



## Introduction

Motor drives have a critical need for a precision signal chain to measure motor speed, position, torque, and power rails for high performance system robustness and efficiency. This applies to all motor systems such as servo drives, AC Inverter and speed-controlled BLDC drives as they all share common subsystems such as [Voltage/Current Sensing](#), [SIN/COS AFE](#), and [Analog I/O](#). [External Voltage References](#) are able to help maximize the resolution and accuracy of the analog signal chain, which optimize the drive performance and efficiency.

## Motor Drive Basics

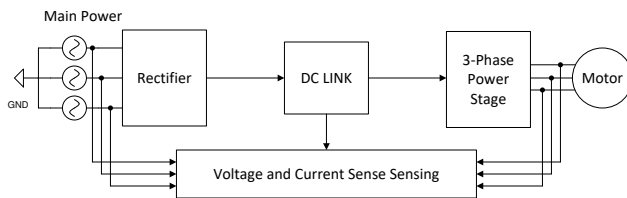


Figure 1. Motor Power Stage Example

All motor drives require a motor power stage to provide power and control the motor but they can be inefficient due to its high power consumption. There is a need for lower power consumption that is partially driven by government regulations such as EN 50598 which call for higher power efficiency of variance speed drives which include its power stage. The power stage typically convert a fixed frequency AC input into a variable frequency 3-phase AC output as shown in [Figure 1](#) but due to motor reliability and high power requirements, this stage requires constant sensing.

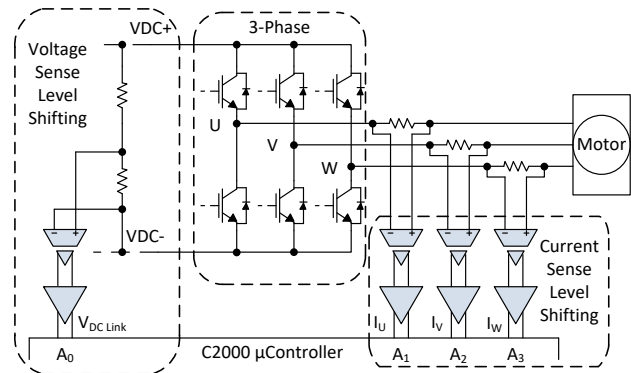


Figure 2. Voltage and Current Sense Example Use Case

There are two common ways of measuring voltage and current in motor power stage and they both involve an isolated amplifier as shown in [Figure 2](#). For voltage measurements, there is a resistor divider that is connected to an isolated amplifier and for current measurements there is typically an inline resistor in each of the 3 phases isolated amplifier. The isolated amplifier is used because it enables the rejection of large common-mode voltages and transients and it is also a requirement of safety standard [IEC 61800-5-1](#). The use of an isolated amplifier is typically required to be level shifted and scaled to the input of the ADC.

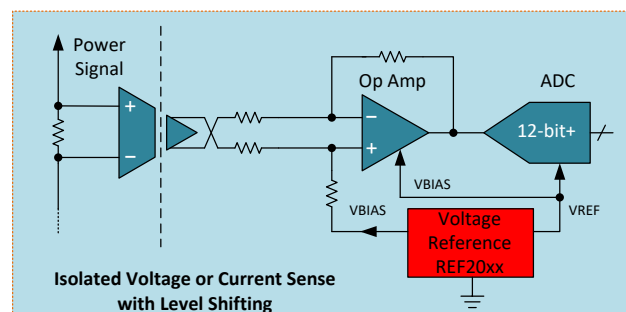


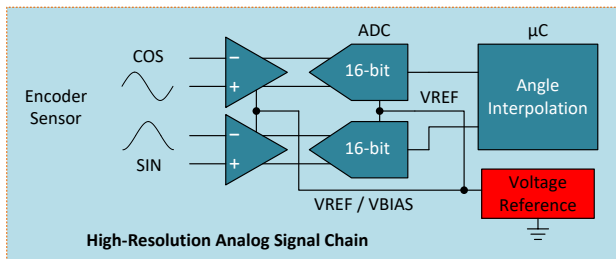
Figure 3. Level Shifting with Voltage Reference

[TIDA-00366](#) is a design that focuses on high-bandwidth phase current and voltage measurements in 3-phase motor power drives. In this design the required voltage sense accuracy is 1% and current sense accuracy is 0.5% across temperature. This design uses the [REF2033](#), a 8 ppm/°C low temperature drift series voltage reference, is used to provide a high precision voltage that is used for level shifting from the isolated amplifier for the internal

C2000 ADC. This is because the low 8 ppm/°C in the wide industrial temperature range will only contribute a temperature offset of 0.1%. For example, a higher temperature coefficient of 50ppm/C would have a variation of 0.8% across temperature, which is outside the specification.

