Application Note

Isolated Amplifiers With Differential, Single-Ended Fixed Gain and Ratiometric Outputs for Voltage Sensing Applications

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ABSTRACT

Texas Instruments introduces the AMC0xxxD/S/R product family, a new portfolio of isolated AC and DC voltage sensing amplifiers with options of a differential output, single-ended fixed gain output, and single-ended ratiometric output.

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1 Introduction

Several automotive systems and industrial systems operate at high voltages in harsh environments, making high-performance isolated voltage sensing designs critical for maintaining system efficiency and long-term reliability. Selecting the correct isolated amplifier requires many considerations, such as system accuracy, PCB space, and cost for the system that the device is being implemented into. To design systems with improved accuracy at a reduced design size and cost, while still meeting performance requirements, Texas Instruments introduces the AMC0xxxD/S/R product family, a new portfolio of isolated AC and DC voltage sensing amplifiers with options of a differential output, single-ended fixed gain and ratiometric output.

2 Overview of Differential, Single-Ended Fixed Gain and Ratiometric Outputs

2.1 Isolated Amplifiers with Differential Output

Differential output amplifiers are widely desired in systems requiring high accuracy, noise immunity, and designed for signal integrity. The differential output amplifier provides two outputs: a positive and a negative output that are equal in magnitudes but opposite in phase. With two equally balanced output signals, the differential output amplifier has the ability to handle ground shifts without signal degradation, making the differential output amplifier designed for high-precision and performance applications. Because of the amplifier's insensitivity to ground shifts, these devices enable routing for the output signal over long distances while still maintaining signal integrity.

There are a few design considerations with a differential output amplifier. One of these considerations is PCB layout. Having poor PCB layout can compromise the amplifier’s ability to maintain an accurate common-mode output voltage. Since differential amplifiers rely on both the inverting and non-inverting paths, maintaining symmetry by making sure equal PCB trace lengths for both output lines is essential for minimizing output errors. There are different design options for configuring the differential output amplifier to an analog-to-digital converter (ADC). Option one, as shown in Figure 2-1, is a configuration that directly interfaces the differential output amplifier to a differential input ADC. However, processors such as the MSP430 and the C2000 have embedded single-ended input ADC. This consideration creates the need to convert from the differential signal to a single-ended signal to interface directly with the ADC. The best design for outputting to single-ended input ADC has been the conversion of the differential to single-ended output, as shown as Option 2 in Figure 2-1.

