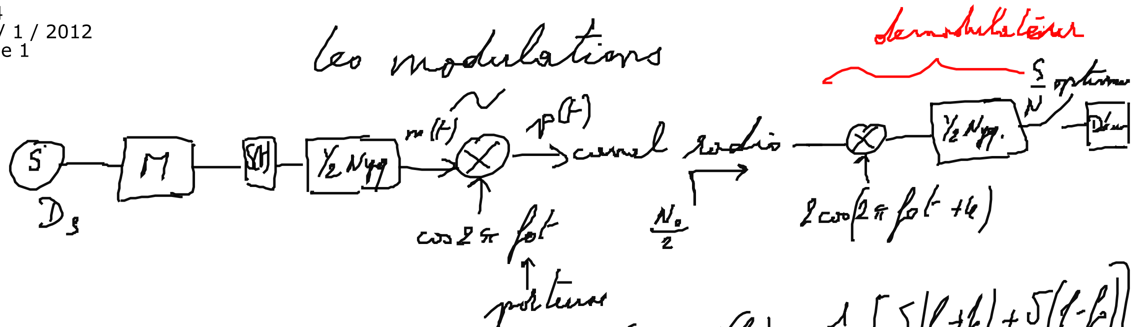
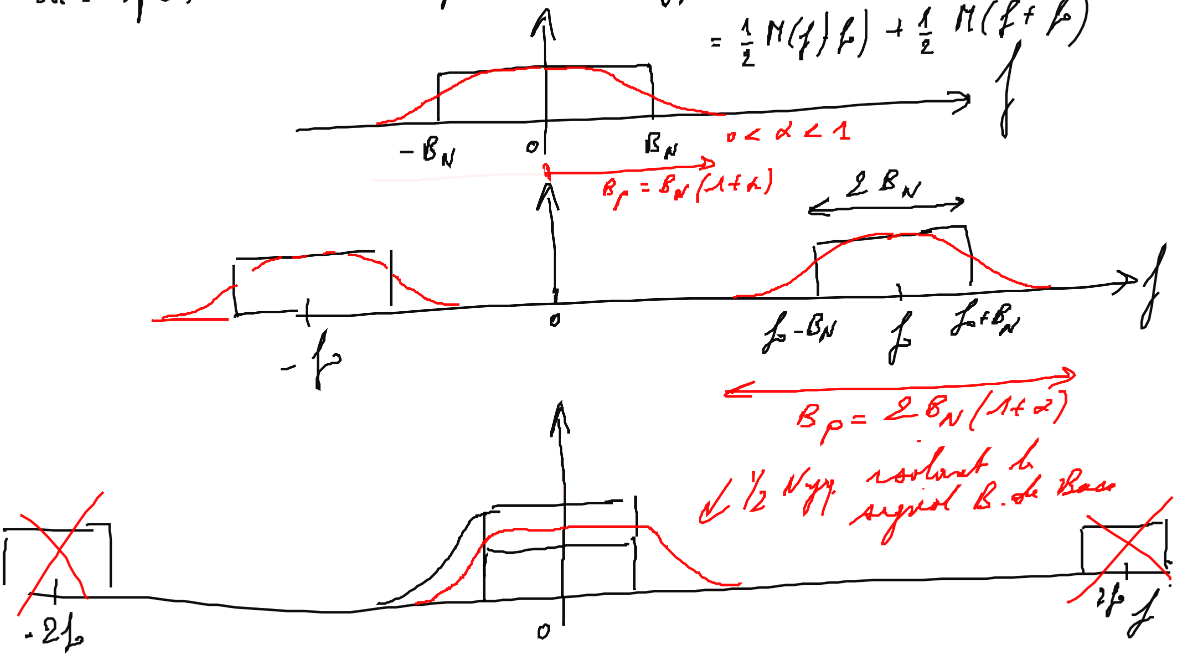
Les modulations



On a $p(t) = m(t) \cdot \cos 2\pi f_0 t \longrightarrow P(f) = M(f) * \frac{1}{2}\left[\delta(f+f_0) + \delta(f-f_0)\right]$

$= \frac{1}{2} M(f - f_0) + \frac{1}{2} M(f + f_0)$



Effet du déphasage φ de l'Oscillateur local (L.O.) O.L.

