Problem 1、

(a) 求 transmit power.

- 已知 $BER_{BPSK} = Q(\sqrt{2\gamma_b}) = 5\times10^{-6} \rightarrow \gamma_s = SNR = 9.755\,dB$ (γ_s)
- $SNR = P_{RX} - P_N$

(i) $P_{RX} = P_{TX} + G_{BS} + G_{MS} - PL(d)$

$$PL(d) = 20\log_{10}\left(\frac{4\pi}{\lambda_c}\right) + 20\log_{10}(d_{break}) + n\cdot10\log_{10}\left(\frac{d}{d_{break}}\right)$$

$$= 32 + 2.7 + 45\log_{10}(110) = 137.86$$

$\Rightarrow P_{RX} = P_{TX} - 117.86$

(ii) $N_0B = KT_eB = (1.38\times10^{-23})\times290(7-1)\times2\times10^7$

$$= 4.8\times10^{-13} = -123\,dBW = -93\,dBm$$

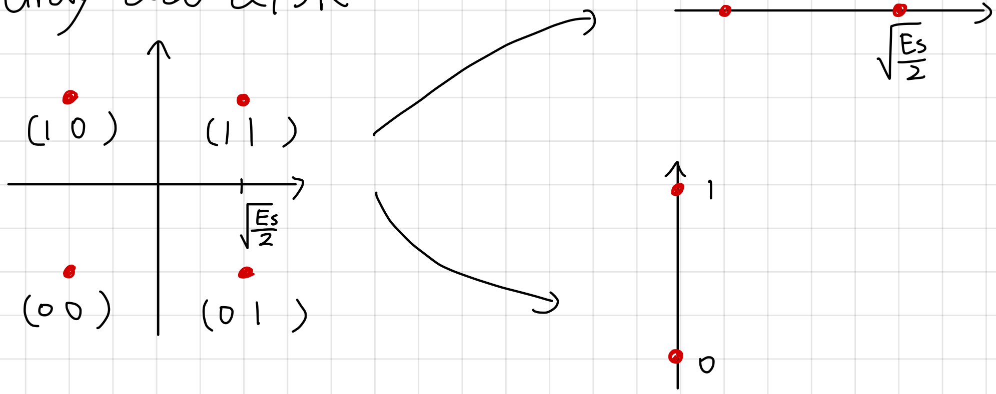
$P_N = -93+7 = -86\,dBm$

$\rightarrow SNR = 9.755 = P_{TX} - 117.86 - (-86)$

$\Rightarrow P_{TX} = 41.615\,dBm$ Ans: $P_{TX} = 41.615\,dBm$

(b)

Gray-code QPSK



- $BER = Q\left(\sqrt{\frac{2E_s}{2N_0}}\right) = Q(\sqrt{\gamma_s}) = \underline{Q(\sqrt{2\gamma_b})}$
- $SER = 1-(1-P_e)^2 = 2P_e - P_e^2 = \underline{2Q(\sqrt{2\gamma_b}) - Q^2(\sqrt{2\gamma_b})}$

Problem 1.

(c)

If use gray code. QPSK, $\gamma_s = 2\gamma_b$

$BER = Q(\sqrt{2\gamma_b}) = Q(\sqrt{\gamma_s}) = 5\times10^{-6} \Rightarrow \gamma_s = 9.755 \underline{+3} = 12.755\,dB$

$\Rightarrow P_{TX} = 41.615 + 3 = 44.615\,dBm$

Ans: 44.615 dBm #

(d)

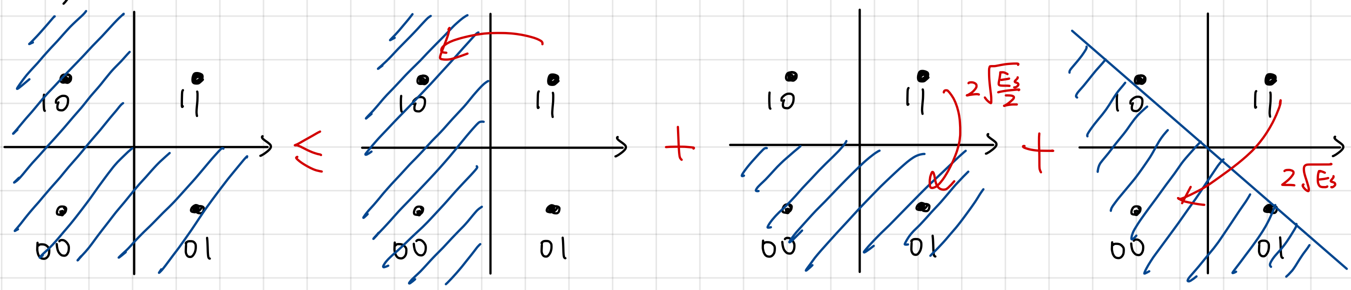
$Q(\sqrt{\gamma_s}) = 10^{-7}$, $\gamma_s = (Q^{-1}(10^{-7}))^2 = 14.32\,dB$

