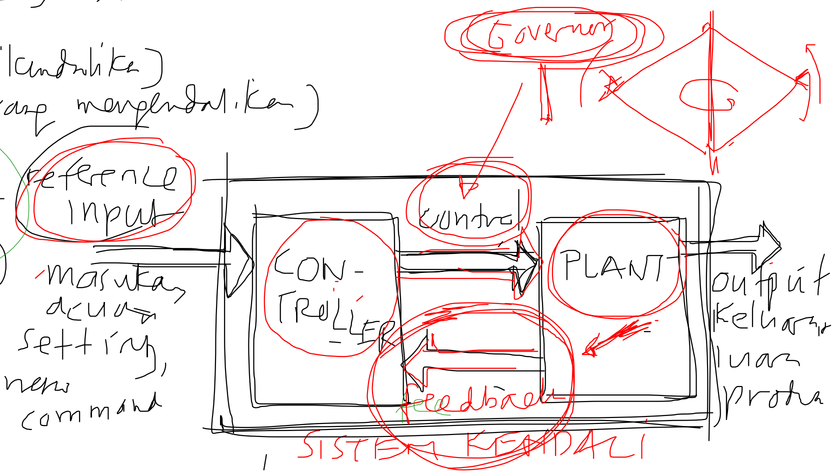
Apa itu SISTEM KENDALI ???

Sistem Kendali adalah sistem apa saja, yang terdiri dari 2 (dua) bagian:
* Kendalian (PLANT, yang dikendalikan)
* Pengendali (CONTROLLER, yang mengendalikan)

Teknik Kendali (Control Engineering) adalah bidang ilmu yang mempelajari Sistem Kendali (Control Systems)



Kendali

1996: MASDALI → Masy. Sistem Kendali Indonesia

"Control" ⟷ "Kendali"

→ ~~kontrol~~
→ ~~pengaturan (ITB EL)~~
→ ~~mengatur (ITB MS)~~
→ ~~pengendalian (UGM)~~

* Otomatis { Keterlibatan MANUSIA
* Manual

DASAR SISTEM KENDALI

Rhiza +6281643121 62
rhiza@unhas.ac.id
http://www.unhas.ac.id/rhiza/arsip/kuliah/
http://www.unhas.ac.id/rhiza/arsip/nilai/

Penilaian: (40% MID + 60% FIN } N.A)
(open book, no laptop)

16x pertemuan @ 100 menit:

Bab I: Pengantar
Bab II: Alat-alat Matematik
Bab III: Istilah-istilah sistem Kendali
Bab IV: Analisis Kestabilan

MID
FIN

Buku bacaan:
* Ogata, "Modern Control Engineering"
* Kuo: "Automatic Control Systems"
* Schaum Series: "Feedback and Control Systems"

Bab I: Pengenalan SISTEM KENDALI

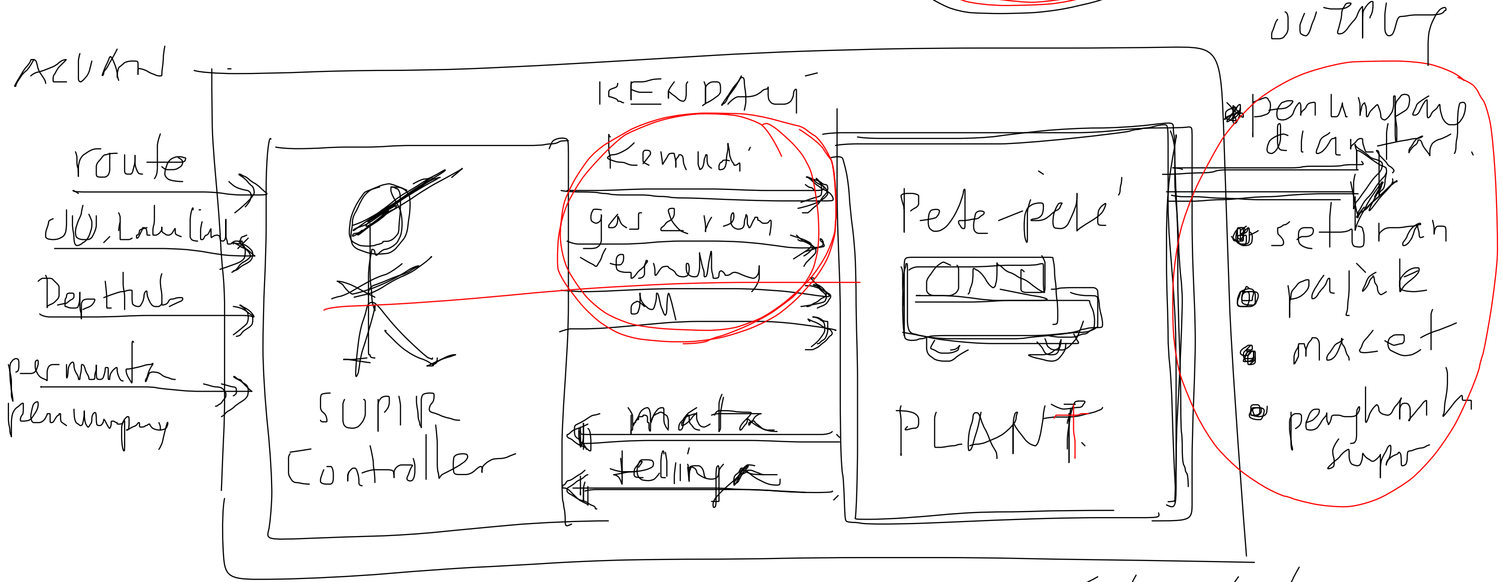
Introduction to Control Systems

1995 Konsorsium Ilmu-Ilmu Teknik menetapkan:

TEKNIK ELEKTRO
Electrical Engineering

* Teknik ENERGI
* Teknik TELEKOMUNIKASI
* Teknik ELEKTRONIKA
* Teknik KENDALI
* Teknik KOMPUTER

Contoh SISTEM KENDALI MANUAL



Sistem Kendali Operasional PÉTÉ-PÉTÉ

BAB II Alat-alat MATEMATIK

Teori Kendali
Control theory

- * Teori Kendali KLASIK
- * Teori Kendali MODERN

paket 1. Bagan kotak & Aljabar-nya

paket 2: Model Nisbah-Alih dan Jelmaan LAPLACE

Paket 1.

