

# Signal & System

**Week-1:**

**Intro, Ref, Journey, Sinyal, Sistem,  
Transformasi, Terms, Symbol**

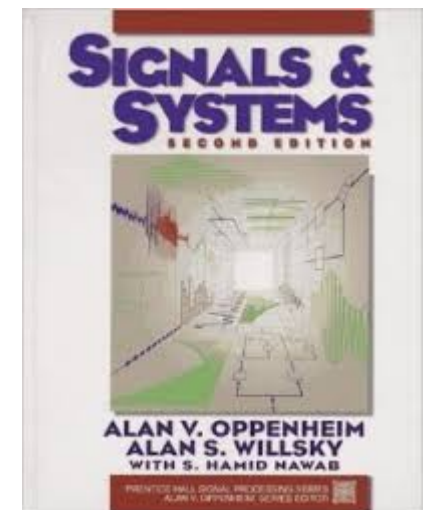
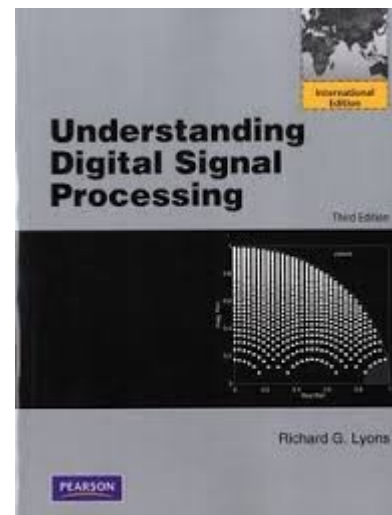
**“There is no royal road to mathematics” -Menaechmus**

**@btatmaja**

**Adopted from “Sistem Linear” by D. Prananto**


# Referensi

- [1] Lyon, Understanding Digital Signal Processing.
- [2] A. V. Oppenheim, A. S. Willsky, S. H. H. Nawab, *Sinyal dan Sistem jilid 1*, (Penerbit Erlangga, Jakarta, 2000)
- [3] Wikipedia
- [4] Octave / MATLAB



# RESOURCES

<https://github.com/bagustris/sinyalsistem>

 bagustris / sinyalsistem

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Description

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# THE JOURNEY

Periodic Sampling

How can the spectra of sampled signal be analyzed?

Window Function

How can the effective sample rate of discrete signal be changed?

How can DFT measurement be improved?

How can digital filter freq response be improved?

Discrete Fourier Transform

How can spectra be modified?

Digital Filter

How does windowing works

Why are discrete spectra periodic and what causes DFT leakage

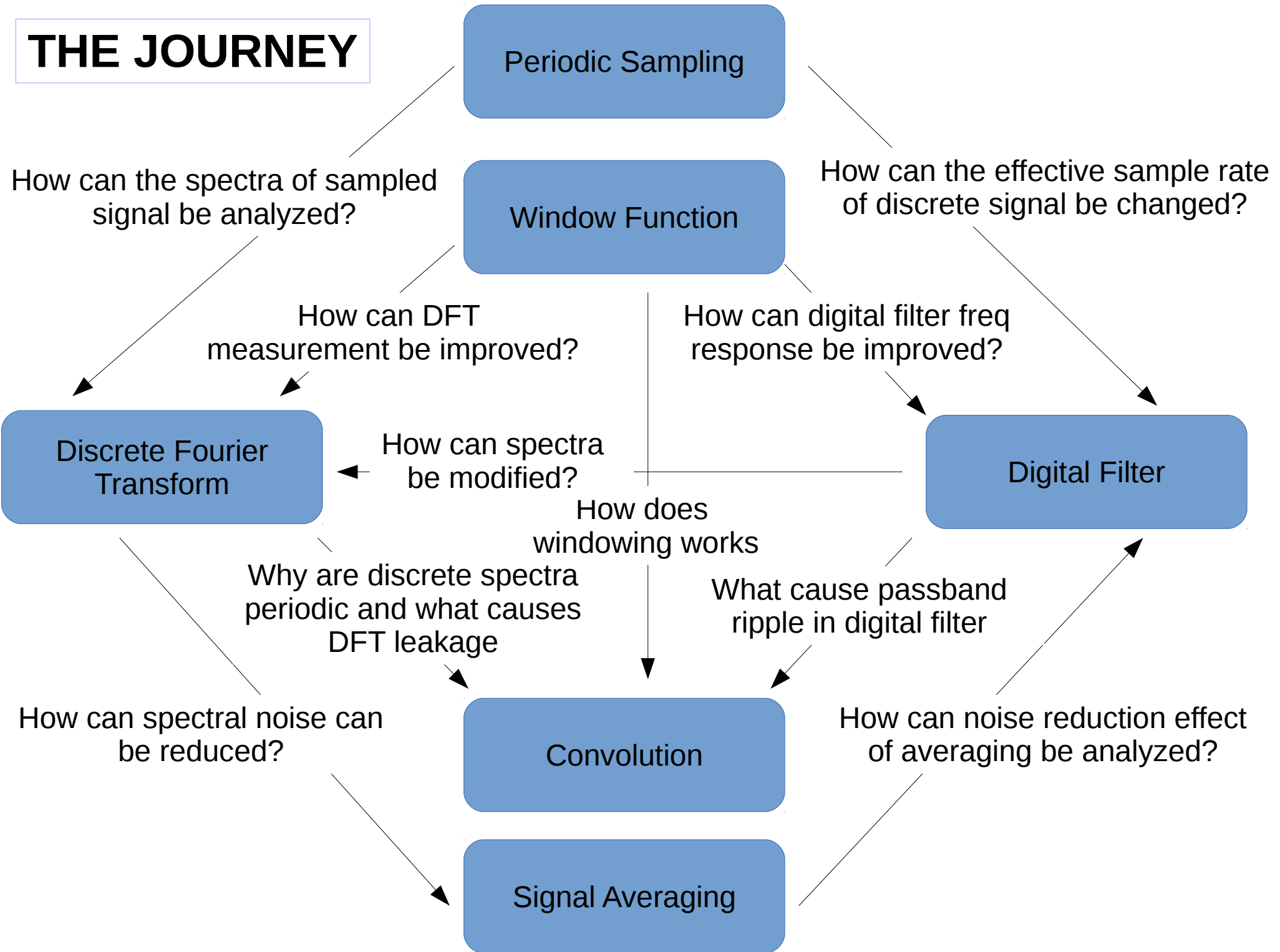
What cause passband ripple in digital filter

How can spectral noise can be reduced?

Convolution

How can noise reduction effect of averaging be analyzed?

Signal Averaging



# Sinyal & sistem

## SINYAL

Pola-pola yang berubah/bervariasi terhadap satu atau lebih variabel bebas, yang di dalamnya terkandung informasi

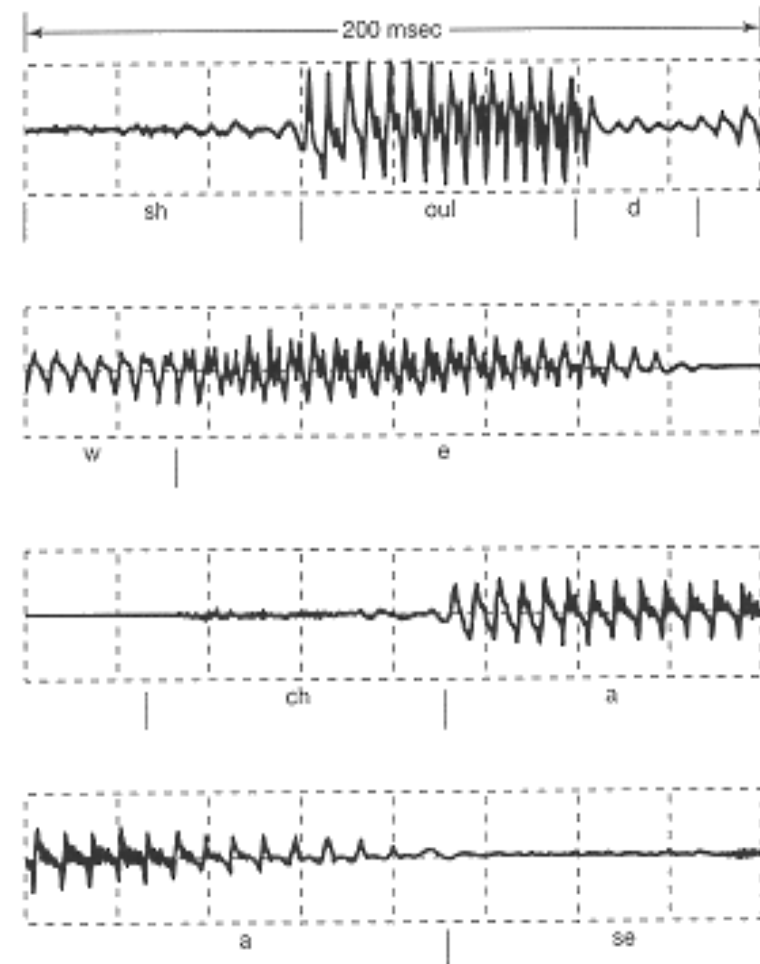


x

y

Variasi  
kecerahan  
titik-titik  
terhadap  
posisi (2D)

Variasi tekanan akustik



Joseph Fourier (21 Maret 1768 – 16 Mei 1830)  
(Kredit gambar: wikimedia commons)

# Sinyal & sistem

**SISTEM** Kumpulan beberapa komponen dengan fungsionalitas berbeda yang saling terhubung satu sama lain yang bekerja sama untuk mencapai suatu tujuan

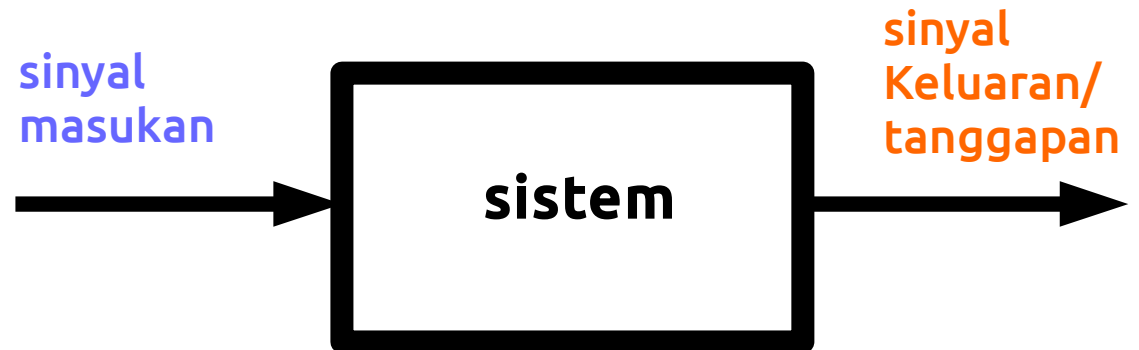


**ADA  
DI  
SEKITAR  
KITA**



# Sinyal & sistem

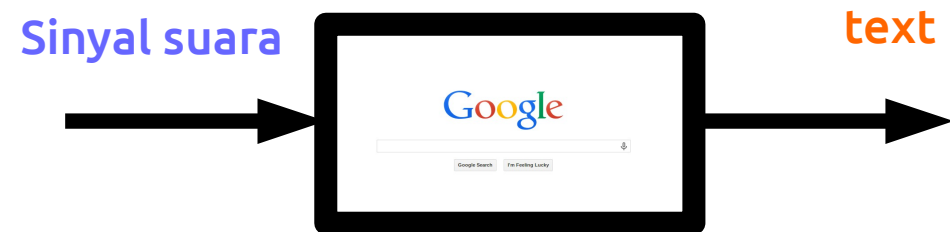
## SINYAL & SISTEM, HUBUGANNYA?



