Application Report

Applying the ALM2403-Q1 Single-Chip Resolver Solution to Reduce System Costs, and Improve the Reliability and Performance of Automotive and Industrial Applications

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ABSTRACT

This application report introduces a resolver driver reference design that combines the single chip ALM2403-Q1, a dual-integrated power amplifier, filtering, and an all-in-one differential output architecture. The resolver driving solution reduces design complexity, lowers system cost, and improves reliability and performance for automotive and industrial applications.

Features

- Combines filter and differential output architecture for driving resolver
- Cascaded output to input differential op amp drive
- Single-chip, all in one resolver driving approach
- Minimum part count and small PCB footprint
- Low cost and improved reliability
- Reduces design complexity and improves performance
- Minimize DC offset voltage across the excitation windings of the resolver
- Direct or capacitive couplings with resolver load
- Features a Pulse Width Modulation (PWM) input as a sinusoidal signal generator (Optional DAC as input)

Applications

- AC Differential Rotary Transformer Driver
- Automotive/Industrial Servo Driver
- Hybrid-Electric Vehicle (HEV/EV) – Inverter and Motor Control
- E-bike

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Trademarks

1 System Description and Overview

A resolver is a rugged, high precision and high-performance analog electromechanical device that is traditionally used in a wide range of motor control and loop feedback applications applied specifically for speed and position sensing. Examples include: traction inverters for Hybrid-Electric Vehicles (HEV), Electric Vehicles (EV), electric power steering, motor drives, and servomechanisms in automotive and industrial applications. A resolver is one of the most popularly applied angular sensing devices due to its reliability, durability, and ratiometric output.

Various resolver reference designs are available; however, some consist of discrete analog front end driving solutions. While others implement integrated IC solutions that consolidate elaborate approaches implemented to achieve the design requirements. When it comes to PWM-based sinusoidal driving topology, the analog front end of the resolver design still poses challenges to achieve certain application design objectives at a low, reasonable cost.

This article introduces the latest all-in-one resolver driving solution from TI, the ALM2403-Q1. It provides two Power Operational Amplifiers on a single IC. They serve dual roles as Power Amplifiers (PAs) and support a low-pass active filter function in the PWM signal path. It achieves high reliability, high performance at low cost, while being capable of meeting the stringent functional safety compliance requirements for automotive and industrial applications.

2 ALM2403-Q1 Resolver Design Requirements

Table 2-1 details the ALM2403-Q1 resolver design requirements.

Table 2-1. Design Requirements

Parameters	Design Requirements
Input Supply Voltage	Single power rail from 5 V_{DC} to 24 V_{DC}
Operating Temperature	–40°C to 125°C
Resolver Excitation Frequency	400 Hz–40 kHz typical, $f_{excitation\ (exct)}$ = 10 kHz nominal
Sinusoidal PWM Input	f_{sw_320kHz} = 320 kHz, 3.3 V_{p-p} PWM sinewave generator
Power Amplifier (PA)	Single chip, dual integrated op amps, 50 V/µs in slew rate
PWM Filters	Multiple Feedback(MFB), second-order LPF combined with PAs
Gain-Bandwidth Product (GBW)	21 MHz
PA Output Signal Amplitude	Differential sinewave output at 7 V_{RMS} or 10 V_{p-p}
PA Output Drive Current	Differential drive with output current ±200 mA_{p-p} or higher
Low Voltage Offset	±6 mV typical, ±25 mV maximum at $T_{ambient}$ = 25°C
Component Counts	Low parts count, single ALM2403-Q1 PA IC
Resolver Load	N_{exct}: N_{rotor} = 2:1, L_{exct} = 1.6 mH and R_{exct} = 28 Ω

Table 2-2 details the ALM2403-Q1 additional performance features.

