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Bridge Sensing with the MCP6S2X PGAs

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INTRODUCTION

Resistive sensors configured as Wheatstone bridges are primarily used to sense pressure, temperature or loads. An external A/D converter (ADC) and a digitally Programmable Gain Amplifier (PGA) can easily be used to convert the difference voltage from these resistor bridge sensors to usable digital words for manipulation by the microcontroller. When the PGA is used in this system, the other channels of the MCP6S2X can be used for other sensors without an increase in signal conditioning hardware or PICmicro® microcontroller I/O pin consumption. The multiplexer and high-speed conversion response of the PGA/Analog-to-Digital (A/D) conversion allows a differential input signal to be sampled and converted in the analog domain and then subtracted in the digital domain with the microcontroller.

BRIDGE DATA ACQUISITION SYSTEM

An application circuit for this type of sensor environment is shown in Figure 1.

In this circuit, the bridge is excited by a voltage source (V_{SEN}). This reference voltage can be V_{DD}, generated using a current source or provided by a voltage reference device. Regardless of the approach used to generate this source, it is utilized across the circuit in order to provide a ratiometric digital result. The two outputs of the sensor are connected to the internal multiplexor of the MCP6S26 PGA. The PGA is controlled digitally for gain, as well as toggling between CH0 and CH1. The gain options for the PGA are: 1, 2, 4, 5, 8, 10, 16 and 32 V/V.
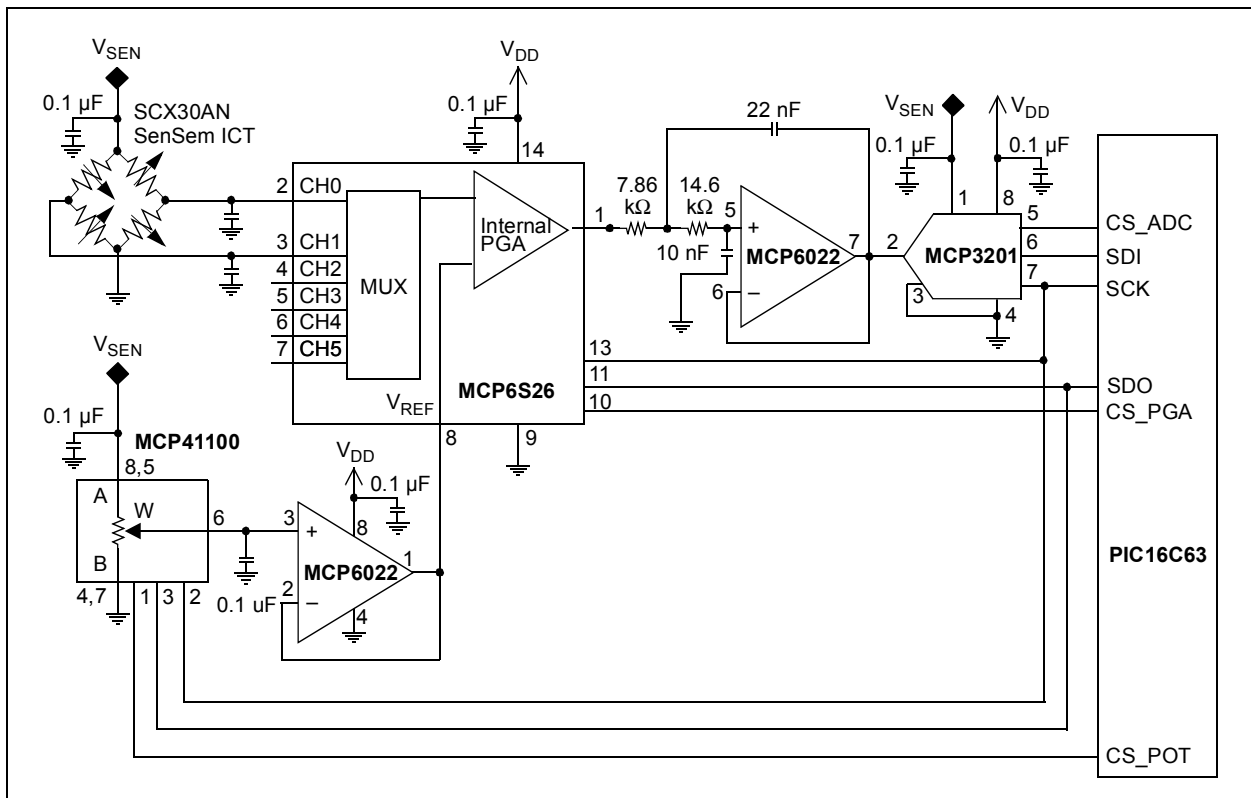

