Learning Objective 4.2: I can describe PAM theory and identify the pulse-shaping, symbol-rate, and bandwidth trade-offs.
Learning Objective 4.3: I can apply matched filtering and symbol-timing recovery to a received PAM signal.

Show your work. Write a **Documentation** line at the end (**None** if you did not collaborate).

1. **Constellations and Gray coding.**

   (a) Sketch the 4-PAM constellation on the I/Q plane and label its four points with a Gray code. Explain why a Gray code is worth using.

   (b) 8-PSK places eight points evenly around a circle, three bits each. Label them with a Gray code, going around the circle.

   (c) On a constellation sink, a 2-PAM signal shows two tight clouds at ± 1. The noise is turned up. Describe what changes on the display, and say when the receiver starts making wrong decisions.

2. **Fitting a channel.** A telemetry link must fit a 25 kHz channel and carry at least 32 kb/s. Use RRC pulse shaping, with bandwidth $B = (1 + \alpha)R_s$.

   (a) With 2-PAM and $\alpha = 0.35$, find the largest symbol rate that fits and the bit rate it carries. Does it meet the requirement?

   R_s:

   meets it?

   (b) Switch to 4-PAM at the same α. Which block setting changes, and what is the bit rate now? In words, what would you expect to see on the Symbol Sync output at the same noise as before, and why?

   R_b:

   (c) Keep 2-PAM instead and send 32 kbaud. What roll-off would fit 25 kHz? Explain why that answer rules out this option.

3. **Setting up the transmit filter.** A flowgraph runs at `samp_rate` = 48 kHz and sends 2-PAM at 4.8 kbaud with $\alpha = 0.25$.

   (a) Find the samples per symbol and the occupied bandwidth.

   `sps`: ____

   B: ____

   (b) Write the `firdes.root_raised_cosine` call for the transmit taps, with a filter 11 symbols long, and name the block that uses them and its interpolation.

   (c) A teammate wants 4.4 kbaud at the same sample rate. Explain why the flowgraph cannot do this as built, and give one way to fix it.

   (d) The teammate shortens the filter to `2*sps` taps to save computation. What happens to the spectrum, and why?

4. **Reading an eye.** A QT GUI Eye Sink shows a 2-PAM signal at $\mathtt{sps} = 8$ after the receive filter. The eye is widest open 3 samples after the start of each symbol period, where the traces cluster at ± 0.8 with a spread of ± 0.2 around each level.

   (a) Where should the receiver sample, and what is the eye opening there as a fraction of the ideal gap from -0.8 to $+0.8$?

   (b) For each change below, say how the eye changes: (i) the noise standard deviation doubles; (ii) the receiver drops its filter; (iii) the receiver samples 4 samples away from the best instant.

   (c) In words, explain why a smaller roll-off makes the receiver more sensitive to timing error.

5. **The matched filter.** The L9 matched-filter flowgraph runs at `samp_rate` = 32 kHz, `sps` = 8, and $\alpha = 0.35$.

   (a) The transmitter uses an RRC filter. What filter should the receiver use, and why does that choice also give zero ISI?

   (b) In the L9 matched-filter screenshot, at a noise amplitude of 0.6, the eye before the filter is closed and the eye after it is open. The signal occupies about ± 2.7 kHz of the 32 kHz the samples represent. Explain in words what the filter did to make the difference.

   (c) A classmate puts a full raised-cosine filter at the transmitter and no filter at the receiver. The eye at the receiver has zero ISI. Explain what is still wrong with this design.

6. **Timing recovery.** A 2-PAM receiver at 4 kbaud uses Keep 1 in N to pick one sample per symbol, starting at the center of the eye. Its sample clock is 50 ppm fast relative to the transmitter's.

   (a) How many symbols, and how many seconds, until the sampling point has drifted half a symbol, to the zero crossings?

   symbols: ____

   time: ____

   (b) You replace Keep 1 in N with a Symbol Sync block. A teammate then puts a Keep 1 in N block in front of it to save computation, so Symbol Sync receives one sample per symbol, and sets its samples per symbol to 1. Explain why timing recovery no longer works, and say where the one-sample-per-symbol step belongs.

   (c) The Symbol Sync output jitters around ± 1 even with little noise. Which parameter should change, in which direction, and what is the trade-off?

Documentation: _____