Application Report

Overvoltage Protection of Resolver-Based Circuits

TEXAS INSTRUMENTS

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ABSTRACT

All analog IC's are prone to over-voltage damage when exposed to voltages above or below the supply voltage used to power them. However, this is especially true in the case of automotive resolver applications where supplies used to power the ICs are typically much lower than the battery voltage. This application report covers in great detail several schemes that can be employed at the board level under various circuit conditions to prevent damage resulting from the accidental shorts.

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1 Introduction

To minimize the power dissipation inside an op amp, and thus to improve efficiency of the solution, most of the resolver type of applications are powered from the sub-regulated voltage supply below the battery voltage. For this reason, most high current output amplifiers used in the automotive resolver applications, like ALM2402F-Q1 and ALM2403-Q1, must be fault protected at the PCB level against possible over-voltage (EOS), and or excessive output current, caused by accidental shorting of the amplifier output to the battery or other voltage source beyond the op amp's power supplies. Since the battery voltage may be higher than the amplifier's power supply voltage, or even higher than op amp absolute maximum rated voltage, any accidental shorting of the op amp output to the battery may result in damaging the part and thus must be protected.

2 ALM2402F-Q1 Output Fault Protection

Figure 2-1 shows the ALM2402F-Q1 under normal quiescent condition being powered from 12 V single supply with its input and output voltage at 6 V mid-supply (no fault condition).

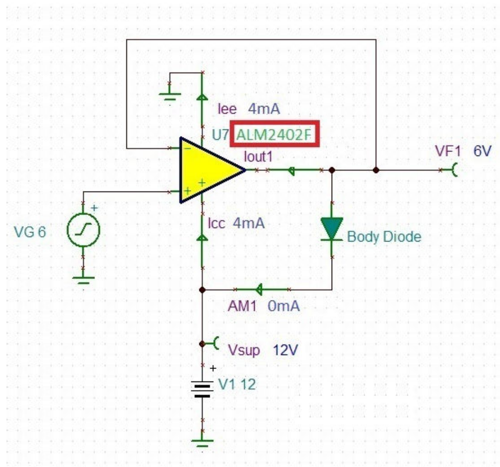

Figure 2-1. ALM2402F-Q1 Normal Operation

Figure 2-2 shows ALM2402F-Q1 under a fault condition with its output being shorted to an 18 V battery while being powered by a 12 V supply, requiring only protection of a blocking Schottky diode, SD2. Since the absolute maximum rated supply voltage for ALM2402F-Q1 is 18 V, adding the blocking diode, SD2, allows the battery voltage, Vbat, to pull up the amplifier's positive supply pin, Vsup, to 17.6 V without any damage.

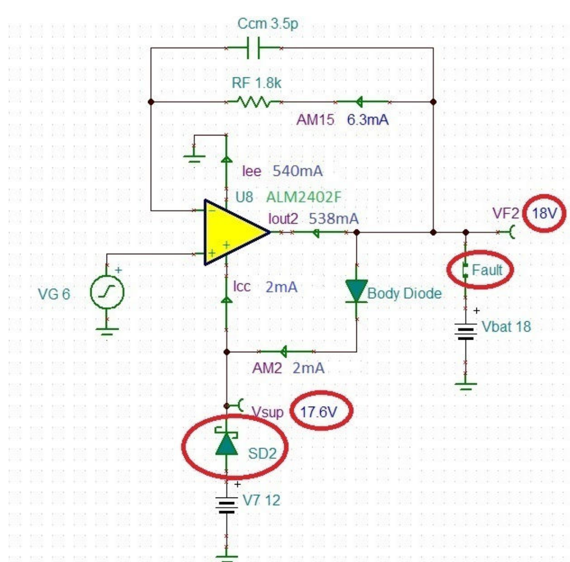

Figure 2-2. ALM2402F-Q1 18 V Battery Fault Protection

The addition of 1.8kΩ resistor in the feedback, RF, shown in Figure 2-2, limits to 10mA maximum allowable current through the internal back-to-back input protection diodes located between the ALM2402F-Q1 input terminals.

