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AN-1392
APPLICATION NOTE

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How to Calculate Offset Errors and Input Impedance in ADC Converters with Chopped Amplifiers
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INTRODUCTION

Integrated buffers and amplifiers in analog-to-digital converters (ADCs) are typically chopped. An example of this implementation of chopping can be found in the AD7124-8 and the AD7779 data sheets. This chopping technique is required to minimize offset and flicker noise (1/f) of the amplifier, as the CMOS transistors are noisy and hard to match compared to other processes like a bipolar process. By chopping the amplifier, the 1/f and offset are translated to higher frequencies, as shown in Figure 1.
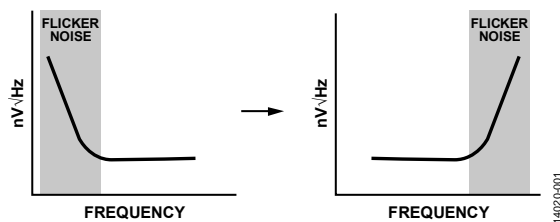

Figure 1. Flicker Noise (1/f) Against Chopping

During the chopping transitions, there are peaks of current due to the charge injection of the switches that generate drops or peaks in any direction (sink and/or source) of the voltage applied to the inputs of the ADC. The voltage drops are proportional to the output impedance of the transducer or sensor connected to the input of the ADC.

AVERAGE CURRENT VALUE

Generally, data sheets do not provide the peak of the current because it is difficult to measure and does not add any relevant information. The information is not relevant because the chopping frequency of the buffer is at a higher frequency than the input signal bandwidth of the ADC. Consequently, any low-pass filter added to the input pins to eliminate frequencies or tones above the Nyquist frequency, or to reduce coupled noise, averages the peak current, as shown in Figure 2.
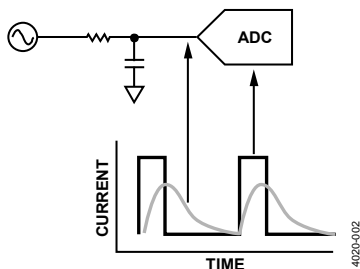

Figure 2. Input Current vs. Time

Measure the input current with a current meter, connecting one terminal to VDD/2 and another terminal to the analog input pin of the ADC.

If the current meter connects to one of the voltage rails, the measured current can be higher than the specifications in a data sheet because of the input voltage headroom.

INPUT CURRENT VS. INPUT IMPEDANCE

The input impedance specification does not help accurately calculate the error in the dc because the main contributor is the input bias current compared to the load effect introduced by the internal ADC input impedance.

There are two specifications related to the input bias current: absolute and differential.

The absolute value ($I_{ABSOLUTE}$) is the input current measured in any of the analog input pins. The differential input current ($I_{DIFFERENTIAL}$) is the current difference measured between the analog input pin pair. This only applies to differential input ADCs.

HOW TO CALCULATE THE DC ERROR

The input current generates an offset voltage (V_{OFFSET}) that is directly dependent on the impedance connected to the input pin.

Generally, as shown in Figure 3, the offset generated is
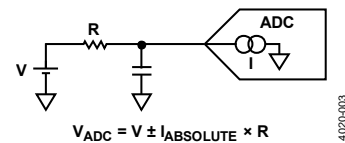
$$V_{OFFSET} = I_{ABSOLUTE} \times R$$

Figure 3. Voltage Drop due to Leakage Current

If the analog input pin is driven by a low impedance source like an operational amplifier, the error is not noticeable.

The error measured by the ADC depends on the type of input signal applied, such as a true differential input signal or a pseudo differential/single-ended input signal.

In the case of a true differential input signal, assuming a perfect input resistance (R) match, the error measured by the ADC is due to the differential input current between the analog input pin pair as described in the following equation:

$$V_{ADC} = V \pm I_{DIFFERENTIAL} \times R$$
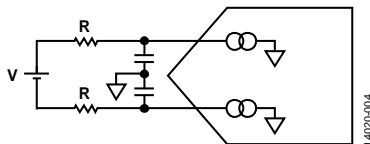
where V_{ADC} is the ADC input voltage.

Figure 4. Differential Input ADC

If the resistances do not perfectly match, the resistance mismatch generates an error in addition to the differential input current contribution.

In general, assuming a 1% tolerance resistance, the worst case scenario is defined as,

$$V_{OFFSET} = 2 \times I_{ABSOLUTE} \times 1\% \, R + I_{DIFFERENTIAL} \times (R)$$

In the case of pseudo differential/single-ended input signal, there are two scenarios:

• One of the analog inputs connects to a low impedance source (see Figure 5). The error is defined as

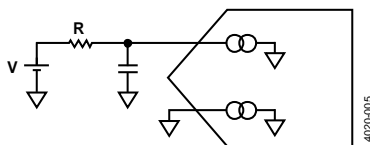$$V_{OFFSET} = R \times I_{ABSOLUTE}$$

Figure 5. Pseudo Differential/Single-Ended ADC

• Both inputs connect to a high impedance source (see Figure 6). The error is the same as when using a true differential signal.
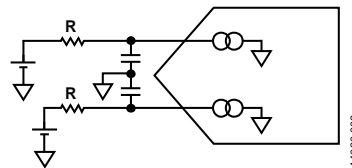

Figure 6. Pseudo Differential ADC

THE AC ERROR

The ac component directly depends on the input impedance specification. The input impedance can be resistive or capacitive. If the input impedance is capacitive, calculate the impedance at the given frequency as

$$Z_C = \frac{1}{2 \times \pi \times C_{IN} \times f_{IN}}$$

where:
Z_C is the input impedance.
C_{IN} the input capacitance stated in a data sheet.
f_{IN} is the input frequency.

As an example, assuming an 8 pF capacitance with an input bandwidth of 1 kHz, the minimum input impedance is about 20 MΩ.

MINIMIZING ERRORS

To minimize errors due to resistor mismatches in low-pass filters, it is preferable to use small resistors and large capacitors, as the offset and the Johnson noise generated in the resistor is lower.

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