

## Periodični signali

### Snaga

$$\begin{aligned} P &= \lim_{k \rightarrow \infty} \left[ \frac{1}{kT_0} \int_0^{kT_0} |x(t)|^2 dt \right] \\ &= \frac{1}{T_0} \int_0^{T_0} |x(t)|^2 dt \\ &= \sum_{k=-\infty}^{\infty} |c_k|^2 \end{aligned}$$

Za sinusni signal:

$$P = \frac{A^2}{2}$$

Za slijed pravokutnih impulsa:

$$P = A^2 \frac{\tau}{T}$$

### Fourierovi parovi

$$x(t) = \sin(\omega_0 t) \leftrightarrow -j \frac{A}{2} [\delta(f - f_0) - \delta(f + f_0)]$$

$$x(t) = \cos(\omega_0 t) \leftrightarrow \frac{A}{2} [\delta(f - f_0) + \delta(f + f_0)]$$

## Neperiodični signali

$X(f) = |X(f)|e^{j\theta(f)}$ , gdje je  $|X(f)|$  amplitudni spektar, a  $\theta(f)$  fazni spektar.

### Parsevalov teorem

$$E = \int_{-\infty}^{\infty} |x(t)|^2 dt = \int_{-\infty}^{\infty} |X(f)|^2 df = \frac{1}{2\pi} \int_{-\infty}^{\infty} |X(\omega)|^2 d\omega$$

### Pravokutni impuls

$$P = 0 \quad (\text{beskonačnost}), \quad E = A^2 \tau$$

## Slučajni signali

### Pravila očekivanja (E)

- $E[c] = c, \quad c \in \mathbb{R}$
- $E[cX] = cE[X]$
- $E[X + Y] = E[X] + E[Y]$
- $E[XY] = E[X]E[Y]$

### Stacionarnost

Uvjeti:

- $E[X(t)] = \mu_x$
- $\forall t_1, t_2, \quad R_x(t_1, t_2) = R_x(t_1 - t_2) = R_x(\tau)$   
Pri tome:  $R_x$  je parna funkcija,  $|R_x(\tau)| \leq R_x(0) \geq 0$

Srednja snaga:

$$P = E[X^2(t)] = R_x(0) = \int_{-\infty}^{\infty} S_X(f) df$$

Ako  $E[X] = 0$ :

$$P = \text{var}(X) = \sigma_X^2$$

## Bijeli šum

$W(t)$  je bijeli šum ako:

- $R_W(\tau) = C_1 \delta(\tau)$
- $C_W(\tau) = C_2 \delta(\tau)$

Svojstva:

- $\mu_W = 0$
- $R_W(\tau) = \sigma^2 \delta(\tau) = N_0/2$
- $S_W(f) = \sigma^2 \int_{-\infty}^{\infty} \delta(t) e^{-j2\pi ft} dt = \sigma^2 = N_0/2$

Gaussova razdioba:

$$f_x(x) = \frac{1}{\sigma_X \sqrt{2\pi}} e^{-(x-\mu_X)^2/(2\sigma_X^2)}$$

## Prijenos

Izlazni signal:

$$y(t) = \int_{-\infty}^{\infty} x(\tau) h(t - \tau) d\tau = \int_{-\infty}^{\infty} h(\tau) x(t - \tau) d\tau$$

Prijenosna funkcija:

$$H(f) = \int_{-\infty}^{\infty} h(t) e^{-j2\pi ft} dt$$

Amplitudni odziv RC kruga:

$$20 \log \frac{|H(f)|}{|H(0)|} = 20 \log |H(f)|$$

Za idealni filter:

$$|H(f)| = \begin{cases} 1, & |f| \leq f_g \\ 0, & |f| > f_g \end{cases}$$

Impulsni odziv i prijenosna funkcija:

$$y(t) = x(t) * h(t)$$

$$Y(f) = X(f)H(f)$$

Amplitudni odziv je parna funkcija, a fazni neparna:

$$|H(-f)| = |H(f)|$$

$$\theta(-f) = -\theta(f)$$

Ako je  $X(t)$  stacionarni slučajni proces:

$$\mu_Y = \mu_X H(0)$$

$$S_Y(f) = S_X(f) |H(f)|^2$$

Ako je ulaz  $x(t)$  sa spektrom  $X(f) = |X(f)|e^{j\varphi(f)}$ :

$$Y(f) = |Y(f)|e^{j\vartheta(f)}$$

$$|Y(f)| = |X(f)| |H(f)|$$

$$\vartheta(f) = \varphi(f) + \theta(f)$$

Amplitudni odziv RC kruga:

$$|H(f)| = \left| \frac{U_{\text{izlaz}}(f)}{U_{\text{ulaz}}(f)} \right| = \frac{1}{\sqrt{1 + (2\pi f RC)^2}}$$

