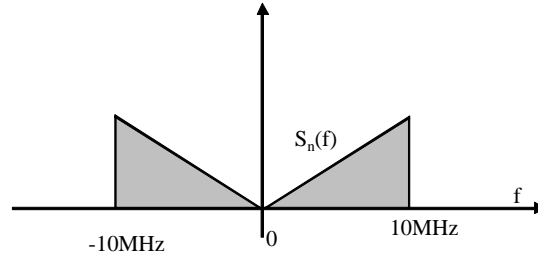


Quick translation is only to ease foreign-language students, make always reference to italian's text in any case

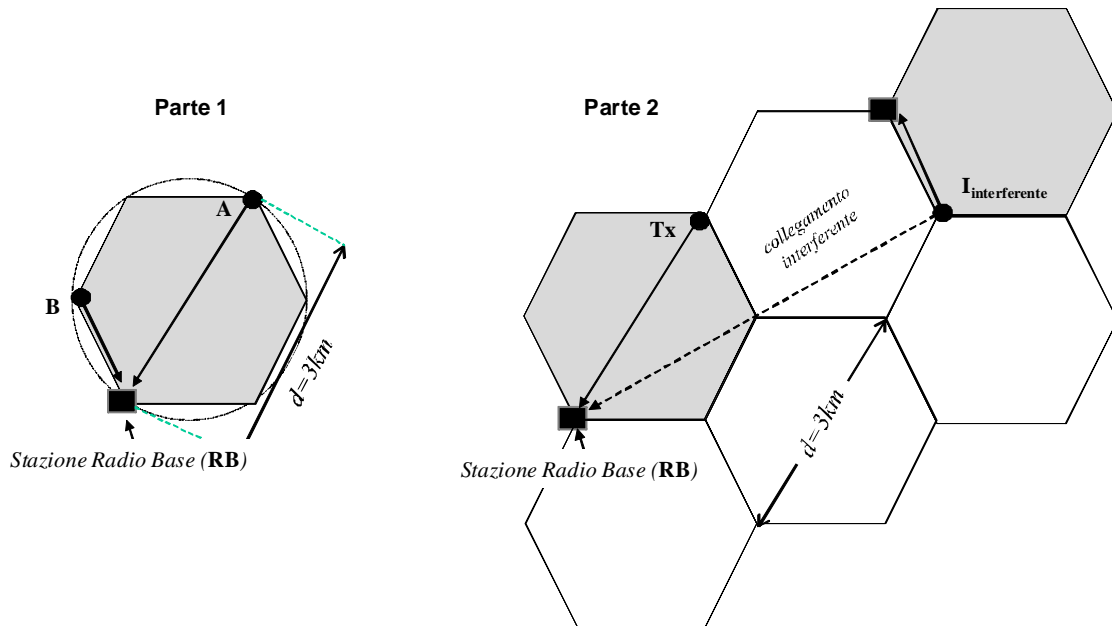
**Domanda di ammissione (obbligatoria) (foglio azzurro con nome)**

Noise  $n(t)$  has power 3dBm and power spectral density  $S_n(f)$  up to 10MHz as in figure below. Evaluate the power (in dBm) after filtering with high-pass filter with cut-off frequency  $f_{low} = 7.5MHz$ .



**Progetto (foglio bianco - 26 punti)**

In cellular system users are connected to base station (RB) with some users re-using the same frequency interfering with in-cell users. Here we evaluate the least favourable link Tx to RB (up-link) in presence of one interferer as in fig.(Part2) for hexagonal cells size  $d = 3km$ .



All the links have the same specifications (except power): QPSK modulation roll-off  $\alpha = 25\%$ ,  $R_b = 3Mb/s$ , error probability as follows from transmission of PCM signals quantized at 8bit/sample, carrier  $f_c = 1GHz$ , antenna at mobile (Tx) with gain  $G_T = 4dB$ , receiving antenna gain (at RB)  $G_R = 12dB$ , equivalent noise temperature at antenna  $T_{ant} = 400K$ . The receiving equipment: first amplifier  $G_1 = 6dB$  e noise factor  $F_1 = 8dB$ , second stage gain  $G_2 = 30dB$  and  $F_2 = 10dB$  (recall that noise factor is referred to  $T_0 = 290K$ , with  $KT_0 = -173dBm/Hz$ ).

**Parte 1:**

- 1) Block diagram of TX and RB, calculate spectral bandwidth at carrier frequency.
- 2) Evaluate power spectral density of noise at the receiver

3) Assume that there are NO interferers (as in Part 1 of figure), evaluate the min transmission power at points A e B in figure as  $P_{T-A}$  and  $P_{T-B}$ .