- Car system*



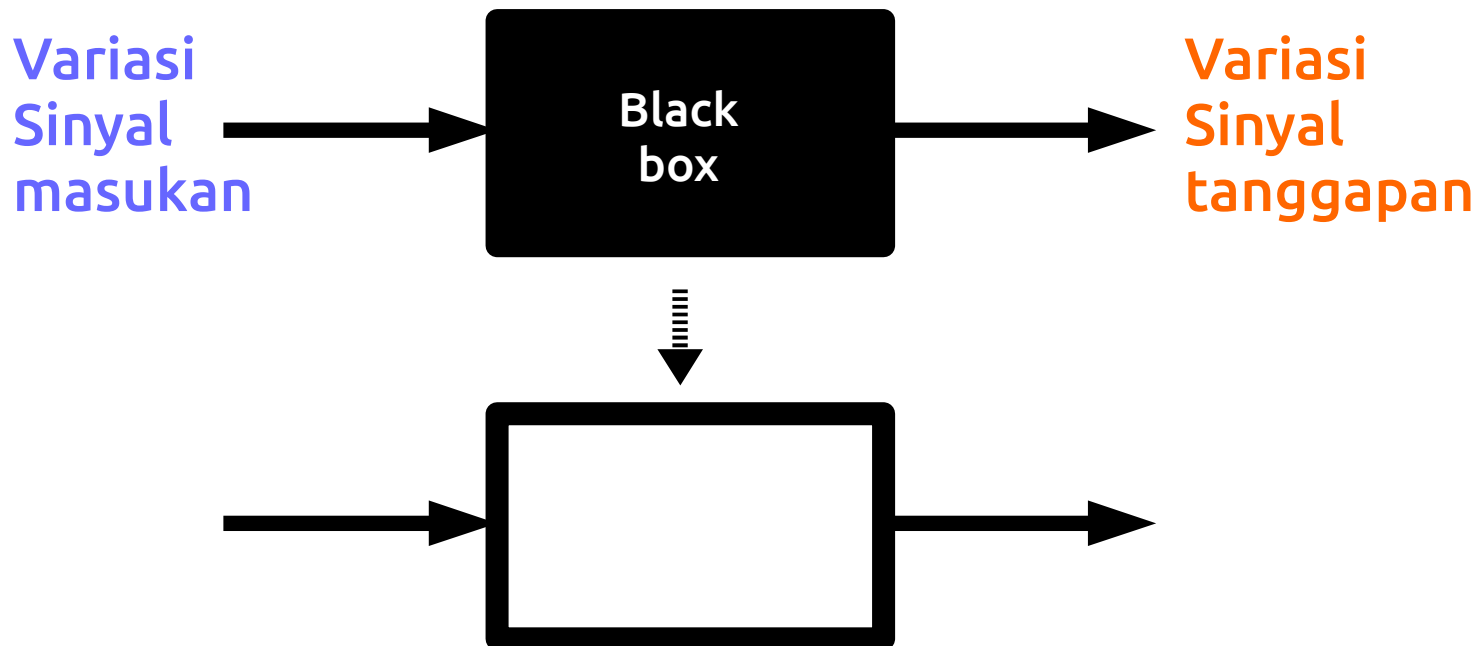
- Google's Speech-to-text system*



# Sinyal & sistem

**DENGAN KONSEP SINYAL & SISTEM,**  
**Apa yang bisa diperbuat?**

- Karakterisasi sistem



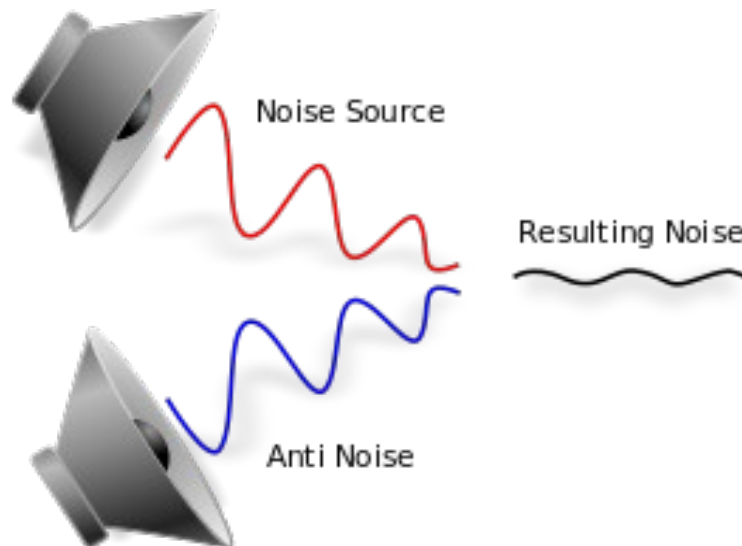


# Sinyal & sistem

**DENGAN KONSEP SINYAL & SISTEM,**  
**Apa yang bisa diperbuat?**

- Pemrosesan sinyal (*signal processing*)

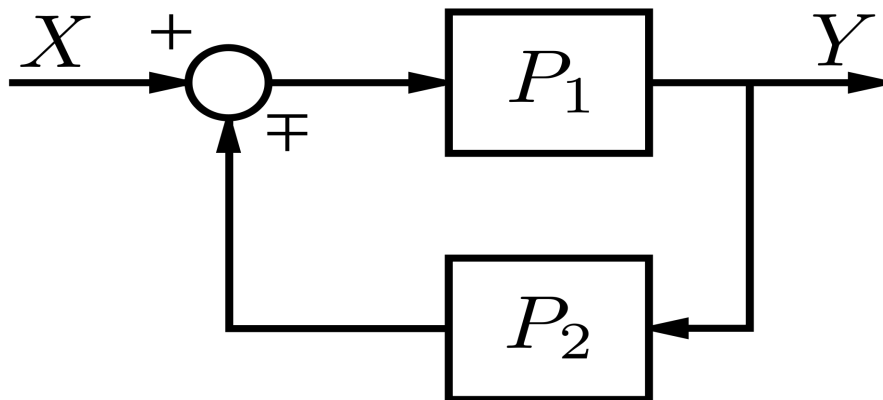
**Active  
Noise  
Canceling**



# Sinyal & sistem

DENGAN KONSEP SINYAL & SISTEM,  
Apa yang bisa diperbuat?

- Sistem kendali otomatis



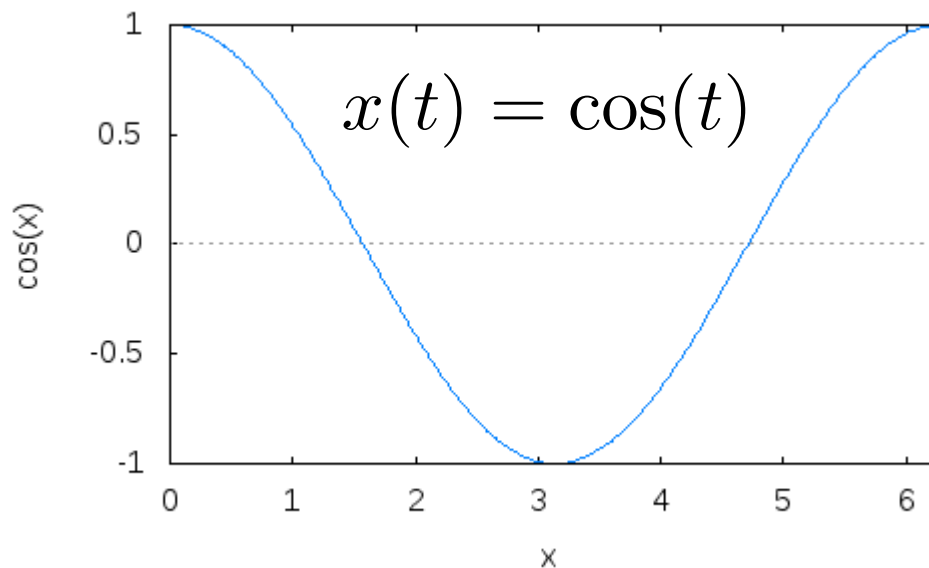
# Sinyal & sistem

## KATEGORI SINYAL

- Sinyal waktu-kontinu

Variabel bebas berubah secara kontinu

$x(t)$   $t$  merupakan variable bebas waktu-kontinu



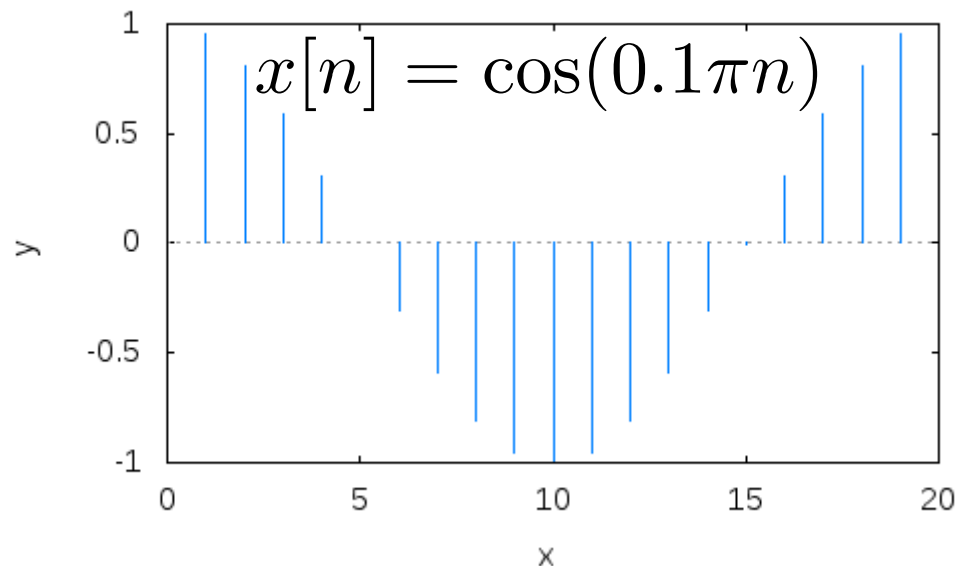
# Sinyal & sistem

## KATEGORI SINYAL

- Sinyal waktu-diskrit → Discrete Sequence

Variabel bebas berubah secara diskrit

$x[n]$   $n$  merupakan variable bebas waktu-diskrit



# Sinyal & sistem

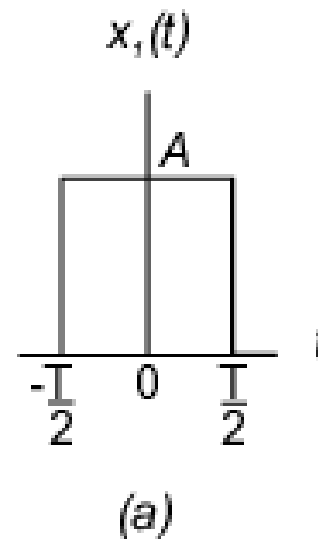
## SINYAL GANJIL & GENAP

### Sinyal genap

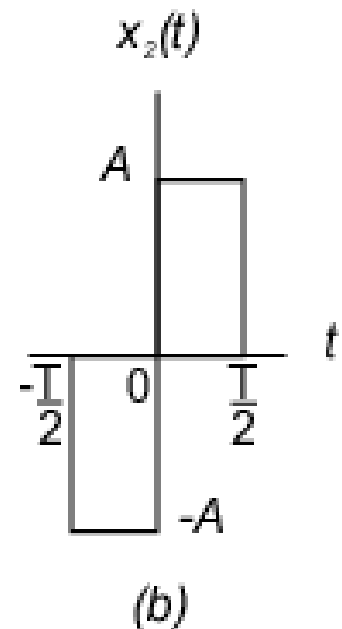
$$x(t) = x(-t) \text{ Untuk semua } t$$

### Sinyal ganjil

$$x(t) = -x(-t) \text{ Untuk semua } t$$



Sinyal genap  
Simetris  
Terhadap  
Waktu asal



Sinyal ganjil  
Tak-simetris  
Terhadap  
Waktu asal

# Sinyal & sistem

## SINYAL PERIODIK

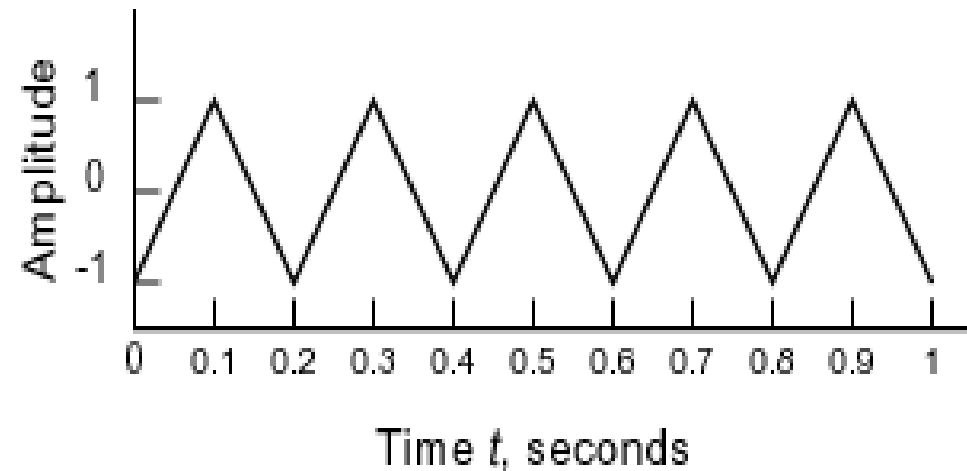
- Sinyal tak berubah dengan pergeseran waktu

