Application Report

SLVA696–April 2015

Abstract

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ABSTRACT

Traditionally engineers have used discrete active devices in order to boost the output current of an opamp. ALM2402Q1 is able to eliminate these due to its own class AB output stage that can drive up to 400 mA. In addition to its output drive capability, it has many protection features that are optimal for driving low impedances, making it a robust device in industrial and automotive applications. This application note will describe the features of the ALM2402Q1 and provide some suggested applications for which it may be used.

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1 Key Benefits

- High Voltage and Current Support
  - 400 mA Continuous Sink/Source Support
  - 18 V Absolute Maximum
- Wide Load Capacitance Stability Range
  - 0 pF to 3 µF
- Protections Features --> Ilimit & Thermal Shutdown
- Rail to Rail Output with Low Rdson PMOS/NMOS
- Great Package Thermals from DRR & PWP
- Wider temperature range, –40°C to 125°C

2 Features

2.1 Output Drive

The major feature that differentiates the ALM2402Q1 from most operational amplifiers is its output current drive ability. Most Opamps, general purpose to high performance, can drive up to 30 mA. As will be described in the applications section, this is a big limitation for many applications, leading designers to go towards discrete implementations (like Figure 1). The drawbacks to this are increased BOM size/cost, power efficiency, distortion and complexity (difficult to stabilize and bias). ALM2402Q1 integrates this power stage in CMOS technology, along with heavy internal compensation and protection/indication features. It also provides low resistance rail to rail output, eliminating cross-over distortion.

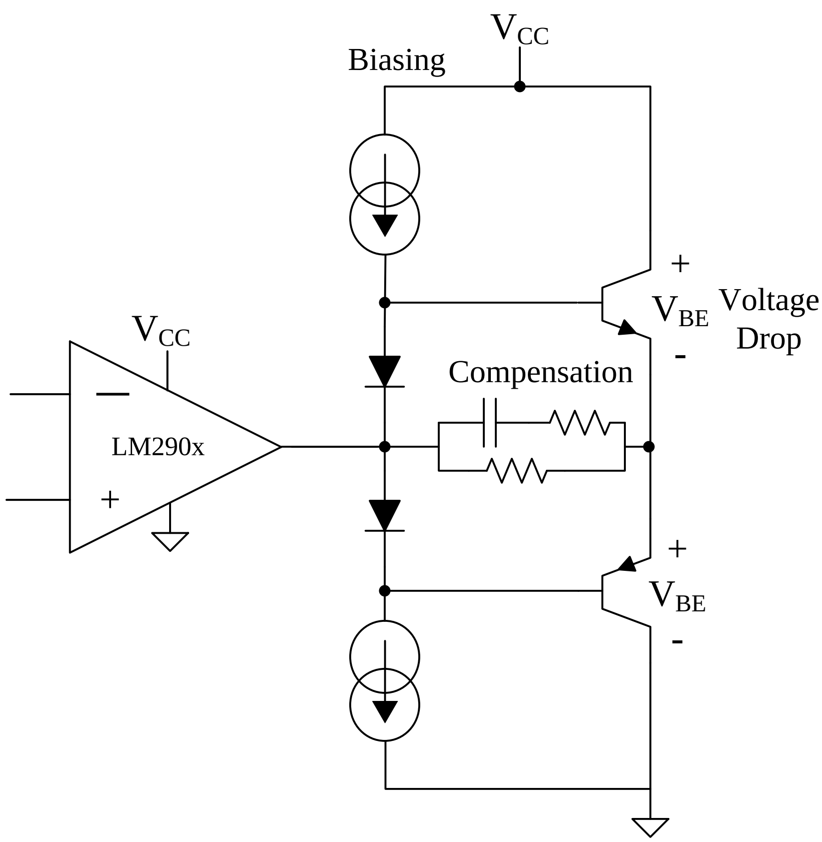


Figure 1. Discrete Power Opamp Implementation

ALM2402Q1 is designed to continuously sink and source 400 mA across the operating temperature and voltage range. It can pulse much more current, however its internal current limit will activate and not allow it passed a certain point. When designing high current applications, it is very important to take in to consideration the IC's power dissipation. The Power Budgeting and Thermal Properties section discusses this in more detail.