Bagan Kotak dan Aljabar Bagan Kotak

* ISYARAT (signal)
* SISTEM (system)

Dalam bagan kotak isyarat digambarkan dengan "anak panah"

sumber → arah propagasi "tunggal" ~~↔~~

⇒ "jamak"/banyak

→ Isyarat masukan

→ arus I

* NOTASI ISYARAT

→ ~~x~~(t)

$x(t)$ * isyarat ~~x~~ yang berubah dengan t (t ≡ time)

$u(k)$ * isyarat u yang berubah dengan k (k = 0, 1, 2, 3, ...)

$V_i(j\omega)$ * V = voltage (tegangan)

i = input

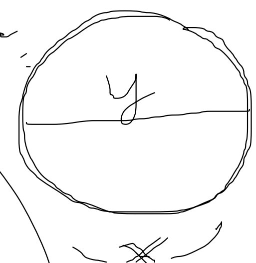
$j = \sqrt{-1}$ Ω = OMEGA

ω = "omega" = $2\pi f$;

$\omega = 2\pi f$ [rad/sec]

f = frekuensi [Hertz]

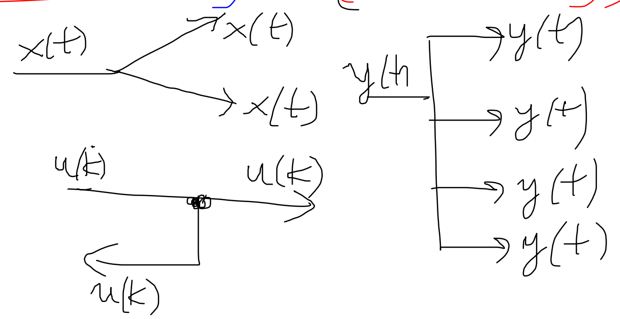
π :



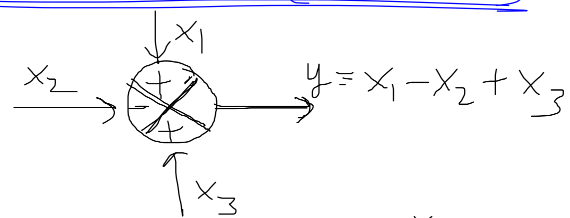
$\pi = \frac{x}{y}$

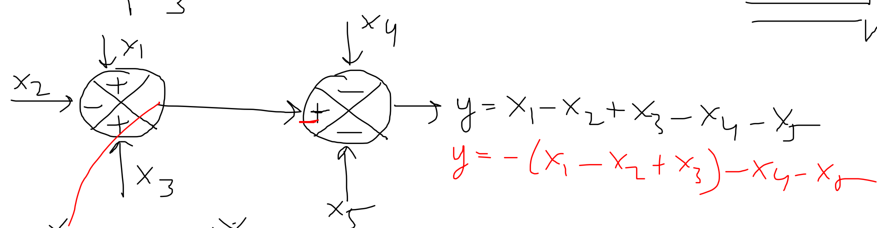
* Percabangan dan Pertemuan ISYARAT

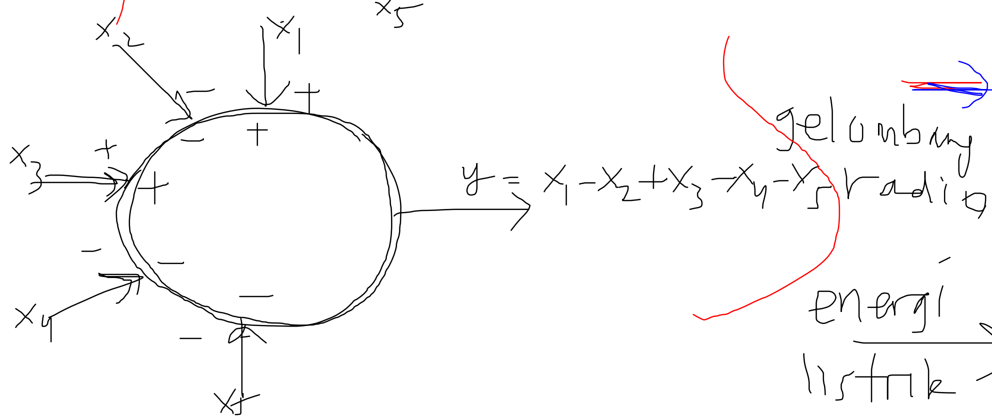
* Percabangan (Branching)



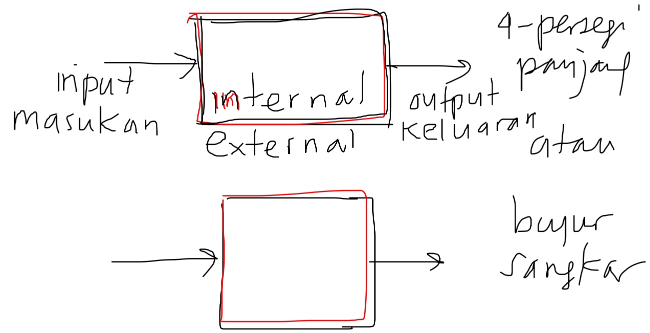
* Pertemuan (Junction)