Under the short to battery conditions output of ALM2402F-Q1 sinks 538mA short-circuit current (see Figure 2-2) attempting to bring down the output voltage. At the same time a body diode - an internal drain-to-nwell, p-n junction of P-channel output transistor - supplies 2mA quiescent current to bias the first two internal stages of the amplifier. Under normal operation of the output PMOS transistor, the current flows through the enhanced p-channel from Vcc to Vout. However, under the fault conditions, when Vout is above Vcc, normal operation of PMOS is shut down (Vgs=0) and thus the current flows in a reverse direction from the output, Vout, through drain-to-nwell body diode to a positive supply – see Figure 2-3. For this reason, under fault condition Vsup gets pulled up within a diode drop below Vbat voltage (see Figure 2-2).

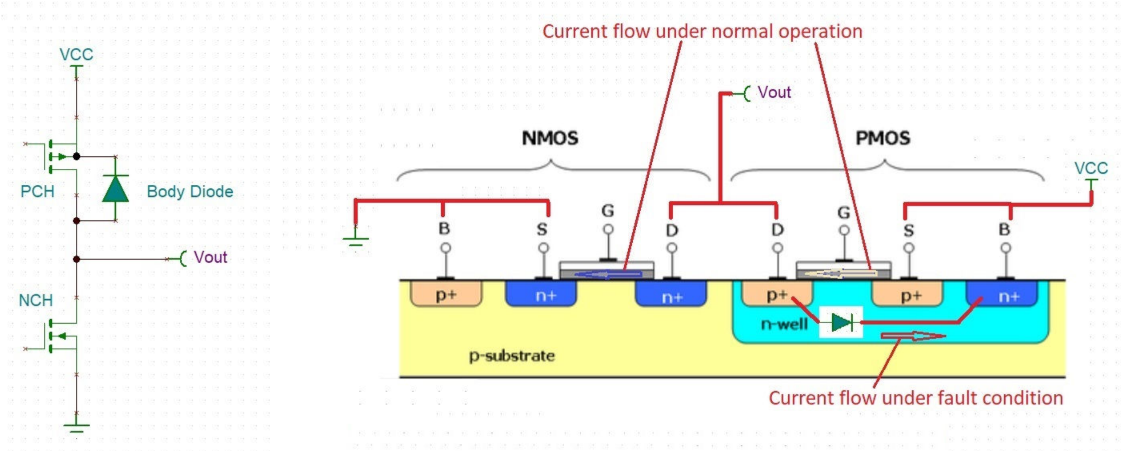

Figure 2-3. Normal vs. Fault Operation of the Output Stage

3 ALM2402F-Q1 and ALM2403-Q1 Overvoltage Protection for Low Battery Voltages

Since the absolute maximum rated supply voltage for ALM2402F-Q1 is 18 V, shorting the output above said voltage requires extra circuitry to prevent EOS damage. To this end, Vsup must be protected by Transient Voltage Suppressor (TVS), a fast activated Zener diode with a breakdown voltage of 18 V or lower, from being pulled close to Vbat through the body diode since this would exceed its maximum rated supply voltage (see Figure 3-1). Additionally, the current through the body diode must be limited to a short-circuit level by adding R4 series resistor, which under short to 26 V fault condition results in over 7 V drop across its 7Ω power resistor (total current of ~1.05A)