$14.32 - 12.755 = 1.565$

Ans: increase 1.565 dB #

Problem 2.

(a)



- By union bound,

$$SER \le Q\left(\sqrt{\frac{2E_s}{2N_0}}\right)\times 2 + Q\left(\sqrt{\frac{4E_s}{2N_0}}\right) = 2Q(\sqrt{\gamma_s}) + Q(\sqrt{2\gamma_s}) \quad ; \gamma_s = 2\gamma_b$$

錯2個bit

$$BER \le \frac{2Q(\sqrt{\gamma_s}) + Q(\sqrt{2\gamma_s})\times \underline{2}}{\log_2 4} = Q(\sqrt{2\gamma_b}) + Q(\sqrt{4\gamma_b}) = 5\times 10^{-5}$$

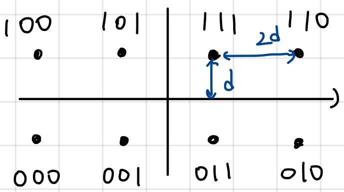
$$\Rightarrow \underline{\gamma_b \approx 7.566} \text{ ※}$$

- 1(b) 的 $BER = Q(\sqrt{2\gamma_b}) = 5\times10^{-5}$, $\gamma_b = \left(Q^{-1}(5\times10^{-5})\right)^2 / 2$

$$\Rightarrow \underline{\gamma_b = (3.89)^2/2 = 7.566} \text{ ※}$$

$\rightarrow$ They are almost same, the union bound is a good approximate ※

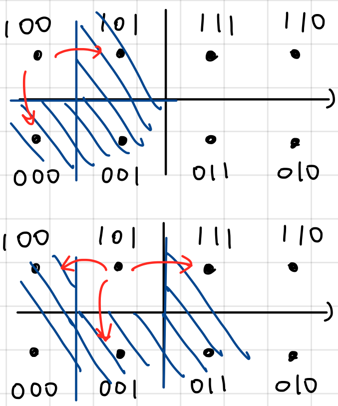
(b)



$$E_s = \frac{1}{2}(d^2 + d^2 + 9d^2 + d^2) = 6d^2 \qquad d = \sqrt{\frac{E_s}{6}}$$

Ans: 距離為 $2d = 2\sqrt{\frac{E_s}{6}} = \sqrt{\frac{2E_s}{3}}$ ※

(c)



$$SER_1 = Q\left(\sqrt{\frac{E_s/6}{N_0/2}}\right)\times 2 = 2Q\left(\sqrt{\frac{E_s}{3N_0}}\right)$$

$$SER_2 = Q\left(\sqrt{\frac{E_s/6}{N_0/2}}\right)\times 3 = 3Q\left(\sqrt{\frac{E_s}{3N_0}}\right)$$

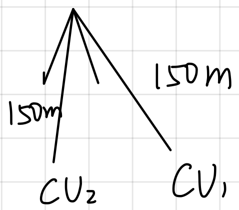
$$SER = \frac{5}{2}Q\left(\sqrt{\frac{E_s}{3N_0}}\right) = \frac{5}{2}Q\left(\sqrt{\frac{E_b}{N_0}}\right)$$

$$\Rightarrow BER = \frac{SER}{\log_2 8} = \frac{5}{6}Q(\sqrt{\gamma_b})$$

Ans: $BER = \frac{5}{6}Q(\sqrt{\gamma_b})$ ※

Problem 3 (a) $\circ\ P_{ms} = 0.1\,W = 20\,dBm$

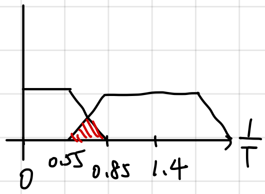
$\circ\ N_0 B = -174 + 10\log_{10}(1.7\times10^5) = -121.7\,dBm$



