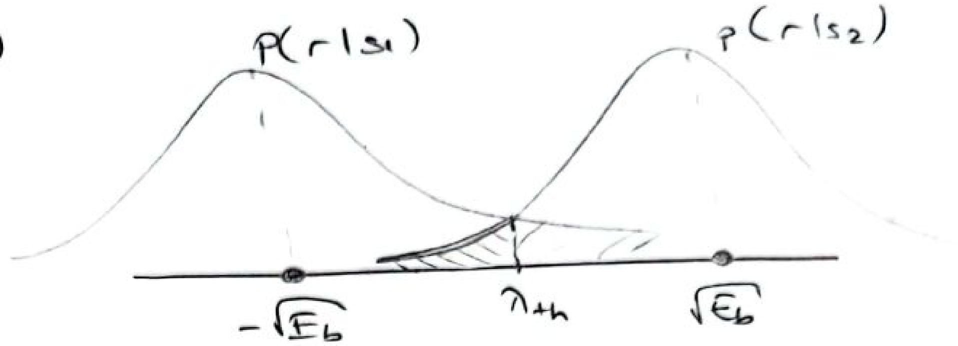
Q1) $r\sqrt{E_b} \underset{s_2}{\overset{s_1}{\gtrless}} \frac{\sigma_n^2}{2} \ln \frac{1-p}{p} = \frac{N_0}{4} \ln \frac{1-p}{p}$

a)



$$\lambda_{th} = \frac{N_0}{4\sqrt{E_b}} \ln \frac{1-p}{p}$$

$$P_e = p \cdot P(e|s_1) + (1-p)\, P(e|s_2)$$

$$= p \int_{\lambda_{th}}^{\infty} p(r|s_1)\, dr + (1-p) \int_{-\infty}^{\lambda_{th}} p(r|s_2)\, dr$$

$$= p \int_{\lambda_{th}}^{\infty} \frac{1}{\sqrt{2\pi\sigma_n^2}}\, e^{-\frac{(r+\sqrt{E_b})^2}{2\sigma_n^2}}\, dr$$

$z = \frac{r+\sqrt{E_b}}{\sigma_n}$

$dz = \frac{dr}{\sigma_n}$

$$+ (1-p) \int_{-\infty}^{\lambda_{th}} \frac{1}{\sqrt{2\pi\sigma_n^2}}\, e^{-\frac{(r-\sqrt{E_b})^2}{2\sigma_n^2}}\, dr$$

$$\Rightarrow \int_{\frac{\lambda_{th}+\sqrt{E_b}}{\sigma_n}}^{\infty} \frac{1}{\sqrt{2\pi\cancel{\sigma_n^2}}} \cdot e^{-\frac{z^2}{2}}\, dz \cdot \cancel{\sigma_n} = \int \frac{1}{\sqrt{2\pi}}\, e^{-\frac{z^2}{2}}\, dz$$

$$\int_{-\infty}^{\lambda_{th}} \frac{1}{\sqrt{2\pi\sigma_n^2}} e^{-\frac{(r-\sqrt{E_b})^2}{2\sigma_n^2}} dr$$

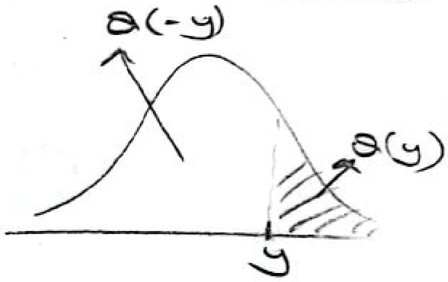
$$y = \frac{r-\sqrt{E_b}}{\sigma_n}$$

$$dy = \frac{dr}{\sigma_n}$$

$$= \int_{-\infty}^{\frac{\lambda_{th}-\sqrt{E_b}}{\sigma_n}} \frac{1}{\sqrt{2\pi\cancel{\sigma_n^2}}} e^{-\frac{y^2}{2}} dy \cdot \cancel{\sigma_n}$$

$$= \int_{-\infty}^{\frac{\lambda_{th}-\sqrt{E_b}}{\sigma_n}} \frac{1}{\sqrt{2\pi}} e^{-\frac{y^2}{2}} dy =$$

Remark: $$\boxed{Q(y) = \frac{1}{\sqrt{2\pi}} \int_{y}^{\infty} e^{-\frac{x^2}{2}} dx}$$



$$P_e = p \cdot Q\left(\frac{\lambda_{th}+\sqrt{E_b}}{\sigma_n}\right) + (1-p)\, Q\left(\frac{-\lambda_{th}+\sqrt{E_b}}{\sigma_n}\right)$$

$$\sigma_n^2 = \frac{N_b}{2} \Rightarrow \sigma_n = \sqrt{\frac{N_b}{2}}$$

$$\lambda_{th} = \frac{N_b}{4\sqrt{E_b}} \ln\left(\frac{1-p}{p}\right)$$

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b) $p = 0.3$, $\frac{E_b}{N_b} = 10$