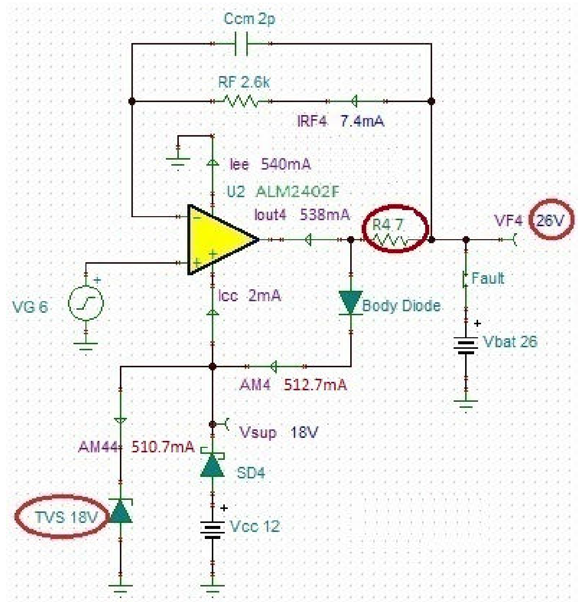

Figure 3-1. ALM2402F-Q1 26V Battery Fault Protection

However, there is a simpler solution to the above problem by using another part - ALM2403-Q1. Because of its higher absolute maximum rated supply voltage, it eliminates the need for extra protection up to 26 V - see Figure 3-2. As was the case with ALM2402F-Q1 shown in Figure 2-2, all that is required here is a blocking diode, SD5, which allows Vsup to be pulled to 25.6 V with no damage.

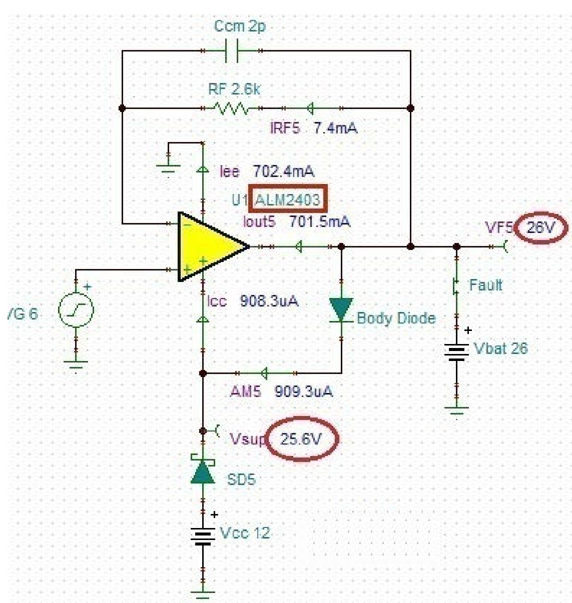

Figure 3-2. ALM2403-Q1 26V Battery Fault Protection

Nevertheless, as was the case with Vbat above 18 V in case of ALM2402F-Q1, shorting ALM2403-Q1 output above 26 V will similarly require a transient voltage suppressor (TVS) to clamp Vsup at 26 V (or lower). Also, a series output power resistor has to be added to limit the current through internal structures. Therefore, any protection against short to battery or other fault condition must not only protect against over-voltage at the supply pin, Vsup, but also assure that the resulting current through internal and/or external protection structures, does not exceed maximum rated limit specified in the respective product data sheets.

Therefore, for short to battery condition just above 26 V, the simplest way to limit the current through body diode is to include a small resistor inside the feedback loop in series with the ALM2403-Q1 output. For example, under short to 28 V Vbat condition, Isc current (701mA) is being sunk by the amplifier output and adding just 1Ω power resistor, R5, between Vbat and output pin results in safe Vsup of 25.9 V. R5 also limits the body diode current to a safe 713.1mA, thus fully protects ALM2403-Q1 from any damage – see Figure 3-3.