**kontinu**

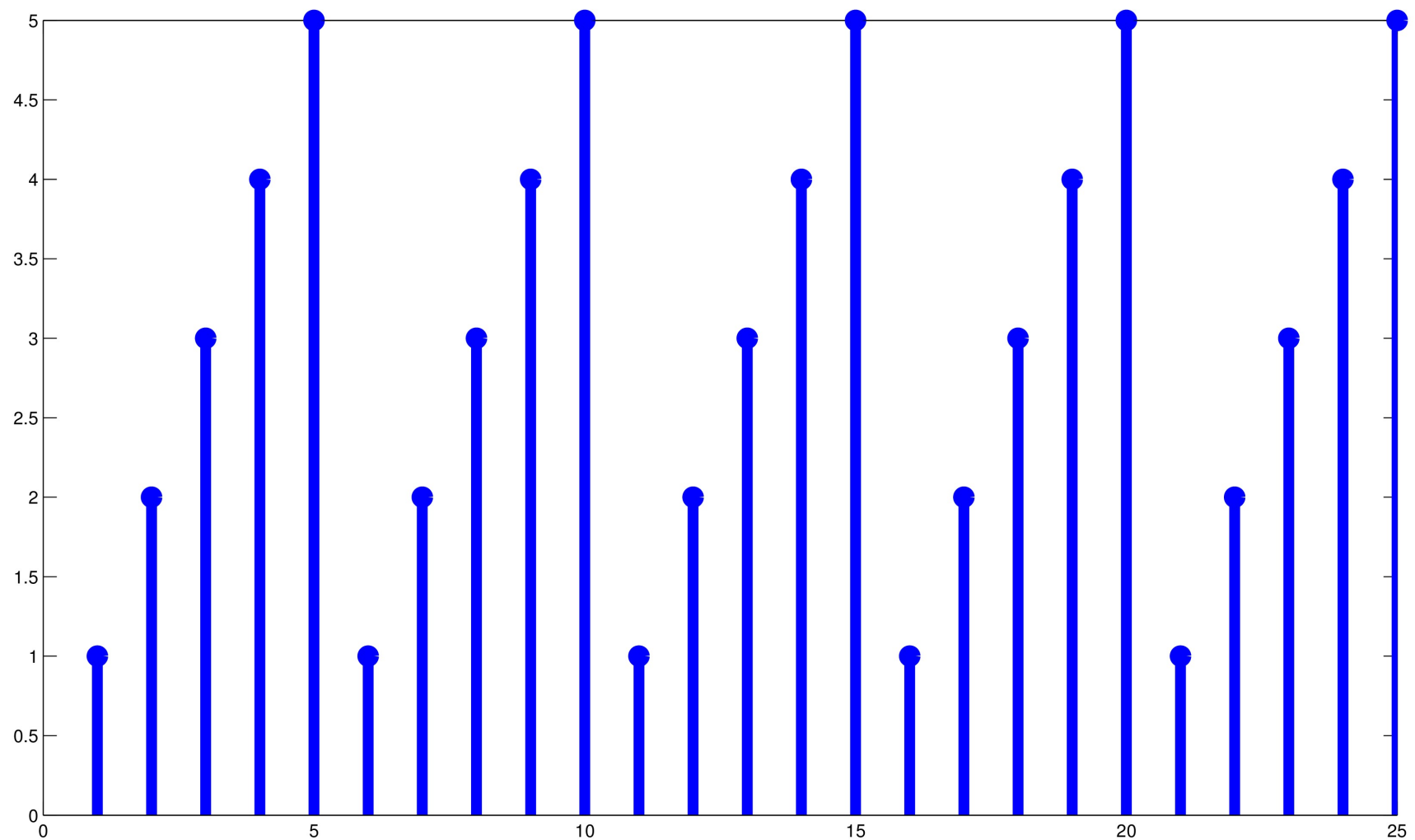
$$x(t) = x(t + T) \text{ Untuk semua } t$$

**diskrit**

$$x[n] = x[n + N] \text{ Untuk semua } n$$



# Periodic Seq.





# Sinyal & sistem

## SINYAL EKSPONENSIAL REAL

- Bentuk umum

$$x(t) = Ce^{at}$$

- **C dan a bilangan real**

$a > 0$  → Eksponensial  
meningkat

$a < 0$  → Eksponensi  
meluruh

**Plot:**

$$x(t) = 4e^{0.5t}$$

**dan**

$$x(t) = 4e^{-0.5t}$$

# Sinyal & sistem

## SINYAL EKSPONENSIAL KOMPLEKS PERIODIK

Merupakan sinyal periodik

$$x(t) = e^{j\omega_0 t}$$

- **C** bilangan real
- **a** bilangan imajiner

Periode Dasar



$$T = \frac{2\pi}{\omega_0}$$

Bukti periodik

$$x(t) = e^{j\omega_0(t+T)}$$

$$x(t) = e^{j\omega_0 t} e^{j\omega_0 T}$$

Syarat periodik

$$e^{j\omega_0 T} = 1$$

# Sinyal & sistem

## SINYAL EKSPONENSIAL KOMPLEKS UMUM

- $C$  dan  $a$  bilangan kompleks dengan bentuk berbeda

$$C = |C|e^{j\phi} \rightarrow \text{bentuk polar}$$

$$a = r + j\omega_0 \rightarrow \text{bentuk rektangular}$$

$$Ce^{at} = |C|e^{j\phi}e^{(r+j\omega_0)t} = |C|e^{rt}e^{j(\omega_0 t + \phi)}$$

# Sinyal & sistem

## SINYAL EKSPONENSIAL KOMPLEKS UMUM

Bentuk hubungan Euler

$$Ce^{at} = |C|e^{rt} \cos(\omega_0 t + \phi) + j|C|e^{rt} \sin(\omega_0 t + \phi)$$

Plot:

$$x(t) = 4e^{-0.5t} \cos(2\pi t) \quad r < 0 \rightarrow \text{sinyal sinusoidal meluruh}$$

$$x(t) = 4e^{0.5t} \cos(2\pi t) \quad r > 0 \rightarrow \text{sinyal sinusoidal meningkat}$$

# Sinyal & sistem

## KARAKTERISTIK SINYAL EKSPONENSIAL WAKTU-KONTINU

Karakteristik	$C$	$a$
Sinyal eksponensial real	real	real
Sinyal eksponensial kompleks periodik	real	imajiner
Sinyal eksponensial kompleks umum	kompleks	kompleks

# Sinyal & sistem

## SINYAL EKSPONENSIAL KOMPLEKS WAKTU-DISKRIT

- Bentuk umum

$$x[n] = C\alpha^n$$

atau

$$x[n] = Ce^{\beta n}$$

dimana  $\alpha = e^{\beta}$

# Sinyal & sistem

## SINYAL EKSPONENSIAL REAL WAKTU-DISKRIT

Karakteristik:

$$x[n] = C\alpha^n$$

$\alpha > 1 \rightarrow$  Eksponensial meningkat

$0 < \alpha < 1 \rightarrow$  Eksponensial meluruh

$\alpha = 1 \rightarrow$  Konstan dengan amplituda  $+C$

$\alpha = -1 \rightarrow$  Konstan dengan amplituda  $-C$

$-1 < \alpha < 0 \rightarrow$  Eksponensial meluruh dengan amplituda bergantian antara  $+C$  dan  $-C$

$\alpha < -1 \rightarrow$  Eksponensial meningkat dengan amplituda bergantian antara  $+C$  dan  $-C$



# Sinyal & sistem

## SINYAL EKSPONENSIAL KOMPLEKS WAKTU-DISKRIT

$C$  dan  $\alpha$  bilangan kompleks dengan bentuk polar

$$C = |C|e^{j\phi}$$

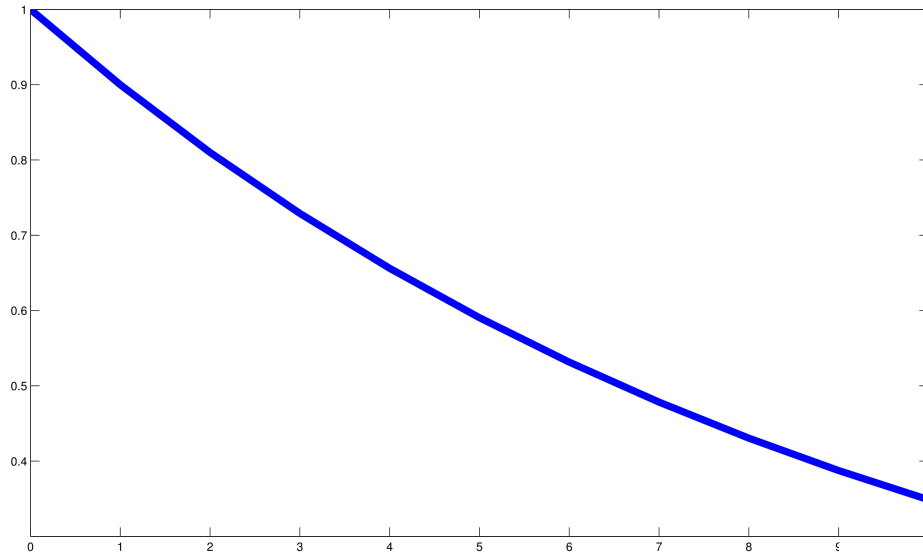
$$\alpha = |\alpha|e^{j\omega_0}$$

$$C\alpha^n = |C||\alpha|^n \cos(\omega_0 n + \phi) + j|C||\alpha|^n \sin(\omega_0 n + \phi)$$

$|\alpha| < 1 \rightarrow$  Sinusoidal waktu-diskrit meluruh

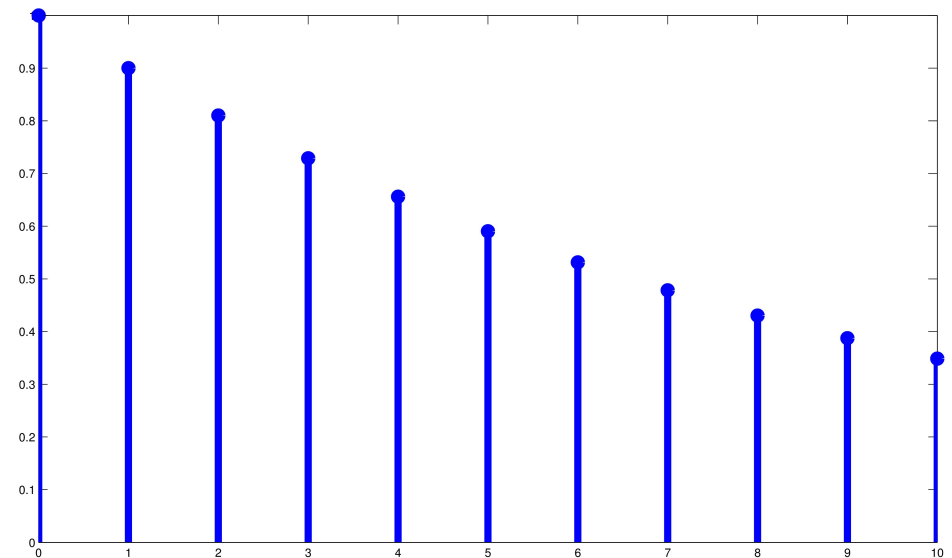
$|\alpha| > 1 \rightarrow$  Sinusoidal waktu-diskrit meningkat

# Exponential Signal



Sinyal Eksponensial Real Kontinyu

Sinyal Eksponensial Real Diskrit



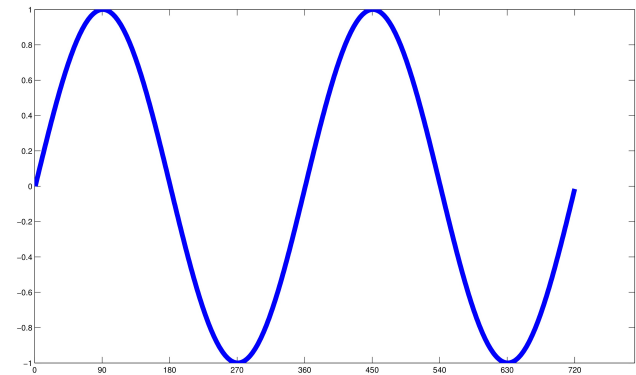
# Sinyal & sistem

## SINYAL SINUSOIDAL

- Bentuk umum

$$x(t) = A \cos(\omega_0 t + \phi)$$

$A$	→	Amplituda
$\omega_0$	→	Frekuensi sudut (rad/s)
$\phi$	→	Fase (rad)