$$P_e = 0.3\, Q(\cdots) + 0.7\, Q(\cdots)$$

$$= 3.535 \times 10^{-6}$$

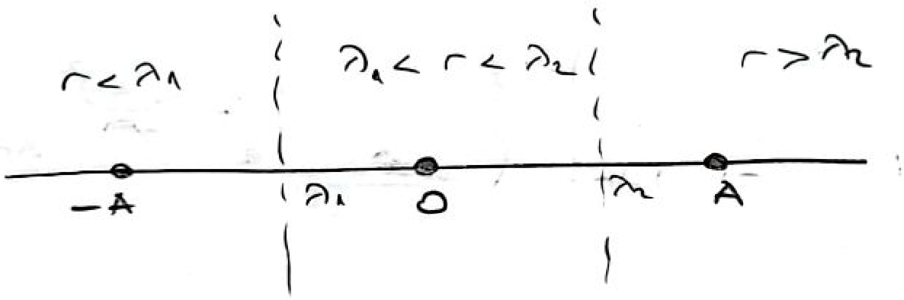
if $p = 0.5$, $\frac{E_b}{N_b} = 10$

$$P_e = \frac{1}{2} Q\left(\sqrt{\frac{2E_b}{N_b}}\right) + \frac{1}{2} Q\left(\sqrt{\frac{2E_b}{N_b}}\right)$$

$$= Q\left(\sqrt{\frac{2E_b}{N_b}}\right)$$

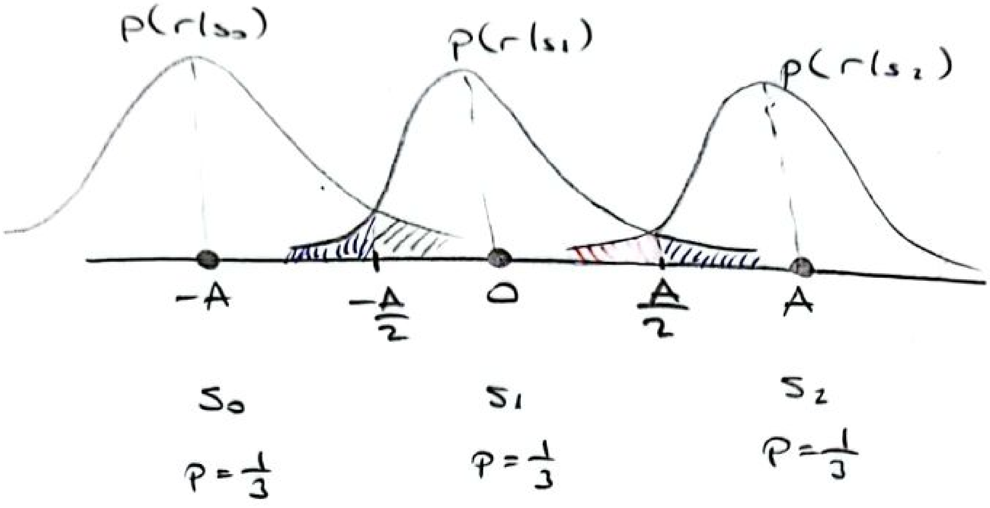
$$= 3.88 \times 10^{-6}$$

Q2)



Assumption

Equally probable symbols $\Rightarrow$ $\left.\begin{array}{l} \lambda_1 = -\frac{A}{2} \\ \lambda_2 = \frac{A}{2} \end{array}\right\}$ opt. threshold to minimize P_e.



AWGN with σ_n^2

$$P_e = \frac{1}{3} P(e|s_0) + \frac{1}{3} P(e|s_1) + \frac{1}{3} P(e|s_2)$$

$$P(e|s_0) = \int_{-\frac{A}{2}}^{\infty} p(r|s_0)\, dr = \int_{-\frac{A}{2}}^{\infty} \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(r+A)^2}{2\sigma_n^2}} dr$$

$$= Q\left(\frac{-\frac{A}{2}+A}{\sigma_n}\right) = Q\left(\frac{A}{2\sigma_n}\right)$$

$$P(e|s_2) = \int_{-\infty}^{\frac{A}{2}} p(r|s_2)\, dr = \int_{-\infty}^{\frac{A}{2}} \frac{1}{\sqrt{2\pi\sigma_n^2}} e^{-\frac{(r-A)^2}{2\sigma_n^2}} dr$$

$$= \int_{-\infty}^{\frac{\frac{A}{2}-A}{\sigma_n}} \frac{1}{\sqrt{2\pi}} e^{-\frac{y^2}{2}} dy$$

$$= Q\left(-\frac{\frac{A}{2}-A}{\sigma_n}\right) = Q\left(\frac{A}{2\sigma_n}\right)$$

$$P(e|s_1) = \int_{-\infty}^{-\frac{A}{2}} p(r|s_1)\,dr + \int_{\frac{A}{2}}^{\infty} p(r|s_1)\,dr$$

$$= \int_{-\infty}^{-\frac{A}{2}} \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(r-0)^2}{2\sigma^2}}\,dr + \int_{\frac{A}{2}}^{\infty} \text{same}$$

$$= \int_{-\infty}^{\frac{-\frac{A}{2}}{\sigma}} \cdots dy + \int_{\frac{\frac{A}{2}}{\sigma}}^{\infty} \cdots dy$$

$$= Q\left(-\frac{-A}{2\sigma}\right) + Q\left(\frac{A}{2\sigma}\right)$$

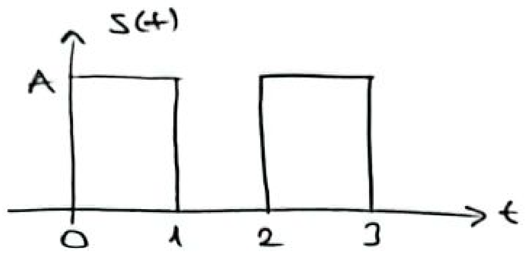
$$= 2Q\left(\frac{A}{2\sigma}\right)$$

$$P_e = \frac{1}{3} Q\left(\frac{A}{2\sigma}\right) + \frac{1}{3} 2Q\left(\frac{A}{2\sigma}\right) + \frac{1}{3} Q\left(\frac{A}{2\sigma}\right)$$

$$= \frac{4}{3} Q\left(\frac{A}{2\sigma}\right)$$

Q3)

