

**CONVERTING A SINGLE-ENDED SIGNAL TO A DIFFERENTIAL SIGNAL BEFORE THE ANALOG-TO-DIGITAL CONVERSION CAN IMPROVE THE PERFORMANCE OF YOUR DATA-ACQUISITION SYSTEM.**

# Maximize performance when driving differential ADCs

USING DIFFERENTIAL SIGNALS in data-acquisition systems is becoming increasingly popular because differential signals are highly immune to system noise based on the common-mode rejection of a differential ADC (see sidebar “The operation of a differential ADC”). System noise accumulates in signals as they travel across a pc board or through long cables, but this noise does not interfere with the analog-to-digital conversion because the differential ADC rejects any signal noise that appears as a common-mode voltage. Because differential signals cancel out even-order harmonics, they also provide better distortion performance than do single-ended signals. Another benefit is that differential signals double the ADC’s dynamic range. Some sensors use differential signals, and a differential ADC can convert these signals without much manipulation, especially if the ADC can operate with a low reference voltage.

However, you need not have a complete differential-signal chain to achieve the benefits of differential signals. Some applications lack signals preconditioned for differential operation. So, before the differential analog-to-digital conversion occurs, you often need to design a single-ended-to-differential conversion stage to provide a signal of the correct format for the ADC input. Three methods of performing single-ended to differential conversion are using a differential amplifier, configuring a dual op amp, or using an RF transformer.

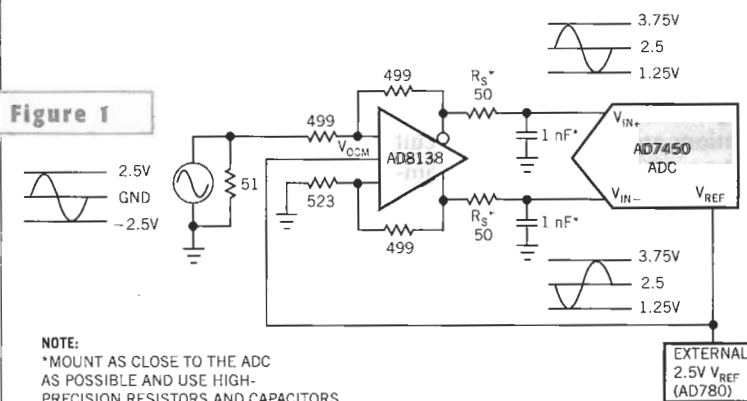
**USE DIFFERENTIAL AMPLIFIER FOR EASE OF DESIGN**

A good method of performing single-ended-to-differential conversion to drive a differential ADC is to use a differential amplifier (Figure 1). This circuit uses an amplifier, the AD8138, with low distortion and a wide input bandwidth, and you can use this amplifier as a single-ended-to-differential amplifier or as a differential-to-differential amplifier. This amplifier is the best to use with bipolar input

signals. It also provides common-mode level shifting and buffering of the analog input signal.

In Figure 1, a bipolar, single-ended signal with an amplitude of two times the reference voltage drives the positive input of the AD8138. The reference voltage, which provides the reference for the ADC, also connects to the amplifier’s  $V_{OCM}$  pin to set up the common-mode voltage for the differential outputs. The positive and negative outputs of the AD8138 connect to the respective inputs of the ADC via a pair of series resistors to minimize the effects of transient currents that arise because of the switched-capacitive front end of the ADC. You should use an RC lowpass filter on each analog input in ac applications to remove any high-frequency components of the analog input. The outputs of the amplifier are perfectly matched, balanced differential outputs of identical amplitude that are exactly 180° out of phase, which the differential ADC requires.

