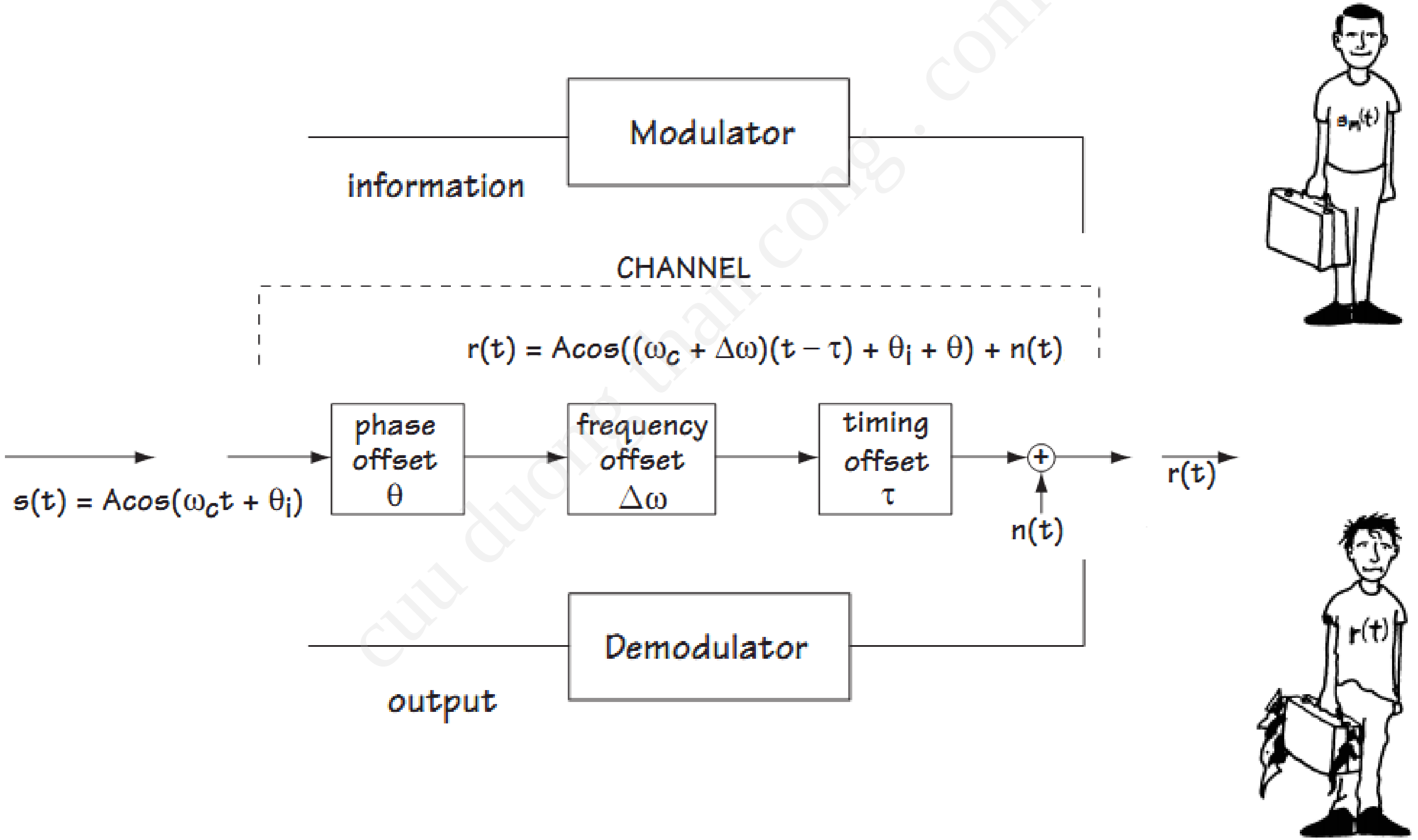
Chương 7: Nhiễu trong các hệ thống điều chế tương tự

7.1. Nhiễu băng dải

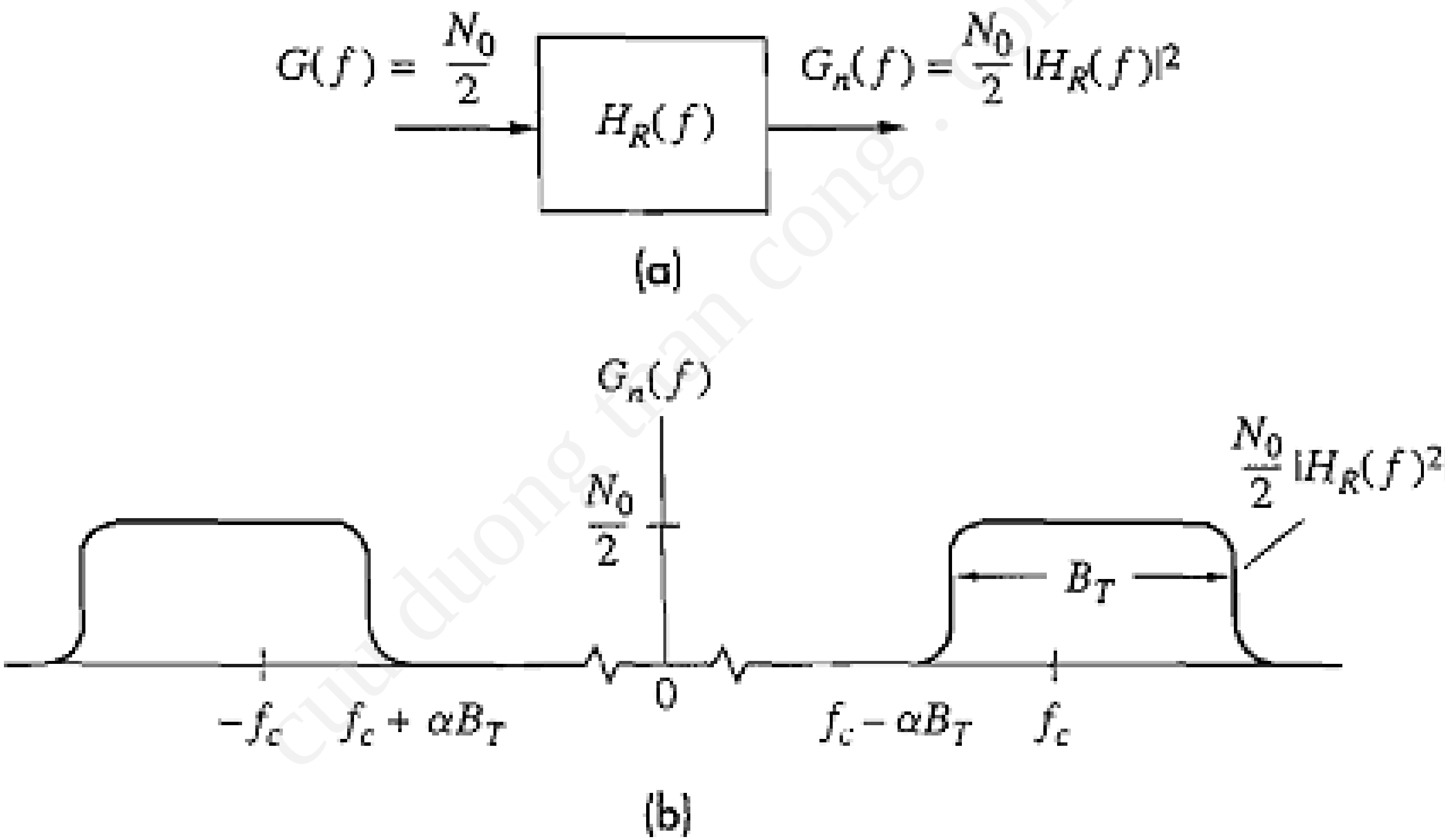
7.2. Nhiễu trong hệ thống điều chế sóng mang liên tục

