INSTITUT TEKNOLOGI TELKOM

DTG2F3

Sistem Komunikasi

Noise dalam Sistem Komunikasi

By : Dwi Andi Nurmantris

NOISE DALAM SISTEM KOMUNIKASI

OUTLINE

- ❑ PENDAHULUAN
- ❑ RANDOM PROCESS
- ❑ NOISE
- ❑ AWGN
- ❑ NOISE FIGURE DAN SISTEM NOISE

NOISE DALAM SISTEM KOMUNIKASI

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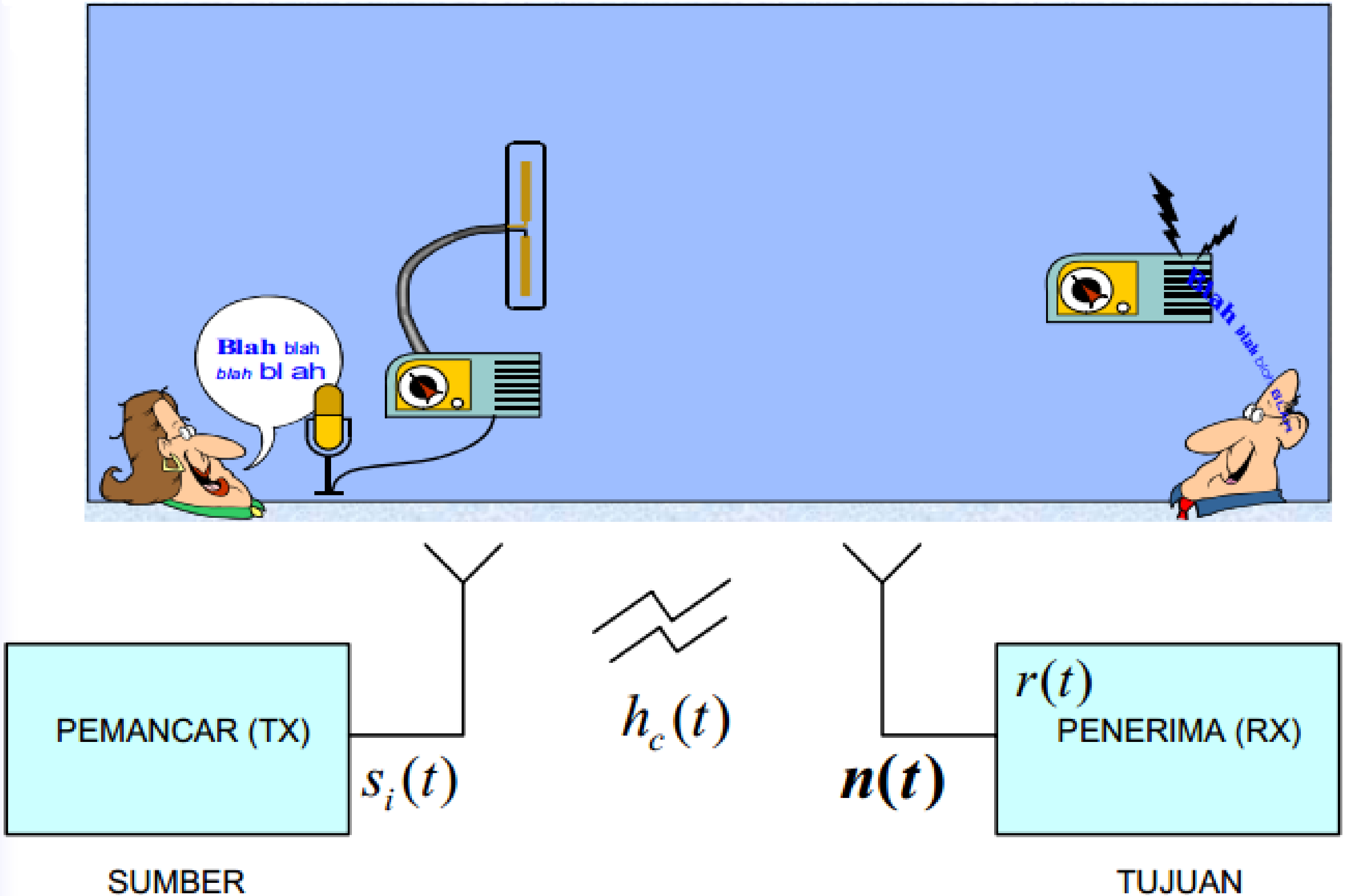
NOISE DALAM SISTEM KOMUNIKASI

Model Komunikasi Radio



Signal yang diterima di receiver biasanya terdiri dari :

1. Signal Informasi
2. Interferensi
3. Noise

NOISE DALAM SISTEM KOMUNIKASI

Model Matematika Untuk Sistem Komunikasi

- model matematika untuk menggambarkan kejadian/phenomena fisik telah banyak digunakan dalam sciences dan engineering
- Ada dua model matematika : deterministic dan Stochastic (Random)
- Model dikatakan deterministik jika tidak ada ketidakpastian nilai pada setiap waktu yang diamati.
- Model dikatakan Stochastic/random jika ada ketidakpastian nilai pada setiap waktu yang diamati, sehingga perlu didekati secara probabilistik.
- Kejadian/fenomena fisik dalam sistem komunikasi tidak cukup dimodelkan dengan model deterministik karena fenomena-fenomena fisik tadi melibatkan banyak faktor yang tidak diketahui sehingga menyebabkan signal yang diterima di sistem komunikasi adalah random.
- meskipun tidak mungkin untuk memprediksi nilai yang sesungguhnya tetapi sangat memungkinkan untuk menggambarkan suatu signal dalam parameter-parameter statistika seperti daya rata-rata dan power spectral density

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Klasifikasi Signal

- Deterministic signal: No uncertainty with respect to the signal value at any time.
- Random signal: Some degree of uncertainty in signal values before it actually occurs.
  - Thermal noise in electronic circuits due to the random movement of electrons
  - Reflection of radio waves from different layers of ionosphere

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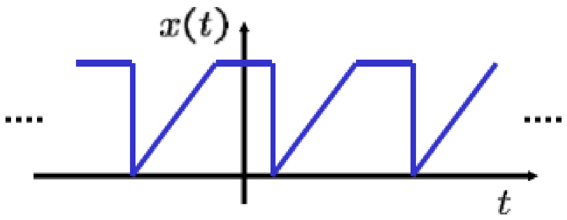
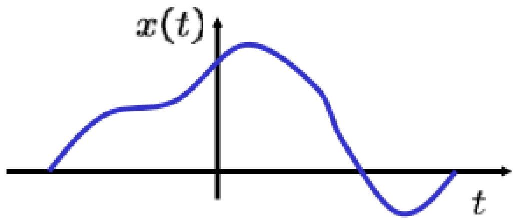
NOISE DALAM SISTEM KOMUNIKASI

Klasifikasi Signal

- Periodic and non-periodic signals

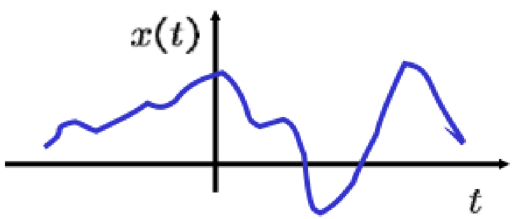


A periodic signal

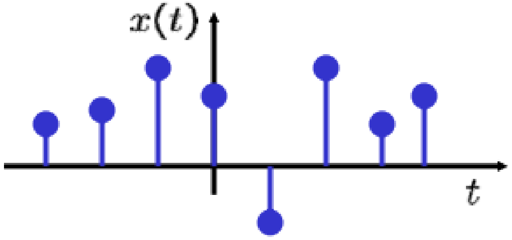


A non-periodic signal

- Analog and discrete signals



Analog signals



A discrete signal

NOISE DALAM SISTEM KOMUNIKASI

Power Vs Energi

- signal dapat direpresentasikan sebagai tegangan atau arus dengan daya sesaat pada resistor R didefinisikan sebagai :

$$P(t) = \frac{V^2(t)}{R}$$

$$P(t) = I^2(t)R$$

- Dalam sistem komunikasi, daya biasanya dinormalisasi pada R=1 Ω

$$P(t) = V^2(t) = I^2(t) = x^2(t)$$

- Performansi dari sitem komunikasi tergantung dari energi dari signal yang diterima. semakin tinggi energi akan semakin reliable (eror makin kecil)

$$E = \int_{-T/2}^{T/2} x^2(t)dt$$

- Daya rata-rata yang diterima :

$$P_{av} = \frac{1}{T}E = \frac{1}{T}\int_{-T/2}^{T/2} x^2(t)dt$$

NOISE DALAM SISTEM KOMUNIKASI

Energy signal Vs Power Signal

Energy and power signals

Finite energy but zero average power

- A signal is an energy signal if, and only if, it has nonzero but finite energy for all time: $(0 < E_x < \infty)$

$$E_x = \lim_{T\to\infty} \int_{T/2}^{T/2} |x(t)|^2 dt = \int_{-\infty}^{\infty} |x(t)|^2 dt$$

- A signal is a power signal if, and only if, it has finite but nonzero power for all time: $(0 < P_x < \infty)$

$$P_x = \lim_{T\to\infty} \frac{1}{T} \int_{T/2}^{T/2} |x(t)|^2 dt$$

finite average power but infinite energy

- General rule: Periodic and random signals are power signals. Signals that are both deterministic and non-periodic are energy signals.

