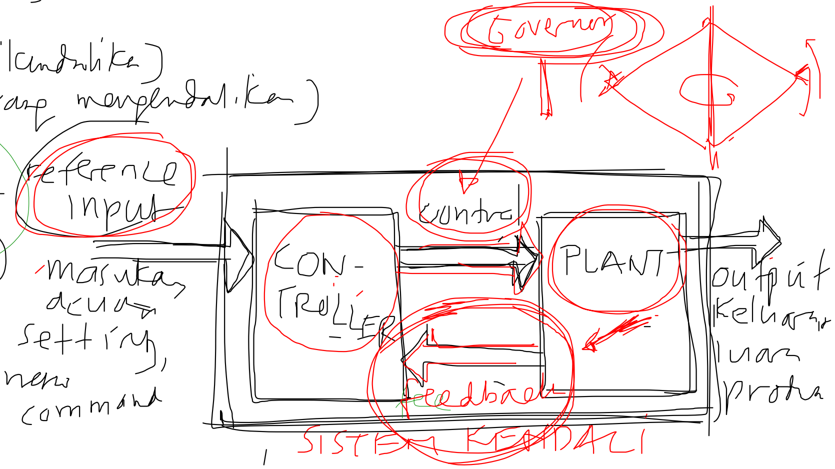
Apa itu SISTEM KENDALI ???

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
* Manual

{ Keterlibatan MANUSIA

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 → MID
Bab IV: Analisis Kestabilan → FIN

Buku bacaan

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

Bab I: Pengenalan SISTEM KENDALI

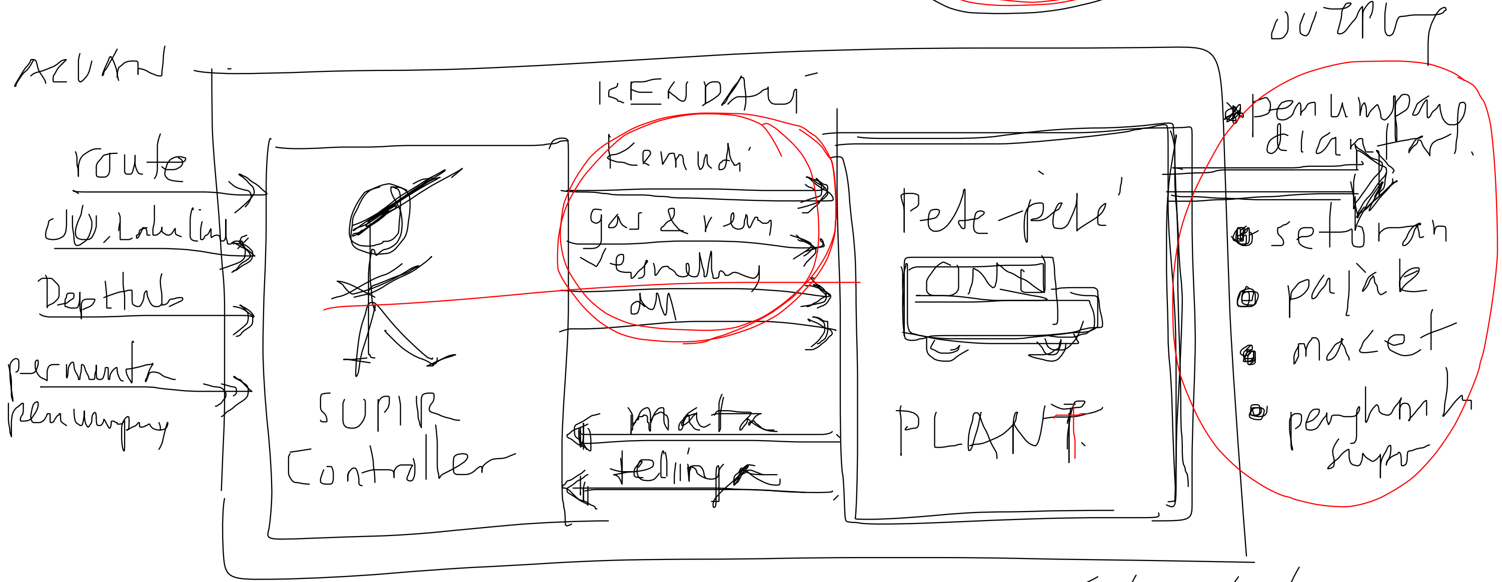
Introduction to Control Systems

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"