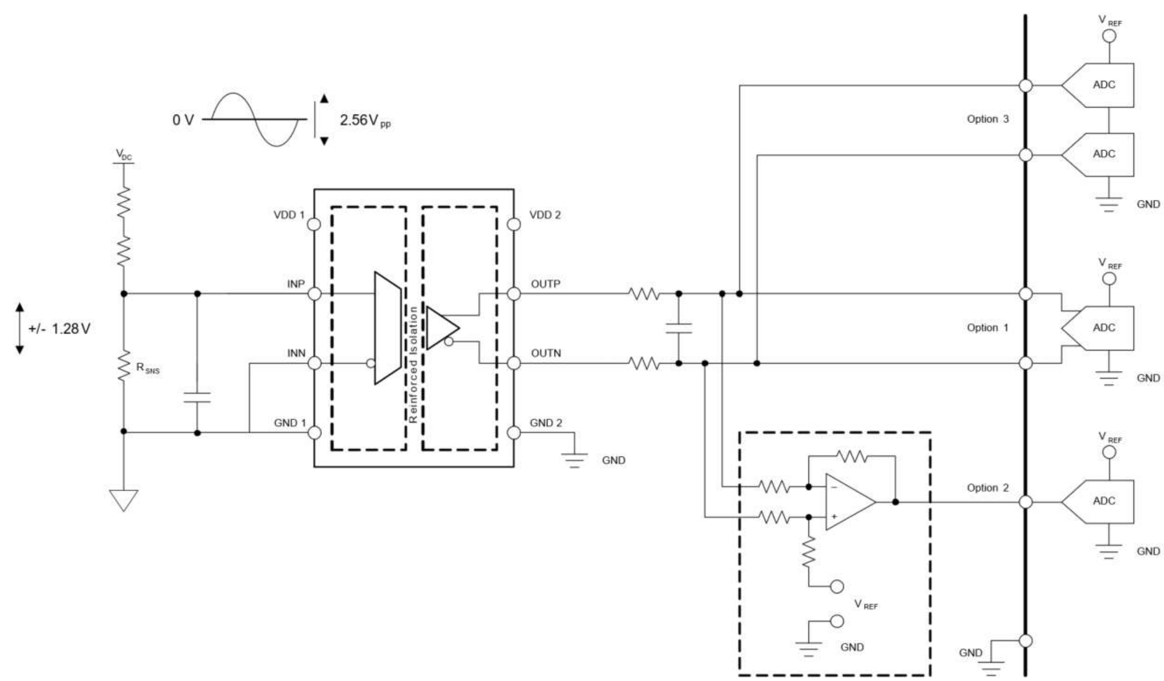

Figure 2-1. Differential Output Configuration

This configuration introduces an additional amplifier, which allows for the conversion of a differential signal to a single-ended signal that outputs directly to the ADC. For more information about interfacing a differential to single-ended output stage, see, *Isolated Current-Sensing Circuit With ±250-mV Input Range and Single-Ended Output Voltage*, analog engineer's circuit. Another design is using two single-ended input ADC and subtracting the values in the MCU, as shown as Option 3 in Figure 2-1. However, Option 3 has the drawback of compound error and the need for an extra ADC, which makes this option less attractive.

2.2 Isolated Amplifiers With Single-Ended, Fixed-Gain Output

The new product family offers alternative devices for compact designs that do not benefit from the differential output. The differences between a differential and single-ended output amplifier can be summarized primarily by how these amplifiers handle noise, output signals, and the design characteristics. The new device family introduces two options of single-ended amplifiers: the single-ended amplifier with fixed gain and the single-ended amplifier with ratiometric gain.

The single-ended fixed gain amplifier is widely desired due to the ease of use and cost-effectiveness. The single ended fixed gain amplifier can output a single-ended signal that is proportional to the input voltage of the amplifier. As this device was designed to interface directly with a single-ended input ADC, the additional differential to single-ended amplifier conversion stage, as previously referenced in Figure 2-1, is no longer necessary. Therefore, this design requires less components which enables a smaller design size and lower BOM cost, making this device designed for compact systems.

One design consideration for the single-ended fixed gain devices is the device's ground noise sensitivity. Fluctuations to the ground potential can bring distortions to the output signal by introducing noise or error to the signal, which can be eliminated with proper grounding and component selection. If not considered, this can potentially decrease your signal to noise ratio and decrease overall performance. Another design consideration is the voltage applied to the reference (REFIN) pin of the device - the pinout of the device is shown in Figure 2-4 . Figure 2-2 shows the input-to-output transfer characteristic for the AMC0x11S device, which is the single-ended fixed gain output device that has an input voltage range of 0-2.25V.

