Learning Objective 6.1: I can transmit and receive CW (Morse) using GNU Radio and decode a received CW stream.

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

1. **Morse timing.** A dit lasts one unit of $1.2/W$ seconds at W words per minute. A dah lasts 3 units, and the key stays up for 1 unit inside a letter, 3 between letters, and 7 between words. SOS is `... --- ...`.

   (a) Find the length of a dit, a dah, and the gap between words at 15 WPM.

   $$t_{\text{dit}} = \frac{1.2\ \text{s}}{15} = 80\ \text{ms}$$
   $$t_{\text{dah}} = 3 \times 80 = 240\ \text{ms}$$
   $$t_{\text{word}} = 7 \times 80 = 560\ \text{ms}$$

   dit: 80 ms

   dah: 240 ms

   word gap: 560 ms

   (b) Count the units in SOS, including the 7-unit gap after it, and find how long it takes to send at 15 WPM.

   Each S is three dits with two 1-unit gaps, 5 units. O is three dahs with two gaps, 11 units. Two letter gaps add 6 and the word gap 7:

   $$5 + 11 + 5 + 6 + 7 = 34\ \text{units}$$
   $$34 \times 80\ \text{ms} = 2.72\ \text{s}$$

   units: 34

   time: 2.72 s

   (c) A beacon sends its three-letter identifier at 7 WPM. In words, explain why the standard word PARIS lets us state its speed without knowing which letters it sends.

   WPM defines the unit, not the letters: one WPM sends the 50 units of PARIS once a minute, so at 7 WPM every unit lasts $1.2/7 = 171$ ms whatever the letters are. The identifier takes a different number of units than PARIS, so it does not take exactly a seventh of a minute, but its dits, dahs, and gaps all follow from that one unit.

2. **Decoding marks and spaces.** The L12 decoder is set to 15 WPM, so one unit is 80 ms. It calls a mark under 2 units a dit and a longer one a dah, ends a letter when a space reaches 2 units, ends a word when it reaches 5, and ignores any change that lasts less than 0.3 unit. A human operator sends the following, in milliseconds, starting with a mark:

Mark	230		255		245		240		75		250
Space		85		70		260		95		80	

and then the key stays up for 700 ms.

(a) Find the decoder's boundaries in milliseconds, and decode the text.

A length of $2 \times 80 = 160$ ms separates a dit from a dah, and a gap inside a letter from a gap between letters; $5 \times 80 = 400$ ms ends a word, and $0.3 \times 80 = 24$ ms is the noise limit. The marks of 230, 255, and 245 ms are dahs, and the 260 ms space ends the letter: `---` is O. Then 240, 75, and 250 ms read `-.-`, which is K, and the 700 ms space ends the word. The text is OK.

OK

(b) The operator pauses, and the 260 ms space stretches to 420 ms. What does the decoder print now?

420 ms is more than 400 ms, so the decoder ends a word there and prints `O K` with a space between the letters.

O K

(c) During the 700 ms space, a noise burst holds the key down for 15 ms. Explain what the decoder does with it, and what it would do with a 60 ms burst.

15 ms is less than the 24 ms noise limit, so the decoder ignores it and the space continues. A 60 ms burst lasts longer than 24 ms, so the decoder accepts it as a mark under 160 ms, a dit, and if the key then stays up long enough, it prints an extra E.

3. **Key clicks.** The CW Keyer Explorer on the Lesson 12 page has a readout, "1 kHz away, vs hard," that compares the shaped spectrum with hard keying 1 kHz from the carrier. At 20 WPM a cadet drags the edge time and reads -10 dB at 1 ms, -24 dB at 2 ms, -40 dB at 5 ms, and -53 dB at 10 ms.

   (a) A club station must keep its keying at least 30 dB below hard keying, 1 kHz from the carrier. Which of the four edge times meet that, and which is the shortest that does?

   The 5 ms and 10 ms edges meet it, at -40 and -53 dB. The 2 ms edge reaches only -24 dB. The shortest that meets the limit is 5 ms.

