

**King Fahd University of Petroleum & Minerals**  
 Electrical Engineering Department  
 EE418: Satellite Communications (101)  
**Quiz 4: Modulation and Multiplexing in Satellite Systems**  
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**Serial #**

- 1 points for not writing your serial number

Name: Key

A satellite data transmission system transmits data at 6.176 Mbps using QPSK. The satellite link uses ideal RRC filters with  $\alpha=0.5$ . At the receiving terminal the clear air value of overall  $(C/N)_o$  is 17.0 dB and the implementation margin of the QPSK demodulator is 1 dB.

**a. What is the symbol rate?**

$$R_s = R_b / \log_2(4) = 3.088 \text{ Msps}$$

**b. What is the bandwidth occupied by this signal, and the noise bandwidth of the receiver for this signal?**

$$B = R_s(1 + \alpha) = R_s(1.5) = 4.632 \text{ MHz}$$

$$B_n = R_s = 3.088 \text{ MHz}$$

**c. Find the BER at the receiver output and the average time between errors. (Tables attached)**

$$\frac{E_b}{N_o} = \frac{CT_b}{N/B_n} = \frac{C(T_s/2)}{N/R_s} = \frac{C(1/2R_s)}{N/R_s} = \frac{C}{2N}$$

$$C/N = 17 - 1 = 16 \text{ dB} \text{ equivalent to } 39.8107$$

$$BER_{QPSK} = \frac{1}{2} \text{erfc} \left( \sqrt{\frac{E_b}{N_o}} \right)$$

$$BER_{QPSK} = \frac{1}{2} \text{erfc} \left( \sqrt{\frac{39.8107}{2}} \right) = \frac{1}{2} \text{erfc}(4.4615)$$

$$\text{Using linear interpolation } \text{erfc}(4.4615) = 2.85 \text{E-}10 + .0015 / (4.47 - 4.46) * (2.6 - 2.85) * 1 \text{E-}10$$

$$= 2.8125 \text{E-}10$$

$$BER_{QPSK} = 1.4062 \text{E-}010$$

Average time between errors =  $1 / BER / R_b = 1151.41 \text{ sec} = \text{about } 19.19 \text{ min} = \text{about } .03198 \text{ of an hour}$

**d. Rain affects the downlink from the satellite and the overall C/N ratio in the receiver falls by 3.0 dB. What is the bit error rate now?**

$$C/N = 17 - 3 - 1 = 13 \text{ dB} \text{ equivalent to } 19.9526$$

$$BER_{QPSK} = \frac{1}{2} \text{erfc} \left( \sqrt{\frac{19.9526}{2}} \right) = \frac{1}{2} \text{erfc}(3.1585)$$

$$\text{Using linear interpolation } \text{erfc}(3.1585) = 8.41 \text{E-}6 + .0085 / (3.16 - 3.15) * (7.87 - 8.41) * 1 \text{E-}6$$

$$= 7.9510 \text{E-}006$$

$$BER_{QPSK} = 3.9755 \text{E-}006$$

Extra work: average time between errors =  $0.0407 \text{ sec} = \text{about } 1 / 0.0407 = 24.5527 \text{ errors/sec!}$   
 Notice the big difference due to rain loss