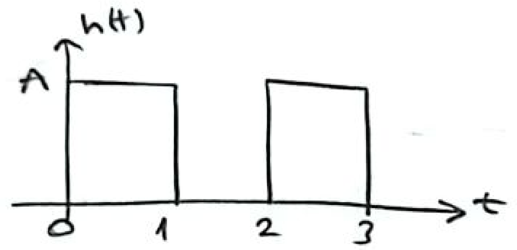
$$r(t) = s(t) + n(t)$$



$\Rightarrow T_b = 3$

$$h(t) = s(T_b - t) = s(3-t) = s(t)$$

a)



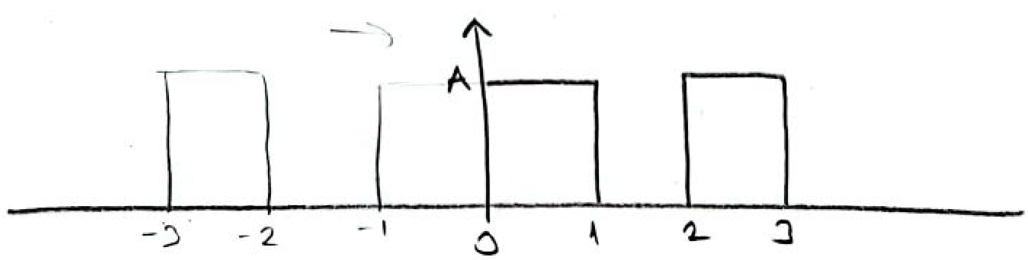
$r(t) \longrightarrow \boxed{MF} \longrightarrow y(t)$

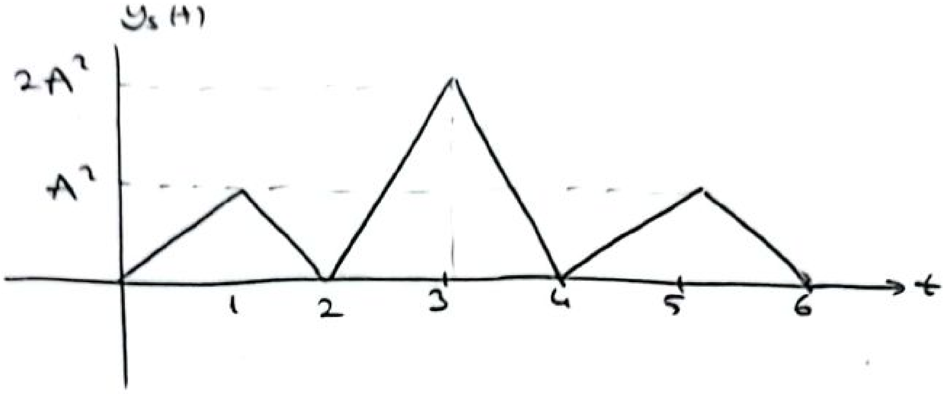
b) $y(t) = r(t) * h(t)$

$$= (s(t) + n(t)) * h(t)$$

$$= \underbrace{s(t) * h(t)}_{y_s(t)} + \underbrace{n(t) * h(t)}_{y_n(t)}$$

$$y_s(t) = s(t) * h(t) = s(t) * s(t)$$





$$y_n(t) = n(t) * h(t) = \int_0^{T_b} n(\tau)\, h(t-\tau)\, d\tau$$

$$t = T_b = 3 \Rightarrow \int_0^{T_b} n(\tau)\, \underbrace{h(T_b-\tau)}_{s(\tau)}\, d\tau$$

$$y_n(t)\Big|_{t=T_b} = \int_0^{T_b} n(\tau)\, s(\tau)\, d\tau$$

c)

the variance

$$E\{(y_n(t) - \mu_{y_n})^2\} \Rightarrow$$

aksi belirtilmediği için zero-mean noise kabul ettim.

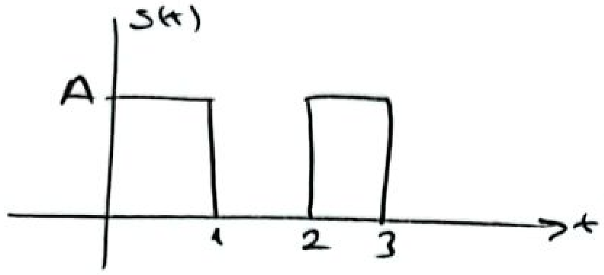
$$E\{y_n^2(t)\} = E\left\{ \int_0^{T_b} n(\tau) s(\tau)\, d\tau \cdot \int_0^{T_b} n(u)\, s(u)\, du \right\}$$

$$= E\left\{ \int_0^{T_b}\int_0^{T_b} n(\tau)\, n(u)\, s(\tau)\, s(u)\, d\tau\, du \right\}$$

$$= \int_0^{T_b}\int_0^{T_b} \underbrace{E\{n(\tau)\, n(u)\}}_{\frac{N_0}{2}}\, s(\tau)\, s(u)\, d\tau\, du \Big\}$$

$$\text{Var}(y_n(t)) = \frac{N_b}{2}\int_0^{T_b} s^2(\tau)\,d\tau = \frac{N_b}{2}\left[A^2 + A^2\right]$$

$$= N_b A^2$$



d) $P_e = Q\left(\sqrt{\left(\frac{S}{N}\right)_o}\right)$ antipodal equiprobable signals

$$\left(\frac{S}{N}\right)_o = \frac{y_s^2(T_b)}{E\{y_n^2(t)\}} = \frac{(2A^2)^2}{N_b A^2} = \frac{4A^4}{N_b A^2} = \frac{4A^2}{N_b}$$

or

$$\left(\frac{S}{N}\right)_o = \frac{2E_s}{N_b} = \frac{2(2A^2)}{N_b} = \frac{4A^2}{N_b}$$

$$P_e = Q\left(\sqrt{\frac{4A^2}{N_b}}\right)$$

The output SNR depends on the signal energy E_s not on the particular shape that is used.