NOISE DALAM SISTEM KOMUNIKASI

Energy Spectral Density (ESD) vs Power Spectral Density (PSD)

Spectral Density suatu signal memberikan informasi distribusi dari energi signal atau power pada domain frequency

Untuk Energy Signal

$$E = \int_{-\infty}^{\infty} x^2(t)dt = \int_{-\infty}^{\infty} |X(f)|^2 df$$

$|\mathbf{X}(f)|^2 \rightarrow$ **Energy Spectral Density**

Transformasi Fourier/Deret Fourier

$\mathbf{x}(t)$ $\quad f(t) \overset{\mathcal{F}}{\longleftrightarrow} F(j\omega) \quad$ $\mathbf{X}(f)$

Untuk Power Signal

$$P_{av} = \frac{1}{T}E = \frac{1}{T}\int_{-T/2}^{T/2} x^2(t)dt = \sum_{-\infty}^{\infty} |C_n|^2$$

Power Spectral Density

$$G_x(f) = \sum_{-\infty}^{\infty} |C_n|^2 \delta(f - nf_0)$$

Transformasi Fourier/Deret Fourier

$\mathbf{x}(t)$ $\quad f(t) \overset{\mathcal{F}}{\longleftrightarrow} F(j\omega) \quad$ $\{C_n\}$

$$f_0 = \frac{1}{T_0}$$

NOISE DALAM SISTEM KOMUNIKASI

Autocorrelation

Autocorrelation bisa didefinisikan kesesuaian dari suatu signal dengan signal tadi yang telah didelay

Untuk Energy Signal

$$R_x(\tau) = \int_{-\infty}^{\infty} x(t)x(t+\tau)\,dt \qquad \text{for } -\infty < \tau < \infty$$

Fungsi Autocorrelation $\boldsymbol{R_x(\tau)}$ menggambarkan seberapa dekat signal tersebut bersesuaian dengan signal tadi yang telah tergeser sejauh $\boldsymbol{\tau}$ unit waktu

Properties :

1.	$R_x(\tau) = R_x(-\tau)$	symmetrical in τ about zero
2.	$R_x(\tau) \le R_x(0)$ for all τ	maximum value occurs at the origin
3.	$R_x(\tau) \leftrightarrow \psi_x(f)$	autocorrelation and ESD form a Fourier transform pair, as designated by the double-headed arrows
4.	$R_x(0) = \int_{-\infty}^{\infty} x^2(t)\,dt$	value at the origin is equal to the energy of the signal

NOISE DALAM SISTEM KOMUNIKASI

Autocorrelation

Autocorrelation bisa didefinisikan kesesuaian dari suatu signal dengan signal tadi yang telah didelay

Untuk Power Signal

$$R_x(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{T/2} x(t) x^*(t-\tau) dt$$

- For a periodic signal:

$$R_x(\tau) = \frac{1}{T_0} \int_{-T_0/2}^{T_0/2} x(t) x^*(t-\tau) dt$$

Properties :

1. $R_x(\tau) = R_x(-\tau)$ — symmetrical in τ about zero
2. $R_x(\tau) \le R_x(0)$ for all τ — maximum value occurs at the origin
3. $R_x(\tau) \leftrightarrow G_x(f)$ — autocorrelation and PSD form a Fourier transform pair
4. $R_x(0) = \frac{1}{T_0} \int_{-T_0/2}^{T_0/2} x^2(t)\, dt$ — value at the origin is equal to the average power of the signal

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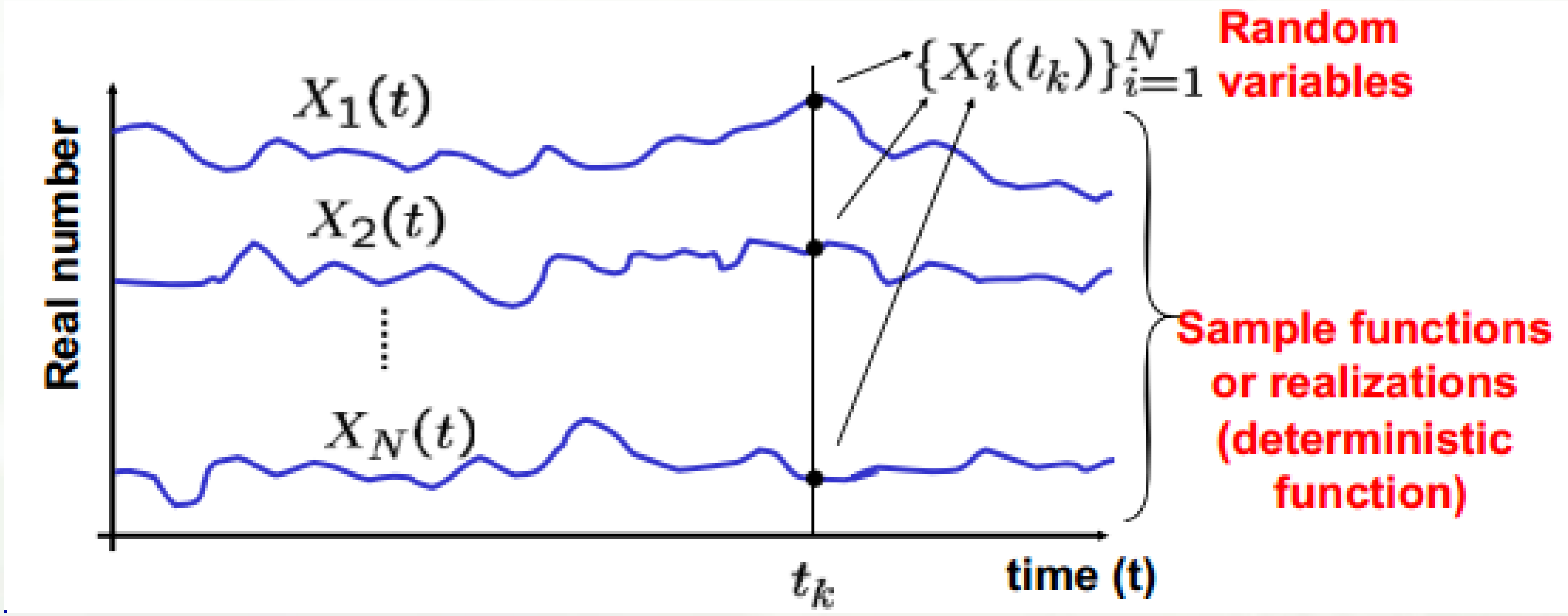
NOISE DALAM SISTEM KOMUNIKASI

Random Process

- *A random process* is a collection of time functions, or signals, corresponding to various outcomes of a *random experiment*. For each outcome there exists a deterministic function, which is called *a sample function or a realization*.



NOISE DALAM SISTEM KOMUNIKASI

Random Variable

Distribution Function / Cummulative Distribution Function (CDF)

$$F_X(x) = P(X \le x)$$

$P(X \le x)$ menunjukkan peluang nilai yang diperoleh dari random variable X kurang dari sama dengan nilai sesungguhnya x

Properties :

1. $0 \le F_X(x) \le 1$
2. $F_X(x_1) \le F_X(x_2)$ if $x_1 \le x_2$
3. $F_X(-\infty) = 0$
4. $F_X(+\infty) = 1$

Joint CDF

$$F(x, y) = \mathrm{P}(X \le x, Y \le y),$$

Probability Density Function (PDF)

$$p_X(x) = \frac{dF_X(x)}{dx}$$

Properties :

1. $p_X(x) \ge 0.$
2. $\int_{-\infty}^{\infty} p_X(x)\, dx = F_X(+\infty) - F_X(-\infty) = 1.$

$$\begin{aligned} P(x_1 \le X \le x_2) &= P(X \le x_2) - P(X \le x_1) \\ &= F_X(x_2) - F_X(x_1) \\ &= \int_{x_1}^{x_2} p_X(x)\, dx \end{aligned}$$

$P(X_1 \le x \le X_2)$ menunjukkan Peluang Suatu random variable X bernilai pada rentang x1 dan x2 sama dengan total pdf pada batas x1 dan x2

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Random Variable

Mean (Rata-rata)

Mean

$E\{\cdot\}$ → disebut Expected Value operator

$$m_X = \mathbf{E}\{X\} = \int_{-\infty}^{\infty} x p_X(x)\, dx$$

$$\bar{x} = \frac{\sum x}{n} = \frac{x_1 + x_2 + \ldots + x_n}{n}$$

$$\mathbf{E}\{X^2\} = \int_{-\infty}^{\infty} x^2 p_X(x)\, dx$$

Mean Square Value

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Random Variable

Variansi

Variansi

$$\mathrm{var}(X) = \mathbf{E}\{X - m_X)^2\} = \int_{-\infty}^{\infty} (x - m_X)^2 p_X(x)\, dx$$

$$\begin{aligned}\sigma_X^2 &= \mathbf{E}\{X^2 - 2m_X X + m_X^2\} \\ &= \mathbf{E}\{X^2\} - 2m_X \mathbf{E}\{X\} + m_X^2 \\ &= \mathbf{E}\{X^2\} - m_X^2\end{aligned}$$

Variansi merupakan ukuran seberapa random (randomness) dari suatu random variabel X

σ_X → disebut Standard Deviasi

$$\sigma = \sqrt{\frac{d_1^2 + d_2^2 + d_3^2 + \ldots + d_n^2}{n-1}}$$

$$d = x - \bar{x}$$

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Random Sequences or Random Processes

