U(s)}$$

$$G(s) = \frac{\text{Polynomial } s \text{ berderajat } m,\ N(s)}{\text{Polynomial } s \text{ berderajat } n,\ D(s)}$$

$m \leq n$

[Kasus $m > n$ adalah HPF (High Pass Filter) yang "physically unrealizable"]

$$N(s) = b_m s^m + b_{m-1} s^{m-1} + b_{m-2} s^{m-2} + \dots + b_1 s + b_0$$

$$D(s) = a_n s^n + a_{n-1} s^{n-1} + a_{n-2} s^{n-2} + \dots + a_1 s + a_0$$

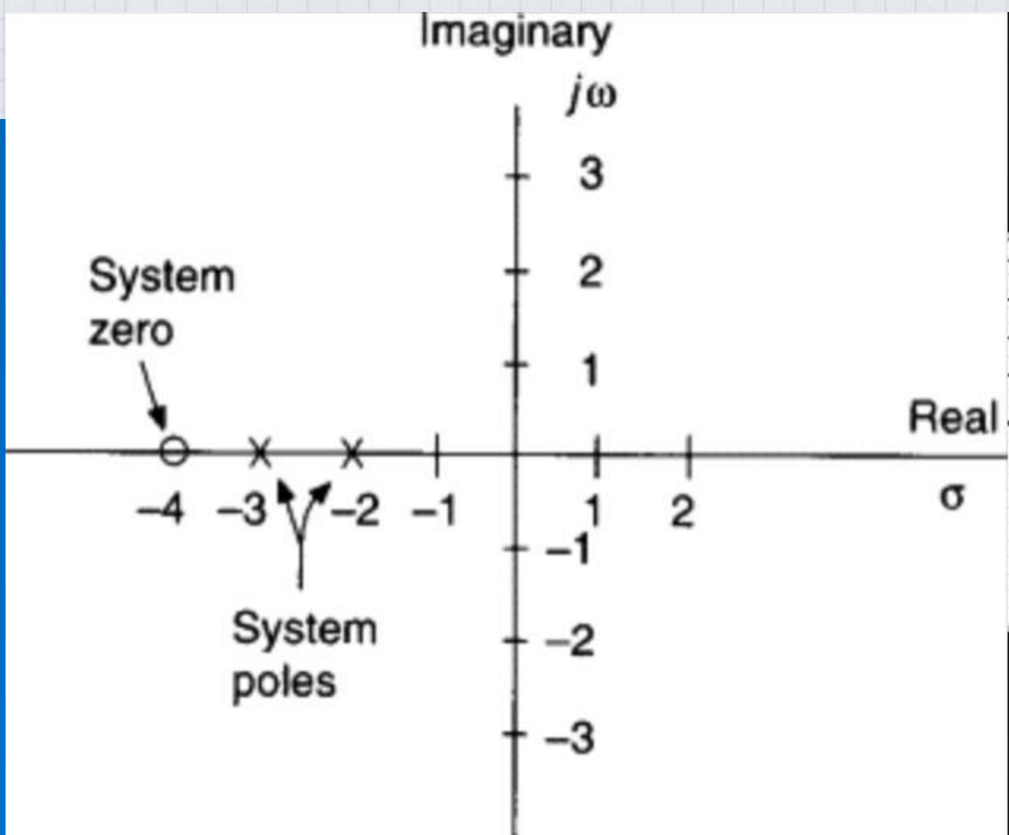
$m \leq n$, koefisien $a_0, \dots, a_n, b_0, \dots, b_m \in$ Real

* Akar² pers. $N(s) = 0$ disebut ZERO, z_1 s/d z_m
* Akar² pers. $D(s) = 0$ disebut POLE, p_1 s/d p_n

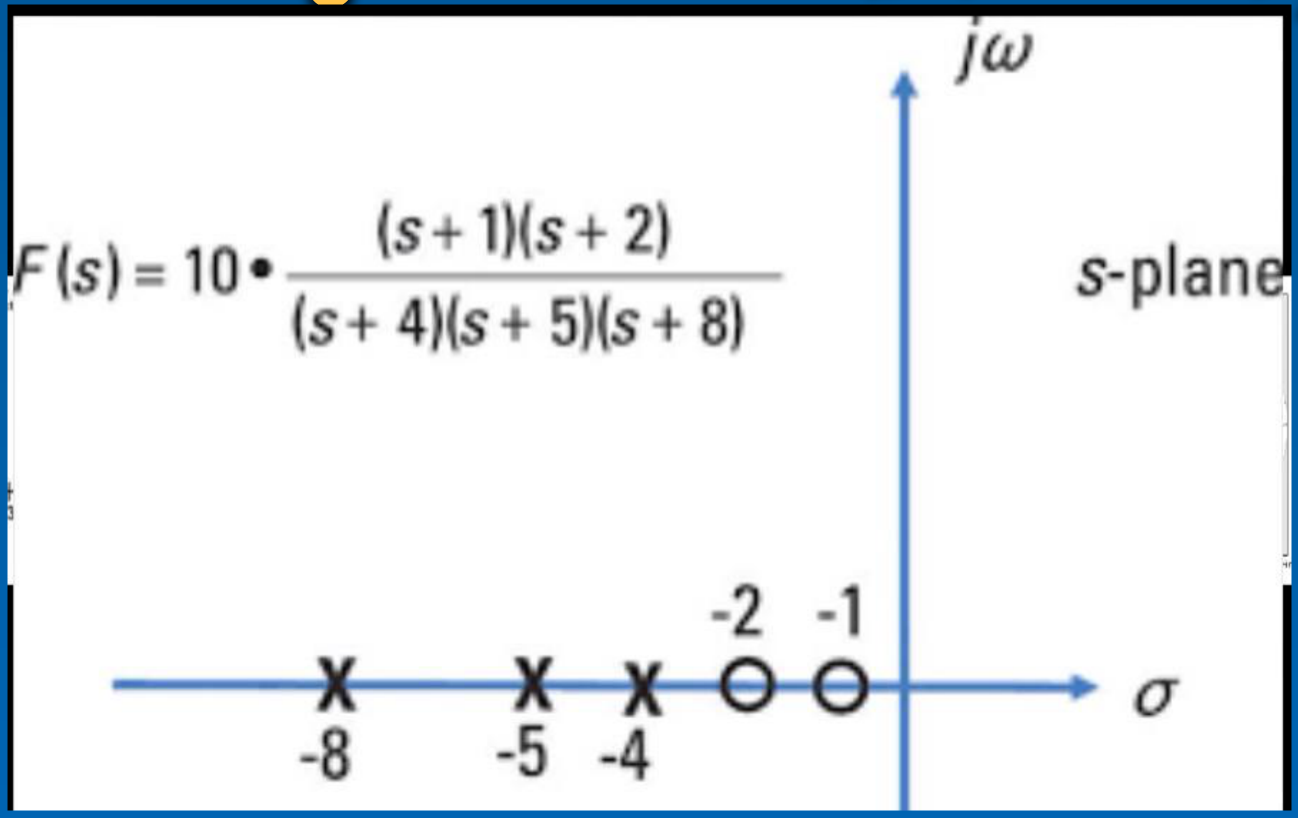
POLE dan ZERO dapat dipetakan pada BIDANG KOMPLEKS masing² dengan notasi ✖ untuk pole dan O untuk zero

