Application Brief

Position Feedback: Capturing 1V_{PP} Sin or Cos Encoder Signals With a Simultaneous-Sampling SAR ADC

Introduction

Precision motion systems require high-resolution position feedback to make sure of accurate control. This is particularly critical in applications like servo drives, industrial automation, robotics, and CNC machining. To cater to these demands, encoders in such industries often generate 1V_{PP} differential sine and cosine signals. These outputs provide higher noise immunity and allow for more precise interpolation, ultimately contributing to increased system accuracy and reliability.

This application brief describes a signal chain implementation that enables 16-bit interpolation from 1V_{PP} Sin or Cos inputs.

Sine or Cosine Encoder Signals

Encoders are widely used in motion control systems to track rotary or linear position and speed. While TTL and HTL digital output formats are common, encoders offer limited resolution. Analog Sin/Cos encoders, by contrast, deliver high-resolution feedback through continuous waveforms with a 90° phase shift. These signals are differential, centered around a DC offset, and standardized at 1V_{PP}.

To maintain accuracy as motor speed increases, the analog front end and ADC must provide sufficient bandwidth and support simultaneous differential sampling.

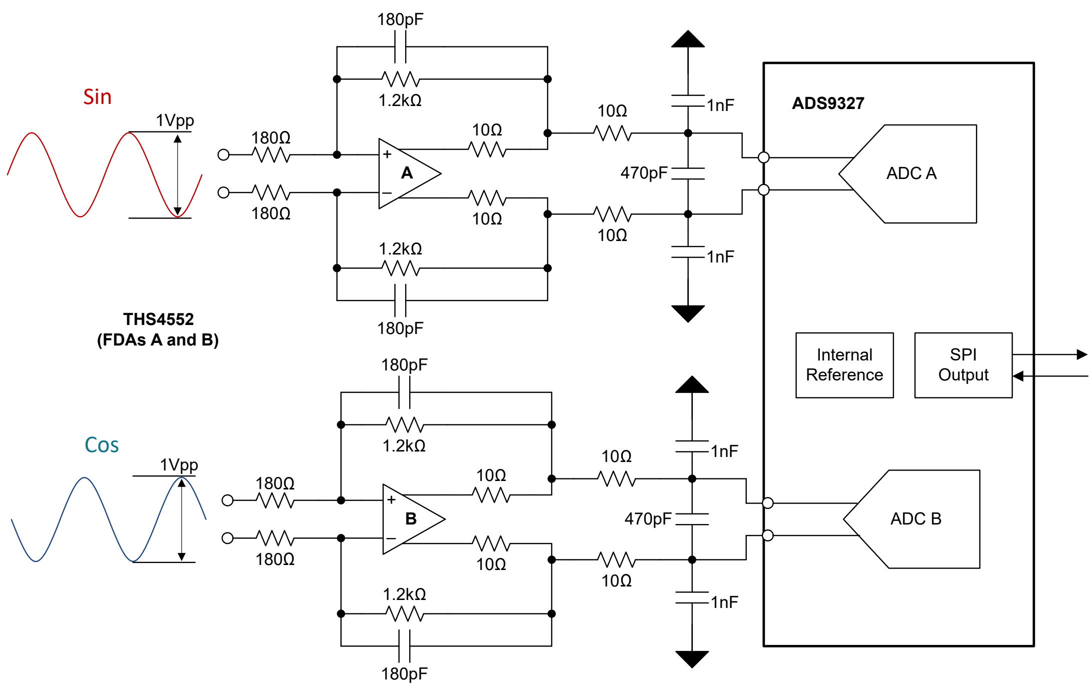

Figure 1. Circuit for Measuring 1V_{PP} Sine and Cosine Signals

Signal Chain 1V_{PP} Incremental Signals

This application note presents a compact, high-performance 2-channel signal chain for digitizing 1V_{PP} differential sine and cosine signals from analog encoders. The design leverages the THS4552, a dual fully-differential amplifier, and the ADS9327, a dual 16-bit, 5MSPS SAR ADC in a space-efficient 3.5mm × 3.5mm QFN package.

Both devices support fully differential signaling, enabling high common-mode rejection and robust performance in electrically noisy motor environments. The THS4552 conditions the differential encoder signals by providing gain, level shifting, and low-distortion drive to the ADC. The ADS9327 captures the sine and cosine inputs simultaneously with excellent channel matching.

By integrating dual channels in both the amplifier and ADC, this circuit reduces component count and PCB footprint—making the circuit an excellent choice for space-constrained applications that require up to 16-bit interpolation accuracy for motor position feedback.

Circuit Design

The analog front end (AFE) was designed to amplify and filter 1 Vpp differential sin/cos encoder signals for digitization by a simultaneous-sampling SAR ADC (ADS9327), which features a ±4.096V differential input range.