**Plot:**

$$x(t) = 2\cos(2\pi t + \pi/6)$$

**Hubungan Euler**

$$e^{j\omega_0 t} = \cos \omega_0 t + j \sin \omega_0 t$$

# Sinyal & sistem

## SINYAL SINUSOIDAL WAKTU-DISKRIT

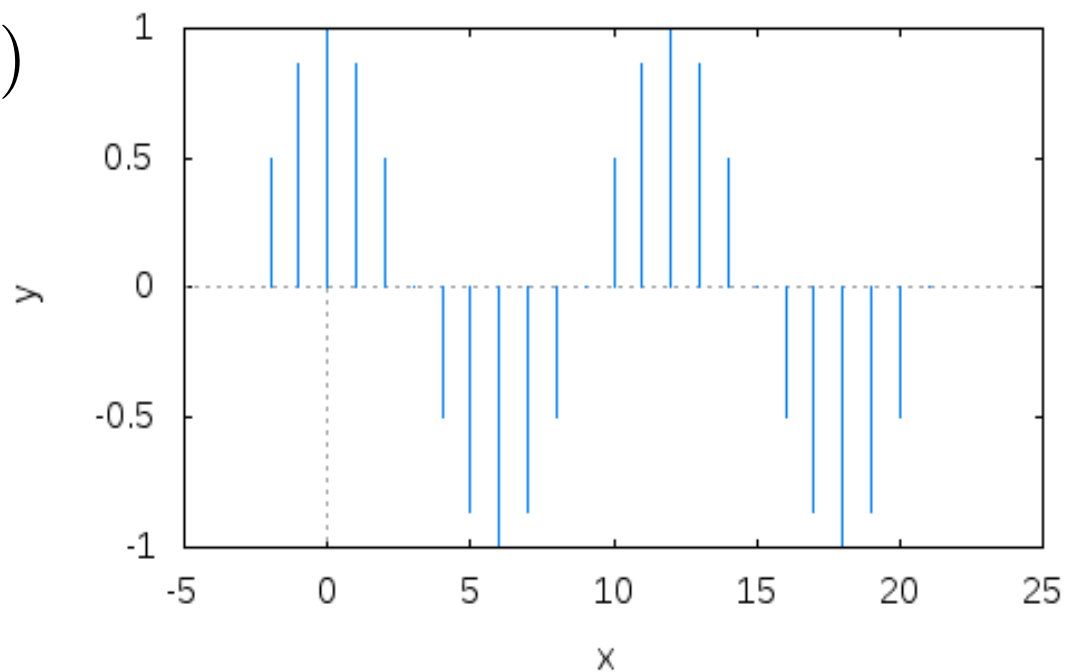
$$x[n] = A \cos(\omega_0 n + \phi)$$

Hubungan Euler

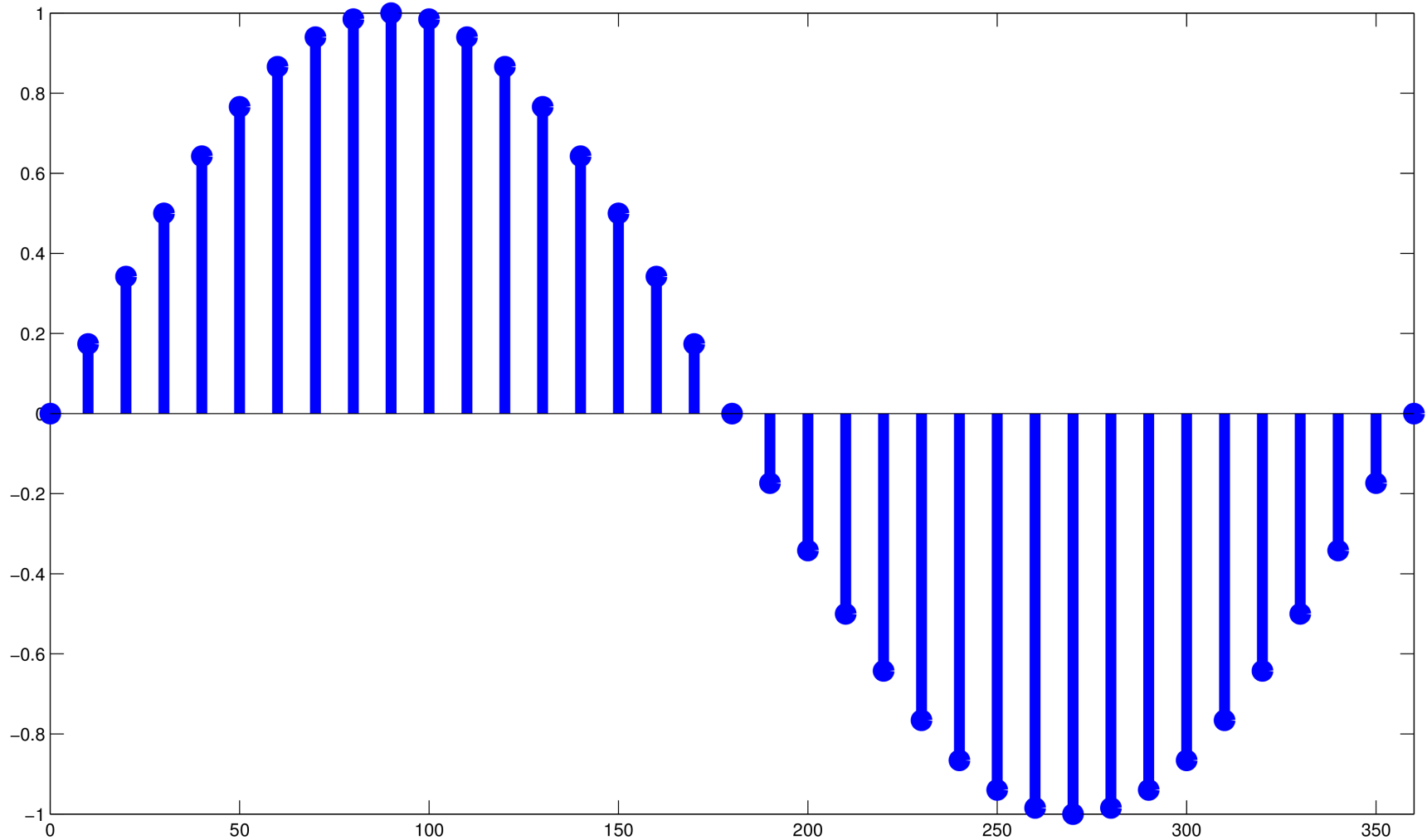
$$x[n] = e^{j\omega_0 n} = \cos \omega_0 n + j \sin \omega_0 n$$

periode dasar  $\rightarrow N = m\left(\frac{2\pi}{\omega_0}\right)$

$$x[n] = \cos(2\pi n/12)$$



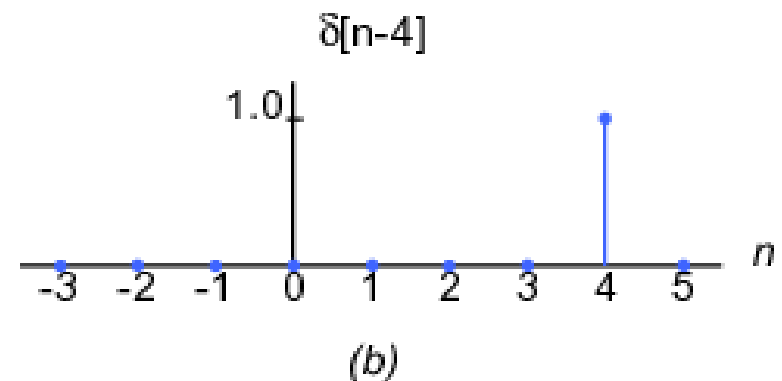
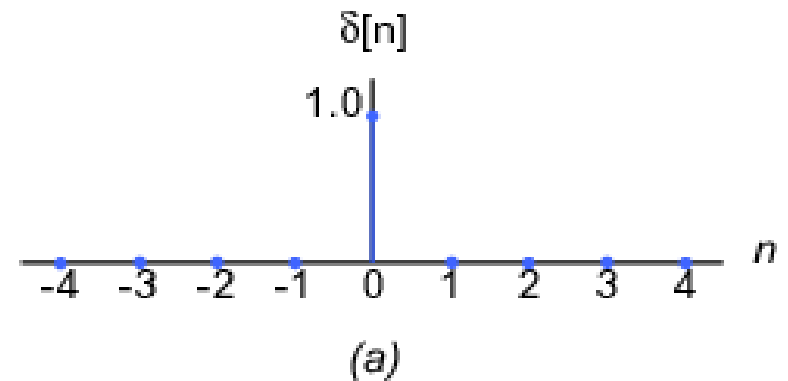
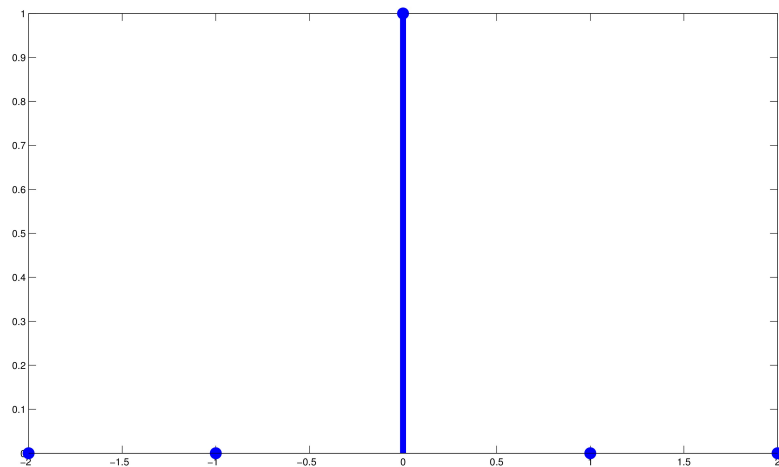
# Sinusoidal Seq.



