A2DSignalProcessing

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One of the limitations of many low cost, single supply, analog-to-digital (A/D) converter ICs today is that they have a limited input voltage range. This article discusses various ways to implement input processing to allow these devices to operate in the real world. I use the ADS7870 as an example A/D, but the equations and samples are generic enough so that you can configure the circuits for other devices.

The ADS7870 has three possible internal voltage reference values. We will assume that the 2.048V reference has been selected and that its programmable gain amplifier is set to 1.0. When used in its single ended mode, the A/D then has a useful input voltage range of 0 volts to V_{ref} – 1 LSB and has 11 bit resolution.

When used in its differential mode, the useful input voltage range increases to -V_{ref} to V_{ref} – 1 LSB (relative to the + input) and therefore has 12 bits of resolution where the MSB becomes the sign bit. However, the input voltage must always be positive.

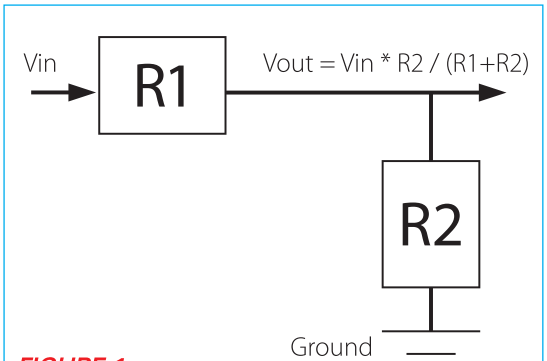

FIGURE 1

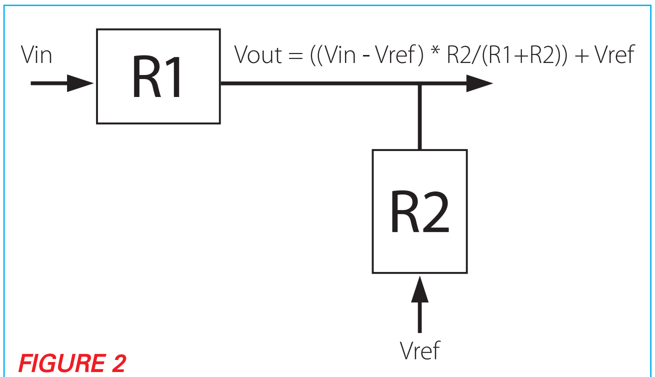

FIGURE 2

Some A/Ds have an input voltage limit of 2*Vref, so be sure to keep that in mind when determining the maximum input voltage.

For the circuits in Figures 1 and 2, the value of R2 should be adjusted based on the input resistance of the A/D. However, if the calculated value is much greater than the A/D resistance, then simple calibration should be all that is required.

The simplest form of scaling only works for unipolar inputs and is a voltage divider (see Figure 1). If your system only needs to measure between 0 volts and some positive voltage greater than the reference, then this might be adequate. By rearranging the equation in the figure and specifying the required input resistance, you can determine the value for R2:

R2 = Vout * R1 / (Vin - Vout)

If R1 = 100K and Vin = 10V when Vout = 2.048V, then R2 = 25.7K

Just as a practical matter it would be a good idea to use a slightly higher value as the maximum for Vin just to insure that you have some "headroom." If we use 10 volts as the actual maximum Vin, the scale factor for converting from A/D counts to volts is 10/2047 = 4.8851mV/count (2047 is the maximum count value for an 11 bit device). This can be used but is somewhat awkward. It also does not allow for headroom. A better solution is to round up the value calculated above to 5 mV. This yields a maximum input voltage value of 10.235 volts.

The applied voltage can be calculated from the count value as measured by the A/D:

Vin = Count * .005

This is similar to the circuit in Figure 1 except that it allows you to measure bipolar voltages.

You can see that if Vref = 0, the equation reduces to the same as in Figure 1. Solving the equation for the reference voltage yields: Vref = Vout(R1+R2)/R1 – Vin*R2/R1.

"Now what?" you may ask. The next step is to set Vout = 0 (because the minimum input voltage to the A/D must be 0V) and see what happens: Vref = -Vin*R2/R1. If we assume that the largest negative input voltage will yield Vout = 0, then Vref must be positive. Substituting -10 in the above equation yields: Vref = 10*R2/R1.

