MEC E 301
Lab 4: Strain Gauges

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Question 1

Define a list of the design criteria:

- Pressure range: 0-0.9 kPa
- Resolution should be maximized since the number of bits is fixed to 2^{12}
- Working unit: kPa

One pressure range meets these constraints: $\boxed{\text{001KD}}$.

Question 2

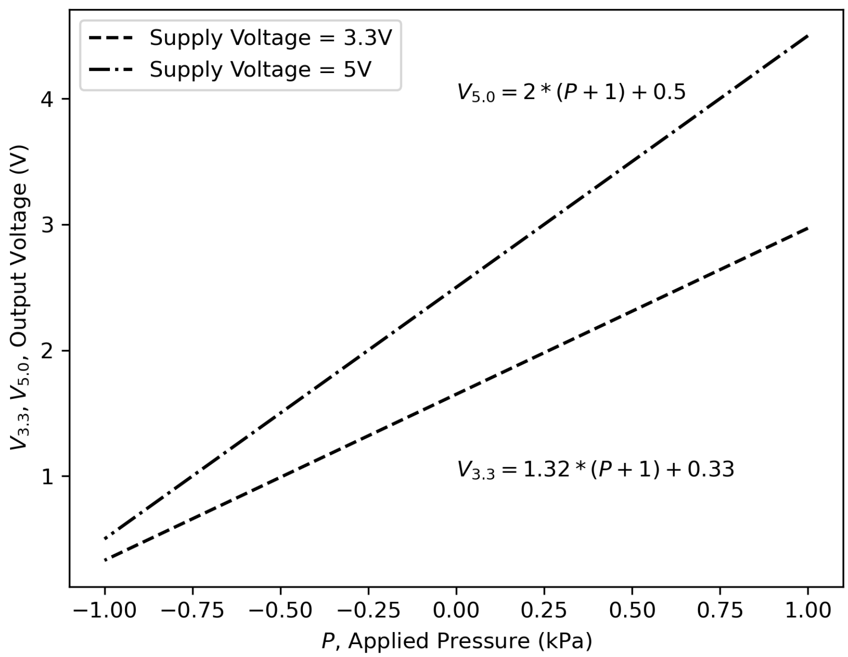

Figure 1: Voltage output of the sensor as a function of pressure over the range of the sensor if the supply voltage is 3.3 V and if it is 5V.

The sensitivity of the sensor for each supply voltage is calculated by taking the derivative of the voltage output with respect to pressure. Since the equations for the voltage output are linear, the sensitivity is constant.

$$\boxed{\begin{aligned}\text{Sensitivity}_{3.3V} &= \frac{d}{dP}\left(1.32 * (P+1) + 0.33\right) = 1.32 \text{ V/kPa}\\ \text{Sensitivity}_{5V} &= \frac{d}{dP}\left(2 * (P+1) + 0.5\right) = 2 \text{ V/kPa}\end{aligned}}$$

Question 3

The transfer function being used has an output range of 10% to 90% of the input range. That means the maximum output of the sensor is $0.9V_{\text{input}}$.

The voltage that the sensor outputs at 0.9 kPa is not the maximum voltage. Determining that from the equations from Fig. 1 gives:

$$V_{3.3,\text{max}} = 1.32(0.9 + 1) + 0.33 = 2.838\,\text{V} < 0.9 \times 3.3 = 2.97\,\text{V}$$
$$V_{5.0,\text{max}} = 2(0.9 + 1) + 0.5 = 4.3\,\text{V} < 0.9 \times 5 = 4.5\,\text{V}$$

These values correspond to the maximum output of the sensor in practice. There is some wiggle room since the EDC can read up to 5V,

$$\boxed{\begin{aligned} \text{Amplification}_{3.3\text{V}} &= \frac{V_{\text{EDC, max}} - V_{\text{EDC, min}}}{V_{3.3,\text{max}}} = \frac{5-0}{2.838} = 1.76 \\ \text{Amplification}_{5.0\text{V}} &= \frac{V_{\text{EDC, max}} - V_{\text{EDC, min}}}{V_{5.0,\text{max}}} = \frac{5-0}{4.3} = 1.16 \end{aligned}}$$