Table 2-2. Additional Performance Features

Parameters	Performance Features
Functional Safety Capable	Yes (see the *ALM2403-Q1 Product Folder* and the *Functional Safety FIT Rate, FMD and Pin FMA Functional Safety Information*)
ESD Protection	Yes (built-in, see the *ALM2403-Q1 Automotive, Low-Distortion, Dual-Channel Operational Amplifier With Integrated Protection for Resolver Drive Data Sheet*)
Thermal Protection	Yes (built-in, see the *ALM2403-Q1 Automotive, Low-Distortion, Dual-Channel Operational Amplifier With Integrated Protection for Resolver Drive Data Sheet*)
Output Current Limit	Yes (built-in, see the *ALM2403-Q1 Automotive, Low-Distortion, Dual-Channel Operational Amplifier With Integrated Protection for Resolver Drive Data Sheet*)
Overvoltage Protection	Yes (see the *Overvoltage Protection of Resolver-Based Circuits Application Note*)
Short Circuit Current Protection	Yes (built-in, see the *ALM2403-Q1 Automotive, Low-Distortion, Dual-Channel Operational Amplifier With Integrated Protection for Resolver Drive Data Sheet*)
PCB Footprint	14 pins in HTSSOP package, 5.00 mm × 4.40 mm in size

Figure 2-1 shows the ALM2403-Q1 block diagram.

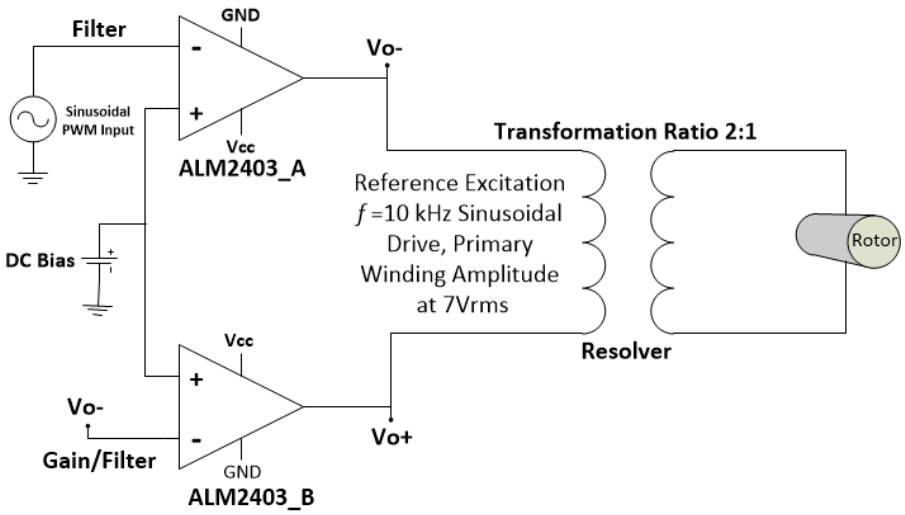

Figure 2-1. Single-Chip, ALM2403-Q1 Resolver Driver Block Diagram

2.1 Simulation Schematic Diagram

Figure 2-2 illustrates the ALM2403-Q1 resolver solution differential driving stages.

