

AN842

Differential ADC Biasing Techniques, Tips and Tricks

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INTRODUCTION

True differential converters can offer many advantages over single-ended input A/D Converters (ADC). In addition to their common mode rejection ability, these converters can also be used to overcome many DC biasing limitations of common signal conditioning circuits. Listed below are some typical application issues that can be solved with proper biasing of a differential converter:

- · Limited output swing of amplifiers
- · Unwanted DC-bias point
- · Low level noise riding on ground
- Unwanted or changing common mode level of input signal

This application note discusses differential input configurations and their operation, circuits to implement these input modes and techniques in choosing the correct voltage levels to overcome the previously mentioned challenges.

DIFFERENTIAL AND SINGLE-ENDED INPUT CONFIGURATIONS

Before discussing biasing solutions, it is important to understand the functionality of differential A/D converters. The true differential A/D converter outputs a digital representation of a differential input signal, typically a two's complement binary formatted output. The converter output can be either signed positive or negative, depending on the voltage level of the differential pair. The following equation expresses this relationship for the MCP330X devices:

EQUATION:

Digital Code =
$$\frac{2^{(n)}(IN^+ - IN^-)}{2V_{REF}}$$

The binary output for the MCP330X is a 13-bit output (12-bit plus sign output).

It is important to note that the converter output is zero when the inputs are equal. As the voltage difference between IN+ and IN- increases, the output code also increases. The maximum voltage at which digital code saturation will occur is V_{REF}. The differential conversion of the MCP330X converters will reject any DC common mode signal at the inputs. For the MCP330X converters, the common mode input range is rail-to-rail, V_{SS}-0.3V to V_{DD}+0.3V.

The circuit in Figure 1 shows a differential signal being applied to the IN+ and IN- pins of the converter. This method is referred to as full differential operation of the converter. The graph below the circuit shows possible voltage levels for a differential application. The inputs are centered around a common mode voltage, V_{CM} . V_{REF} is equal to the maximum input swing, shown here as V_{DD} . By setting V_{REF} equal to the maximum input swing of the signal, the full range of the A/D converter is being used.

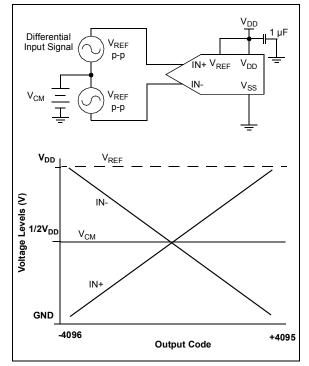


FIGURE 1: Driving a true differential converter with a true differential input.

SINGLE-ENDED SIGNALS

Some signals are single-ended, and a true differential converter can be used in this situation as well. Figure 2 shows a single-ended signal being applied to the IN+ terminal. The common mode voltage is connected to the negative input of the A/D converter, with the signal connected to the positive input. This method is referred to as pseudo-differential operation, with only one of the inputs being used to obtain a bipolar output of all codes.

The graph below the circuit in Figure 2 shows that by setting V_{REF} and IN- to half of the input swing of the signal, all codes will be present at the output. (The numbers shown in this example are for a 13-bit converter).

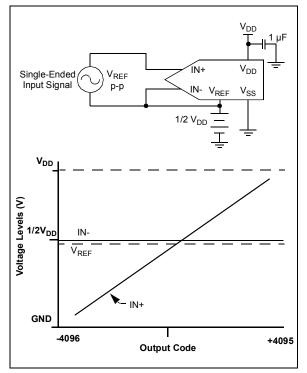


FIGURE 2: Driving a true differential converter with a single-ended input to obtain bipolar output codes.

PSEUDO DIFFERENTIAL BIASING CIRCUITS FOR SINGLE-ENDED APPLICATIONS

In most applications, the voltage reference of the ADC will be the most stable voltage source in the system. The accuracy of your data acquisition system is no more accurate than the voltage reference for the converter itself. This same reference should be used as your DC bias point in pseudo differential systems. Figure 2 shows that with a single-ended input, the IN-and V_{RFF} need to be near the midscale of the signal

input swing. An example circuit using this approach is shown in Figure 3. For a signal with a 5Vp-p swing, IN- and V_{REF} need to be biased at 2.5V.

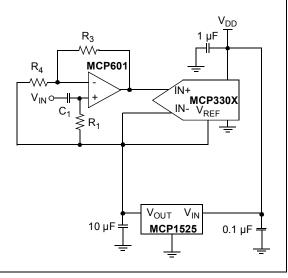


FIGURE 3: Example of pseudo differential biasing circuit.

The MCP1525, 2.5V voltage reference was chosen where no greater than 1% initial accuracy or 50 ppm tempco is required. This reference voltage is driving three nodes of the circuit: the V_{REF} for the converter, the common mode signal of the signal and the DC bias point of the signal input going into the positive channel of the A/D converter. With capacitor C₁, AC-coupling V_{IN} , we are effectively blocking any DC component of the input signal. This allows us to regulate the DC bias point and match this voltage to the common mode voltage and A/D voltage reference.

