Techniques that Reduce System Noise in ADC Circuits

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ANALOG DESIGN NOTE ADN007

It may seem that designing a low noise, 12-bit Analog-to-Digital Converter (ADC) board or even a 10-bit board is easy. This is true, unless one ignores the basics of low noise design. For instance, one would think that most amplifiers and resistors work effectively in 12-bit or 10-bit environments. However, poor device selection becomes a major factor in the success or failure of the circuit. Another, often ignored, area that contributes a great deal of noise, is conducted noise. Conducted noise is already in the circuit board by the time the signal arrives at the input of the ADC. The most effective way to remove this noise is by using a low-pass (anti-aliasing) filter prior to the ADC. Including by-pass capacitors and using a ground plane will also eliminate this type of noise. A third source of noise is radiated noise. The major sources of this type of noise are Electromagnetic Interference (EMI) or capacitive coupling of signals from trace-to-trace.

If all three of these issues are addressed, then it is true that designing a low noise 12-bit ADC board is easy.

An example of a 12-bit circuit is shown in Figure 1. The signal originates at the resistive load cell, part number LCL-816-G. The differential output ports of the LCL-816-G are connected to a discrete, two-op-amp instrumentation amplifier (A1, A2, R3, R4 and RG). The signal then travels through a second order, low-pass filter (A3, R5, R6, C1 and C2). This low-pass filter eliminates unwanted, higher frequency noise. Finally, the signal couples into a 12-bit ADC (A4, MCP3201). The converter is configured to accept signals from 0V to 5V. The output of the converter is sent to the PIC16C623 microcontroller.

If this circuit is built without using low noise precautions, it is very easy to produce an output similar to Figure 2. Here, 1024 samples were taken at the output of the ADC (MCP3201) at a data rate of 30 ksps. These samples have a 44 code "spread" centered around code 2982. From this data, the system is approximately 5.45-bit accurate. Clearly this circuit is not good enough even for a 10-bit system. The specific configuration of this board is:

R3 = 300 kΩ

R4 = 100 kΩ

RG = 4020Ω

A1 = A2 = single supply, CMOS op amp, MCP604

No low-pass anti-aliasing filter included

No by-pass capacitors included

No ground plane used

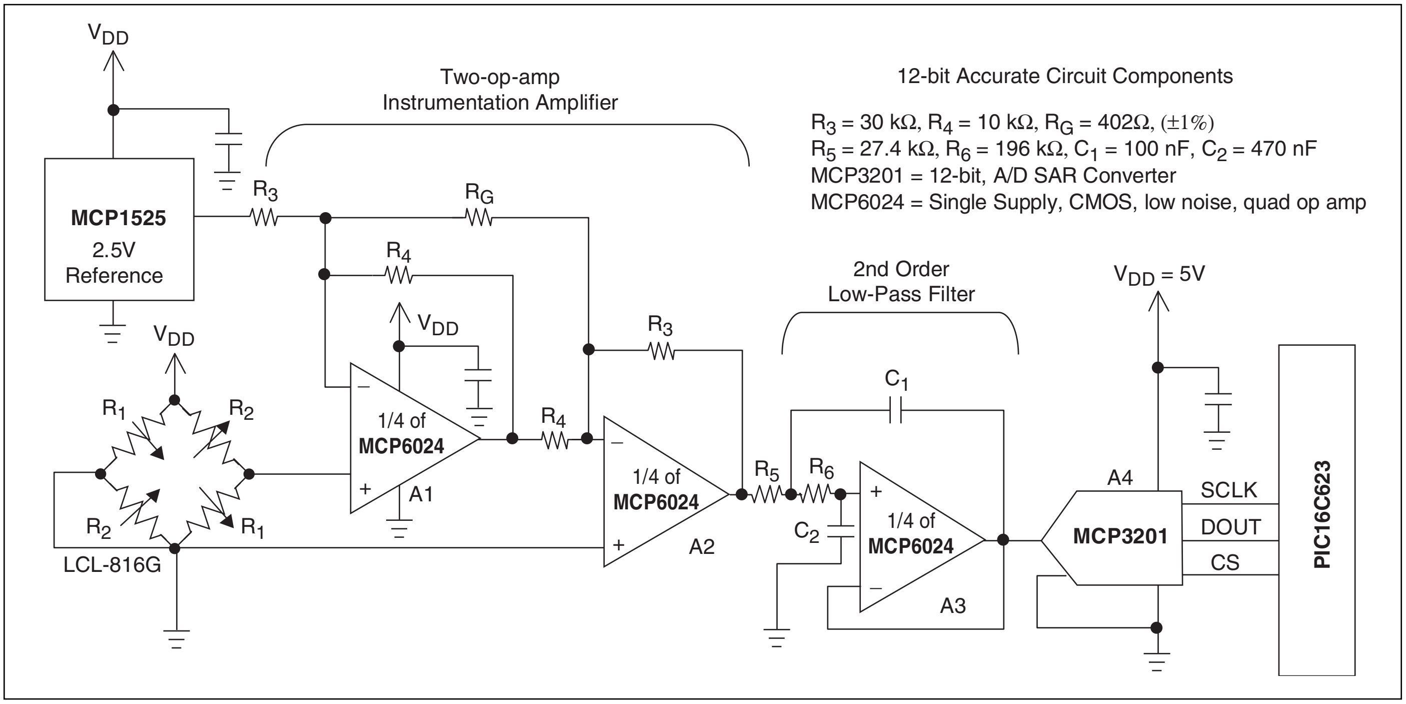

Figure 1. When you use low noise devices, a ground plane, by-pass capacitors and a low-pass filter, it is possible to produce an accurate, 12-bit conversion every time.

