Application Note

Increased Accuracy and Performance with Integrated High Voltage Resistor Isolated Amplifiers and Modulators

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ABSTRACT

This application note introduces the new AMC038x devices, galvanically isolated amplifiers and modulators with integrated resistive dividers for high-voltage sensing, and highlights the benefits and common use cases.

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1 Introduction

As high voltage automotive and industrial designs evolve, the need for precise, safe, and power-efficient galvanically isolated voltage sensing designs intensify. The AMC038x product family is a group of isolated amplifiers and modulators with increased accuracy, enhanced integration, and greater functionality that can meet these requirements. Designed with integrated high voltage (HV) resistors, these devices are a significantly reduced design size contrasted to the conventional design using an external resistive divider. External high voltage resistive dividers can be large and costly to step the voltage down to a 1V or 2V level. Furthermore, the integrated resistors have very low temperature and lifetime drift in comparison to discrete resistors. This allows the AMC038x products to achieve better than 1% accuracy over temperature and lifetime without the need for calibration.

2 High Voltage Resistor Isolated Amplifiers and Modulators Advantages

The AMC038x product family provides many benefits over the standard 2V input with external resistor divider voltage sensing devices, including improved accuracy and reduced board space.

2.1 Space Savings

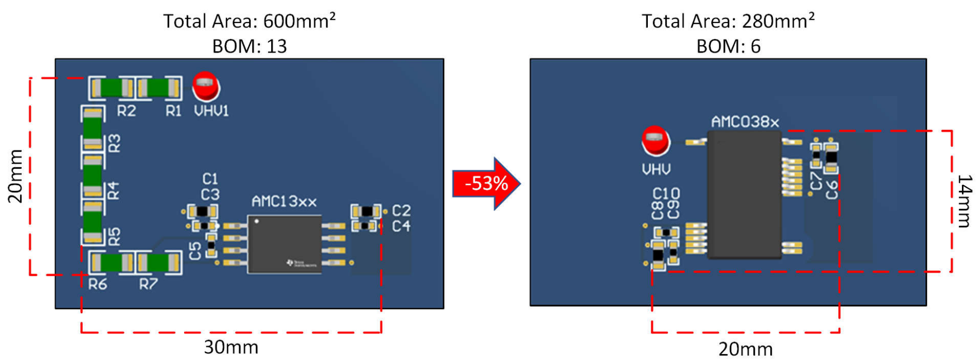

Figure 2-1. Board Space Savings

Current discrete high voltage resistors can consume a significant portion of space on PCB. Typically, voltage drops across a single resistor are limited by manufacturers and customers prefer using smaller footprint resistors due to board-level reliability concerns. Given this, a system can need as many as 15 HV resistors to step down the voltage and maintain the system's isolation ratings. By contrast, the AMC038x product family integrates HV resistors into the device which equates to a simpler, smaller design. This offers 8mm creepage and clearance distance between the HV input and the next closest pin. As demonstrated in Figure 2-1, this is a design size reduction of over 50% and decreases the BOM count significantly.

2.2 Improved Temperature and Lifetime Drift of Integrated HV Resistors

Along with space saving benefits, the integration of the HV resistive divider also increases accuracy. Previous designs with external resistors have higher temperature and lifetime drifts; the elimination of external resistors eliminates a majority of the total error. More specifically, the temperature drifts of external resistors can drift apart, compounding over time. Ordinarily, external resistor dividers use HV resistors in the upper part of the divider and low voltage (LV) resistors in the lower part of the divider. These LV resistors are frequently of a different type, construction, or material. An integrated resistive divider uses the same material for both the upper and lower resistors, which results in a very low temperature coefficient. Any remaining error of the resistive divider is then calibrated out at production, practically eliminating the resistive divider error entirely. Consider the following example:

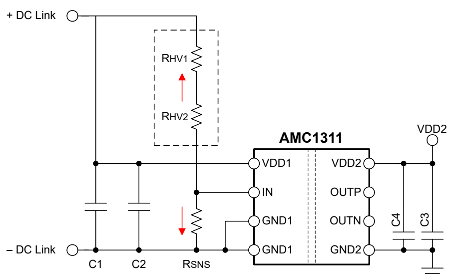

Figure 2-2. External Resistor Design

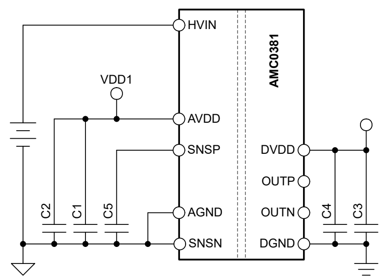

Figure 2-3. Integrated Resistor Design

External Resistor Worst Case Drift Error:

$$50ppm/°C(R_{HV1}/R_{HV2}) - (-50ppm/°C)(R_{SNS}) + 40ppm/°C(AMC1311\,Gain\,Error\,Drift) = 140ppm/°C \quad (1)$$

$$Drift\ Error\ over\ Temperature\ \% = 140ppm/°C \times 100°C = 1.4\% \quad (2)$$

Integrated Resistor Worst Case Drift Error:

$$40ppm/°C(AMC0381\,Gain\,Error\,Drift) \quad (3)$$

$$Drift\ Error\ over\ Temperature\ \% = 40ppm/°C \times 100°C = 0.4\% \quad (4)$$

As the external resistors can shift in opposite directions, this amounts to over 2/3 of the total signal chain error; an additional 1%. This makes it challenging for external resistor designs to achieve <1% accuracy over temperature and lifetime unlike the HV integrated resistor products.

