Tracking down excessive noise in an Analog-to-Digital system

Background

A/D converters produce a reading with certain number of bits of resolution. A 16 bit A/D converter resolves one part in 65,536, which is 2 to the 16 power. A 24 bit A/D converter resolves one part in 16,777,216, which is 2 to the 24 power. The number of bits alone does not tell you much about how much usable information is represented by the less significant bits because noise may dominate the lower value bits. The reproducibility of an A/D converter is one way to quantify its stability. Reproducibility does not equate to accuracy, but accuracy cannot exceed reproducibility, so reproducibility must come first.

The standard way to quantify reproducibility is to take a block of readings of a steady voltage and to calculate the RMS noise. That calculation is the square root of the average of the squares of the differences between each sample and the overall average. You can just think of it as the average noise, as opposed to the peak noise. The RMS noise is then converted to its equivalent in bits. If the least significant bit in a converter represented 1 mV, and the RMS noise was 2 mV, the RMS noise in bits would be 2. Subtract the RMS noise in bits from the total bits of resolution to get the effective resolution, in bits. Most Lawson Labs sample software displays that effective resolution for confirmation that the system is functioning properly.

In general, noise can be further reduced by averaging. Typically, you need to average four readings in order to reduce the noise by half. Don't be too quick to average your data to reduce the noise. You could take totally random data and average it to get a number with what appears to be a lot of precision. You would be fooling yourself. Forgo averaging to the extent possible. You can average at the end, if needed. It is almost always better to reduce the noise as close to the source as possible. The further through your system that noise penetrates, the more mischief it can make. Look for a future article on why digitally filtered noisy data is inferior to clean unfiltered data. Here, we will describe methods for reducing noise in your data.

Tracking down noise

Suppose your data shows more noise than you would like. How do you go about fixing it? The noise could be part of the actual data itself. If so, there are ways to deal with that through post-processing, but that is another subject. First, you need to minimize extraneous noise that is picked up through the air, or injected by other means.

Start by establishing a baseline. Nothing in should yield nothing out. You will have two wires connecting your data system with the voltage to be measured. The data system is differential, that is, it responds to the difference between the voltage at the two wires. If the two wires are connected to the same point, that difference is zero. That is the place to start. The data system can only quantify voltages within a certain range, called the common mode range. The data system inputs draw a tiny input current, but not zero input current. That means there must be a DC path for that input current to flow. That path should not be through either of the two input wires, a third connection is needed. If your voltage source is floating compared to the data system ground, like a battery, the third wire should go from the negative end of the battery to ground at the data system. If your input voltage source is already referenced to the data system power ground, no extra wire is needed. The complication is that redundant grounding forms ground loops, which are undesirable. (More on grounding elsewhere.) The takeaway is that no ground, or two grounds, will cause trouble. You want one and only one ground path.

Lets say your two wires are connected together at a point that is ground-referenced, and that point carries a 60 Hz signal compared to ground at the data system. The 60 Hz might be noise picked up through the air. Because it is present at both input wires, it is called a common mode signal, and we would like our data system to ignore it. That insensitivity is defined as common mode rejection.

Lawson Labs data systems dedicate a channel to zero volts input, usually channel 7. The effective resolution at channel 7 then becomes the background noise of the system, itself. If you see more noise on your input channel with two wires connected together then on channel 7, that additional noise is either due to grounding, or shielding, or imperfect common mode rejection. If the noise is essentially the same as channel 7, you can proceed to the next section.

Touch, or physically move, the input wiring. If that changes the voltage or the effective resolution, you are picking up noise through the air. The first defense is minimizing loop area. Twist the input wires together to minimize pick-up. If the noise is higher in frequency, asymmetry of wiring can have a big effect. Equalize the length of the two input wires. If pick-up persists, use shielded wiring. The shield should connect to power ground at the data system and to nothing at the far end. If noise pick-up remains, the next step is to look for the noise source, and to either move it physically away, or to shield it. Remember that shielding works better when it is ferrous or copper, and when it is grounded.

If the wiring is not sensitive but the extra noise remains, it may be higher frequency common mode noise that is harder to reject. Put a capacitor from the ground at the voltage source to ground at the data system. Again, use a unique wire for the connection. If the capacitor helps, try different values of capacitor to maximize the improvement. A 0.1 uf cap might be a good guess to start.

Next, connect the plus wire to the voltage to be measured

There is bound to be some increase in noise, once the signal is introduced, even if the signal itself is pure DC, like a battery. The battery will have a temperature coefficient, and if you touched the battery, you changed its temperature, so its voltage will change. Think back to the RMS noise calculation. If the reading over the sample period is ramping up or down, the differences for each point compared to the average point will increase, so the RMS noise will increase and the effective resolution will decrease. Reduced effective resolution caused by this sort of thermal drift can be hard to distinguish from reduced effective resolution caused by ordinary AC noise superimposed on a steady reading.

Of course there can also be be noise in the signal itself. A capacitor across the input terminals will remove AC noise from the signal, but it will also slow down the response. Some voltage sources become unstable if too much capacitive load is connected. If you need to filter more, add a resistor in series with the output, before the capacitor, to regain stability. The higher value the resistor, the more important that the capacitor be a low-leakage type. It is always safe to use a film capacitor as a filter. An electrolytic filter capacitor is only satisfactory with a small series resistor value. You may need a balanced filter that treats the plus and minus inputs symmetrically, each with its own resistor. Capacitors may go from each input to ground, or, between the inputs, or both. Determine experimentally what works best for you.

If you use too much series resistance, the inputs will interact as you change channels. 100k ohms is a good maximum value. If you can't get enough filtering consistent with fast enough response, there are countless digital filtering techniques for post processing. That subject subject is touched on at www.lawsonlabs.com/HowtoMinimizeNoise.pdf, and will be addressed here at a later time.

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