* ORDER dari $G(s)$ adalah order ke-n

⇒ * Order dari $G(s)$ sesuai dengan jumlah pole-nya

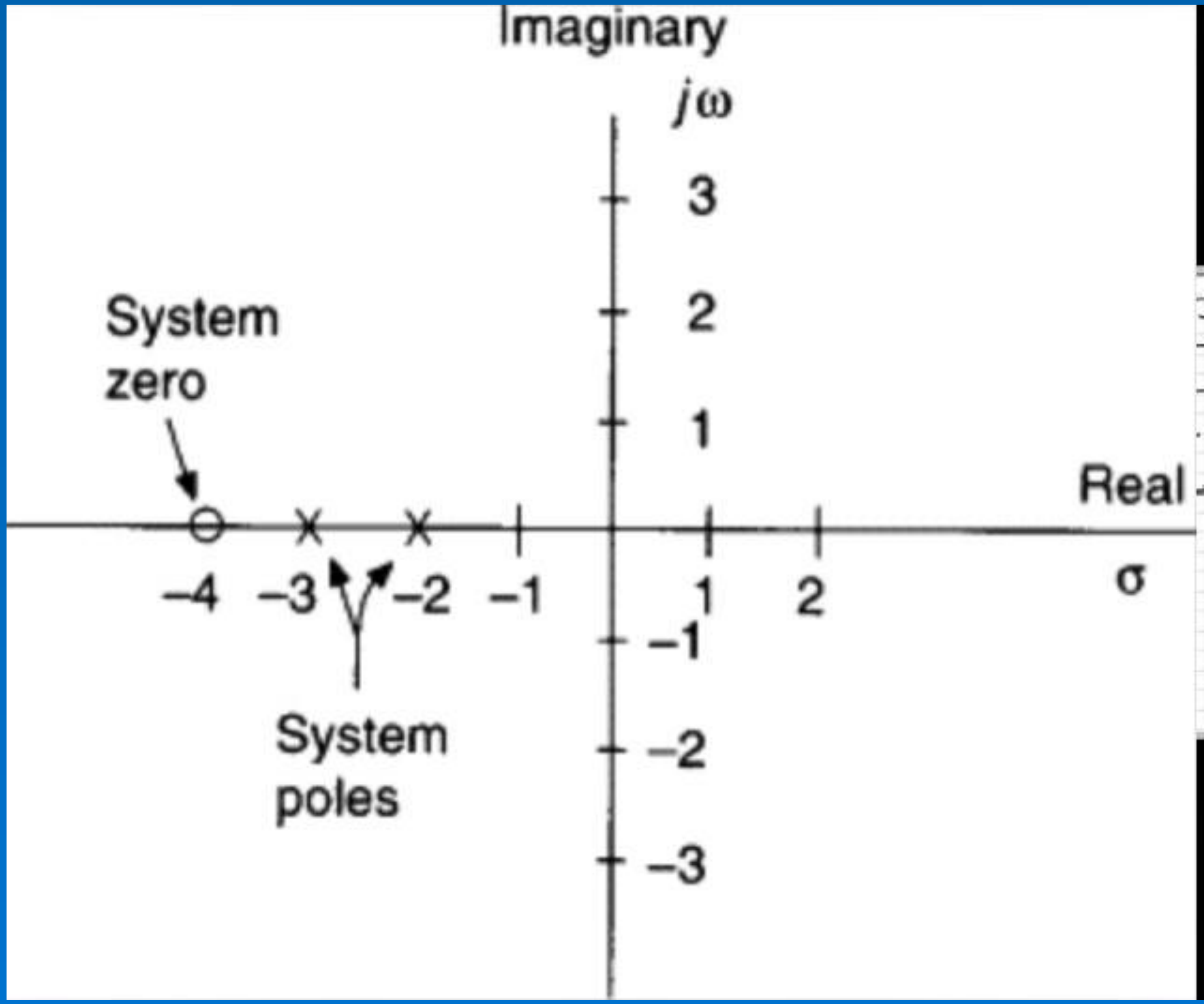


Hubungan antara Order, Pole dan Zero



Contoh Nisbah Alih Sistem **Order Ketiga**

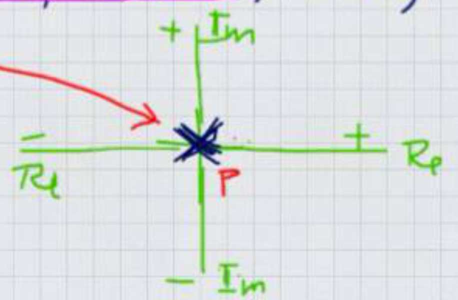
Contoh Nisbah Alih Sistem **Order Kedua**