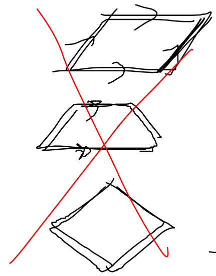






* SISTEM

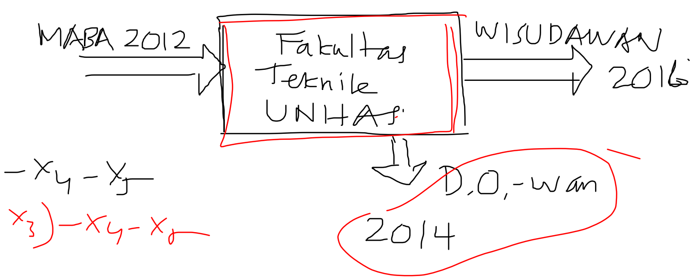


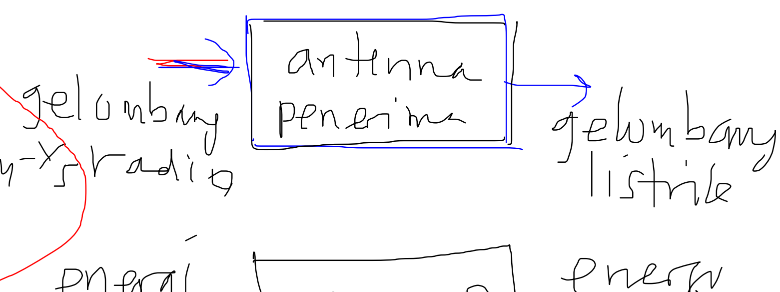


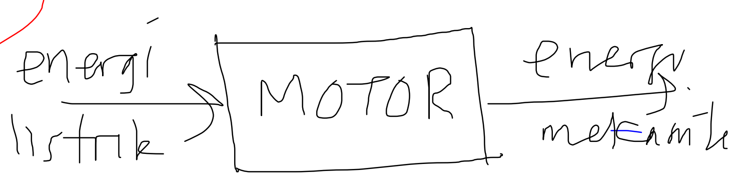
gangguan (disturbance)
derau (noise)

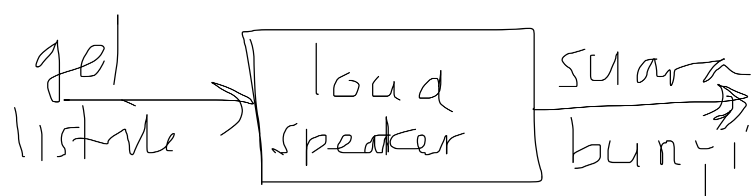
* Notasi SISTEM

⇒ kalimat & kata²,



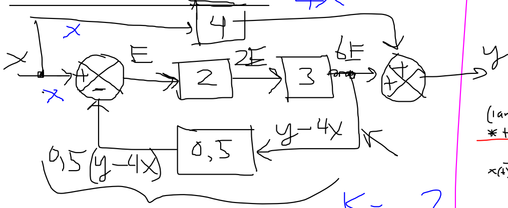






Contoh

* Contoh Matematis: $4x$



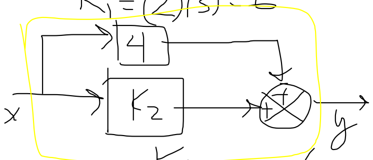
$$0{,}5(y-4x)$$

$K = \ldots ?$

I. Dengan Aljabar Bagan Kotak

Hubungan serial

$K_1 = (2)(3) = 6$



$$K_2 = \frac{K_1}{1+0{,}5K_1} = \frac{6}{4} = 1{,}5$$

Hubungan umpan-maju

$$K = K_2 + 4 = 1{,}5 + 4 = 5{,}5$$

II. Percabangan & Pertemuan

$$E = x - 0{,}5(y-4x)$$

$$= x - 0{,}5y + 2x$$

$$= 3x - 0{,}5y$$

$$y - 4x = 6E$$

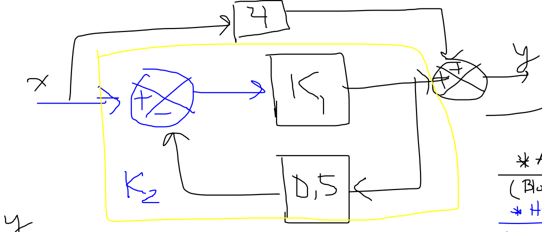
$$= 6[3x - 0{,}5y]$$

$$= 18x - 3y$$

$$y + 3y = 18x + 4x$$

$$4y = 22x \longrightarrow y = \frac{22}{4}x = 5{,}5x$$

$$K = 5{,}5$$



$\longrightarrow$ Hubungan umpan balik

(lanjut Notasi SISTEM)

* Huruf/angka, misalnya

$x(t) \to \boxed{K} \to y(t) = Kx(t)$

$K>1 \to$ Amplifier (Penguat)

$0<K<1 \to$ Attenuator (Redaman)

$K<0 \to$ Inverting Amplifier (Penguat Membalik)

Catatan: $0{,}1$ dBm $\to \boxed{3\text{dB}} \to 3{,}1$ dBm — Amplifier

$x(t) \to \boxed{10} \to y(t) = 10x(t)$ — Amplifier

$x(t) \to \boxed{-2} \to y(t)$ — Penguat Membalik

$x(t) \to \boxed{0{,}1} \to y(t) = 0{,}1x(t)$ — Attenuator

$x(t) \to \boxed{-0{,}2} \to y(t)$

$v_i(t) \to \boxed{A_v} \to v_o(t)$ — Penguat Tegangan

A_v = Voltage Amplification, Voltage Gain.

* Operator Matematis, misalnya:

$x(t) \to \boxed{\int dt} \to y(t) = \int x(t)\,dt$ — integrator

$x(t) \to \boxed{\frac{d}{dt}} \to y(t) = \frac{dx(t)}{dt}$ — diffrensiator

$x(t) \to \boxed{K\log} \to y(t) = K\log|x(t)|$ — log. amp.

