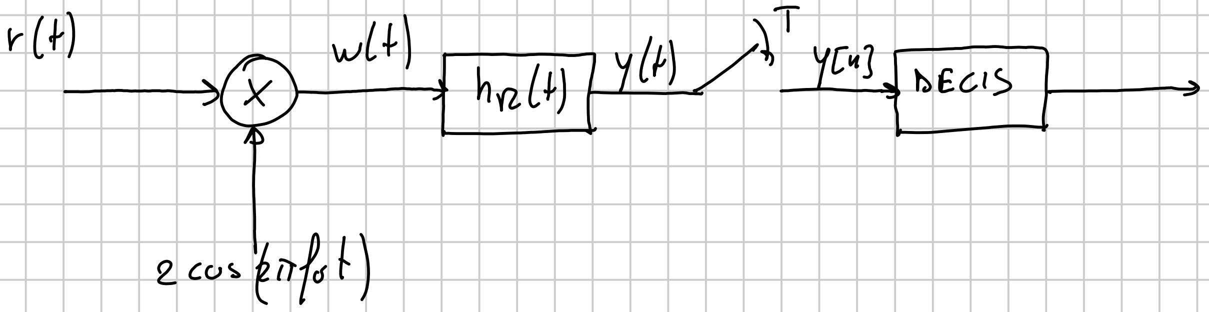
Esercizio 2 - 18/09/08



$$r(t) = \sum_{k=-\infty}^{+\infty} x[n]\, p(t-kT) \cos(2\pi f_0 t + \theta) + n(t) \qquad f_0 \gg \frac{1}{T}, \ \theta = \frac{\pi}{3}$$

$x[n] \in A_s = \{\pm 1\}$ equiprob. ed indip.

$$S_n(f) = \frac{N_0}{2} \left[\left(1 - \frac{|f-f_0|}{B}\right) \text{rect}\left(\frac{f-f_0}{2B}\right) + \left(1 - \frac{|f+f_0|}{B}\right) \text{rect}\left(\frac{f+f_0}{2B}\right) \right]$$

B = banda dell' impulso trasmesso

$p(t) \Rightarrow P(f) = \sqrt{T}\, \text{rect}(Tf)$

$h_R(t) = p(t)$, $c(t) = \delta(t)$

1) $E_s = ?$

2) P_{n_u} (Potenza media del rumore in uscita da $h_R(t)$)

3) $P_E(b)$

Soluzione

1) $E_s = ?$

$$s_1(t) = p(t) \cos(2\pi f_0 t + \theta)$$
$$s_2(t) = -p(t) \cos(2\pi f_0 t + \theta)$$

$$E_{s_1} = E_{s_2} = \int_{-\infty}^{+\infty} p^2(t) \cos^2(2\pi f_0 t + \theta)\, dt = \frac{E_P}{2} = \frac{1}{2}$$

$$E_p = \int_{-\infty}^{+\infty} p^2(t)\, dt = \int_{-\infty}^{+\infty} P^2(f)\, df = T \cdot \frac{1}{T} = 1$$

$$E_s = \frac{1}{2} E_{s_1} + \frac{1}{2} E_{s_2} = \frac{1}{2}$$

2) P_{n_u}

$$w(t) = \underbrace{s(t) \cdot 2\cos(2\pi f_0 t)}_{w_s(t)} + \underbrace{n(t) \cdot 2\cos(2\pi f_0 t)}_{w_n(t)}$$

$$w_n(t) = \left[n_c(t)\cos(2\pi f_0 t) - n_s(t)\sin(2\pi f_0 t) \right] \cdot 2\cos(2\pi f_0 t)$$
$$= n_c(t)\left(1 + \cos(4\pi f_0 t)\right) - n_s(t)\sin(4\pi f_0 t)$$

Il filtro $h_R(t)$ è passa-basso per cui rimane solo la componente in b.b.

$$y(t) = s_u(t) + n_u(t)$$

$$n_u(t) = w_n(t) \otimes h_R(t) = n_c(t) \otimes h_R(t)$$

$$S_{n_u}(f) = S_{n_c}(f)\, |H_R(f)|^2$$

$$S_{n_c}(f) = S_n(f+f_0) + S_n(f-f_0) = N_0 \left(1 - \frac{|f|}{B}\right) \mathrm{rect}\left(\frac{f}{2B}\right)$$

$$S_{n_u}(f) = N_0 \cdot \frac{1}{2B} \left(1 - \frac{|f|}{B}\right) \mathrm{rect}\left(\frac{f}{2B}\right)$$

$$B = \frac{1}{2T} \Rightarrow T = \frac{1}{2B}$$

$$P_{n_u} = \int_{-\infty}^{+\infty} S_{n_u}(f)\, df = \frac{N_0}{2B} \cdot B = \frac{N_0}{2}$$

3) $P_E(b) = P_E(2) = \frac{1}{2}\,\mathrm{erfc}\left(\sqrt{SNR}\right) = Q\left(\sqrt{SNR}\right)$