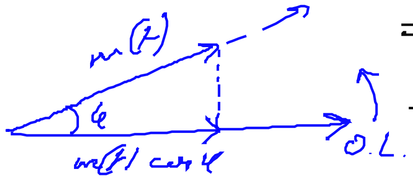
On reçoit $p(t) = m(t) \cos 2\pi f_0 t$

on démodule $\rightarrow p(t) \cdot 2 \cos(2\pi f_0 t + \varphi)$

$$= m(t) \cdot \cos \underbrace{2\pi f_0 t}_{a} \cdot 2 \cos(\underbrace{2\pi f_0 t + \varphi}_{b})$$

$\cos(a \pm b) = \cos a \cos b \mp \sin a \sin b$

démodu = produit scalaire = projection



$$= m(t) \left[\cos(4\pi f_0 t + \varphi) + \cos \varphi \right]$$

$$= \underbrace{m(t) \cos(2\pi\, 2 f_0 t + \varphi)}_{\text{termes centrés sur } 2f} + \underbrace{m(t) \cos \varphi}_{\text{terme b. de base}}$$

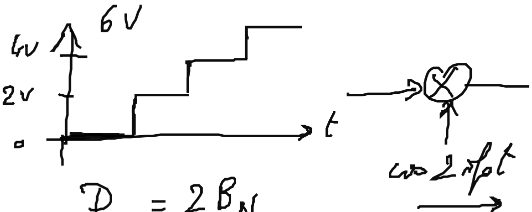
Après le ½ Nyquist

il reste $m(t) \cos \varphi < m(t)$ $\quad 0 < \cos \varphi < 1$

Si mauvais asservissement de phase du récepteur, on a une perte de niveau sur $m(t)$ et donc une dégradation du $\frac{S}{N}$ avant échantillonnage

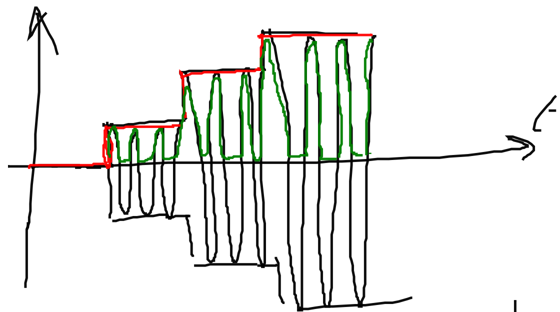
Les différentes modulations :

a) **Amplitude** (ASK) Amplitude Shift Keying



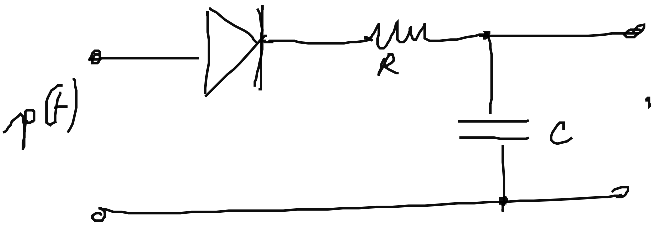
$D_C = 2B_N$

$B_p = B_N(1+\alpha)$



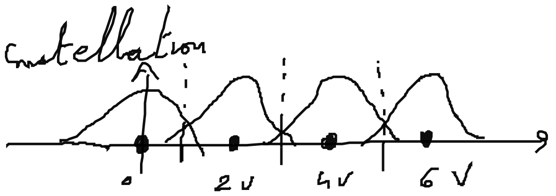
$B_p = 2B_N(1+\alpha)$

Démodulateur à diode :



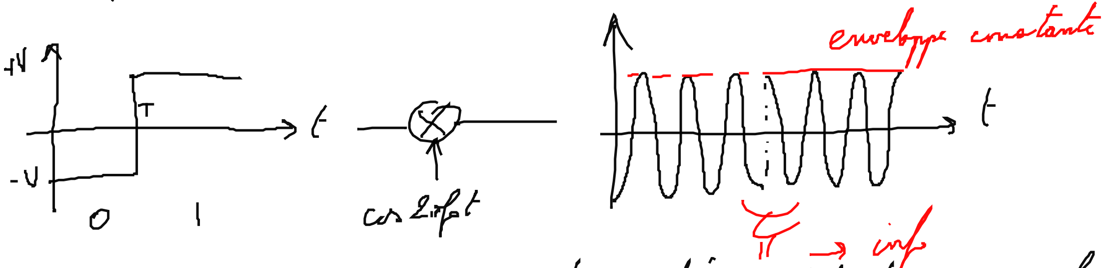
détecteur asynchrone ou incohérent.