7.3. Nhiễu trong các hệ thống điều chế góc

Vấn đề tín hiệu thu



7.1 Nhiễu băng dải



Bandpass filtered white noise. (*a*) Block diagram; (*b*) power spectrum.

Đặc tính nhiễu băng dải

$$n(t) = n_i(t)\cos\omega_c t - n_q(t)\sin\omega_c t = A_n(t)\cos[\omega_c t + \phi_n(t)]$$

$$\overline{n_i} = \overline{n_q} = 0 \qquad \overline{n_i(t)n_q(t)} = 0 \qquad A_n^2 = n_i^2 + n_q^2 \qquad \phi_n = \tan^{-1}\frac{n_q}{n_i}$$

$$\overline{n_i^2} = \overline{n_q^2} = \overline{n^2} = \sigma_N^2 = N_R \qquad n_i = A_n\cos\phi_n \qquad n_q = A_n\sin\phi_n$$

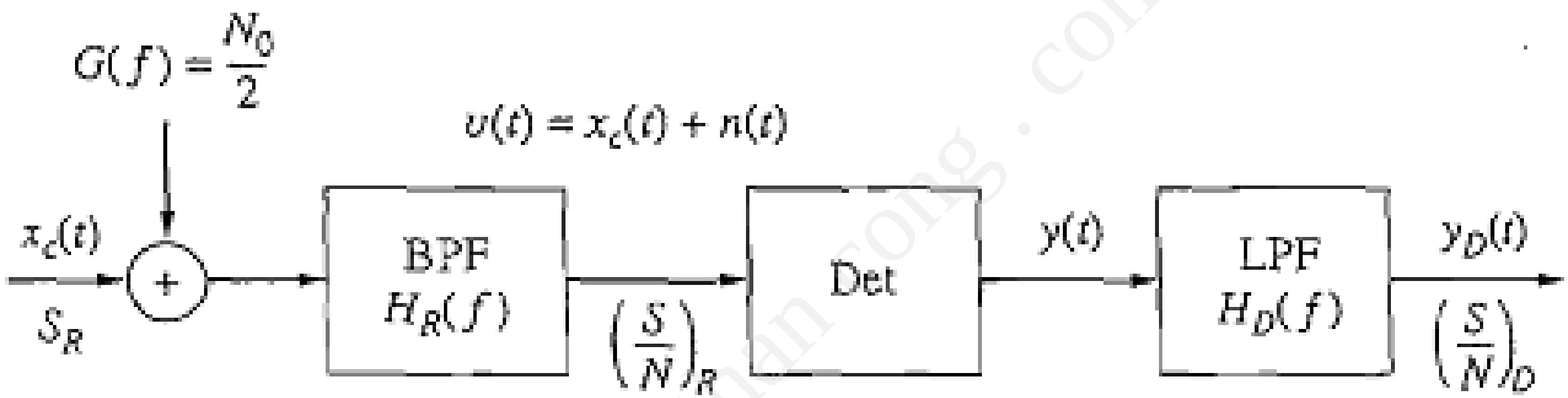
$$G_{n_i}(f) = G_{n_q}(f) = G_n(f+f_c)u(f+f_c) + G_n(f-f_c)[1-u(f-f_c)]$$

The envelope A_n has the Rayleigh distribution: $P(A_n > a) = e^{-a^2/2N_R}$

$$p_{A_n}(A_n) = \frac{A_n}{N_R}e^{-A_n^2/2N_R}u(A_n) \qquad \overline{A_n} = \sqrt{\pi N_R/2} \qquad \overline{A_n^2} = 2N_R$$

The phase ϕ_n has a uniform distribution over [0, 2π]

Mô hình bộ thu có giải điều chế



$$\left(\frac{S}{N}\right)_R = \frac{S_R}{N_R} = \frac{S_R}{N_0 B_T} = \frac{W}{B_T}\gamma \qquad \gamma \triangleq S_R/N_0W$$

$$v(t) = x_c(t) + n(t)$$
$$n(t) = n_i(t)\cos\omega_c t + n_q(t)\sin\omega_c t$$

$$\overline{x_c^2} = S_R$$
$$\overline{n^2} = \overline{n_i^2} = \overline{n_q^2} = N_R$$

7.2 SNR điều biên

- **Tách sóng đồng bộ**: chỉ cho ngõ ra thành phần cùng pha với tín hiệu sóng mang và triệt tiêu thành phần vuông pha với tín hiệu sóng mang .

- **Tách sóng đường bao**: chỉ cho ngõ ra thành phần đường bao dương (biên độ) của tín hiệu ngõ vào (thường có thêm chức năng loại bỏ thành phần DC trong tín hiệu ngõ ra).