Gain Configuration

To maximize ADC resolution without risking input clipping, a gain of 6.8V/V was chosen to account for up to 20% input signal over range (for example, 1.2V_{PP} maximum), making sure that even under worst-case conditions, the signal remains within the ADC's input limits. This trade-off provides headroom for amplitude drift, overdrive, and gain calibration error.

$$V_{ADCpeak} = \left(\frac{1.2V}{2}\right) \times 6.8 = 4.096V \quad (1)$$

$$Gain\left(V/V\right) = \frac{R_f}{R_g} = \frac{1.2k\,\Omega}{180\,\Omega} \cong 6.8V/V \quad (2)$$

Bandwidth and Filtering

The amplifier's closed-loop bandwidth is defined by the feedback RC network, which also implements first-order active low-pass filtering. This configuration attenuates high-frequency noise and preserves amplifier stability, especially in the presence of capacitive loading and output filtering stages.

The feedback values were selected to achieve a -3dB bandwidth of approximately 500kHz, providing a balanced trade-off between noise suppression, phase response, and settling performance for typical encoder signal frequencies.

$$f_{-3dB} = \frac{1}{2\pi R_f C_f} = \frac{1}{2\pi \times 1.2k\,\Omega\ \times 180pF} \approx 700kHz \quad (3)$$

This balance of gain and bandwidth provides sufficient dynamic range and low distortion for accurate encoder signal capture.

Output Filtering

A combination of small series resistors and differential or common-mode output capacitors form a passive low-pass filter at the amplifier output. These components attenuate high-frequency noise without significantly impacting signal bandwidth. The dominant bandwidth control remains in the amplifier's feedback path.

Test Results

To evaluate the performance of the analog front end, key characteristics such as gain, bandwidth, and signal integrity were measured under representative conditions. A $1V_{PP}$ differential input signal was applied to simulate typical Sin/Cos encoder outputs, and the output response was captured and analyzed across a range of frequencies. The results verify that the design meets the specified bandwidth and gain targets while maintaining consistent performance designed for high-resolution encoder applications.

Table 1. Analog Signal Chain Test Results

f_{in}	SNR	THD
2kHz	91.72dB	-113.02dB
5kHz	91.72dB	-112.14dB
10kHz	91.87dB	-112.37dB
20kHz	91.62dB	-112.27dB
50kHz	90.79dB	-111.62dB

Table 2. DC Offset Histogram Results

Standard Deviation	SNR
0.568812	95.2096dB

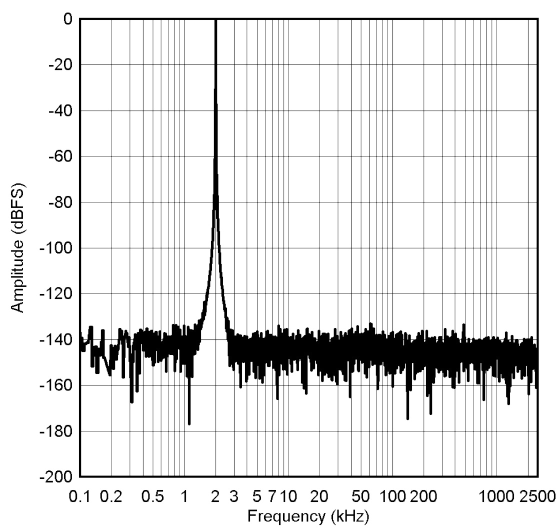

Figure 2. FFT for f_{in} = 2kHz

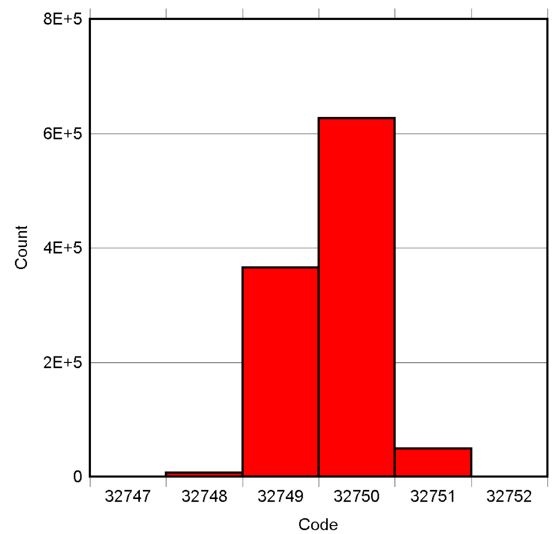

Figure 3. Shorted-Input DC Offset Histogram

Conclusion

This analog front end design demonstrates a practical and effective approach for interfacing with Sin/Cos encoders in precision motion control systems. By balancing gain, bandwidth, filtering, the circuit achieves reliable signal acquisition while preserving accuracy and stability . With support for $1V_{PP}$ differential signals and a carefully tuned 500kHz bandwidth, the design is well-designed for high-resolution encoder applications operating across a wide range of speeds. The implementation aligns with real-world system demands and provides a robust foundation for integration into a dual-channel ADC architecture.

Learn More

- Texas Instruments, *Precision ADCs in Servo Drives*, application brief
- Texas Instruments, *Precision ADCs for Motor Encoders and Position Sensing*, product overview
- Texas Instruments, *1MHz Signal-Chain for Wide Bandwidth Data Acquisition*, application brief
- Texas Instruments, *Interface to Sin/Cos Encoders with High-Resolution Position Interpolation*, reference design

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