Learning Objective 2.1: I can describe what a Software Defined Radio is, contrast it with a traditional hardware radio, and identify the SDR used in this course, the PlutoSDR.
Learning Objective 2.2: I can identify the roles of the RF frontend, ADC/DAC, and host in an SDR signal chain and describe sample-rate, bandwidth, and dynamic-range trade-offs.

Use the PlutoSDR table from the lesson page. Show your work. Write a **Documentation** line at the end (**None** if you did not collaborate).

1. **Planning a capture.** The course radio is the PlutoSDR: 70 to 6000 MHz in the extended-frequency mode the course Plutos use, about 4 MS/s sustained over USB and up to 61.44 MS/s in short bursts, 12 bits, full duplex.

   (a) For each task, say whether the PlutoSDR can do it and how, or name the specification that rules it out.

   (i) Receive ship AIS at 162 MHz.
   (ii) Display the whole FM broadcast band, 88 to 108 MHz, at once.
   (iii) Transmit a 915 MHz test signal into a cable, through a 30 dB attenuator, and receive it at the same time.
   (iv) Find the direction of a 10.3 GHz beacon.

   (i) Yes. 162 MHz is inside the extended-frequency range, 70 to 6000 MHz; a stock Pluto, which starts at 325 MHz, could not tune it.

   (ii) Not while streaming: its 4 MS/s shows only 4 MHz of the 20 MHz band. A short burst capture at 20 MS/s or more shows the whole band at once, and a rate above 20 MS/s leaves margin for the filters' roll-off at the edges.

   (iii) Yes. The PlutoSDR is full duplex, so its transmit port is cabled through the 30 dB attenuator to its receive port and both run at once.

   (iv) No. 10.3 GHz is above the top of its tuning range, 6 GHz.

   (b) Explain how an SDR differs from a hardware FM radio, and why the same PlutoSDR can decode both broadcast FM and aircraft ADS-B.

   A hardware radio builds its filters and demodulator as circuits for one kind of signal. An SDR only tunes, filters, and digitizes a band, and software does the filtering, demodulation, and decoding. Both 100 MHz and 1090 MHz are inside the PlutoSDR's extended-frequency tuning range, so receiving either one is a matter of setting the center frequency and running a different flowgraph.

2. **The mixer and I and Q.** We set a PlutoSDR's center frequency, its LO, to 433.0 MHz, and a key fob transmits at 433.92 MHz.

   (a) Find the two frequencies at the mixer output, and say which one the low-pass filter keeps.

   $$433.92 - 433.0 = 0.92 \text{ MHz}$$
   $$433.92 + 433.0 = 866.92 \text{ MHz}$$

   The low-pass filter keeps the 0.92 MHz difference and removes the sum.

   kept: 0.92 MHz

   removed: 866.92 MHz

   (b) With a single real mixer, a second transmitter would also come out at 0.92 MHz. Find its frequency, and explain how the PlutoSDR's I and Q outputs tell the two apart.

   $$433.0 - 0.92 = 432.08 \text{ MHz}$$

   The second mixer, driven by the LO shifted 90°, gives Q. In $I + jQ$ the 433.92 MHz signal rotates one way and appears at $+0.92$ MHz, and the 432.08 MHz signal rotates the other way and appears at -0.92 MHz.

   432.08 MHz

   (c) A classic FM superheterodyne mixes every station to an IF of 10.7 MHz, with its first LO 10.7 MHz above the station. Tuned to 94.5 MHz, find the LO frequency and the image, the other station that also lands on 10.7 MHz. Then explain why the preselector must remove the image before the first mixer.

   $$f_{LO} = 94.5 + 10.7 = 105.2 \text{ MHz}$$
   $$f_{image} = 105.2 + 10.7 = 115.9 \text{ MHz}$$

   After the mixer, the image sits at 10.7 MHz on top of the wanted station, and no filter after the mixer can separate them. The preselector removes it while it is still at 115.9 MHz, far from the wanted 94.5 MHz.

   LO: 105.2 MHz

   image: 115.9 MHz

3. **Sample rate and data rate.** A team captures a 10 MHz-wide test signal centered on 2437 MHz with a PlutoSDR, in a short burst. The usable window is somewhat narrower than f_s, because the radio's filters roll off near its edges.

   (a) Find the lowest sample rate whose window just holds the signal. Then choose a rate 25% higher, to leave margin at the edges, and find the band that window covers.

   A complex window is f_s wide, so the signal needs at least 10 MS/s. With 25% margin:

   $$f_s = 1.25 \times 10 = 12.5 \text{ MS/s}$$
   $$2437 \pm 6.25 = 2430.75 \text{ to } 2443.25 \text{ MHz}$$

   lowest: 10 MS/s

   chosen: 12.5 MS/s

   band: 2430.75 to 2443.25 MHz

   (b) GNU Radio stores each complex sample in 8 bytes. At 12.5 MS/s, find the data rate through the flowgraph and the size of a 10 s File Sink capture.

   $$8 \times 12.5 \times 10^6 = 100 \text{ MB/s}$$
   $$10 \times 100 = 1 \text{ GB}$$

   rate: 100 MB/s

   file: 1 GB

   (c) The PlutoSDR sends each 12-bit I and Q over USB as a 16-bit word. Find the USB data rate at 12.5 MS/s, and compare it with the rate at the 4 MS/s the Pluto streams without dropped samples.

   $$4 \text{ bytes} \times 12.5 \times 10^6 = 50 \text{ MB/s}$$
   $$4 \text{ bytes} \times 4 \times 10^6 = 16 \text{ MB/s}$$

   USB: 50 MB/s

   at 4 MS/s: 16 MB/s

   The capture needs about three times what the Pluto streams over its USB 2.0 link, so it works only as a short burst into the Pluto's memory.

   (d) A teammate suggests streaming the capture live at 12.5 MS/s instead of taking a burst. Explain what goes wrong.

   The Pluto streams only about 4 MS/s over its USB 2.0 link without dropping samples. At 12.5 MS/s it drops most of them, so the recording has gaps and the spectrum shows false signals and a raised floor.

4. **Bits and clipping.** Use the L4 flowgraph, `L04-adc-bits.grc`, and its plots on the lesson page.

   (a) How many levels does the ADC block round to with 8 bits, the resolution of an 8-bit radio, and with 12 bits, the PlutoSDR's?

   $2^8 = 256, \qquad 2^{12} = 4096$

   8 bits: 256

   12 bits: 4096

   (b) At 8 bits the weak tone at -0.49 MHz is not visible. Switching the menu to 12 bits makes it appear, about 40 dB above the floor. Did the weak signal change? Describe what changed on the spectrum, and why.

   The weak signal did not change; the input is the same. The floor dropped by about 20 dB and the spurs disappeared, because 12 bits round in much finer steps, so the rounding error is smaller. The weak tone was always there, below the 8-bit floor.

   (c) Set the flowgraph back to 8 bits. Raise the gain slider in steps until the time sink's I and Q just begin to flatten at full scale. Did the weak tone appear on the spectrum? Explain what you saw, and name one thing that would let an 8-bit radio show the weak signal.

   No. Gain raised the strong tone, the weak tone, and the spurs together, so the weak tone stayed hidden below the spurs, and the strong tone reached full scale first. Raising the gain further only clipped the strong tone. More bits would help, or a filter that keeps the strong signal out of the ADC.

   (d) In the L4 flowgraph, name two things on the plots that show the ADC is clipping.

   The time sink shows I and Q flattened at ± 1, and the spectrum shows new signals where nothing transmits. The strong tone also rises by less than the gain increase.

Documentation: _____