

AN-233 The A/D Easily Allows Many Unusual Applications

ABSTRACT

Two design features of the Texas Instruments ADC0801 series of A/D converters provide for easy solutions to many system design problems. The combination of differential analog voltage inputs and a voltage reference input that can range from near zero to $5V_{DC}$ are key to these application advantages.

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1 Accommodation of Arbitrary Analog Inputs

In many systems, the analog signal that has to be converted does not range clear to ground ($0.00 V_{DC}$) nor does it reach up to the full supply or reference voltage value. This presents two problems: 1) a “zero-offset” provision is needed—and this may be volts, instead of the few millivolts that are usually provided; and 2) the “full scale” needs to be adjusted to accommodate this reduced span. (“Span” is the actual range of the analog input signal, from $V_{IN\ MIN}$ to $V_{IN\ MAX}$.) This is easily handled with the converter as shown in [Figure 1](#).

Note that when the input signal, V_{IN} , equals $V_{IN\ MIN}$ the “differential input” to the A/D is zero volts and therefore a digital output code of zero is obtained. When V_{IN} equals $V_{IN\ MAX}$, the “differential input” to the A/D is equal to the “span” (for reference applications convenience, there is an internal gain of two to the voltage that is applied to pin 9, the $V_{REF}/2$ input), therefore the A/D will provide a digital full scale. In this way a wide range of analog input voltages can be easily accommodated.

An example of the usefulness of this feature is when operating with ratiometric transducers that do not output the complete supply voltage range. Some, for example, may output 15% of the supply voltage for a zero reading and 85% of the supply for a full scale reading. For this case, 15% of the supply should be applied to the $V_{IN(-)}$ pin and the $V_{REF}/2$ pin should be biased at one-half of the span, which is $\frac{1}{2}$ (85%–15%) or 35% of the supply. This properly shifts the zero and adjusts the full scale for this application. The $V_{IN(-)}$ input can be provided by a resistive divider that is driven by the power supply voltage and the $V_{REF}/2$ pin should be driven by an op amp. This op amp can be a unity-gain voltage follower that also obtains an input voltage from a resistive divider. These can be combined as shown in [Figure 2](#).

This application can allow obtaining the resolution of a greater than 8-bit A/D. For example, 9-bit performance with the 8-bit converter is possible if the span of the analog input voltage should only use one-half of the available 0V to 5V span. This would be a span of approximately 2.5V that could start anywhere over the range of 0V to $2.5V_{DC}$.

The RC network on the output of the op amp of [Figure 2](#) is used to isolate the transient displacement current demands of the $V_{REF}/2$ input from the op amp.

2 Limits of $V_{REF}/2$ Voltage Magnitude

A question arises as to how small in value the span can be made. An ADC0801 part is shown in [Figure 3](#) where the $V_{REF}/2$ voltage is reduced in steps: from A), 2.5V (for a full scale reading of 5V); to B), 0.625V (for a full scale reading of 1.25V—this corresponds to the resolution of a 10-bit converter over this restricted range); to C), 0.15625V (for a full scale reading of 0.3125V—which corresponds to the resolution of a 12-bit converter). Note that at 12 bits the linearity error has increased to $\frac{1}{2}$ LSB.

For these reduced reference applications the offset voltage of the A/D has to be adjusted as the voltage value of the LSB changes from 20 mV to 5 mV and finally to 1.25 mV as we go from A) to B) to C). This offset adjustment is easily combined with the setting of the $V_{IN\ MIN}$ value at the $V_{IN(-)}$ pin.

Operation with reduced $V_{REF}/2$ voltages increases the requirement for good initial tolerance of the reference voltage (or requires an adjustment) and also the allowed changes in the $V_{REF}/2$ voltage over temperature are reduced.

An interesting application of this reduced reference feature is to directly digitize the forward voltage drop of a silicon diode as a simple digital temperature sensor.