constellation



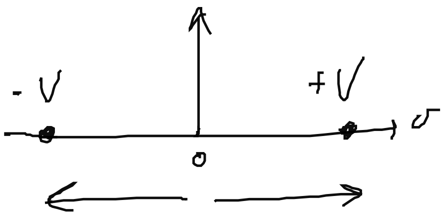
$P_e = \frac{6}{4} Q\left(\frac{V}{\sigma}\right) = \frac{3}{2} Q\left(\frac{V}{\sigma}\right)$

b) La BPSK (Modulation de phase binaire)



utilisation obligatoire d'un détecteur synchrone ou cohérent
(multiplicateur + O. Local asservi en phase)

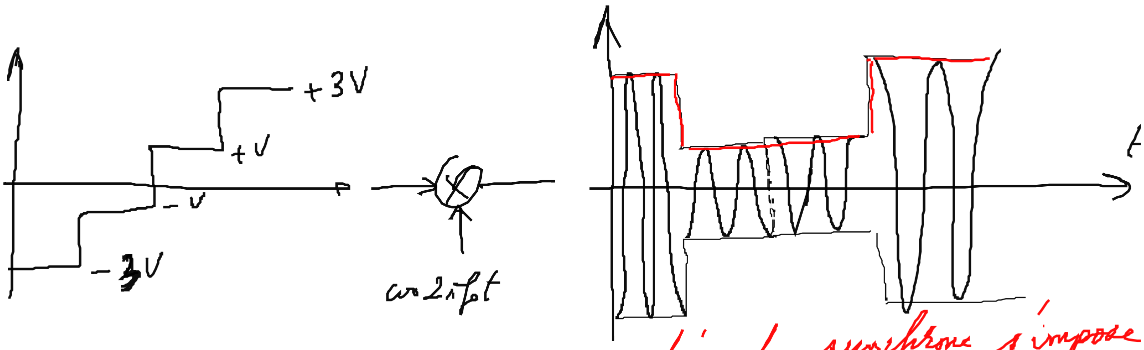
constellation :



$$P_e = Q\left(\frac{V}{\sigma}\right)$$

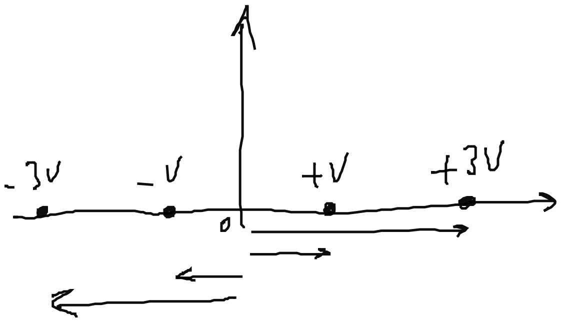
$$= Q\left(\sqrt{\frac{2E_B}{N_0}}\right)$$

c) L'APK (Amplitude and Phase Shift Keying)



un démodu synchrone s'impose

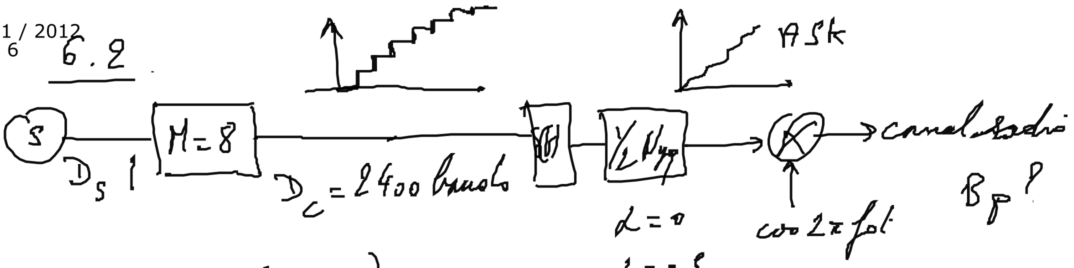
Constellation



$$P_e = \frac{6}{4} Q\left(\frac{V}{\sigma}\right)$$

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

6.2



$B_p = 2B_N(1+\alpha)$

$D_c = 2400$ bauds
$= 2B_N$ (critère de Nyquist)

