# AN1100

# Analog to Digital Converter Resolution Extension Using a Motorola Pressure Sensor

## PURPOSE

This paper describes a simple method to gain more than 8–bits of resolution with an 8–bit A/D. The electronic design is relatively simple and uses standard components.

## PRINCIPLE

Consider a requirement to measure pressure up to 200 kPa. Using a pressure sensor and an amplifier, this pressure can be converted to an analog voltage output. This analog voltage can then be converted to a digital value and used by the microprocessor as shown in Figure 1.

If we assume for this circuit that 200 kPa results in a +4.5 V output, the sensitivity of our system is:/

$$S = 4.5 \ V/200kPa \qquad (1)$$
$$= 0.0225 \ V/kPa$$
$$\text{or} \quad S = 22.5 \ mV/kPa$$

If an 8–bit A/D is used with 0 and 5 Volt low and high references, respectively, then the resolution would be:

$$S = 5V/\left(2^8 - 1 = 5V/255\right) \qquad (2)$$
$$= 0.01961 \ V$$
$$\text{or} \quad R_V = 19.60 \ mV \ per \ bit$$

This corresponds to a pressure resolution of:

$$R_P = 5V/\left(19.60 \ mV/bit\right)/\left(22.5 \ mV/kPa\right) \qquad (3)$$
$$= 0.871 \ kPa \ per \ bit$$

Assume a resolution of at least 0.1 kPa/bit is needed. This would require an A/D with at least 12 bits ($2^{12} = 4096$ steps).

One can artificially increase the A/D resolution as described below.

Refer to Figure 1 and assume a pressure of 124 kPa is to be measured. With this system, the input signal to the A/D should read (assuming no offset voltage error):

$$V_m(measured) = 4.5 \ (Papp) \ x \ (S) \qquad (4)$$
$$= (124 \ kPa) \ x \left(22.5 \ mV/kPa\right)$$
$$= 2790 \ mV,$$

where Papp is the pressure applied to the sensor.

Due to the resolution of the A/D, the microprocessor receives the following conversion:

$$M = (2790 \ mV)/\left(19.60 \ mV/bit\right) \qquad (5)$$
$$= 142.35$$
$$= 142 \ (truncated \ to \ integer)$$

The calculated voltage for this stored value is:

$$V_c \ (calculated) = (142 \ count) \ x \left(19.60mV/ \ count\right) \qquad (6)$$
$$= 2783 \ mV$$

The microprocessor will output the stored value M to the D/A. The corresponding voltage at the analog output of the D/A, for an 8–bit D/A with same references, will be 2783 mV.

The calculated pressure corresponding to this voltage would be:

$$P_c \ (calculated) = (2783 \ mV)/\left(22.5 \ mV/kPa\right) \qquad (7)$$
$$123.7 \ kPa$$

Thus, the error would be:

$$E = Papp - Pc \qquad (8)$$
$$= 124 \ kPa - 123.7 \ kPa$$
$$= 0.3 \ kPa$$

This is greater than the 0.1 kPa resolution requirement.