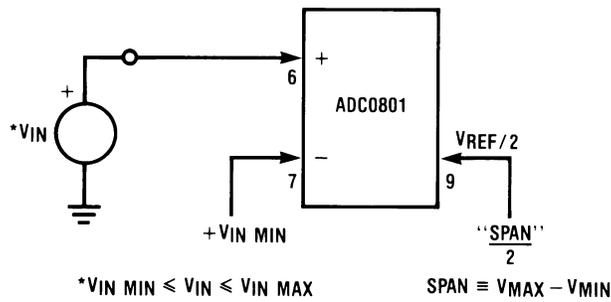


Figure 1. Providing Arbitrary Zero and Span Accommodation

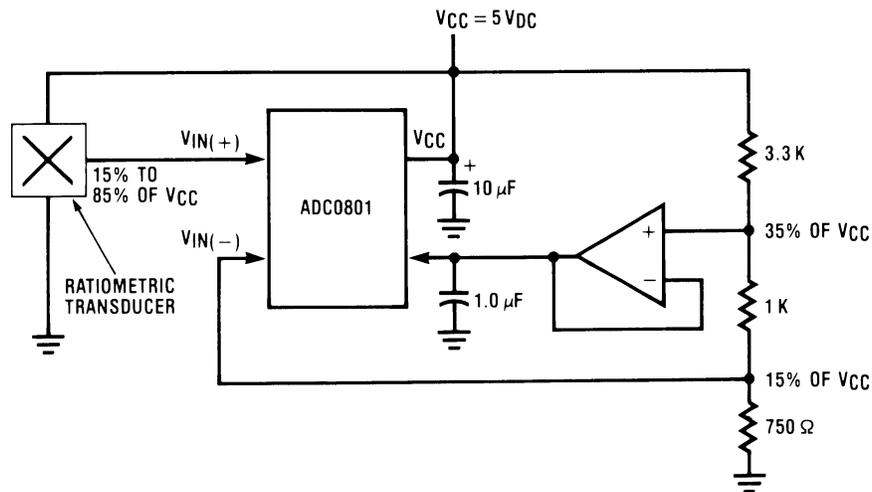


Figure 2. Operating with a Ratiometric Transducer that Outputs 15% to 85% of V_{CC}

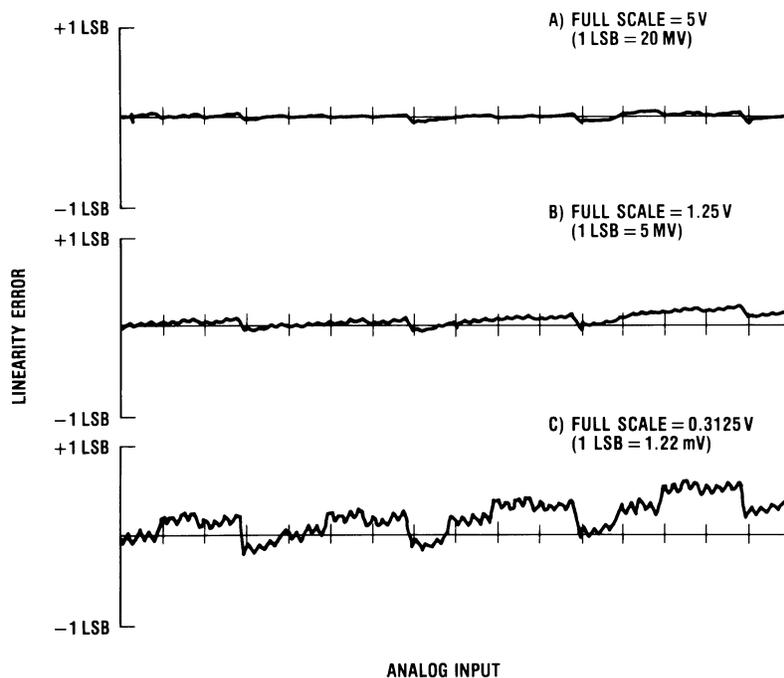


Figure 3. Linearity Error for Reduced Analog Input Spans

3 A 10-Bit Application

This analog flexibility can be used to increase the resolution of the 8-bit converter to 10 bits. The heart of the idea is shown in Figure 4. The two extra bits are provided by the 2-bit external DAC (resistor string) and the analog switch, SW1.

Note that the $V_{REF}/2$ pin of the converter is supplied with $\frac{1}{8} V_{REF}$ so each of the four spans that are encoded will be:

$$2 \times \frac{1}{8} V_{REF} = \frac{1}{4} V_{REF} \quad (1)$$

In actual implementation of this circuit, the switch would be replaced by an analog multiplexer (such as the CD4066 quad bilateral switch) and a microprocessor would be programmed to do a binary search for the two MS bits. These two bits plus the 8 LSBs provided by the A/D give the 10-bit data. For a particular application, this basic idea can be simplified to a 1-bit ladder to cover a particular range of analog input voltages with increased resolution. Further, there may exist a *priori* knowledge by the CPU that could locate the analog signal to within the 1 or 2 MSBs without requiring a search algorithm.