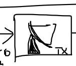
$0{,}1 \longrightarrow 1000$

$-1 \longrightarrow 3$

$x_1, x_2 \to \boxed{\times} \to y = x_1 x_2$ — multiplier

$x_1, x_2 \to \boxed{\Pi} \to y = x_1 x_2$

* Simbol-simbol khusus,



gel mikro "lemah" → gel mikro "kuat"

$x(t) \to$ Penyearah (Rectifier) $\to y(t) = |x(t)|$

gel suara → Microphone → gel. listrik → Loudspeaker → gel. suara

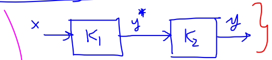
energi listrik → Motor Listrik → energi mekanik → Generator → energi listrik

* dan lain-lain

next! Contoh Mekanik

* Aljabar Bagan Kotak (Block Diagram Algebra)

* Hubungan serial (cascade)

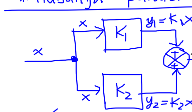


$y^* = K_1 x$

$y = K_2 y^* = K_2 K_1 x$

$\boxed{y = K_1 K_2 x}$ → $\boxed{y = Kx}$, $\boxed{K = K_1 K_2}$

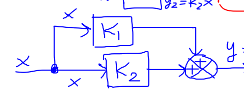
* Hubungan paralel



$y_1 = K_1 x$, $y_2 = K_2 x$

$y = y_1 + y_2 = K_1 x + K_2 x$

$\boxed{y = (K_1 + K_2)x}$ → $\boxed{y = Kx}$, $\boxed{K = K_1 + K_2}$

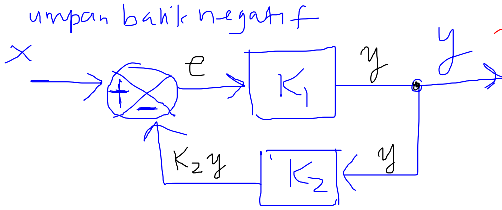


$y = (K_1 + K_2)x$

Hubungan umpan-maju (feed-forward)

* Hubungan umpan-balik (feedback)

umpan balik negatif



$K = \ldots ?$ $\boxed{y = Kx}$

$$e = x - K_2 y$$

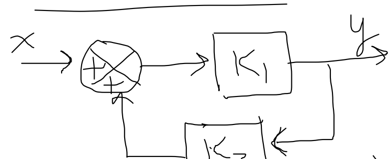
$$y = K_1 e = K_1[x - K_2 y] = K_1 x - K_1 K_2 y$$

$$y + K_1 K_2 y = K_1 x$$

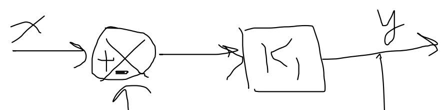
$$[1 + K_1 K_2]y = K_1 x \longrightarrow \boxed{y = \frac{K_1}{1+K_1K_2}x}$$

$$\boxed{K = \frac{K_1}{1+K_1K_2}}$$

Cari sendiri!



umpan balik positif



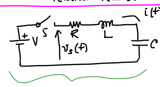
negative unity feed back

umpan-balik satuan negatif ($K_2 = 1$)

BAB I
BAB II Alat-alat Matematik
Paket I Bagan kotak & Aljabarnya.
Paket II Model NISBAH ALIH dan Transf. LAPLACE

* Contoh ELEKTRIK

Rangkaian Pemuatan Kapasitor melalui RL seri



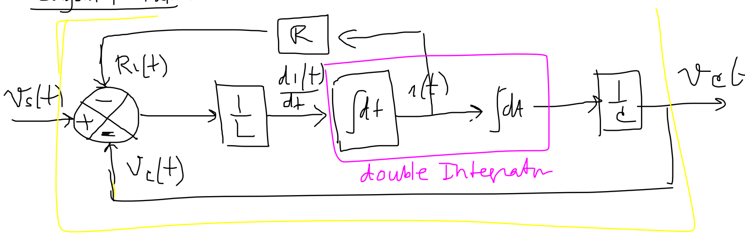
Hukum Ohm

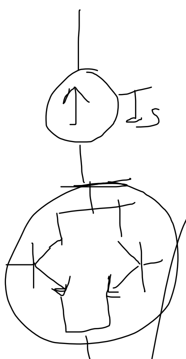
$$v_s(t) - v_c(t) = Ri(t) + L\frac{di(t)}{dt} \quad (1)$$

$$v_c(t) = \frac{1}{C}\int i(t)\,dt \quad (2)$$

(1) ⇒ $\frac{di(t)}{dt} = \frac{1}{L}\left[v_s(t) - v_c(t) - Ri(t)\right]$

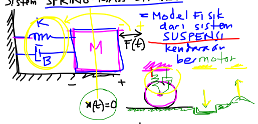
Bagan Kotak :





* Contoh MEKANIK

Sistem "SPRING-MASS-DAMPER"



= Model Fisik dari sistem SUSPENSI kendaraan bermotor

Hukum NEWTON

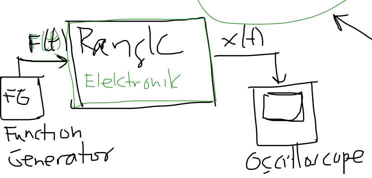
Pers. Diff

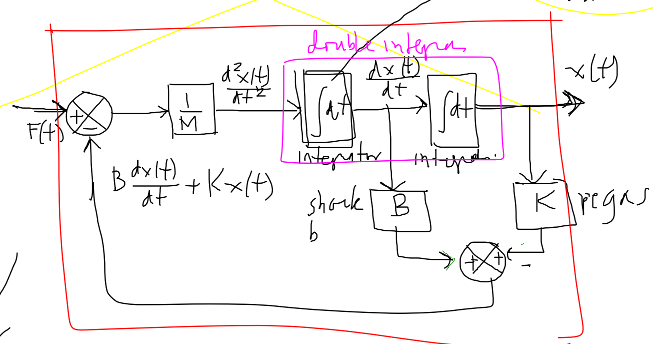
$$F(t) = M\underbrace{\frac{d^2x(t)}{dt^2}}_{\text{percepatan sesaat}} + B\underbrace{\frac{dx(t)}{dt}}_{\text{kecepatan sesaat}} + K\underbrace{x(t)}_{\text{posisi sesaat}}$$

