

11.6 Digital modulation

Name: _____ Class: _____ Date: _____

Total: 24 marks

KEY WORDS constellation

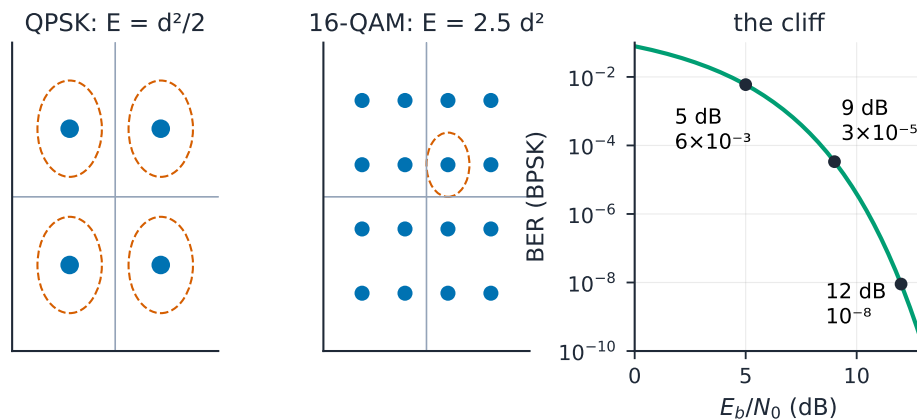
Objective

Derive constellations for ASK, PSK and QAM, compare their error performance under AWGN, and match bit rate, bandwidth and energy in a link design.

1 Key knowledge and worked examples

■ The constellation plane

I/Q axes; ASK moves radially, PSK rotates, QAM does both. Bits per symbol $\log_2 M$: QPSK 2, 16-QAM 4, 64-QAM 6 – spectral efficiency scales with $\log_2 M$, noise tolerance falls.



Equal minimum distance d : 16-QAM packs $2\times$ the bits per symbol for $5\times$ the average energy.

■ Worked example: energy accounting

Equal minimum distance $d = 2$: QPSK average symbol energy 2 (points at $(\pm 1, \pm 1)$); 16-QAM average 10 (grid $\pm 1, \pm 3$) – a factor 5 = 7.0 dB more energy for $2\times$ the bits per symbol ✓.

■ The cliff

BPSK: $BER = Q(\sqrt{2E_b/N_0})$ – 5 dB gives 6×10^{-3} , 9 dB gives 3×10^{-5} , 12 dB reaches 9×10^{-9} : each dB buys an order of magnitude near the wall.

2 Practice

2.1 How many bits per symbol does 64-QAM carry? [3]

2.2 Compute BPSK's BER at $E_b/N_0 = 8$ dB (Q of 3.55 is 1.9×10^{-4} – verify the argument first). [3]

2.3 For equal minimum distance, how much more average symbol energy does 16-QAM need than QPSK (in dB)? [3]

3 Exam-style questions

3.1 A 2 Mbps link may use QPSK or 16-QAM with raised-cosine shaping ($\alpha = 0.35$ available).

Compute the symbol rate for each scheme. Compute the required bandwidth for each. Compute each scheme's spectral efficiency (bps/Hz) and verify against the Shannon capacity of that bandwidth at 20 dB SNR. State the energy cost of choosing 16-QAM. [8]

3.2 A satellite receiver delivers $E_b/N_0 = 5$ dB to a BPSK link.

Compute the BER. The operator raises power by 4 dB: compute the new E_b/N_0 and BER. A switch to QPSK at the SAME symbol energy and rate halves E_b (two bits share the symbol): compute the resulting E_b/N_0 and BER, and state the design lesson about bits, symbols and energy. [7]