$\longrightarrow$ "tunggal"

sumber, arah propagasi

~~$\longleftrightarrow$~~

$\Longrightarrow$ "jamak"/banyak

$\longrightarrow$ isyarat masukan

$\longrightarrow$ arus I

* NOTASI ISYARAT

$\longrightarrow x(t)$

$x(t)$ * 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

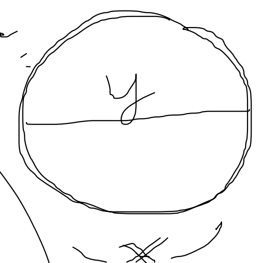
$j = \sqrt{-1}$ $\quad \Omega$ = OMEGA

ω = "omega" $= 2\pi f$

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

f = frekuensi (Hertz)

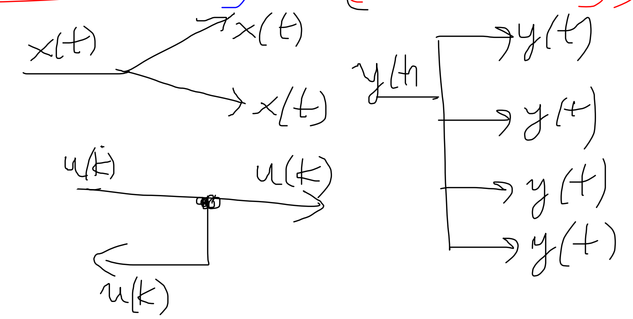
π :