x	erfc x	x	erfc x	x	erfc x	x	erfc x	x	erfc x	x	erfc x
0.01	9.89E-01	0.77	2.76E-01	1.53	3.05E-02	2.29	1.20E-03	3.05	1.61E-05	3.81	7.13E-08
0.02	9.77E-01	0.78	2.70E-01	1.54	2.94E-02	2.30	1.14E-03	3.06	1.52E-05	3.82	6.59E-08
0.03	9.66E-01	0.79	2.64E-01	1.55	2.84E-02	2.31	1.09E-03	3.07	1.42E-05	3.83	6.09E-08
0.04	9.55E-01	0.80	2.58E-01	1.56	2.74E-02	2.32	1.03E-03	3.08	1.33E-05	3.84	5.63E-08
0.05	9.44E-01	0.81	2.52E-01	1.57	2.64E-02	2.33	9.84E-04	3.09	1.24E-05	3.85	5.20E-08
0.06	9.32E-01	0.82	2.46E-01	1.58	2.55E-02	2.34	9.36E-04	3.10	1.17E-05	3.86	4.80E-08
0.07	9.21E-01	0.83	2.40E-01	1.59	2.45E-02	2.35	8.89E-04	3.11	1.09E-05	3.87	4.44E-08
0.08	9.10E-01	0.84	2.35E-01	1.60	2.37E-02	2.36	8.45E-04	3.12	1.02E-05	3.88	4.09E-08
0.09	8.99E-01	0.85	2.29E-01	1.61	2.28E-02	2.37	8.03E-04	3.13	9.59E-06	3.89	3.78E-08
0.10	8.88E-01	0.86	2.24E-01	1.62	2.20E-02	2.38	7.63E-04	3.14	8.98E-06	3.90	3.49E-08
0.11	8.76E-01	0.87	2.19E-01	1.63	2.12E-02	2.39	7.25E-04	3.15	8.41E-06	3.91	3.22E-08
0.12	8.65E-01	0.88	2.13E-01	1.64	2.04E-02	2.40	6.89E-04	3.16	7.87E-06	3.92	2.97E-08
0.13	8.54E-01	0.89	2.08E-01	1.65	1.96E-02	2.41	6.54E-04	3.17	7.36E-06	3.93	2.74E-08
0.14	8.43E-01	0.90	2.03E-01	1.66	1.89E-02	2.42	6.21E-04	3.18	6.89E-06	3.94	2.52E-08
0.15	8.32E-01	0.91	1.98E-01	1.67	1.82E-02	2.43	5.89E-04	3.19	6.45E-06	3.95	2.33E-08
0.16	8.21E-01	0.92	1.93E-01	1.68	1.75E-02	2.44	5.59E-04	3.20	6.03E-06	3.96	2.15E-08
0.17	8.10E-01	0.93	1.88E-01	1.69	1.68E-02	2.45	5.31E-04	3.21	5.64E-06	3.97	1.98E-08
0.18	7.99E-01	0.94	1.84E-01	1.70	1.62E-02	2.46	5.03E-04	3.22	5.27E-06	3.98	1.82E-08
0.19	7.88E-01	0.95	1.79E-01	1.71	1.56E-02	2.47	4.78E-04	3.23	4.93E-06	3.99	1.68E-08
0.20	7.77E-01	0.96	1.75E-01	1.72	1.50E-02	2.48	4.53E-04	3.24	4.61E-06	4.00	1.55E-08
0.21	7.66E-01	0.97	1.70E-01	1.73	1.44E-02	2.49	4.29E-04	3.25	4.31E-06	4.01	1.42E-08
0.22	7.56E-01	0.98	1.66E-01	1.74	1.39E-02	2.50	4.07E-04	3.26	4.02E-06	4.02	1.31E-08
0.23	7.45E-01	0.99	1.61E-01	1.75	1.33E-02	2.51	3.86E-04	3.27	3.76E-06	4.03	1.21E-08
0.24	7.34E-01	1.00	1.57E-01	1.76	1.28E-02	2.52	3.66E-04	3.28	3.51E-06	4.04	1.11E-08
0.25	7.24E-01	1.01	1.53E-01	1.77	1.23E-02	2.53	3.46E-04	3.29	3.28E-06	4.05	1.02E-08
