Learning Objective 1.3: I can describe signal-space concepts (basis functions, constellations, decision regions) and apply them to a digital modulation scheme.

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

1. **Three families of modulation.** A link must carry 1 Mb/s.

   (a) For each family, say what the transmitter changes from one symbol to the next: ASK/PAM, PSK, and FSK.

   (b) How many bits per symbol do 4-PAM, 8-PSK, and 16-PSK carry?

   4-PAM: ____

   8-PSK: ____

   16-PSK: ____

   (c) Find the symbol rate the link needs with BPSK and with 8-PSK. This is the number a modulator block's samples-per-symbol setting is built around.

   BPSK: ____

   8-PSK: ____

2. **Binary PAM and noise.** A binary PAM receiver samples each pulse once. A 1 is sent as $+1$ V and a 0 as -1 V.

   (a) State the decision rule, and sketch the two points and the threshold on a line.

   (b) Decide each of these received samples: $+0.83$, -1.20, $+0.07$, -0.31 V. The bits sent were 1, 0, 0, 0. Which sample did the receiver decide wrong, and why?

   (c) The SDR display shows the SNR falling from 14 dB to 4 dB. Describe what happens to the received samples, and what you would see on a time sink of the slicer's output.

   (d) Name two changes that would keep more samples on the right side of the threshold.

3. **Antipodal, orthogonal, and constellations.**

   (a) Sketch binary PAM (antipodal) and binary FSK (orthogonal) at the same energy, with the boundary between the two points of each. Which pair is farther apart?

   (b) Both are sent through the same noise. Which one puts more samples in the wrong region, and why?

   (c) Sketch QPSK and 4-PAM at the same average energy, mark the decision regions of each, and explain why a radio uses QPSK rather than 4-PAM on a carrier.

4. **Gray coding.** An 8-PSK modem places its points every 45° around a circle.

   (a) Label the eight points with a Gray code, starting from 000 at 0°.

   (b) With natural binary labels instead (000, 001, 010, ..., 111), how many bits does a slip from the point labeled 011 to its neighbor 100 corrupt?

   (c) Explain in one or two sentences why a Gray code helps, given where noise usually pushes a sample.

5. **Choosing a modulation.** In the constellation explorer, QPSK at an SNR of 12 dB shows almost no samples in the wrong region. Switching to 8-PSK at the same SNR turns a steady trickle of samples red.

   (a) Explain what changed on the plot, using the decision regions.

   (b) What does 8-PSK give you in exchange?

   (c) A link's SDR display shows only a little more SNR than QPSK needed to stay clean. Which modulation do you choose, and what would make you change your mind?

6. **Reading a constellation.** Three QPSK receivers each show one problem on a constellation sink. Name the cause of each.

   (a) The four points sit in the middle of their quadrants, but each is a round cloud about a third of the way to the boundaries.

   (b) Four tight clouds, each rotated 30° counterclockwise from where it belongs, standing still.

   (c) The points are smeared into a ring of constant radius.

   (d) Explain why the constellation in part (b) would put every symbol in the wrong region if the rotation passed 45°, even with no noise.

Documentation: _____