CONTOH SOAL

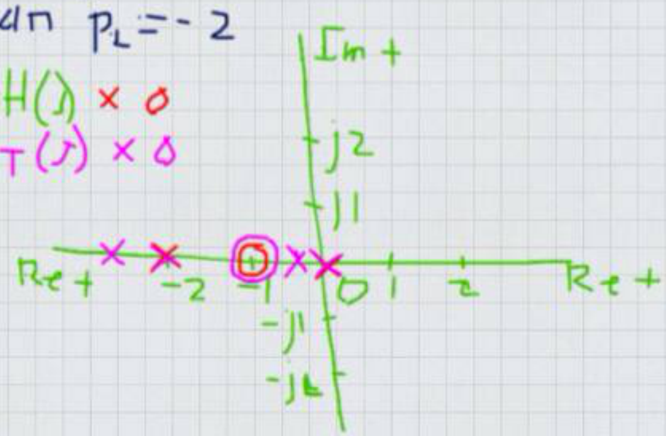
Contoh: Suatu sistem kendali mempunyai kendalian $G(s) = \frac{1}{s}$ dan $H(s) = \frac{s+1}{s+2}$ (phase compensator) sebagai pengendali-nya

* $G(s)$ sistem order pertama (1st order) yg tidak punya zero, dengan pole $p = 0$



* $H(s)$ adalah sistem order pertama dengan ZERO $z = -1$, dan POLE $p = -2$
* OLTF $G(s).H(s)$ adalah sistem order kedua, dengan $z = -1$, dan 2 POLE-nya $p_1 = 0$ dan $p_2 = -2$

OLTF $G(s)H(s)$ × o
$G_T(s)$ × o



Poles and Zeros

$$H(s) = K \frac{\prod_{i=1}^{m}(s - z_i)}{\prod_{i=1}^{n}(s - p_i)}$$

- K is the transfer gain
- The roots of numerator is called zeros of the system. Zeros correspond to signal transmission-blocking properties.
- The roots of denominator are called poles of the system. Poles determine the stability properties and natural or unforced behavior of the system.
- Poles and zeros can be complex quantities.
- $z_i = p_i$, cancellation of pole-zero may lead to undesirable system properties.

* CLTF $G_T(s) = \frac{G(s).H(s)}{1 + G(s)H(s)}$ — sistem kendali dengan KOMPENSATOR

$$= \frac{\frac{1}{s} \cdot \frac{s+1}{s+2}}{1 + \frac{1}{s} \cdot \frac{s+1}{s+2}} = \frac{s+1}{s^2 + 2s + s + 1} = \frac{s+1}{s^2 + 3s + 1}$$

mempunyai 1 zero $z = -1$

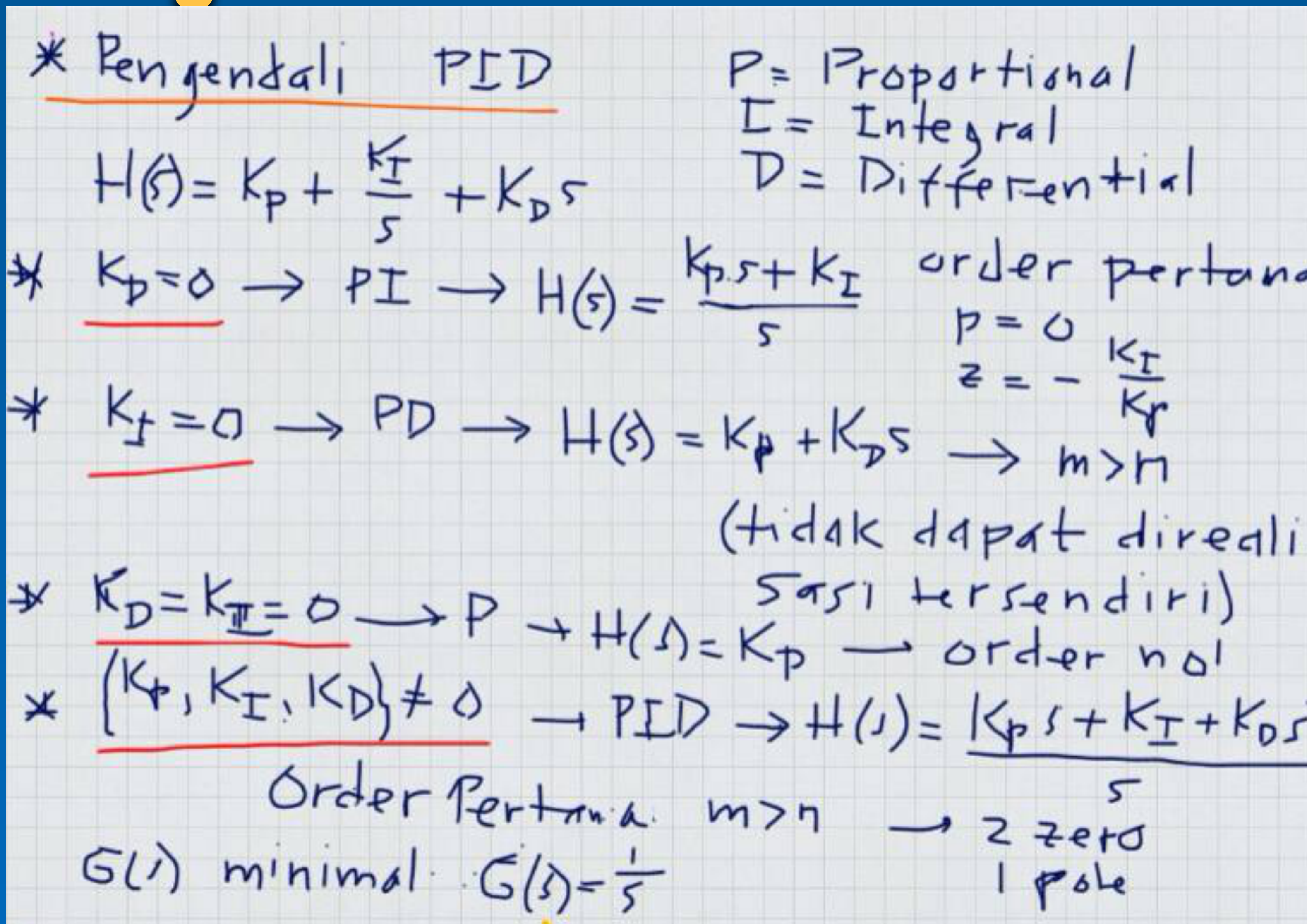
2 pole : $p_{1,2} = \frac{-3 \pm \sqrt{9-4}}{2} = -\frac{3}{2} \pm \frac{1}{2}\sqrt{5}$