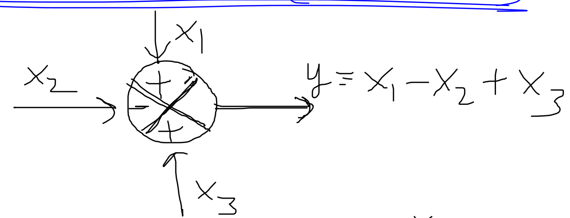
$\pi = \frac{x}{y}$

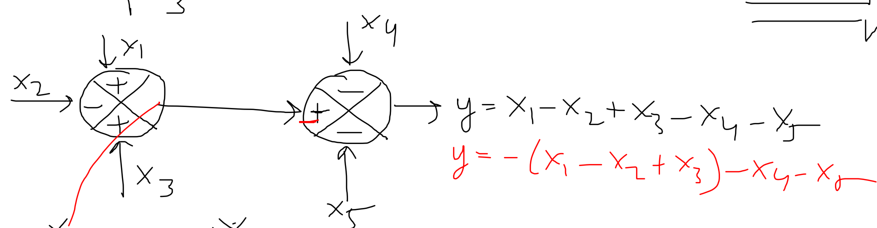
* Percabangan dan Pertemuan ISYARAT

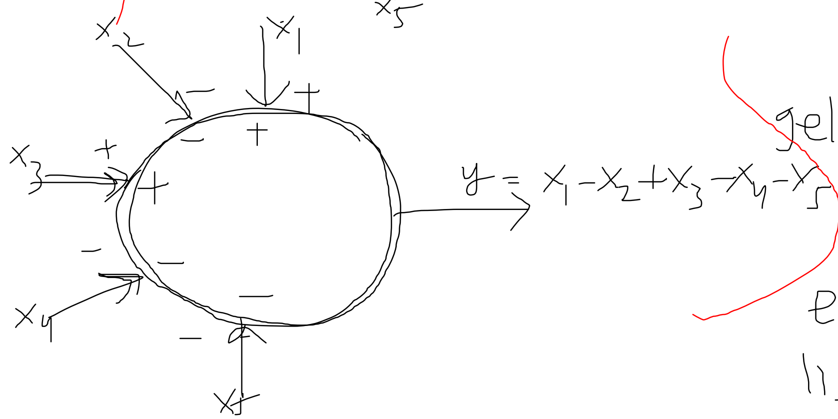
* Percabangan (Branching)



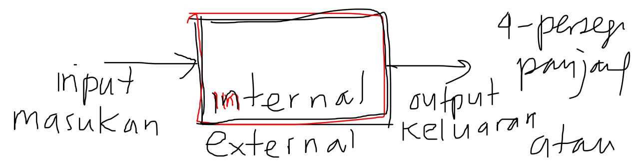
* Pertemuan (Junction)

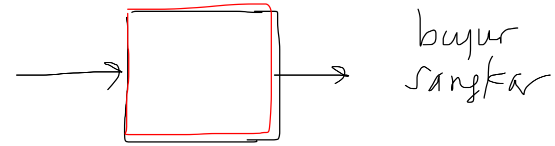


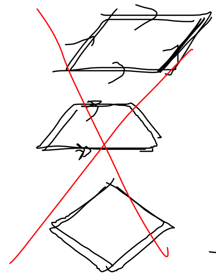




* SISTEM



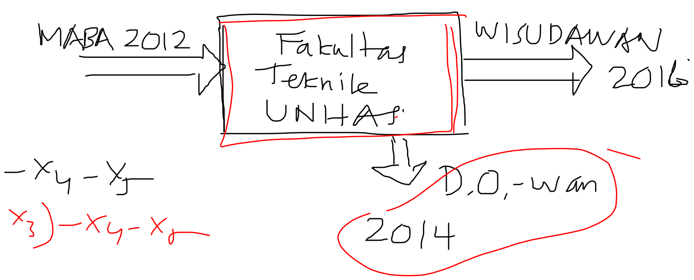


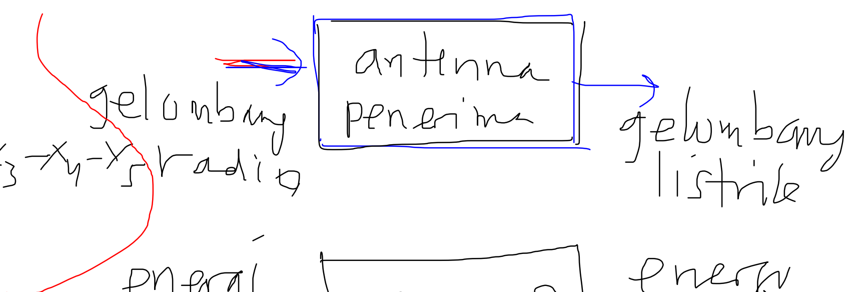


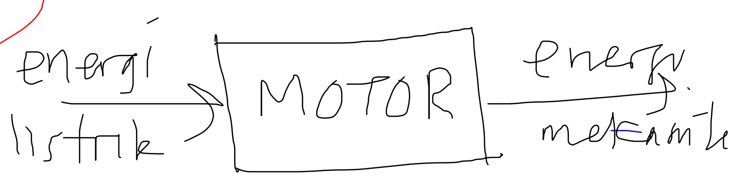
gangguan (disturbance)
derau (noise)