Another drawback of the above implementation is the Vbe voltage drop on the output transistors limiting the output swing capability and increasing the power dissipation. In order for the output BJTs to be in the proper operating region for an opamp, there must be at least a Vbe (~0.7 V) between collector and emitter. This does not even include the voltage headroom needed to bias the output BJTs, which could end up limiting the output voltage to > 1 V below Vcc and above ground.

ALM2402Q1's class-AB stage is resistive causing a V_{OH}/V_{OL} that is proportional to output current (see Figure 3 and Figure 2), enabling near rail output voltage with low output currents. This type of output is very important for power amplifiers, as the power dissipation is proportional to V_{OH}/V_{OL}. More is discussed in the Power Budgeting and Thermal Properties section.

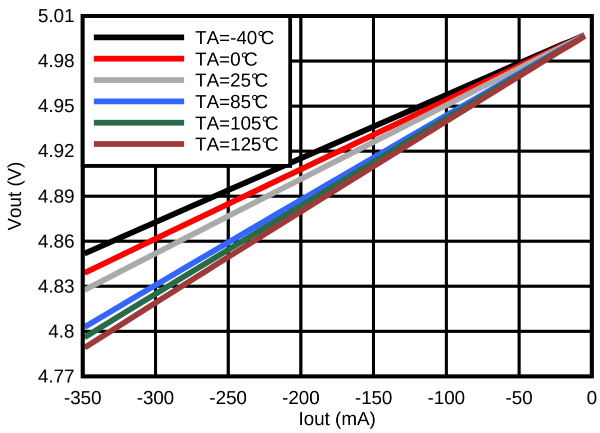


Figure 2. Output High (VOH) vs. Temperature

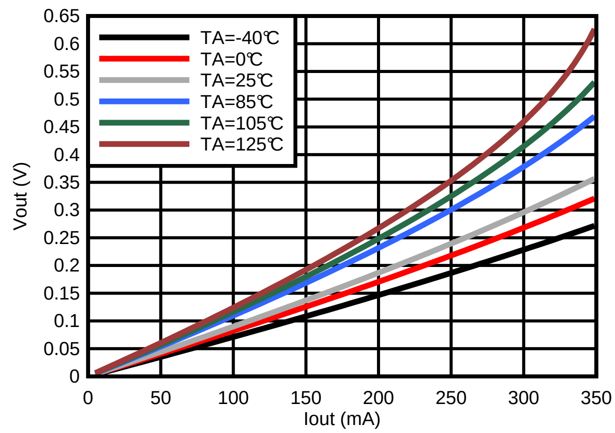


Figure 3. Output Low (VOL) vs. Temperature

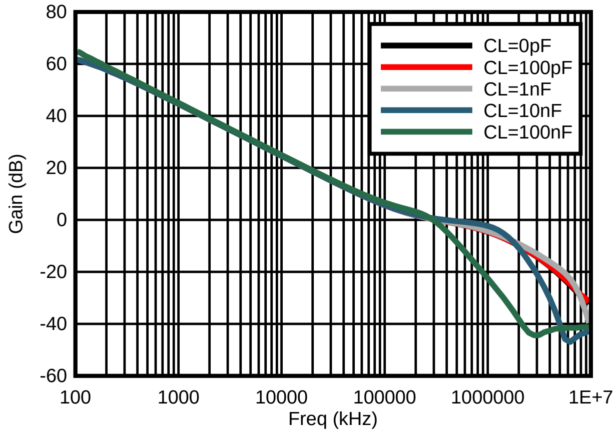
2.2 Stability

ALM2402Q1 is internally compensated to be stable with large capacitive loads. Opamps can see heavy loads for many applications, especially those that involve driving analog signals off of the PCB.

Figure 4, Figure 5, Figure 7 and Figure 6 show the loop gain and phase frequency response of ALM2402Q1 for decade load capacitors up to 100nF. The internal compensation of the opamps adds a zero near unity gain, enabling >120º phase margin with light loads. This also assists in the opamps having great phase margin with heavier loads, as can be seen in the figures below (Figure 4, Figure 5, Figure 7 and Figure 6).