The resolution of the measurement systems are:

$$\boxed{\begin{aligned} \text{Resolution}_{3.3\text{V}} &= \frac{V_{\text{EDC, max}} - V_{\text{EDC, min}}}{2^n G(\text{sensitivity}_{3.3V})} \\ &= \frac{5-0}{2^{12} \times 1.76 \times 1.32} = 5.2 \times 10^{-4}\,\text{kPa} \\ \text{Resolution}_{5.0\text{V}} &= \frac{V_{\text{EDC, max}} - V_{\text{EDC, min}}}{2^{12} G(\text{sensitivity}_{5V})} \\ &= \frac{5-0}{2^{12} \times 1.16 \times 2} = 5.2 \times 10^{-4}\,\text{kPa} \end{aligned}}$$

Question 4

At the operating temperature range of -20 to 85 °C, the bias uncertainty of the sensor is ±3.5% FSS (Full Scale Span). Full scale, as defined by the manufacturer, is the difference between the maximum and minimum output signals at the limits of pressure range.

The total bias uncertainty of the system is the RSS of the two independent uncertainties.

For the 3.3V supply voltage, the bias uncertainty of the sensor is:

$$\begin{aligned} \text{Bias Uncertainty}_{3.3V} &= \%\text{err} \times \frac{\text{FSS}}{\text{sensitivity}} \\ &= \pm 0.035 \times \frac{0.9 \times 3.3 - 0.1 \times 3.3}{1.32} = 0.070\,\text{kPa} \end{aligned}$$

For the 5V supply voltage, the bias uncertainty of the sensor is:

$$\begin{aligned} \text{Bias Uncertainty}_{5V} &= \%\text{err} \times \frac{\text{FSS}}{\text{sensitivity}} \\ &= \pm 0.035 \times \frac{0.9 \times 5 - 0.1 \times 5}{2} = 0.070\,\text{kPa} \end{aligned}$$

The bias uncertainty in kPa for 3.3V and 5V supply voltages are the exact same. In addition their resolutions are also the exact same. Calculating the RSS for total uncertainty:

$$\boxed{\begin{aligned} \delta P_{3.3\text{V}} = \delta P_{5.0\text{V}} &= \sqrt{\text{Quantization Uncertainty}^2 + \text{Bias Uncertainty}^2} \\ &= \sqrt{(5.2 \times 10^{-4}/2)^2 + (7.0 \times 10^{-2})^2} = 7.0 \times 10^{-2}\,\text{kPa} \end{aligned}}$$

Observe that the bias uncertainty is much larger than the resolution of the system, and is the major contributor to the total uncertainty.

Question 5

The unamplified 5.0V system will be used.

Amplifiers are generally cheap; however, sourcing a low-error amplifier may be more costly. Amplification would reduce the quantization uncertainty, however this is negligible compared to bias. The larger concern is the added error-complexity of the amplifier. **As such, this design will not use an amplifier.**

The resolution of the unamplified 3.3V system ($5.2 \times 10^{-4} \times 1.76 = 9.2 \times 10^{-4}\,\text{kPa}$) and the 5.0V system ($5.2 \times 10^{-4} \times 1.16 = 6.0 \times 10^{-4}\,\text{kPa}$), which are both reasonably close to the amplified system resolution of $5.2 \times 10^{-4}\,\text{kPa}$. **Since an unamplified system is simpler, cheaper, and sufficiently resolving, the 5.0V system will be selected due to having a higher resolution than the 3.3V system.**

The uncertainty for this system is $\delta P_{5.0\text{V}} = 7.0 \times 10^{-2}\,\text{kPa}$, which is acceptable for this application. For example, 0.7 ± 0.07 kPa is sufficient for this application as the error is an order of magnitude smaller than the measurement.

Question 6

Since the design is concerned with sustained (lower frequency) pressures, a low-pass filter can be used to filter out the higher frequency signals.

Transform the signal into the frequency domain using FFT, then employ a low-pass filter as the transfer function. Then inverse transform the signal back into the time domain to obtain the filtered signal!