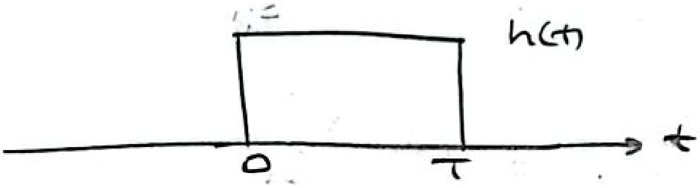
a4)

$$H(f) = \frac{1 - e^{-j2\pi f T}}{j2\pi f} \Rightarrow \text{sinc}$$

a) $h(t) = \mathcal{F}^{-1}\{H(f)\} \Rightarrow$ rectangular

$$H(f) = \underbrace{\frac{1}{j2\pi f}}_{\Downarrow \text{ unit step fnc.}} - \underbrace{\frac{e^{-j2\pi f T}}{j2\pi f}}_{\Downarrow \text{ delayed unit step fnc}}$$

$$h(t) = \text{sgn}(t) - \text{sgn}(t - T)$$

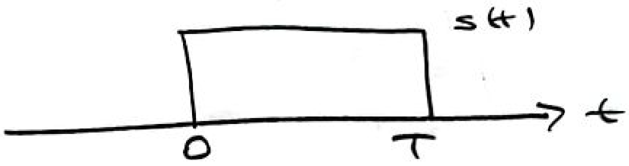


b) $h(t) = s(T - t)$

$$h(T - t) = s(\cancel{T} - (\cancel{T} - t))$$

$$\boxed{h(T - t) = s(t)}$$

$$h(T - t) = h(t) = s(t)$$



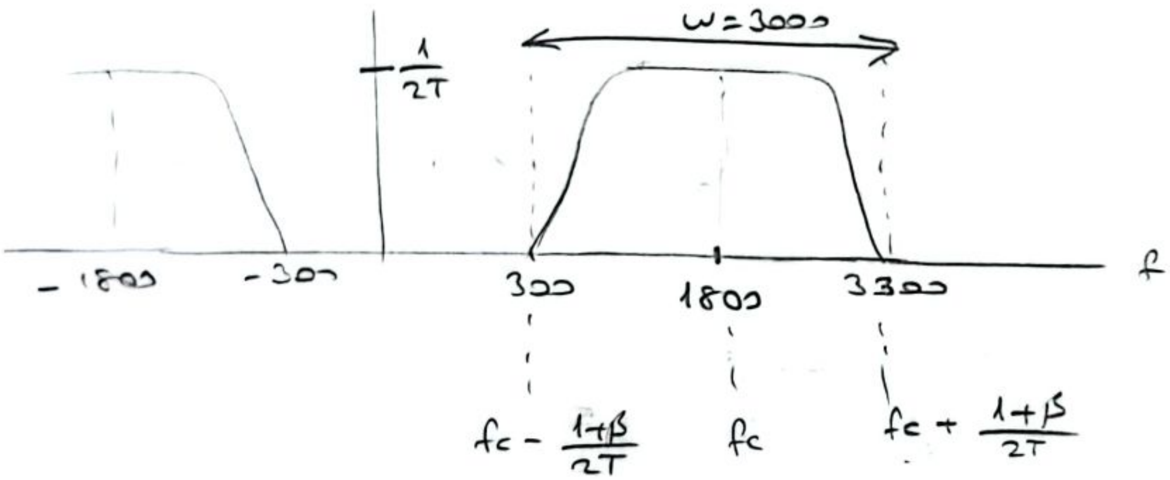
Q5) BW of the bandpass channel

$$W = 3300 - 300 = 3000 \text{ Hz}$$

$R = 2400$ symbols/s $\Rightarrow \frac{1}{T} = 2400 \frac{\text{sym}}{s}$

9600 bits/s

$$k = \frac{9600 \text{ bits/s}}{2400 \text{ sym/s}} = 4 \frac{\text{bits}}{\text{symbol}} \Rightarrow 16\text{-QAM}$$



$$X_{rc}(f) = \begin{cases} T & 0 \le |f| \le \frac{1-\beta}{2T} \\ \frac{T}{2}\left[1 + \cos\frac{\pi T}{\beta}\left(|f| - \frac{1-\beta}{2T}\right)\right] & \frac{1-\beta}{2T} \le |f| \le \frac{1+\beta}{2T} \\ 0 & |f| > \frac{1+\beta}{2T} \end{cases}$$