VALIDA SOTTO L'IPOTESI: NO ISI

$$SNR = \frac{E[s_u^2[n]]}{E[n_u^2[n]]} = \frac{E[s_u^2[n]]}{P_{n_u}}$$

Bisogna determinare $s_u[n]$

$$s_u(t) = w_s(t) \otimes h_R(t)$$

$$w_s(t) = 2 \sum_{n=-\infty}^{+\infty} x[n]\,p(t-nT)\cos(2\pi f_0 t + \theta)\cos(2\pi f_0 t)$$

$$= \sum_{n=-\infty}^{+\infty} x[n]\,p(t-nT)\left[\cos\theta + \underbrace{\cos(4\pi f_0 t + \theta)}_{\text{viene eliminata dal } h_R(t)}\right]$$

$$s_u(t) = \sum_{n=-\infty}^{+\infty} x[n]\,h(t-nT)\cos\theta$$

$$h(t) = p(t) \otimes h_R(t) = p(t) \otimes p(t) = p(t) \otimes p(-t) = c_p(t)$$

$$s_u[n] = x[n]\,c_p(0)\cos\theta + \underbrace{\sum_{\substack{n=-\infty \\ n\neq k}}^{+\infty} x[n]\,c_p((n-k)T)\cos\theta}_{ISI}$$

$$c_p(t) = TCF^{-1}\left[P^2(f)\right] = \mathrm{sinc}\left(\frac{t}{T}\right) \Rightarrow c_p((n-k)T) = 0 \quad n \neq k$$

NO ISI

$$c_p(0) = \int_{-\infty}^{+\infty} P^2(f)\,df = 1$$

$$s_u[n] = x[n]\cos\theta$$

$$E[s_u^2[n]] = \cos^2\theta\, E[x^2[n]] = \cos^2\theta$$

$$SNR = \frac{\cos^2\theta}{N_0/2}$$

$$P_e(b) = Q\left(\sqrt{\frac{\cos^2\theta}{N_0/2}}\right)$$

(Applicabile vista l'assenza di ISI e simboli equip. ed ind.)

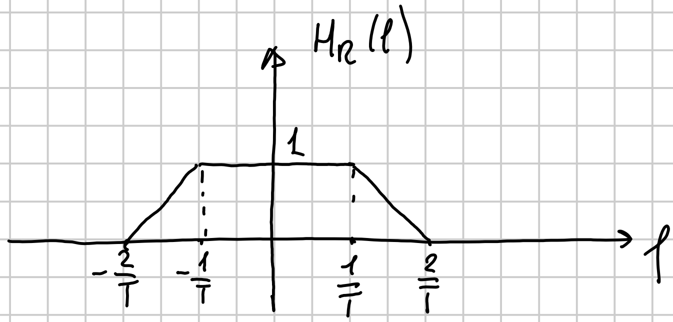
Es. 2 - 12/11/09

$$r(t) = \sum_{k=-\infty}^{+\infty} x[k]\, p(t-kT) + n(t)$$

$$x[n] \in A_s = \{0, 4\}$$

$n(t)$ è Gaussiano Bianco con $S_n(f) = \frac{N_0}{2}$

$$p(t) \Rightarrow P(f) = T \cdot |fT| \, \mathrm{rect}\left(\frac{fT}{2}\right)$$



Strategia di decisione:

$$\hat{x}[n] = \begin{cases} 0 & \text{se } y[n] \le \lambda \\ 4 & \text{se } y[n] > \lambda \end{cases}, \quad \lambda = \frac{3}{2}$$

Calcolare:

1) E_s
2) P_{n_u}
3) $P_E(b)$

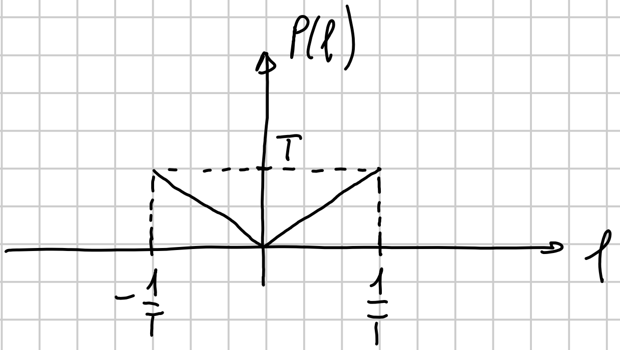
Soluzione

1) $E_s = ?$

$$s_1(t) = 0 \quad , \quad s_2(t) = 4\,p(t)$$

$E_{s_1} = 0$

$$E_{s_2} = \int_{-\infty}^{+\infty} 16\, p^2(t)\, dt = 16 \int_{-\infty}^{+\infty} P^2(f)\, df = 16 \cdot \frac{2}{3} T^2 \cdot \frac{1}{T} = \frac{32}{3} T$$



$$E_s = \frac{1}{2} \cdot 0 + \frac{1}{2} \cdot \frac{32}{3} T = \frac{16}{3} T$$