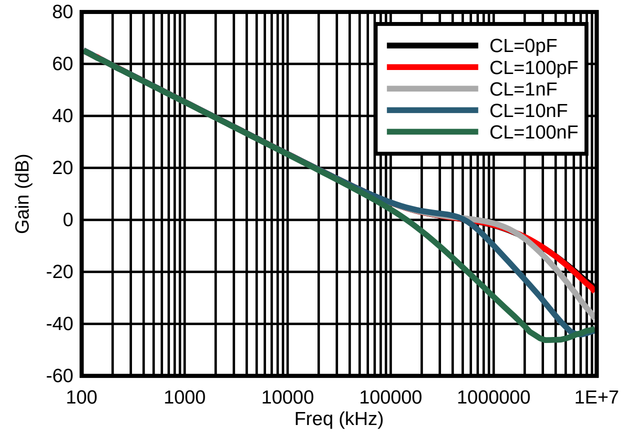
The output pole presented to the load is dominated by the load capacitance. One of the benefits to ALM2402Q1's rail-rail output stage is the very low output impedance (~100 mΩ @ 1 kHz). This impedance will dominate the parallel resistance seen at the load of the opamp, making the output pole and zero locations (and phase margin) to be mostly adjustable by the load capacitance. This is why there isn't much difference between the phase margin between heavy load and light load.

The below plots show a trend of gain and phase rolling off earlier with larger load capacitance, causing a decrease in phase margin. However, this is not necessarily a linear relationship. The lowest phase margin shown below is ~45° for 100 nF & RL = ∞. This does not mean that 200 nF will have much lower phase margin (actually 50° according to SLOS912). This is why (for capacitive loads > 100 nF) it is recommended to measure and characterize the transient or frequency response of ALM2402Q1 in the lab to obtain desired phase margin or ringing/overshoot performance. SLOA077 is a great resource for explaining the relationship between phase margin and overshoot along with other feedback stability fundamentals.



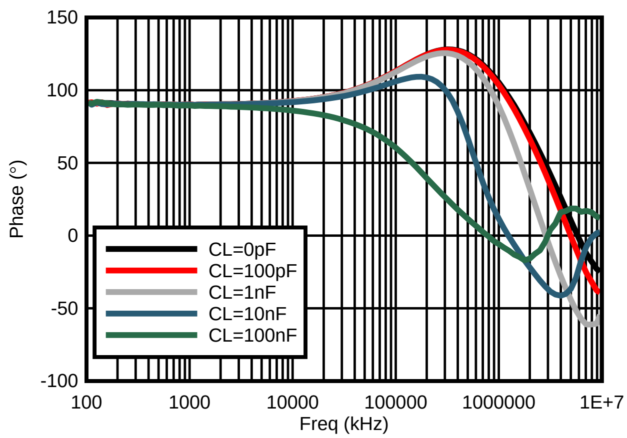
RL = 50 Ω

Figure 4. Heavy Load Gain



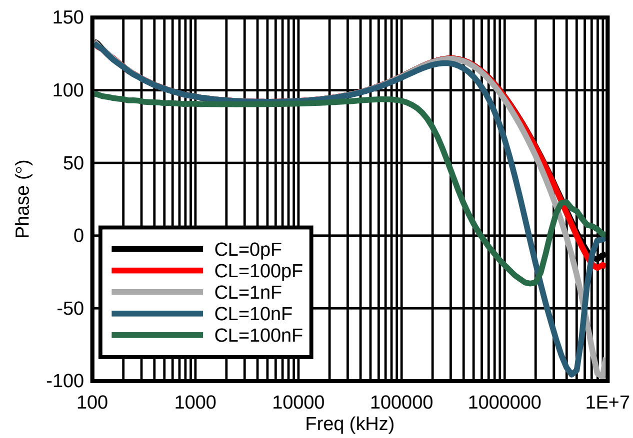
RL = ∞

Figure 5. Light Load Gain



RL = 50 Ω

Figure 6. Heavy Load Phase



RL = ∞

Figure 7. Light Load Phase

3 Power Budgeting and Thermal Properties

With ALM2402Q1 being a high voltage and high current (power), power budgeting is of upmost importance. Though, ALM2402Q1 has thermal shutdown, it will not prevent the device from damaging or shortening it's lifetime. This is because the maximum shutdown junction temperature is 175°C and the thermal hysteresis is ~10°C, meaning that the device may toggle between operation states between junction temperatures of 165°C and 175°C. This is well above the required maximum junction temperature limitation of 150°C. Hence, stressing the importance for users to limit the maximum junction temperature when determining system level requirements like ambient temperature, layout and output voltage/current.