Now let's set Vout = 2.0V, a little below the maximum allowed by the A/D converter. This will be achieved when Vin = 10V. The equation becomes: Vref = 2*(R1+R2)/R1 – 10*R2/R1.

We now have two equations with three unknowns. We should now pick a value for R1 since it is the major contributor to the input resistance. As in the first example, let's make it 100K. The two equations become:

Vref = 10*R2/100K *and*
Vref = 2*(100K+R2)/100K – 10*R2/100K

This allows us to solve for R2 since:

10*R2/100K = 2*(100K+R2)/100K – 10*R2/100K

which reduces to: R2 = 200K/18 = 11.1K. If you want to be really exact, the value of R2 should take into account the input resistance of the A/D. Although the error incurred by not including the input resistance can be compensated by properly calibrating the system.

Now we can solve for Vref: 10*11.11K/100K = 1.111V.

To check, we can substitute an input voltage back into the equation of Figure 2:

Let Vin = 10v:
Vout = (10-1.111)*11.1K/(100K+11.1K) + 1.111
Vout = 8.889 * .1 + 1.111 = 1.999

Let Vin = -10v:
Vout = (-10-1.111)*11.1K/(100K+11.1K) + 1.111
Vout = -11.111 * .1 + 1.111 = 0.0001

Without roundoff errors, the results are exactly 2.0 and 0.0, respectively.

Op-amp Discussion for A/D Converter Scaling

Now let's look at the circuit in Figure 3. It is based on the following characteristics of an ideal operational amplifier:

1) Infinite input resistance

2) 0 volts between the two inputs – in a properly configured circuit

3) 0 ohms output resistance

Since the input resistance is infinite, there is no current flow into the inverting input; therefore, I1 across R1 must equal I2 across R2. Also, the voltage being forced on the positive input will be present at the inverting input. These two characteristics result in Formula (1).

(1): (Vin – Vref)/R1 = (Vref-Vout)/R2

Rearranging the formula allows you to solve for Vout in terms of Vin and Vref:

(2): (Vin – Vref)(R2/R1) = Vref–Vout

(2a): Vout = Vref – (R2/R1)(Vin – Vref)

(2b): Vout = Vref(1 + R2/R1) – Vin(R2/R)

IMPORTANT: Since Vin is applied to the negative input, Vout(min) occurs at Vin(max).

This circuit may be used to implement a function similar to that in Figure 2, as we did previously, but with higher input resistance. The easiest place to start is to determine the ratio of the input and output voltages. This will determine the ratio of R1 and R2. If you need an input voltage range of -10V to +10V and an output voltage range of 0V to +2.048V, the ratio is 20/2.048. The calculations will be easier if the input voltage range is expanded to: -10.24V to +10.24V. This yields a ratio of 20.48/2.048 = 10.0, as well as giving the circuit some headroom.

The voltage values used to calibrate any of the above systems can be chosen approximately as:

Vmincal = Vmin + Vspan/20
Vmaxcal = Vmax – Vspan/20

This enables calibration at the 5% and 95% points. It is not a good idea to calibrate at the endpoints since your applied voltage may be slightly outside the measurable range.

Where:

Vmincal = the minimum applied calibration voltage

Vmin = minimum allowed input voltage

Vmaxcal = the mamimum applied calibration voltage

Vmax = maximum allowed input voltage

Vspan = Vmax- Vmin **NV**

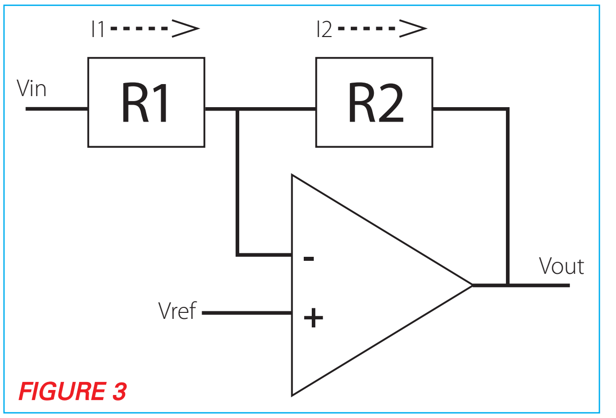

FIGURE 3