Tách sóng đồng bộ cho DSB

$$x_c(t) = A_c\, x(t) \cos \omega_c t$$

$$v(t) = [A_c\, x(t) + n_i(t)] \cos \omega_c t - n_q(t) \sin \omega_c t$$

$$y(t) = v_i(t) = A_c\, x(t) + n_i(t)$$

$$y_D(t) = A_c x(t) + n_i(t)$$

$$G_{n_i}(f) \approx N_0 \Pi(f/2W)$$

$$N_D = \overline{n_i^{\,2}} \qquad S_D = A_c^{\,2}\,\overline{x^2} = A_c^{\,2} S_x \qquad S_R = \overline{x_c^{\,2}} = \frac{1}{2} A_c^{\,2} S_x$$

$$\left(\frac{S}{N}\right)_D = \frac{S_D}{N_D} = \frac{2S_R}{N_0 B_T} = 2\left(\frac{S}{N}\right)_R = \frac{S_R}{N_0 W} = \gamma$$

Tách sóng đồng bộ cho AM (100%)

$$x_c(t) = A_c[1 + x(t)]\cos\omega_c t$$

$$y_D(t) = y(t) = A_c x(t) + n_i(t)$$

$$S_D = A_c^2 S_x \qquad N_D = \overline{n_i^2} \qquad S_R = \frac{1}{2}A_c^2(1 + S_x)$$

$$\left(\frac{S}{N}\right)_D = \frac{2S_x}{1 + S_x}\left(\frac{S}{N}\right)_R = \frac{S_x}{1 + S_x}\gamma$$

Tách sóng đồng bộ cho SSB/VSB

$$x_c(t) = \frac{1}{2} A_c \left[x(t)\cos\omega_c t \mp \hat{x}(t)\sin\omega_c t\right]$$

$$y_D(t) = \tfrac{1}{2} A_c x(t) + n_i(t)$$

$$B_T = W, \quad S_R = 1/4 A_c^2 S_x \text{ and } S_D = 1/4 A_c^2 S_x = S_R$$

$$G_{n_i}(f) \approx \frac{N_0}{2} \Pi(f/2W) \qquad N_D = \overline{n_i^2} = N_0 W$$

$$\left(\frac{S}{N}\right)_D = \left(\frac{S}{N}\right)_R = \gamma$$

SNR với tách sóng đồng bộ

$$\left(\frac{S}{N}\right)_D = \frac{2S_x}{1+S_x}\left(\frac{S}{N}\right)_R = \frac{S_x}{1+S_x}\gamma \qquad \text{AM}$$

$$\left(\frac{S}{N}\right)_D = 2\left(\frac{S}{N}\right)_R = \frac{S_R}{N_0 W} = \gamma \qquad \text{DSB}$$

$$\left(\frac{S}{N}\right)_D = \left(\frac{S}{N}\right)_R = \gamma \qquad \text{SSB}$$

Đặc tính nhiễu với tách sóng đồng bộ

By assuming that the average transmission power is fixed, the results derived above show that:

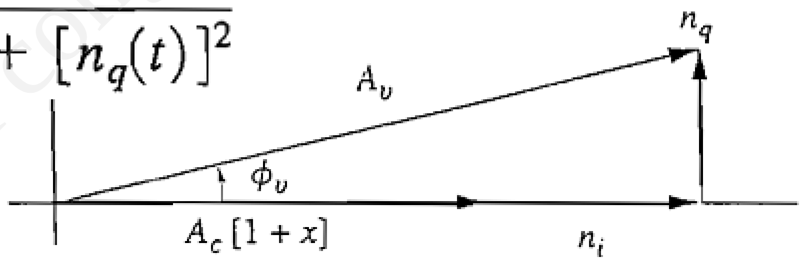
- The message and noise are additive at the output if they are additive at the detector input.
- If the pre-detection noise spectrum is reasonably flat over transmission bandwidth, the destination noise spectrum is essentially constant over the message bandwidth.
- Relative to S/N ratio after the detection, VSB and SSB have no particular advantage over AM and DSB, respectively.
- **The same S/N ratio can be achieved with the linear modulations as with the baseband transmission** (assuming flat noise spectrum).
- Modulations with suppressed carrier (DSB, SSB) provide better S/N ratio than modulations where the carrier is not suppressed (AM, VSB+C).

Tách sóng đường bao cho AM (100%)

$$v(t) = A_c[1 + x(t)]\cos\omega_c t + [n_i(t)\cos\omega_c t - n_q(t)\sin\omega_c t]$$

$$A_v(t) = \sqrt{\{A_c[1 + x(t)] + n_i(t)\}^2 + [n_q(t)]^2}$$

$$\phi_v(t) = \tan^{-1}\frac{n_q(t)}{A_c[1 + x(t)] + n_i(t)}$$



(1) Large signal power: $A_c^{\,2} >> \overline{n_i^{\,2}} \quad \Rightarrow \quad (S/N)_R >> 1$

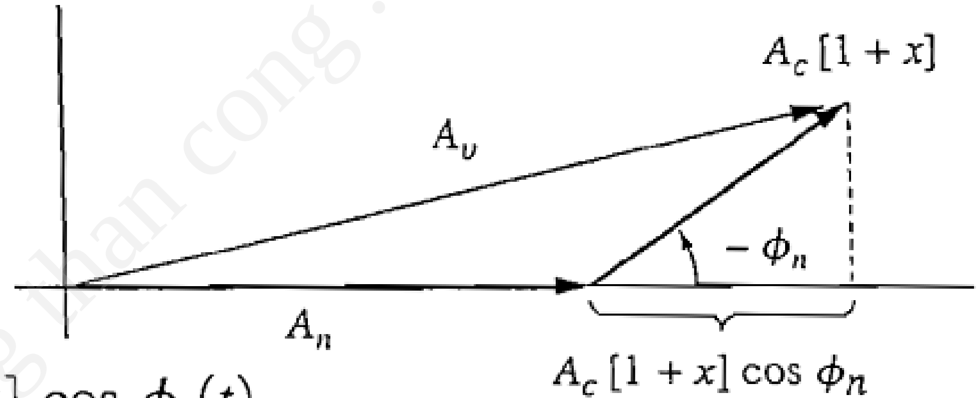
$$A_v(t) \approx A_c[1 + x(t)] + n_i(t)$$

$$y_D(t) = A_v(t) - \overline{A_v} = A_c x(t) + n_i(t)$$

Tách sóng đường bao thất bại

(2) Small signal power: $A_c^2 << \overline{n_i^2} \Rightarrow (S/N)_R << 1$

$$n(t) = A_n(t)\cos[\omega_c t + \phi_n(t)]$$



$$A_v(t) \approx A_n(t) + A_c[1 + x(t)]\cos\phi_n(t)$$

$$y_D(t) = A_n(t) + A_c x(t)\cos\phi_n(t) - \overline{A_n} \qquad \overline{A_n} = \sqrt{\pi N_R/2}$$

Through signal and noise were **additive at input**, the detected message term is **multiplied by noise** in form of $\cos\phi_n(t)$, which is random. Thus, **the message is hopelessly mutilated**.

Hiệu ứng ngưỡng trong tách sóng đường bao

There is a **threshold effect when using the envelope detection**: for moderate-to-high $(S/N)_R$ ratio (i.e., pre-detection SNR), the envelope detector works as well as the synchronous detector. But, **under certain threshold SNR level, the message signal is lost in noise**.