**Figure 1. Block Diagram**

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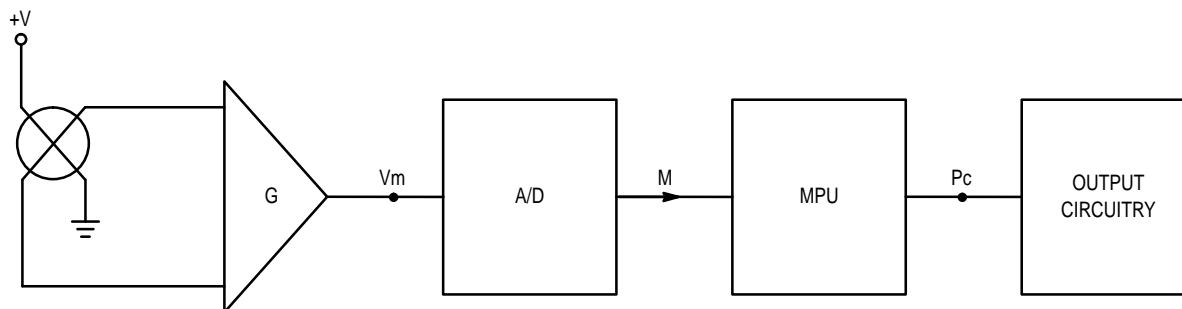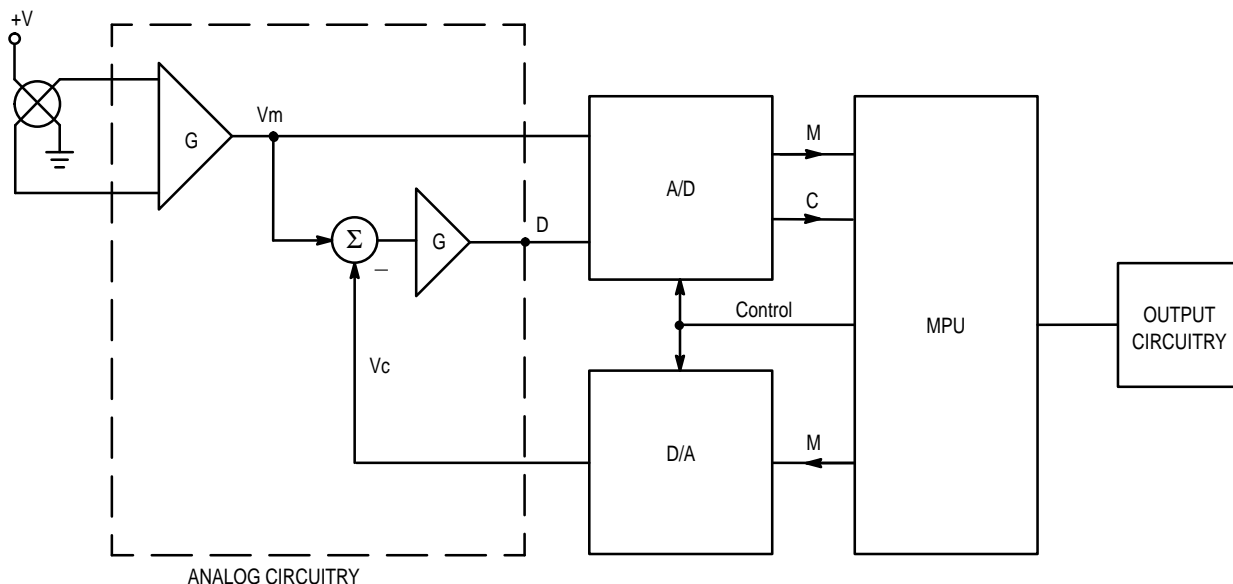**Figure 2. Expanded Block Diagram**

Figure 2 shows the block diagram of a system that can be used to reduce the inaccuracies caused by the limited A/D resolution. The microprocessor would use the stored value M, as described above, to cause a D/A to output the corresponding voltage, Vc. Vc is subtracted from the measured voltage, Vm, using a differential amplifier, and the resulting voltage is amplified. Assuming a gain, G, of 10 for the amplifier, the output would be:

$$D = (Vm–Vc) \times G \qquad (9)$$
$$= (2790 \ mV–2783 \ mV) \times 10$$
$$= 70 \ mV$$

The microprocessor will receive the following count from the A/D:

$$C = 70mV/(19.60 \ mV/count) \qquad (10)$$
$$= 3.6$$
$$= 3 \ full \ counts$$

The microprocessor then computes the actual pressure with the following equations:

$$Expanded \ Voltage = Vc + ((C \times R)/G) \qquad (11)$$
$$= 2783 + ((3 \times 19.60)/10)$$
$$= 2789 \ mV,$$
NOTE: R is resolution of 8-bit d/A

$$Corresponding \ Pressure = 2789 \ mV/ \qquad (12)$$
$$= 22.5 \ mV/kPa$$
$$= 123.9 \ kPa$$

Thus the error is:

$$Pressure \ Error = Actual - Measured \qquad (13)$$
$$= 124 \ kPa - 123.9 \ kPa$$
$$= 0.1 \ kPa$$

Figures 3 and 4 together provide a more detailed description of the analog portion of this system.
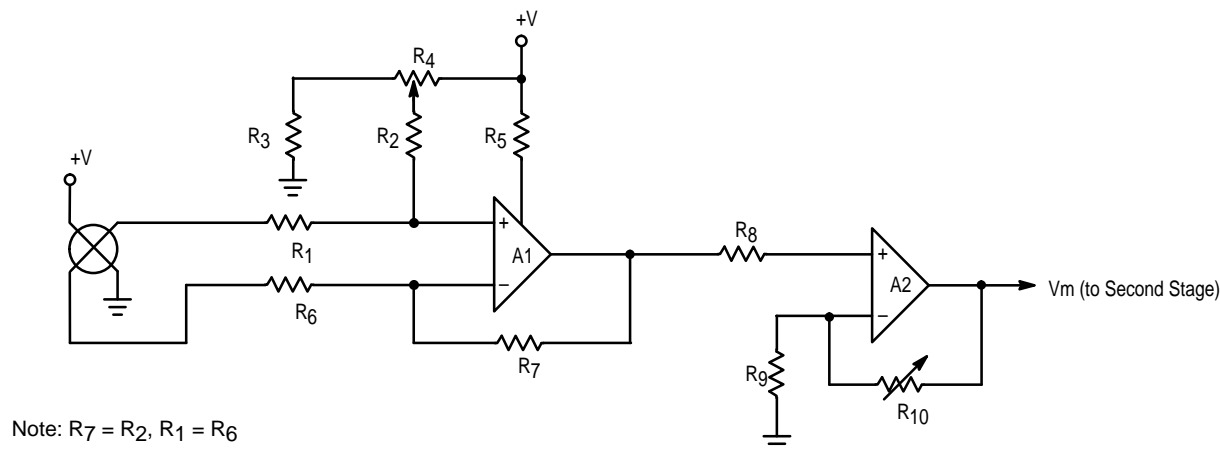