Equation 1 represents the relationship between junction temperature and power, package and ambient temperature. The user must limit each variable, such that sustained/continuous junction temperature does not exceed to 150°C.

$$T_J = P_D * \theta_{JA} + T_A \quad (1)$$

Designers have the most control over power dissipation and thermal impedance (θ_{JA}) by choice of loads and power voltages along with PCB layout. IC power dissipation is dominated by the supply power minus the power delivered to the load (Equation 2).

Power Supply Power	Power Delivered to Load

$$P_D = P_S - P_L \quad (2)$$

A more specific power calculation is shown in Equation 3. This representation is good for AC signals, where the output voltage may not be driven all the way to the supply rails. For AC or PWM applications that forces the output to swing between power and ground, $V_{CCO(X)}$ - $V_{OUT(RMS)}$ can be replaced by ((5V-V_{OH})+V_{OL}). Where V_{OH} & V_{OL} can be determined by Figure 3 and Figure 2.

$$P_D = V_{CC} * I_{CC} + \left(V_{CCO(X)} - V_{OUT}(RMS)\right) * I_{OUT}(RMS) \quad (3)$$

Once the power dissipation is determined, the thermal impedance must determined. The thermal impedances for the two packages that this part is offered in (DRR & PWP) are different. It is common for designers to make the mistake of just selecting the values given in the datasheet and not consider the layout and PCM implications. θ_{JA} is a measure of the thermal performance of an IC package mounted on a specific test coupon. The intent of θ_{JA} is to give a metric by which the relative thermal performance of a package can be compared. It does not apply to every layout or PCB material. For more details on determining and designing for the proper thermal impedance see the IC Package Thermal Metrics application report, SPRA953.

4 Applications

4.1 Tracking LDO

The chassis of a car is grounded to the battery, and power is supplied to the peripheral circuits by the wiring harness fastened throughout the body of the vehicle. A wiring harness has many points of failure due to its length, multiple connections, and exposure. Sometimes wires or connectors can be cut or exposed creating the potential to short a power supply line to the vehicle chassis or other wire connections. ALM2402Q1 is great for applications that need protection from such faults.

One application that must take these faults into consideration is when power must be supplied along a wire (external to PCB) to power a sensor or peripheral. Due to the wire routing area of many vehicles being potential danger zones for shorts to ground, designers need to isolate the system power supply (LDO or SMPS) from this. Else, they face damaging the supply or other devices that are powered by the system supply. The solution for this is a tracking power supply that essentially isolates the system power supply output voltage from the external device that needs to be powered while supplying the same system voltage. The tracking regulator will allow the system to supply voltage and not current to the external load. The current will be provided by the tracking regulator.