$0 \le \beta \le 1$ $\quad \beta = 0.5 \Rightarrow$ excess BW %50

$\beta = 1 \Rightarrow$ " " %100

$$\frac{1+\beta}{\cancel{2}T} = \frac{3000}{\cancel{2}} \Rightarrow 1+\beta = \frac{3000}{2400}$$

$$\boxed{\beta = 0.25}$$

CamScanner ile tarandı

Q6) $300 < f < 3000$ Hz passband

a) $9600 \frac{bits}{s}$

the BW $\Rightarrow$ $W = 3000 - 300 = 2700$ Hz

max. symbol rate $R_{max} = 2700 \frac{sym}{s}$

If M-ary PAM is used;

$$9600 \frac{bits}{s} = R \cdot k$$

$$\frac{9600}{k} = R \leq R_{max} = 2700 \frac{sym}{s}$$

$k=1 \Rightarrow R = 9600$ ✗

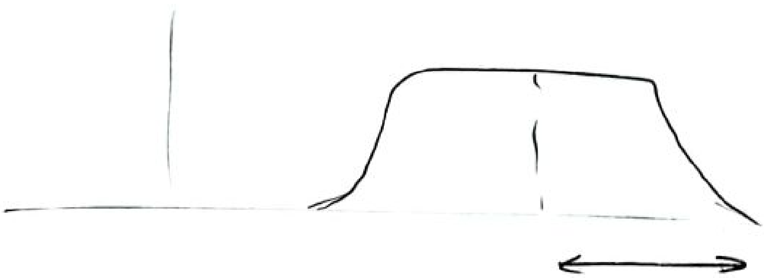
$k=2 \Rightarrow R = 4800$ ✗

$k=3 \Rightarrow R = 3200$ ✗

$\boxed{k=4} \Rightarrow \boxed{R = 2400}$ ✓

$$M = 2^k = 16$$

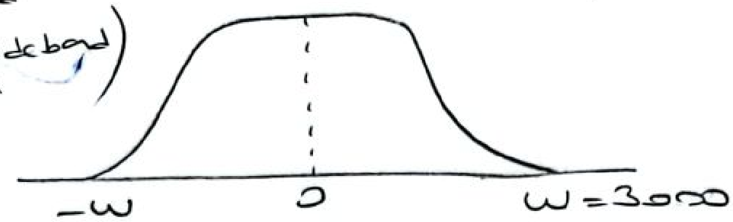
$$T = \frac{1}{R} = \frac{1}{2400} \text{ sec}$$



$$\frac{1+\beta}{\cancel{2}\underbrace{T}_{2400}} = \frac{2700}{\cancel{2}} \qquad \boxed{\beta = 0.125}$$

Q7) $W = 3000$ Hz

if baseband (single-sideband PAM)



$$\frac{1+\beta}{2T}$$

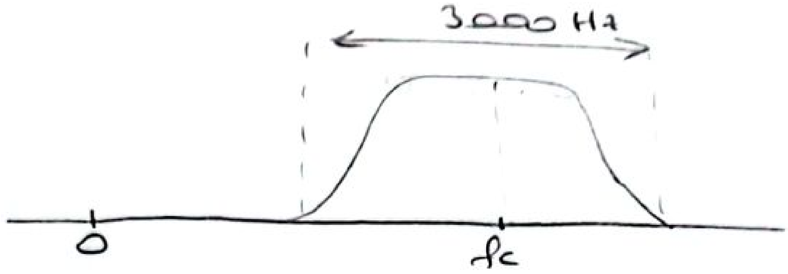
$$\frac{1+\beta}{2T} = 3000$$

$$\frac{1+\beta}{T} = 6000 \qquad R = \frac{1}{T}$$

$$R(1+\beta) = 6000$$

- $\beta = 0.25$ $R = 4800$
- $\beta = 0.33$ $R = 4512$
- $\beta = 0.5$ $R = 4000$
- $\beta = 0.67$ $R = 3592$
- $\beta = 0.75$ $R = 3428$.
- $\beta = 1$ $R = 3000$

if passband
(double-sideband PAM)



$$\frac{1+\beta}{2T} = 1500$$

$$R(1+\beta) = 3000$$

- $\beta = 0.25 \Rightarrow R = 2400$
- $\beta = 0.33 \Rightarrow R = 2256$
- $\beta = 0.5 \Rightarrow R = 2000$
- $\beta = 0.67 \Rightarrow R = 1796$
- $\beta = 0.75 \Rightarrow R = 1714$
- $\beta = 1 \Rightarrow R = 1500$

$\beta \uparrow , \quad R \downarrow$

Q8)

$$y_m = a_m + n_m + i_m$$

$a_m \to +1, -1$

$n_m \to N(0, \sigma_n^2)$

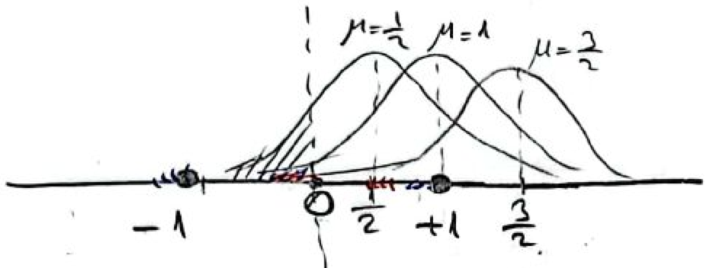
$i_m \to$ ISI $-\frac{1}{2}, 0, \frac{1}{2}$

