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Question

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Coherent orthogonal binary FSK modulation is used to transmit two equiprobable symbol waveforms $s_1(t) = \alpha \cos 2\pi f_1 t$ and $s_2(t) = \alpha \cos 2\pi f_2 t$, where $\alpha = 4$ mV.

Assume an AWGN channel with two-sided noise power spectral density $\frac{N_0}{2} = 0.5 \times 10^{-12} \text{ W/Hz}$. Using an optimal receiver and the relation

$Q(v) = \frac{1}{\sqrt{2\pi}} \int_v^\infty e^{-u^2/2} du$, the bit error probability for a data rate of 500 kbps is

This question was previously asked in

GATE EC 2014 Official Paper: Shift 2

[Attempt Online](#)[View all GATE EC Papers >](#)1. $Q(2)$ 2. $Q(2\sqrt{2})$ 3. $Q(4)$ 4. $Q(4\sqrt{2})$

Answer (Detailed Solution Below)

Option 3 : $Q(4)$

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Detailed Solution

Concept:

FSK Modulation:

In FSK: transmission of 1 is represented as:

$$s_1(t) = A_c \cos 2\pi f_H t$$

Transmission of 0 is represented as:

$$s_2(t) = A_c \cos 2\pi f_L t$$

and the Bit error probability $= Q \left[\sqrt{\frac{E_d}{2N_0}} \right]$

Where E_d is the energy of $s_1(t) - s_2(t)$

$$E_d = \int_0^{T_b} \{s_1(t) - s_2(t)\}^2 dt$$

$$E_d = \int_0^{T_b} s_1^2(t) dt + \int_0^{T_b} s_2^2(t) dt - 2 \int_0^{T_b} s_1(t) - s_2(t) dt$$

Since $s_1(t)$ & $s_2(t)$ are orthogonal, we can write:

$$\therefore \int_0^{T_b} s_1(t) - s_2(t) dt = 0$$

$$E_d = \int_0^{T_b} s_1^2(t) dt + \int_0^{T_b} s_2^2(t) dt$$

$$E_d = \frac{A_c^2 T_b}{2} + \frac{A_c^2 T_b}{2} = A_c^2 T_b$$

$$BER = Q \left(\sqrt{\frac{A_c^2 T_b}{2N_0}} \right)$$

Analysis:



Given:

$$A_c = \alpha = 4 \text{ mV}$$

$$\frac{N_0}{2} = 0.5 \times 10^{-12} \text{ w/Hz}$$

$$N_0 = 10^{-12} \text{ w/Hz}$$

$$T_b = \frac{1}{R_b} = \frac{1}{800 \times 10^3}$$

$$T_b = 0.2 \times 10^{-5}$$

$$T_b = 2 \times 10^{-6} \text{ sec.}$$

$$BER = Q \left(\sqrt{\frac{A_c^2 T_b}{2 N_0}} \right)$$

$$BER = Q \left(\sqrt{\frac{(4 \times 10^{-3})^2 \times 2 \times 10^{-6}}{2 \times 10^{-12}}} \right)$$

$$BER = Q \left(\sqrt{\frac{16 \times 10^{-6} \times 2 \times 10^{-6}}{2 \times 10^{-12}}} \right)$$

$$BER = Q(\sqrt{16})$$

$$BER = Q(4)$$