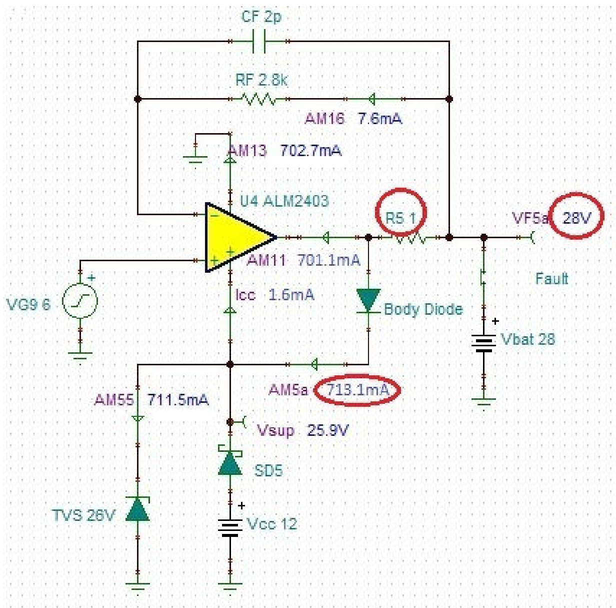

Figure 3-3. ALM2403-Q1 28V Battery Protection

This approach works well for battery voltages up to few volts above the part's absolute maximum rated supply voltage but requires much higher value series output power resistor for higher Vbat that negatively affects the output voltage swing from the rails, and lowers power efficiency, under normal operating conditions. For example, in order to prevent over-current damage to the part under short to a 48 V battery, one would need to add around 20Ω resistor in series with ALM2403-Q1 output. However, under normal linear conditions, with +/-200mA peak output current, this would lower the output voltage swing to each rail by additional +/-4V (total of 8 V), requiring a significant increase in the minimum supply voltage. This in turn would results in much lower power efficiency of the solution and thus may not be a viable option.

Therefore, in order to protect ALM2403-Q1 under short to high voltage (48 V) Vbat condition, it may be necessary to add an external Schottky diode, SD7, in parallel with the body diode and capable of carrying a very high current – see Figure 3-4. Under such scenario, in order to limit the current through Schottky diode to 20A (or less) this would require adding R66 1Ω power resistor between Vbat and the Schottky diode. Even though for a given current level the forward bias voltage of Schottky diode is much lower than that of the body diode (thus much more of the current would flow through external Schottky and not the body diode), under high current flow of 20A, its forward bias voltage may be 1 V or higher. Therefore, in order to limit the current through the body diode to a safe operating level, it may also be necessary to add another 1Ω series resistor, R6, between SD7 and the amplifier's output, VF12 – see Figure 3-4.

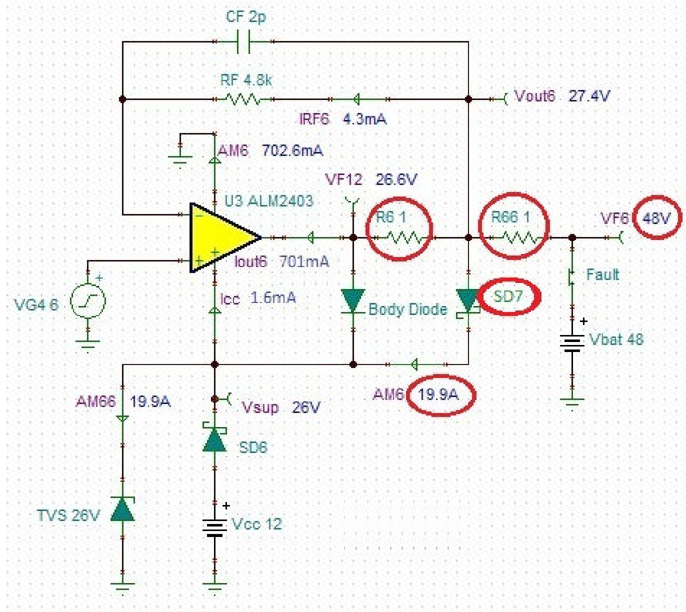

Figure 3-4. ALM2403-Q1 48V Battery Protection

4 ALM2403-Q1 Overvoltage Protection Schemes for High Vbat Voltages

Most of the ALM2403-Q1 protection circuits discussed so far involved adding a TVS on the supply pin to prevent over-voltage damage and a Schottky diode with a series output power resistor to guard against the over-current damage – these schemes typically work well but are both bulky and costly solutions. However, there is yet another novel approach that greatly limits the current level under fault conditions (thus eliminates the need for the Schottky diode) without limiting the output voltage swing to rail under normal circuit conditions.