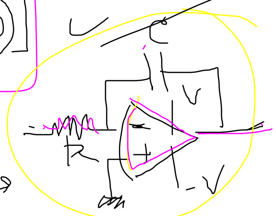
$$\frac{d^2x(t)}{dt^2} = \frac{1}{M}\left[F(t) - \left(B\frac{dx(t)}{dt} + Kx(t)\right)\right]$$

Bagan Kotak :

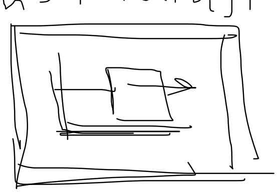
elektronik







Program Simulasi



animasi

Next :
Paket 2
* Model Nisbah Alih dan Transf Laplace

* Suatu sistem:

$\delta(t) \to$ SISTEM $\to g(t)$

$\delta(t) \to \boxed{g(t)} \to g(t)$

$x(t) \neq \delta(t) \to \boxed{g(t)} \to y(t) = ??$

$x(t) \to \boxed{g(t)} \to y(t)$

Transformasi Laplace

menghindari konvolusi

~~$y(t) = g(t) \cdot x(t)$~~

$y(t)$ = Konvolusi $x(t)$ dan $g(t)$:

$$y(t) = \int_{-\infty}^{\infty} x(t-\tau)\, g(\tau)\, d\tau \qquad \tau = \text{"tau"}$$

$$= \int_{-\infty}^{\infty} x(\tau)\, g(t-\tau)\, d\tau$$

Integral KONVOLUSI

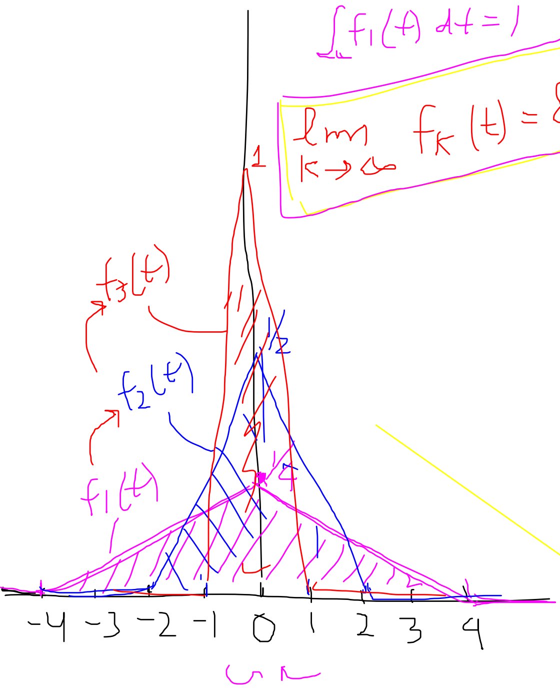
Transformasi Laplace

* Bagaimana membuat $\delta(t)$?

$\delta(t)$ dapat dibuat secara matematis dengan berbagai cara. Salah satu caranya adalah sbb

$$\int f_1(t)\, dt = 1$$

$$\lim_{k \to \infty} f_k(t) = \delta(t)$$



* Model Nisbah Alih & transf Laplace

* Apa itu NISBAH ALIH ??

What is a TRANSFER FUNCTION ?

Nisbah Alih adalah tanggapan denyut

Transfer Function is the impulse response

δ, delta

Δ. DELTA

Artinya,

Jika suatu sistem menghasilkan isyarat $g(t)$ ketika diberi masukan isyarat denyut satuan $\delta(t)$, maka nisbah-alih sistem itu adalah $g(t)$

$\delta(t) \to \boxed{???} \to g(t) \qquad \to \boxed{g(t)} \to$

* Apa itu isyarat denyut satuan ($\delta(t)$)?

Unit Impulse

$\delta(t)$ adalah suatu isyarat matematis, yang TIDAK ADA realisasi fisik-nya yang IDEAL.

Fenomena alam yang paling mendekati $\delta(t)$, misalnya:

- Sambaran petir
- Pukulan stick golf pada bola golf
- bunga api listrik

sesuatu yang sangat "keras" berlangsung sangat "cepat"

Secara matematis, isyarat denyut satuan $\delta(t)$ mempunyai 2 (dua) sifat:

* $\delta(t)$ hanya ada pada $t = 0$.

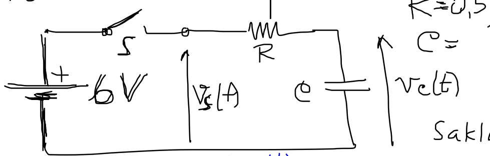
$$\delta(t) \begin{cases} = 0, & t \neq 0 \\ \neq 0, & t = 0 \end{cases}$$

* Luas bidang antara $\delta(t)$ dan sumbu t adalah 1 satuan luas

$$\int_{-\infty}^{+\infty} \delta(t)\, dt = 1$$

* Contoh ELEKTRIK

Pemuatan Kapasitor



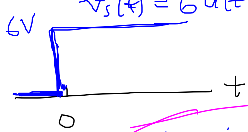
$R = 0{,}5\,M\Omega$

$C = 2\ \mu F$

Saklar S ditutup pada t=0, tentukan $v_c(t),\ t \geq 0$

$v_c(t) = \mathcal{L}^{-1}\, V_c(s)$

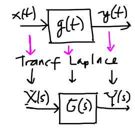
$v_s(t) = 6u(t)$



u(t) = isyarat undak satuan = unit step function

$V_s(s) = \mathcal{L}\, v_s(t)$
$= \mathcal{L}\, 6u(t)$
$= 6\,\mathcal{L}\, u(t)$
$= 6/s$