FIGURE 1: *A resistive bridge output voltage is gained and converted to a 12-bit word using the MCP6S26, six-channel PGA for analog gain and a 12-bit ADC (MCP3201).*

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The reference to the PGA in Figure 1 (MCP6S26, pin 8) is provided by the digital potentiometer, MCP41100. Alternatively, the voltage reference pin of the PGA can be driven with a D/A voltage-out converter, a dedicated voltage reference chip, a resistive divider circuit or tied to ground or V_{DD}. In all cases, the voltage reference source should be low-impedance. A variable voltage reference may be required because of the various requirements on other channels of the PGA. If a variable voltage reference is required, the circuit in Figure 1 can be used.

The potentiometer in Figure 1 (MCP41100) is a 100 kΩ element that can be programmed in V_{SEN}/256 step sizes. For this application, the digital potentiometer should be programmed approximately at the center voltage of the bridge outputs, or approximately V_{SEN}/2. For more detailed information on the determination of the reference voltage value, refer to the "PGA Reference Voltage" section. If this circuit is used to sense additional inputs on CH2 through CH5, the digital potentiometer could be used to adjust each input. If this circuit is only used to measure a bridge, a resistor divider could be used instead. The output of the MCP41100 is buffered with the MCP6022 operational amplifier (op amp). This amplifier is selected to isolate the digital potentiometer from the PGA and was specifically chosen to match the speed of the MCP6S26. The MCP6022 is a CMOS, 10 MHz unity gain stable op amp. This device is capable of responding to any fast current requirements to drive the resistor array in the MCP6S26 during ac operation.

At the output of the PGA, an anti-aliasing filter is inserted. This is done prior to the A/D conversion in order to reduce noise. The anti-aliasing filter can be designed with a gain of one or higher, depending on the circuit requirements. Again, the MCP6022 op amp is used to match the frequency response of the PGA. Microchip's FilterLab® software can be used to easily design this filter's frequency cut-off and gain.

The anti-aliasing filter in this circuit is a Sallen-Key (non-inverting configuration) with a cut-off frequency of 1 kHz. Generally speaking, the corner frequency of this filter should be designed to complement all of the input signals to the multiplexer in your specific design. For more information regarding the design of anti-aliasing filters, refer to Microchip Technology's AN699, "Anti-Aliasing, Analog Filters for Data Acquisition Systems" (DS00699).

The signal at the output of the filter is connected to the input of a 12-bit ADC, MCP3201. In this circuit, if noise is kept under control, it is possible to obtain 12-bit accuracy from the converter. Beyond the anti-aliasing filter, noise is kept under control by appropriate bypass capacitors, short traces, linear supplies and a solid ground plane. The entire system is manipulated on the same Serial Peripheral Interface (SPI™) bus of the PIC16C63 for the PGA, digital potentiometer and ADC with no digital feedthrough from the converter during conversion. Any PICmicro® microcontroller can be used in this circuit. In Figure 1, the PIC16C623 was selected for it's SPI ports and clock speed. In this circuit, the PGA is toggled between CH0 and CH1. In each state, the voltage at the output of the PGA is converted by the 12-bit ADC. It is important to keep CH0 and CH1 relatively static (within 12-bit accuracy) during this dual measurement. To derive the final voltage difference between CH0 and CH1, the data taken from CH0 and CH1 is subtracted and divided by the gain in the microcontroller to derive the voltage across the bridge.

Bus lines to the microcontroller can be eliminated by changing the digital potentiometer to a voltage divider or voltage reference, such as the MCP1525 (2.5V Precision Reference). Alternatively, the microcontroller's internal ADC can replace the MCP3201, if one is available. As an option, the PGA and digital potentiometer can be daisy-chained, eliminating the use of one I/O line. Refer to DS21117, "Single Ended, Rail-to-Rail I/O, Low Gain PGA", and DS11195, "Single/Dual Digital Potentiometer with SPI™ Interface", for details.

DETAILS OF PGA CIRCUIT OPERATION

An instrumentation amplifier (INA) is typically used instead of the PGA used in this circuit. The PGA's strength in this application is its front-end multiplexer and gain adjustability, allowing an easy interface to a variety of sensors and/or channels in the same application circuit. With an INA, the gain and reference voltage to the INA are not easily adjusted from the microcontroller. The PGA is easily adjusted in this respect by offering gain selectability, channel selectability and easy voltage reference adjustment.