2) $P_{n_u} = ?$

$$S_{n_u}(f) = S_n(f)\, |H_R(f)|^2 = \frac{N_0}{2} |H_R(f)|^2$$

$$P_{n_u} = \int_{-\infty}^{+\infty} S_{n_u}(f)\, df = \frac{N_0}{2} \int_{-\infty}^{+\infty} |H_R(f)|^2\, df =$$

$$= \frac{N_0}{2} \cdot \left(\frac{2}{T} + \frac{2}{3} \cdot \frac{1}{T} \right) = \frac{4}{3} \frac{N_0}{T}$$

3) $P_E(b) = ?$

$$\begin{cases} P_E(b) = Q\left(\sqrt{SNR}\right) \\ SNR = \dfrac{E[s_u^2[n]]}{P_{n_u}} \end{cases}$$

(se i simboli sono equip. ind., se c'è assenza di ISI e se la soglia è quella ottima)

$$s_u(t) = \sum_{k=-\infty}^{+\infty} x[n]\, h(t - kT)$$

$$h(t) = p(t) \otimes h_R(t)$$

$$H(f) = P(f)\, H_R(f) = P(f)$$

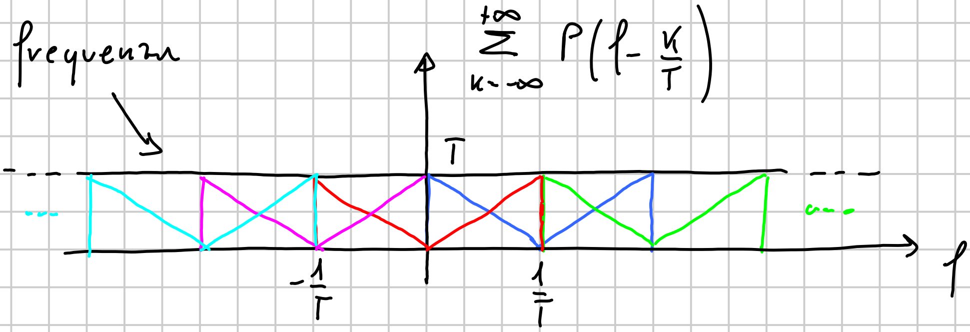
Verifica sull'ISI:

•) $\sum_{k=-\infty}^{+\infty} P\left(f - \frac{k}{T}\right) = \text{cost}$ criterio di Nyquist in freq.

•) $p(kT) = \begin{cases} \neq 0 & \text{se } k = 0 \\ = 0 & \text{altrove} \end{cases}$ criterio di Nyquist nel tempo

Verifica in entrambi i modi

in frequenza



Nel tempo:

$$P(f) = T\,\text{rect}\left(\frac{f}{2/T}\right) - T\left(1 - \frac{|f|}{1/T}\right)\text{rect}\left(\frac{f}{2/T}\right)$$

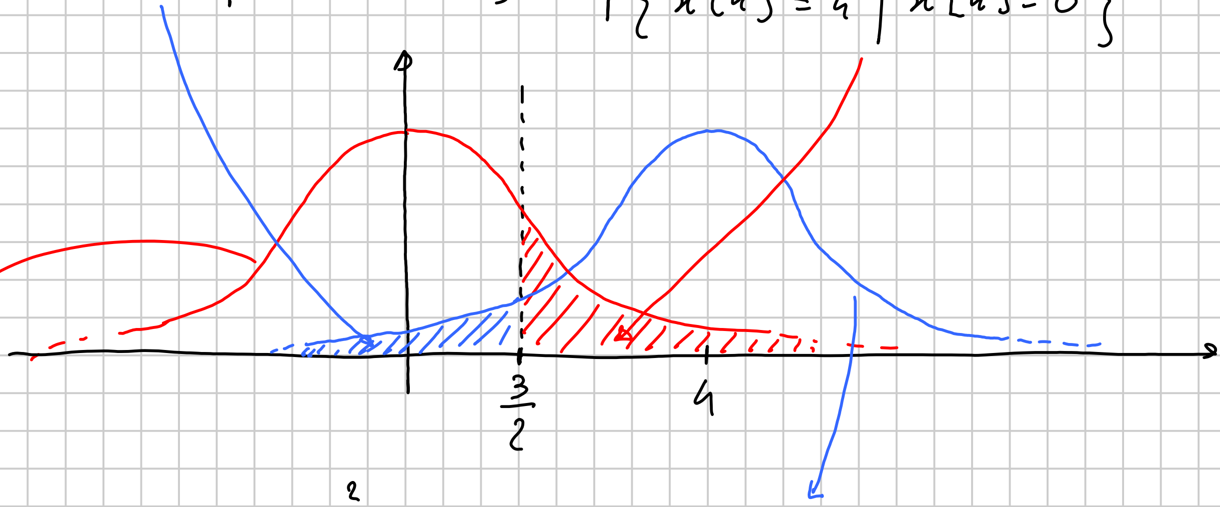
$$p(t) = 2\,\text{sinc}\left(\frac{t}{T/2}\right) - \text{sinc}^2\left(\frac{t}{T}\right)$$