$1 + G(s)H(s) = 0$
$s^2 + 3s + 1 = 0$

$p_1 = -1,5 + 1,118 = -0,382$
$p_2 = -1,5 - 1,118 = -2,618$

→ akar² pers. karakter. $1 + G(s)H(s) = 0$

Pengendali PID



* Pengendali PID

P = Proportional
I = Integral
D = Differential

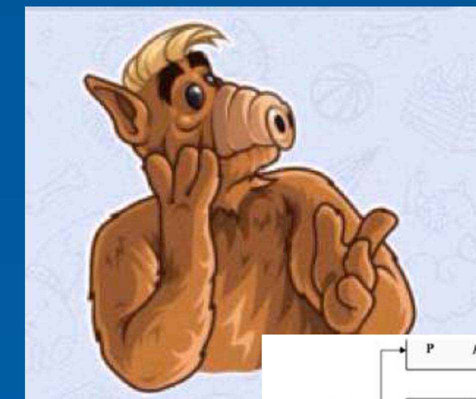
$$H(s) = K_p + \frac{K_I}{s} + K_D s$$

* $K_D = 0 \rightarrow PI \rightarrow H(s) = \frac{K_p s + K_I}{s}$ order pertama
$p = 0$
$z = -\frac{K_I}{K_p}$

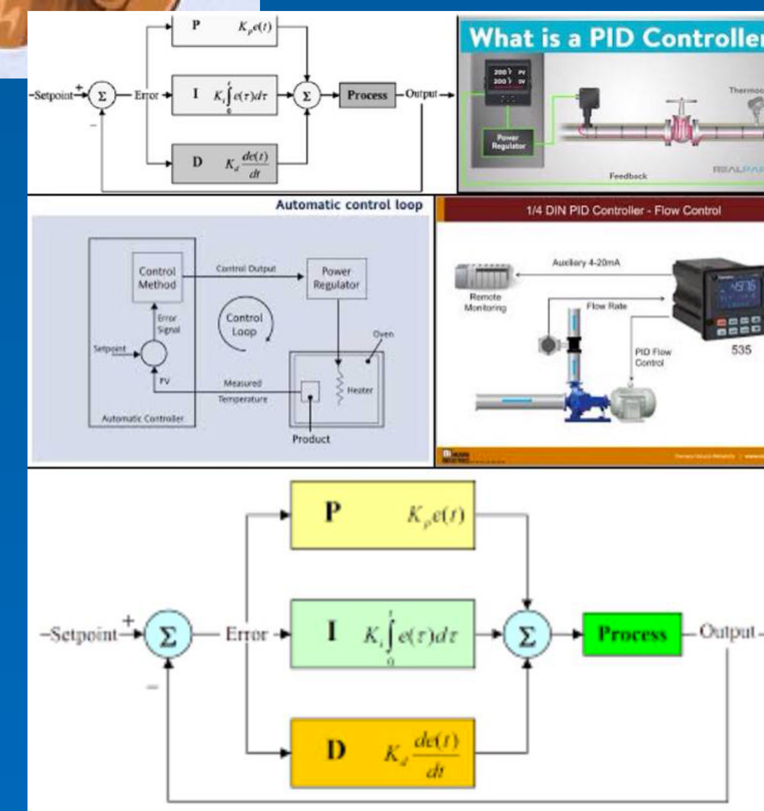
* $K_I = 0 \rightarrow PD \rightarrow H(s) = K_p + K_D s \rightarrow m > n$
(tidak dapat direalisasi tersendiri)

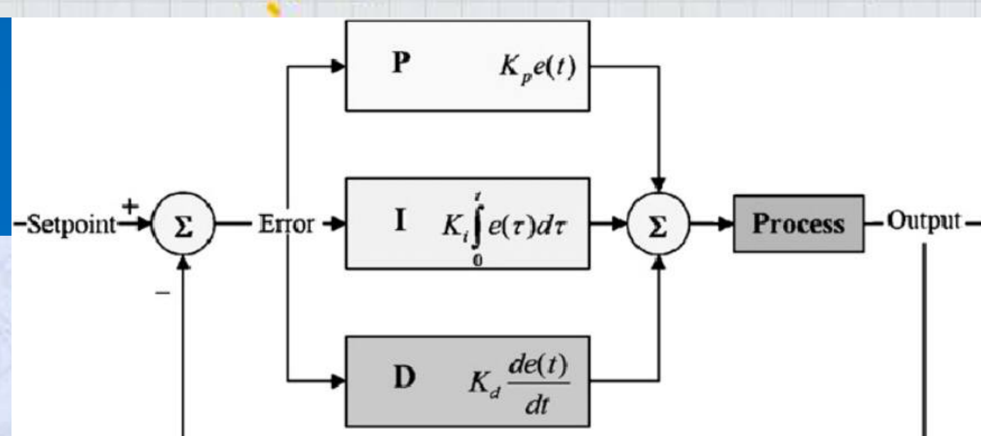
* $K_D = K_I = 0 \rightarrow P \rightarrow H(s) = K_p \rightarrow$ order nol

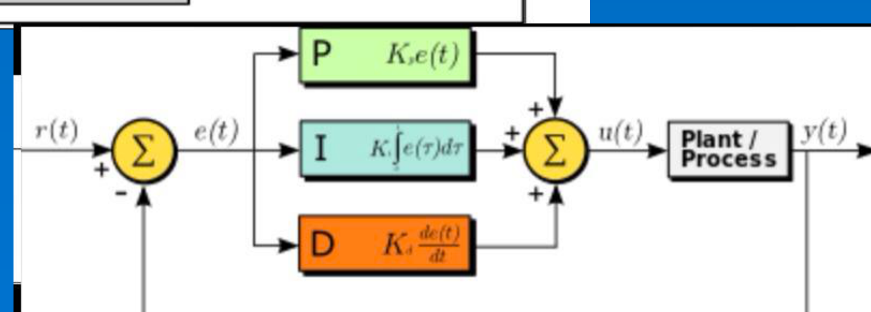
* $(K_p, K_I, K_D) \neq 0 \rightarrow PID \rightarrow H(s) = \frac{K_p s + K_I + K_D s^2}{s}$
Order Pertama $m > n \rightarrow$ 2 zero, 1 pole
G(s) minimal $G(s) = \frac{1}{s}$