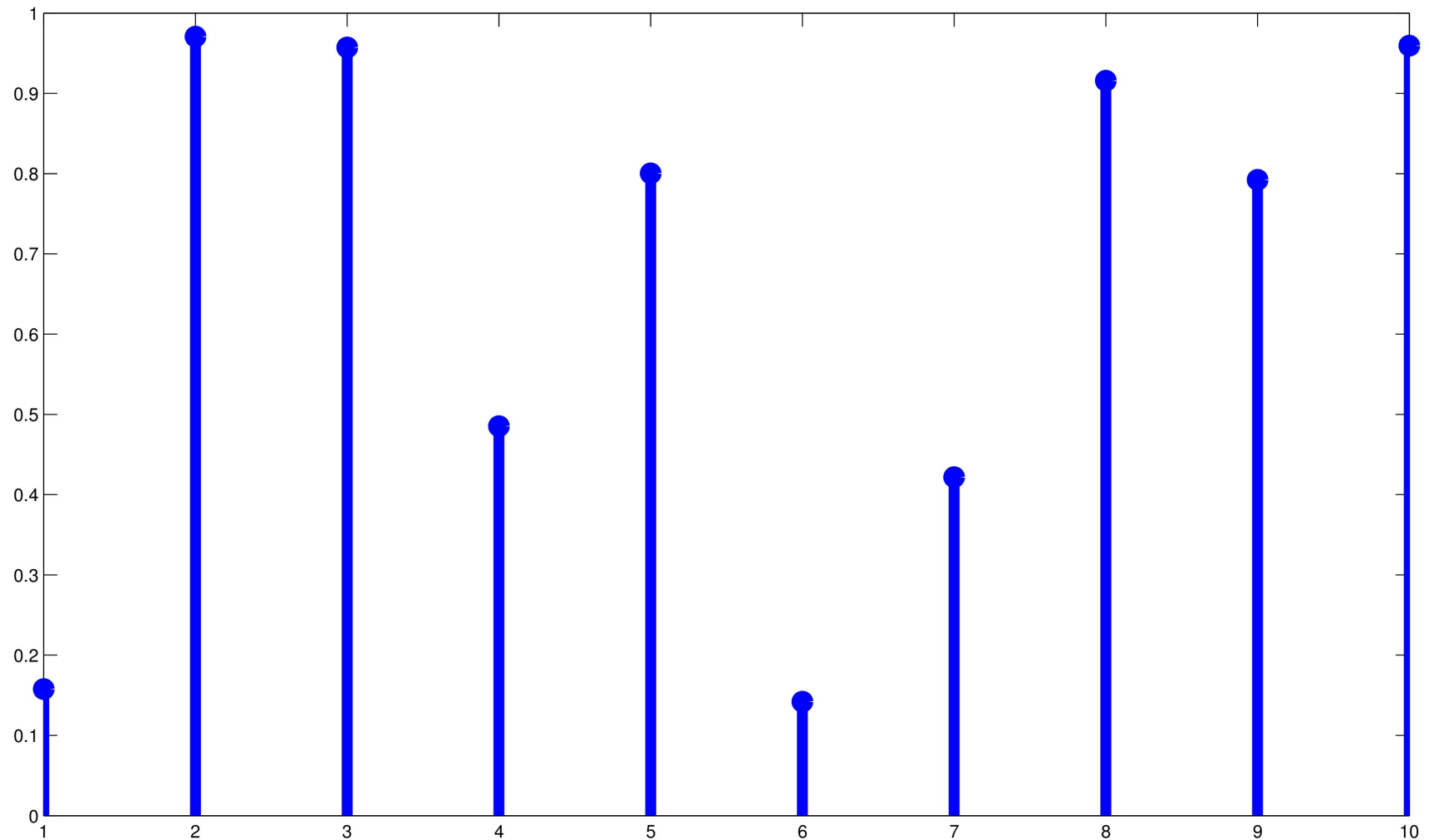
# Sinyal & sistem

## SINYAL IMPULS WAKTU-DISKRIT

$$\delta[n] = \begin{cases} 0, & n \neq 0 \\ 1 & n = 0 \end{cases}$$



# Random Seq.

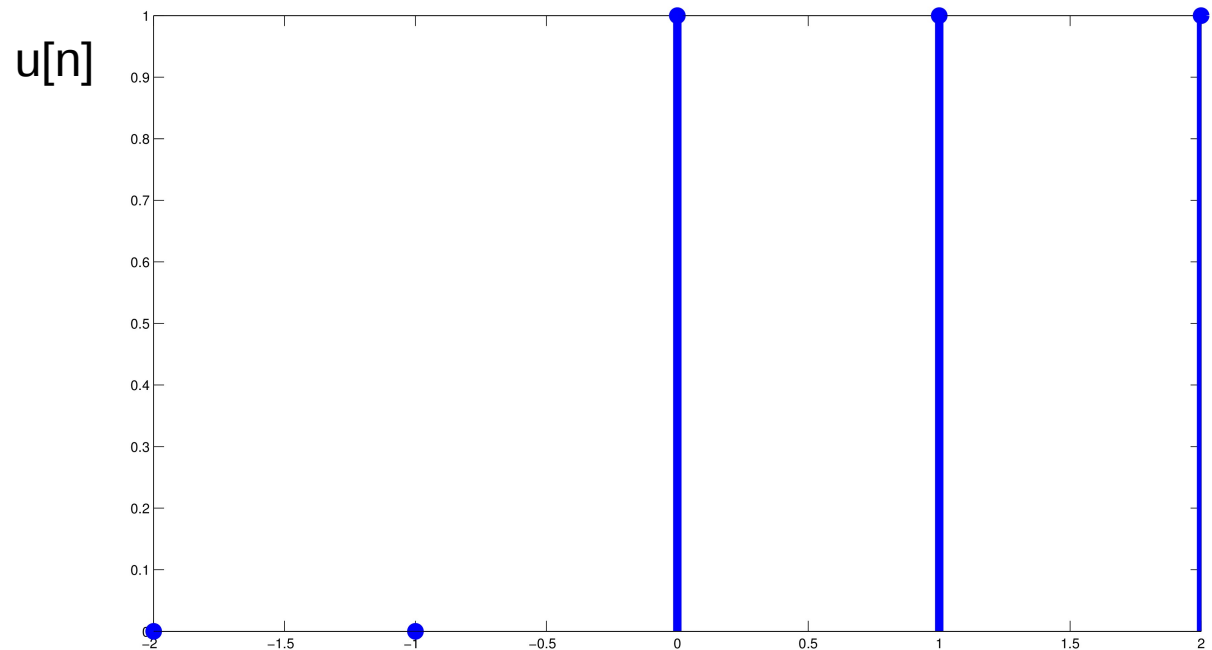




# Sinyal & sistem

## SINYAL STEP WAKTU-DISKRIT

$$u[n] = \begin{cases} 0, & n < 0 \\ 1 & n \geq 0 \end{cases}$$



# Sinyal & sistem

## HUBUNGAN SINYAL IMPULS & STEP WAKTU-DISKRIT

- Sinyal impuls adalah perbedaan pertama dari sinyal step

$$\delta[n] = u[n] - u[n - 1]$$

- Sinyal step adalah jumlahan sinyal impuls

$$u[n] = \sum_{m=-\infty}^n \delta[m] = \sum_{k=0}^{\infty} \delta[n - k]$$

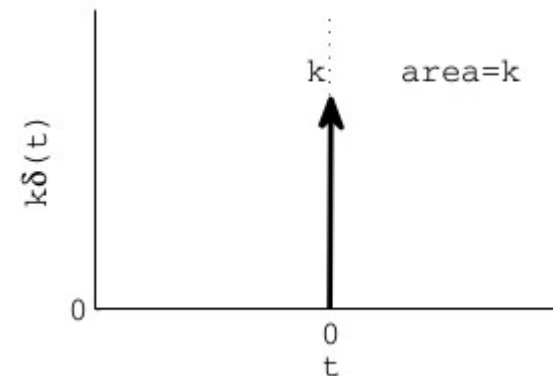
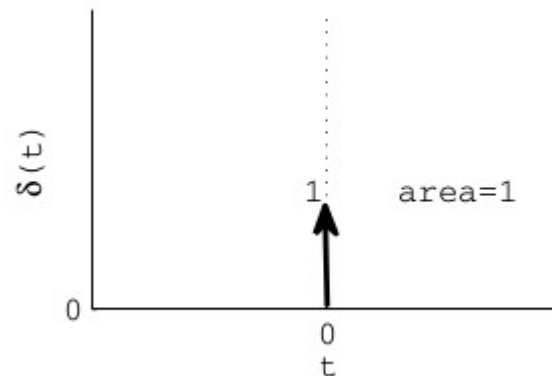
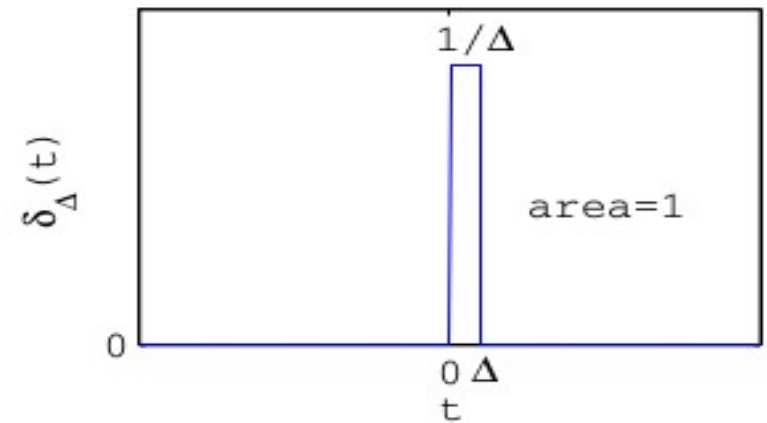
# Sinyal & sistem

## SINYAL IMPULS WAKTU-KONTINU

$$\delta(t) = \lim_{\Delta \rightarrow 0} \delta_{\Delta}(t)$$

dimana

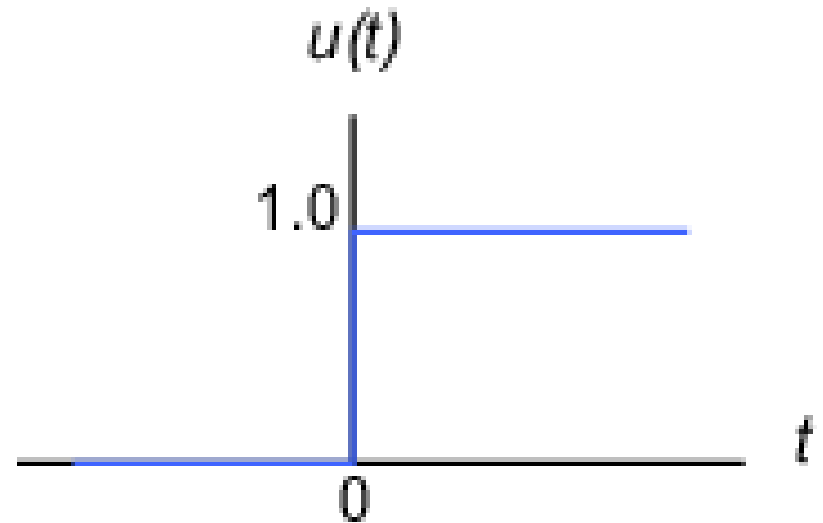
$$\delta_{\Delta t} = \frac{u(t) - u(t - \Delta)}{\Delta}$$



# Sinyal & sistem

## SINYAL STEP WAKTU-KONTINU

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



# Sinyal & sistem

## HUBUNGAN SINYAL IMPULS & STEP WAKTU-KONTINU

- Sinyal step adalah integrasi sinyal pulsa

$$u(t) = \int_{-\infty}^t \delta(\tau) d\tau = \int_0^{\infty} \delta(t - \tau) d\tau$$

- Sinyal pulsa adalah derivatif sinyal step

$$\delta(t) = \frac{du(t)}{dt}$$

# Sinyal & sistem

## TRANSFORMASI SINYAL

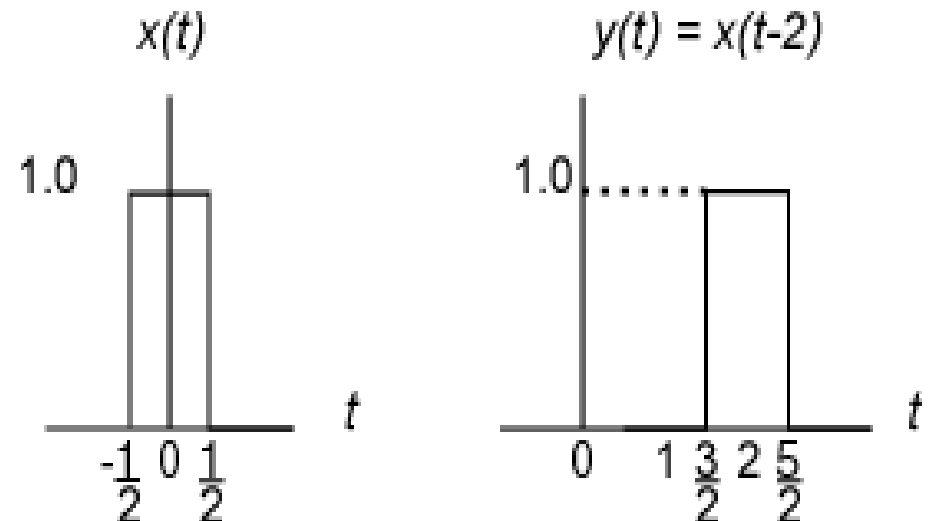
- Pergeseran waktu (*time shift*)

$$x'(t) = x(t - t_0)$$

$t_0 > 0$  → Geser ke kanan  
(*time delay*)