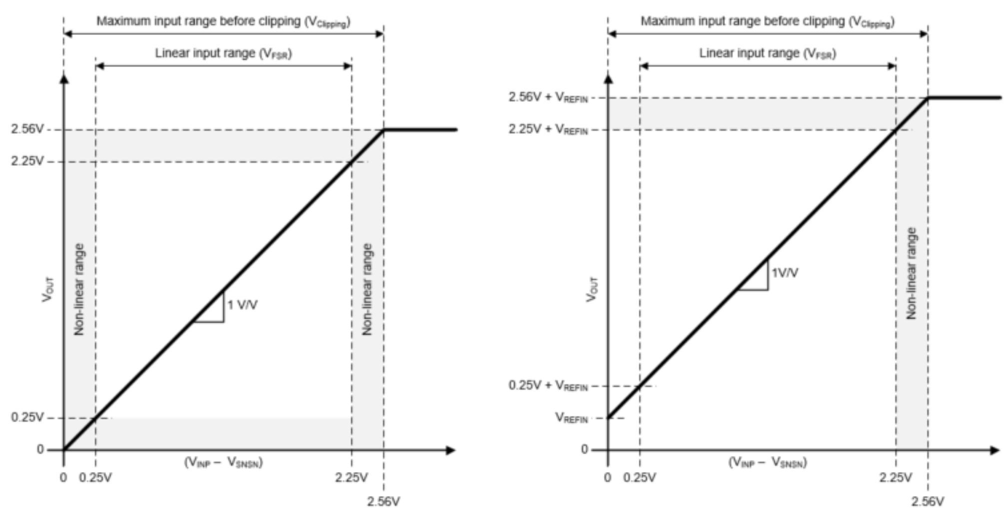

Figure 2-2. Input-to-output Transfer Characteristic for AMC0x11S

The left image shows the case in which REFIN is shorted to GND2. The right image shows when V_{REFIN} = 250mV. Supplying a voltage to REFIN that is ≥250mV extends the linear input voltage range to 0V. The output buffer requires a minimum headroom of 250mV for linear operation. Therefore, with REFIN shorted to GND2, the device shows non-linear behavior for input voltages near 0V. The equation for the output voltage of AMC0x11S device is:

Output Voltage of AMC0x11S:

$$V_{OUT} = (V_{INP} - V_{SNSN}) + V_{REFIN}. \quad (1)$$

For the AMC0x30S device, which is the single-ended, fixed gain device that has an input voltage range of ±1V, the output is directly proportional to the input voltage (V_{IN}), where REFIN is referred to GND2. The output can be defined by the following equation:

Output Voltage of AMC0x30S:

$$V_{OUT} = (V_{INP} - V_{SNSN}) + V_{REFIN}. \quad (2)$$

Figure 2-3 shows the input-to-output transfer characteristic for the AMC0x30S device. For input voltages below –1V and above +1V, the output of the device continues to follow the input but with reduced linearity performance.

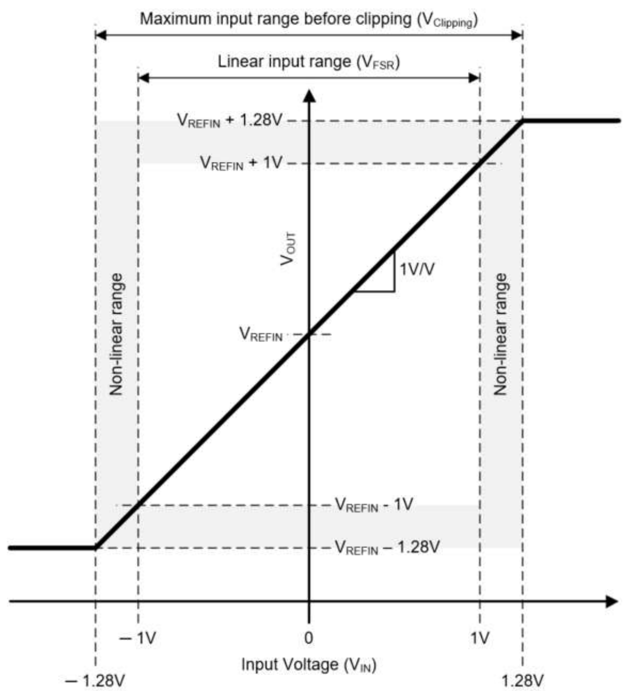

Figure 2-3. Input-to-output Transfer Characteristic for AMC0x30S

2.3 Isolated Amplifiers With Single-Ended, Ratiometric Output

To provide a comprehensive portfolio of devices that covers the need for high performance, cost-efficient, and smaller system sizes, the new product family includes options of single-ended devices with a ratiometric output. The single-ended ratiometric output devices of the new product family are designed to adjust the gain in proportion to the reference voltage of the ADC. One disadvantage of the fixed gain output is that the fixed gain can only provide a 2V output swing. Systems with a 5V analog IO can only use 50% of the ADC input range, therefore losing 1 bit of resolution on the measurement. The ratiometric output makes sure that the amplifier fully utilizes the ADC dynamic range, thereby maximizing the resolution of the measurement. Figure 2-4 and Figure 2-5 refer to two different configurations for the ratiometric devices:

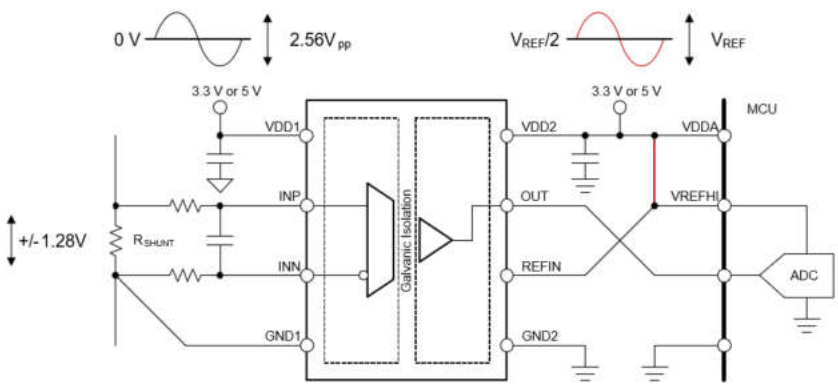

Figure 2-4. REF Derived from Supply

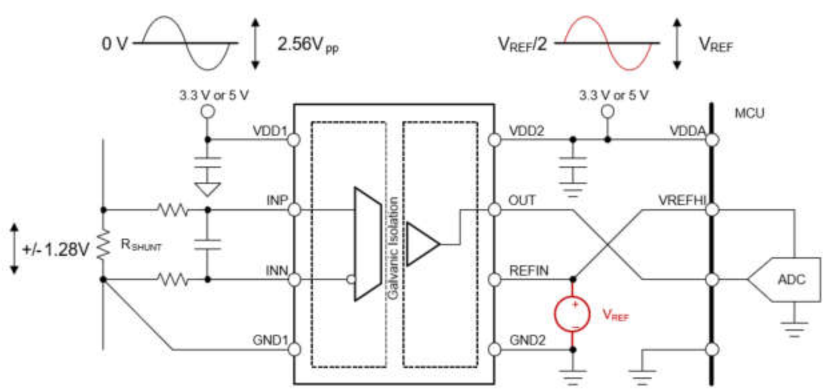

Figure 2-5. REF Supplied by External Reference

Having the reference voltage derived from the power supply rail can contribute to lower costs, as there can be less components involved. However, having the reference voltage derived from an external reference can lead to lower noise.

The design of the single-ended ratiometric output device makes the device insensitive to the value of the reference voltage and tolerant of inaccuracy and AC disturbance. Because of the device's ability to achieve increased resolution, accuracy and stability while eliminating the need for the additional differential to single-ended amplifier stage, the ratiometric option is desired greatly for the cost savings and ability to take up less PCB space and contribute to lower BOM cost, all while meeting performance specifications.

One design consideration for the single-ended, ratiometric device is the input voltage range of the ADC. Because the ratiometric devices can support 2.75-5.5V reference voltages, the ratiometric devices are best designed for ADC with an input voltage range of 3.3V and 5V. Another design consideration for this device is routing. Because the reference voltage of both the ADC and the amplifier are proportional, the reference voltage of the ADC needs to be routed to the ratiometric device.