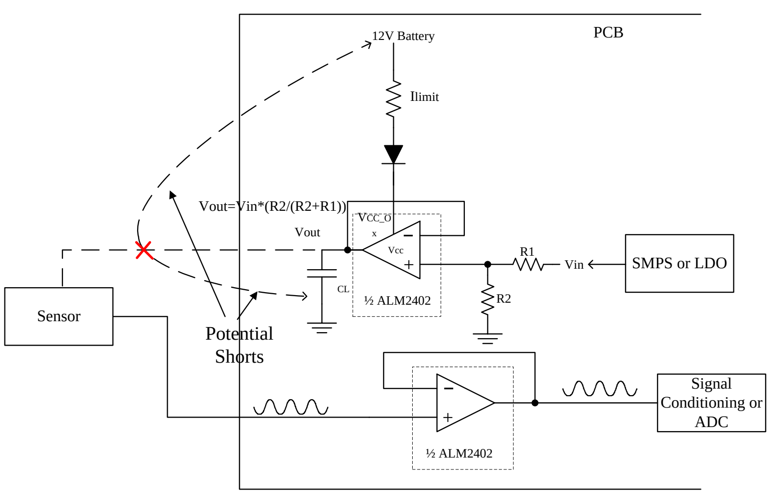


Figure 8. Tracking LDO Example

The ALM2402Q1 can be used as a tracking LDO to supply power to vehicle peripheral circuits and provide them with over current protection in case of a short. Figure 8 shows an example circuit. The ALM2402Q1 is configured as a voltage follower which sets its output to the voltage present on the positive terminal. The over current protection for the ALM2402 turns the device off at ~750 mA, but the output current may be limited further by adding the resistor Rlimit between the supply/battery and V_{CC_Ox}. To block reverse currents, a diode can be placed in series with the supply and V_{CC_Ox}.

Outside of the integrated protection features, ALM2402Q1 is great for this application due to it's stability with large ceramic capacitors (up to 3 µF) and the stability of the device not being load resistance dependent (see the Stability section), unlike many LDOs. With ALM2402Q1, being a dual opamp, it also provides another opamp for sensor signal conditioning or buffering.

Motor Drive

The ALM2402Q1 may be used to control the speed of a DC motor as shown in Figure 10. Many features of the ALM2402Q1 make it useful for driving small brushed DC motors.

The low RDS(on) of the output allows it to drive close to the rails. This allows for low power dissipation from current draw in the output stage of the op amp.

The current-limiting feature of ALM2402Q1 will protect the motor and other circuitry from large startup current or high currents drawn when the rotor is locked. In the event when a rotor is locked for a long time, the thermal shutdown feature will turn off the ALM2402Q1 until it cools. In this situation, the ALM2402 will pulse the output, saved by current-limiting and over-temperature protection.

When changing direction of the motor or electrically braking it, the clamping diodes on the outputs of the ALM2402Q1 will allow current in the motor’s coils to flow after the voltage across the motor has changed polarity. Table 1 shows the forward voltage and current of these diodes.

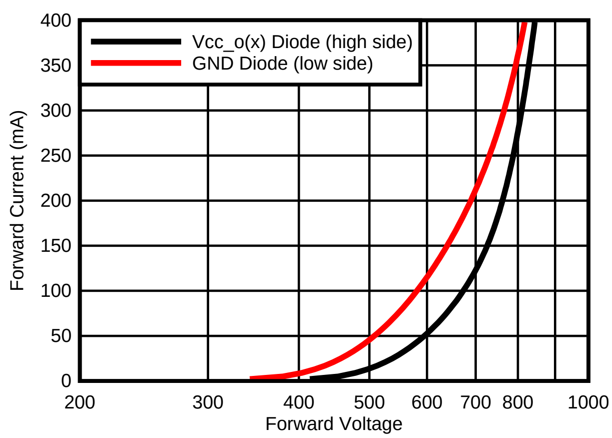


Figure 9. PMOS (High Side) & NMOS (Low Side) Output Diode Forward Voltage

In applications where the motor needs to be turned off, but allowed to coast to a stop, the ALM2402 can be disabled using the OTF pin.