## Uzorkovanje i kvantizacija

Frekvencija uzorkovanja u pomaknutom pojasu:

$$f_u = 2 \frac{B + B_0}{M + 1}, \quad M_m = \left\lfloor \frac{B_0}{B} + 1 \right\rfloor$$

Varijanca kvantizacijskog šuma (srednja snaga):

$$\text{var}(Q) = \sigma_Q^2 = \frac{\Delta^2}{12} = \frac{1}{3} m_{\max}^2 2^{-2r}, \quad \Delta = \frac{2m_{\max}}{L}$$

Omjer srednje snage signala i snage kvantizacijskog šuma:

$$\frac{S}{N} = \frac{S}{\sigma_Q^2} = \left( \frac{3S}{m_{\max}^2} \right) 2^{2r}$$

U decibelima (samo za sinusni signal):

$$\left( \frac{S}{N_q} \right)_{dB} = 1.76 + 6.02r$$

Brzina prijenosa:

$$R = f_u r \quad \left[ \frac{\text{bit}}{s} \right]$$

## Entropija u kontinuiranom kanalu

$f$  su funkcije gustoće vjerojatnosti.

$$H(X) = E[-\log f_X(X)] = - \int_{-\infty}^{\infty} f_X(x) \log f_X(x) dx$$

$$f_X(x) = \int_{-\infty}^{\infty} f(x, y) dy$$

$$f_Y(y) = \int_{-\infty}^{\infty} f(x, y) dx$$

$$H(X|Y) = E[-\log f_{X|Y}(X|Y)] = - \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x, y) \log \left( \frac{f(x, y)}{f_Y(y)} \right) dx dy$$

$$H(X, Y) = E[-\log f(X, Y)] = - \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x, y) \log f(x, y) dx dy$$

$$I(X; Y) = E[-\log f_{Y|X}(Y|X)] = - \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x, y) \log \left( \frac{f(x, y)}{f_X(x)f_Y(y)} \right) dx dy$$

Prijenos u prisutnosti aditivnog šuma:

$$f_{Y|X}(y|x) = f_Z(y - x)$$

$$I(X; Y) = H(Y) - H(Y|X) = H(Y) - H(Z)$$

Kapacitet:

$$C = \max I(X; Y) = \max \left[ \frac{1}{2} \ln[2\pi e(\sigma_X^2 + \sigma_Z^2)] - \frac{1}{2} \ln(2\pi e\sigma_Z^2) \right] \\ = \frac{1}{2} \ln \left( 1 + \frac{S}{N} \right) \quad \left[ \frac{\text{bit}}{s} \right]$$

$$C = \frac{1}{2} \log_2 \left( 1 + \frac{S}{N} \right) \quad [\text{bit/simbol}]$$

## Maksimizacija entropije u kontinuiranom kanalu

- $x \in [a, b] \rightarrow f(x) = \frac{1}{b-a}, \quad H(X) = \ln(b-a) \quad [\text{nat/sym}]$
- $x \geq 0 \wedge E[X] = a > 0 \rightarrow f(x) = \frac{1}{a} e^{-x/a}, \quad H(X) = \ln(ae) = 1 + \ln a$
- $E[X] = 0 \wedge \exists \sigma_X \rightarrow f \text{ Gaussova}, \quad H(X) = \ln(\sigma_X \sqrt{2\pi e})$

## Ostalo

Srednja kvadratna pogreška,  $u_{qi}$  kvantizacijske razine:

$$N_q^2 = \sum_{u_{qi}} \int_{u_{qi}-\Delta/2}^{u_{qi}+\Delta/2} (u - u_{qi})^2 f(u) du \quad [V^2]$$

## Konverzije

U decibele (dB):

$$x \rightarrow 10 \log_{10}(x)$$

## Jedinice

$$c_k \leftrightarrow \left[ \frac{V}{Hz} \right]$$

$$S_X(f) \leftrightarrow \left[ \frac{W}{Hz} \right]$$