### Motor Feedback

One of the most important features of a high-performance motor control drive is how the system handles the control loop feedback of the speed or position sensors. Motor control feedback is a feature common in synchronous servo motors and in high end AC/VFD motors. The two traditional ways of measuring motor speed are done with either a resolver or an encoder. For example, in a resolver the sine (SIN) and cosine (COS) signals are induced through the resolver excitation windings and are used to calculate the angular speed of the motor. the other hand, an encoder will add sensors on the motor to read either SIN/COS signals or quadrature signals to calculate the angular speed.



**Figure 4. Encoder Sensing Circuits**

The benefit of encoders over resolvers is that they can achieve higher accuracy but at the cost of an increase in system complexity. It is common to see motors with only digital or analog encoders such as in [Figure 4](#) but a combination of both can yield a much more accurate system. For example, in [TIDA-00176](#), the encoder sensor signal chain is a combination of comparators and a ADS8354 ADC that sample the SIN/COS signals to produce a high resolution interpolated position. In this design the [REF2033](#) is used to provide the same voltage reference for both the SIN and COS channels because the gain drift of the reference cancels out due to the operation of SIN/ COS. The critical component of a voltage reference is going to be its effect on the SIN/COS offset and offset drift, for more information see [TIDA-00176](#) section 1.4.1. Additionally, the [TIDA-00316](#) shows how to interface with hall sensors such as the ones used in encoders. In this design the [REF2033](#) and [REF2025](#) are used to create a high accuracy reference for level shifting for hall sensors to guarantee an accuracy of 0.5% across temperature. More details on resolvers and encoders can be found [in this white paper](#).

There is a need for a high precision on the voltage reference due to the gain and quantization error that can cause the ADC to increase the phase error. The gain error is affected by parameters such as initial accuracy, temperature drift, and long term drift such as in the [Equation 1](#). In table 7 of [TIDA-00176](#), a gain error of 0.1% will translate to a phase error of 0.15° and this is the combination of the gain error of the voltage reference and ADC such as in equation. It is common to have initial calibration and routine calibration to keep the phase error low as even the temperature drift, as shown in [Table 1](#), can significantly affect the gain error..

$$\text{Gain Error}_{VREF|Total} = \sqrt{(\text{Accuracy})^2 + (\text{TempCo})^2 + (\text{TempHyst})^2 + (\text{Long Term Drift})^2 + (1/1 \text{ Noise})^2} \quad (1)$$

$$\text{Gain Error}_{VREF+ADC|Total} = \sqrt{(\text{Gain Error}_{VREF@AIN|Total})^2 + (\text{Error}_{ADC|Total})^2} \quad (2)$$

**Table 1. External Voltage Device Recommendations for Resolvers and Encoders**

Temp Co (ppm/°C)	Gain Error (-40°C to 85°C)	Gain Error (-40°C to 125°C)
1	0.0125%	0.0165%
5	0.0625%	0.0825%
10	0.125%	0.165%
50	0.625%	0.825%

### Analog I/O

Another area in motor drives that require high accuracy is the analog I/O module which is commonly used to communicate between the motor control board with the motor control drive. Common analog I/Os are ±10V analog signals or 4-20mA current signals. Typically the communication has to be very robust and accurate across temperature. Since most systems are very customizable, the analog I/O is often discrete. External voltage references can be used in a variety of ways such as level shifting, VREF for an ADC/DAC, and provide a precision power source.

The most common way to increase the accuracy of a motor drive is to use a precision voltage references in the ADC of the 4-20mA receiver or DAC of the 4-20mA transmitter. This is common when using the C2000 integrated ADCs to sample the input signal. In this case, it is common to use a [REF3030](#) to provide the input VREF for the C2000 processor as it is often a 12-Bit multichannel SAR ADC. The resolution for the ADC signal chain in analog I/O commonly go up to 16-Bit through external ADCs and at this ADC resolution there is always a need for a precision voltage reference. Common ADCs that are used in Analog I/O are the ADS8688 and the external voltage reference pairings for this ADC are the [REF3440](#) and [REF3140](#). Both the REF3440 and REF3140 provide very low noise inputs to the ADC which can allow

for a greater effective resolution. But the REF3440 is a higher performance voltage reference compared to the REF3140 and the higher performance is often chosen to make the calibration process easier and to maximize the accuracy of the ADC. An comparison table for series voltage references is shown in [Table 2](#).

**Table 2. External Voltage Device Recommendations for Motor Drives**

DEVICE	INITIAL ACCURACY	TEMPERATURE DRIFT
REF3030	0.2%	75 ppm/°C
REF3140	0.2%	15 ppm/°C
REF2033	0.05%	8 ppm/°C
REF3440	0.05%	6 ppm/°C

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