HW 6: Respiration
(10 problems for 100 pts)

Assume a pneumotachometer has a flow resistance of R = 20 Pa·s/L, and we want to measure a maximum flow rate of 16 L/s. Your instrumentation amplifier is powered by +5V and GND with an offset Vref = 1.5V. Assume the amplifier output is limited to +4V (max) and 1V (min). Your ADC operates from 0 to +5V. Suppose the noise voltage of the measurement system is 15 mV_{RMS}.

- Problem 1: Suppose you used a differential pressure sensor with a responsivity $S = \Delta V/\Delta P$ = 25 mV/psi. You must choose either A_d = 500, 1000, 1500, 2000, or 2500. Which is the best choice?

- Problem 2: Compute the number of bits needed to ensure the ADC vertical resolution is smaller than half the noise voltage.

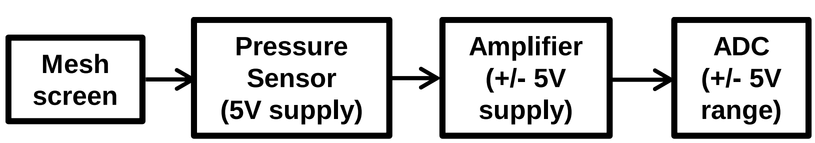
- Problem 3: Compute the minimum detectable flow in your system. Express your answer in L/s. Hint: You should get ΔF_{MIN} = 0.1 L/s.

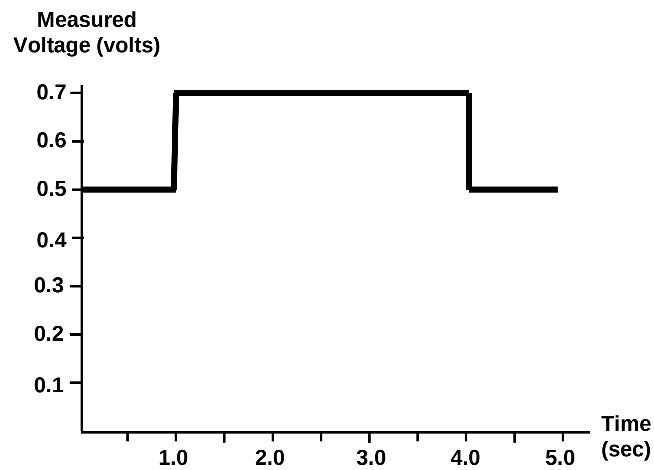
You are asked to design a Lilly-type spirometer that can measure a maximum flow rate of +/-15 L/s with a sensitivity of ΔF_{MIN} = 0.05 L/s. The mesh screen has a flow resistance R = 25 Pa·s/L. The instrumentation amplifier has Vref = 0V and is powered with +/- 10V, so you can assume the output is limited to +9V (max) and -9V (min). The ADC operates over a +/- 10V span with 12 bits and $V_{N,RMS}$ = 10 mV.

- ➢ The two available pressure sensors have a responsivity $S = \Delta V/\Delta P$ = 8 mV/kPa and 30 mV/kPa.
- ➢ The two available amplifiers have a fixed gain of A_d = 1500 ($V_{N,RMS}$ = 14 mV) or 2500 ($V_{N,RMS}$ = 20 mV).
- ➢ You can mix together any components (e.g. Sensor #2, Amplifier #1).
- ➢ The total noise from two components (e.g. amplifier + ADC) is computed by: $V_{N,TOTAL} = \sqrt{{V_{N1}}^2 + {V_{N2}}^2}$

- Problem 4: What combination of sensor and amplifier is the best choice? Show all work! Hint: You should get Sensor #1 and Amplifier #2.

You are asked to upgrade a flow spirometer system to achieve F_{MAX} = 20 L/s and ΔF_{MIN} = 0.05 L/s.





You know the pressure sensor has S = 24 mV/psi and the instrumentation amplifier has A_d = 1500. Assume the amplifier output is limited to +4V (max) and -4V (min).

The current system is calibrated by injecting 3 liters of air into the spirometer over a 3 second interval. The measured voltage V_{MEAS} during the calibration is shown to the right.

- Problem 5: What is the flow resistance R of the mesh screen? Express your answer in Pa·s/L. Show all work!

  Hint #1: First figure out the voltage offset V_{REF}.

  Hint #2: Remember that V_{MEAS} is related to flow, but the syringe injects a known VOLUME.

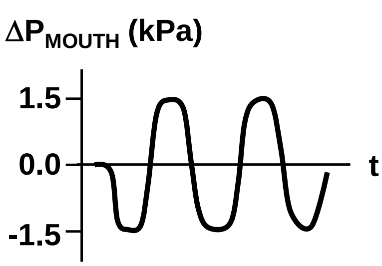
  Hint #3: You should get around R = 38 Pa·s/L.

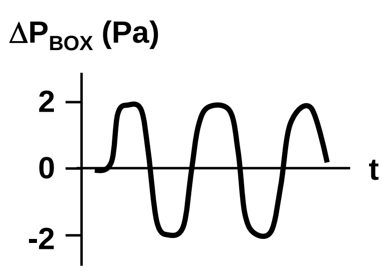
- Problem 6: Suppose the amplifier has $V_{N,RMS}$ = 8 mV and the ADC has 10 bits and $V_{N,RMS}$ = 15 mV. Does the current system satisfy both design specifications?

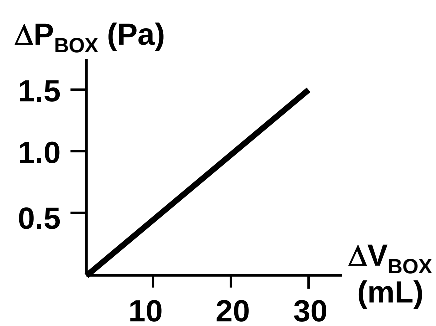
  The total noise from two components is computed by: $V_{N,TOTAL} = \sqrt{V_{N1}^2 + V_{N2}^2}$

- Problem 7: Suppose you also have another amplifier with A_d = 1000 ($V_{N,RMS}$ = 5 mV) and the same V_{REF}. You also have another ADC with 12 bits and $V_{N,RMS}$ = 4 mV. Would you replace just the amplifier, just the ADC, or both? Show all work! Hint: You should find that it is necessary to replace both components.

- Problem 8: Suppose a whole body plethysmography procedure has an initial P_{MOUTH} = 101 kPa. Plots of P_{MOUTH} and P_{BOX} during the panting maneuver are shown below. The calibration of P_{BOX} is also shown below (right). Compute the FRC. NOTE: Be careful with units (kPa versus Pa)! Hint: Between 2.5 to 3L.







- Problem 9: Suppose the helium dilution method is used on a patient. The volume spirometer has a volume of 8L and the initial helium concentration is 7.5%. At the end of the procedure, the final helium concentration is 5.8%. What is the patient's FRC? Hint: Between 2 to 2.5L.

- Problem 10: Consider the nitrogen washout technique. The patient's initial N2 concentration is 9%. The subsequent N2 measurements are shown below:

	Breath Number											
	1	2	3	4	5	6	7	8	9	10	11	12
Volume	0.40L	0.35L	0.40L	0.40L	0.35L	0.35L	0.45L	0.45L	0.40L	0.35L	0.35L	0.35L
N2	8.5%	7.7%	6.9%	6.0%	5.2%	4.4%	3.6%	2.8%	2.0%	1.2%	0.6%	0%

Compute the FRC. Hint: Between 2 to 2.5L.

(End of HW6)