It is difficult to determine the threshold. One criterion is the level where $A_c \geq A_n$ with the probability of 0.99. Then $(S/N)_R = 4\ln 10 \approx 10$ dB.

In audio broadcasting, the smallest useful S/N ratio is about 30 dB, and thus, the threshold effect is not a problem. However, the threshold effect is a problem in some digital modulation methods, which are used in much lower S/N ratios.

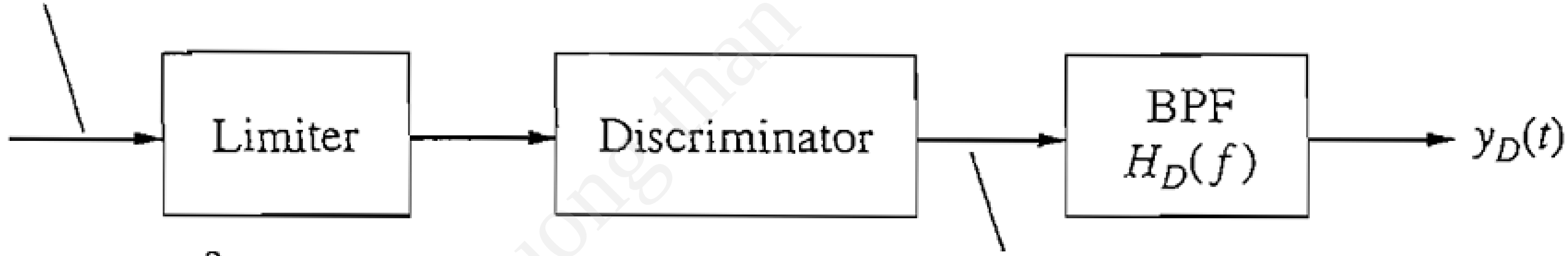
7.3 SNR điều góc

$$x_c(t) = A_c \cos[\omega_c t + \phi(t)]$$

$\phi(t) = \phi_\Delta x(t)$ PM - modulation

$\dot{\phi}(t) = 2\pi f_\Delta x(t)$ FM - modulation

$$v(t) = x_c(t) + n(t) = A_v(t) \cos[\omega_c t + \phi_v(t)]$$



$$\left(\frac{S}{N}\right)_R = \frac{A_c^2/2}{N_0 B_T}$$

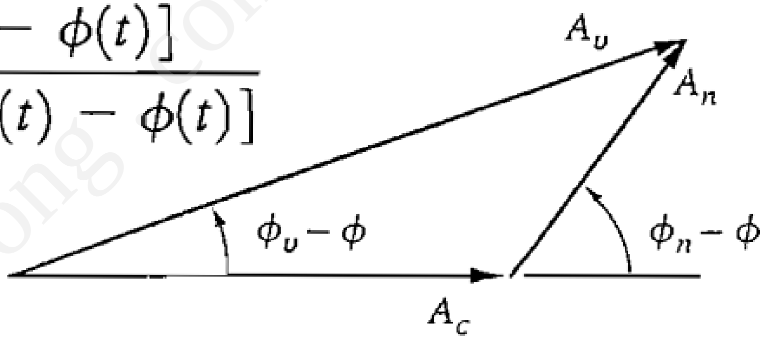
carrier-to-noise ratio (CNR)

$$y(t) = \begin{cases} \phi_v(t) & \text{PM} \\ \dfrac{1}{2\pi}\dot{\phi}_v(t) & \text{FM} \end{cases}$$

$$v(t) = A_c \cos[\omega_c t + \phi(t)] + A_n(t) \cos[\omega_c t + \phi_n(t)]$$

Nhiễu trong điều chế góc

$$\phi_v(t) = \phi(t) + \tan^{-1}\frac{A_n(t)\sin[\phi_n(t - \phi(t)]}{A_c + A_n(t)\cos[\phi_n(t) - \phi(t)]}$$



- **<u>Simplified noise model: Large signal powers</u>** $A_c >> A_n(t)$

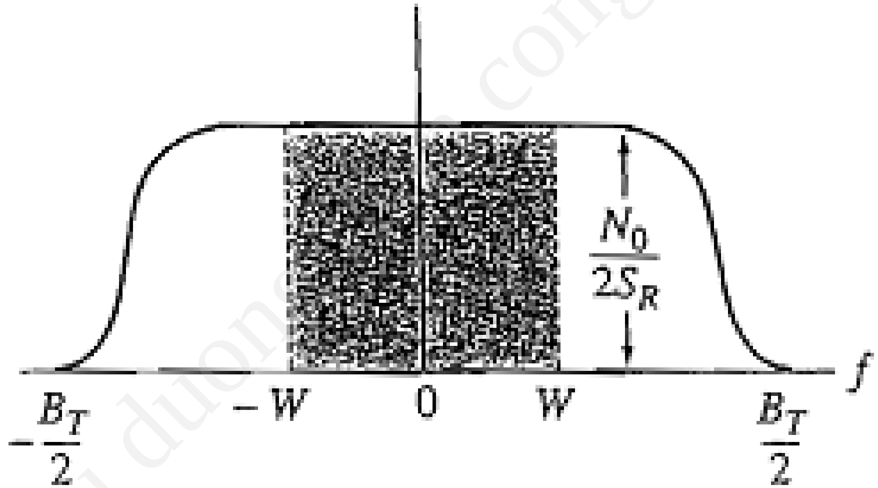
assume that $\phi_n(t) - \phi(t) = \phi_n(t)$ so $(S/N)_R >> 1$

$$\phi_v(t) \approx \phi(t) + \psi(t) \qquad \psi(t) \triangleq \frac{A_n \sin \phi_n(t)}{A_c} = \frac{1}{\sqrt{2S_R}} n_q(t)$$

$$\phi_v(t) \approx \phi(t) + \frac{1}{\sqrt{2S_R}} n_q(t) \qquad n_q(t) = A_n(t)\sin[\phi_n(t)]$$

Nhiễu trong tách sóng pha (Giải điều chế PM)