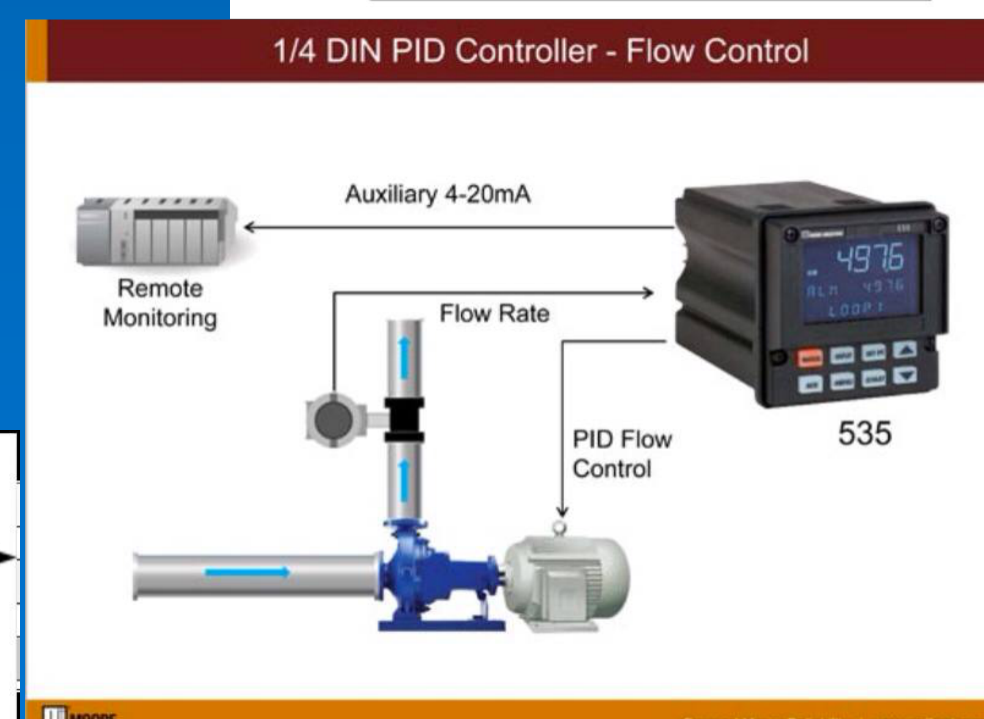


PID Controller

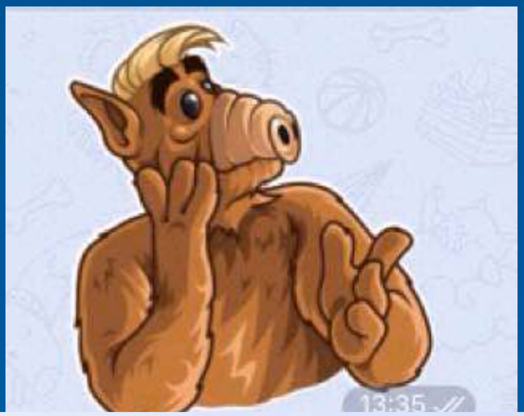








Sistem-sistem Order PERTAMA



First-Order Systems

- Are measurement systems with storage elements that can't respond immediately to a change in input.
- In general, systems with a storage or dissipative capability but negligible inertial forces can be modeled by a 1st order differential equation (ODE).

$$a_1\dot{y} + a_o y = F(t)$$

$$\tau\dot{y} + y = KF(t) \qquad \text{where } K = \frac{1}{a_o}$$

$$\tau = \frac{a_1}{a_o} = \text{time constant}$$

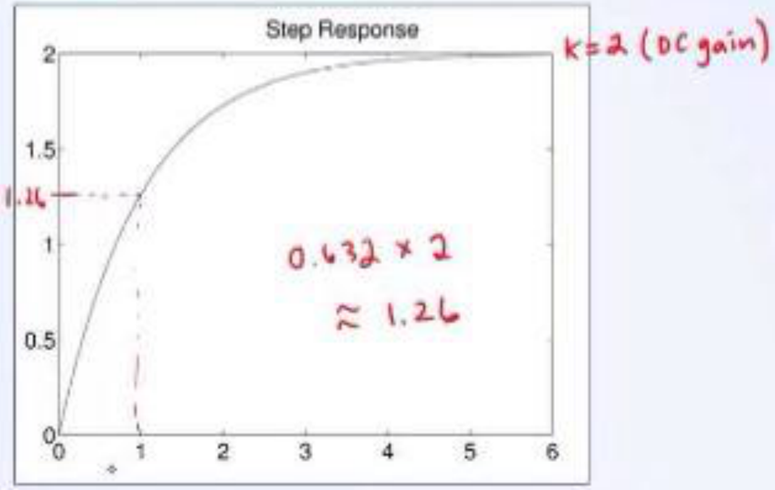
- The time constant, τ, is the measurement of the speed of system response to an input.
- The smaller the value of τ, the faster the system response.

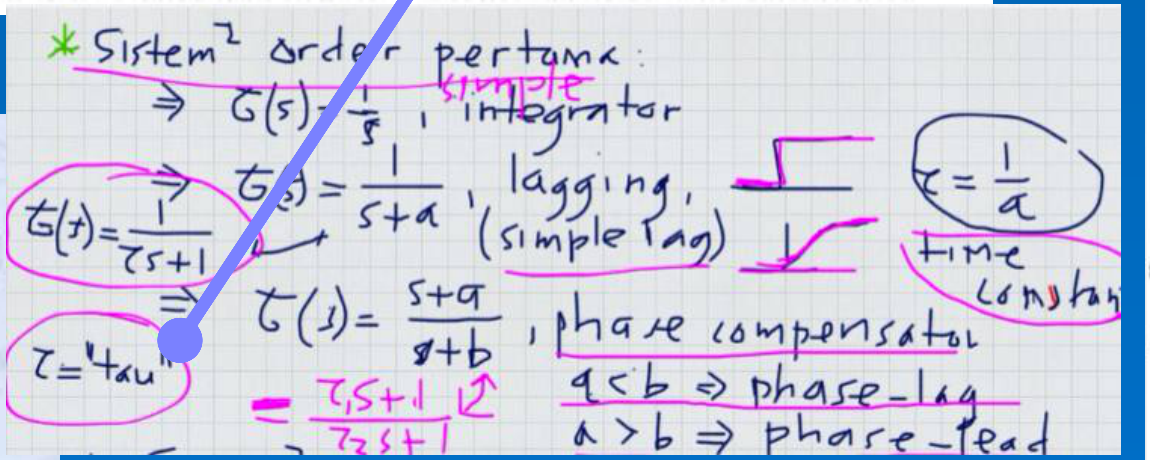
τ = "tau"