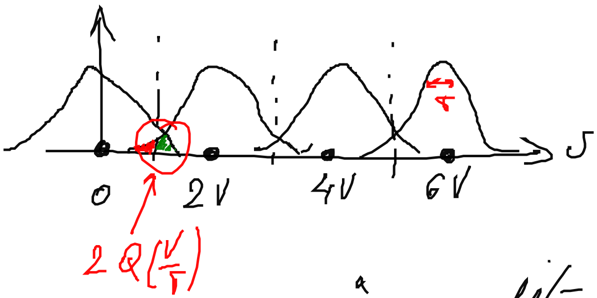
$2B_N = 2400$ Hz

a/ $\alpha = 0$
$B_p = 2B_N = 2400$ Hz

b) $\alpha = 0,5$
$B_p = 2400(1+0,5) = 3600$ Hz

Calcul du taux d'erreur pour la 4-ASK

constellation :



$$P_e = \frac{6}{4} Q\left(\frac{V}{\sigma}\right) = \frac{3}{2} Q\left(\frac{V}{\sigma}\right) = \frac{2(M-1)}{M} Q\left(\frac{V}{\sigma}\right)$$

grâce au filtrage adapté :

$$P_e = \frac{3}{2} Q\left(\sqrt{\frac{2V^2 T_{sy}}{N_0}}\right)$$

Retour au signal :

$$P_{moy} = \frac{(0)^2 + (2V)^2 + (4V)^2 + (6V)^2}{4} \rightarrow \Sigma x^2 p(x)$$

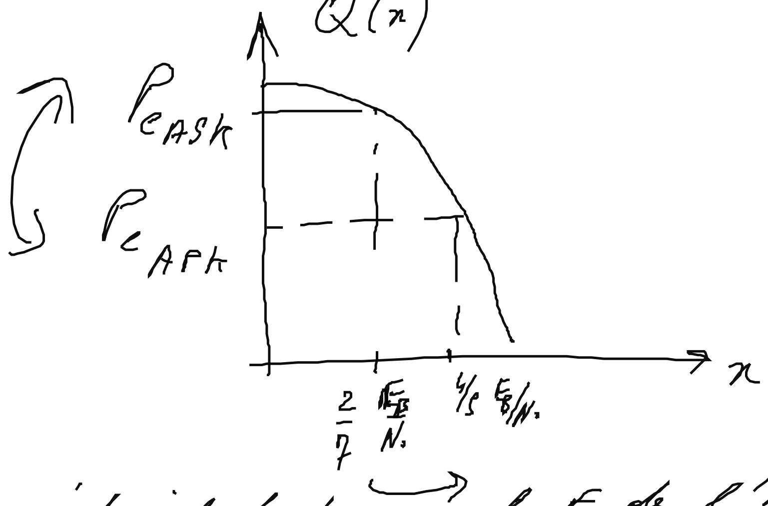
$$= \frac{4V^2 + 16V^2 + 36V^2}{4} = \frac{56V^2}{4} = 14V^2$$

$$\overline{E_S} = P_{moy} \cdot T_{sy} = 14V^2 T_{sy} \qquad E_B = \frac{\overline{E_S}}{\log_2 M} = \frac{14V^2}{2} = 7V^2 T_{sy} \text{ J/bit}$$

$$V^2 T_{sy} = \frac{1}{7} E_B \Rightarrow P_{e_{sy}} = \frac{3}{2} Q\left(\sqrt{\frac{2}{7}\frac{E_B}{N_0}}\right) \rightarrow P_{e_{bit}} = \frac{3}{4} Q\left(\sqrt{\frac{2}{7}\frac{E_B}{N_0}}\right)$$

Comparaison 4-ASK / 4APK

$$P_{e\,bit} = \frac{3}{4} Q\left(\sqrt{\frac{2}{7}\frac{E_B}{N_0}}\right) \qquad P_{e\,bit} = \frac{3}{4} Q\Big(\underbrace{\sqrt{\frac{4}{5}\cdot\frac{E_B}{N_0}}}_{x}\Big)$$



A P_e égale, il faut augmenter E_B de l'ASK pour rattraper l'APK → moins bon bilan énergétique pour l'ASK

6.9

$D_s = 64$ kbits/s $\longrightarrow$ 8-ASK $\qquad \alpha = 0{,}33$

B_p ?