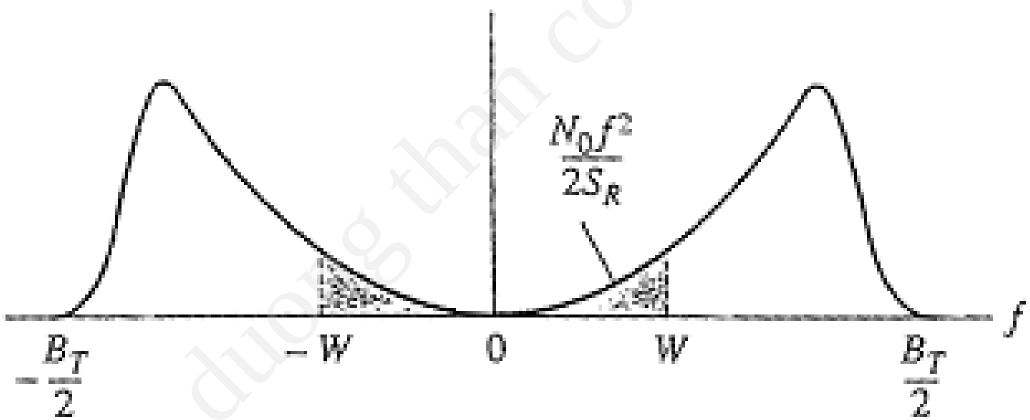
$$G_\psi(f) \approx \frac{N_0}{2S_R}\Pi\left(\frac{f}{B_T}\right)$$



$$N_D = \int_{-W}^{W} G_\psi(f)\,df = \frac{N_0 W}{S_R} \qquad \text{PM}$$

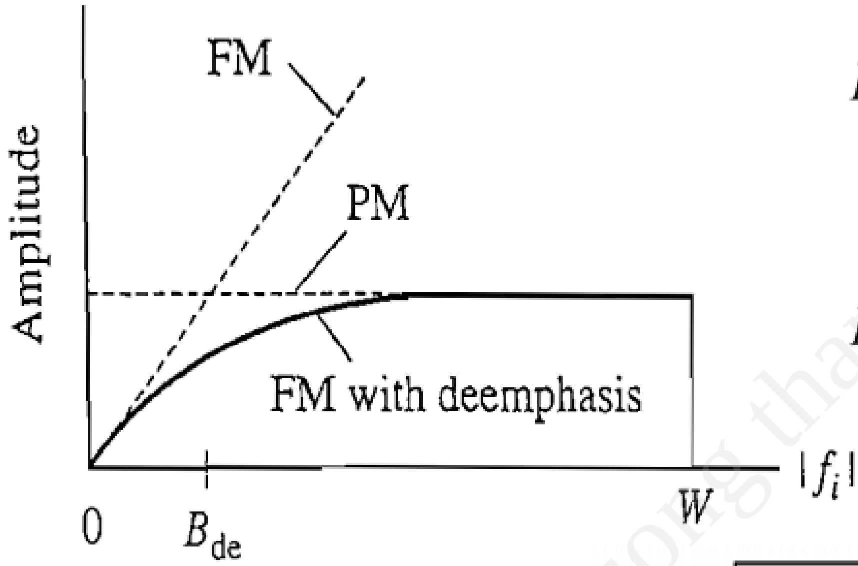
Nhiễu trong tách sóng tần số (Giải điều chế FM)

$$G_\xi(f) = (2\pi f)^2 \frac{1}{8\pi^2 S_R} G_{n_q}(f) = \frac{N_0 f^2}{2S_R}\Pi\left(\frac{f}{B_T}\right)$$



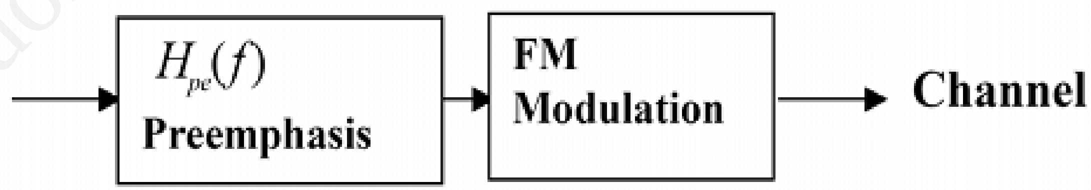
$$N_D = \int_{-W}^{W} G_\xi(f)df = \frac{N_0 W^3}{3S_R} \qquad \text{FM}$$