$t_0 < 0$  → Geser ke kiri

Sinyal kontinu



# Sinyal & sistem

## TRANSFORMASI SINYAL

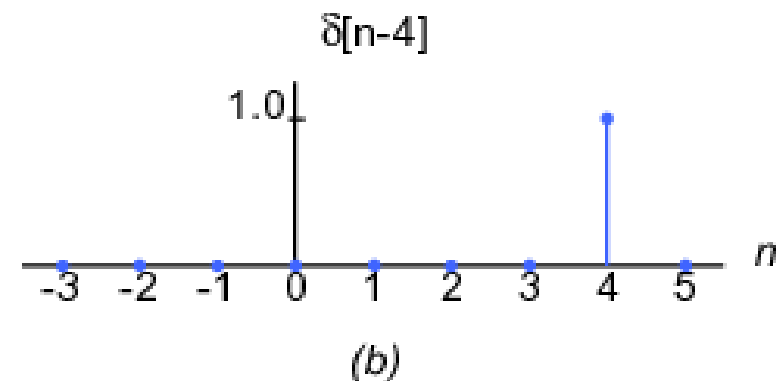
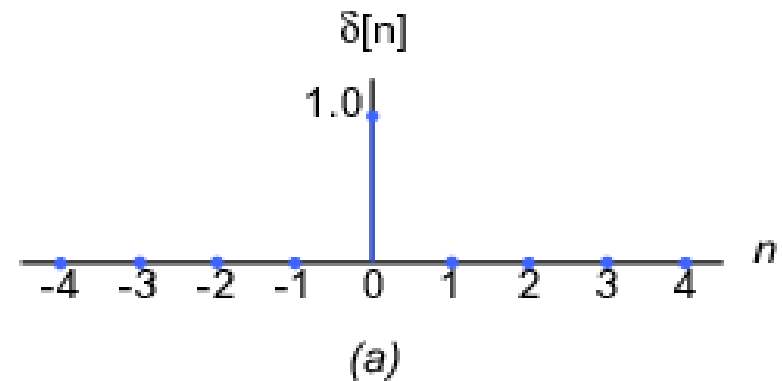
- Pergeseran waktu (*time shift*)

### Sinyal diskrit

$$x'[n] = x[n - n_0]$$

$n_0 > 0 \rightarrow$  Geser ke kanan  
(*time delay*)

$n_0 < 0 \rightarrow$  Geser ke kiri



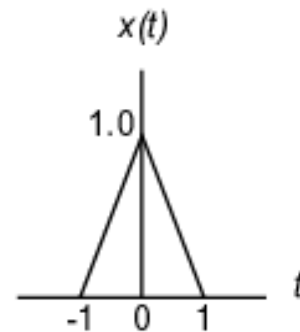


# Sinyal & sistem

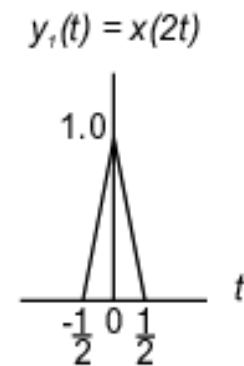
## TRANSFORMASI SINYAL

- Penskalaan waktu (*time scaling*)

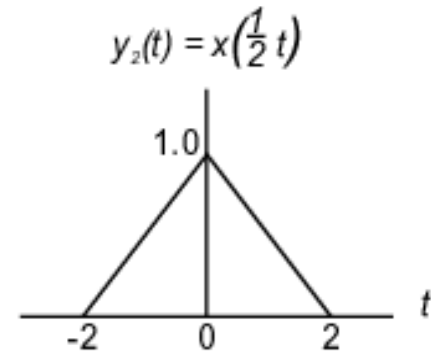
$$x'(t) = x(at)$$



(a)



(b)

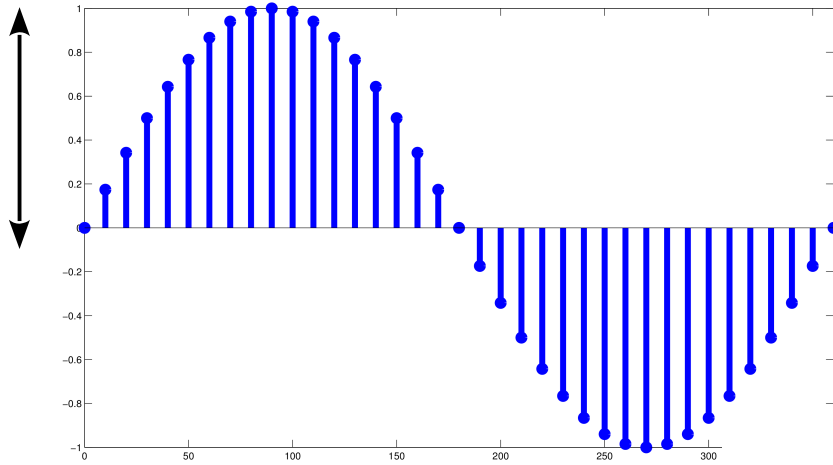


(c)

$a > 1 \longrightarrow$  Sinyal terkompresi

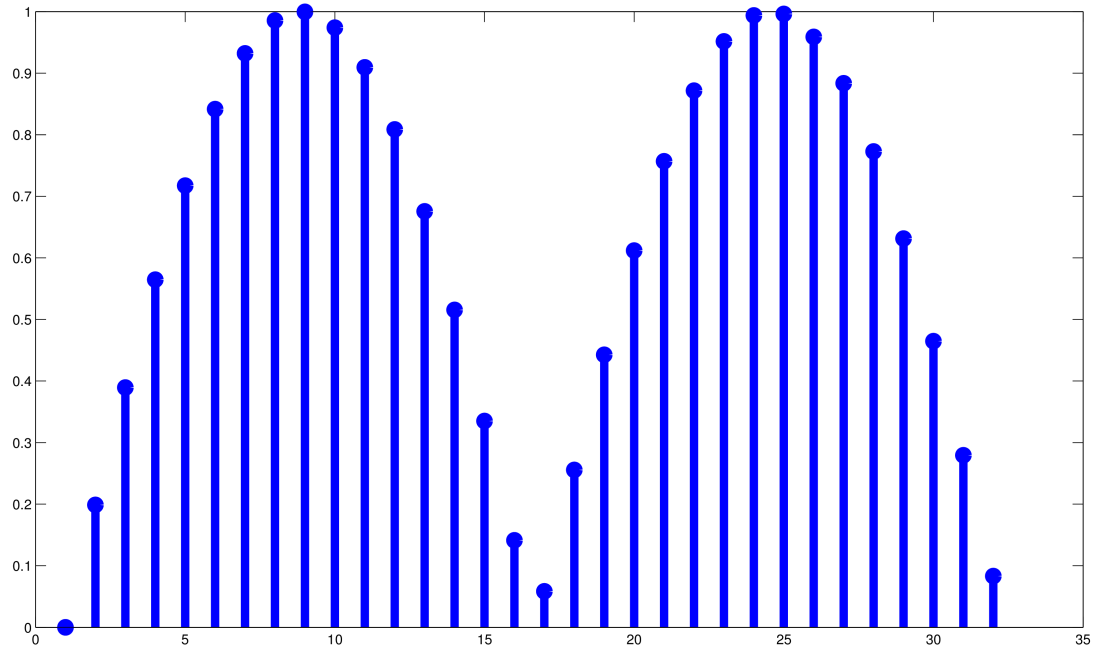
$0 < a < 1 \longrightarrow$  Sinyal melar

# Amplitude Vs Magnitud



Amplitude  $\rightarrow 1$

Magnitude :  
Absolute Value  
of amplitude

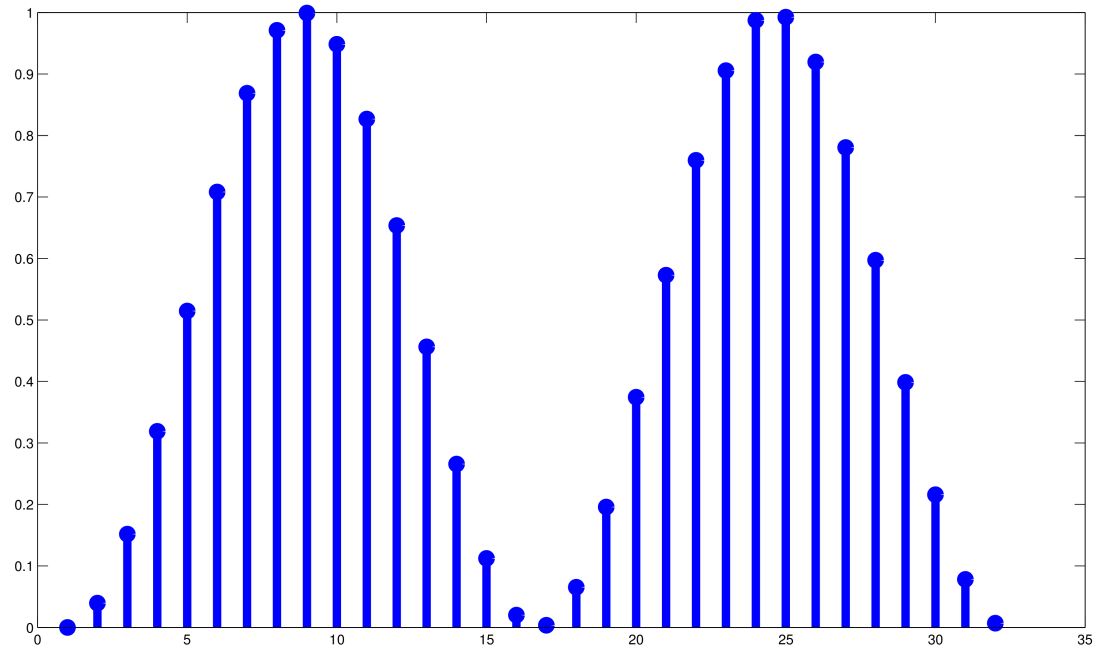


# Signal Power

The power of signal is proportional to its amplitude/magnitude squared

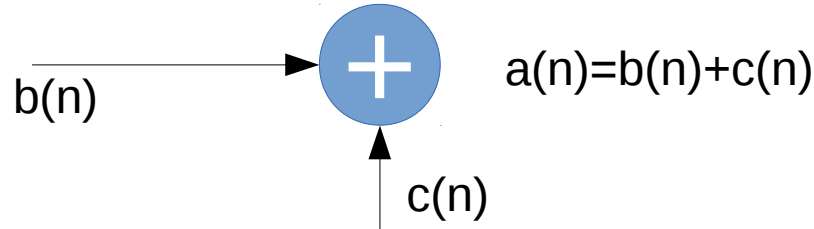
$$x_{\text{pwr}}(n) = x(n)^2 = |x(n)|^2,$$