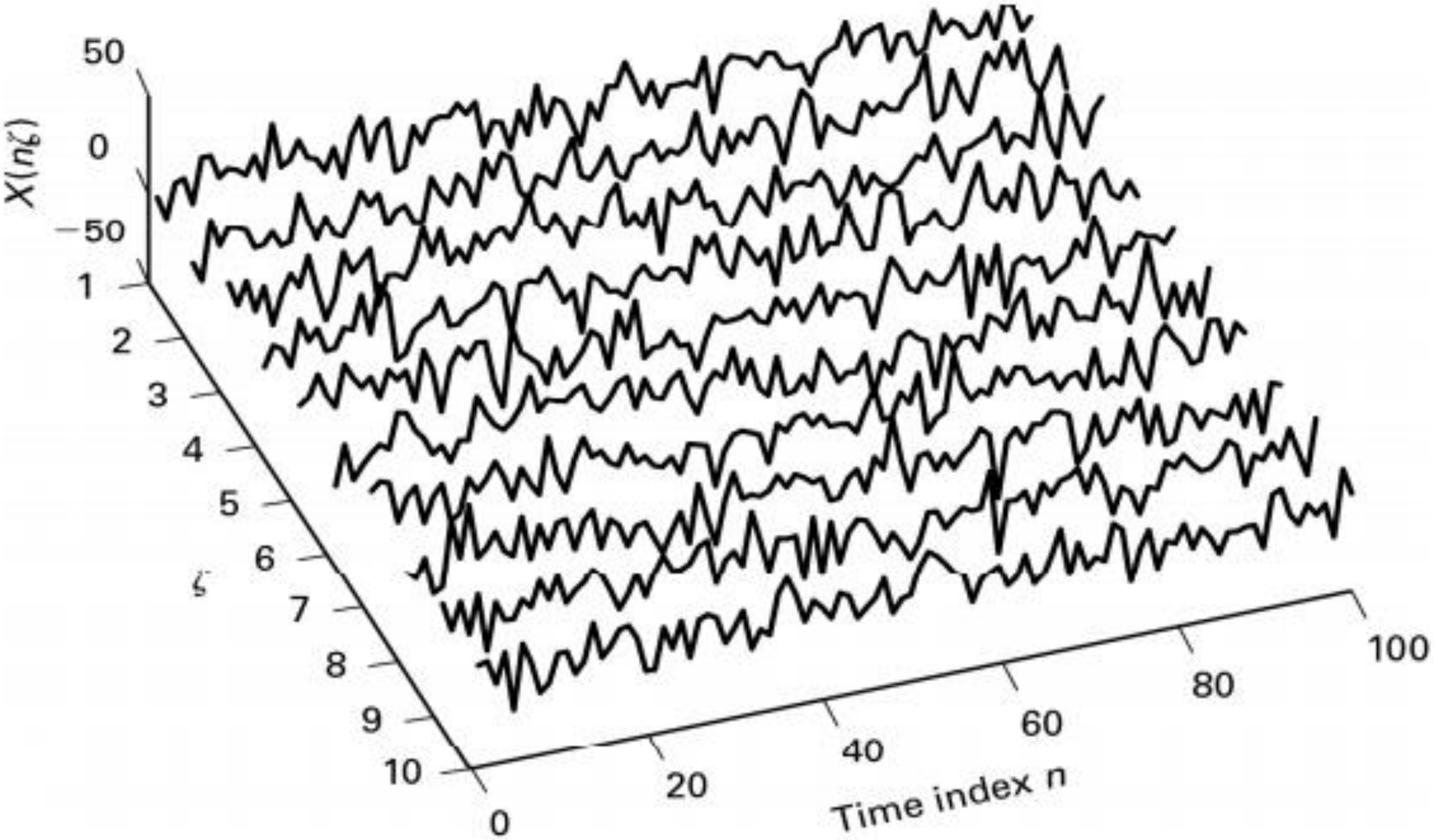

Illustration of the concept of *random sequence* $X(n, \zeta)$ where the ζ domain (i.e., the sample space Ω) consists of just 10 values. (Samples connected for plot.)

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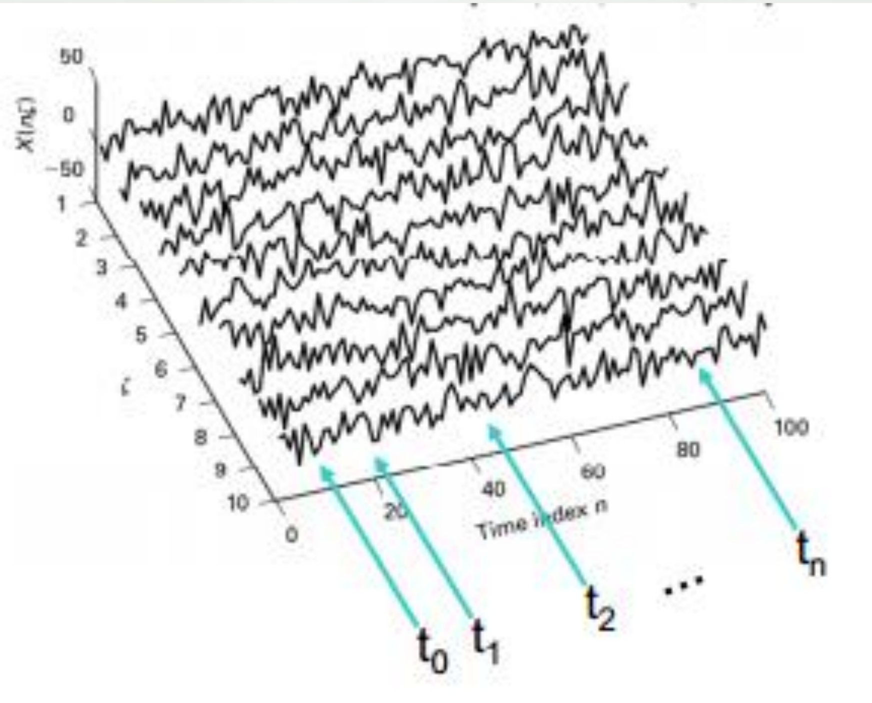
Random Sequences or Random Processes



Fungsi **autocorrelasi** adalah fungsi yang mengukur tingkat dimana 2 sample waktu pada random process yang sama saling berhubungan

Mean of Random Process

$$\mathbf{E}\{X(t_k)\} = \int_{-\infty}^{\infty} x p_{X_k}(x)\, dx = m_X(t_k)$$

Dimana $X(t_k)$ adalah random variable yang didapat melalui pemgamatan random process pada waktu t_k

Autocorrelation of Random Process

$$R_X(t_1, t_2) = \mathbf{E}\{X(t_1)X(t_2)\}$$

Dimana $X(t_1) dan\ X(t_2)$ adalah random variable yang didapat melalui pemgamatan random process pada waktu t_1 dan t_2

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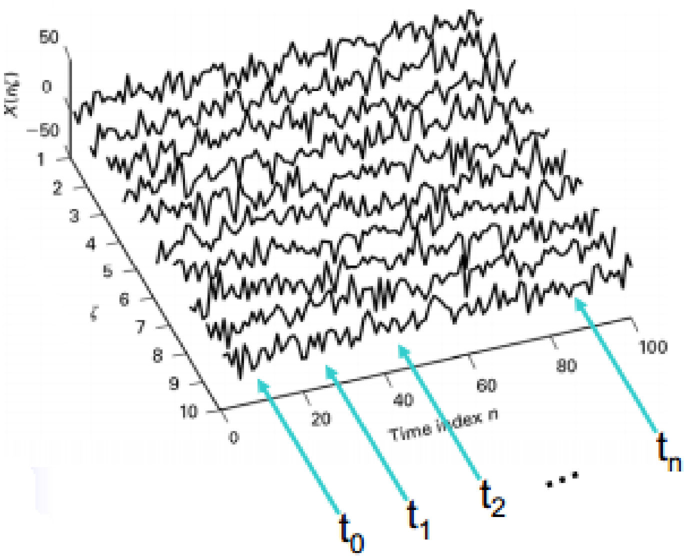
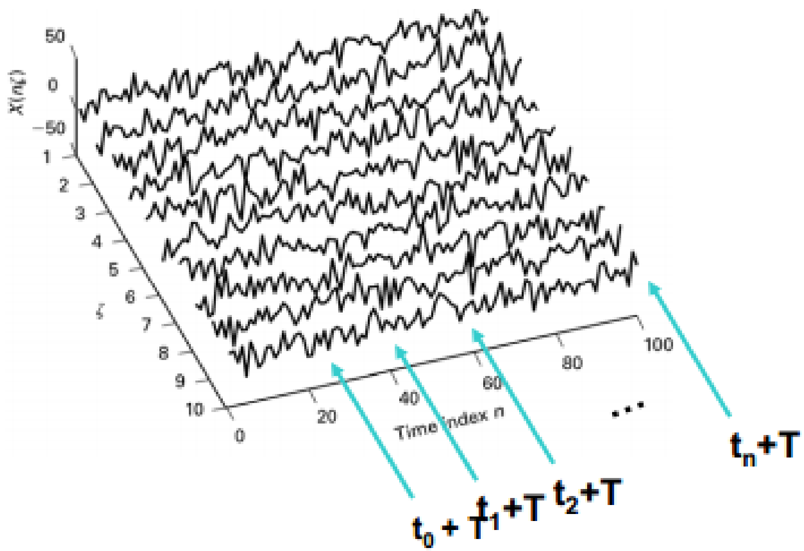
Strict-Sense-Stationarity

If time-shifts (any value *T*) do not affect its joint CDF

$$p(X(t_0) \le x_0, X(t_1) \le x_1, \ldots, X(t_n) \le x_n) =$$
$$p(X(t_0+T) \le x_0, X(t_1+T) \le x_1, \ldots, X(t_n+T) \le x_n).$$