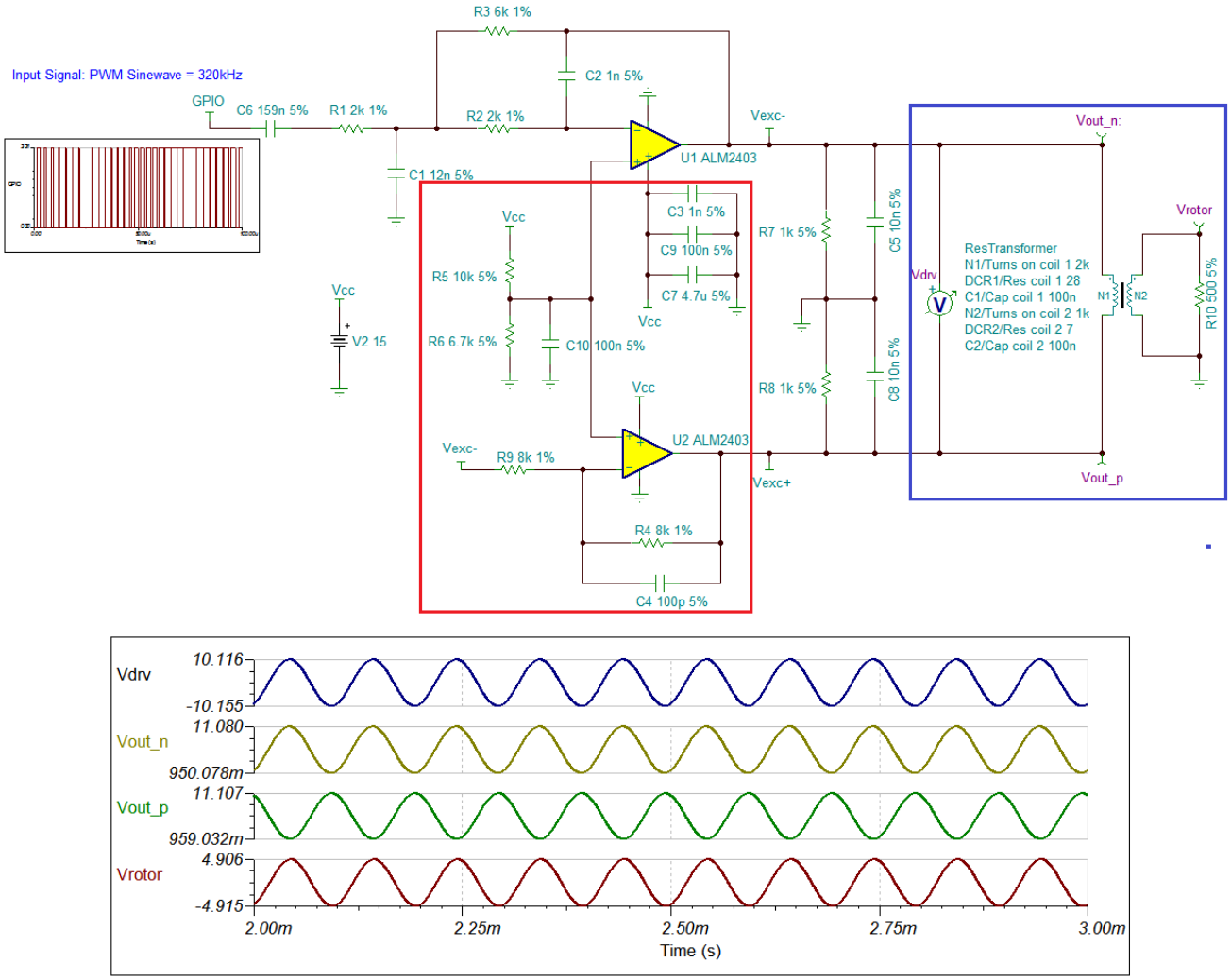

Figure 2-2. ALM2403-Q1 Resolver Solution Differential Driving Stages

3 Highlighted Resolver Design Architecture

The following sections describe the system design in the order of signal flow from input to output.

- Power amplifier driver combined with MFB second-order LPF
- Cascaded output-to-input Power (Excitation) Amplifier scheme
- Differential driving requirements in resolver

3.1 Power Amplifier Driver Combined With MFB Second-Order LPF

The corner frequency of the second-order LP filter is configured at approximate $f_{sw\_320kHz}/20$ of PWM switching frequency, which is configured at 320 kHz. The LP filter provides a second-order response which rolls off at a rate of –40dB/decade, as Figure 3-1 shows.

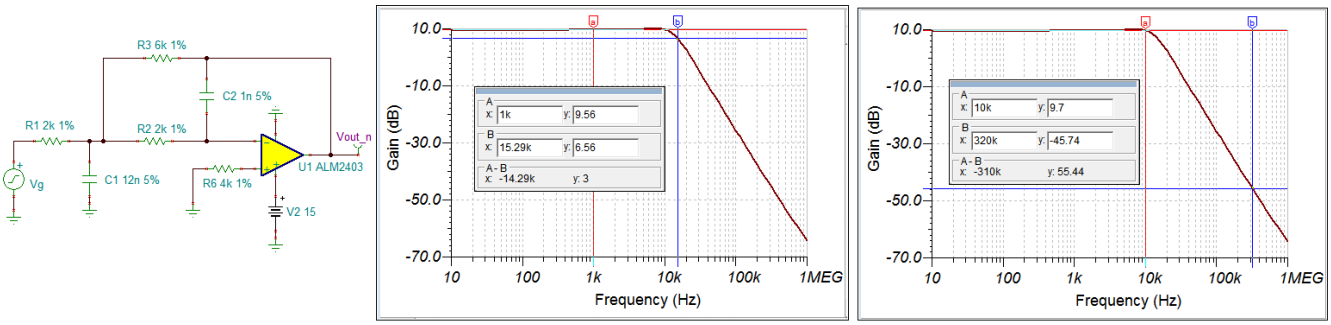

Figure 3-1. Second-Order MFB LP Filter, Driven From PWM Based Sinusoidal Input

Equation 1 shows the corner frequency of the MFB second-order LP filter is defined at –3 dB:

$$f_p = \frac{1}{2\pi\sqrt{R_3 C_1 R_2 C_2}} \tag{1}$$

The MFB second-order active LP filter uses an inverted input topology, Gain = –3 V/V, which is determined by the resistor ratios of R_3 and R_1 in Equation 2.