Transformasi Laplace



$\cancel{y(t) = g(t)\,x(t)}$ → integral konvolusi
tidak sahih

$G(s) = \mathcal{L}\, g(t) \rightleftharpoons g(t) = \mathcal{L}^{-1} G(s)$
$X(s) = \mathcal{L}\, x(t) \rightleftharpoons x(t) = \mathcal{L}^{-1} X(s)$
$Y(s) = \mathcal{L}\, y(t) \rightleftharpoons y(t) = \mathcal{L}^{-1} Y(s)$

$Y(s) = G(s) \cdot X(s)$

$G(s) = \dfrac{Y(s)}{X(s)}$

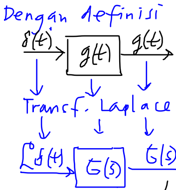
(time) $t \underset{\mathcal{L}^{-1}}{\overset{\mathcal{L}}{\rightleftharpoons}} s$ (peubah Laplace)
REAL COMPLEX $a + jb$
$j = \sqrt{-1}$

Contoh: * CONTOH MATEMATIS.

Tentukan Transformasi Laplace dari isyarat denyut satuan $\delta(t)$!

$\mathcal{L}\,\delta(t) = \ldots$?

→ Dengan definisi



$G(s) = G(s) \cdot \mathcal{L}\,\delta(t)$

$\mathcal{L}\,\delta(t) = \dfrac{G(s)}{G(s)} = 1$

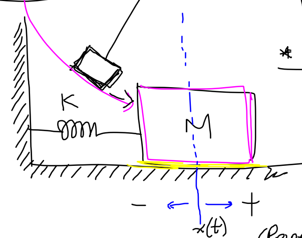
→ Dengan Tabel Laplace Laplace Table

Baris 1 Table 4.1: $f(t) = \delta(t) \to F(s) = 1$

Baris 1 Appendix. $F(s) = 1 \to f(t) = \delta(t)$

$\mathcal{L}\,\delta(t) = 1$

* CONTOH MEKANIK



M = 1 kg
K = 4 N/m.

* Pers. diffrensial

$F(t) = M\dfrac{d^2x(t)}{dt^2} + Kx(t)$

Transf Laplace

$F(s) = Ms^2 X(s) + KX(s)$

(Property #3, hal 58)

$F(t) = \delta(t)$

$F(s) = \mathcal{L}\,F(t) = \mathcal{L}\,\delta(t) = 1 \to$

$1 = 1s^2 X(s) + 4X(s)$

$1 = (s^2 + 4)\,X(s)$

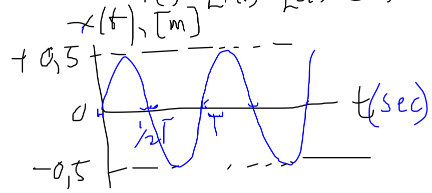
$X(s) = \dfrac{1}{s^2+4}$

$x(t) = \mathcal{L}^{-1} X(s) = \mathcal{L}^{-1} \dfrac{1}{s^2+4}$

$= \mathcal{L}^{-1} \dfrac{1}{2}\left(\dfrac{2}{s^2+2^2}\right)$

$= \dfrac{1}{2}\,\mathcal{L}^{-1}\left(\dfrac{2}{s^2+2^2}\right)$

(baris 6, Table 4.1.) $\to x(t) = \dfrac{1}{2}\sin 2t$

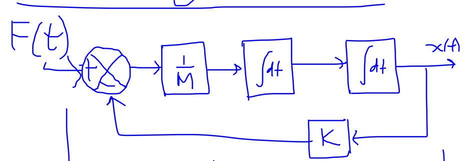


$\omega = 2\pi f = 2$

$f = \dfrac{1}{\pi}$ Hertz

$T = \dfrac{1}{f} = \pi$ second

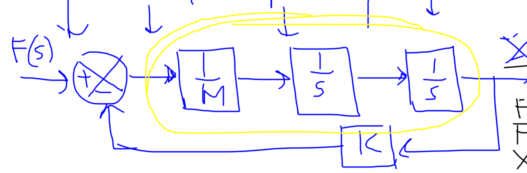
* Bagan Kotak.

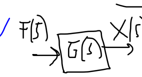


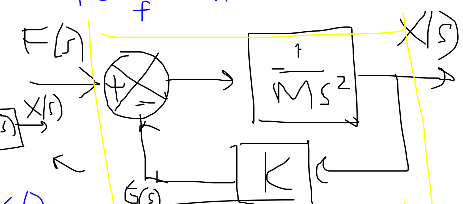
Transf. Laplace

Property #4 hal. 58

$\mathcal{L} \int f\,dt = \dfrac{1}{s}$







$F(t) = \delta(t)$

$F(s) = 1$

$X(s) = \dfrac{1}{Ms^2+K}$

$G(s) = \dfrac{X(s)}{F(s)} = \dfrac{1/Ms^2}{1 + K/Ms^2}$

$G(s) = \dfrac{1}{Ms^2+K} \to X(s) = G(s)\,F(s)$

* "ORDER" dari SISTEM

Order dari suatu sistem/sistem kendali, dapat dilihat dari model Nisbah-Alih-nya.