**Parte 2:**

Refer to Part 2 of figure now with interferer  $I_{interferente}$  that trasmit at power  $P_{T-B}$  in position indicated.

- 4) Illustrate that the scenario is the least favourable for intererence in link **Tx→RB**
- 5) Calculate the error prob.  $P_b(E)$  by accounting also for interference.

Since performance are degraded by interference, compare the two solutions:

- 6) Assume that BCH coding is used with  $(n, k, d) = (15, 7, 5)$ , evaluate the error probability when using an hard-decoder.
- 7) Assume to use a spread spectrum for all terminals, evaluate the spectrum expansion factor to comply with specifications even in presence of interference.

**Domande (fogli gialli/rosa - 16 punti)** indicare sul foglio la domanda a cui si sta' rispondendo, si riporti brevemente (max 1 pagina) il procedimento e si evidenzi il risultato finale.

**D1-giallo. punti: 4)**

Packet transmission with packet size  $N = 100\text{bit}$  and ARQ (even for just 1 error/packet). The transmitter's battery has max capacity  $E_{Tot} = 1000\text{Joule}$ , the bit error probability  $P_b(E) = 10^{-2}$  and the energy spent to transmit one bit is  $E_1 = 100\text{pJ}$ , the required (net) rate for the information bits is  $R_b = 100\text{kb/s}$ :

- a) Illustate the system
- b) Calculate the packet error probability
- c) How many information bits can you send and for how long before the system runs out of battery capacity.

**D2-giallo. punti: 5)**

Communication system with 64QAM and  $R_b = 2\text{Mb/s}$  has  $P_b(E) \leq 10^{-3}$  using  $P_T = 20\text{dBm}$ .

The link is now affected by rayleigh fading caused by multipath, we need to have an outage of 1msec every 1sec of operation:

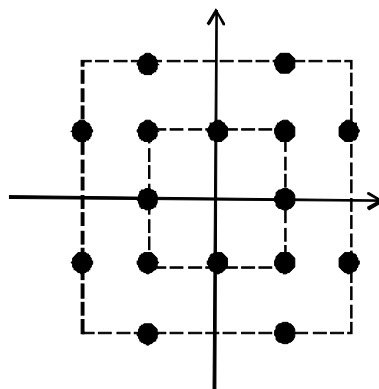
- a) Calculate the new transmission power  $P_T$  in this case.
- b) For space diversity with 4 antennas at receiver, calculate the new transmission power  $P_T$  in this case and give the schematics of TX and RX.
- c) For frequency diversity over 4 independent frequency calculate the new transmission power  $P_T$  in this case and give the schematics of TX and RX.
- d) Assume that for case (a1) the Tx can choose to use BPSK by preserving the RF bandwith: evaluate the new  $R_b$  and the new transmission power  $P_T$  in this case.

**D3-rosa. punti: 2)**

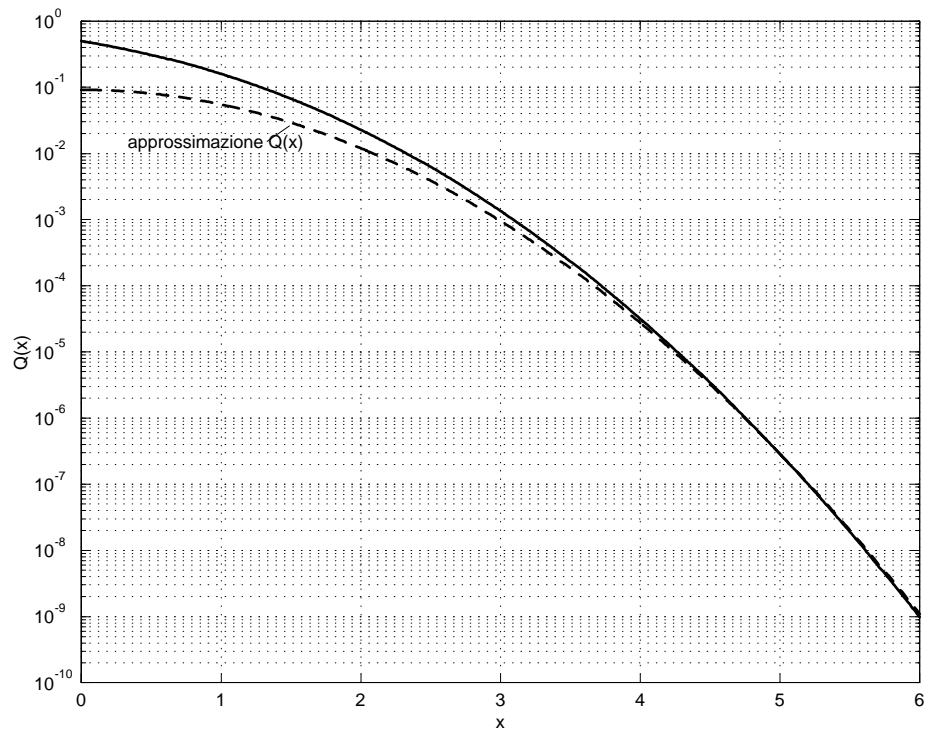
Discuss shortly (max 1page) what is the intermodulation in power amplifier and illustrate the consequences for an FDM communication system