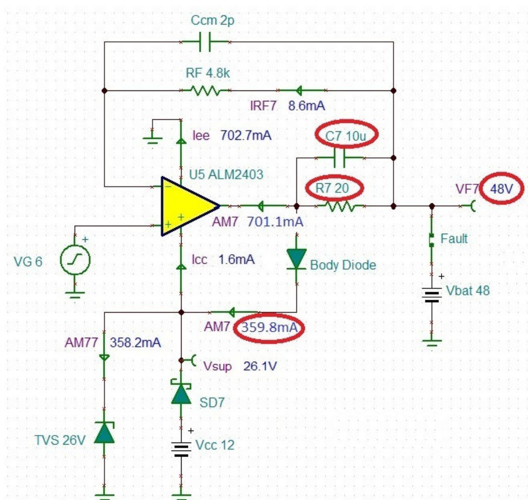

Figure 4-1. ALM2403-Q1 48 V Battery Fault Protection

Figure 4-1 shows that under a short to 48 V battery fault condition it may take as much as 20Ω of series output power resistor, R7, to limit the current through the body diode to a safe magnitude. This means that under normal operation, with typical current load of +/-200mA, this would result in additional loss of 8 V of the voltage supply headroom, greatly diminishing power efficiency of the solution. However, if the R7 resistor is placed inside the feedback loop and bypassed with a large, non-polarized capacitor, C7, the resolver normal operation performance is hardly affected.

At the typical frequency of 10kHz used in most automotive resolver excitation applications, the impedance of 10uF bypass capacitor is around 1.6Ω, which lowers the output voltage swing to the rail under +/-200mA peak load by just +/-320mV instead of +/-4 V. This means that there is little need to increase supply voltage, which results in higher efficiency of the resolver solution.

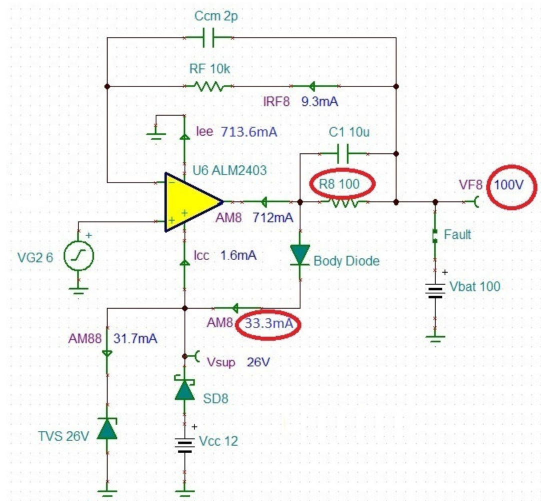

Figure 4-2. ALM2403-Q1 100V Battery Fault Protection

The same scheme may easily be employed to protect the ALM2403-Q1 output against a short to a much higher battery voltage, like 100 V, shown in Figure 4-2 above. The only difference between the two fault protections is that it now takes a higher value series power output resistor, R8, to properly limit the current under fault condition. Nevertheless, since the 100Ω series output resistor is similarly bypassed by the same 10uF capacitor, C1, the normal resolver operation of the circuit is hardly effected and thus almost identical as in the case shown in Figure 4-1. It should be noted that the output resistor bypass capacitor’s maximum rated voltage should be sufficient to withstand the DC voltage imposed across it during a fault condition.

The only other consideration of the effects of adding a large series output resistor paralleled with 10uF capacitor inside the feedback loop has to do with their effect on the modified open-loop output impedance, Zo, which controls the stability of the circuit while driving complex loads. However, as may be seen in the simulation of Zo vs frequency graph shown in Figure 4-3, the R||C inclusion inside the feedback loop hardly makes any difference especially at the 10kHz frequency typically used in most automotive resolver applications. Thus, the circuit is capable of driving the same complex loads as in the case with no additional R||C fault protection circuitry.