The main benefit of using a differential amplifier



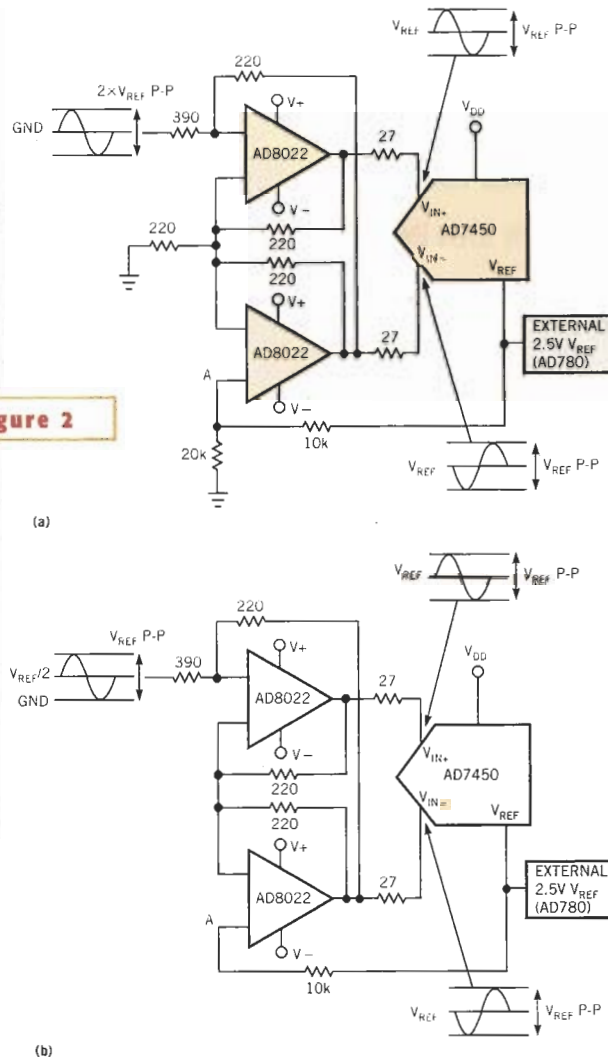
**Using a differential amplifier to drive the ADC effectively performs single-ended-to-differential conversion.**

is that you need only one amplifier to perform the single-ended-to-differential conversion. In addition to performing this conversion, the amplifier also buffers the bipolar, single-ended input signal and level-shifts it to the desired common-mode voltage, which the user sets up. If the analog input signal has a low amplitude, you can add gain to **Figure 1's** configuration to increase the small signal to the reference level of the ADC. The architecture of the AD8138 provides highly balanced differential outputs without requiring tightly matched external components. This differential amplifier can operate with a single 3 or 5V supply, meaning that it can operate off the same supply as the ADC and still handle a bipolar input signal. Therefore, this circuit is a good approach for an application that requires a bipolar ADC operating with single supplies.

**DUAL OP AMP FOR FLEXIBILITY**

Another method of performing single-ended-to-differential conversion is to use a dual op amp. Many configurations are possible. One converts a single-ended, ground-referenced, bipolar signal to a differential signal centered at the reference level of the ADC (**Figure 2a**). Another configuration converts a single-ended, unipolar signal to a differential signal (**Figure 2b**).

The differences between the bipolar and the unipolar configurations are minor. In both circuit diagrams, Point A sets up the common-mode voltage of the differential outputs. Point A connects in some way to the reference of the ADC in each circuit, but you can apply any voltage within the common-mode range of the ADC here to set up the common-mode voltage. Also, both circuits use series resistors at the analog inputs of the ADC to minimize the effects on the amplifier of the tran-



**Figure 2**

**Dual-op-amp configurations convert a single-ended bipolar (a) or single-ended unipolar (b) signal into a differential signal.**

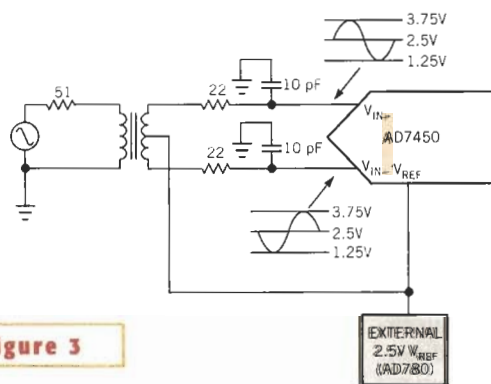
sient currents from the ADC's switched-capacitive front end. These dual-op-amp driver circuits are best for dc-coupling applications that require optimum

distortion performance.