$$X_{\text{pwr}}(m) = X(m)^2 = |X(m)|^2.$$

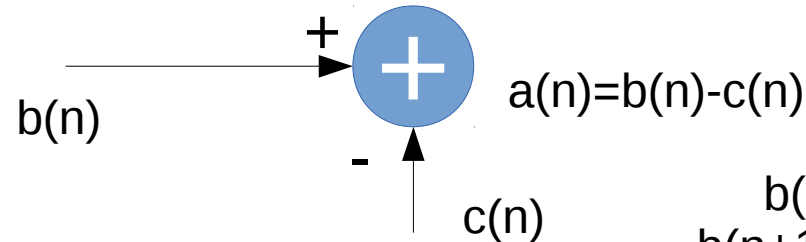


# Operational & Symbol

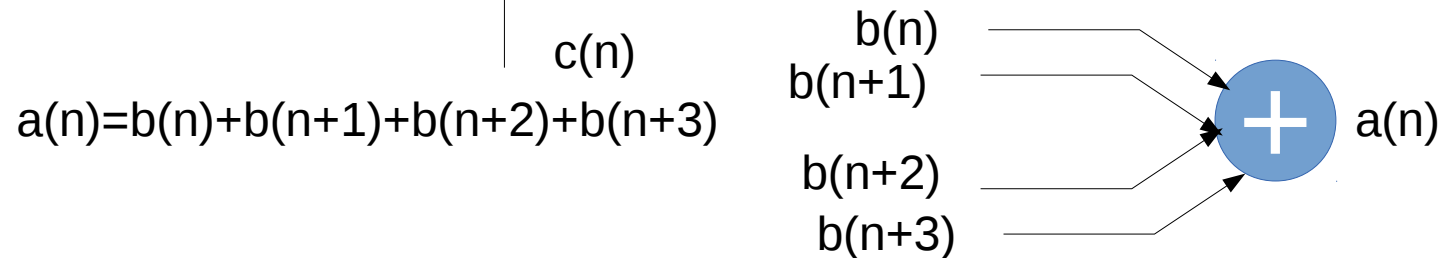
- Adder



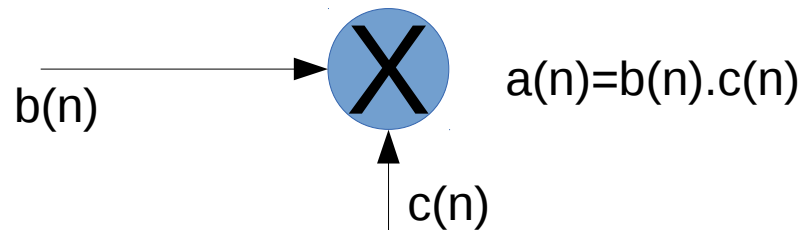
- Subtractor



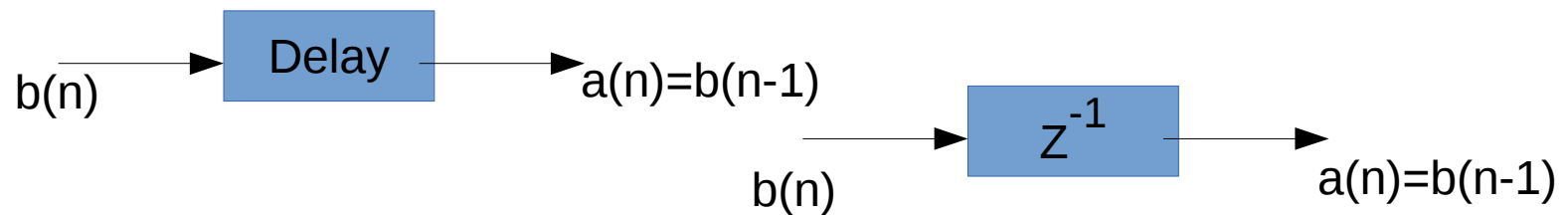
- Summation



- Multiplication



- Unit delay



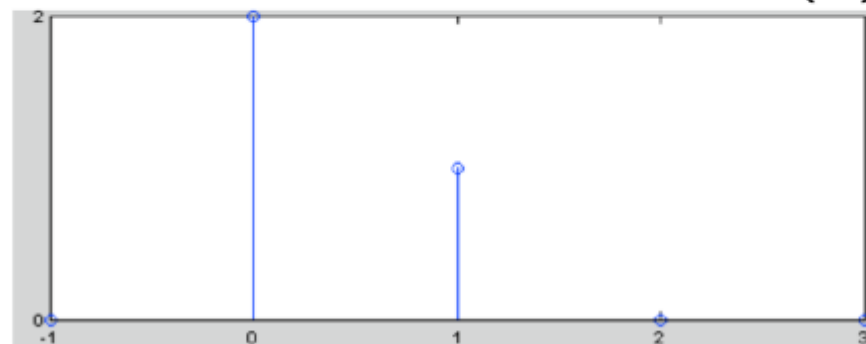
# Addition



$x_1(n)$



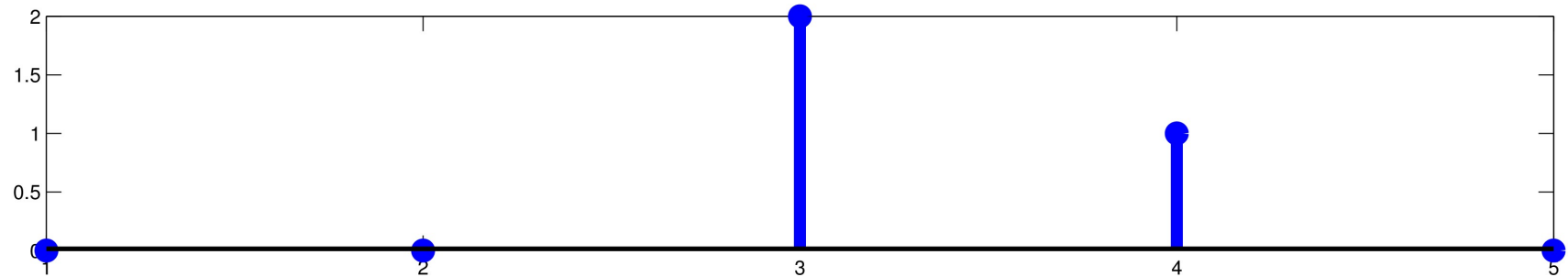
$x_2(n)$



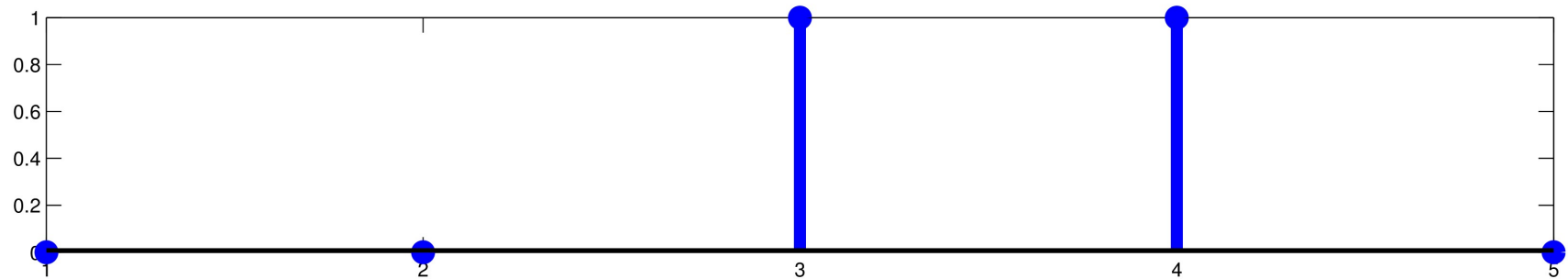
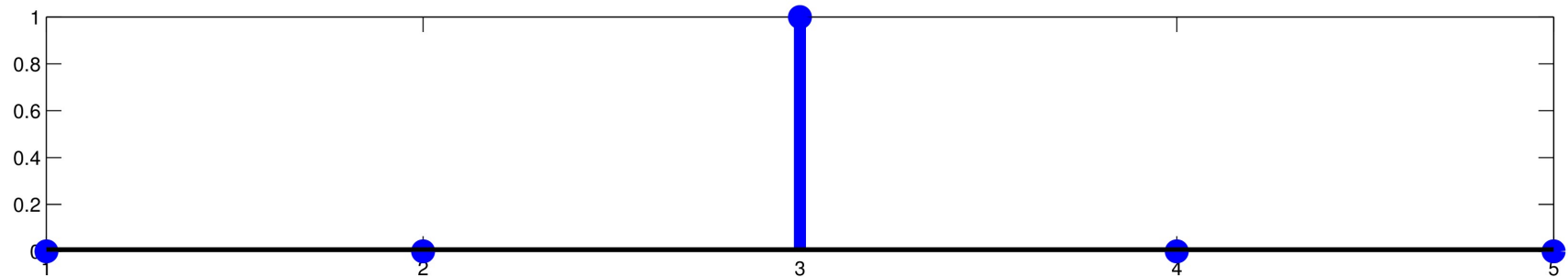
$$y(n) = x_1(n) + x_2(n)$$

# Subtraction

$x_1[n]$

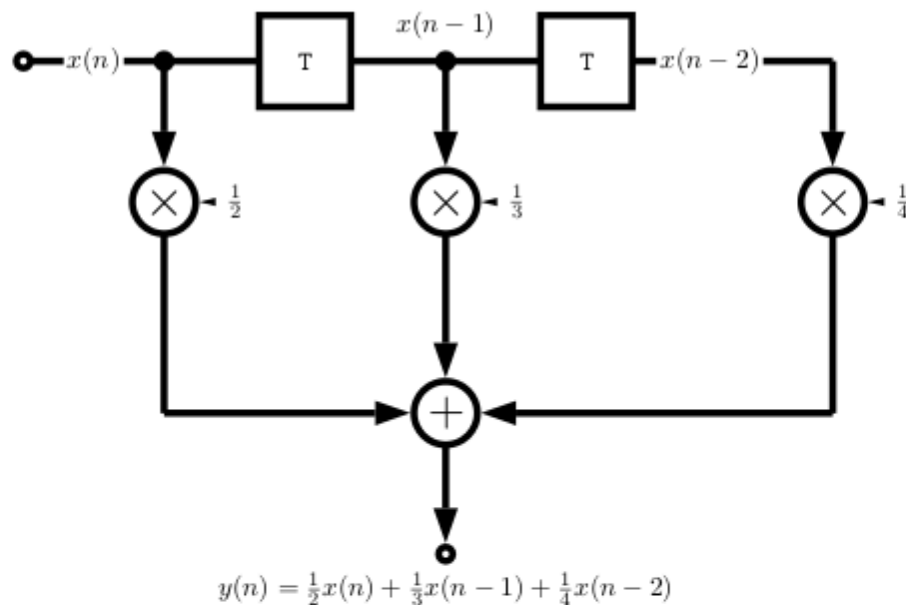


$x_2[n]$

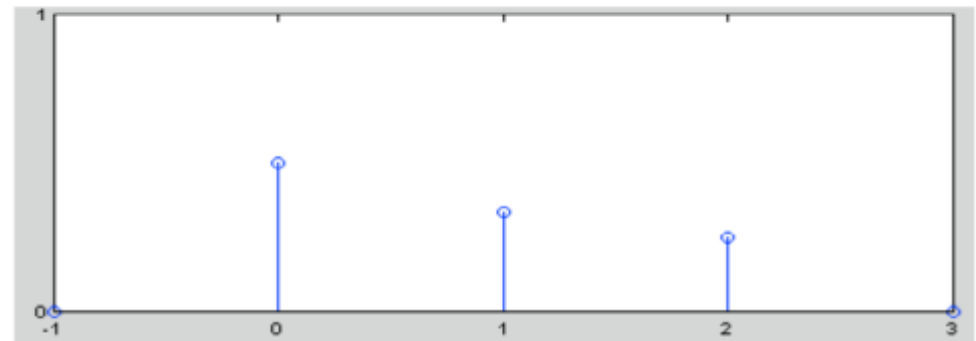


$$x_3 = x_1[n] - x_2[n]$$

# Summation



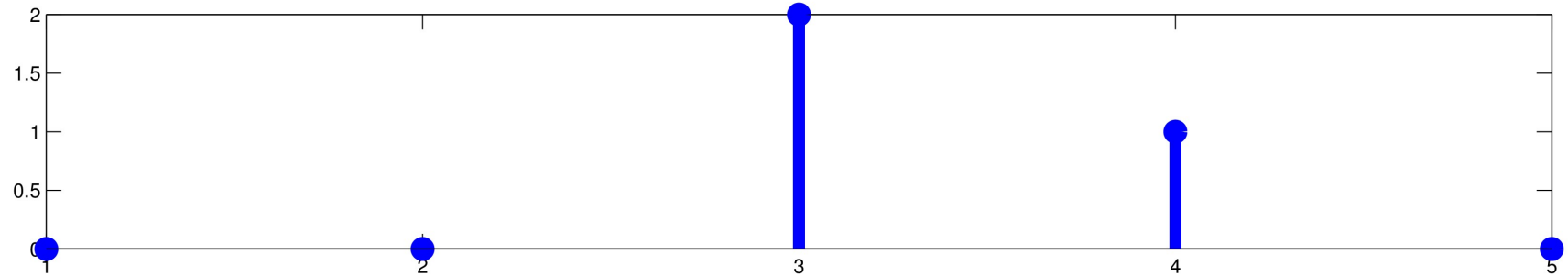
$x[n]$



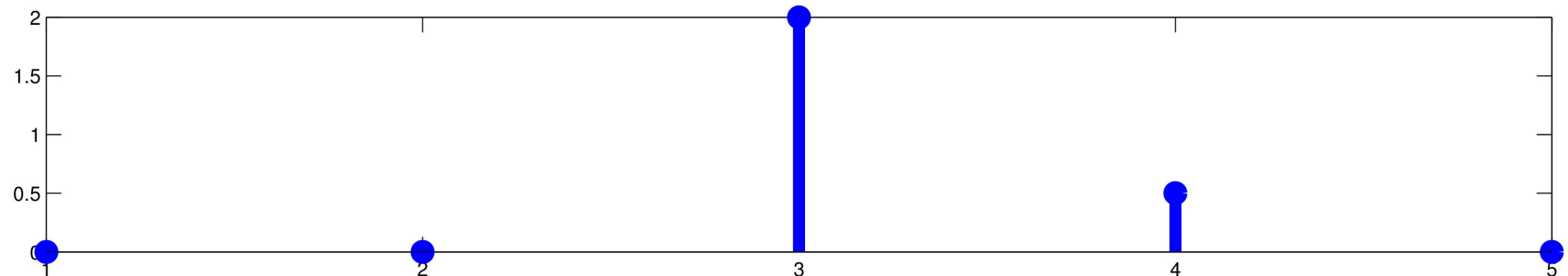
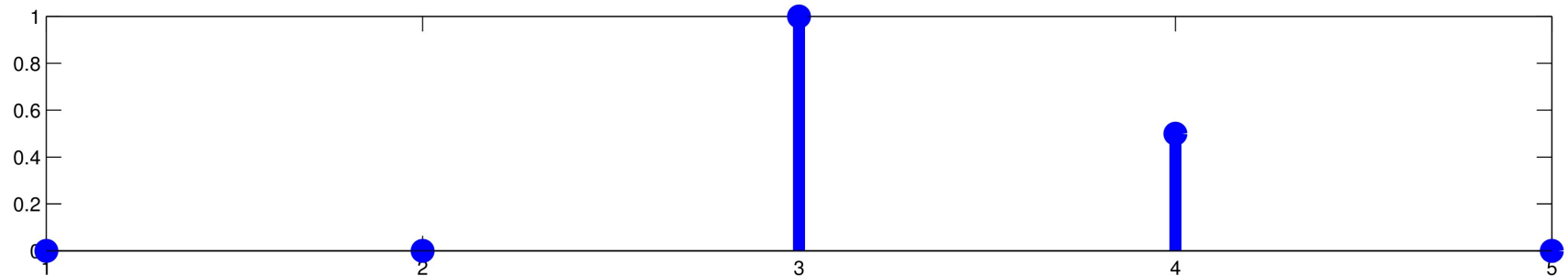
$y[n] = \frac{1}{2}x[n] + \frac{1}{3}x[n-1] + \frac{1}{4}x[n-2]$