$$Gain = -\frac{R_3}{R_1} \tag{2}$$

The attenuation characteristics of the MFB second-order LP filter at 10 kHz, the –3dB point and 320 kHz are shown in Figure 3-1.

The resistor ratios of R3 and R1 in Equation 2 determines the gains of MFB second-order LP filter and resolver driving amplitudes. The gain settings are based on the output driving requirements and input sinusoidal PWM signal level. For applications with different input sinusoidal PWM amplitudes and output voltage swing requirements, the filter characteristics may need to be reformulated and simulated accordingly.

The quality factor of the LP filter is configured at Q ≈ 1. The purpose is to extend the gains of the pass band near the 10 kHz region, which is designed to maintain the AC gains and minimize the output attenuation at the corner frequency. The Q factor of the MFB second-order filter is defined in Equation 3:

$$Q = \frac{\sqrt{C_1/C_2}}{\sqrt{R_3/R_2} + \sqrt{R_2/R_3} + \sqrt{R_3 R_2/R_1}} \tag{3}$$

3.2 Cascaded Output-to-Input Differential Power (Excitation) Amplifier Driver

The ALM2403-Q1 resolver driver implements a cascaded output-to-input architecture, where the output of the upper PA feeds into the inverting input of the lower PA. The output of the power amplifiers create a diphased, or differential output driving configuration to the excitation windings of a rotary transformer. Key design considerations of the asymmetrical differential op amp driving architectures are discussed in the following sections.

In the highlighted, red rectangular section outlined in Figure 2-2, the capacitor C4 in the lower op amp driver is selected by introducing a pole near the PWM switching frequency to eliminate undesired phase shift. This approach is chosen instead of establishing a band limited frequency, which may integrate high-frequency noise throughout its bandwidth.

The voltage divider created by R5 and R6 is implemented to establish a DC bias voltage used to drive the high-impedance non-inverting inputs of both power amplifiers. R5 and R6 resistor values are selected in such a way that R5‖R6 matches the input impedances of the op amps. The value of the DC bias voltage level is not critical as long as the voltage swings at V_{out_n} and V_{out_p} nodes are elevated above the ground potential level seen at the excitation windings of a resolver.

3.3 Input Driving Requirements for the Resolver

The differential output voltage swings to the excitation windings are required to be balanced, where the upper half of the sine wave has to be equal to lower half of the sine wave. This is to comply with the steady-state, volt-second balance criteria in accordance with Faraday's law.

In the highlighted blue rectangular section in Figure 2-2, the ALM2403-Q1 driver is designed to interface with the load of the resolver directly, or capacitively at the excitation windings. With the low DC voltage offset, high bandwidth, and high driving current of the integrated solution, the differential resolver driver will attain low DC offset characteristics at its output, the V_{drv} node. The delta DC voltage is simulated and measured at this node resulting in approximately 40 mV across the input windings of the resolver. In the cascaded output-to-input ALM2403-Q1 driving scheme, the predominate DC gain errors are mainly from the lower PA stage operating as a unity gain inverter. Its noise gain of 2 V/V amplifies its DC offset and establishes overall offset at the output stages of the differential driver. The DC offset errors generated from the upper stage are nulled out when the lower PA stage takes the input of the upper stage and generates a complementary differential sinusoidal drive at a resolver load.

4 Conclusion

The cascaded output-to-input PA driving scheme generates desired, low-output DC offset voltages. And it takes advantage of the design features of the ALM2403-Q1 device that are tailored specifically for resolver applications. With sinusoidal PWM based inputs, the combined second-order LPF and PA driving stages create a single chip, all-in-one design solution. This is accomplished with low parts count and low complexity that result in a high-performance resolver drive solution.

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