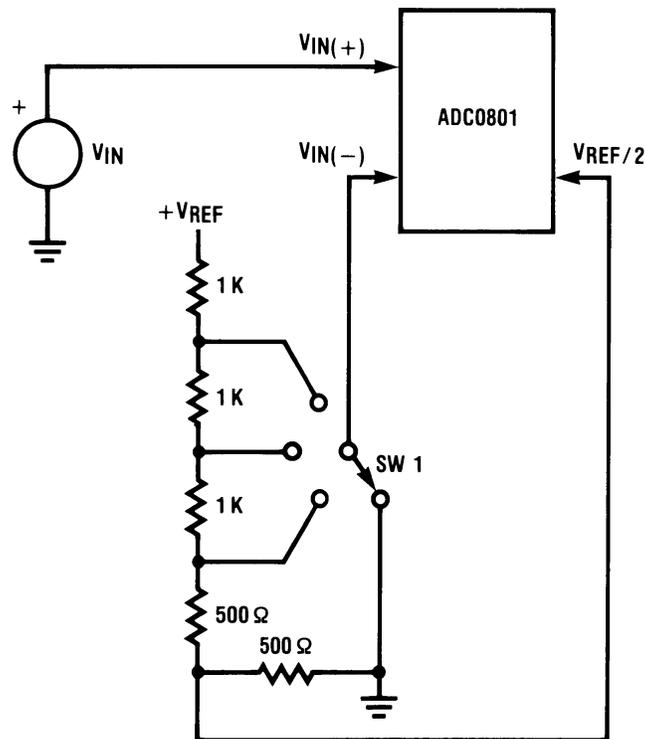


Figure 4. 10-Bit A/D Using the 8-Bit ADC801

4 A Microprocessor Controlled Voltage Comparator

In applications where set points (or “pick points”) are set up by analog voltages, the A/D can be used as a comparator to determine whether an analog input is greater than or less than a reference DC value. This is accomplished by simply grounding the $V_{REF}/2$ pin (to provide maximum resolution) and applying the reference DC value to the $V_{IN(-)}$ input. Now with the analog signal applied to the $V_{IN(+)}$ input, an all zeros code will be output for $V_{IN(+)}$ less than the reference voltage and an all ones code for $V_{IN(+)}$ greater than the reference voltage. This reduces the computational loading of the CPU. Further, using analog switches, a single A/D can encode some analog input channels in the “normal” way and can provide this comparator operation, under microprocessor control, for other analog input channels.

5 DACs Multiply and A/Ds Divide

Computation can be directly done with converter components to either increase the speed or reduce the loading on a CPU. It is rather well known that DACs multiply—and for this reason many are actually called “MDACs” to signify “multiplying DAC.” An analog product voltage is provided as an output signal from a DAC for a hybrid pair of input signals—one is analog (the V_{REF} input) and the other is digital.

The A/D provides a digital quotient output for two analog input signals. The numerator or the dividend is the normal analog input voltage to the A/D and the denominator or the divisor is the V_{REF} input voltage.

High speed computation can be provided external to the CPU by either or both of these converter products. DACs are available that provide 4-quadrant multiplications (the MDACs and MICRO-DACs™), but A/Ds are usually limited to only one quadrant.

6 Combine Analog Self-Test with Your Digital Routines

A new innovation is the digital self-test and diagnostic routines that are being used in equipment. If an 8-bit A/D converter and an analog multiplexer are added, these testing routines can then check all power supply voltage levels and other set point values in the system. This is a major application area for the new generation converter products.

7 Control Temperature Coefficients with Converters

The performance of many systems can be improved if voltages within the system can be caused to change properly with changes in ambient temperature. This can be accomplished by making use of low cost 8-bit digital to analog converters (DACs) that are used to introduce a “dither” or small change about the normal operating values of DC power supplies or other voltages within the system. Now, a single measurement of the ambient temperature and one A/D converter with a MUX can be used by the microprocessor to establish proper voltage values for a given ambient temperature. This approach easily provides non-linear temperature compensation and generally reduces the cost and improves the performance of the complete system.

8 Save an Op Amp

In applications where an analog signal voltage that is to be converted may only range from, for example, $0V_{DC}$ to 500 mV_{DC} , an op amp with a closed-loop gain of 10 is required to allow making use of the full dynamic range ($0V_{DC}$ to $5V_{DC}$) of the A/D converter. An alternative circuit approach is shown in Figure 5. Here we, instead, attenuate the magnitude of the reference voltage by 10:1 and apply the 0 to 500 mV signal directly to the A/D converter. The $V_{IN(-)}$ input is now used for a V_{OS} adjust, and due to the “sampled-data” operation of the A/D there is essentially no V_{OS} drift with temperature changes.