$$B_p = 2B_N(1+\alpha)$$

$$= D_c \cdot (1+\alpha) \quad \text{(Nyquist)}$$

$$= \frac{D_s}{\log_2 M}(1+\alpha)$$

$$= \frac{64000}{3}(1+0{,}33) = 28373{,}33 \text{ Hz}$$

$$\simeq 28 \text{ kHz}$$

7.1 BPSK $B_p = 8000\ Hz$

D_s max ? $\alpha = 0$

$$B_p = 2 B_N \cdot (1 + \alpha)$$

$$8000 = 2 B_N (1 + 0)$$

$$= 2 B_N$$

$$= D_c \text{ (Nyquist)}$$

$$D_c = 8000 \text{ bauds}$$

$$D_s = D_c \cdot \log_2 M \quad M = 2 \text{ (Binary PSK)}$$

$$= 8000 \text{ bits/s}$$

7.4 $D_S = 2{,}08$ Mbits/s $P_{e\,bit} \leq 10^{-6}$

$\frac{N_0}{2} = 10^{-8}$ $\alpha = 1$

B_p ? S ?

a) Bande de base $(M = 2)$

$D_S = D_c \log_2 M \rightarrow D_S = D_c \rightarrow D_c = 2{,}08$ Mbauds

$D_c = 2 B_N \rightarrow 2 B_N = 2{,}08$ MHz

$B_p = \cancel{2} B_N (1+\alpha) = 2{,}08 \cdot 10^6 (1+1)$

$= \cancel{4{,}16}$ $2{,}08$ MHz

$P_{e\,bit} = Q\Big(\underbrace{\sqrt{\tfrac{2E_B}{N_0}}}_{x}\Big) < 10^{-6} \Rightarrow \sqrt{\frac{2E_B}{N_0}} = x = 4{,}75$

$E_B/N_0 = 4{,}75^2 \cdot \frac{1}{2} = 11{,}28 \rightarrow 10{,}5$ dB

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$$E_B = \frac{E_B}{N_0} \cdot N_0 \qquad \frac{N_0}{2} = 10^{-8}$$

$$= 11{,}28 \cdot 2 \cdot 10^{-8} = 22{,}56 \cdot 10^{-8}$$

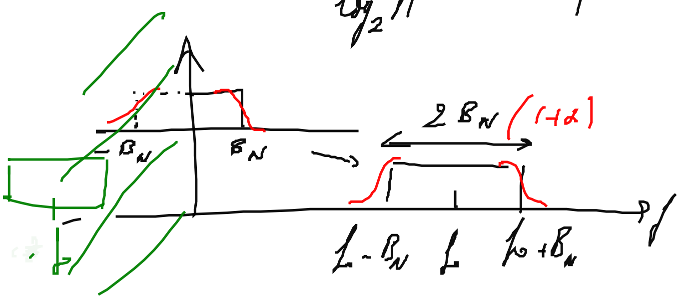
$$S = E_B \cdot D_S = 22{,}56 \cdot 10^{-8} \cdot 2{,}08 \cdot 10^{6} = 46{,}92 \cdot 10^{-2}$$

$$J/bit \times bit/A = J/A = W \qquad \cong 0{,}5\,W$$

b) Cas de la 16 APK

$$B_p = 2B_N(1+\alpha) = 4B_N$$

$$D_C = \frac{D_S}{\log_2 M} = \frac{2{,}08 \cdot 10^6}{4}$$



$$B_p = \frac{2{,}08 \cdot 10^6}{4/2} \cdot 2$$

$$= 1{,}04\ MHz$$

S nécessaire pour la 16-APK

$$P_{e_{symb}} = \frac{2(M-1)}{M} Q\left(\sqrt{\frac{6}{M^2-1}\frac{E_B}{N_0}\cdot \log_2 M}\right)$$

$$= \frac{30}{16} Q\left(\sqrt{\frac{24}{255}\frac{E_B}{N_0}}\right)$$

$$= \frac{15}{8} Q\left(\sqrt{\frac{8}{85}\cdot\frac{E_B}{N_0}}\right) \leq 10^{-6}$$

$$P_{e_{bit}} = \frac{P_{e_{sy}}}{\log_2 M} = \frac{15}{32} Q\left(\sqrt{\frac{8}{85}\cdot\frac{E_B}{N_0}}\right) \leq 10^{-6}$$

$$Q\left(\sqrt{\frac{8}{85}\frac{E_B}{N_0}}\right) \leq 10^{-6}\cdot\frac{32}{15} = 2{,}13 \cdot 10^{-6}$$

$$\sqrt{\frac{8}{85}\cdot\frac{E_B}{N_0}} = 4{,}60 \Rightarrow \frac{E_B}{N_0} = 4{,}60^2 \cdot \frac{85}{8} = 224{,}8$$