$$\bullet\ PL(d) = 20\log_{10}\left(\frac{4\pi}{\lambda_c}\right) + 20\log_{10}(d_{break}) + 10n\log_{10}\left(\frac{d}{d_{break}}\right)$$

$$= 32 + 20\log_{10}(0.9) + 20 + 45\log_{10}(15)$$

$$= 32 - 0.915 + 20 + 52.92 = 104\,dB$$



$$\Rightarrow SNR = (20+3+3-104) - (-121.7) = 43.7\,dB$$

$\to 23442.28$

$$G_{NO}(f,\alpha,T) = \begin{cases} 1 & ;\ 0 \le |f| \le \frac{1-\alpha}{2T} \\ \frac{1}{2}\left(1-\sin\left(\frac{T}{2\alpha}\left|2\pi f - \frac{\pi}{T}\right|\right)\right) & ;\ \frac{1-\alpha}{2T} \le |f| \le \frac{1+\alpha}{2T} \end{cases}$$

$$S = \int_{-\frac{0.85}{T}}^{\frac{0.85}{T}} |G_{NO}(f,\alpha,T)G_{NO}^*(f,\alpha,T)|^2\,df = 6.8281\times10^4$$

$$I = \int_{\frac{0.55}{T}}^{\frac{0.85}{T}} \left|G_{NO}(f,\alpha,T)\cdot G_{NO}^*\left(f-\frac{1.4}{T},\alpha,T\right)\right|^2 df = 1.7023$$

$$\Rightarrow SIR = \frac{6.828\times10^4}{1.7023} = 40110 = 46.03\,dB$$

$$\Rightarrow SINR = \frac{S}{P_N+I} = \frac{1}{1/SNR + 1/SIR} = \frac{1}{\frac{1}{23442.5}+\frac{1}{40110}}$$

$$= 14795.22 = 41.7\,dB$$

Ans: SNR = 43.7dB
SIR = 46.03dB
SINR = 41.7dB #

(b)

$$BER = Q(\sqrt{2\gamma_b}) = Q(\sqrt{\gamma_s}) = Q(\sqrt{41.7}) \approx 0 \ \#$$

$$SER = 2Q(\sqrt{\gamma_s}) + Q^2(\sqrt{\gamma_s}) \approx 0 \ \#$$

(c) $P_1 = X,\quad P_2 = X + 45\log_{10}(15) - 45\log_{10}(10) = X + 7.92$

$$SIR_1' = SIR - 7.92 = 38.11\,dB = 6471.42$$

$$\to SINR_{u1} = \frac{1}{1/6471 + 1/23442} = 5071.42 = 37\,dB,\quad Q(\sqrt{37}) \approx 0 \begin{cases} BER_1 \simeq 0 \\ SER_1 \simeq 0 \end{cases} \#$$

$$SIR_2' = SIR + 7.92 = 53.95\,dB = 248313.$$

$$\to SINR_{u2} = \frac{1}{1/248313 + 1/23442} = 21420 = 43.3\,dB,\quad Q(\sqrt{43.3}) \approx 0 \begin{cases} BER_2 \simeq 0 \\ SER_2 \simeq 0 \end{cases} \#$$

Problem 4.

(a)

$\gamma_{Req} = 20dB = 100$, $P_{out.req} = 0.03$

$$\begin{cases} \cdot\ P_{out} = 1 - \exp\left(-\frac{100}{\bar{\gamma}_s}\right) \Rightarrow \underset{\swarrow \text{SNR}}{\bar{\gamma}_s} = -\frac{100}{\ln(0.97)} = 3283.08 = 35.16dB \\ \cdot\ N_0B = 10\log_{10}\left[(1.38\times10^{-23})\cdot 290(7-1)\cdot 10\times10^{6}\right] = -96.2 \\ \rightarrow P_N = -96.2 + 7 = -89.2\ dBm \\ \cdot\ PL(d) = 20\log_{10}\left(\frac{4\pi d_{break}}{\lambda_c}\right) + 10n\log\left(\frac{d}{d_{break}}\right) = 32 + 20 + 41\cdot\log_{10}(12) = 96.246 \end{cases}$$

$\Rightarrow P_{TX} + 5 + 0 - 96.246 - (-89.2) = 35.16$ Ans: $P_{TX} = 37.2\ dBm$ ※