The conversion speed of this circuit was affected by the conversion time of the ADC and channel-to-channel switching time of the PGA. The conversion time of the ADC was 50 ksps, taking 20 µsecs to convert and store data. The PGA channel-switching time was 20 µsecs. The total time that was required to switch from channel-to-channel was 50 µsecs, including additional PICmicro code. In this manner, the interfering main's noise was rejected.

Discussion of the design of other PGA circuits that can be implemented with different sensors is found in Microchip Technology's AN865, "Sensing Light with a Programmable Gain Amplifier" (DS00865).

PGA Reference Voltage

The input range of the reference voltage pin is V_{SS} to V_{DD} of the PGA. In this case, V_{SS} = Ground and V_{DD} = 5V. The transfer function of the PGA is equal to:

EQUATION

$$V_{OUT} = GV_{IN} - (G-1)V_{REF}$$

With this ideal formula, the actual restrictions on the output of the PGA should be taken into consideration. Generally speaking, the output swing of the PGA is less than 20 mV from the positive rail and 125 mV above ground, as specified in the MCP6S2X PGA data sheet (DS21117). However, to obtain good, linear performance, the output should be kept within 300 mV from both rails. This is specified in the conditions of the "DC gain error" and "DC output non-linearity".

Consequently, beyond the absolute voltage limitations on the PGA voltage reference pin, the voltage output swing capability further limits the selection of the voltage at pin 8. This is illustrated in Figure 2 and Figure 3 below.
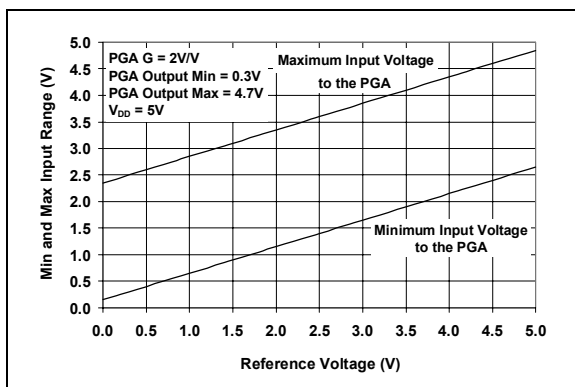

FIGURE 2: *If the programmed gain to the PGA is 2, the voltage applied to V_{REF} (pin 8) is limited to approximated 1/2 of the range in a gain of 1 V/V.*
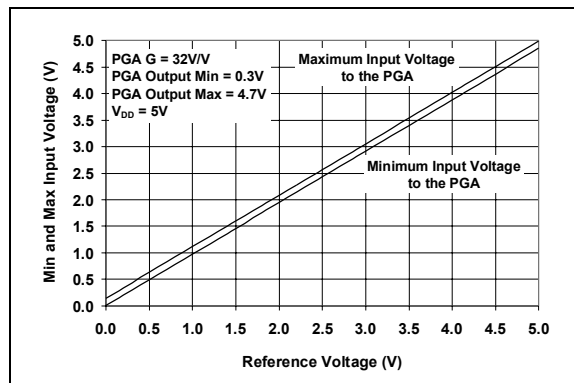

FIGURE 3: *If the programmed gain to the PGA is 32, the voltage applied to V_{REF} (pin 8) is limited to approximated 1/32 of the range in a gain of 1 V/V.*

As shown in Figure 2 and Figure 3, the reference voltage of the PGA should be programmed between the expected input voltage range of the PGA. For instance, in a gain of 2 V/V (Figure 2) with an input range of 1.0V to 3.2V, the voltage reference at pin 8 of the MCP6S26 should be equal to 1.7V for optimum performance.

The formulas that are to be used to calculate the appropriate gain setting (G) for the PGA and the optimum V_{REF} value are:

EQUATION

$$V_{IN}(min) \geq (V_{OUT}(min) + (G-1)V_{REF})/G$$

$$V_{IN}(max) \geq (V_{OUT}(max) + (G-1)V_{REF})/G$$

where:

V_{IN} = input voltage to the PGA.

$V_{OUT}(min)$ = minimum output voltage of PGA = V_{SS} + 0.3V.

$V_{OUT}(max)$ = minimum output voltage of PGA = V_{DD} - 0.3V.

G = gain of the PGA.

V_{REF} = Voltage reference applied to pin 8 of the PGA.