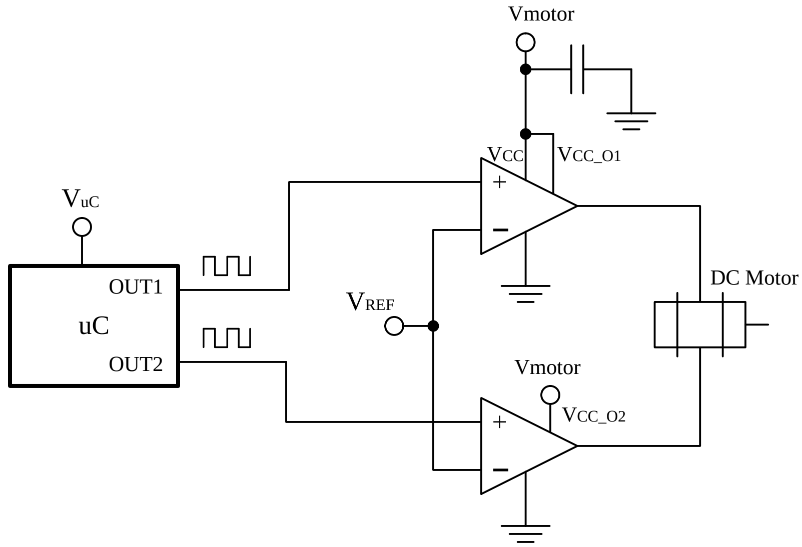


Figure 10. ALM2402Q1 Used as a Brushed DC Motor Driver

The comparator configuration and the internal high-side/low-side drivers turn ALM2402Q1 into a full bridge driver, allowing for bidirectional control of the motor. A PWM signal from a microcontroller or other control logic can be used to control the direction of the motor (see Table 1). Two separate PWM signals are generated, as to not cause any overlap in PWM signals, to avoid possible shoot-through current.

Table 1. Motor Control Signal and Communication Direction

Motor control signal and commutation direction			
OTF	**OUT1**	**OUT2**	**Motor Direction**
LOW	X	X	Coast
HI	LOW	LOW	Brake
HI	LOW	HI	Reverse
HI	HI	LOW	Forward
HI	HI	HI	Brake

4.2 Servo (Analog) Motor Drive

Servo motor driving is a closed loop motor drive technique that provides much more accurate position setting than the open loop DC drive explained in the section above. It is popular in robotic and automation where precise movements are desirable. Servo motor control uses a potentiometer (mechanically connected to the rotor) to sense the rotor position and the control system will use this signal to regulate the motor position by minimizing the error between the desired position (voltage) and the actual position (potentiometer voltage). This can be accomplished using an error amplifier op amp configuration with a discrete power booster stage. However, as explained in the Output Drive section, this has many complications and draw backs.