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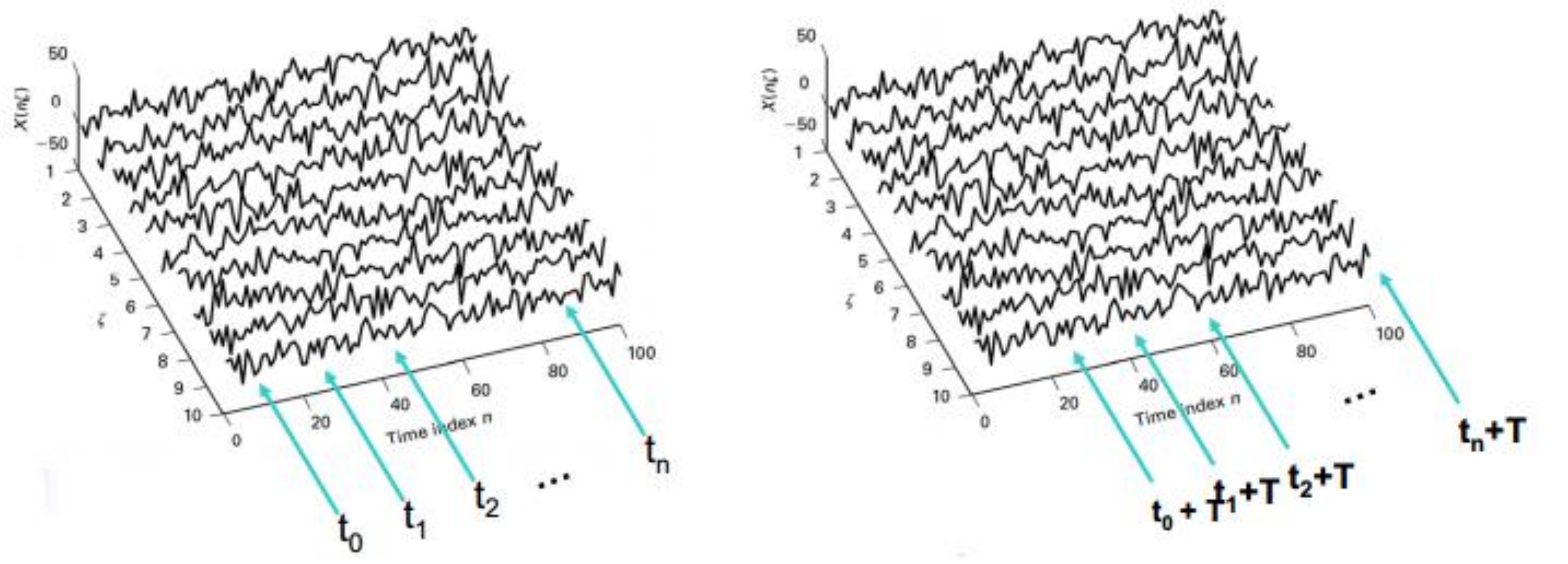
Wide-Sense-Stationary (WSS)



Random Process dikatakan WSS jika **<u>Mean dan fungsi Autokorelasi</u>** nya tidak berubah dengan bergesernya waktu

$$\mathbf{E}\{X(t)\} = m_X = \text{a constant}$$

$$R_X(t_1, t_2) = R_X(t_1 - t_2)$$

Biasanya dalam sistem komunikasi, Signal informasi yang random dan noise dikategorikan dalam proses random WSS

NOISE DALAM SISTEM KOMUNIKASI

Ergodicity

Time averages = Ensemble averages

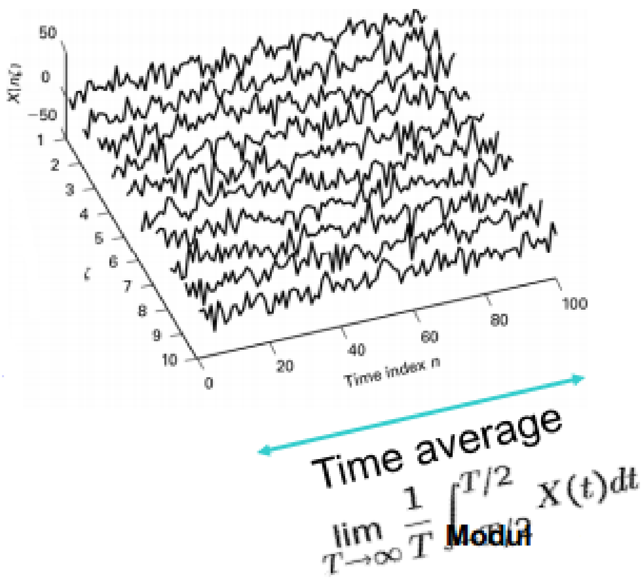
[i.e. "***ensemble***" averages like mean/autocorrelation can be computed as "***time-averages***" over a single realization of the random process]

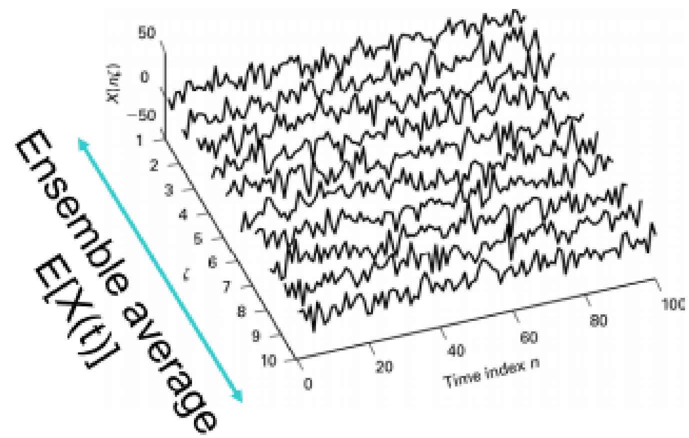
- A random process: ergodic in *mean* and *autocorrelation* (like w.s.s.) if

$$m_X = \lim_{T\to\infty} \frac{1}{T}\int_{-T/2}^{T/2} X(t)dt$$

and

$$R_X(\tau) = \lim_{T\to\infty} \frac{1}{T}\int_{-T/2}^{T/2} X(t)X^*(t-\tau)dt$$





NOISE DALAM SISTEM KOMUNIKASI

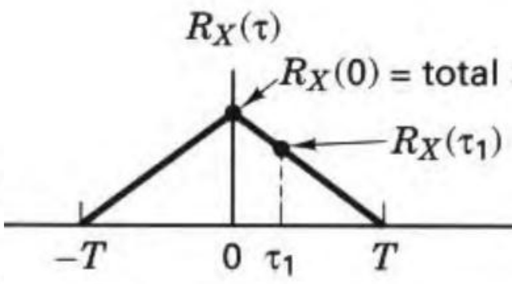
Autocorrelation of WSS random process

$$R_X(\tau) = \mathbf{E}\{X(t)X(t+\tau)\} \qquad \text{for } -\infty < \tau < \infty$$

Autocorrelation hanya fungsi dari *time difference* $\tau = t_1 - t_2$

Properties :

1.	$R_X(\tau) = R_X(-\tau)$	symmetrical in τ about zero
2.	$R_X(\tau) \le R_X(0)$ for all τ	maximum value occurs at the origin
3.	$R_X(\tau) \leftrightarrow G_X(f)$	autocorrelation and power spectral density form a Fourier transform pair
4.	$R_X(0) = \mathbf{E}\{X^2(t)\}$	value at the origin is equal to the average power of the signal



Misal grafik autocorelasi disamping dengan mean = 0 --> jika nilai Autokorelasi berubah dengan lamban ketika τ meningkat (dari 0 ke suatu nilai tertentu), hal ini mengindikasikan bahwa nilai sample dari X(t) yang diamati pada t = t1 dan t = t1+ τ nilainya hampir sama.
sedangkan jika nilai autokorelasi berkurang dengan cepat ketika t meningkat, hal tersebut menunjukkan perubahan yang cepat pada sample X(t)

NOISE DALAM SISTEM KOMUNIKASI

PSD of random process

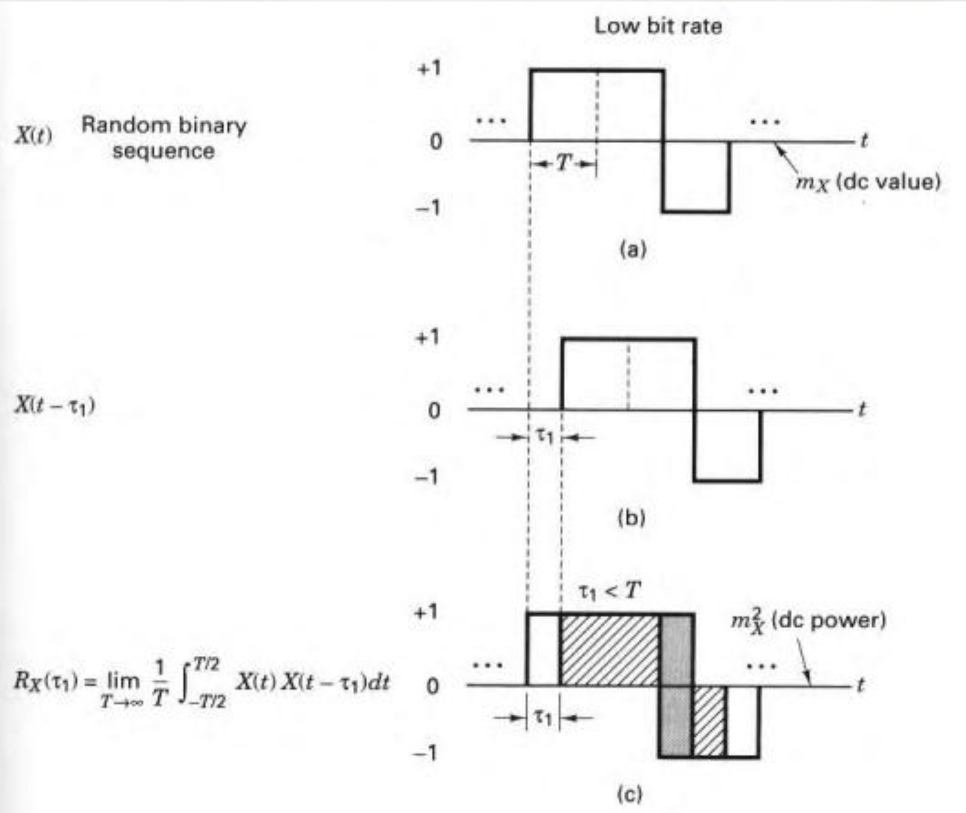
Power spectral density (PSD): $G_X(f) = \mathcal{F}[R_X(\tau)]$