2.3 Accuracy Results

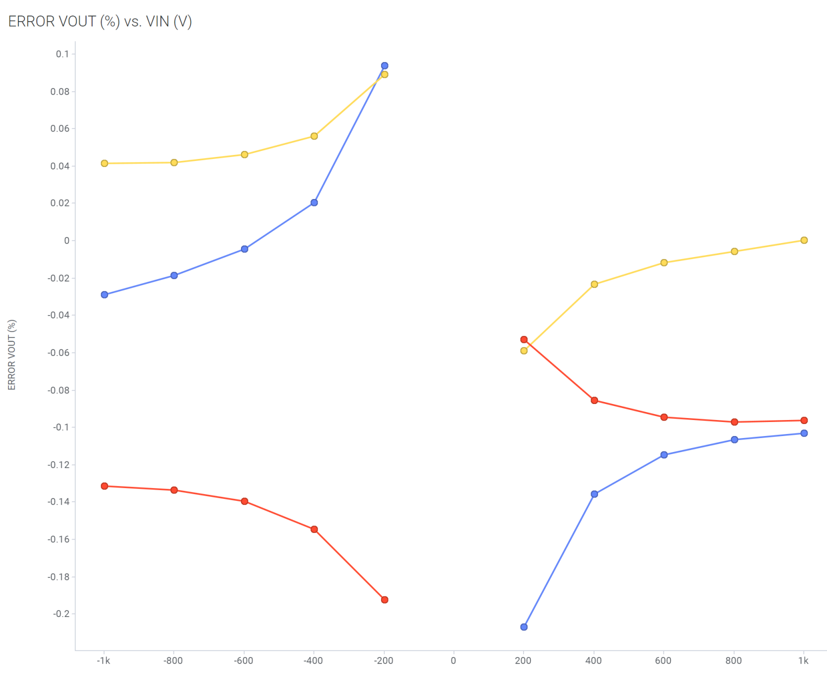

Figure 2-4. Total Output Referred Error Percentage vs. Input Voltage

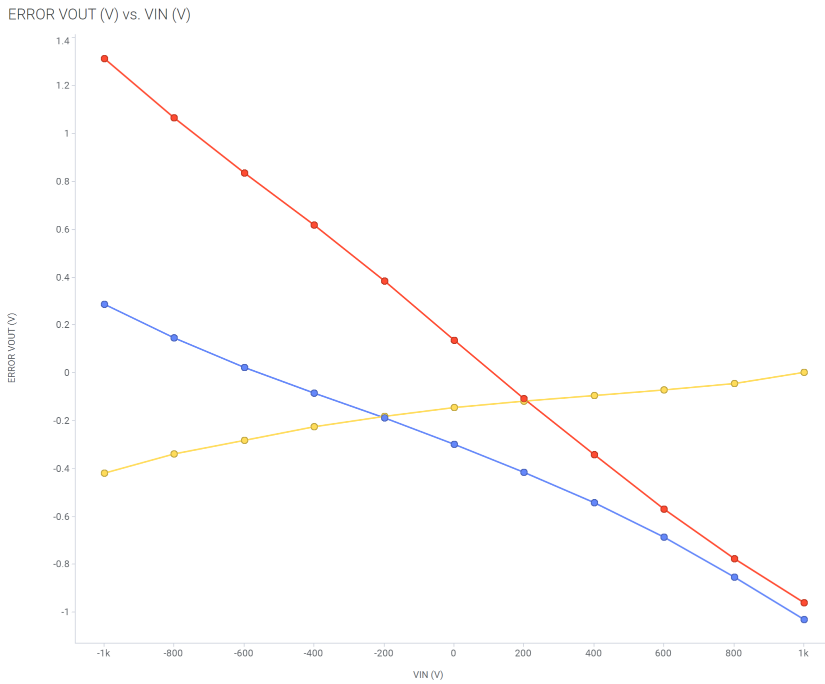

Figure 2-5. Total Output Referred Error Voltage vs. Input Voltage

To illustrate, Figure 2-4 and Figure 2-5 show the typical accuracy of the AMC038x devices over temperature. The figures show that the AMC038x delivers better than 0.4% accuracy above 100V and that 0.5V absolute error below 100V input can be achieved over temperature without system level calibration. Saving the calibration routine reduces production cost in implementing precise voltage measuring applications.

Figure 2-6. AMC038x Thermal Results: 12.5MΩ

Additionally, the AMC0381D10 thermal results demonstrate the steady performance of the device family at very high voltages. At 1000V, the θ JA thermal resistance of the package is 107°C/W and expects a temperature increase of 8°C which matches well with lab measurements. This is more than tolerable and confirms safe performance also at elevated ambient temperatures.

2.4 Fully Integrated Resistors vs. Additional External Resistor Example

Accurate voltage measurement and performance over temperature is crucial in onboard charger (OBC) applications. Achieving full state of charge on the battery is necessary for the battery to fully charge after years of use. Ergo, increased accuracy and low lifetime drift directly contribute to the continued success of these systems. These principles can extend to other HEV, Energy Infrastructure, and Motor Drive applications as well.

Some applications can alternatively consider including an external resistor to manually adjust the gain of the internal resistor divider. This is feasible; however, the caveat is reintroducing temperature drift and gain error that is virtually foregone when using integrated resistor devices. With integrated resistors, the gain drift of the HV and LV resistors can drift in the same direction and remain stable over temperature, effectively going unmeasured. When introducing an external resistor, R_{EXT}, the gain drift of the internal resistors and R_{EXT} can shift in opposite directions in the worst case and add secondary error to the system. For example, if a user wanted to sense 1200V on a 1000V device, the user can consider the following demonstration:

