Hardware Decision Reasoning - Table Approximation

With the recommendation of two sensors to a single microcontroller, the new requirements are as follows. According to Nyquist, the minimum requirement for sampling frequency from bandwidth is given.

$f_s = 2 \times 70\, kHz = 140\, ksps$

Since we will be sampling two sensors in a single microcontroller module, our minimum sampling rate requirement is given.

$f_{s,min} = 2 \times 140\, ksps = 280\, ksps$

To ensure effective sampling, and to avoid any unnecessary complications, the recommended sampling rate was decided to be at least 500 ksps.

$f_{s,eff} = 500\, ksps > 280\, ksps$

MCU

To save resources and to keep familiarity with PIC32, I have opted to keep the original microcontroller decision in the final design. For this reason, I will be basing my peripheral component decisions on this microcontroller.

Based on our requirements, the MCU is required to handle at least 4 differential sensor inputs, each at 500 kHz or higher.

PIC32MZ2048EFG064-I/PT

- 252 MHz Clock
- 2048 KB Program Memory
- 512 KB Data Memory
- 12-bit ADC

Given our maximum clock frequency:

$T_{period} = \frac{1}{252E6} = 3.97\, ns$

ADC

Along with the changes to resolution, we will now be dealing with the reduction to two sensors per microcontroller with two microcontrollers total. The parameters of this configuration are as follows:

MCP33131D-10T-I/MS

- 16-bit Resolution
- Single Channel Differential Inputs
- Sampling Rate = 1 Msps

- Vref = 2.5-5.1 V

Based off of these hardware characteristics:
Since we will be using differential functionality the effective voltage resolution is

Vref = 2.5 V
$V_{step} = \frac{2Vref}{2^n} = \frac{2*2.5}{2^{16}} = 76.294\ \mu V$ In a range between -2.5V and +2.5V

Of course, we will need amplification to be within the ADC range, but the voltage resolution offered will be highly useful.

To measure the bridge resistance of the sensor I will employ the use of a shunt resistance and measure the voltage difference across to calculate bridge resistance. For this measurement I will attempt to save resources by utilizing the 12-bit ADC located on the microcontroller. My reasoning for this is to reduce the amount of external ADCs used, thus reducing cost and decreasing complexity. Since the 12-bit ADCs are built in, SPI line usage is not necessary, and we can still have accurate measurements without straining resources.

According to the microcontroller, the maximum SPI Clock frequency is 50 MHz and our ADC Clock frequency is 100 MHz. So we are limited by the microcontrollers SPI Clock rate.

$Cycles_{SPI} = 16$
$SPI\ Clock = 50\ MHz$
$ADC\ Clock = 100\ MHz$

$T_{sampling} = T_{acquisition} + T_{conversion} = 1\ \mu s$
$T_{SPI} = 16 \times \frac{1}{50E6} = 320\ ns$

Thus the total time commitment to sample and receive data is:
$T_{total} = T_{SPI} + T_{sampling} = 1.32\ \mu s$

To process this data between each sampling, we will require
$Available\ MCU\ cycles = 1.32\ \mu s \times 252\ MHz = 332\ cycles$

At this time I do not have an accurate estimation to how many instructions the final program will require, but usage of things like DMA to free up MCU resources will be looked into.

Signal Conditioning
The purpose of signal conditioning in this circuit is to bring the sensor voltage up to the magnitude we can sample with the ADC at good resolution. The differential ADC driver chosen also offers isolation between the sensor and our ADC to avoid any discrepancies due to high

impedance mismatch. The nature of differential ADC drivers also yields high resistances to common mode noise with high CMRR.

$$Voltage\ Range_{differential} = \sim [0, 0.1]V$$

$$Gain = \frac{2.5}{0.1} = 25$$

$$GBP_{min} = 70\ kHz \times 25 = 1.75\ MHz$$

$$Slew\ Rate_{min} = 2\pi \times 70\ kHz \times 0.1/2 = 21.99\ mV/\mu s$$

It is recommended that the slew rate is at least three times the minimum calculated value.

Along with amplification, I will be including a low pass RC filter to block any frequencies not in our desired BW resolution. To avoid attenuation I will shoot for around 75 kHz bandwidth filtering.

Summary
In summary, my proposed design will employ two ADCs for each microcontroller (one per sensor). I will be using a shunt resistor to record bridge resistance along with the built in 12-bit ADC. All of these differential inputs will have signal conditioning included before the ADC, including: anti-aliasing, noise reduction, and amplification. This sums up to 4 signal conditioning IC and circuits for each microcontroller. Each microcontroller will then be paired with two DACs.

MCU

PIC32MZ2048EFG064-I/PT

- 252 MHz Clock
- 2048 KB Program Memory
- 512 KB Data Memory
- 12-bit ADCs
- Price = $14.41 x 1 = $14.41

ADC

MCP33131D-10T-I/MS

- 16-bit Resolution
- Single Channel Differential Inputs
- Sampling Rate = 1 Msps
- Vref = 2.5-5.1 V
- Price = $9.12 x 2 = $18.24

ADC Driver

MCP6D11T-E/MS

- GBP = 90 MHz
- Slew Rate = 20V/us
- Adjustable Gain
- Price = $2.06 x 4 = $8.24

DAC

DAC8830ICD

- 16-bit
- Clock limit = 50 MHz
- Settling time = 1us
- Price = $18.23 x 2 = $36.46

Tentative Total = $77.35

General 2 Sensor Module Outline