$$E_B = 224{,}8 \cdot 2 \cdot 10^{-8} = 449{,}6 \cdot 10^{-8} \text{ J/bit}$$

$$S = 449{,}6 \cdot 10^{-8} \cdot 2{,}08 \cdot 10^{+6} = 9{,}35 \text{ W}$$

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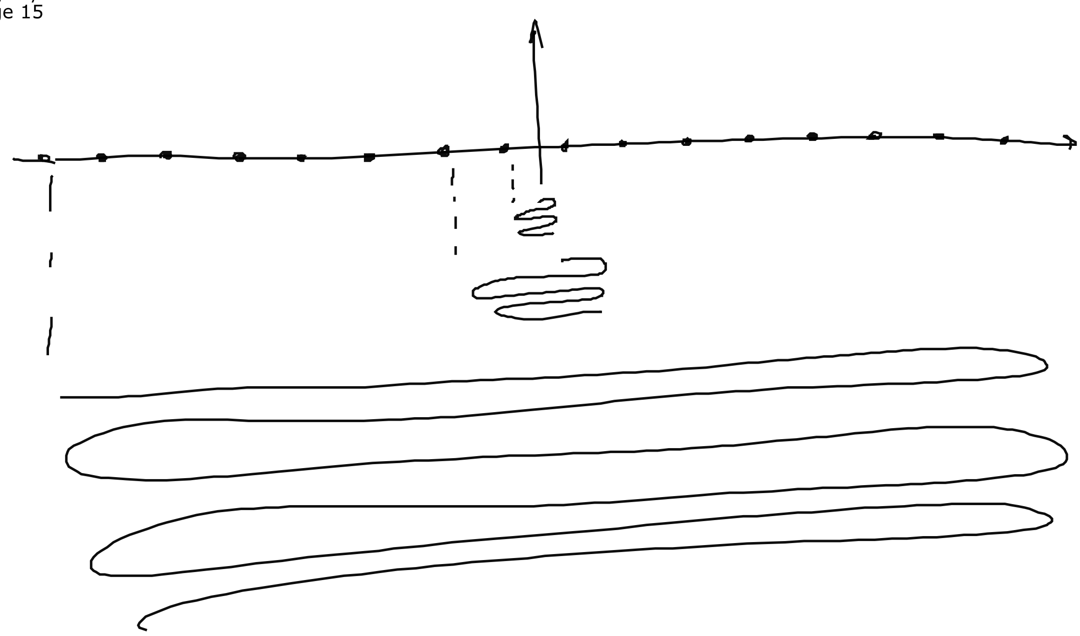
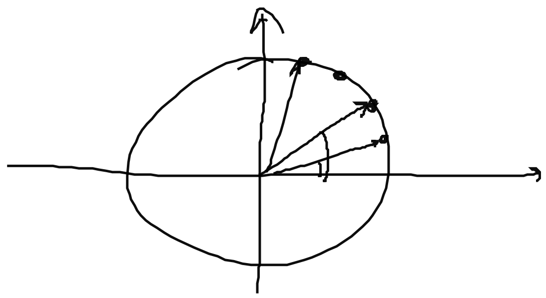


c) Cas de la 16 - PSK



$\hat{M}$ bande passante que pour APK

$$P_{e_{sy}} = 2Q\left(\sqrt{2\frac{E_B}{N_0}\cdot\log_2 M}\cdot\sin\frac{\pi}{M}\right)$$

$$P_{e_{bit}} = \frac{1}{2}Q\left(\sqrt{2\frac{E_B}{N_0}\cdot 4}\ \sin\frac{\pi}{16}\right) = \frac{1}{2}Q\left(\sqrt{8\frac{E_B}{N_0}}\ \sin\frac{\pi}{16}\right) \leq 10^{-6}$$

$$Q\left(\sqrt{8\frac{E_B}{N_0}}\ \sin\frac{\pi}{16}\right) \leq 2.10^{-6}$$

$$\sqrt{8.\frac{E_B}{N_0}}\cdot\sin\frac{\pi}{16} = 4,61 \longrightarrow \frac{E_B}{N_0} = \left(\frac{4,61}{\sin\frac{\pi}{16}}\right)^2\cdot\frac{1}{8} = 69,8$$

$$E_B = 69,8 . 2.10^{-8} = 139,6.10^{-8} \Rightarrow S = 139,6.10^{-8}.2,08.10^6 = 2,9\ W$$