$p = \{\frac{1}{4}, \frac{1}{2}, \frac{1}{4}\}$

<u>if $a_m = +1$</u>

$$y_m = +1 + n_m + i_m$$

i_m: $-\frac{1}{2}, 0, \frac{1}{2} \xrightarrow{+1} \frac{1}{2}, +1, \frac{3}{2}$ $\quad p = \frac{1}{4}, \frac{1}{2}, \frac{1}{5}$



$$P(e|+1) = \frac{1}{4}\int_{-\infty}^{0} \frac{1}{\sqrt{2\pi\sigma_n^2}} e^{\frac{-(r-\frac{1}{2})^2}{2\sigma_n^2}} dr + \frac{1}{2}\int_{-\infty}^{0} \frac{1}{\sqrt{2\pi\sigma_n^2}} e^{-\frac{(r-1)^2}{2\sigma_n^2}} dr$$

$$+ \frac{1}{4}\int_{-\infty}^{0} \frac{1}{\sqrt{2\pi\sigma_n^2}} e^{-\frac{(r-\frac{3}{2})^2}{2\sigma_n^2}} dr$$

$$= \frac{1}{4} Q\left(-\frac{0-\frac{1}{2}}{\sigma_n}\right) + \frac{1}{2} Q\left(-\frac{0-1}{\sigma_n}\right)$$

$$+ \frac{1}{4} Q\left(-\frac{0-\frac{3}{2}}{\sigma_n}\right)$$

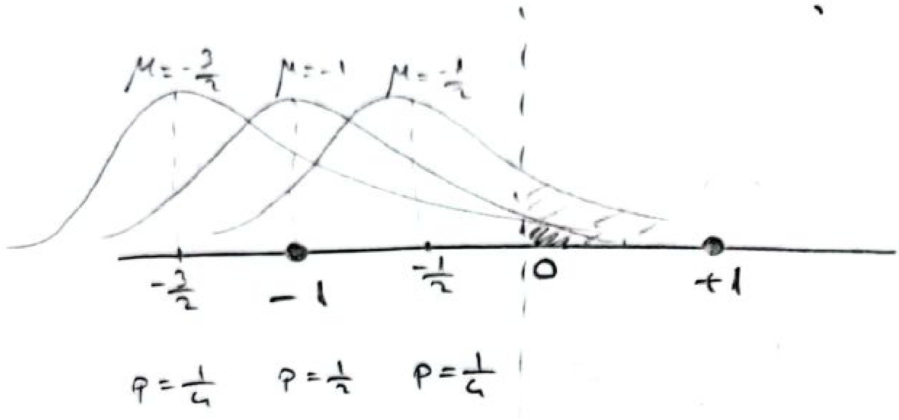
$$= \frac{1}{4} Q\left(\frac{1}{2\sigma_n}\right) + \frac{1}{2} Q\left(\frac{1}{\sigma_n}\right) + \frac{1}{4} Q\left(\frac{3}{2\sigma_n}\right)$$

$$P(e|-1) = P(e|+1)$$

if $a_m = -1$

$$y_m = -1 + n_m + i_m$$

$-\frac{1}{2} \quad 0 \quad \frac{1}{2}$



$y_m = -\frac{3}{2} + n_m$

$-1 + n_m$

$-\frac{1}{2} + n_m$

$$P(e|a_m=-1) = \frac{1}{4} Q\left(\frac{1}{2\sigma}\right) + \frac{1}{2} Q\left(\frac{1}{\sigma}\right) + \frac{1}{4} Q\left(\frac{3}{2\sigma}\right)$$

$$P_e = \underbrace{P(a_m=-1)}_{0.5} \cdot P(e|a_m=-1) + \underbrace{P(a_m=+1)}_{0.5} P(e|a_m=+1)$$

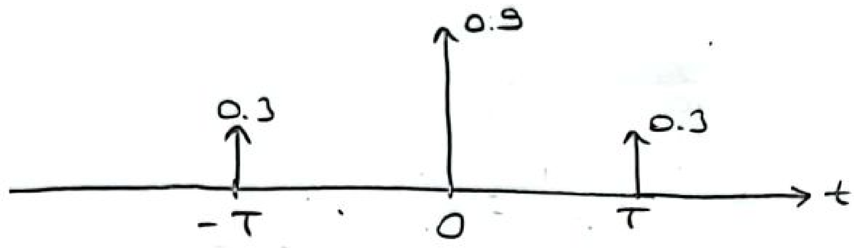
$$= \frac{1}{4} Q\left(\frac{1}{2\sigma}\right) + \frac{1}{2} Q\left(\frac{1}{\sigma}\right) + \frac{1}{4} Q\left(\frac{3}{2\sigma}\right)$$

99)

$$x_m = \begin{cases} 0.3 & m=1 \rightarrow h_1 \\ 0.9 & m=0 \rightarrow h_0 \\ 0.3 & m=-1 \rightarrow h_{-1} \\ 0 & \text{otherwise} \end{cases}$$

$$x(t) = s(t) * h(t)$$
$$= s(t) * 0.3\,\delta(t+T)$$
$$= 0.3\,\underbrace{s(t+T)}_{t=-T}$$

$$h(t) = \overbrace{0.3}^{h_{-1}}\,\underbrace{\delta(t+T)}_{t=-T} + \overbrace{0.9}^{h_0}\,\delta(t) + \overbrace{0.3}^{h_1}\,\underbrace{\delta(t-T)}_{t=T}$$