$$G(s) = \frac{N(s)}{D(s)} = \frac{b_m s^m + b_{m-1} s^{m-1} + b_{m-2} s^{m-2} + \dots + b_1 s + b_0}{a_n s^n + a_{n-1} s^{n-1} + a_{n-2} s^{n-2} + \dots + a_1 s + a_0}$$

m, n bilangan bulat. $0, 1, 2, 3, \dots$, $\boxed{m \leq n}$

$a_0, a_1, a_2, a_3, \dots, a_n$ koefisien REAL

$b_0, b_1, b_2, b_3, \dots, b_m$ koefisien REAL

Order dari sistem ditentukan oleh derajat polynomial penyebut, yaitu n. Jadi sistem di atas adalah sistem order ke-n

Contoh:

* "Double Integrator" $G(s) = \frac{1}{s^2}$ adalah sistem order kedua (second order)
* "Phase Compensator" $H(s) = \frac{s+a}{s+b}$ adalah sistem order pertama (first order)
* "Sistem Kendali dengan Kompensator"

$$G_T(s) = \frac{s+a}{s^3 + bs^2 + s + a}$$ adalah sistem orde ketiga (third order sistem)

Catatan:

Sistem order ketiga atau yang lebih tinggi, selalu bisa diuraikan menjadi sistem orde pertama dan/atau sistem orde kedua

next: "POLE" dan "ZERO"

* Pole dan Zero

Jika suatu sistem kendali/kendalian dimodelkan dengan nisbah-alih

$$G(s) = \frac{N(s)}{D(s)}$$

maka nilai-nilai s yang memenuhi (akar-akar) persamaan

$N(s) = 0$, disebut "zero" dari $G(s)$

$D(s) = 0$, disebut "pole" dari $G(s)$

Karena itu, order dari sebuah sistem adalah jumlah pole-nya, dan akar-akar persamaan karakteristik adalah pole-pole dari CLTF-nya (mengapa???)

Contoh: Suatu kendalian "simple integrator" $G(s) = \frac{1}{s}$ dikendalikan dengan kompensator $H(s) = \frac{s+2}{s+3}$.

Tentukan:
(a) Pole dan Zero dari $G(s)$ dan $H(s)$
(b) Pole dan Zero dari OLTF $G(s)H(s)$
(c) Pole dan Zero dari CLTF
(d) Order dari Sistem Kendali
(e) Persamaan Karakteristik dan akar²nya

(a) $G(s) = \frac{1}{s} \longrightarrow$ no zero! Pole, $s = 0 \rightarrow p = 0$

$H(s) = \frac{s+2}{s+3} \longrightarrow$ Zero $s + 2 = 0 \rightarrow z = -2$

Pole $s + 3 = 0 \rightarrow p = -3$

(b) OLTF. $G(s)H(s) = \left(\frac{1}{s}\right)\left(\frac{s+2}{s+3}\right) = \frac{s+2}{s(s+3)}$

Zero $G(s)H(s)$: $s + 2 = 0 \rightarrow z = -2$

Pole $G(s)H(s)$: $s(s+3) = 0 \rightarrow p_1 = 0$, $p_2 = -3$

(c) CLTF. $G_T(s) = \frac{G(s)H(s)}{1 + G(s)H(s)}$

$$\frac{\frac{s+2}{s(s+3)}}{1 + \frac{s+2}{s(s+3)}} \longrightarrow = \frac{s+2}{s^2 + 3s + s + 2} = \frac{s+2}{s^2 + 4s + 2}$$

Zero: $s + 2 = 0$

$z = -2$

Pole: $s^2 + 4s + 2 = 0$

$$p_{1,2} = \frac{-4 \pm \sqrt{16 - 8}}{2}$$

$= -2 \pm \sqrt{2}$

(d) Jumlah pole CLTF ada 2, maka sistem kendali ini adalah sistem orde KEDUA

(e) Akar-akar pers. karakteristik: $1 + G(s)H(s) = 0$

$$1 + \frac{s+2}{s(s+3)} = 0 \longrightarrow s^2 + 4s + 2 = 0$$

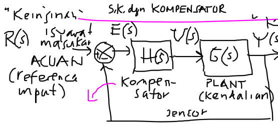
$$s_{1,2} = \frac{-4 \pm \sqrt{16-8}}{2}$$

$= -2 \pm \sqrt{2} \longrightarrow$ pole² CLTF

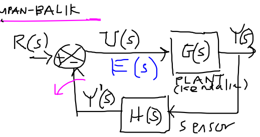
Bab III Istilah-istilah Khusus

* Sistem Kendali dengan KOMPENSATOR dan Sistem Kendali dengan UMPAN-BALIK

"Keinginan" S.K. dgn KOMPENSATOR



S.K. dgn UMPAN-BALIK "Kenyataan"



Pada sistem kendali dengan kompensator, isyarat kendali $U(s)$ dihasilkan dari "kompensator" isyarat selisih ($E(s)$, error)

$E(s) = R(s) - Y(s)$

$U(s) = H(s).E(s)$

$= H(s)\,[R(s) - Y(s)]$

$Y(s) = G(s).U(s)$

$= G(s).H(s)\,[R(s) - Y(s)]$

$= G(s).H(s).R(s) - G(s).H(s).Y(s)$

$Y(s) + G(s)H(s).Y(s) = G(s).H(s).R(s)$

$[1 + G(s)H(s)]\,Y(s) = G(s).H(s).R(s)$

$$\boxed{G_T(s) = \frac{Y(s)}{R(s)} = \frac{G(s).H(s)}{1 + G(s)H(s)}}$$

Pada Sistem Kendali dengan umpan-balik, isyarat kendali $U(s)$ merupakan selisih antara masukan acuan $R(s)$ dengan manipulasi keluaran $Y(s)$