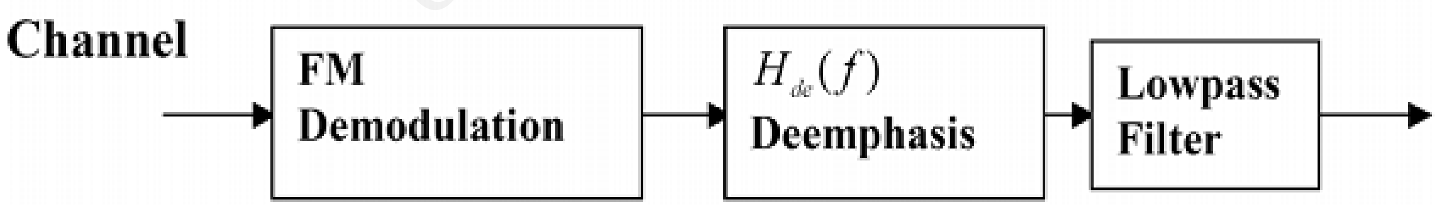
Bộ tiền/giải nhấn trong FM

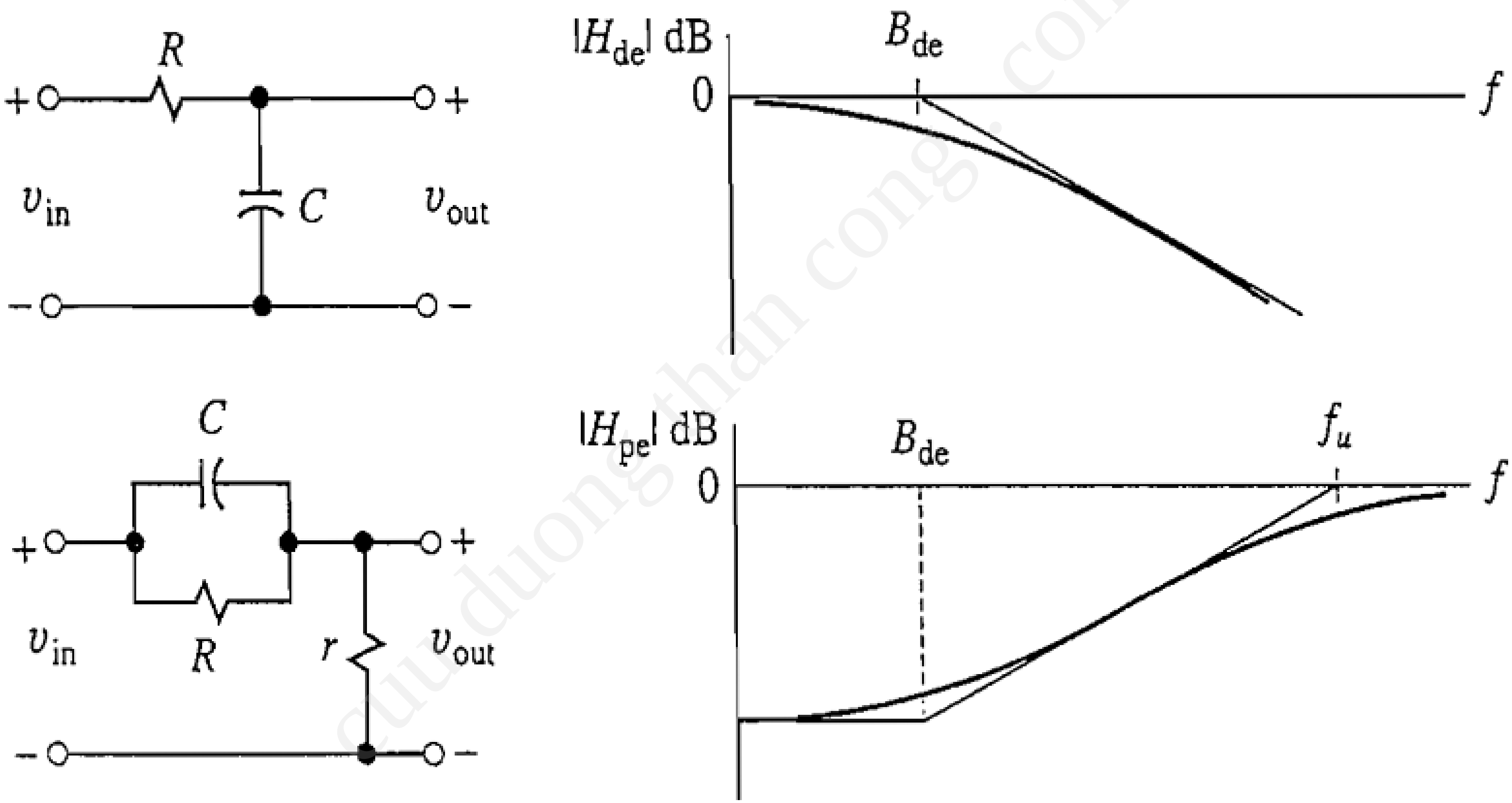


$$H_{de}(f) = \frac{1}{1 + j\dfrac{f}{B_{de}}} \approx \begin{cases} 1 & |f| << B_{de} \\ B_{de}/jf & |f| >> B_{de} \end{cases}$$

$$H_{pe}(f) = 1 + j\frac{f}{B_{de}} \approx \begin{cases} 1 & |f| << B_{de} \\ jf / B_{de} & |f| >> B_{de} \end{cases}$$







RC-time constant: 75 μs USA $\Rightarrow B_{de} \cong 2.1$ kHz

50 μs Europe $\Rightarrow B_{de} \cong 3.2$ kHz

Nhiễu trong tách sóng tần số (Giải điều chế FM có giải nhấn)

$$|H_D(f)| = |H_{de}(f)|\Pi\left(f/2W\right) = \frac{1}{\sqrt{1+(f/B_{de})^2}}\Pi\left(f/2W\right)$$

$$N_D = \int_{-W}^{W} |H_{de}(f)|^2 G_\xi(f)df \doteq \frac{N_0 B_{de}^3}{S_R}\left[\left(\frac{W}{B_{de}}\right) - \tan^{-1}\left(\frac{W}{B_{de}}\right)\right]$$

In the case of $W/B_{de} >> 1$, then

$N_D \approx N_0 B_{de}^2 W/S_R$ Deemphasized FM

SNR cho PM/FM

$$y(t) = \phi_v(t) = \phi_\Delta x(t) + \psi(t) \qquad S_D = \phi_\Delta^2 \overline{x^2} = \phi_\Delta^2 S_x$$

$$\left(\frac{S}{N}\right)_D = \frac{\phi_\Delta^2 S_x}{(N_0 W / S_R)} = \phi_\Delta^2 S_x \frac{S_R}{N_0 W} = \phi_\Delta^2 S_x \gamma \qquad \text{PM}$$

$$y(t) = \frac{1}{2\pi}\dot{\phi}_v(t) = f_\Delta x(t) + \xi(t) \qquad S_D = f_\Delta^2 S_x$$

$$\left(\frac{S}{N}\right)_D = \frac{f_\Delta^2 S_x}{(N_0 W^3 / 3 S_R)} = 3\left(\frac{f_\Delta}{W}\right)^2 S_x \frac{S_R}{N_0 W} = 3D^2 S_x \gamma \qquad \text{FM}$$

- So sánh độ cải thiện SNR tối đa?

Hiệu ứng ngưỡng trong giải điều chế FM/PM

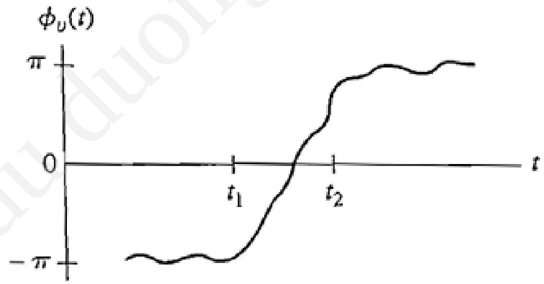
small signal condition: $A_c << A_n(t)$ $(S/N)_R << 1$

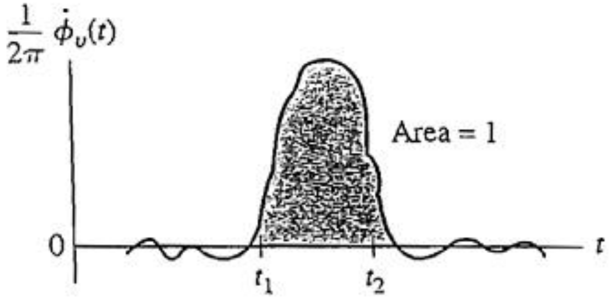
$$\phi_v(t) \approx \phi_n(t) + \frac{A_c \sin[\phi(t) - \phi_n(t)]}{A_n(t)}$$

Therefore in the case $(S/N)_R << 1$, the noise dominates and the message contained in $\phi(t)$ can not be recovered.

$$(S/N)_{Rth} = 10$$

$$\gamma_{th} = 10\frac{B_T}{W}$$





Even small noise variations may then produce large spikes to the demodulated FM signal.