Properties :

1. $G_X(f) \geq 0$	and is always real valued
2. $G_X(f) = G_X(-f)$	for $X(t)$ real-valued
3. $G_X(f) \leftrightarrow R_X(\tau)$	PSD and autocorrelation form a Fourier transform pair
4. $P_X = \int_{-\infty}^{\infty} G_X(f)\, df$	relationship between average normalized power and PSD

NOISE DALAM SISTEM KOMUNIKASI

Contoh#1



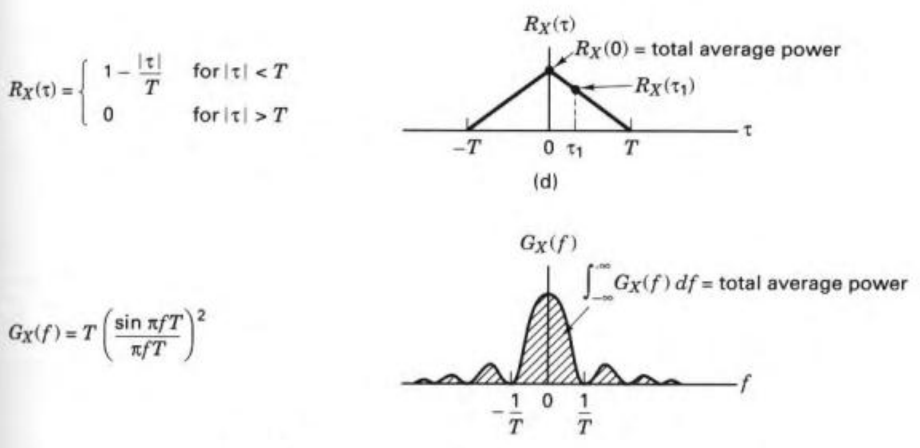
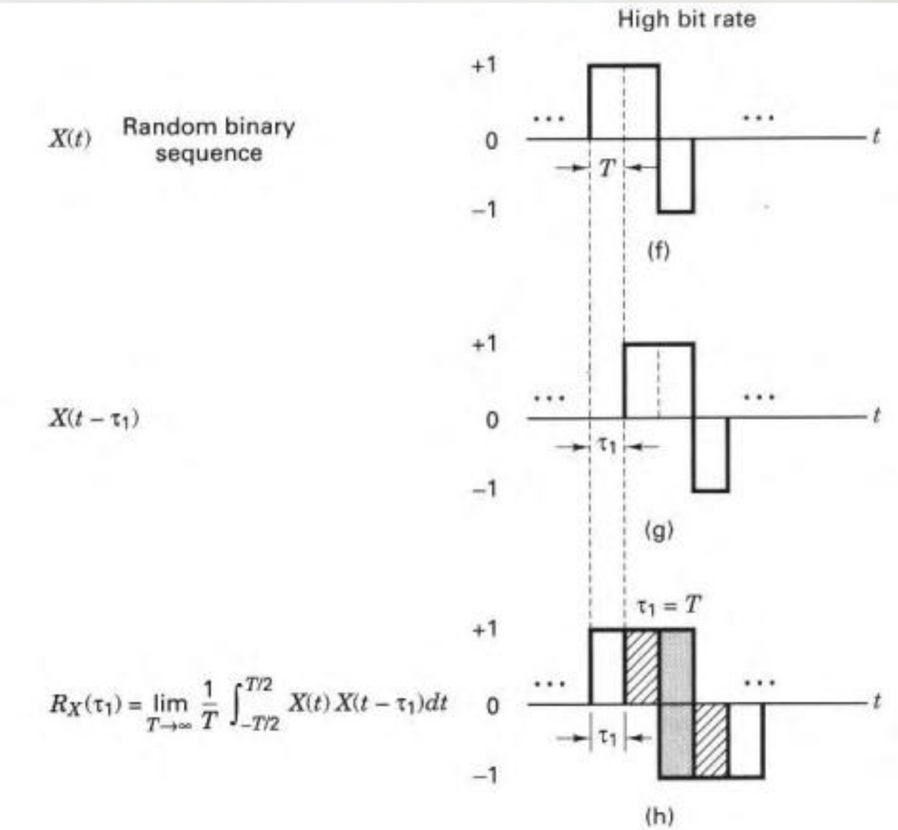
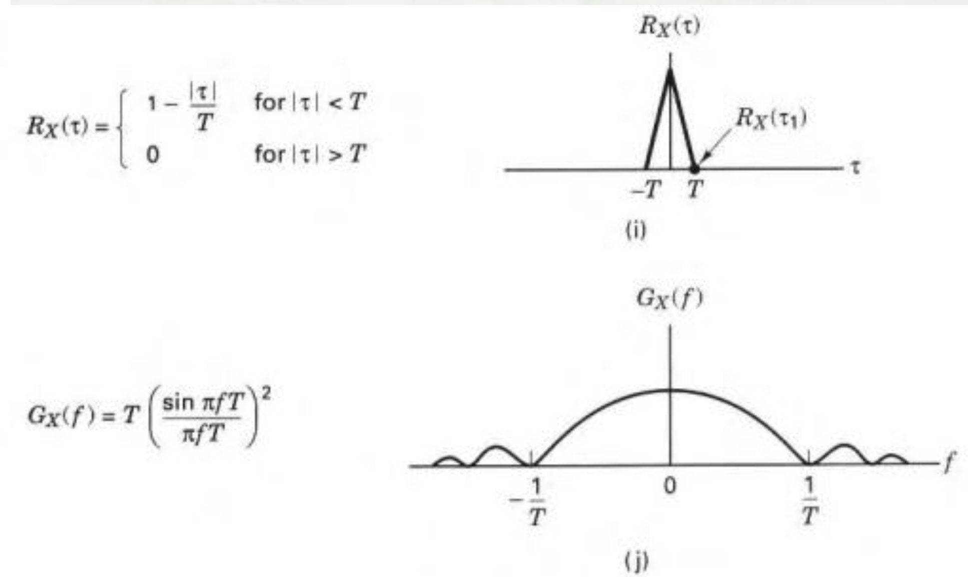


Figure 1.6 Autocorrelation and power spectral density.

NOISE DALAM SISTEM KOMUNIKASI

Contoh#2





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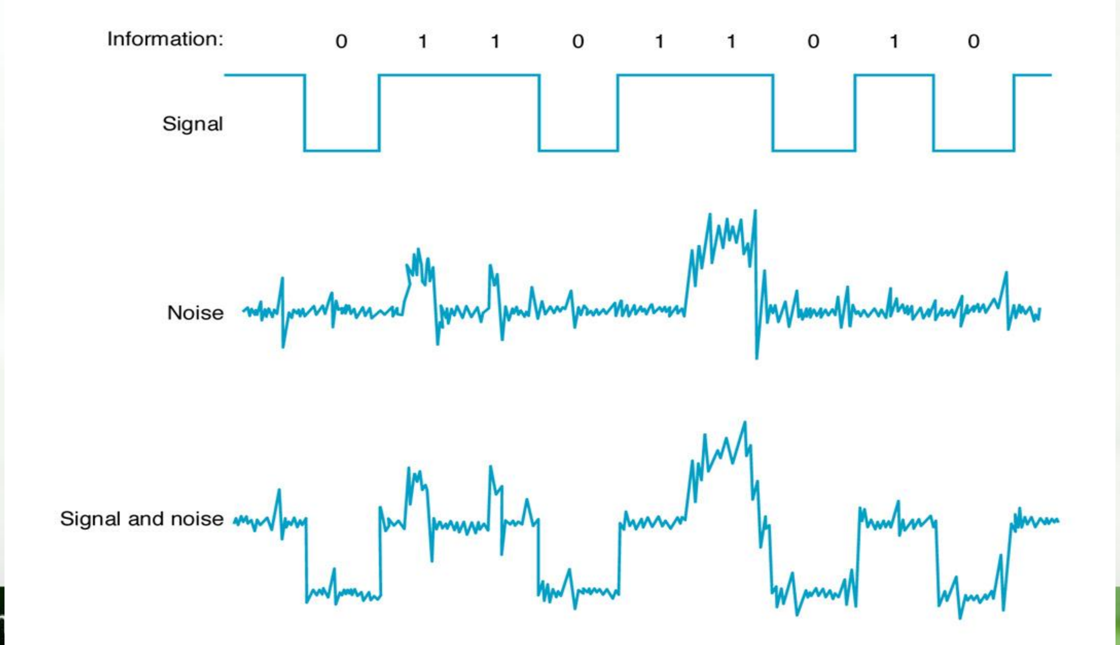
NOISE DALAM SISTEM KOMUNIKASI