As shown in Figure 5, all zeros will be output by the A/D for an input voltage (at the $V_{IN(+)}$ input) of $0V_{DC}$ and all ones will be output by the A/D for a 500 mV_{DC} input signal. Operation of the A/D in this high sensitivity mode can be useful in many low cost system applications.

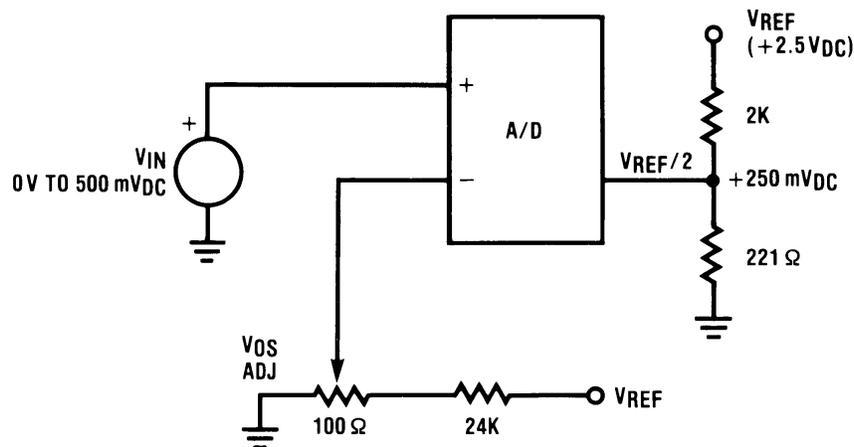


Figure 5. Directly Encoding a Low Level Signal

9 Digitizing a Current Flow

In system applications there are many requirements to monitor the current drawn by a PC card or a high current load device. This typically is done by sampling the load current flow with a small valued resistor. Unfortunately, it is usually desired that this resistor be placed in series with the V_{CC} line. The problem is to remove the large common-mode DC voltage, amplify the differential signal, and then present the ground referenced voltage to an A/D converter.

All of these functions can be handled by the A/D using the circuit shown in Figure 6. Here we are making use of the differential input feature and the common-mode rejection of the A/D to directly encode the voltage drop across the load current sampling resistor. An offset voltage adjustment is provided and the $V_{REF}/2$ voltage is reduced to 50 mV to accommodate the input voltage span of 100 mV. If desired, a multiplexer can be used to allow switching the $V_{IN(-)}$ input among many loads.

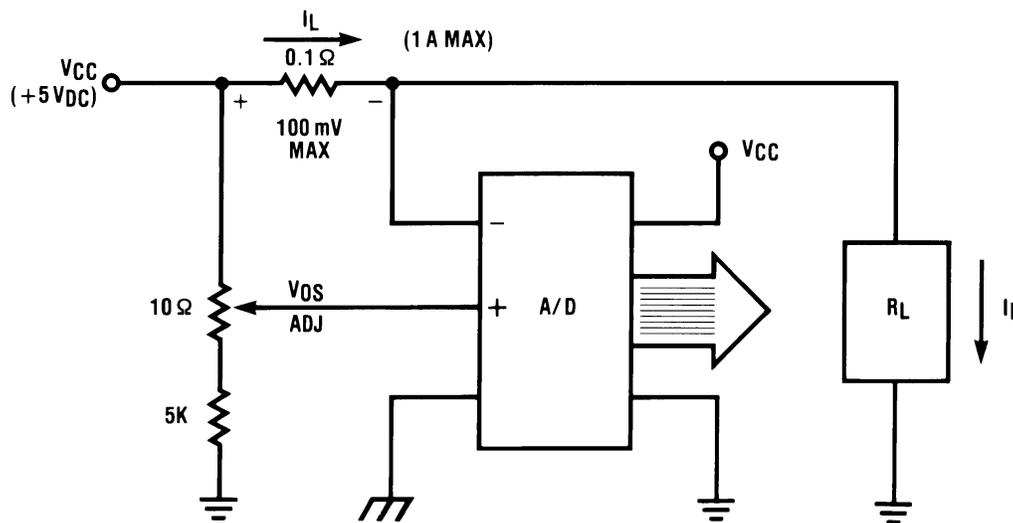


Figure 6. Digitizing a Current Flow

10 Conclusions

At first glance it may appear that the A/D converters were mainly designed for an easy digital interface to the microprocessor. This is true, but the analog interface has also been given attention in the design and a very useful converter product has resulted from this combination of features.

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