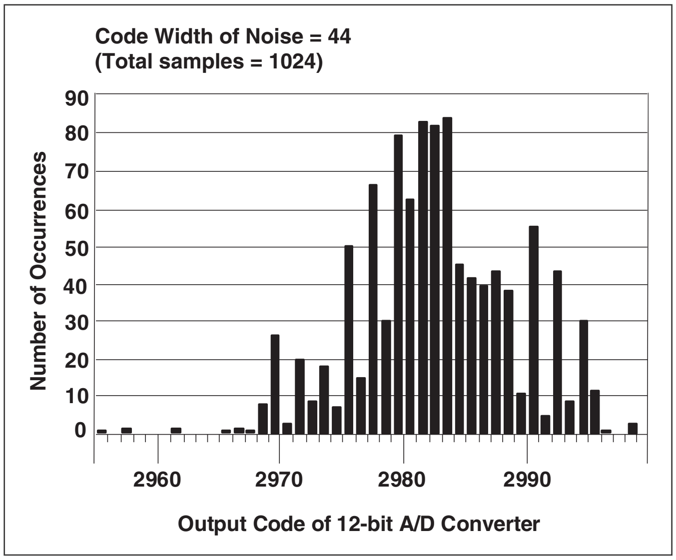

Figure 2. *When low noise precautions are not taken during circuit design and board layout, a 12-bit ADC system under-performs with approximately 5.45-bit accuracy (or 5.45 Effective Number of Bits).*

Modifying this circuit and board can result in a 12-bit accurate solution. As a first step, lower noise devices are used. For instance, the resistors are made 10 times lower. When this is done, the gain remains the same, but the noise is reduced by approximately 3 times. Additionally, the amplifiers are changed from the MCP604 to the MCP6044. The MCP604's voltage noise density, at 1 kHz, is 29 nV/ √Hz (typ). The MCP6024's voltage noise density, at 10 kHz, is 8.7 nV/ √Hz (typ). This is over 3 times improvement. As a third modification, a ground plane is added to the Printed Circuit Board (PCB). This ground plane is implemented so that interruptions in the metal are parallel instead of horizontal to the signal path.

The performance of the board changes dramatically with these three modifications. Tests show that the histogram output of the ADC changes from a code width of 44 codes down to 9 codes. This dramatic change converts the circuit in Figure 1 into approximately a 9-bit system.

This sounds good, but there is a 12-bit system to be found in this application. Adding a second order filter (A3, R5, R6, C1 and C2), which is designed using the FilterLab® software, improves the performance. Additionally, including the by-pass capacitors turns this system into a true 12-bit accurate system. This is illustrated in Figure 3 where 1024 samples are collected from the converter at a data rate of 30 ksps and all 1024 samples are equivalent to one code: 2941.

It is easy to design a true 12-bit ADC system by using a few key low noise guidelines. First, examine your devices (resistors and amplifiers) to make sure they are low noise. Second, use a ground plane whenever possible. Third, include a low-pass filter in the signal path if you are changing the signal from analog to digital. Finally, and always, include by-pass capacitors. These capacitors not only remove noise but also foster circuit stability.

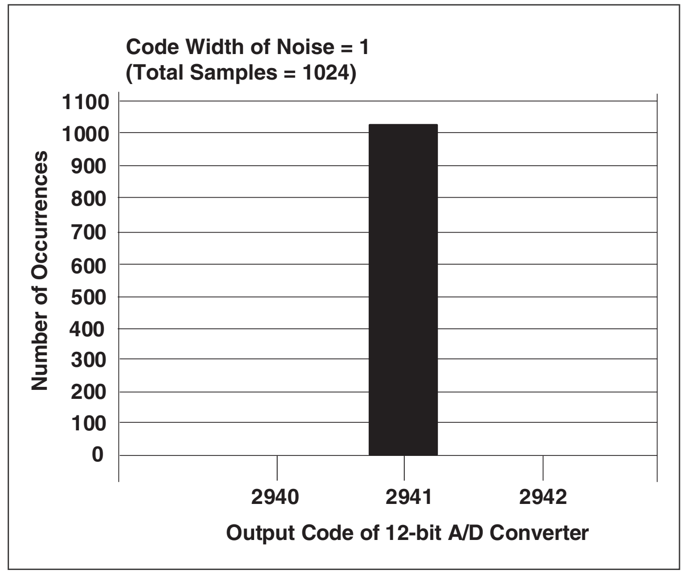

Figure 3. *If low noise, active and passive devices are used, a ground plane is included, by-pass capacitors are added and a low-pass (anti-aliasing) filter is placed in the signal path. The code width of 1024 samples is equal to one.*

Recommended References:

AN681 - *Reading and Using Fast Fourier Transforms (FFTs), Baker, Bonnie C., Microchip Technology Inc.*

AN688 - *Layout Tips for 12-Bit A/D Converter Application, Baker, Bonnie C., Microchip Technology Inc.*

AN695 - *Interfacing Pressure Sensors to Microchip's Analog Peripherals, Baker, Bonnie C., Microchip Technology Inc.*

AN699 - *Anti-Aliasing, Analog Filters for Data Acquisition Systems,* Baker, Bonnie C., *Microchip Technology Inc.*

Noise Reduction Techniques in Electronic Systems, Henry Ott, John Wiley, N.Y., 1998.

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