0.26	7.13E-01	1.02	1.49E-01	1.78	1.18E-02	2.54	3.28E-04	3.30	3.06E-06	4.06	9.40E-09
0.27	7.03E-01	1.03	1.45E-01	1.79	1.14E-02	2.55	3.11E-04	3.31	2.86E-06	4.07	8.65E-09
0.28	6.92E-01	1.04	1.41E-01	1.80	1.09E-02	2.56	2.94E-04	3.32	2.67E-06	4.08	7.95E-09
0.29	6.82E-01	1.05	1.38E-01	1.81	1.05E-02	2.57	2.79E-04	3.33	2.49E-06	4.09	7.31E-09
0.30	6.71E-01	1.06	1.34E-01	1.82	1.01E-02	2.58	2.64E-04	3.34	2.32E-06	4.10	6.72E-09
0.31	6.61E-01	1.07	1.30E-01	1.83	9.65E-03	2.59	2.50E-04	3.35	2.17E-06	4.11	6.18E-09
0.32	6.51E-01	1.08	1.27E-01	1.84	9.26E-03	2.60	2.36E-04	3.36	2.02E-06	4.12	5.68E-09
0.33	6.41E-01	1.09	1.23E-01	1.85	8.89E-03	2.61	2.23E-04	3.37	1.88E-06	4.13	5.21E-09
0.34	6.31E-01	1.10	1.20E-01	1.86	8.56E-03	2.62	2.11E-04	3.38	1.75E-06	4.14	4.79E-09
0.35	6.21E-01	1.11	1.16E-01	1.87	8.18E-03	2.63	2.00E-04	3.39	1.64E-06	4.15	4.40E-09
0.36	6.11E-01	1.12	1.13E-01	1.88	7.84E-03	2.64	1.89E-04	3.40	1.52E-06	4.16	4.04E-09
0.37	6.01E-01	1.13	1.10E-01	1.89	7.52E-03	2.65	1.79E-04	3.41	1.42E-06	4.17	3.71E-09
0.38	5.91E-01	1.14	1.07E-01	1.90	7.21E-03	2.66	1.69E-04	3.42	1.32E-06	4.18	3.40E-09
0.39	5.81E-01	1.15	1.04E-01	1.91	6.91E-03	2.67	1.59E-04	3.43	1.23E-06	4.19	3.12E-09
0.40	5.72E-01	1.16	1.01E-01	1.92	6.62E-03	2.68	1.51E-04	3.44	1.15E-06	4.20	2.87E-09
0.41	5.62E-01	1.17	9.80E-02	1.93	6.34E-03	2.69	1.42E-04	3.45	1.07E-06	4.21	2.63E-09
0.42	5.53E-01	1.18	9.50E-02	1.94	6.08E-03	2.70	1.34E-04	3.46	9.94E-07	4.22	2.41E-09
0.43	5.43E-01	1.19	9.24E-02	1.95	5.82E-03	2.71	1.27E-04	3.47	9.25E-07	4.23	2.21E-09
0.44	5.34E-01	1.20	8.97E-02	1.96	5.57E-03	2.72	1.20E-04	3.48	8.60E-07	4.24	2.03E-09
0.45	5.25E-01	1.21	8.70E-02	1.97	5.34E-03	2.73	1.13E-04	3.49	8.00E-07	4.25	1.86E-09
0.46	5.15E-01	1.22	8.45E-02	1.98	5.11E-03	2.74	1.07E-04	3.50	7.44E-07	4.26	1.70E-09
0.47	5.06E-01	1.23	8.19E-02	1.99	4.89E-03	2.75	1.01E-04	3.51	6.92E-07	4.27	1.56E-09
0.48	4.97E-01	1.24	7.95E-02	2.00	4.88E-03	2.76	9.50E-05	3.52	6.43E-07	4.28	1.43E-09
0.49	4.88E-01	1.25	7.71E-02	2.01	4.48E-03	2.77	8.96E-05	3.53	5.98E-07	4.29	1.31E-09
0.50	4.79E-01	1.26	7.48E-02	2.02	4.28E-03	2.78	8.44E-05	3.54	5.56E-07	4.30	1.20E-09