Yêu cầu SNR ứng dụng thực tế

Signal Type	Frequency Range	dB
Barely intelligible voice	500 Hz to 2 kHz	5–10
Telephone-quality voice	200 Hz to 3.2 KHz	25–35
AM broadcast quality audio	100 Hz to 5 kHz	40–50
High-fidelity audio	20 Hz to 20 kHz	55–65
Video	60 Hz to 4.2 MHz	45–55

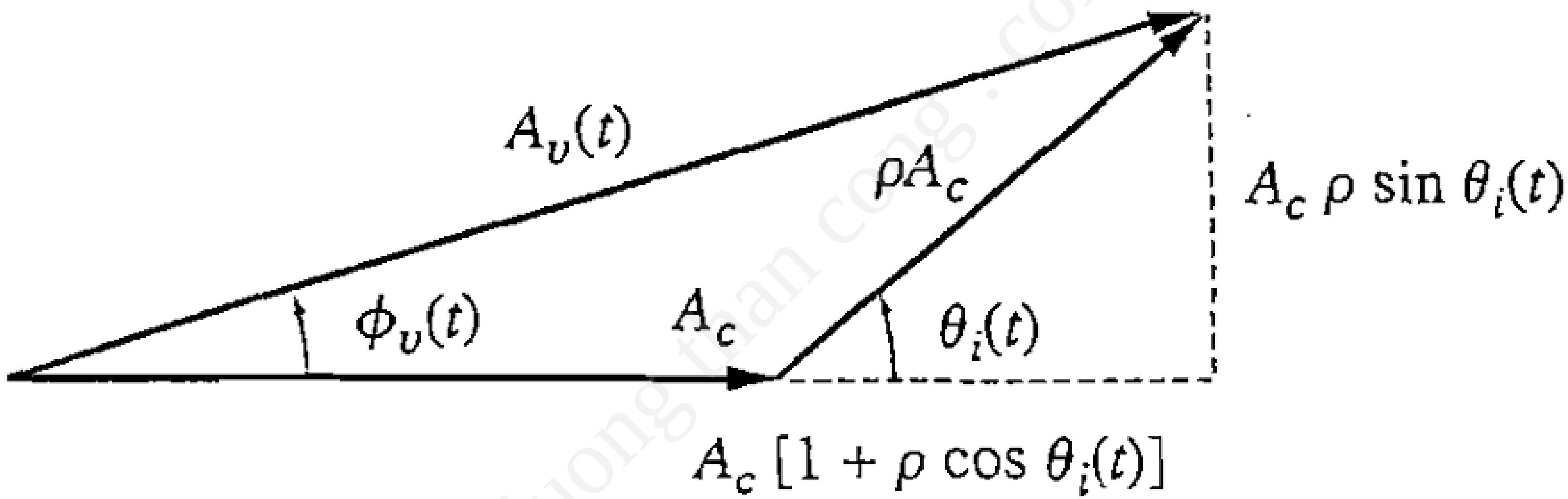
Can nhiễu

- Nhiễu đồng kênh (CCI)
- Nhiễu kênh kề (ACI)

$$v(t) = \underbrace{A_c \cos(\omega_c t)}_{\text{desired signal}} + \underbrace{A_i \cos((\omega_c + \omega_i)t + \phi_i)}_{\text{interference}}$$

$$\rho \triangleq A_i / A_c \qquad \theta_i(t) \triangleq \omega_i t + \phi_i$$

$$v(t) = A_v(t) \cos\left[\omega_c t + \phi_v(t)\right]$$



$$A_v(t) = A_c\sqrt{1+\rho^2+2\rho\cos\theta_i(t)}$$

$$\phi_v(t) = \arctan\frac{\rho\sin\theta_i(t)}{1+\rho\cos\theta_i(t)}$$

For $\rho << 1$, **interference can cause tone modulation at frequency f_i with amplitude modulation** (modulation index $\mu = \rho$) **and frequency modulation or phase modulation** (modulation index $\beta = \rho$).

$$A_v(t) \approx A_c[1 + \rho \cos(\omega_i t + \phi_i)]$$

$$\phi_v(t) \approx \rho \sin(\omega_i t + \phi_i)$$

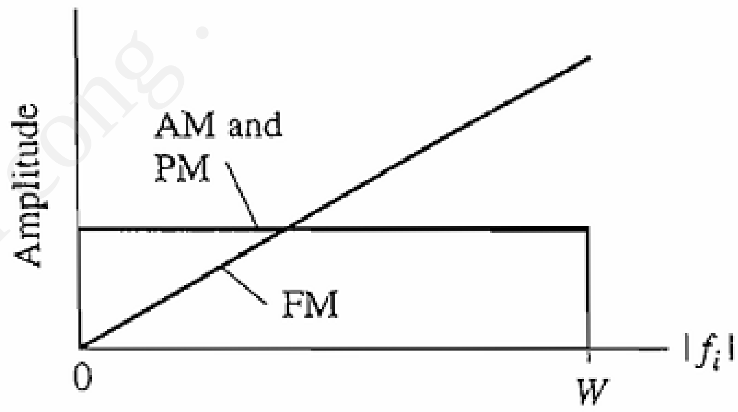
For $\rho >> 1$, **interference still cause tone modulation at frequency f_i with amplitude modulation** (modulation index $\mu = \rho^{-1}$) **but the phase corresponds to a shifted carrier frequency $f_c + f_i$ plus the constant ϕ_i.**

$$A_v(t) \approx A_i[1 + \rho^{-1} \cos(\omega_i t + \phi_i)]$$

$$\phi_v(t) \approx \omega_i t + \phi_i$$

For different modulation methods, the detected signal is (here $\phi_i = 0$ and $f_i \le W$, $\rho \ll 1$):

$$y_D(t) \approx \begin{cases} K_D(1+\rho\cos\omega_i t) & \text{AM} \\ K_D\rho\sin\omega_i t & \text{PM} \\ K_D\rho f_i\cos\omega_i t & \text{FM} \end{cases}$$



- In AM and PM a tone interference produces a tone to reception whose amplitude is comparable to ρ.
- In FM, the interference is more severe the more distant the interfering tone is from the carrier (**adjacent channel interference**).
- On the other hand, it can be seen that FM is much better that AM or PM when the disturbing frequency is close to the carrier frequency (**co-channel interference**).

Hiệu ứng bắt trong FM

Capture effect is a phenomenon that takes place in FM systems, when there are two FM modulated signals in the same channel and the amplitude of these signals is nearly the same.