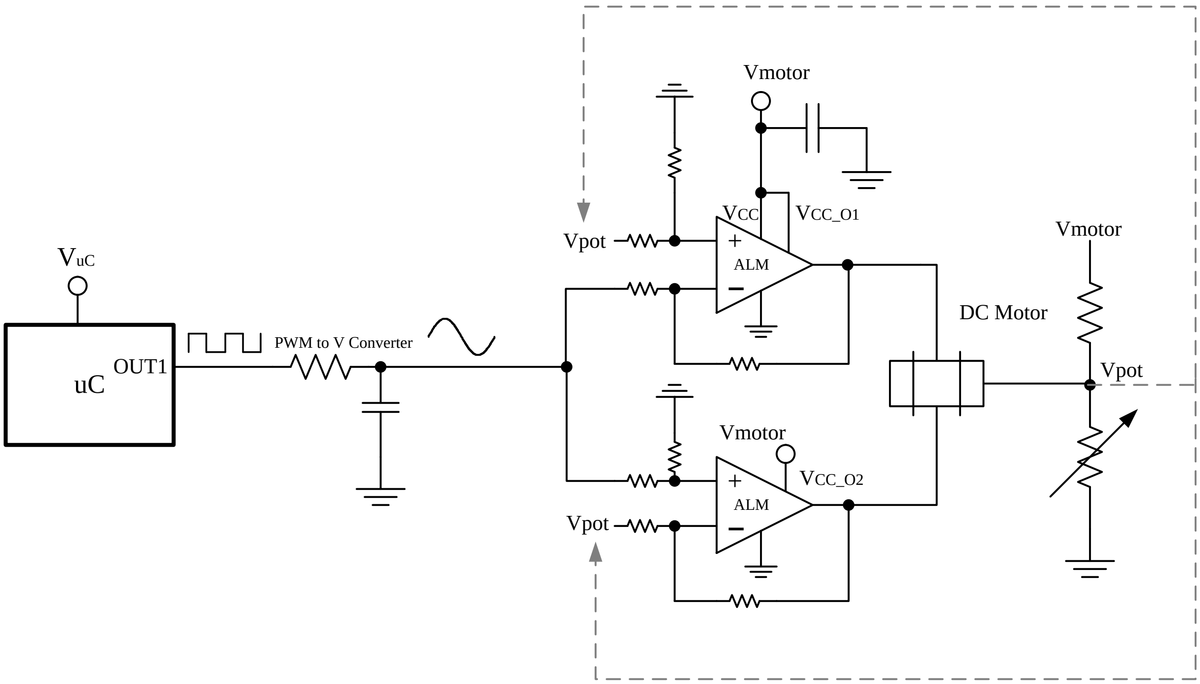


Figure 11. ALM2402Q1 Used as a Servo Motor Driver

ALM2402Q1 is a great solution for this application, as it can provide easy analog feedback and enough current and voltage to a good sized servo along with the protection benefits discussed in the previous section. Figure 11 shows ALM2402Q1 in servo drive control implementations. Both opamps can be used to apply a bipolar or differential drive to the motor allowing bi-directional motor control. Another key benefit is the low offset of 1mV that ALM2402Q1 provides, allowing very minimum error in the drive signal.

As explained in the Power Budgeting and Thermal Properties section, when power dissipation is crucial it is best to operate the output voltage near the supply rails. In this case, one can use the error amplifier in a PWM IC like the 555 timer and drive the ALM2402Q1 (in open loop, as shown in Figure 10) to PWM the motor for actuation.

4.3 Resolver Excitation

ALM2402Q1 can be used in motor position acquisition as a resolver excitation driver. The SLOS912 provides more information on this application. Design procedure and key considerations are detailed are the.

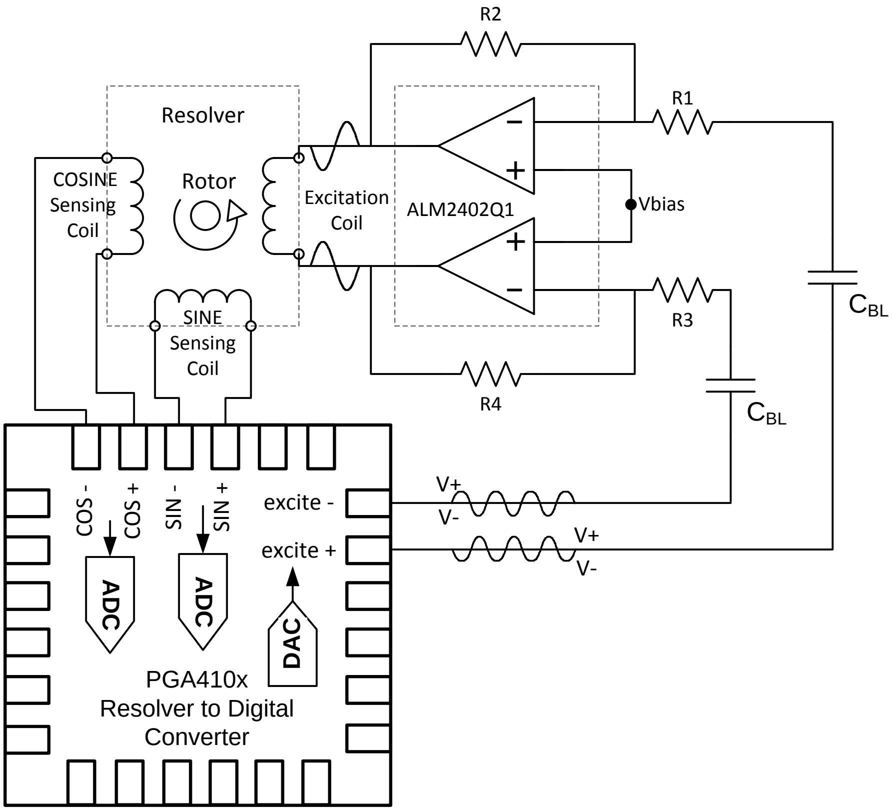


Figure 12. Resolver Exciation

5 Conclusion

As discussed in this document, ALM2402Q1 has many features that make it optimum across a range of applications that traditional opamps or discrete implementations may have limitations in. The protection features help protect this device and the system against potential faults in harsh environments, while the drive current and stability allow complex or heavy load driving.

The function and power stage integration in the small form factor 3mm x 3mm DRR package with low thermal impedance that this device is offered in, makes this device optimal in space constrained power applications. The low V_{OH}/V_{OL} of this device also assists in minimizing power dissipation.

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