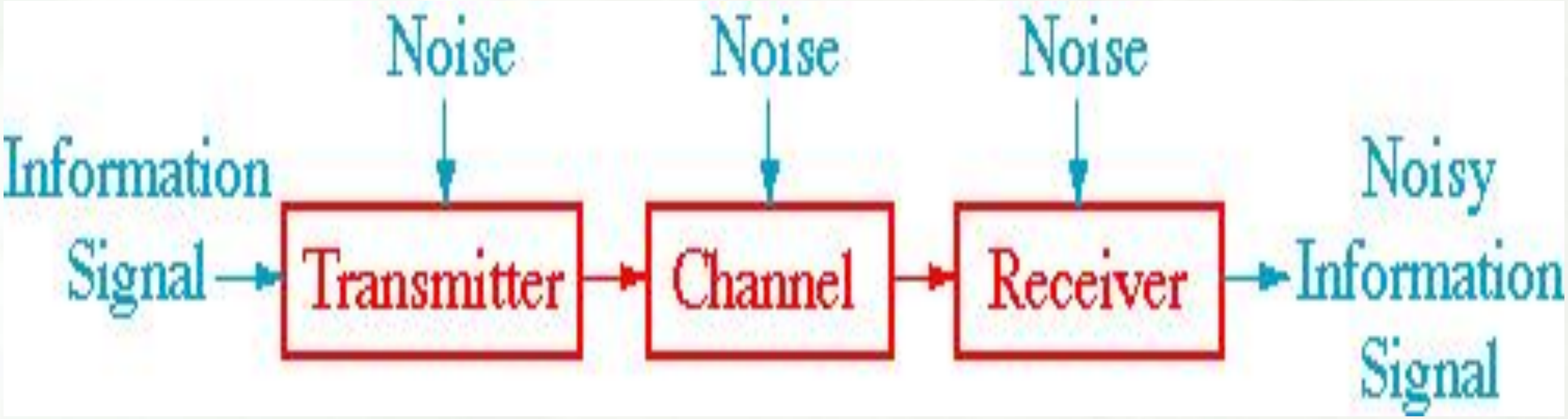
What is Noise ?

- Undesired random variations that interface with the desired signal and inhibit communication.
- Refers to random and unpredictable electrical signals produced by natural process.
- Superimposed on information bearing signal, the message partially corrupted or totally erased.
- Can be reduced by filtering but can't totally eliminated.



NOISE DALAM SISTEM KOMUNIKASI

Noise Source



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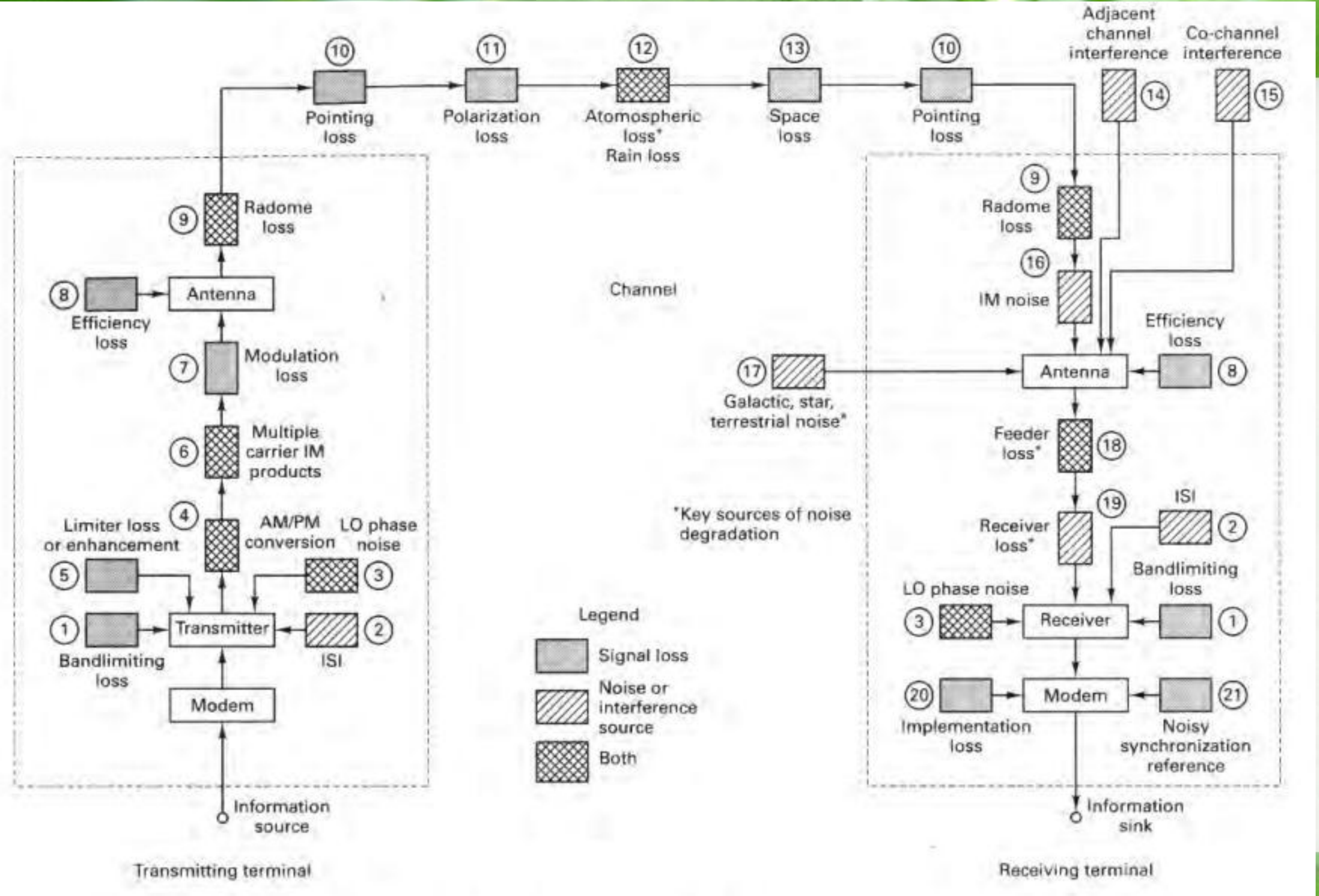

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NOISE DALAM SISTEM KOMUNIKASI

Model Sinyal Terima

- Noise / Derau sebagai unsur pengganggu yang hampir selalu terlibat dalam Siskom memerlukan pemodelan yang representative untuk memudahkan keperluan analisis bagi penentuan kualitas ataupun kinerja Siskom.
- Klasifikasi noise berdasarkan sumbernya :
  - *Dari luar system*
  - *Dari dalam system (umumnya paling dominan)*
- Klasifikasi noise berdasarkan “equivalensi” dengan suhu:
  - *Thermal-Noise*
  - *Non Thermal-Noise*
- Klasifikasi noise berdasarkan model matematis/statistic :
  - *Gaussian Noise*
  - *White noise*
  - *White Gaussian Noise*

NOISE DALAM SISTEM KOMUNIKASI

Type of Noise

External

1- Manmade (artificial): These could be eliminated via better design
- Machinery
- Switches
- Certain types of lamps

2- Natural
- Atmospheric noise: causing crackles on our radios
- Cosmic noise (space noise):

Internal

Noise in Electrical Components

- Thermal noise: Random free electron movement in a conductor (resistor) due to thermal agitation
- Shot noise: Due to random variation in current superimposed upon the DC value. It is due to variation in arrival time of charge carriers in active devices.
- Flicker noise: Observed at very low frequencies, and is thought to be due to fluctuation in the conductivity of semiconductor devices.

NOISE DALAM SISTEM KOMUNIKASI

External Noise

- Human-Made Noise: Noise produced by spark-producing system such as engine ignition systems, fluorescent lights, commutators in electric motors, and power lines.
- Atmospheric Noise: Noise caused by naturally occurring disturbances in the earth's atmosphere.
- Space Noise: Noise produced outside the earth's atmosphere.

NOISE DALAM SISTEM KOMUNIKASI

Internal Noise

- Thermal Noise: Noise caused by thermal interaction between free electrons and vibrating ions in a conductor.
- Shot Noise: Noise introduced by carriers in the pn junctions of semiconductors
- Excess Noise: Noise occurring at frequencies below 1khz, varying in amplitude inversely proportional to the frequence
- Transit-Time Noise: Noise produced in semiconductors when the transit time of the carriers crossing a junction is close to the signal’s period.

NOISE DALAM SISTEM KOMUNIKASI

Thermal Noise

- Thermal Noise: Noise caused by thermal interaction between free electrons and vibrating ions in a conductor.
- Johnson Noise: Another name for thermal noise, first studied by J. B. Johnson in 1928.
- White Noise: Another name for thermal noise because its frequency content is uniform across the spectrum.