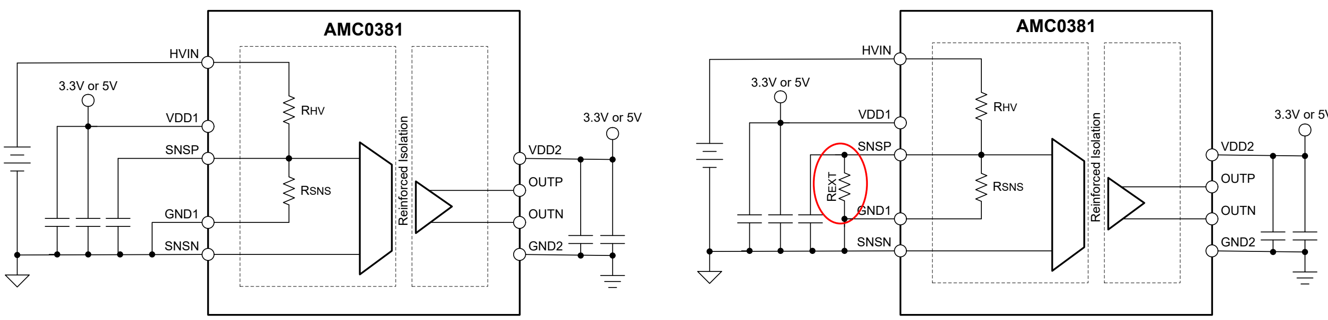

Figure 2-7. Gain Error Resistor Divider Variation Schematics

Case 1: Sensing 1000V on a 1000V Device (AMC0381R10):

For 1000V Devices: R_{HV} = 12.5MΩ; R_{SNS} = 12.5kΩ

Integrated resistors have a tolerance of ±20%. Both the HV and LV resistors, R_{HV} and R_{SNS}, drift in the same direction.

Nominal Resistor Divider Voltage at SNSP Pin:

$$V_{NOM} = V_{PEAK} \times \frac{R_{SNS}}{R_{HV} + R_{SNS}} \tag{5}$$

$$V_{NOM} = 1000V \times \frac{12.5k\Omega}{12.5M\Omega + 12.5k\Omega} = 0.999V \tag{6}$$

Maximum Resistor Divider Voltage at SNSP Pin:

$$V_{MAX} = V_{PEAK} \times \frac{R_{SNS + 20\%}}{R_{HV + 20\%} + R_{SNS + 20\%}} \tag{7}$$

$$V_{MAX} = 1000V \times \frac{15.0k\Omega}{15.0M\Omega + 15.0k\Omega} = 0.999V \tag{8}$$

Gain Error Output Referred:

$$V_{GAIN\ ERROR\ OUTPUT} = (V_{MAX} - V_{NOM}) \times V_{OUTPUT} \tag{9}$$

$$V_{GAIN\ ERROR\ OUTPUT} = (0.999V - 0.999V) \times 2V = 0V \tag{10}$$

$$Gain\ \ Error\ \ \% = \frac{V_{MAX} - V_{NOM}}{V_{NOM}} \times 100 \tag{11}$$

$$Gain\ \ Error\ \ \% = \frac{0.999V - 0.999V}{0.999V} \times 100 = \mathbf{0\,\%} \tag{12}$$

Not maximizing full scale input range can result in the offset error contributing to a larger portion of the full scale error. Please refer to the isolated voltage sensing calculator for more information.

Case 2: Sensing 1200V using a 1000V Device (AMC0381R10):

For 1000V Devices: R_{HV} = 12.5MΩ; R_{SNS} = 12.5kΩ

This design requires including an external resistor, R_{EXT}, from SNSP to AGND. This can introduce secondary error to the system and is unadvised. The absolute maximum ratings of the device must not be exceeded.

$$\frac{R_{EXT} \parallel 12.5k\Omega}{12.5M\Omega + R_{EXT} \parallel 12.5k\Omega} = \frac{1}{1200} \tag{13}$$

$$R_{EXT} = 62.8k\Omega \tag{14}$$

Integrated resistors have a tolerance of ±20% and external resistors have a tolerance of 0.1%. In the worst case scenario, R_{EXT} can drift in the opposite direction of R_{HV} and R_{SNS}.