$E(s) = U(s) = R(s) - Y'(s)$

$U(s) = R(s) - H(s).Y(s)$

$Y(s) = G(s)\,U(s)$

$= G(s)\,[R(s) - H(s)\,Y(s)]$

$= G(s).R(s) - G(s)H(s)Y(s)$

$Y(s) + G(s)H(s)Y(s) = G(s).R(s)$

$[1 + G(s)H(s)]\,Y(s) = G(s).R(s)$

$$\boxed{G_T(s) = \frac{Y(s)}{R(s)} = \frac{G(s)}{1 + G(s)H(s)}}$$

Istilah-istilah

* Nisbah Alih Daur Terbuka
Open-loop Transfe Fuction (OLTF)
* Nisbah Alih Daur Tertutup
Closed-loop Transf Function
* Persamaan Karakteristik
Characteristic Equation

sama² $G(s)H(s)$

$G_T(s) = \frac{G(s)H(s)}{1 + G(s)H(s)}$ (s.k dg. KOMPENSATOR)

$G_T(s) = \frac{G(s)}{1 + G(s)H(s)}$ (s.k. UMPAN BALIK)

sama² $1 + G(s)H(s) = 0$

Contoh soal

Suatu kendalian "double integrator" ($G(s) = \frac{1}{s^2}$) dikendalikan dengan "phase-compensator" $\underbrace{H(s) = \frac{s+a}{s+b}}_{\text{phase lead/lag}}$.

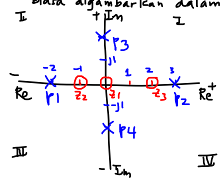
Tentukanlah.
* OLTF
* CLTF
* Persamaan Karakteristik-nya

* OLTF. $G(s)H(s) = \frac{1}{s^2}\,\frac{s+a}{s+b} = \frac{s+a}{s^2(s+b)}$
* CLTF. $G_T(s) = \frac{G(s)H(s)}{1 + G(s)H(s)} = \frac{\frac{s+a}{s^2(s+b)}}{1 + \frac{s+a}{s^2(s+b)}} = \frac{s+a}{s^3 + bs^2 + s + a}$
* Pers. karakteristik, $1 + G(s)H(s) = 0$

$$1 + \frac{1}{s^2}\,\frac{s+a}{s+b} = 0 \longrightarrow 1 + \frac{s+a}{s^3 + bs^2} = 0 \longrightarrow s^3 + bs^2 + s + a = 0$$

Bagaimana jika $H(s) = \frac{s+a}{s+b}$ ditempatkan pada umpan balik

* Pole dan zero dari suatu Nisbah Alih biasa digambarkan dalam bidang kompleks



Pole - ×
Zero - O
Contoh

$$G(s) = \frac{s(s+1)(s-2)}{(s+2)(s-3)(s^2+4)}$$

Zero : $z_1 = 0$, $z_2 = -1$, $z_3 = 2$

Pole $p_1 = -2$ $p_2 = 3$

$s^2 + 4 = 0 \rightarrow p_3 = j2$

$p_4 = -j2$

$j = \sqrt{-1}$

* Isyarat-isyarat uji (Test Signals)

* Isyarat denyut satuan $\delta(t)$, (sudah dipelajari)

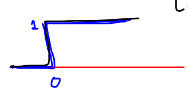
$$\delta(t) \begin{cases} = 0, & t \neq 0 \\ \neq 0, & t = 0 \end{cases}$$

* Isyarat undak satuan $u(t)$

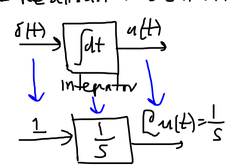
Unit step function

Definisi :

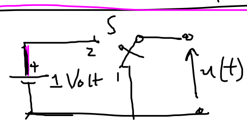
$$u(t) \begin{cases} = 0, & t < 0 \\ = 1, & t \geq 0 \end{cases}$$



* Realisasi matematisi



* Realisasi secara fisik

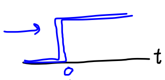


Saklar S dipindahkan dari posisi 1 ke posisi 2 pada $t = 0$

Transformasi Laplace

Isyarat $u(t) \rightarrow$

$$u(t) \begin{cases} = 0, & t < 0 \\ = 1, & t \geq 0 \end{cases}$$

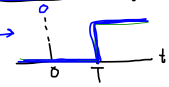


$U(s) = \frac{1}{s}$

$e = 1 + 1 + \frac{1}{2} + \frac{1}{6}$
$= 2{,}718\ldots$

Isyarat $u(t-T) \rightarrow$

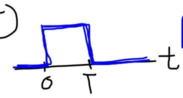
$$u(t-T) \begin{cases} = 0, & t < T \\ = 1, & t \geq T \end{cases}$$



$\mathcal{L}u(t-T) = \frac{1}{s} e^{-Ts}$

Isyarat $u(t) - (t-T)$

$$u(t) - u(t-T) \begin{cases} = 0, & t < 0 \\ = 1, & 0 \leq t < T \\ = 0, & t \geq T \end{cases}$$



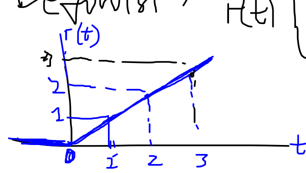
$\mathcal{L}[u(t) - u(t-T)] = \frac{1}{s}\left(1 - e^{-Ts}\right)$

* Isyarat tanjak satuan $r(t)$

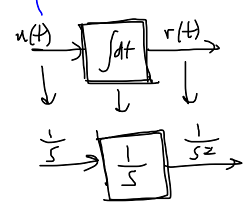
Unit Ramp function

Definisi :

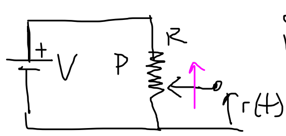
$$r(t) \begin{cases} = 0, & t < 0 \\ = t, & t \geq 0 \end{cases}$$



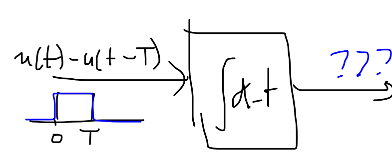
Realisasi matematis



Realisasi fisik :



P : Potensimeter digeser dengan kecepatan tetap $r(t)$ naik $1\,V/\text{sec}$



next : Isyarat eksponensial