NOISE DALAM SISTEM KOMUNIKASI

Thermal Noise

- $P_n = kT\Delta f$
- k = Boltzmann's constant (1.38×10^{-23} J/K)
- T = Resistor temperature in kelvin (K)
- Δf = Frequency bandwidth of the system
- The rms noise voltage en has a maximum at

$$e_n = \sqrt{4kT\Delta fR}$$

NOISE DALAM SISTEM KOMUNIKASI

Effect of Noise

- One of the main limiting factor in obtaining high performance of a communication system.
- Decrease the quality of the receiving signal.
- It sets the lower limit for the detectable signals.
- It sets the upper limit for system gains.
- For Digital systems (it limits the receiver's ability to make correct symbol decision and thereby limit the rate of information transmission)

NOISE DALAM SISTEM KOMUNIKASI

Noise Effect on Analog and Digital Systems

- Analog system
  - Any amount of noise will create distortion at the output
- Digital system
  - A relatively small amount of noise will cause no harm at all
  - Too much noise will make decoding of received signal impossible
- Both - Goal is to limit effects of noise to a manageable/satisfactory amount

NOISE DALAM SISTEM KOMUNIKASI

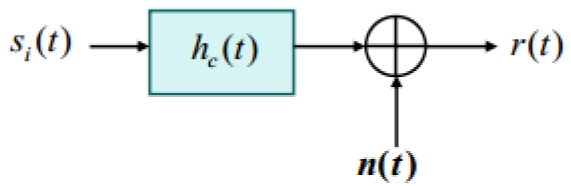
OUTLINE

- ❑ PENDAHULUAN
- ❑ RANDOM PROCESS
- ❑ NOISE
- ❑ **AWGN**
- ❑ NOISE FIGURE DAN SISTEM NOISE

NOISE DALAM SISTEM KOMUNIKASI

Model Sinyal Terima

- Model the received signal

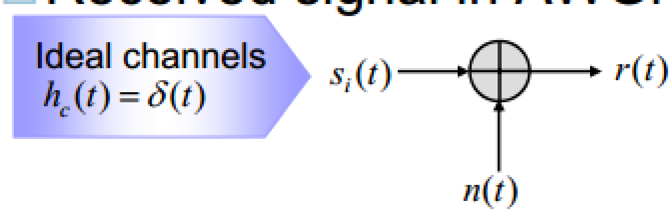


$$r(t) = s_i(t) * h_c(t) + n(t)$$

AWGN = Additive White Gausian Noise

- Simplify the Model

- Received signal in AWGN

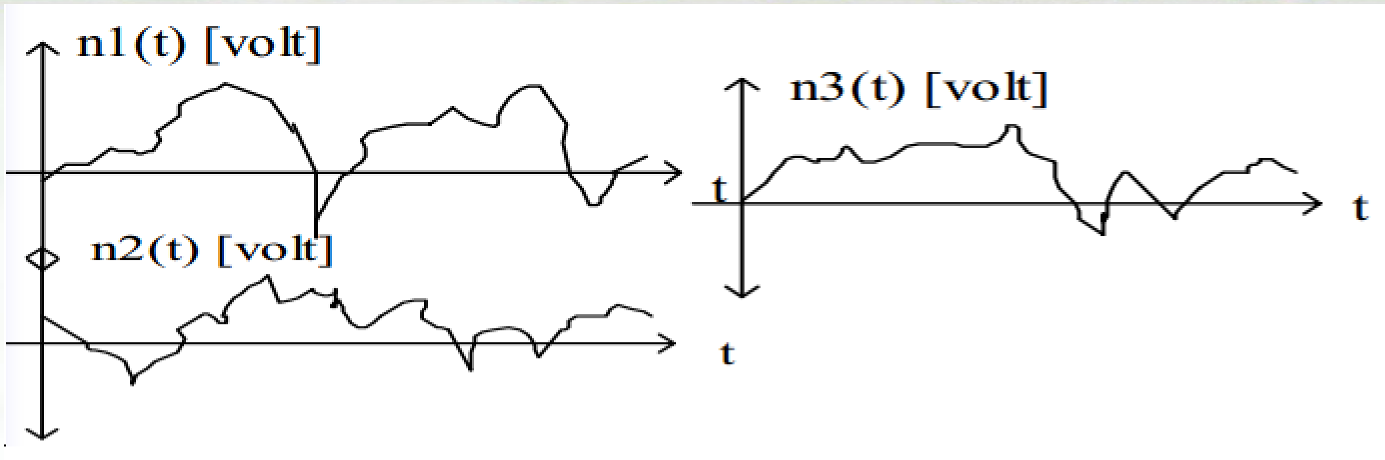


$$r(t) = s_i(t) + n(t)$$

AWGN

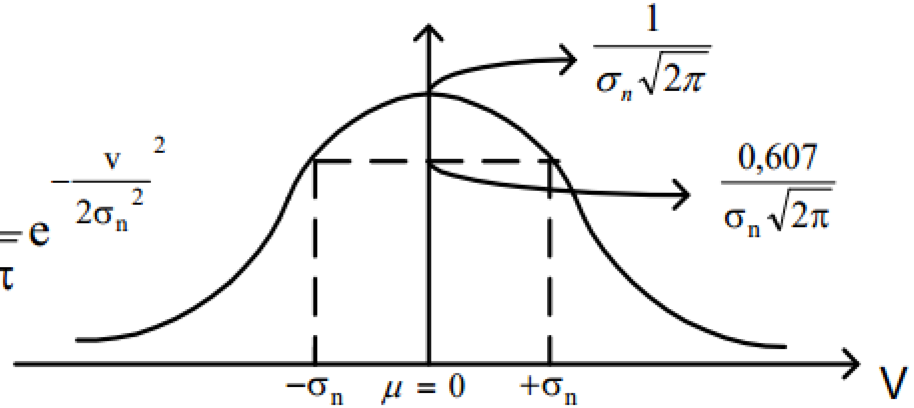
NOISE DALAM SISTEM KOMUNIKASI

Gaussian Noise



- Probability Density Function (PDF) of Gaussian Noise

$$f_n(v) = f_N(v) = \frac{1}{\sigma_n \sqrt{2\pi}} e^{-\frac{v^2}{2\sigma_n^2}}$$



NOISE DALAM SISTEM KOMUNIKASI

Gaussian Noise

- Dimana :

σ_n = standar deviasi, dan $\mu \equiv$ mean = 0

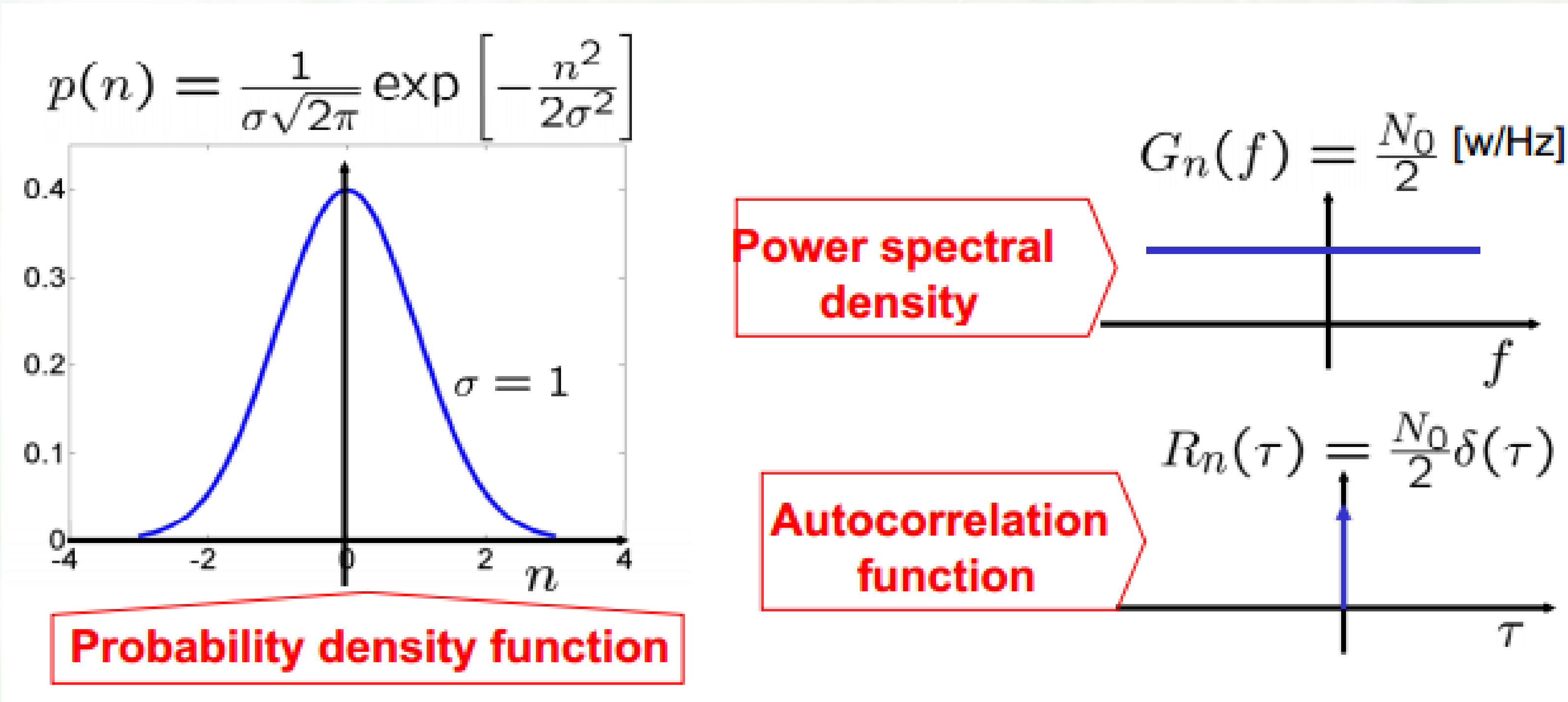
$$\int_{-\infty}^{\infty} f_n(v)dv = \int_{-\infty}^{\infty} f_N(v)dv = 1$$

$$\sigma_n = \sqrt{VAR[N(t)]}$$ $\equiv$akar daya rata-rata
= r.m.s/eff.