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Performance Data

In the circuit of Figure 1, the power supply (V_{DD}) was 5V and the voltage applied to V_{SEN} was also 5V. The reference voltage to the PGA was generated by the MCP1525, a 2.5V precision voltage reference. The gain setting of the PGA is 32 V/V. The analog filter was built to have a 1 kHz cut-off frequency.

The pressure sensor, SCX30AN (a precision compensated pressure sensor) from SenSym ICT was used. The standard full-scale pressure range of this sensor is 30 PSI, with a full-scale output voltage of 90 mV (typ.). Pressure was generated using the PCL425-PUMP pressure pump from Omega™. The pressure from this pump was verified with HHP-102E Handheld Manometer also from Omega.

The data taken from this setup is given in a tabular form in Table 1 and is graphically illustrated in Figure 4.

TABLE 1: DATA TAKEN USING THE CIRCUIT IN FIGURE 1*

PSI	CH0 Code	CH1 Code
0	1569	2063
5.5	1505	2162
7.6	1475	2199
10.9	1421	2262
13.2	1386	2301
18.3	1315	2390
21.4	1286	2446
26.7	1188	2535
27.4	1180	2550
29.9	1140	2590

* This data indicates that the sensor is relatively linear across the PSI range of measurement
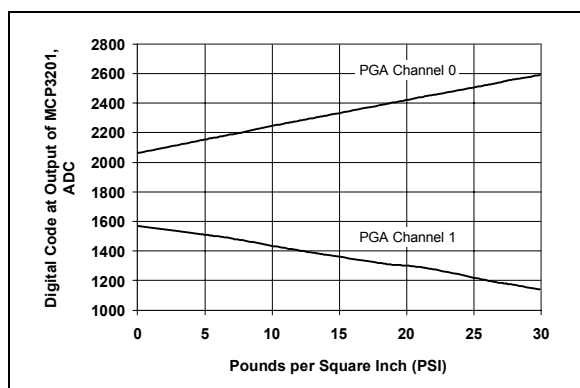

FIGURE 4: *The tabular data from Table 1 is shown graphically in this figure.*

This data was taken using one MCP6S26, MCP3201, MCP6022 and pressure sensor from SenSym ICT. The selected pressure sensor for this application note is not necessarily the appropriate sensor for all applications. The data is reported reliably, but does not represent a statistical sample of the performance of all devices in the products' families. During this test, a 120 Hz interference signal was recorded due to the mains supply. If data is converted from channel-to-channel before the signal changes more than 1/4 LSb (due to this interfering signal), the common mode error signal will not be superimposed on the resulting data. In this manner, the mains common mode signal is rejected.

CONCLUSION

This circuit provides an accurate conversion for Wheatstone bridge networks. With Microchip's line of PGAs, there are several issues that are also resolved before inserting the MCP6S26 in the circuit. Regardless of the gain, the circuit is stable. This is contrary to a stand-alone amplifier, where stability could compromise the circuit. This is particularly true if the gain of the op amp circuit is being changed on the fly. Additionally, the bandwidth with the PGA is kept fairly constant. It is true that the internal amplifier has a voltage feedback topology, but Microchip not only changes the gain, it also changes the compensation with every programmed gain change.

The MCP6S2X family of PGAs have one channel, two channel, six and eight-channel devices in the product offering. Changing from channel-to-channel would require one 16-bit communication to occur between the PGA on the SPI interface. A clock rate of 10 MHz on the SPI interface would require approximately ~1.6 µs. Additionally, the PGA amplifier would need to settle. Refer to the MCP6S2X PGA data sheet (DS21117) for the settling time versus gain specification.

The PGA, a precision device from Microchip Technology Inc., not only offers excellent offset voltage performance, but also the configurations in this sensing circuit are easily designed without the headaches of stability that the stand-alone amplifier circuits present to the designer. Stability with these programmable gain amplifiers have been built-in by Microchip's engineers.

REFERENCES

AN865, "Sensing Light with a Programmable Gain Amplifier", Bonnie C. Baker; Microchip Technology Inc. (DS00865).

AN699, "Anti-Aliasing, "Analog Filters for Data Acquisition Systems", Bonnie C. Baker; Microchip Technology Inc. (DS00699).

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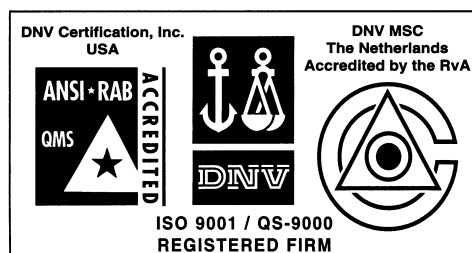
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