Nominal Resistor Divider Voltage with External Resistor at SNSP Pin:

$$V_{NOM} = V_{PEAK} \times \frac{R_{SNS} \parallel R_{EXT}}{R_{HV} + R_{SNS} \parallel R_{EXT}} \tag{15}$$

$$R_{SNS} \parallel R_{EXT} = \frac{12.5k\Omega \times 62.8k\Omega}{12.5k\Omega + 62.8k\Omega} = 10.4k\Omega \tag{16}$$

$$V_{NOM} = 1200V \times \frac{10.4k\Omega}{12.5M\Omega + 10.4k\Omega} = 1.00V \tag{17}$$

Maximum Resistor Divider Voltage with External Resistor at SNSP Pin:

$$V_{MAX} = V_{PEAK} \times \frac{R_{SNS} - 20\% \parallel R_{EXT} + 0.1\%}{R_{HV} - 20\% + R_{SNS} - 20\% \parallel R_{EXT} + 0.1\%} \tag{18}$$

$$R_{SNS} - 20\% \parallel R_{EXT} + 0.1\% = \frac{10.0k\Omega \times 62.9k\Omega}{10.0k\Omega + 62.9k\Omega} = 8.63k\Omega \tag{19}$$

$$V_{MAX} = 1200V \times \frac{8.63k\Omega}{10.0M\Omega + 8.63k\Omega} = 1.03V \tag{20}$$

Gain Error Output Referred:

$$V_{GAIN\ ERROR\ OUTPUT} = (1.03V - 1.00V) \times 2V = 0.069V \tag{21}$$

$$Gain\quad Error\quad \% = \frac{1.03V - 1.00V}{1.00V} \times 100 = \mathbf{3.44\%} \tag{22}$$

Using the integrated resistor devices as is does not incorporate any measurable gain drift. Adding an external resistor to manually adjust the gain of these devices can introduce an additional worst case scenario gain drift error of 3.44% to the total system error and is therefore not recommended.