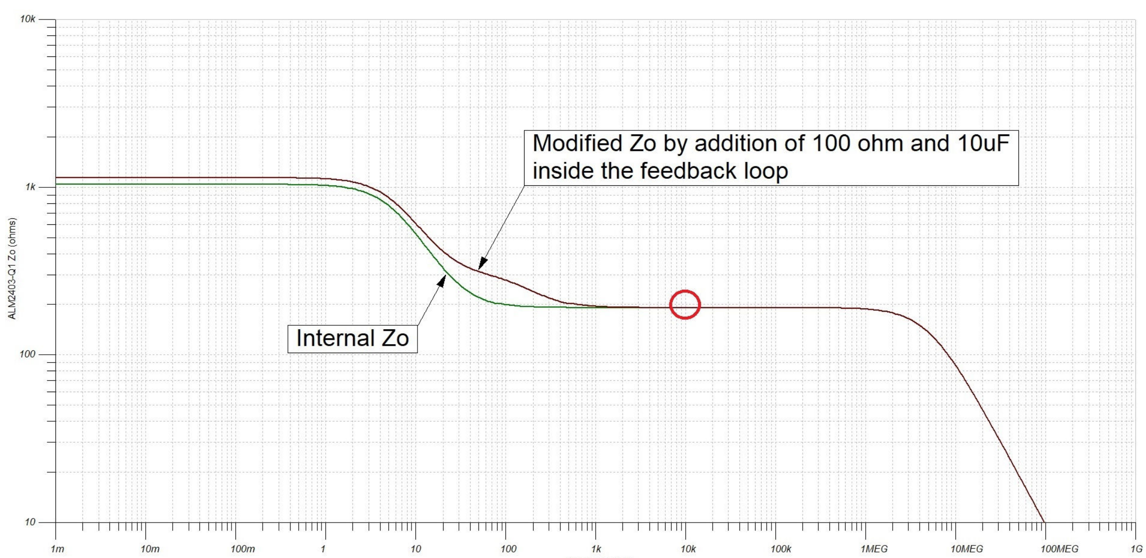

Figure 4-3. ALM2403-Q1 Open-Loop Output Impedance

5 Summary

This application report discussed several schemes that may be employed at the PCB level under various circuit conditions in order to prevent ALM2402F-Q1 and ALM2403-Q1 from over-voltage and/or over-current related damage. Since the amplifiers used in excitation of primary coil in resolver applications require to be powered from sub-regulated supply voltage in order to minimize power dissipation inside the package, this may lead to fault condition damaging the part. For that reason, amplifiers used in the automotive resolver applications must be protected with the external circuitry against a possible damage resulting from accidental shorting of the amplifier output to a battery or any other voltage source higher than the supply voltage, Vcc, used to power the op amps.

Hence, depending on the exact details of the application potential fault conditions, there are a variety of ways to prevent damage to the part:

- In case of battery voltage being within the part's absolute maximum rated voltage, using a simple blocking diode allows Vsup being pulled up by Vbat without damage
- With Vbat just a few volts above the absolute maximum rated voltage of the part, adding blocking diode, TVS and a small output resistor to limit the current through internal body diode to a safe level prevents damage
- For a battery voltage much higher than the part's absolute maximum rated voltage, using a small output resistor while diverting the high current through the external Schottky and TVS diodes may solve the potential problem but it is a bulky and costly solution
- In case of Vbat much higher than the absolute maximum rated voltage of the part, one may also use a large output resistor to limit the current through body diode to a safe level but this requires a large increase in the supply voltage that during resolver normal operation results in the loss of power efficiency
- Therefore, with a battery voltage much higher than part's absolute maximum rated voltage, an alternative approach is to add a large series output resistor inside the feedback loop to limit the current through body diode under fault condition but bypass it with a large non-polarized capacitor, as shown in Figure 4-1 and Figure 4-2, which eliminates the voltage drop across the output resistor under normal operation and thus maintains high power efficiency due to lower required supply voltage

All of the above schemes must be carefully considered in terms of their effectiveness, cost, board space and power efficiency before optimal solution may be chosen based on the potential fault conditions specific to the application. Even though this application note addresses only a single supply conditions found in most automotive resolver circuits, a similar protection schemes may be implemented in a dual supply applications against shorts to voltages below the negative rail. Likewise, similar schemes may be used more broadly to protect other analog IC's from various fault conditions caused by accidental shorting of its output to voltages beyond supplies used to power it.