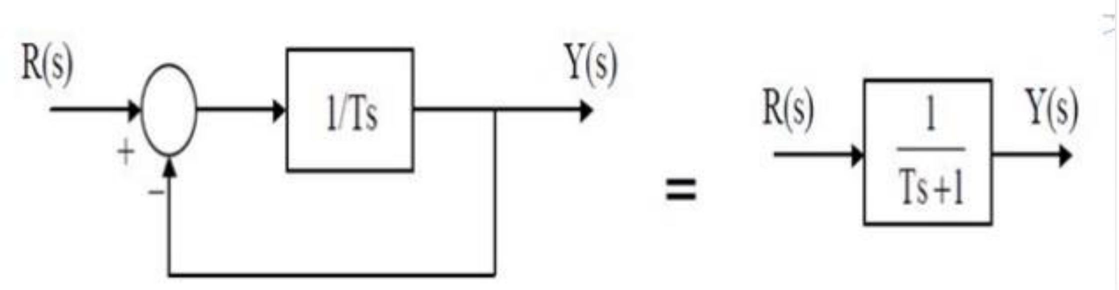
Example

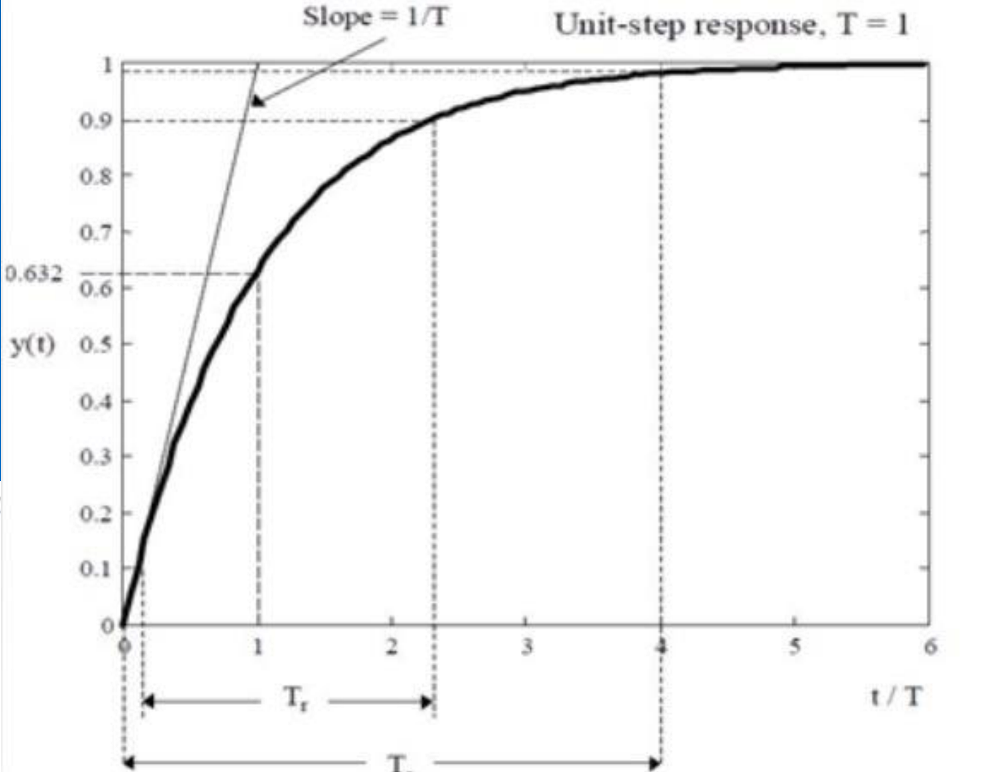
match form $\frac{K}{\tau s+1}$

- Determine the TF of the system that produced the following output in response to a unit step input

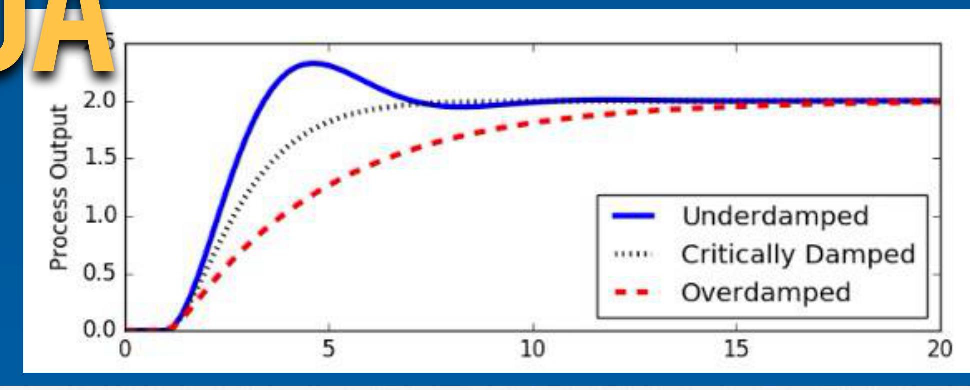








Sistem-sistem Order KEDUA



* Sistem² order kedua:
  - ⇒ $G(s) = \frac{1}{s^2}$, double integrator
  - ⇒ $G(s) = \frac{1}{s(s+a)}$, simple (lag + integrator)