5 ms

   (b) An operator wants 10 ms edges at 60 WPM. Find the dit length, and how much of each dit stays at full power. Each edge takes the full edge time, half of it before the nominal edge and half after.

   $$t_{\text{dit}} = \frac{1.2\ \text{s}}{60} = 20\ \text{ms}$$
   $$20 - 10 = 10\ \text{ms}$$

dit:	20 ms
full:	10 ms

   Half of each dit goes to the rising and falling edges.

   (c) In words, explain which receivers a hard-keyed transmitter interferes with, and why, and why the operator in part (b) should choose a shorter edge.

   Hard keying spreads energy kilohertz away from the carrier, so a receiver tuned to another station nearby hears a click at every edge of the hard-keyed signal. The station itself decodes the same either way. At 60 WPM a 10 ms edge leaves only 10 ms of each 20 ms dit at full power, so the dits lose their flat tops and a receiver in noise has less of each mark to detect. A 5 ms edge keeps 15 ms of each dit at full power and still keeps the clicks well down.

4. **The product detector and the CW filter.** The L12 receiver moves the tuned frequency to 0 Hz, multiplies by a 700 Hz BFO, and keeps the real part. Its CW filter is a band-pass centered on 700 Hz.

   (a) A cadet tunes the receiver 120 Hz above the carrier. What pitch does the tone have, and does it pass a 150 Hz CW filter? A 1 kHz filter?

   Tuned 120 Hz high, the carrier lands at -120 Hz, so the tone is $700 - 120 = 580$ Hz. The 150 Hz filter passes 625 to 775 Hz, so the tone falls outside it and the decoder loses the signal. The 1 kHz filter passes 200 to 1200 Hz, so the tone gets through.

   tone: 580 Hz

   150 Hz: no

   1 kHz: yes

   (b) At a noise amplitude of 8 with the 200 Hz filter, the envelope plot shows a space level of about 0.40 and a mark level of about 0.72, and the text is mostly wrong. The cadet narrows the CW filter to 50 Hz, and the space level drops to about 0.20 while the mark level stays near 0.65. Where should `thr` go now?

   Halfway between the new levels:

   $$\texttt{thr} = \frac{0.20 + 0.65}{2} \approx 0.43$$

   thr: about 0.43

   (c) Explain in words why the 50 Hz filter in part (b) lowered the space level and not the mark level, and what limits its use.

   The signal is only about 100 Hz wide, so most of what a wider filter passes is noise. A narrower filter still passes the tone, so the mark level hardly moves, but it passes much less noise, so the envelope between marks drops and the gap between the two levels opens up. Its limit is tuning: the tone must stay inside the narrow filter, so the receiver must tune within a little less than 25 Hz of the carrier, and a transmitter that drifts by more than that leaves the filter.

5. **Setting the threshold.** In the L12 receiver the Threshold block switches the key on when the envelope rises above $1.2\times$ `thr` and off when it falls below $0.8\times$ `thr`. On a noisy link, the envelope plot shows a space level of about 0.30 and a mark level of about 0.70.

   (a) Choose `thr`, and find the two levels at which the key switches.

   Halfway between the levels:

   $$\texttt{thr} = \frac{0.30 + 0.70}{2} = 0.50$$

   $$\text{on} = 1.2 \times 0.50 = 0.60, \quad \text{off} = 0.8 \times 0.50 = 0.40$$

   thr: 0.50

   on / off: 0.60 / 0.40

   (b) A teammate leaves `thr` at 0.3, the value that worked with little noise. Explain what the key and the decoded text do.

   The key switches on at 0.36, barely above the 0.30 space level, so noise peaks during the spaces turn it on. The decoder sees short extra marks, prints extra Es and Ts, and splits or corrupts letters, so most of the text comes out wrong.

   (c) Another teammate sets `thr` to 0.8. Explain what happens, and why the hysteresis does not help.

   The key now switches on only above 0.96, well above the 0.70 mark level, so only the strongest noise peaks during marks turn it on. The key misses most marks, and the decoder prints few letters, mostly short ones. Hysteresis only stops chatter near the threshold; it cannot fix a threshold that sits outside the range between the two levels.

Documentation: _____