**D4-rosa. punti: 4)**

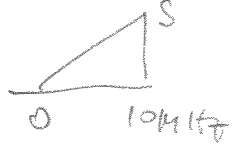
For transmission of  $R_b = 50\text{Mb/s}$  and  $E_s/N_0 = 12\text{dB}$  we use the constellation in figure, define a mapping and calculate the error probability.



Si ricorda l'approssimazione  $\log_{10} Q(x) \simeq -1.04 - 0.22x^2$  riportata anche in figura (linea tratteggiata).



$$S_u(f) = \frac{S}{10 \text{ MHz}} f = \frac{2 \mu\text{W}}{(10 \text{ MHz})^2} f$$



$$S \times 10 \text{ MHz} = 2 \mu\text{W}$$

26/2/10

Sol C 1

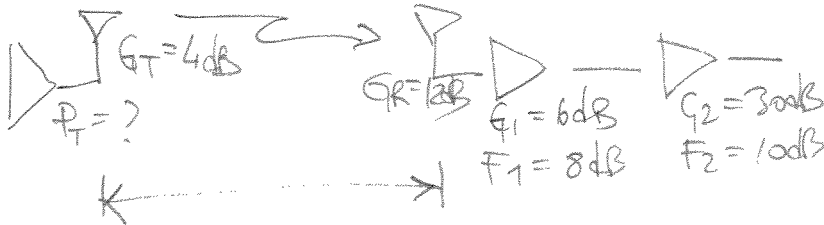
$$P = 2 \int_{7,5}^{10} \frac{2 \mu\text{W}}{(10 \text{ MHz})^2} f \, df = \frac{2 \mu\text{W}}{(10 \text{ MHz})^2} (10^2 - 7,5^2)$$

$$= 2 \mu\text{W} \left(1 - \left(\frac{7,5}{10}\right)^2\right) = 0,88 \mu\text{W}$$

$$= 3 \text{ dBm} - 3,59 = -0,59 \text{ dBm}$$

## Proprietà

$$T_{\text{ant}} = 400 \text{ K}$$



$$B_{\text{RF}} = 1,5 \text{ MHz} (1 + \alpha) = 1,88 \text{ MHz}$$

$$P_b(\epsilon) \approx \frac{2^{-2 \times 8}}{4} \sim 3 \times 10^{-6}$$

$$\gamma = \frac{G_T G_R}{(4\pi)^2} \times \frac{1}{(d/\lambda)^2} = 12 + 4 - 22 - 20 \log_{10}(d/\lambda) = -6 - 20 \log_{10}(d/\lambda)$$

Voilà:

$$T_{\text{amb}} = 400 \text{ K}$$

$$T_{\text{ep1}} = 290 (F_1 - 1) = 1540 \text{ K}$$

$$T_{\text{ep2}} = 290 (F_2 - 1) = 2608 \text{ K}$$

$$T_{\text{ep}} = 400 + 1540 + \frac{2608}{4} = 2592 \text{ K}$$

$$k T_{\text{ep}} = N_0 = -173 \frac{\text{dBm}}{\text{Hz}} + 10 \log_{10} \frac{2592}{290}$$

$$= -163 \text{ dBm/Hz}$$

Atmosfera:

$$\lambda = 0,3 \text{ m}$$

$$d_A = 3 \text{ km} \quad \gamma_A = -6 - 20 \log_{10} \left(\frac{3 \times 10^3}{0,3 \times 10^3}\right) = -86 \text{ dB}$$

$$d_B = 1,5 \text{ km} \quad \gamma_B = \gamma_A + 6 \text{ dB} = -80 \text{ dB}$$