Note: $R_7 = R_2$, $R_1 = R_6$

**Figure 3. First Stage – Differential Amplifier, Offset Adjust and Gain Adjust**
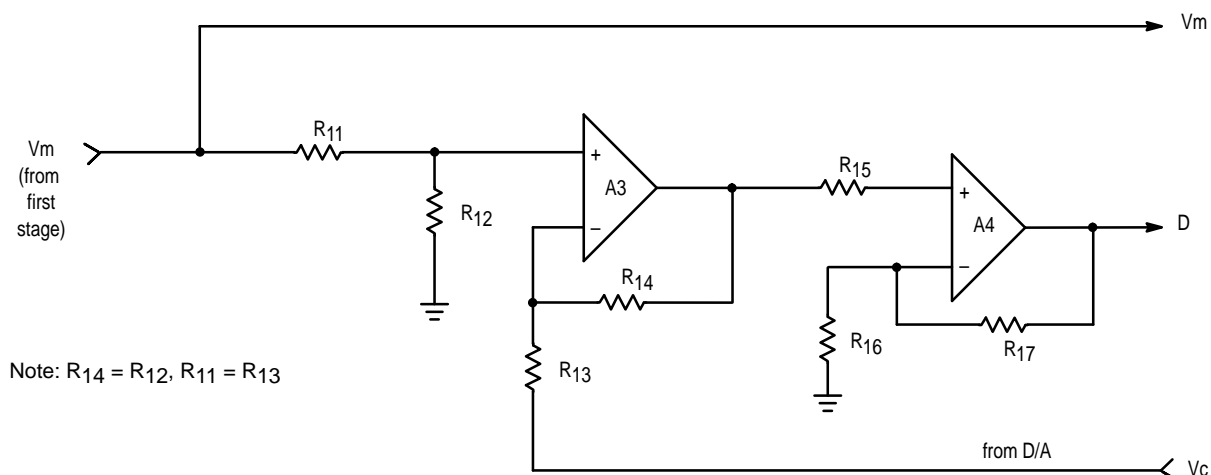
**Figure 4. Second Stage — Difference Amplifier and Gain**

### FIRST STAGE (Figure 3)

The first stage consists of the Motorola pressure sensor; in this case the MPX2200 is used. This sensor typically gives a full scale span output of 40 mV at 200 kPa. The sensor output ($V_S$) is connected to the inputs of amplifier A1 (1/4 of the Motorola MC33079, a Quad Operational Amplifier). The gain, G1, of this amplifier is R7/R6. The sensor has a typical zero pressure offset voltage of 1 mV. Figure 3 shows offset compensation circuitry if it is needed. A1 output is fed to the non–inverting input of A2 amplifier (1/4 of a Motorola MC33079) whose gain, G2, is $1+R_{10}/R_9$. G2 should be set to yield 4.5 volts out with full–rated pressure.

### THE SECOND STAGE (Figure 4)

The output from A2 ($Vm = G1 \times G2 \times Vs$) is connected to the non–inverting input of amplifier A3 (1/4 of a Motorola MC33079) and to the A/D where its corresponding (digital) value is stored by the microprocessor. The output of A3 is the amplified difference between Vm, and the digitized/calculated voltage Vc. Amplifier A4 (1/4 of a Motorola MC33079) provides additional gain for an amplified difference output for the desired resolution. This difference output, D, is given by:

$$D = (Vm - V_c) \times G3$$
$$G3 = (R14/\ R13)\left(1 + \frac{R17}{R16}\right)$$

where G3 is the gain associated with amplifiers A3 and A4.

The theoretical resolution is limited only by the accuracy of the programmable power supply. The Motorola microprocessor used has an integrated A/D. The accuracy of this A/D is directly related to the reference voltage source stability, which can be self–calibrated by the microprocessor. $V_{expanded}$ is the system output that is the sum of the voltage due to the count and the voltage due to the difference between the count voltage and the measured voltage. This is given by the following relation:

$$V_{expanded} = V_c + D/G3$$
$$\text{therefore, } PV_{expanded} = V_{expanded}/S.$$

$P_{expanded}$ is the value of pressure (in units of kPa) that results from this improved–resolution system. This value can be output to a display or used for further processing in a control system.

### CONCLUSION

This circuit provides an easy way to have high resolution using inexpensive microprocessors and converters.

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