0.51	4.71E-01	1.27	7.25E-02	2.03	4.09E-03	2.79	7.96E-05	3.55	5.16E-07	4.31	1.10E-09
0.52	4.62E-01	1.28	7.03E-02	2.04	3.91E-03	2.80	7.50E-05	3.56	4.80E-07	4.32	1.00E-09
0.53	4.54E-01	1.29	6.81E-02	2.05	3.74E-03	2.81	7.07E-05	3.57	4.45E-07	4.33	9.19E-10
0.54	4.45E-01	1.30	6.60E-02	2.06	3.58E-03	2.82	6.66E-05	3.58	4.14E-07	4.34	8.41E-10
0.55	4.37E-01	1.31	6.39E-02	2.07	3.42E-03	2.83	6.28E-05	3.59	3.84E-07	4.35	7.69E-10
0.56	4.28E-01	1.32	6.19E-02	2.08	3.27E-03	2.84	5.91E-05	3.60	3.56E-07	4.36	7.03E-10
0.57	4.20E-01	1.33	6.00E-02	2.09	3.12E-03	2.85	5.57E-05	3.61	3.31E-07	4.37	6.43E-10
0.58	4.12E-01	1.34	5.81E-02	2.10	2.98E-03	2.86	5.24E-05	3.62	3.07E-07	4.38	5.88E-10
0.59	4.04E-01	1.35	5.62E-02	2.11	2.85E-03	2.87	4.94E-05	3.63	2.85E-07	4.39	5.37E-10
0.60	3.96E-01	1.36	5.44E-02	2.12	2.72E-03	2.88	4.64E-05	3.64	2.64E-07	4.40	4.91E-10
0.61	3.88E-01	1.37	5.27E-02	2.13	2.59E-03	2.89	4.37E-05	3.65	2.45E-07	4.41	4.49E-10
0.62	3.81E-01	1.38	5.10E-02	2.14	2.47E-03	2.90	4.11E-05	3.66	2.27E-07	4.42	4.10E-10
0.63	3.73E-01	1.39	4.92E-02	2.15	2.36E-03	2.91	3.87E-05	3.67	2.11E-07	4.43	3.74E-10
0.64	3.65E-01	1.40	4.77E-02	2.16	2.25E-03	2.92	3.64E-05	3.68	1.95E-07	4.44	3.43E-10
0.65	3.58E-01	1.41	4.61E-02	2.17	2.15E-03	2.93	3.42E-05	3.69	1.81E-07	4.45	3.12E-10
0.66	3.51E-01	1.42	4.46E-02	2.18	2.05E-03	2.94	3.22E-05	3.70	1.67E-07	4.46	2.85E-10
0.67	3.43E-01	1.43	4.31E-02	2.19	1.95E-03	2.95	3.02E-05	3.71	1.55E-07	4.47	2.60E-10
0.68	3.36E-01	1.44	4.17E-02	2.20	1.86E-03	2.96	2.84E-05	3.72	1.44E-07	4.48	2.37E-10
0.69	3.29E-01	1.45	4.03E-02	2.21	1.78E-03	2.97	2.67E-05	3.73	1.22E-07	4.49	2.17E-10
0.70	3.22E-01	1.46	3.89E-02	2.22	1.69E-03	2.98	2.51E-05	3.74	1.23E-07	4.50	1.98E-10
0.71	3.15E-01	1.47	3.76E-02	2.23	1.61E-03	2.99	2.35E-05	3.75	1.14E-07		
0.72	3.02E-01	1.48	3.63E-02	2.24	1.54E-03	3.00	2.21E-05	3.76	1.05E-07		
0.73	3.01E-01	1.49	3.51E-02	2.25	1.46E-03	3.01	2.08E-05	3.77	9.76E-08		
0.74	2.95E-01	1.50	3.39E-02	2.26	1.39E-03	3.02	1.95E-05	3.78	9.03E-08		
0.75	2.89E-01	1.51	3.27E-02	2.27	1.33E-03	3.03	1.83E-05	3.79	8.35E-08		
0.76	2.82E-01	1.52	3.16E-02	2.28	1.26E-03	3.04	1.72E-05	3.80	7.72E-08		