$$q_m = \sum_{n=-1}^{1} c_n\, h_{m-n}$$

equalizer

channel

$\Rightarrow$ convolution sum

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

$$q_m = c_{-1}\, h_{m+1} + c_0\, h_m + c_1 \cdot h_{m-1}$$

$m=-1 \Rightarrow q_{-1} = c_{-1} h_0 + c_0 h_{-1} + c_1 h_{-2}$

$m=0 \Rightarrow q_0 = c_{-1} h_1 + c_0 h_0 + c_1 h_{-1}$

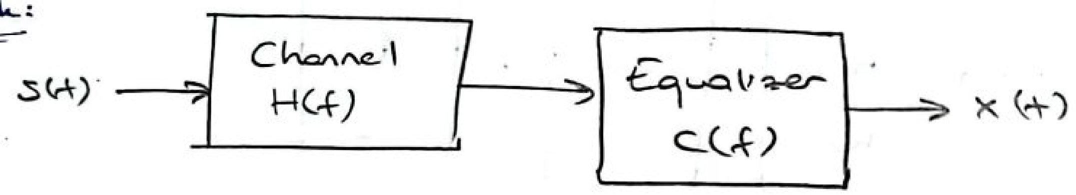
$m=+1 \Rightarrow q_1 = c_{-1} h_2 + c_0 h_1 + c_1 h_0$

$$\begin{bmatrix} h_0 & h_{-1} & h_{-2} \\ h_1 & h_0 & h_{-1} \\ h_2 & h_1 & h_0 \end{bmatrix} \begin{bmatrix} c_{-1} \\ c_0 \\ c_1 \end{bmatrix} = \begin{bmatrix} q_{-1} \\ q_0 \\ q_1 \end{bmatrix}$$

$$\begin{bmatrix} 0.9 & 0.3 & 0 \\ 0.3 & 0.9 & 0.3 \\ 0 & 0.3 & 0.9 \end{bmatrix} \begin{bmatrix} c_{-1} \\ c_0 \\ c_1 \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} c_{-1} \\ c_0 \\ c_1 \end{bmatrix} = \begin{bmatrix} -0.4762 \\ 1.4286 \\ -0.4762 \end{bmatrix}$$

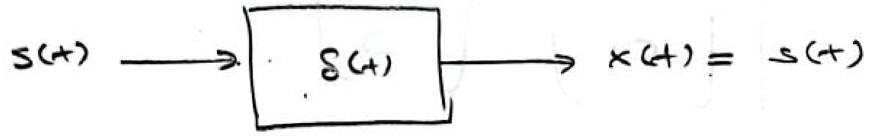
Remark:



$$H(f) \cdot C(f) = 1$$

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

IFFT



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b)

$$q_2 = \sum_{n=-1}^{1} c_n h_{2-n} = c_1 h_1 = -0.1429$$

$$q_{-2} = \sum_{n=-1}^{1} c_n h_{-2-n} = c_{-1} h_{-1} = -0.1429$$

residual interference

$$q_3 = \sum_{n=-1}^{1} c_n h_{3-n} = 0$$

$$q_{-3} = \sum_{n=-1}^{1} c_n h_{-3-n} = 0$$

Q10)

3-tap equalizer

ISI spans 3 symbols

$x(0) = 1 \qquad x(-1) = 0.3 \qquad x(1) = 0.2$

$$h(t) = h_{-1}\,\delta(t+T) + h_0\,\delta(t) + h_1\,\delta(t-T)$$

$$= x(-1)\,\delta(t+T) + x(0)\,\delta(t) + x(1)\,\delta(t-T)$$

$$\begin{bmatrix} h_0 & h_{-1} & h_{-2} \\ h_1 & h_0 & h_{-1} \\ h_2 & h_1 & h_0 \end{bmatrix} \begin{bmatrix} c_{-1} \\ c_0 \\ c_1 \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 0.3 & 0 \\ 0.2 & 1 & 0.3 \\ 0 & 0.2 & 1 \end{bmatrix} \begin{bmatrix} c_{-1} \\ c_0 \\ c_1 \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} c_{-1} \\ c_0 \\ c_1 \end{bmatrix} = \begin{bmatrix} -0.3405 \\ 1.1364 \\ -0.2273 \end{bmatrix}$$

Residual ISI :

$$q_m = \sum_{n=-1}^{1} c_n h_{m-n} = c_{-1} h_{m+1} + c_0 h_m + c_1 h_{m-1}$$

$$q_{-3} = c_{-1} \cancel{h_{-2}} + c_0 \cancel{h_{-3}} + c_1 \cancel{h_{-4}} = 0$$

$$q_{-2} = c_{-1} h_{-1} + c_0 \cancel{h_{-2}} + c_1 \cancel{h_{-3}} = -0.3405 \times 0.3$$
$$= -0.10227$$

$$q_{-1} = c_{-1} h_0 + c_0 h_{-1} + c_1 \cancel{h_{-2}} =$$
$$-0.3405 + 1.1364 \times 0.3 = 0$$

$$q_0 = \dots = 1$$

$$q_1 = \dots = 0$$

$$q_2 = c_{-1} \cancel{h_3} + \cancel{c_0 h_2} + c_1 h_1 = -0.2273 \times 0.2$$
$$= -0.04546$$

$$q_3 = 0$$

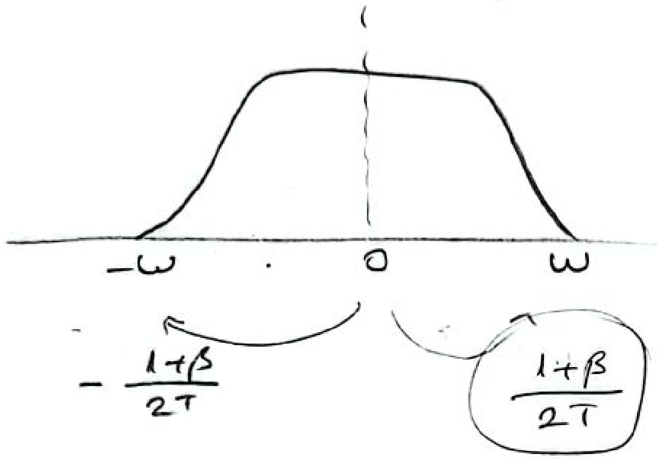
$$q_m = \begin{cases} 0 & m \leq -3 \\ -0.10227 & m = -2 \\ 0 & m = -1 \\ 1 & m = 0 \\ 0 & m = 1 \\ -0.04546 & m = 2 \\ 0 & m \geq 3 \end{cases}$$

residual ISI

Q11) $W_{max} = 75\ kHz$ (baseband channel)