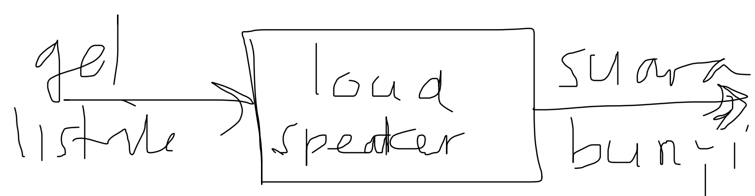
* Notasi SISTEM

⇒ kalimat & kata²,



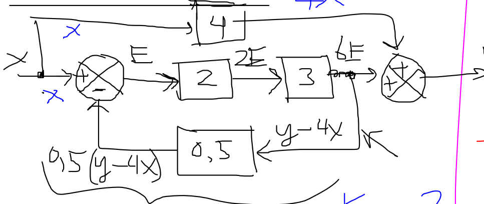






Contoh

* Contoh Matematis : $4x$

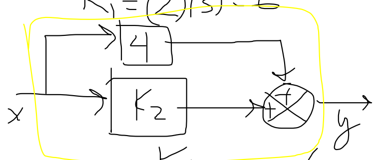


$K = \ldots ?$

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

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

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

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

$y - 4x = 6E$

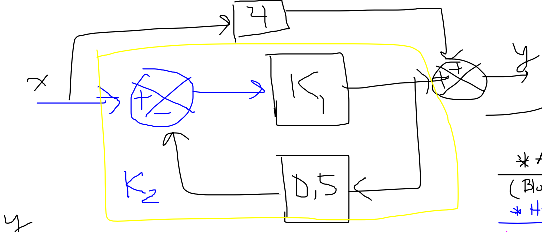
$= 6[3x - 0{,}5y]$

$= 18x - 3y$

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

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

$K = 5{,}5$



Hubungan umpan balik

(lanjut Notasi SISTEM)

* Huruf/angka, misalnya

$x(t) \rightarrow$ K $\rightarrow y(t) = Kx(t)$

$K>1 \rightarrow$ Amplifier (Penguat)

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

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

Catatan: 0,1 dBm → 3dB → 3,1 dBm, Amplifier

$x(t) \rightarrow$ 10 $\rightarrow y(t) = 10x(t)$ Amplifier

$x(t) \rightarrow$ −2 $\rightarrow y(t)$ Penguat Membalik

$x(t) \rightarrow$ 0,1 $\rightarrow y(t) = 0{,}1x(t)$ Attenuator

$x(t) \rightarrow$ −0,2 $\rightarrow y(t)$

$v_i(t) \rightarrow$ Av $\rightarrow v_o(t)$ Penguat Tegangan

Av = Voltage Amplification, Voltage Gain

* Operator Matematis, misalnya :

$x(t) \rightarrow \int dt \rightarrow y(t) = \int x(t)dt$ integrator

$x(t) \rightarrow \frac{d}{dt} \rightarrow y(t) = \frac{dx(t)}{dt}$ diffrensiator

$x(t) \rightarrow$ Klog $\rightarrow y(t) = K\log|x(t)|$ log. amp.

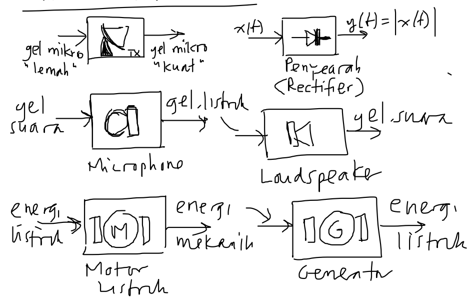
0,1 ⟶ 1000

−1 ⟶ 3

$x_1, x_2 \rightarrow \times \rightarrow y = x_1 x_2$ multiplier

$x_1, x_2 \rightarrow \Pi \rightarrow y = x_1 x_2$

* Simbol-simbol khusus,

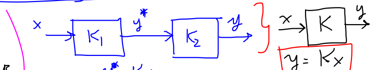


* dan lain-lain

Contoh Mekanik next!