Figure 2-6 shows the input-to-output transfer characteristics for the AMC0x30R, which is the single-ended, ratiometric gain device that has an input voltage range of ±1V. The bipolar input device can output 50% of V_{REF} at V_{IN} = 0 due to the amplifier being biased around the midpoint of the reference voltage

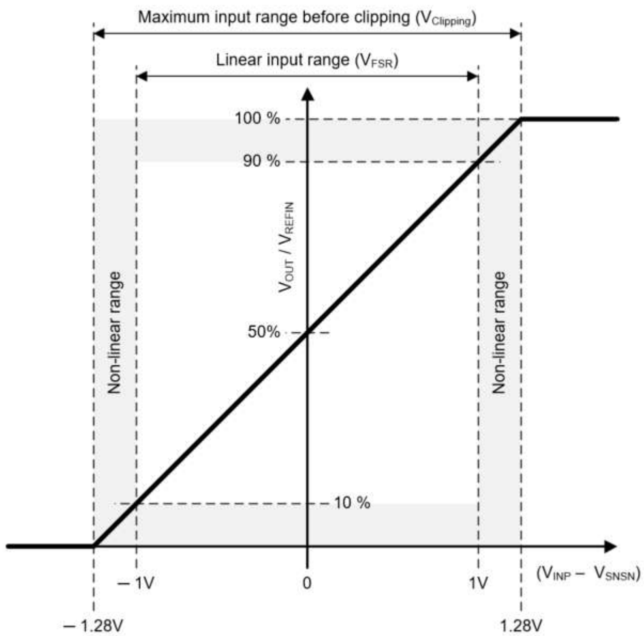

Figure 2-6. Input-to-Output Transfer Characteristic for AMC0x30R

For any input voltage within the specified linear input range, the device outputs a voltage can be defined by the following equation:

Output Voltage of AMC0x30R:

$$V_{OUT} = ((V_{INP}-V_{SNSN}) / V_{Clipping}) \times V_{REFIN} / 2 + V_{REFIN} / 2. \quad (3)$$

For input voltages below –1V and above +1V, the output of device continues to follow the input but with reduced linearity performance.

The AMC0x11R, which is the single-ended, ratiometric device that has an input voltage range of 0.13-2.25V, has an output voltage that is defined by the following equation:

Output Voltage of AMC0x11R:

$$V_{OUT} = ((V_{INP}-V_{SNSN}) / V_{Clipping}) \times V_{REFIN}. \quad (4)$$

Similar to the AMC0x11S, the AMC0x11R device shows non-linear behavior for input voltages near 0V, is shown in Figure 2-7.

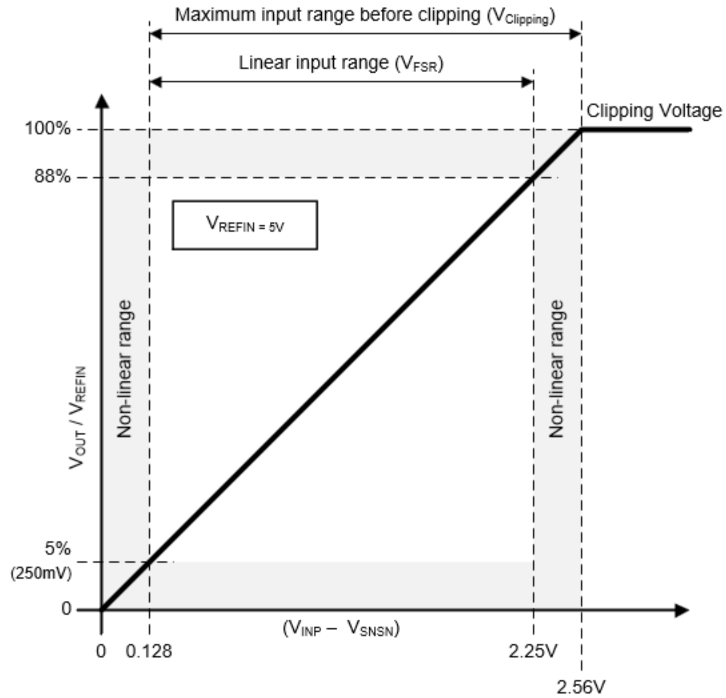

Figure 2-7. Input-to-Output Transfer Characteristic for AMC0x11R

At V_{REFIN}=5V, the minimum input voltage for linear operation is 128mV. The output is 5% of the reference, or 250mV.