$$p(kT) = \begin{cases} 1 & k = 0 \\ 0 & k \neq 0 \end{cases}$$

$$P_E(b) = P_E(2) = P\{\hat{x}[n] = \alpha_1 \mid x[n] = \alpha_2\}\, P\{\alpha_2\} + P\{\hat{x}[n] = \alpha_2 \mid x[n] = \alpha_1\}\, P\{\alpha_1\}$$

$$P\{\alpha_1\} = P\{\alpha_2\} = \frac{1}{2}$$

$P\{\hat{x}[n]=0 \mid x[n]=4\}$ $\quad$ $P\{\hat{x}[n]=4 \mid x[n]=0\}$



$$f_n\left(\frac{y-0}{\sigma_{n_u}}\right)=\frac{1}{\sqrt{2\pi\sigma_{n_v}^2}}\,e^{-\frac{y^2}{2\sigma_{n_u}^2}}\ ,\quad f_n\left(\frac{y-4}{\sigma_{n_u}}\right)=\frac{1}{\sqrt{2\pi\sigma_{n_u}^2}}\,e^{-\frac{(y-4)^2}{2\sigma_{n_u}^2}}$$

$$f_{Y|\alpha_1}(y|\alpha_1)\in\mathcal{N}\left(0,\sigma_{n_u}^2\right)$$

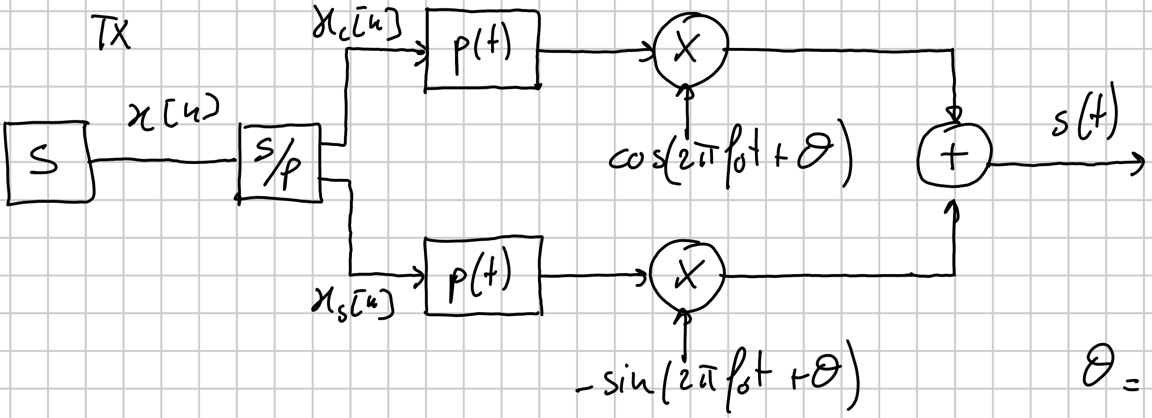
$$f_{Y|\alpha_2}(y|\alpha_2)\in\mathcal{N}\left(4,\sigma_{n_u}^2\right)$$

$$\sigma_{n_u}^2=P_{n_u}=\frac{4}{3}\frac{N_0}{T}$$

$$P_E(b)=\frac{1}{2}Q\left(\frac{3/2}{\sigma_{n_u}}\right)+\frac{1}{2}Q\left(\frac{4-3/2}{\sigma_{n_u}}\right)$$

Esercizio su QAM

TX



$\theta = \frac{\pi}{4}$

$$p(t) \Rightarrow P(f) = \left[1 + \cos\left(2\pi \frac{f}{B}\right)\right] \mathrm{rect}\left(\frac{f}{2B}\right) \quad , \quad B = \frac{2}{T} \ll f_0$$

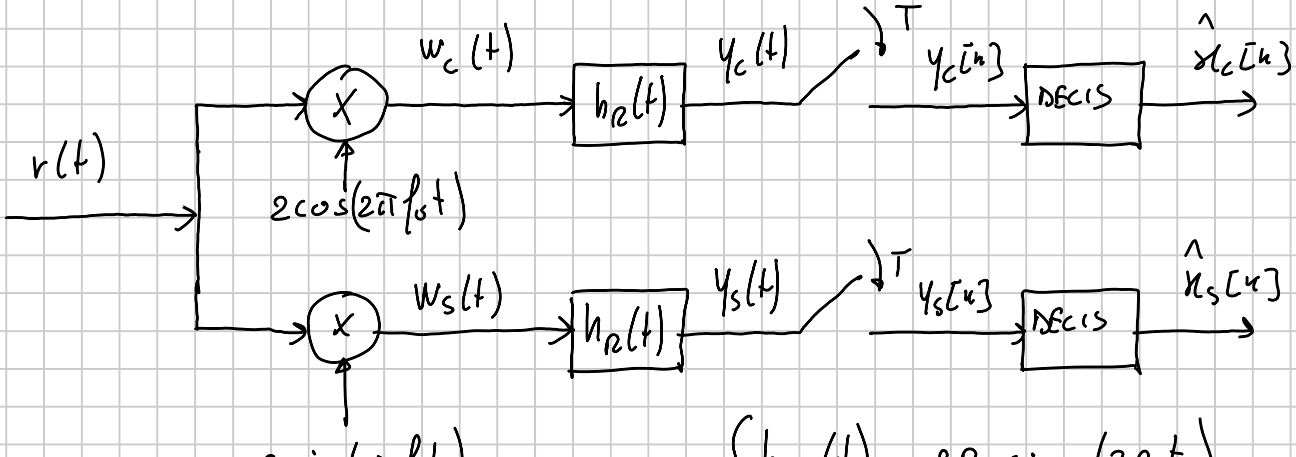
$$x_c[n] \in A_S^c = \{\pm 1\} \quad , \quad x_s[n] \in A_S^s = \{\pm 1\}$$