* Aljabar Bagan Kotak (Block Diagram Algebra)

* Hubungan serial (cascade)

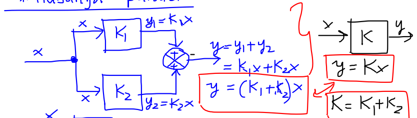


$y^* = K_1 x$

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

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

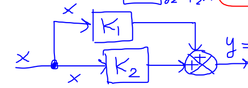
* Hubungan paralel



$y = y_1 + y_2$

$= K_1 x + K_2 x$

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

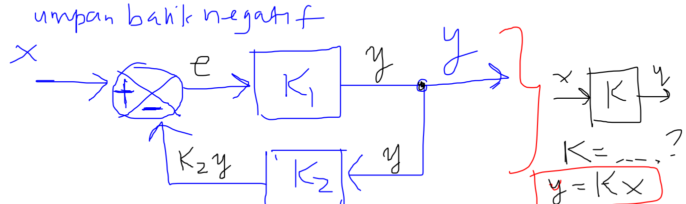


$y = (K_1 + K_2)x$

Hubungan umpan-maju (feed-forward)

* Hubungan umpan-balik (feedback)

umpan balik negatif



$K = \ldots ?$

$\boxed{y = Kx}$

$e = x - K_2 y$

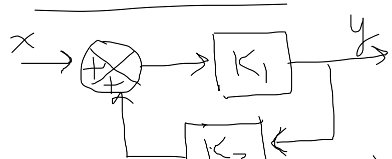
$y = K_1 e = K_1[x - K_2 y] = K_1 x - K_1 K_2 y$

$y + K_1 K_2 y = K_1 x$

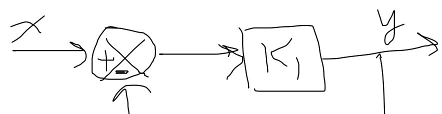
$[1 + K_1 K_2]y = K_1 x \longrightarrow \boxed{y = \frac{K_1}{1+K_1K_2}x}$

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

Cari sendiri!



umpan balik positif



negative unity feedback

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

BAB I

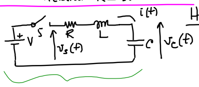
BAB II Alat-alat Matematik

Paket I Bagan kotak & Aljabarnya.

Paket II Model NISBAH ALIH dan Transf. LAPLACE

* Contoh ELEKTRIK

Rangkaian Pemuatan Kapasitor melalui RL seri



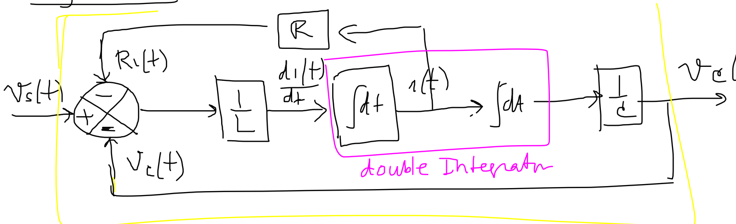
Hukum Ohm

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

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

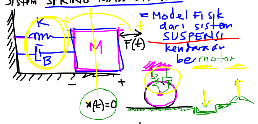
$$(1) \Rightarrow \frac{di(t)}{dt} = \frac{1}{L}\left[v_s(t) - v_c(t) - R\,i(t)\right]$$

Bagan Kotak :



* Contoh MEKANIK

Sistem "SPRING-MASS-DAMPER"



= Model Fisik dari sistem SUSPENSI kendaraan bermotor

Hukum NEWTON

Pers. Diff

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

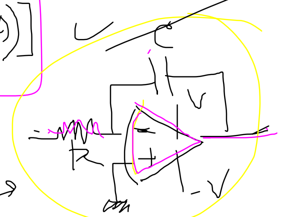
$$\frac{d^2x(t)}{dt^2} = \frac{1}{M}\left[F(t) - \left(B\frac{dx(t)}{dt} + Kx(t)\right)\right]$$

Bagan Kotak :