The stronger dominates or "captures" the output (annoying results when listening to a distant FM station). When the strengths of the two FM signals begin to be nearly the same, the capture effect may cause the signals to alternate in their domination of the frequency. **Small variations in the relative amplitude levels cause sudden change in the station.**

So sánh các điều chế tương tự

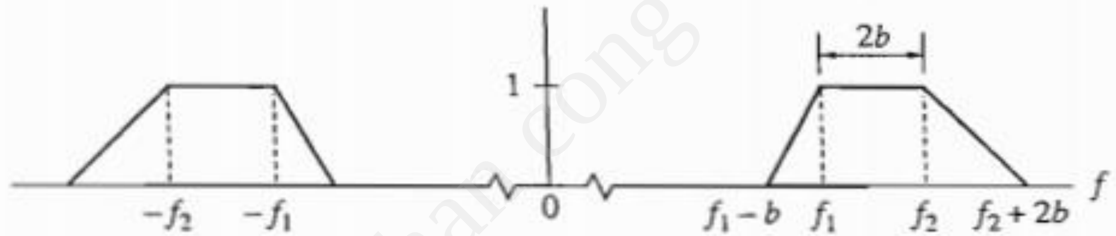
Type	$b = B_T/W$	$(S/N)_D \div \gamma$	γ_{th}	DC	Complexity	Comments
Baseband	1	1	. . .	No[1]	Minor	No modulation
AM	2	$\frac{\mu^2 S_x}{1 + \mu^2 S_x}$	20	No	Minor	Envelope detection $\mu \leq 1$
DSB	2	1	. . .	Yes	Major	Synchronous detection
SSB	1	1	. . .	No	Moderate	Synchronous detection
VSB	1+	1	. . .	Yes	Major	Synchronous detection
VSB + C	1+	$\frac{\mu^2 S_x}{1 + \mu^2 S_x}$	20	Yes[2]	Moderate	Envelope detection $\mu < 1$
PM[3]	$2M(\phi_\Delta)$	$\phi_\Delta^2 S_x$	$10b$	Yes	Moderate	Phase detection, constant amplitude $\phi_\Delta \leq \pi$
FM[3,4]	$2M(D)$	$3D^2 S_x$	$10b$	Yes	Moderate	Frequency detection, constant amplitude

Tóm tắt

- Đặc tính nhiễu băng dải?
- Đặc tính nhiễu biên độ và nhiễu pha?
- Ảnh hưởng của nhiễu trong mỗi loại điều chế?
- SNR trước và sau mỗi loại giải điều chế?

Bài tập 1

10.1–1 White noise with $N_0 = 10$ is applied to a BPF having $|H_R(f)|^2$ plotted in Fig. P10.1–1. Sketch $G_{n_i}(f)$ taking $f_c = f_1$, and show therefrom that $\overline{n_i^2} = \overline{n^2}$.



10.1–2 Do Prob. 10.1–1 taking $f_c = f_2$.

Bài tập 2

10.2–1* A DSB signal plus noise is demodulated by synchronous detection. Find $(S/N)_D$ in dB given that $S_R = 20$ nW, $W = 5$ MHz, and $\mathcal{T}_N = 10\mathcal{T}_0$.

10.2–2 An AM signal plus noise is demodulated by synchronous detection. Find $(S/N)_D$ in dB given that $S_x = 0.4$, $S_R = 20$ nW, $W = 5$ MHz, $\mu = 1$, and $\mathcal{T}_N = 10\mathcal{T}_0$.

10.2–3 A DSB signal plus noise is demodulated by a product detector with phase error ϕ'. Take the local oscillator signal to be $2\cos(\omega_c t + \phi')$ and show that $(S/N)_D = \gamma \cos^2 \phi'$.

Bài tập 3

10.2–6 Explain why an SSB receiver should have a nearly rectangular BPF with bandwidth $B_T = W$, whereas predetection filtering is not critical for DSB.

10.2–10 Explain why an AM receiver should have a nearly rectangular BPF with bandwidth $B_T = 2W$ for envelope detection, whereas predetection filtering is not critical for synchronous detection.

Bài tập 4

10.2–11* An AM system with envelope detection is operating at the threshold point. Find the power gain in dB needed at the transmitter to get up to $(S/N)_D$ = 40 dB with full-load tone modulation.

10.2–12 An AM system with envelope detection has $(S/N)_D$ = 30 dB under full-load tone-modulation conditions with W = 8 kHz. If all bandwidths are increased accordingly, while other parameters are held fixed, what is the largest useable value of W?

Bài tập 5

10.3–4 An FM signal plus noise has $S_R = 1$ nW, $W = 500$ kHz, $S_x = 0.1$, $f_\Delta = 2$ MHz, and $\mathcal{T}_N = 10\mathcal{T}_0$. Find $(S/N)_D$ in dB for FM detection and for deemphasized FM detection with $B_{de} = 5$ kHz.

Bài tập 6

10.3–6* The signal $x(t) = \cos 2\pi 200t$ is sent via FM without preemphasis. Calculate $(S/N)_D$ when $f_\Delta = 1$ kHz, $S_R = 500N_0$, and the postdetection filter is an ideal BPF passing $100 \leq |f| \leq 300$ Hz.

10.3–7 Obtain an expression for $(S/N)_D$ for FM with a gaussian deemphasis filter having $|H_{de}(f)|^2 = e^{-(f/B_{de})^2}$. Calculate the resulting deemphasis improvement factor when $B_{de} = W/7$.

Bài tập 7

10.3–8 A certain PM system has $(S/N)_D = 30$ dB. Find the new value of $(S/N)_D$ when the modulation is changed to preemphasized FM with $B_{de} = W/10$, while B_T and all other parameters are held fixed.

Bài tập 8

10.4–1* An analog communication system has $\overline{x^2} = 1/2$, $W = 10$ kHz, $N_0 = 10^{-15}$ W/Hz, and transmission loss $L = 100$ dB. Calculate S_T needed to get $(S/N)_D = 40$ dB when the modulation is: (*a*) SSB; (*b*) AM with $\mu = 1$ and $\mu = 0.5$; (*c*) PM with $\phi_\Delta = \pi$; (*d*) FM with $D = 1$, 5, and 10. Omit deemphasis in the FM case, but check for threshold limitations.

10.4–2 Do Prob. 10.4–1 with $\overline{x^2} = 1$ and $W = 20$ kHz.

Bài tập 9

10.4–3 An analog communication system has $\overline{x^2} = 1/2$, $W = 10$ kHz, $S_T = 10$ W, and $N_0 = 10^{-13}$ W/Hz. Calculate the path length corresponding to $(S/N)_D = 40$ dB for a transmission cable with loss factor $\alpha = 1$ dB/km when the modulation is: (*a*) SSB; (*b*) AM with $\mu = 1$; (*c*) FM with $D = 2$ and 8.

10.4–4 Do Prob. 10.4–3 for line-of-sight radio transmission at $f_c = 300$ MHz with antenna gains of 26 dB at transmitter and receiver.

Bài tập 10

10.4–5* A signal with $\overline{x^2} = 1/2$ is transmitted via AM with $\mu = 1$ and $(S/N)_D = 13$ dB. If the modulation is changed to FM (without deemphasis) and the bandwidths are increased accordingly while other parameters remain fixed, what's the largest usable deviation ratio and the resulting value of $(S/N)_D$?