Link budget:

$$P_b(\epsilon) = Q\left(\sqrt{\frac{E_s}{N_0}}\right) = 3 \times 10^{-6}$$

$$Q(x) = 3 \times 10^{-6} \rightarrow x \sim 4,5$$

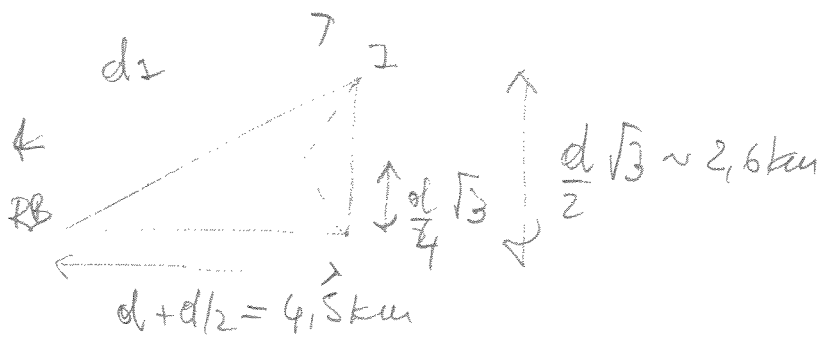
$$\frac{E_s}{N_0} = 4,5^2 = 13,06 \text{ dB} = \frac{E_s \times R_s}{N_0 \times R_s} = \frac{P_R}{N_0 \times R_s}$$

$$P_R \geq 13,06 - 163 \frac{\text{dBm}}{\text{Hz}} + 10 \log_{10} 1,5 \times 10^6 = -88,24 \text{ dBm}$$

$$P_{T_A} \geq -88,24 + 86 = -2,2 \text{ dBm}$$

$$P_{T_B} \geq -8,2 \text{ dBm}$$

(-64 dB in verso A)



$$d_2 = \sqrt{4,5^2 + 2,6^2} = 5,2 \text{ km}$$

$$= d\sqrt{3}$$

$$P_{TX-intenf} = P_{T-B} = -8,2 \text{ dBm}$$

$$P_{RX-intenf} = -8,2 \text{ dBm} + \gamma_{I-RB} = -8,2 \text{ dBm} - 6 \text{ dB} - 20 \log_{10} \frac{5,2 \times 10^3}{3 \times 10^1} =$$

$$\approx -99,77 \text{ dBm}$$

$$P_{RX-segnale} = -88,24 \text{ dBm} \quad (\text{caso nominale})$$

$$P_{noise} = N_0 \times R_s = -163 \text{ dBm/Hz} + 61,76 \text{ Hz} = -101,3 \text{ dBm}$$

$$P_b(f) = Q \left( \sqrt{\frac{E_s R_s}{N_0 R_s + P_{RX-intenf}}} \right) = Q \left( \sqrt{\frac{8,75}{10}} \right) \approx 2 \times 10^{-3}$$

Q(2,74)

$$P_{noise} + P_{RX-intenf} = -101,3 + 9,9 = -97 \text{ dBm}$$

$$P_{segnale} = -88,24 + 97,0 = 8,75 \text{ dB} \quad (\text{per il } 4,25 \text{ dB})$$

↓  
per il resto per il resto.

$$P_{noise} + P_{RX-intenf}$$

BCH (15, 7, 5)

$$p = 2 \times 10^{-3}$$

$$t = 2$$

26/2/12

Sol. C 3

$$P_{\text{cod}}(t) = \binom{14}{2} p^3 = \frac{14!}{2(14-2)!} 8 \times 10^{-9} = \frac{14 \cdot 13 \cdot 12}{2 \cdot 12!} 8 \times 10^{-9} = 7,2 \times 10^{-7} \quad (\text{ok!})$$

CDMA

$$P_{\text{segnale}} = -88,26 + 99 = 11 \text{ dB} \quad | \text{ canale CDMA}$$

Tutte

$P_{\text{RX, interf}}$

quindi è necessario compensare solo 2 dB  
 con un sistema CDMA dove c'è un  
 solo interferente.

$$\frac{P_{\text{segnale}}}{P_{\text{RX, interf}}} \underset{\text{especificazione}}{Q} \geq 13 \text{ dB} \quad (\text{requisito } Q \geq 5)$$

$$Q \geq 2 \text{ dB} \rightarrow \boxed{Q = 2}$$

Entrambi i sistemi hanno una copertura di  
 banda circa doppia  $\rightarrow$  sistema codificato BCH  
 quantifica una fut. di essere fin. favorevole.