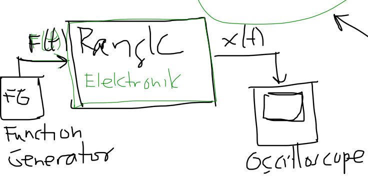
Next :

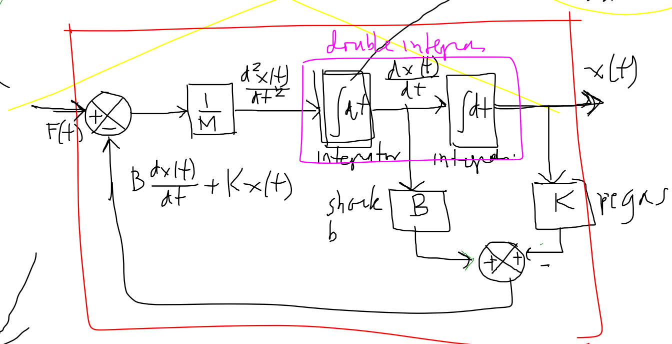
Paket 2

* Model Nisbah Alih dan Transf. Laplace

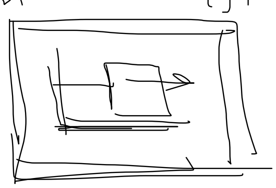


elektronik



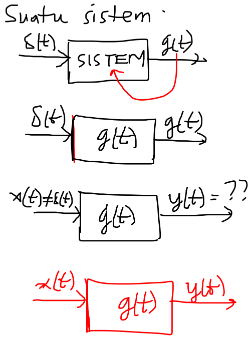


Program Simulasi



animasi

* Suatu sistem:



Transformasi Laplace

menghindari konvolusi

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

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

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

integral KONVOLUSI

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

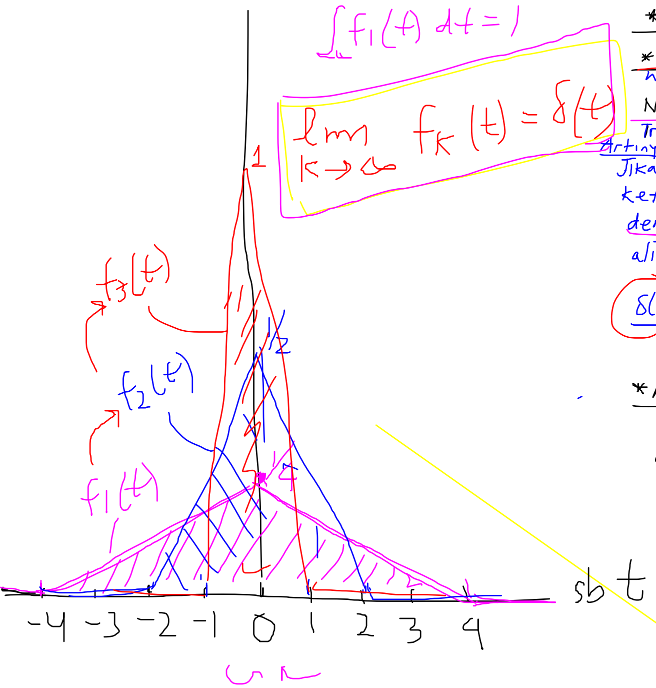
Transformasi Laplace

* 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 ??

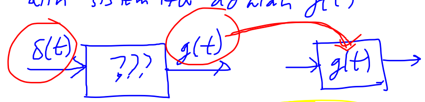
Nisbah Alih adalah tanggapan denyut

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 $g(t)$



* 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 $t = 0$.