2.5 Device Selection Tree and AC/DC Common Use Cases

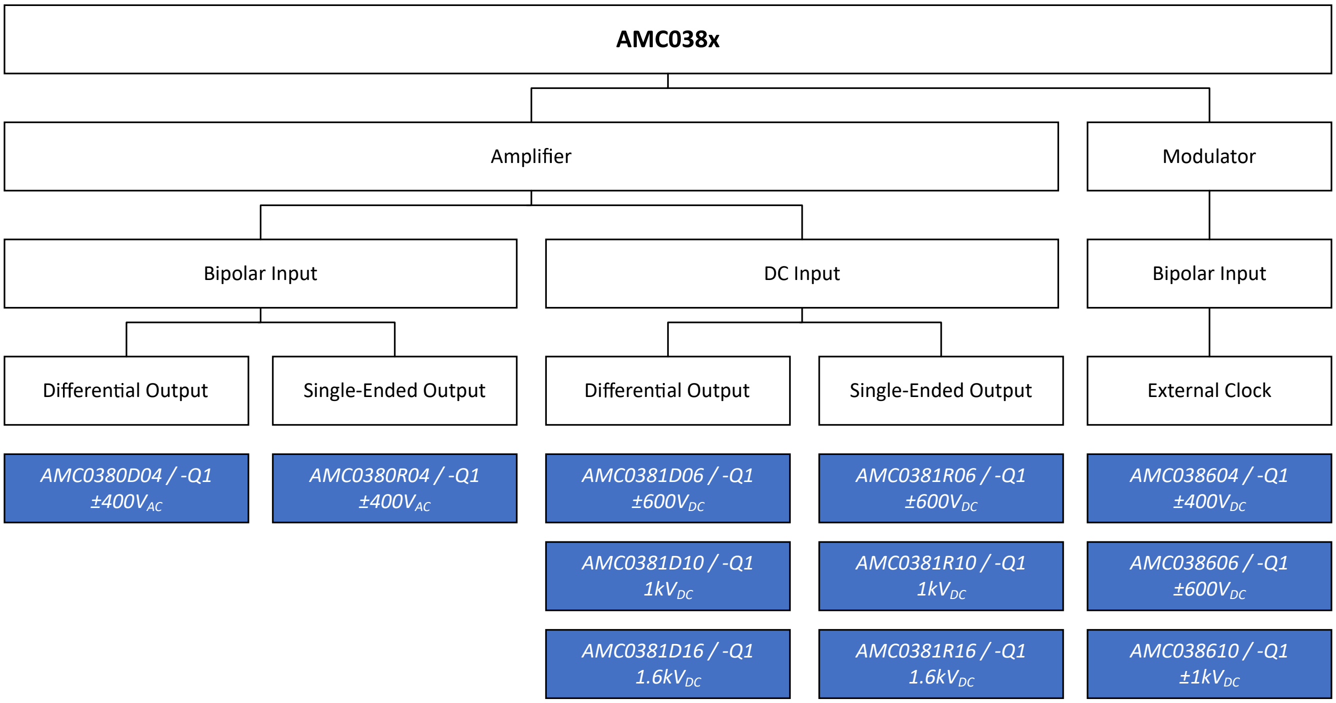

Figure 2-8. AMC038x Selection Tree

Table 2-1. AC Voltage Sensing Use Cases

Use Case	Nominal Voltage Range	Recommended Divider Ratio
Phase-to-Neutral AC Line Voltage Sensing	$120V_{RMS}$ (±10%) / $190V_{PK}$	400:1
	$230V_{RMS}$ (±10%) / $360V_{PK}$	400:1
Phase-to-Phase AC Line Voltage Sensing	$400V_{RMS}$ (±10%) / $620V_{PK}$	600:1
	$690V_{RMS}$ (±10%) / $1070V_{PK}$	1000:1

Table 2-2. DC Voltage Sensing Use Cases

Use Case	Nominal Voltage Range	Recommended Divider Ratio
DC Link derived from Single Phase $120V_{AC}$	Up to 400V + 10%	400:1
DC Link derived from Single Phase $230V_{AC}$	Up to 600V + 10%	600:1
DC Link derived from 3-Phase $230/400V_{AC}$	Up to 1000V + 10%	1000:1
ESS / Solar Applications with 1500V+ String Voltage	Up to 1600V + 10%	1600:1

The AM038x devices come with four fixed ratio options allowing for four different input voltage ranges: 400V, 600V, 1000V, and 1600V. These devices also come with three different output types: differential analog output, single-ended analog output, and digital bit stream modulator output (Figure 2-8). The devices support AC voltage sensing with the bipolar input option (Table 2-1) and DC voltage sensing with the DC input option (Table 2-2). For more information on specific application cases, please see *Maximizing Power Conversion and Motor Control Efficiency With Isolated Voltage Sensing*, marketing white paper.

3 Summary

With reduced size, increased accuracy, and easy integration, the AMC038x product family is a potent design for a variety of applications. The integrated high voltage resistor enables industry leading accuracy of <1%, a 50% smaller PCB design size, and removes the need for end of line calibrations. Such improvements bolster the ability of these isolated amplifiers and modulators to be well suited for HEV, energy infrastructure, and motor drive applications.

4 References

- Texas Instruments, *AMC038XEVM Evaluation board*.
- Texas Instruments, *Maximizing Power Conversion and Motor Control Efficiency With Isolated Voltage Sensing*, marketing white paper.
- Texas Instruments, *Addressing High-Volt Design Challenges w/ Reliable and Affordable Isolation Tech (Rev. C)*, marketing white paper.
- Texas Instruments, *Isolated Voltage Sensing in AC Motor Drives*, analog design journal.
- Texas Instruments, *SBAR013 Isolated Amplifier Voltage Sensing Excel Calculator*.

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