Bentuk Umum Sistem Order Kedua

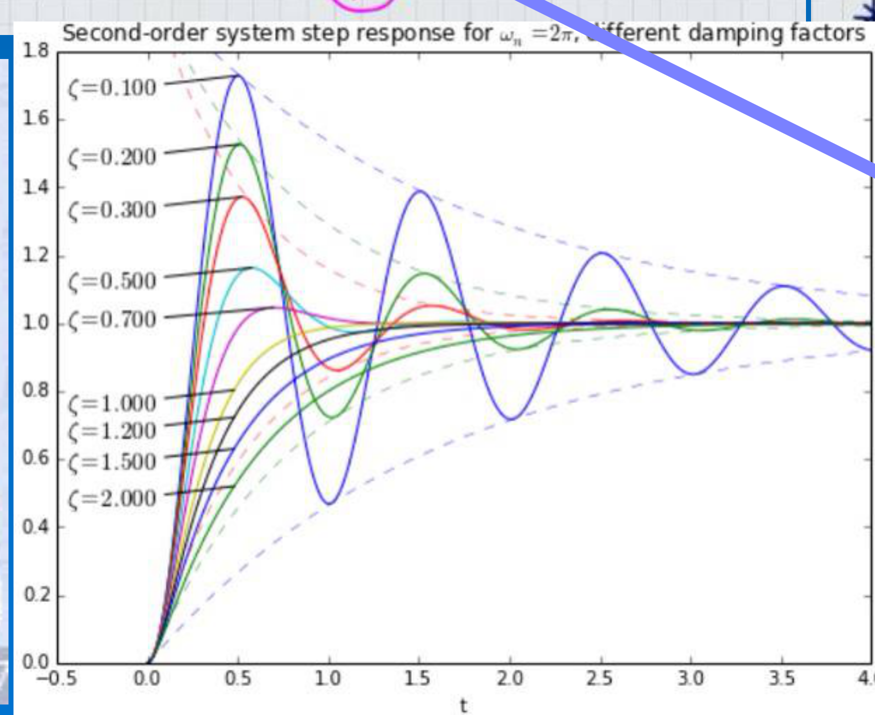
$$G(s) = \frac{K}{s^2 + 2\xi\omega_n s + \omega_n^2}$$

ξ : zeta : nisbah redaman (damping ratio)

ω_n : omega n : frekuensi (sudut, radian/sec) alamiah tak teredam (undamped natural frequency)

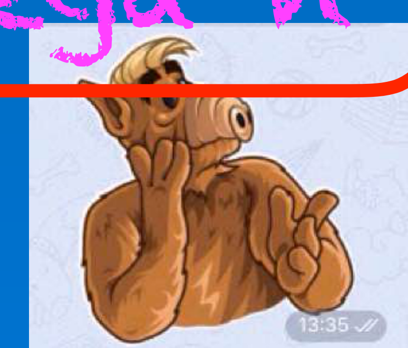
Sistem Order Kedua karakteristiknya tergantung pada nilai ξ

* $\xi > 1$ → teredam lebih (overdamped)
  2 pole Real → $G(s) = \frac{K}{(s+a)(s+b)}$
* $\xi = 1$ → teredam kritis (critically damped)
  $G(s) = \frac{K}{(s+a)^2}$ 2 pole Real KEMBAR
* $0 < \xi < 1$ → teredam kurang (under damped)
  2 pole Pasangan Kompleks Konjugasi
  → $p_{1,2} = a \pm jb$, $j = \sqrt{-1}$
* $\xi = 0$ → Undamped oscillation → $G(s) = \frac{K}{s^2 + \omega_n^2}$ 2 pole pasangan imajiner $p_{1,2} = \pm jb$
* $\xi < 0$ ↳ UNSTABLE

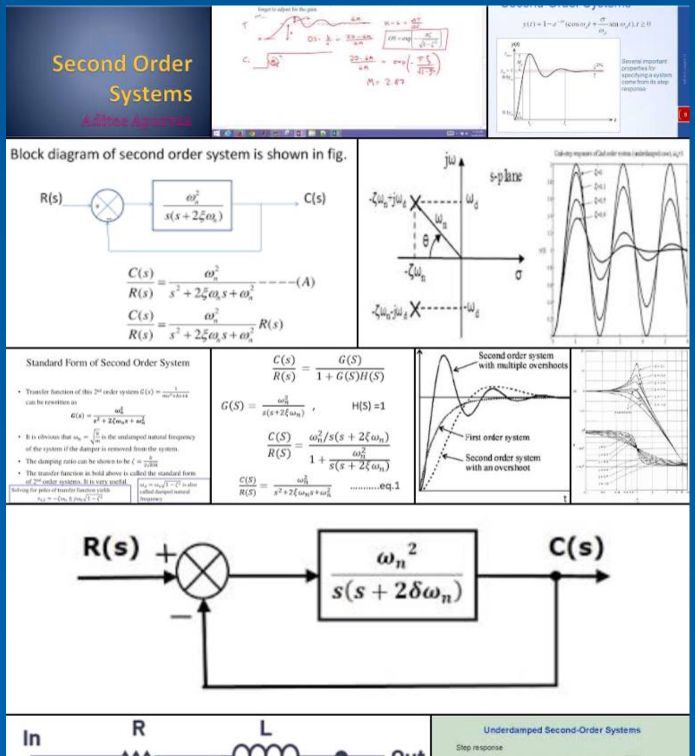


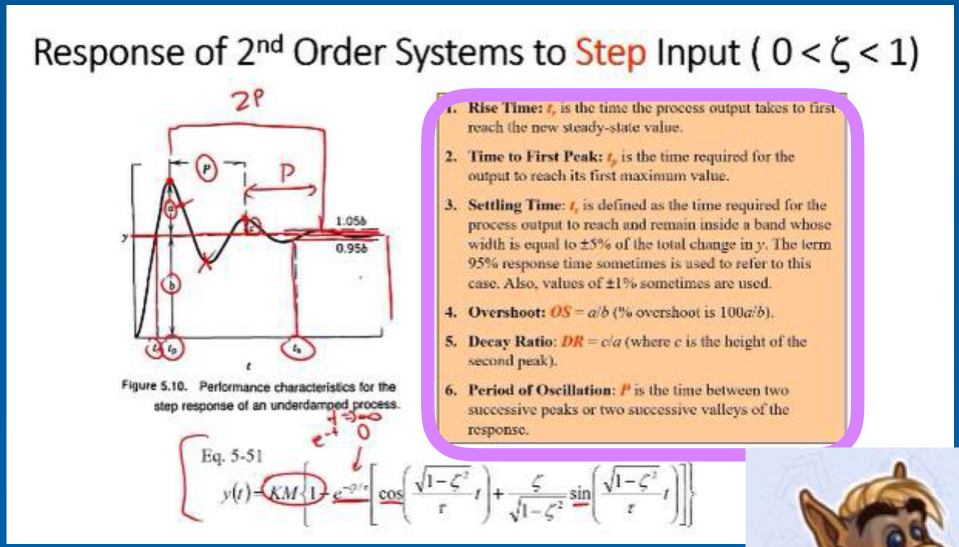
ξ = "zeta"