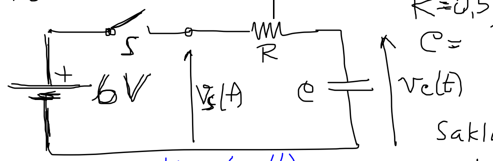
$$\delta(t) \begin{cases} = 0, & t \neq 0 \\ \neq 0, & t = 0 \end{cases}$$

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

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

* Contoh ELEKTRIK

Pemuatan Kapasitor

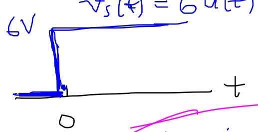


$R = 0{,}5\,M\Omega$
$C = 2\ \mu F$

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

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

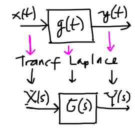
$v_s(t) = 6u(t)$



$u(t)$ = 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



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

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

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

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

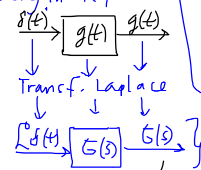
(time) $t \underset{\mathcal{L}^{-1}}{\overset{\mathcal{L}}{\rightleftarrows}} s$ (peubah laplace)
REAL COMPLEX $a + jb$
$j = \sqrt{-1}$

Contoh. * CONTOH MATEMATIS.

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

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

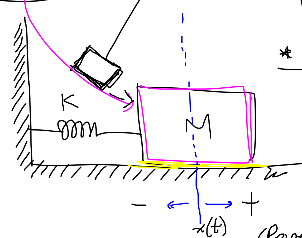
→ Dengan definisi



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

→ 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. differensial

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

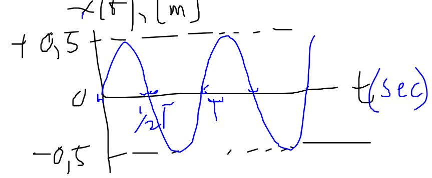
Transf Laplace

$F(s) = Ms^2X(s) + KX(s)$
(Property #3, hal 58)

$F(t) \simeq \delta(t)$
$F(s) = \mathcal{L}\,F(t) = \mathcal{L}\,\delta(t) = 1 \to$
$1 = 1s^2 X(s) + 4X(s)$
$1 = (s^2+4)\,X(s)$
$X(s) = \dfrac{1}{s^2+4}$

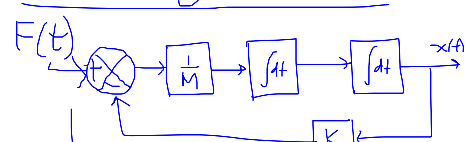
$x(t) = \mathcal{L}^{-1}X(s) = \mathcal{L}^{-1}\dfrac{1}{s^2+4}$
$= \mathcal{L}^{-1}\dfrac{1}{2}\left(\dfrac{2}{s^2+2^2}\right)$
$= \dfrac{1}{2}\mathcal{L}^{-1}\left(\dfrac{2}{s^2+2^2}\right)$

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



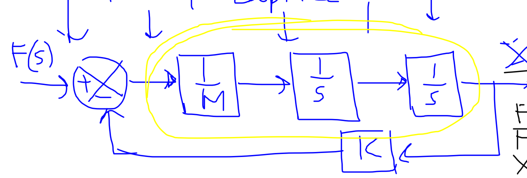
$\omega = 2\pi f = 2$
$f = \dfrac{1}{\pi}$ Hertz
$T = \dfrac{1}{f} = \pi$ second

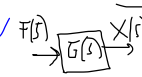
* Bagan Kotak.

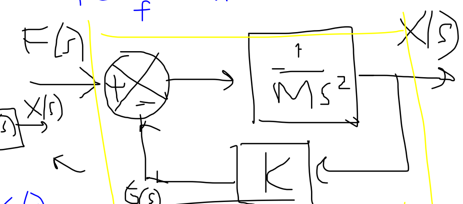


Transf. Laplace

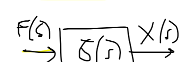
Property #4 hal. 58
$\mathcal{L}\int f\,dt = \dfrac{1}{s}$







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



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

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