Canale:

$$c(t) = \delta(t)$$

$$n(t) \Rightarrow S_n(f) = \frac{N_0}{2}\left[\mathrm{rect}\left(\frac{f-f_0}{2B}\right) + \mathrm{rect}\left(\frac{f+f_0}{2B}\right)\right]$$

Ricevitore:



$$\begin{cases} h_R(t) = 2B\,\mathrm{sinc}(2Bt) \\ \lambda_c = \lambda_s = 0 \end{cases}$$

Calcolare

1) $E_s = ?$
2) $\eta_B = ?$
3) $P_{n_{u_c}}$, $P_{n_{u_s}}$
4) $P_E(4) = ?$

Soluzione

1) $E_s = ?$

$$s_1(t) = p(t)\cos(2\pi f_0 t + \vartheta) - p(t)\sin(2\pi f_0 t + \vartheta) \qquad (1,1)$$
$$s_2(t) = p(t)\cos(2\pi f_0 t + \vartheta) + p(t)\sin(2\pi f_0 t + \vartheta) \qquad (1,-1)$$
$$s_3(t) = -p(t)\cos(2\pi f_0 t + \vartheta) - p(t)\sin(2\pi f_0 t + \vartheta) \qquad (-1,1)$$
$$s_4(t) = -p(t)\cos(2\pi f_0 t + \vartheta) + p(t)\sin(2\pi f_0 t + \vartheta) \qquad (-1,-1)$$

$$E_{s_1} = \int_{-\infty}^{+\infty} s_1^2(t)\,dt = \int_{+\infty}^{+\infty} p^2(t)\left[\cos(2\pi f_0 t) - \sin(2\pi f_0 t)\right]^2 dt$$

$$(\cos\alpha \pm \sin\alpha)^2 = \cos^2\alpha + \sin^2\alpha \pm 2\cos\alpha\sin\alpha =$$
$$= \frac{1}{2} + \frac{1}{2}\cos 2\alpha + \frac{1}{2} - \frac{1}{2}\cos 2\alpha \pm \sin 2\alpha =$$
$$= 1 \pm \sin 2\alpha$$

$$E_{s_1} = \int_{-\infty}^{+\infty} p^2(t)\left(1 - \sin(4\pi f_0 t)\right) dt \simeq E_p$$

$$E_{s_2} = \int_{-\infty}^{+\infty} p^2(t)\left(\cos(2\pi f_0 t) + \sin(2\pi f_0 t)\right)^2 dt =$$
$$= \int_{-\infty}^{+\infty} p^2(t)\left(1 + \sin(4\pi f_0 t)\right) dt \simeq E_p$$

$$s_3(t) = -s_2(t) \Rightarrow E_{s_3} = E_{s_2} \simeq E_p$$

$$s_4(t) = -s_1(t) \Rightarrow E_{s_4} = E_{s_1} \simeq E_p$$

$$E_s = \frac{1}{4}E_{s_1} + \frac{1}{4}E_{s_2} + \frac{1}{4}E_{s_3} + \frac{1}{4}E_{s_4} \simeq E_p$$

$$E_S = E\left[\int_{-\infty}^{+\infty}\left[x_c[n]\cos(2\pi f_0 t) - x_s[n]\sin(2\pi f_0 t)\right]^2 p^2(t)\,dt\right] =$$

$$= \int_{-\infty}^{+\infty} E\left[x_c^2[n]\right]\cos^2(2\pi f_0 t)\,p^2(t)\,dt \; +$$

$$+ \int_{-\infty}^{+\infty} E\left[x_s^2[n]\right]\sin^2(2\pi f_0 t)\,p^2(t)\,dt \; +$$

$$- 2\int_{-\infty}^{+\infty} \underbrace{E\left[x_c[n]\,x_s[n]\right]}_{= 0}\cos(2\pi f_0 t)\sin(2\pi f_0 t)\,p^2(t)\,dt$$

$$= \int_{-\infty}^{+\infty}\left[\frac{1}{2} + \frac{1}{2}\cos(4\pi f_0 t)\right] p^2(t)\,dt \; +$$

$$+ \int_{-\infty}^{+\infty}\left[\frac{1}{2} - \frac{1}{2}\cos(4\pi f_0 t)\right] p^2(t)\,dt \;\simeq\; E_p$$