(b) For Rayleigh fading, $BER_{req} = 1\times10^{-5}$

$\overline{BER}_{DBPSK} \simeq \frac{1}{2\bar{\gamma}_s} = 1\times10^{-5}$, $\bar{\gamma}_s = 5\times10^{4} = 47dB$

$P_{TX} = 37.2 + (47 - 35.16) = 49.04\ dBm$ ※

(c) For Rician fading, $BER_{req} = 1\times10^{-5}$

- With $K_r = 10$, $\overline{BER}_{DBPSK} = \frac{11}{2(11+\bar{\gamma}_s)}\exp\left(-\frac{10\bar{\gamma}_s}{11+\bar{\gamma}_s}\right) = 1\times10^{-5}$ $\bar{\gamma}_s = 18.8dB$

  $P_{TX} = 37.2 + (18.8 - 35.16) = 20.8\ dBm$ ※

- With $K_r = 0$, $\overline{BER}_{DBPSK} = \frac{1}{2(1+\bar{\gamma}_s)} = 1\times10^{-5}$, $\bar{\gamma}_s = 47dB$

  $P_{TX} = 37.2 + (47 - 35.16) = 49.04\ dBm$ ※

When $K_r \rightarrow 0$, Rician fading turn into Rayleigh fading

s.t. the answer equal to 4.(b) ※

Problem 5.

(a)

16QAM gray coding.

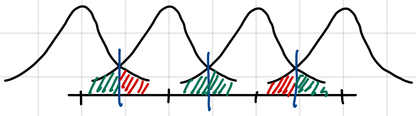
1000	1001	1011	1010
1100	1101	1111	1110
0100	0101	0111	0110
0000	0001	0011	0010

$E_s =$ Average Symbol Energy.

$$= \frac{1}{4} d^2 (1+1+1+9+1+9+9+9) = 10d^2$$

$$\rightarrow d = \sqrt{\frac{E_s}{10}}$$

Consider I- channel



$$SER_I = \frac{1}{4}\left[2Q\left(\sqrt{\frac{4d^2}{2N_0}}\right) + 2\cdot 2Q\left(\sqrt{\frac{4d^2}{2N_0}}\right)\right] = \frac{3}{2}Q\left(\sqrt{\frac{E_s}{5N_0}}\right)$$

$$SER_Q = SER_I = \frac{3}{2}Q\left(\sqrt{\frac{E_s}{5N_0}}\right)$$

可忽略

$$\rightarrow SER = 1-(1-SER_I)(1-SER_Q) = \underline{3Q\left(\sqrt{\frac{E_s}{5N_0}}\right)} - \cancel{\frac{9}{4}Q^2\left(\sqrt{\frac{E_s}{5N_0}}\right)} \quad ; E_s = 4E_b$$

$$BER = \frac{SER}{\log_2 16} = \frac{3}{4}Q\left(\sqrt{\frac{4}{5}\frac{E_b}{N_0}}\right) = \frac{3}{4}Q\left(\sqrt{0.8\gamma_b}\right) \quad \#$$

(b) Formula: $2\int_0^\infty Q(\sqrt{2x})\cdot a\exp(-ax)\,dx = 1-\sqrt{\frac{1}{1+a}}$

$$\overline{BER}_{QAM} = \int_0^\infty \frac{1}{\bar{\gamma}_b}\exp\left(-\frac{\gamma_b}{\bar{\gamma}_b}\right)\cdot\frac{3}{4}Q\left(\sqrt{0.8\gamma_b}\right)d\gamma_b, \quad 令\ x = \frac{2}{5}\gamma_b$$

$$dx = \frac{2}{5}d\gamma_b$$

$$= 2\int_0^\infty Q(\sqrt{2x})\cdot\exp\left(-\frac{5x}{2\bar{\gamma}_b}\right)\cdot\frac{5}{2\bar{\gamma}_b}dx\cdot\frac{3}{4}\cdot\cancel{\frac{5}{2}}\cdot\cancel{\frac{2}{5}}\cdot\frac{1}{2}$$

$$= \frac{3}{8}\left[1-\sqrt{\frac{1}{1+\frac{5}{2\bar{\gamma}_b}}}\right]$$

$$\text{Ans}: \frac{3}{8}\left(1-\sqrt{\frac{0.4\bar{\gamma}_b}{1+0.4\bar{\gamma}_b}}\right) \quad \#$$