$T_b = 10\ \mu s$

binary PAM $\Rightarrow k=1$ $\quad T_b = T_s = 10\ \mu s$



$$R = \frac{1}{T_s} = \frac{1}{10\mu s}$$

$$= \frac{10^6}{10} = 10^5$$

$$= 100.000\ \frac{sym}{sec}$$

$$\frac{1+\beta}{2T} = W$$

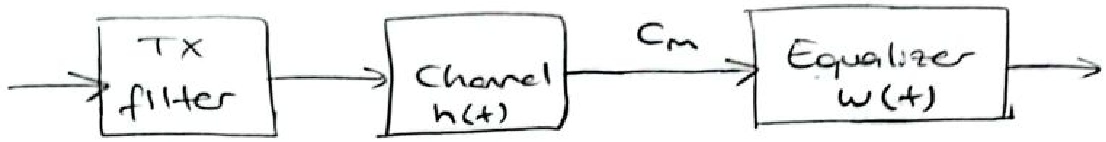
$$R(1+\beta) = 2W$$

$$1+\beta = \frac{2W}{R} = \frac{2W}{10^5}$$

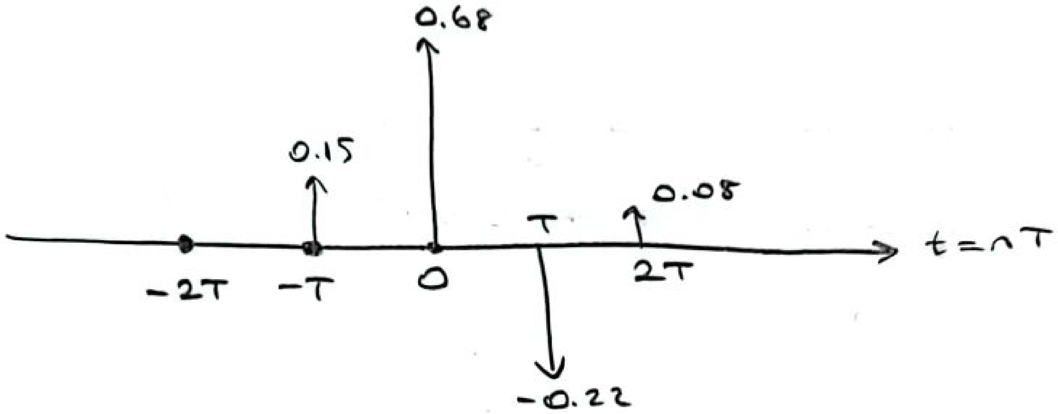
$$\beta = \frac{150 \times 10^3}{10^5} - 1$$

$$\boxed{\beta = 0.5}$$

Q12)



$$c_m = \{ \underset{c_{-2}}{0},\ \underset{c_{-1}}{0.15},\ \underset{c_0}{0.68},\ \underset{c_1}{-0.22},\ \underset{c_2}{0.08} \}$$



$$h(t) = \underbrace{0.15}_{h_{-1}}\,\delta(t+T) + \underbrace{0.68}_{h_0}\,\delta(t) - \underbrace{0.22}_{h_1}\,\delta(t-T) + \underbrace{0.08}_{h_2}\,\delta(t-2T)$$

$$\begin{bmatrix} h_0 & h_{-1} & h_{-2} \\ h_1 & h_0 & h_{-1} \\ h_2 & h_1 & h_0 \end{bmatrix} \begin{bmatrix} w_{-1} \\ w_0 \\ w_1 \end{bmatrix} = \begin{bmatrix} q_{-1} \\ q_0 \\ q_1 \end{bmatrix}$$

$$\begin{bmatrix} 0.68 & 0.15 & 0 \\ -0.22 & 0.68 & 0.15 \\ 0.08 & -0.22 & 0.68 \end{bmatrix} \begin{bmatrix} w_{-1} \\ w_0 \\ w_1 \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} w_{-1} \\ w_0 \\ w_1 \end{bmatrix} = \begin{bmatrix} -0.2825 \\ 1.2805 \\ 0.4475 \end{bmatrix}$$

$$q_m = \sum_{n=-1}^{1} w_n h_{m-n}$$

$$q_{-2} = w_{-1} h_{-1} + \cancel{w_0 h_{-2}} + \cancel{w_1 h_{-3}}$$

$$= -0.2825 \times 0.15$$

$$= -0.0424$$

$$q_2 = \cancel{w_{-1} h_3} + w_0 h_2 + w_1 h_1$$

$$= 1.2805 \times 0.08 + 0.4475 \times (-0.22)$$

$$= 0.004$$

$$q = \begin{bmatrix} -0.0424 \\ 0 \\ 1 \\ 0 \\ 0.004 \end{bmatrix}$$

$\rightarrow$ largest contribution to the residual ISI