The minimum input voltage for linear operation can be calculated using the following equation:

Minimum Input Voltage for Linear Operation for AMC0x11R:

$$V_{INP,\ MIN} = (250mV \times V_{Clipping}) / V_{REFIN}. \quad (5)$$

3 Application Examples

3.1 Product Selection Tree

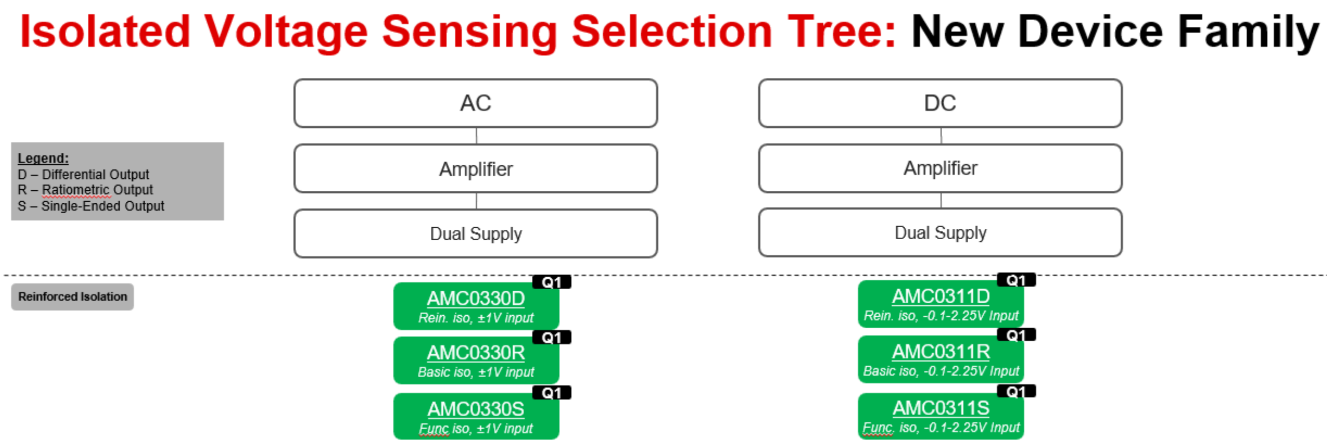

Figure 3-1. Product Selection Tree

The new product family of devices come with six options of reinforced isolated voltage sensing amplifiers, allowing for 0-2V input voltages range for DC applications and ±1V input voltage ranges for AC applications. The AMC0311D, AMC0311R, and AMC0311S devices support DC voltage sensing with the unipolar input option and the AMC0330D, AMC0330R, and AMC0330S devices support AC voltage sensing with the bipolar input option, as showcased in Figure 3-1. For more information on specific application cases, including use cases for the AC and DC voltage sensing amplifiers in power conversion and motor control topologies, please see *Maximizing Power Conversion and Motor Control Efficiency With Isolated Voltage Sensing*, marketing white paper.

4 Summary

There are many decisions to consider when selecting an isolated amplifier for voltage sensing applications. The devices in the new product family are designed to improve accuracy at a reduced design size and cost with the options of a differential output and single-ended output amplifiers.

5 References

- Texas Instruments, *DIYAMC-0-EVM Universal do-it-yourself (DIY) isolated amplifier and modulator evaluation module*.
- Texas Instruments, *Isolated Current-Sensing Circuit With ±250-mV Input Range and Single-Ended Output Voltage*, analog engineer's circuit.
- Texas Instruments, Maximizing Power Conversion and Motor Control Efficiency With Isolated Voltage Sensing, marketing white paper.
- Texas Instruments, *Addressing High-Voltage Design Challenges With Reliable and Affordable Isolation Technologies*, marketing white paper.