You must carefully select a dual amplifier to drive the differential ADC, because the selection depends on the required power supply, input bandwidth, and system-performance requirements. Essentially, the op amp should not in any way degrade the performance of the ADC. **Figure 2** uses the high-speed, wide-bandwidth AD8022 dual op amp. This op amp's good noise and distortion performance do not degrade the performance of the ADC. The op amp can operate with a single 5V supply and can thus share supplies with the AD7450.

The reasons for choosing a dual-op-amp configuration for performing single-ended-to-differential conversion to drive your differential ADC are primarily related to system-performance requirements. A differential amplifier might not reach the critical specifications that your system requires, and using it can sometimes be more expensive than using a dual op amp. Also, in a dual-op-amp configuration, any small harmonics that exist in each op amp cancel each other, resulting in clean, balanced differential outputs. These days,

dual op amps are widely available in small packages, so there is rarely a trade-off in size between a differential amplifier and a dual amplifier.



**Figure 3**

**For applications that require no dc coupling, an RF transformer can convert a single-ended signal into a highly balanced differential signal to drive ADC inputs.**

**RF TRANSFORMER FOR AC APPS**

In systems that require no dc coupling, an RF transformer with a center tap offers a good way to perform single-ended-to-differential conversion on the analog input signal to generate differential inputs to drive your ADC (**Figure 3**). In this circuit, the RF transformer converts a single-ended signal into a highly balanced differential signal to drive the positive and negative inputs of the ADC. The center tap of the transformer level shifts the differential signal to the user-defined common-mode voltage. In this case, the cen-

ter tap connects to the ADC's reference voltage, so that the common-mode voltage is the value of the reference.

This method of driving a differential ADC is simple and provides the differential signals to the ADC without contributing any additional noise and distortion. An RF transformer, which you can use for most ac applications, also pro-

vides electrical isolation between the signal source and the ADC. This approach also uses fewer external components than the previous methods to perform the single-ended-to-differential conversion.

#### OTHER USEFUL TIPS

When directly driving the differential inputs of your ADC, make sure to match

the output impedance of the sources driving the  $V_{IN+}$  and  $V_{IN-}$  inputs of your ADC. Otherwise, offset errors will result when the analog-to-digital conversion takes place. When using the differential-amplifier and the dual-op-amp methods, it is important to account for the impedance of the signal source when setting up the resistor networks to ensure that the differential outputs have the same gain. The resistor networks in the amplifier configurations in figures 1 and 2 take into account a  $50\Omega$  source impedance. Also, when designing the pc board over which the differential signals will travel, it is important that the two signals take as similar a path as possible to reduce the introduction of errors. □

#### AUTHOR'S BIOGRAPHY

Sally Paterson is an applications engineer for Analog Devices Inc (Limerick, Ireland), where she has worked for 2½ years. She received a bachelor's degree in engineering from the University of East Anglia (Norwich, England).

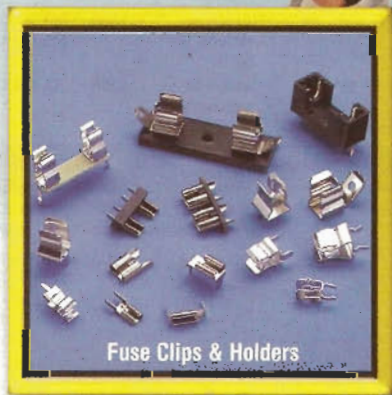
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## THE OPERATION OF A DIFFERENTIAL ADC

A differential ADC has a positive ( $V_{IN+}$ ) and a negative ( $V_{IN-}$ ) analog input. These inputs require two equal drive signals that are  $180^\circ$  out of phase. The amplitude of each drive signal should equal the reference voltage,  $V_{REF}$  of the ADC to use the full dynamic range of the device. When a conversion occurs, the ADC converts only the difference between the two input signals on the  $V_{IN+}$  and  $V_{IN-}$  pins. The ADC subtracts any portion of the signals that are in phase, such as noise, and these in-phase signals thus disappear. The ADC adds the portion of the signals that is out of phase, which is the analog input. Thus, the amplitude of the converted signal is  $2 \times V_{REF}$ .

The common-mode voltage, which you set up externally to the ADC, determines the value on which the differential analog inputs are centered. The reference level of the ADC determines the range of this voltage. When an analog-to-digital conversion occurs, the ADC rejects this common-mode voltage.