D1  $P_{PK} = 1 - (1 - P_e)^{100} = 0.63$

Soll 4

Efeletto = 10 nJ (= 100 pJ x 100)

Energia suff. per  $\frac{10^3 \text{ joule}}{10^{-8} \text{ joule}} = 10^{11}$  pacchetti totali  
(compresi ritrasmissioni)

Ogni pacchetto N=100 bit di informazione  
Moltiplicare le trasmissioni di  $\frac{1}{1 - P_{PK}} = \frac{1}{0.37} = 2.73$  pacchetti  
2.73 = 1 pacchetto informazione + 1.73 pacchetti ritrasmissioni ARQ

N. totale pacchetti (di informazione) =  $10^{11} \times 0.37 = 3.7 \times 10^{10}$  pacchetti.

Tot. bit trasmessi =  $3.7 \times 10^{10} \text{ pacchetti} \times 100 \text{ bit} = 3.7 \times 10^{12} \text{ bit}$

Durata =  $\frac{3.7 \times 10^{12} \text{ bit}}{10^5 \text{ bit/s}} = 3.7 \times 10^7 \text{ sec.} \approx 10^4 \text{ h} = 416 \text{ pp.}$

D2 Vedi analogo tema Soll 4/2/2005 - D3

si intende:

- a)  $\alpha = 30 \text{ dB}$   $P_T = 20 + 30 = 50 \text{ dBm}$
- b)  $\alpha = \frac{20}{4} \text{ dB}$   $P_T = 20 + 7.5 = 27.5 \text{ dBm}$
- c)  $\alpha = \frac{20}{4} = 7.5 \text{ dB}$   $P_T = 20 + 7.5 + 6 = 33.5 \text{ dBm}$   
4 freq.

d)  $R_b = \frac{2}{6} = 333 \text{ kb/s}$ .  $\frac{4}{6} Q\left(\sqrt{\frac{1}{21} \frac{E_s}{N_0}}\right) = P_b(\text{BPSK})$  } uguale esponente  
 $Q\left(\sqrt{\frac{2E_s}{N_0}}\right) = P_b(\text{BPSK})$  } alla funzione Q()  
 fu uguale  
 prestazioni con  
 frequenza:

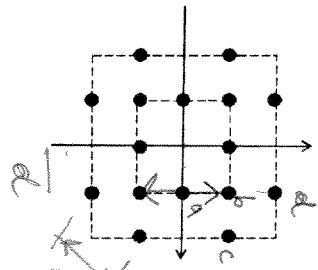
Eventi uguali  
branch:  $\frac{E_s, \text{BPSK}}{21} = 2E_s, \text{BPSK} \rightarrow P_{T, \text{BPSK}} = P_{T, \text{BPSK}} / 42 \rightarrow P_{T, \text{BPSK}} = 33.7 \text{ dBm}$

**D3-rosa. punti: 2)**

Il fenomeno dell'intermodulazione negli amplificatori di potenza; si illustri il problema e le conseguenze per un sistema di trasmissione (si pensi ad un sistema FDM). (Max 1 pagina)

**D4-rosa. punti: 4)**

Per la trasmissione di simboli equiprobabili a ritmo di  $R_b = 50 \text{ Mb/s}$  e rapporto  $E_b/N_0 = 12 \text{ dB}$ , si adotta la costellazione in figura (rappresentata nello spazio dei segnali). Si calcoli sia la probabilità di errore sul simbolo che quella sui bit a valle di un mapping che si ritiene ragionevole.



$$E_s = \frac{1}{16} (4d^2 + 4(\sqrt{2})^2 d^2 + 8(4+1)d^2) = \frac{1}{16} (4 + 8 + 40) d^2 = \frac{13}{4} d^2 = 3.25 d^2$$

$$P_s(E) = \frac{1}{16} \left( 4 \underbrace{2Q\left(\frac{d}{\sqrt{2}N_s}\right)}_2 + 4 \times 4 \times \underbrace{Q\left(\frac{d}{\sqrt{2}N_s}\right)}_4 + 8 \times 1 \times \underbrace{Q\left(\frac{d}{\sqrt{2}N_s}\right)}_{d/2} \right)$$

$$= 2 Q\left(\frac{d}{\sqrt{2}N_s}\right) = 2 Q\left(\sqrt{\frac{1}{2} \frac{d^2}{N_s}}\right) = 2 Q\left(\sqrt{\frac{1}{2 \times 13} \frac{E_s}{N_s}}\right)$$

$$\frac{E_s}{N_s} = 15.85 \quad (= 12 \text{ dB})$$

$$P_s(E) = 2 Q(\sqrt{2.44}) = 2 Q(1.56) \approx 2 \times 10^{-1}$$

Si ricorda l'approssimazione  $\log_{10} Q(x) \approx -1.01 - 0.22x^2$  riportata anche in figura (linea tratteggiata).