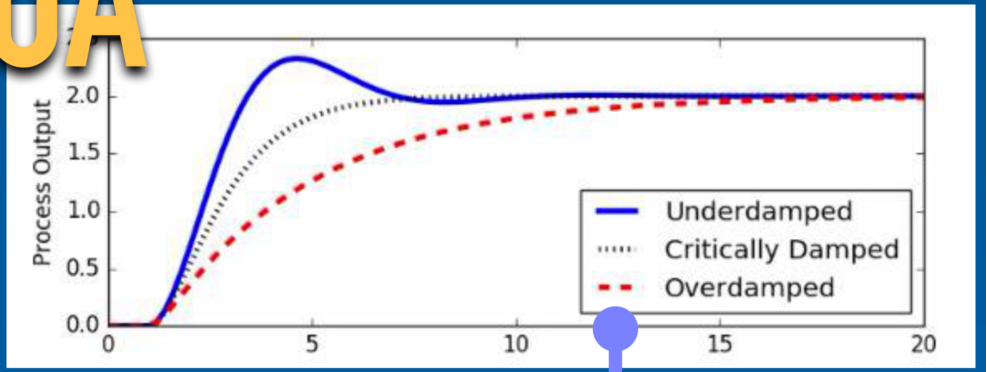
ω_n = "omega-n"



Contoh2 Sistem Order KEDUA







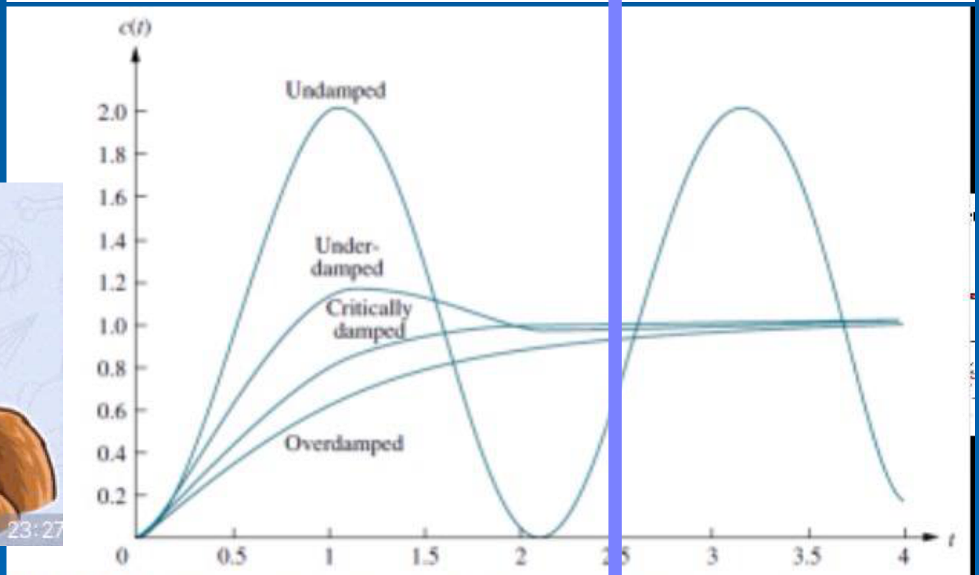


FIGURE 4.10 Step responses for second-order system damping cases

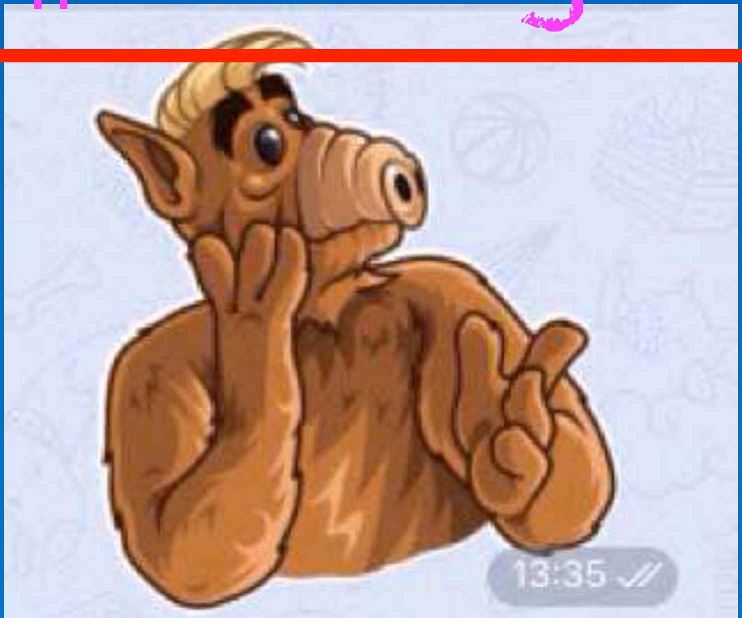
Tentukan tanggapan denyut dari

* $G(s) = \frac{10}{s^2 + 4s + 4}$ → $\xi = 1$ ✓
* $G(s) = \frac{10}{s^2 + 8s + 4}$ → $\xi > 1$ ✓
* $G(s) = \frac{10}{s^2 + s + 4}$ → $0 < \xi < 1$ ✓
* $G(s) = \frac{10}{s^2 + 4}$ → $\xi = 0$ ✓

Note: Gunakan Tabel Laplace ⇒

ξ = "zeta"

ω_n = "omega-n"



MODUL PEMBELAJARAN

- **MODUL 0: PENGANTAR KULIAH**
- **MODUL 1**: **Pengenalan SISTEM KENDALI**
- **MODUL 2**: **Alat-alat Matematik**
    - Sub-MODUL 2A: **Bagan Kotak** dan **Aljabar**-nya
    - Sub-MODUL 2B: **Nisbah-Alih** dan **Transformasi Laplace**
- **MODUL 3**: **Istilah-istilah Khusus**
    - **Sub-Modul 3A: KONFIGURASI DASAR**
    - **Sub-Modul 3B: Isyarat-isyarat TEST**
    - **Sub-Modul 3C: *ORDER*, *Pole* dan *Zero***
- **MODUL 4**: **Pengantar Kestabilan**

MIDTEST

UJIAN FINAL

SELAMAT BELAJAR

Semoga SUKSES meraih PRESTASI!