# Multiplication

$x_1[n]$



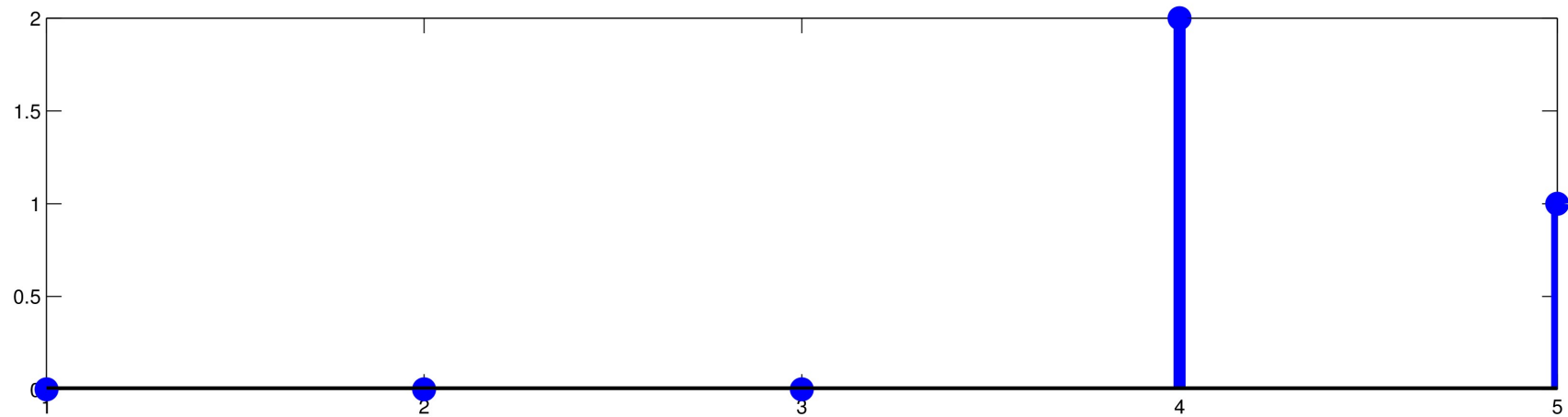
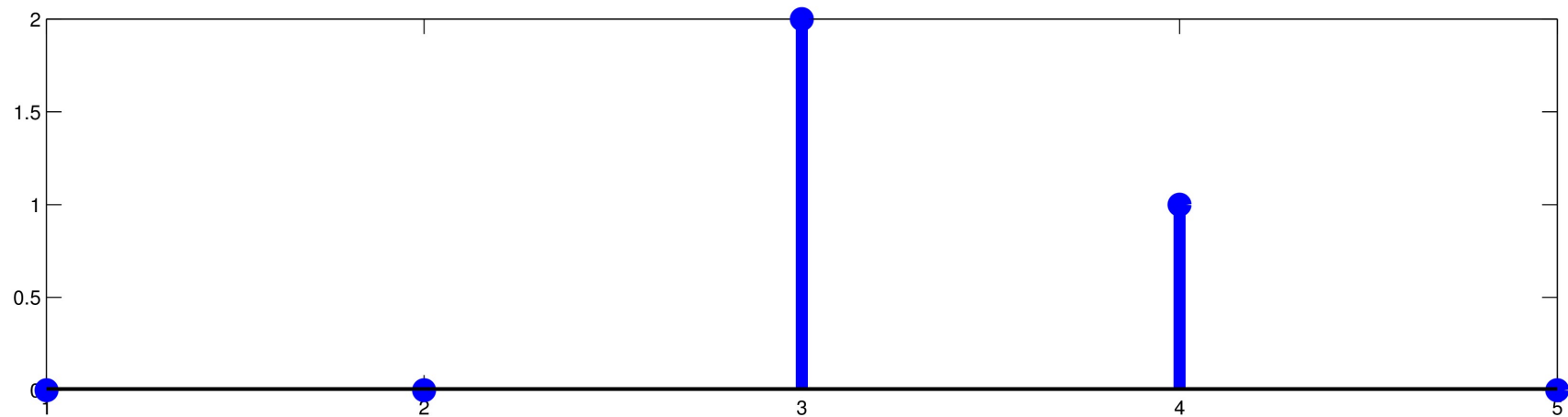
$x_2[n]$



$$x_3 = x_1[n] \cdot x_2[n]$$

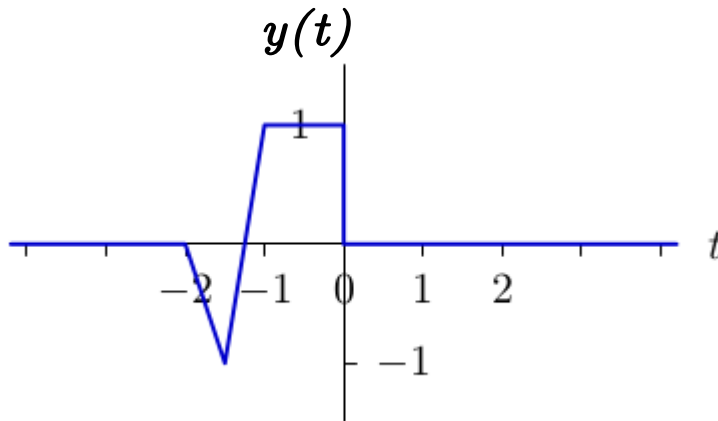
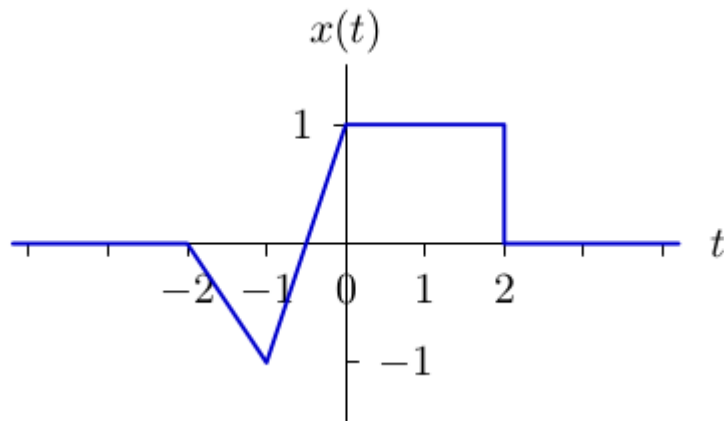


# Delay

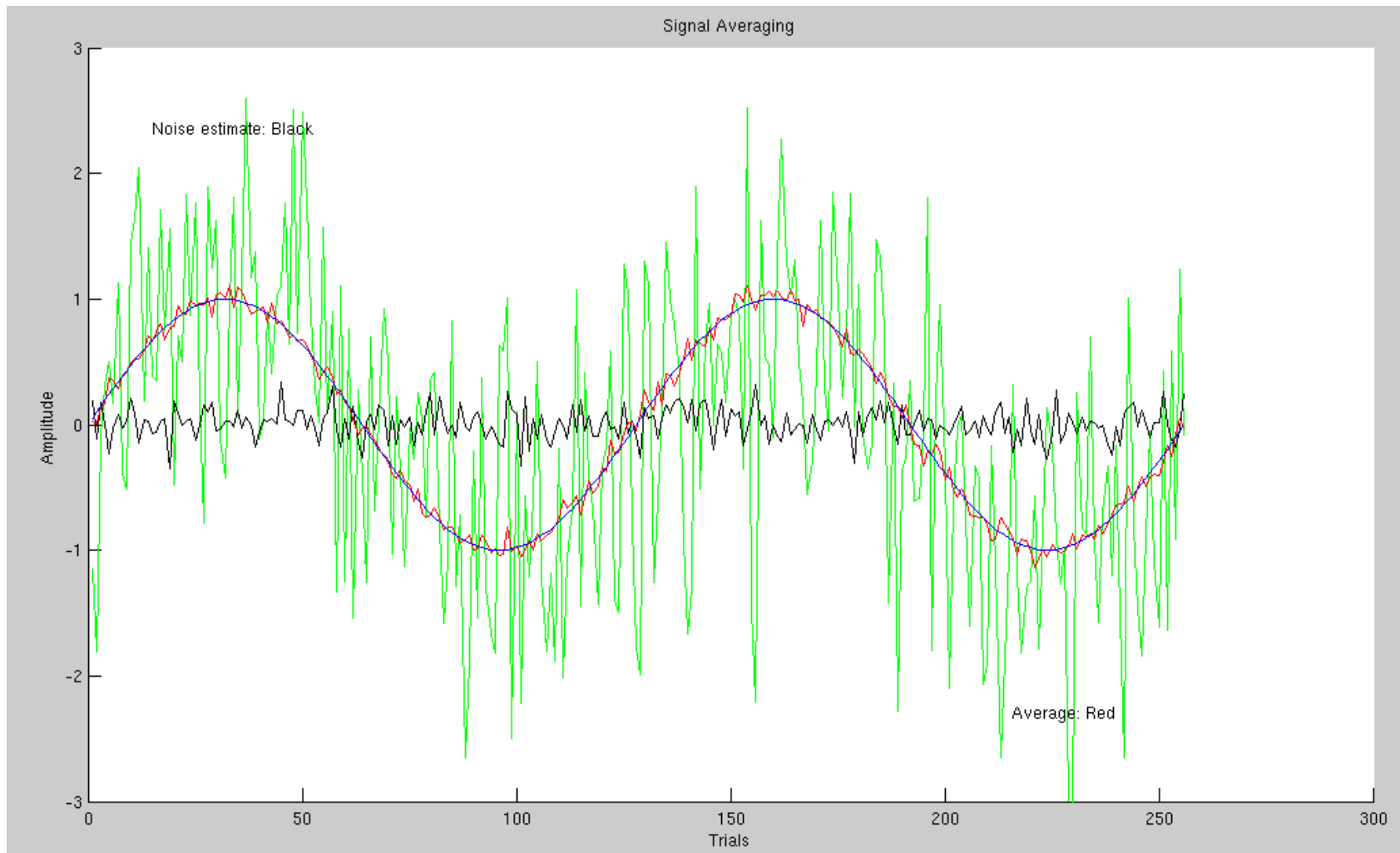


# HOMework #1

- Jelaskan perbedaan **differential equation** dan **difference equation**, berilah contoh masing-masing satu soal beserta solusinya.
- Apa fungsi kedua persamaan tersebut dalam sinyal dan sistem ?
- Tentukan  $y(t)$  dalam fungsi  $x(t)$  sbb:



# Signal Averaging



Signal averaging is a signal processing technique applied in the time domain, intended to increase the strength of a signal relative to noise that is obscuring it