2) $\eta_B = ?$

$$\eta_B = \frac{R_b}{B_T} = \frac{\log_2 M}{B_T\, T}$$

$$R_b = \frac{2}{T} \quad , \quad B_T = \frac{2}{T} \quad \Rightarrow \quad \eta_B = 1$$

3) $P_{n_{u_c}} = ?$, $P_{n_{u_s}} = ?$

$$S_{n_c}(f) = S_{n_s}(f) = N_0\, \mathrm{rect}\left(\frac{f}{2B}\right)$$

$$S_{n_{u_c}}(f) = S_{n_c}(f)\,|H_R(f)|^2 = N_0\,\mathrm{rect}\left(\frac{f}{2B}\right)\cdot\left(\mathrm{rect}\,\frac{f}{2B}\right)^2 =$$

$$= N_0\,\mathrm{rect}\left(\frac{f}{2B}\right) = S_{n_{u_s}}(f)$$

$$P_{n_{u_c}} = P_{n_{u_s}} = 2B N_0 = \frac{4}{T} N_0$$

4) $P_E(4) = ?$

$$P_E(4) = P_E^c(2)\left(1 - P_E^s(2)\right) + P_E^s(2)\left(1 - P_E^c(2)\right) + P_E^c(2)\,P_E^s(2)$$

$$\left.\begin{aligned} P_E^c(2) &= Q\left(\sqrt{SNR_c}\right) \\ P_E^s(2) &= Q\left(\sqrt{SNR_s}\right) \end{aligned}\right\}$$ vere quando non c'è ISI, i simboli sono equip. ed ind. e soglia ottima

$$SNR_c = \frac{E[s_{u_c}^2[n]]}{P_{n_{u_c}}}$$

$$SNR_s = \frac{E[s_{u_s}^2[n]]}{P_{n_{u_s}}}$$

N.B. al denominatore $E[n_{u_c}^2[n]] = P_{n_{u_c}}$ essendo il rumore a media nulla (stesso per il ramo in quad.)

→ Verifica sulla assenza di ISI

$$H(f) = H_R(f)\,P(f) = P(f) = H_{RC}(f)$$

$P(f)$ è a coseno rialzato per cui è soddisfatto il criterio di Nyquist ⇒ NO ISI

→ Calcolo di $E[s_{u_c}^2[n]]$

$$s_{u_c}(t) = \sum_{n=-\infty}^{+\infty} x_c[n]\,h(t - nT)$$

$$s_{u_c}[n] = x[n]\,h(0)$$

$$E[s_{u_c}^2[n]] = E[x_c^2[n]]\,h^2(0) = h^2(0) = \left[\int_{-\infty}^{+\infty} H(f)\,df\right]^2 =$$

$$= \left[\int_{-B}^{B} \left[1 + \cos\left(2\pi \frac{f}{B}\right)\right] df\right]^2 = 4B^2$$

$$SNR_c = \frac{4B^2}{2N_0 B} = \frac{2B}{N_0}$$

$SNR_s = \dfrac{2B}{N_0}$ (ripetendo i calcoli ed essendo $E[x_s^2[n]] = E[x_c^2[n]] = 1$)

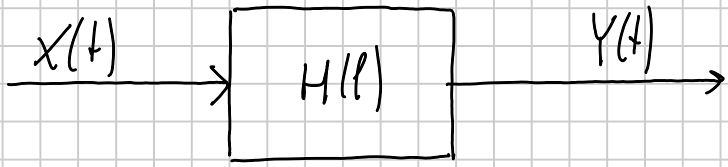
$$P_E^c(2) = P_E^s(2) = Q\left(\sqrt{\frac{2B}{N_0}}\right) = P_E(2)$$

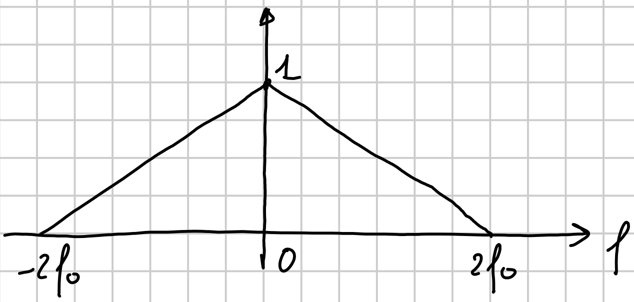
$$P_E(4) = 2\,P_E(2)\left(1 - P_E(2)\right) + P_E^2(2) = 2\,P_E(2) - P_E^2(2)$$

Esercizio su Processi Aleatori Parametrici

$$X(t) = A\cos(2\pi f_0 t) + B\sin(2\pi f_0 t)$$

$$A, B \in \mathcal{N}(0, \sigma^2), \quad \sigma^2 = 4 \qquad \text{indipendenti}$$