In this case, V_{REF} , IN- and V_{CM} have been adjusted to appropriate levels, but still limits the effective input range of the converter. This assumes that the output swing of the amplifier is ideal (i.e. rail-to-rail). In real world applications, this output swing will be limited by tens or hundreds of millivolts, depending on the output swing of the amplifier.

PSEUDO DIFFERENTIAL BIASING TIPS & TRICKS

In choosing the correct V_{REF} and IN- levels, the output swing limitations of the amplifier can be overcome. The objective is to bring the input range of the ADC away from both supply rails. To move the ADC input range away from the upper supply rail, V_{REF} needs to be slightly less than $V_{DD}/2$. To move the ADC input range away from the lower supply rail, IN- needs to be slightly greater than V_{REF} . How far away from the supply rails depends on the output swing of the amplifier. Figure 4 shows this situation graphically.

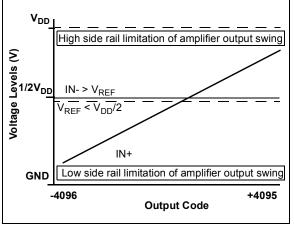


FIGURE 4: Actual input showing amplifier limitations.

In the circuit of Figure 5, a 2.048 V_{REF} is used to supply the reference voltage for the converter. The objective here is to limit V_{REF} < V_{DD}/2, keeping the required high side output swing of the amplifier less than the upper rail. The IN- is biased at 2.5V, slightly above V_{REF}. This keeps the required low side swing of the amplifier away from the rail. R₃ and R₄ are chosen to gain the signal to these levels, which are now within the output swing capability of the amplifier. With this configuration, the entire output range of the A/D converter is being used. For applications requiring greater precision, a separate 2.5V V_{REF} might be required, instead of the voltage divider shown.

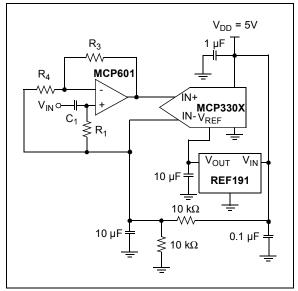


FIGURE 5: Circuit solution to overcome amplifier output swing limitations.

COMMON MODE VS. V_{REF}

From the equation on page one, it can be seen that digital saturation occurs when the difference of the inputs is equal to or greater than the voltage reference. In order to avoid this and maximize the input range of the ADC, care should be taken in setting the common mode voltage for both pseudo differential and true differential configurations.

The input range of the MCP330X devices is slightly wider than the power rails: V_{SS}-0.3 to V_{DD}+0.3. The range of the V_{REF} is 400 mV to V_{DD}. These two constraints, along with the two methods of driving the input, provide specific ranges for the common mode voltage. Figure 6 and Figure 7 show the relationship between V_{REF} and the common mode voltage.

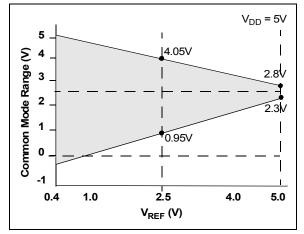


FIGURE 6: Common Mode Range versus V_{REF} for True Differential Input mode.

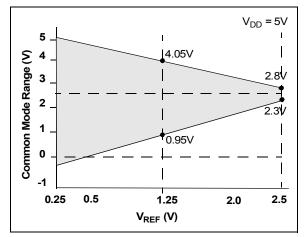


FIGURE 7: Common Mode Range versus V_{REF} for Pseudo Differential Input mode.

A smaller V_{REF} allows for wider flexibility in a common mode voltage. It should be noted however that by decreasing the V_{REF}, linearity performance is sacrificed. Characterization graphs for Microchip's true differential ADCs show this relationship. These graphs can be found in all MCP330X data sheets. Figure 8 shows an example graph, showing slight degradation in INL at lower voltage references. It is specified that no voltage lower than 400 mV should be used as V_{REF} for the MCP330X devices.

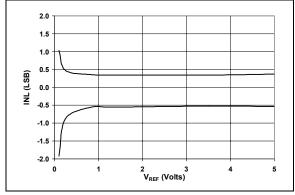


FIGURE 8: Converter linearity is not sacrificed at lower voltage references, down to 400 mV.

The pseudo differential method of driving the ADC using only one input as a signal input limits the V_{REF} range to 2.5V. A reference of larger than 2.5V would require that the input swing of $2*V_{REF}$ be larger than V_{DD} max of 5V in order to exercise all codes.

SUMMARY

Understanding possible input configurations for true differential converters is essential to maximizing their functionality. The two different methods of driving the converter, pseudo differential and true differential mode, each have their own biasing circuitry. Additionally, understanding the relationship between common mode voltage and the ADC voltage reference is necessary to avoid digital code saturation from the A/D. True differential converters can be useful in a wide variety of applications, when biased properly.

REFERENCES

Application Note AN682, "Using Single Supply Amplifiiers in Embedded Systems", DS00682

MCP3301 Data Sheet, DS21700

MCP3302/04 Data Sheet, DS21697

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