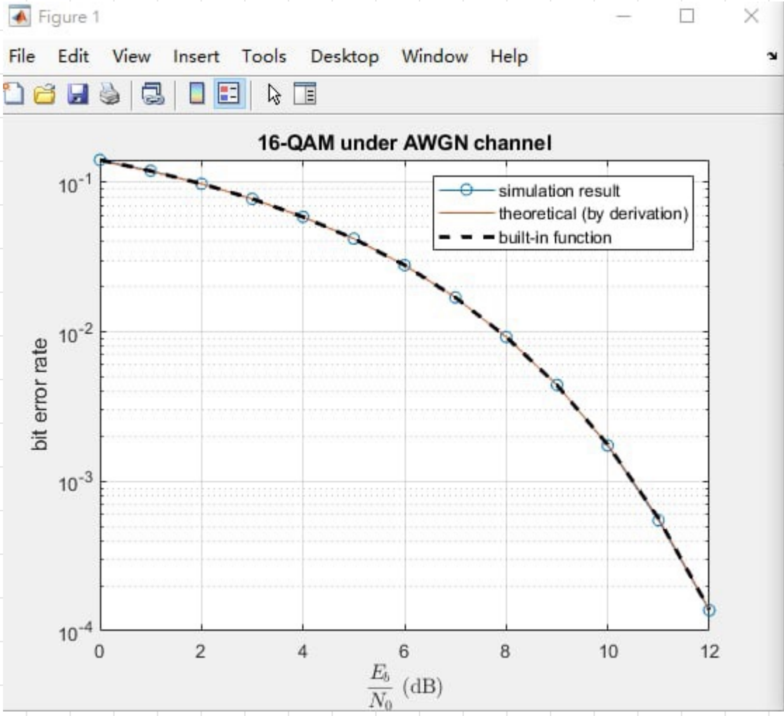


Figure 1
File Edit View Insert Tools Desktop Window Help
16-QAM under AWGN channel
simulation result
theoretical (by derivation)
built-in function
bit error rate
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0 2 4 6 8 10 12
$\frac{E_b}{N_0}$ (dB)

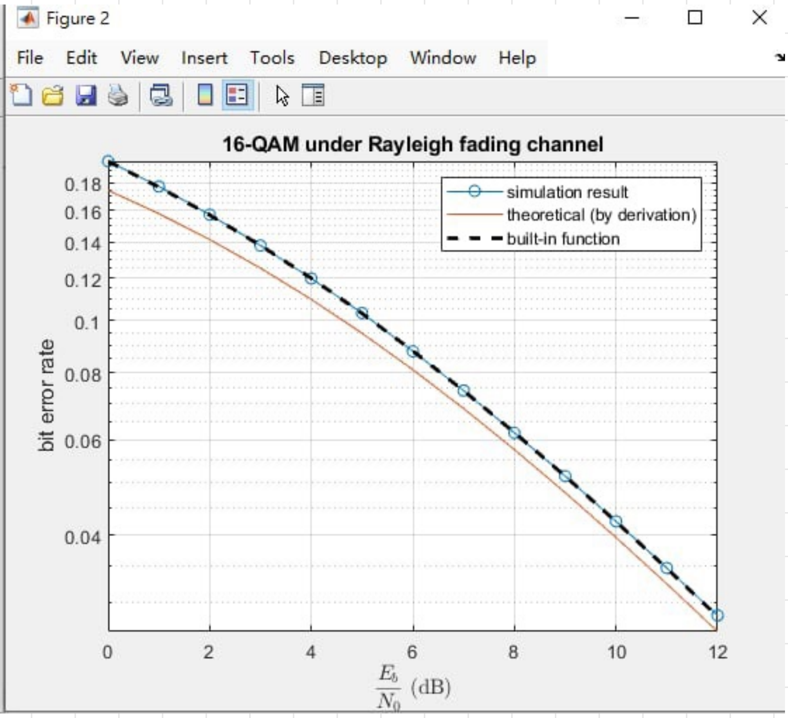


Figure 2
File Edit View Insert Tools Desktop Window Help
16-QAM under Rayleigh fading channel
simulation result
theoretical (by derivation)
built-in function
bit error rate
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0 2 4 6 8 10 12
$\frac{E_b}{N_0}$ (dB)