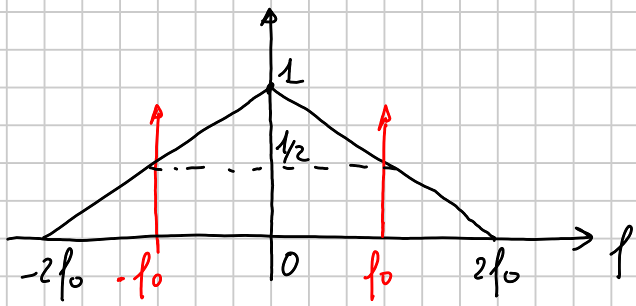
-) Ricavare la $f_Y(y;t)$

Soluzione

Per ogni realizzazione di $X(t)$

$$x_r(t) \Rightarrow X_r(f) = \frac{A}{2}\left(\delta(f-f_0) + \delta(f+f_0)\right) + \frac{B}{2j}\left(\delta(f-f_0) - \delta(f+f_0)\right)$$

$$\Rightarrow Y_r(f) = X_r(f)\,H(f) = \frac{1}{2}X_r(f) \Rightarrow y_r(t) = \frac{1}{2}x_r(t)$$



$$Y(t) = \frac{1}{2} X(t)$$

$$Y = Y(\bar{t}) = A\cos(2\pi f_0 \bar{t}) + B\sin(2\pi f_0 \bar{t}) =$$

$$= K_1 \frac{A}{2} + K_2 \frac{B}{2} \quad , \quad K_1 = \cos(2\pi f_0 \bar{t}) \, , \, K_2 = \sin(2\pi f_0 \bar{t})$$

$$= Y_A + Y_B \quad , \quad Y_A = K_1 \frac{A}{2} \quad , \quad Y_2 = K_2 \frac{B}{2}$$

Y è una V.A. Gaussiana essendo la somma di v.a. Gaussiane. Inoltre essendo A e B indipendenti, lo sono anche Y_A e Y_B. Per cui Y_A e Y_B sono incorrelate.

$$\Rightarrow \eta_{Y_A} = E[K_1 A] = 0$$

$$\Rightarrow \eta_{Y_B} = E[K_2 B] = 0$$

$$\Rightarrow \sigma_{Y_A}^2 = E[K_1^2 A^2] = \frac{K_1^2}{4} \sigma^2$$

$$= \sigma_{Y_B}^2 = E[K_2^2 B^2] = \frac{K_2^2}{4} \sigma^2$$

$$E_Y = E[Y_A + Y_B] = 0$$

$$\sigma_Y^2 = E[(Y_A + Y_B)^2] = E[Y_A^2] + E[Y_B^2] + \underbrace{2E[Y_A Y_B]}_{\substack{= \\ 0 \\ \text{(incorrelate)}}}$$

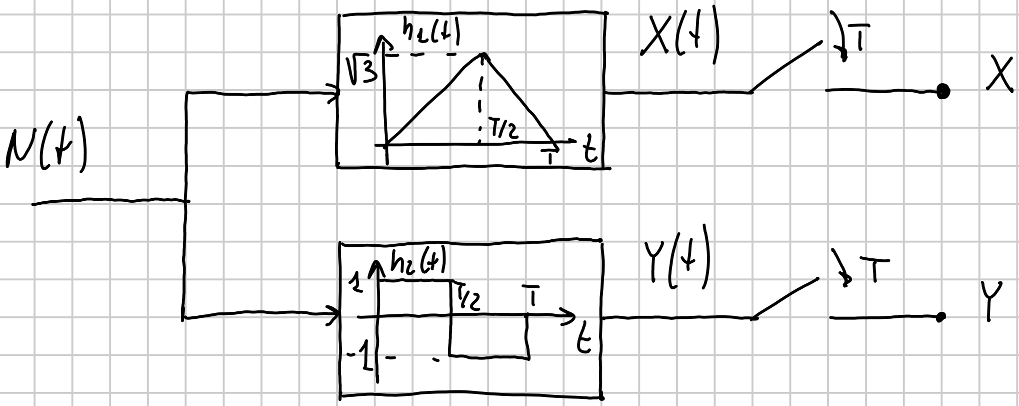
$$= \left(\frac{K_1^2 + K_2^2}{4}\right) \sigma^2 =$$

$$= \left[\cos^2(2\pi f_0 t) + \sin^2(2\pi f_0 t)\right] \frac{4}{4} = 1$$

$$\Rightarrow f_Y(y;t) = \frac{1}{\sqrt{2\pi}} e^{-\frac{y^2}{2}} \in \mathcal{N}(0,1)$$

V.A. GAUSSIANA STANDARD

Esercizio su processi aleatori non-parametrici



N(t) è Gaussiano con $S_n(f) = \frac{N_0}{2}$

- Calcolare la $P\{X > Y\}$
- Calcolare $E[XY]$

Soluzione:

$$\left.\begin{aligned} X &= \int_{-\infty}^{+\infty} N(\tau)\, h_1(T-\tau)\, d\tau \\ Y &= \int_{-\infty}^{+\infty} N(\tau)\, h_2(T-\tau)\, d\tau \end{aligned}\right\} \text{ sono v.a. Gaussiane}$$