NOISE DALAM SISTEM KOMUNIKASI

White Noise

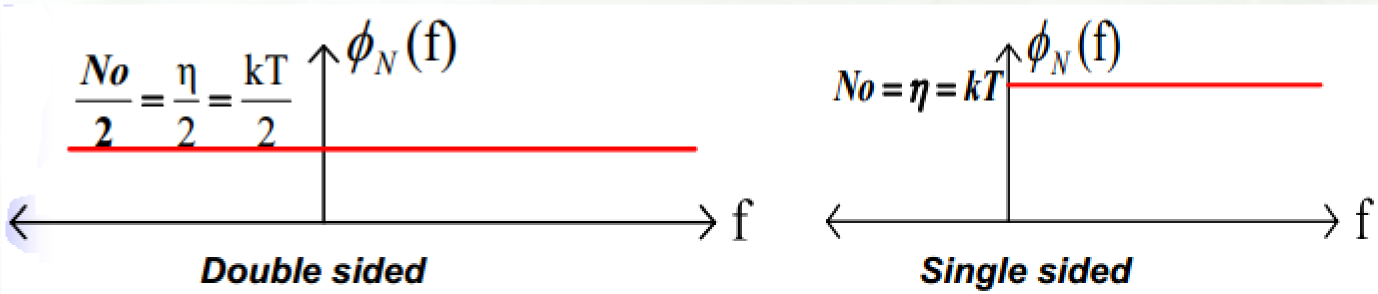
- Its PSD is flat, hence, it is called <u>white noise.</u>



NOISE DALAM SISTEM KOMUNIKASI

AWGN : Additive White Gaussian Noise

- Memiliki sifat gabungan antara Gaussian-noise dan white noise
- Berupa noise dalam/thermal noise :



$$k \equiv \text{konst. Boltzman} = 1{,}38.10^{-23}\, J/{}^\circ K$$

- Rapat daya noise mempunyai ekuivalensi dengan thermal. Sehingga secara praktis dapat juga noise dinyatakan dalam thermal (ekivalensinya).

NOISE DALAM SISTEM KOMUNIKASI

OUTLINE

- ❑ PENDAHULUAN
- ❑ RANDOM PROCESS
- ❑ NOISE
- ❑ AWGN
- ❑ **NOISE FIGURE DAN SISTEM NOISE**

NOISE DALAM SISTEM KOMUNIKASI

Performance of Communication Systems

Performance of Communications Systems Corrupted by Noise

<u>Digital</u>
Bit Error Rate (BER)

<u>Analog</u>
Output SNR

NOISE DALAM SISTEM KOMUNIKASI

Noise Remedies

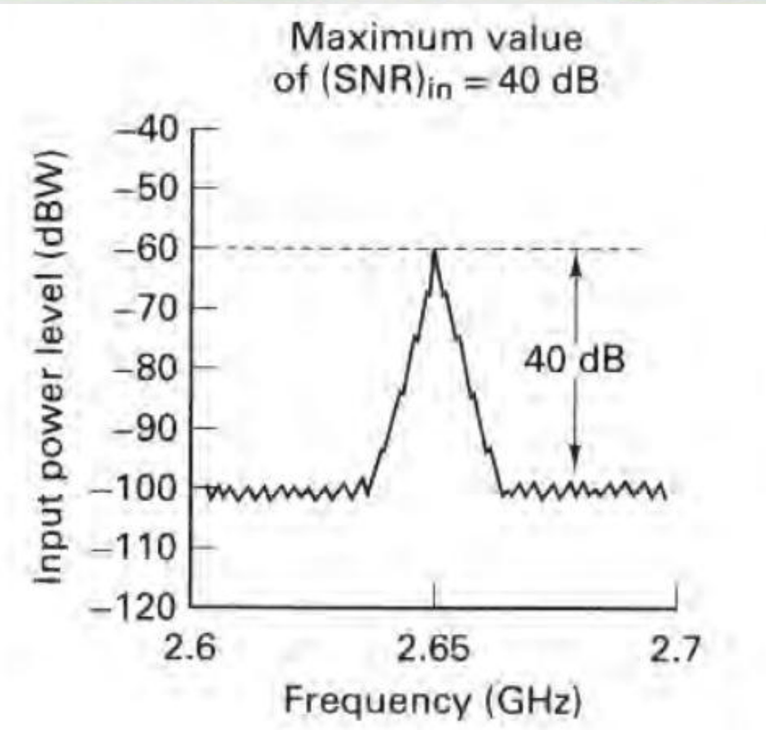
REDUCE BANDWIDTH

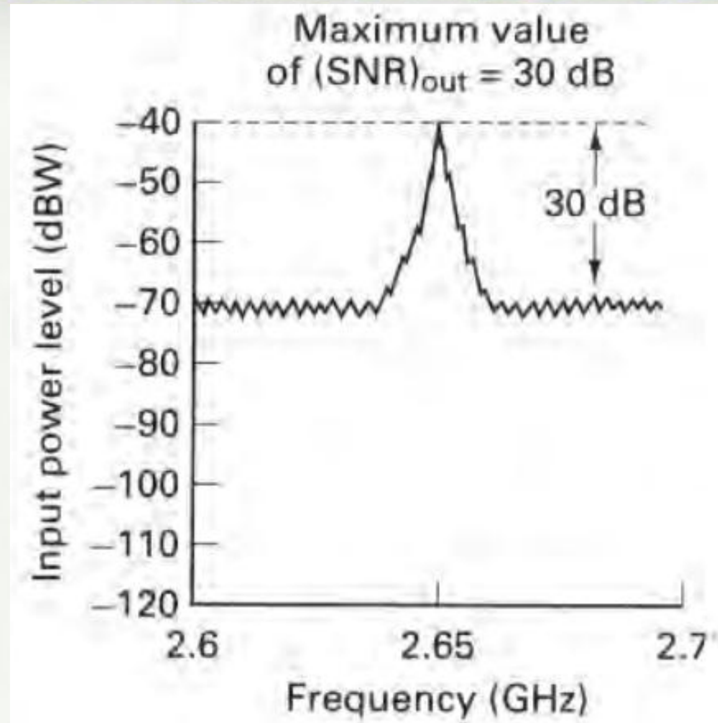
INCREASE TRANSMITTER'S POWER

LOW NOISE AMPLIFIERS

PENGUAT DAN SIMTEM PRADETEKSI

NOISE FIGURE



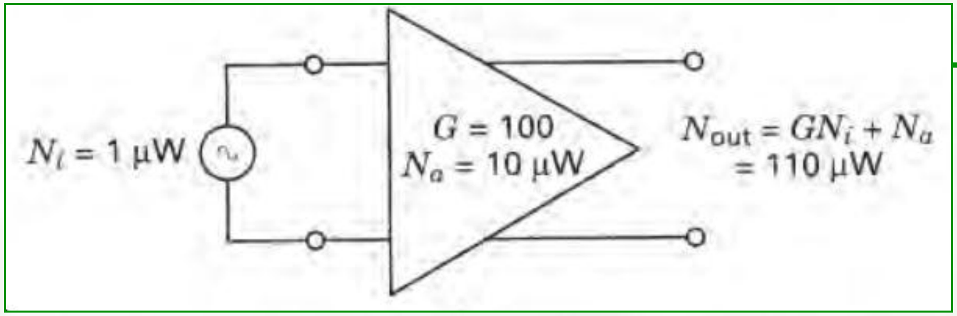


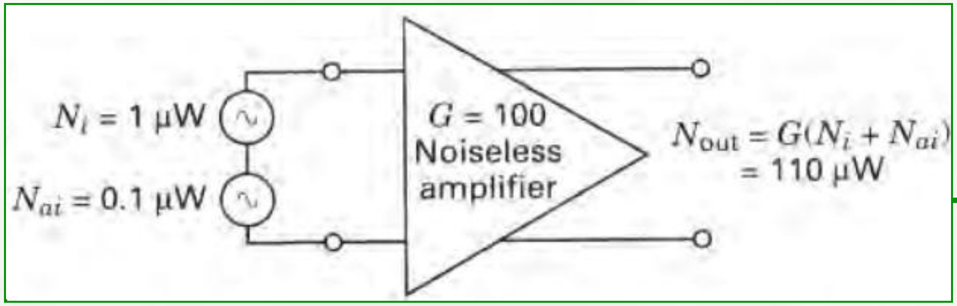
$$F = \frac{(SNR)_{in}}{(SNR)_{out}}$$

PENGUAT DAN SIMTEM PRADETEKSI

Hal yang perlu dievaluasi dalam sistem penguat

- ❑ Sinyal yang dikuatkan (sinyal dan noise)
- ❑ System penguat (dan noise internalnya)





$$F = \frac{(SNR)_{in}}{(SNR)_{out}} = \frac{S_i / N_i}{GS_i / G(N_i + N_{ai})}$$

$$F = \frac{N_i + N_{ai}}{N_i} = 1 + \frac{N_{ai}}{N_i}$$

Keterangan :

Si = Daya signal pada input amplifier
Ni = daya noise pada input amplifier
Nai = daya noise referensi pada input amplifier
Na = daya noise internal amplifier

PENGUAT DAN SIMTEM PRADETEKSI

Equivalent Noise Temperature

- **Te (Equivalent Noise Temperature)** is defined as the temperature at which a noisy resistor has to be maintained such that, by connecting the resistor to the input of a noiseless version of the system, it produce the same available noise power at the output of the system as that produced by all the sources of noise in the actual system

$$F = \frac{N_i + N_{ai}}{N_i} = 1 + \frac{N_{ai}}{N_i}$$

$$N_{ai} = (F-1)N_i$$
$$kT_e{}^\circ W = (F-1)kT_0{}^\circ W$$

$$T_e{}^\circ = (F-1)T_0{}^\circ$$
$$T_e{}^\circ = (F-1)290^\circ$$

Keterangan :
Ni = daya noise pada input amplifier
Nai = daya noise referensi pada input amplifier
k = Konstanta botzman k= 1,38.10^{-23} J/K
T_e=temperature efektif noise/equivalent Noise Temperatur
T_0 = temperatur noise referensi (kesepakatan 290^o)
W = Bandwidth Noise


THANK
YOU