Dobbiamo determinare valor medio e varianza

$\eta_n(t) = 0$ essendo $S_n(f) = \frac{N_0}{2}$ (rumore bianco)

Se $\eta_n(t) \neq 0 \Rightarrow S_n(f)$ avrebbe un $\delta(f)$

$$\eta_X(t) = \eta_N(t) \otimes h_1(t) = 0$$

$$\eta_Y(t) = \eta_N(t) \otimes h_2(t) = 0$$

$$S_X(f) = S_N(f)\,|H_1(f)|^2$$

$$P_X = \int_{-\infty}^{+\infty} S_N(f)\,|H_1(f)|^2\,df = \frac{N_0}{2}\int_{-\infty}^{+\infty} |H_1(f)|^2\,df =$$

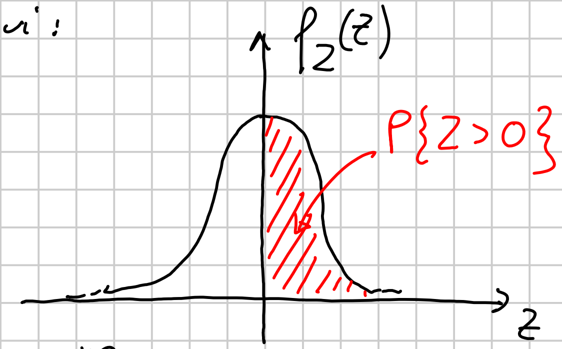
$$= \frac{N_0}{2}\int_{-\infty}^{+\infty} |h_1(t)|^2\,dt = \frac{N_0}{2}\,3\,\frac{2}{3}\,\frac{T}{2} = \frac{N_0 T}{2} = \sigma_X^2$$

$$P_Y = \frac{N_0}{2}\int_{-\infty}^{+\infty} |h_2(t)|^2\,dt = \frac{N_0 T}{2} = \sigma_Y^2$$

$$Z = X - Y \in \mathcal{N}(0, \sigma_Z^2) \quad \Leftarrow E[X-Y] = 0$$

Indipendentemente dal valor di σ_Z^2, $f_Z(z)$ è una Gaussiana a valor medio nullo, per cui:

$$P\{X > Y\} = P\{Z > 0\} = \frac{1}{2}$$



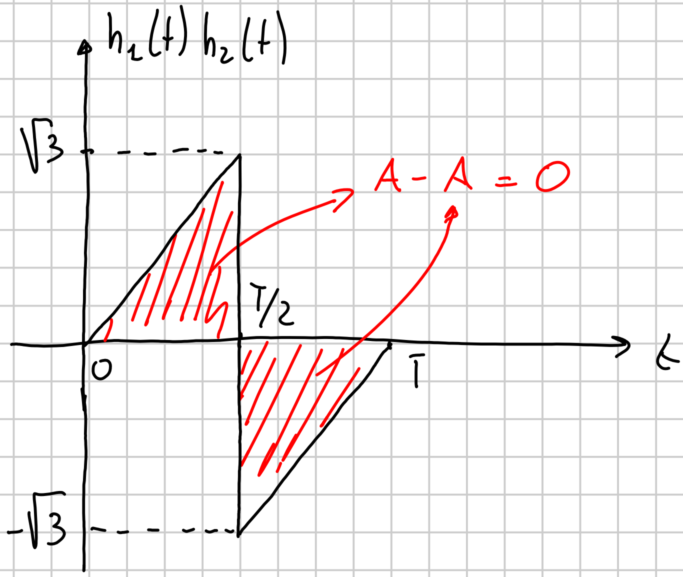
$$E[XY] = E\left[\int_{-\infty}^{+\infty} N(\tau)\,h_1(T-\tau)\,d\tau \int_{-\infty}^{+\infty} N(\alpha)\,h_2(T-\alpha)\,d\alpha\right] =$$

$$= \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} E[N(\tau)N(\alpha)]\,h_1(T-\tau)\,h_2(T-\alpha)\,d\tau\,d\alpha =$$

$$= \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \frac{N_0}{2}\,\delta(\tau-\alpha)\,h_1(T-\tau)\,h_2(T-\alpha)\,d\tau\,d\alpha =$$

$$= \frac{N_0}{2}\int_{-\infty}^{+\infty} h_1(T-\alpha)\,h_2(T-\alpha)\,d\alpha =$$

$$= \frac{N_0}{2}\int_{-\infty}^{+\infty} h_1(t)\,h_2(t)\,dt = 0 \qquad \text{(vedi grafico sotto)}$$


$h_1(t)\,h_2(t)$
$\sqrt{3}$
$-\sqrt{3}$
$T/2$
0
T
t
$A - A = 0$