

High common-mode differential input voltage to $\pm 10\text{-V}$ ADC input circuit

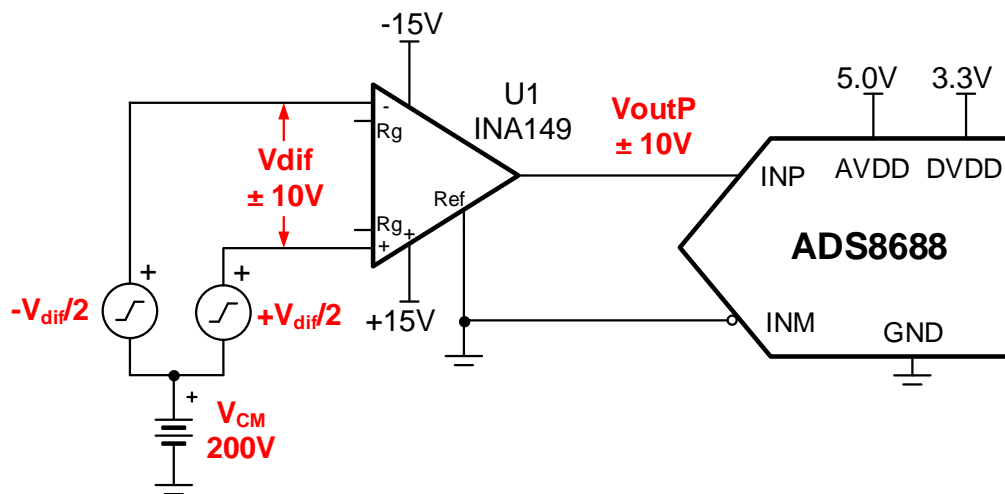
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Input	ADC Input	Digital Output ADS8688
$V_{inDiffMin} = -10.24\text{V}$	$CH_x = -10.24\text{V}$	0000 _H
$V_{inDiffMax} = +10.24\text{V}$	$CH_x = +10.24\text{V}$	FFFF _H

Power Supplies			
AVDD	DVDD	AGND	DGND
5.0V	3.3V	GND	GND

Design Description

The purpose of this cookbook is to demonstrate the advantages and disadvantages of using difference amplifiers or instrumentation amplifiers to translate a signal with a high common mode voltage (V_{cm}) to a level that the **ADS86XX** family can accept. The **ADS86XX** family **cannot** support a high V_{cm} so using a difference or instrumentation amplifier to drive the ADC solves this issue. The **INA828** device is an instrumentation amplifier with very high input impedance ($100\text{G}\Omega$), excellent DC precision, and low noise. The **INA828** can accept common-mode signals in the range of its supply voltage ($\pm 15\text{V}$). The **INA149** device is a unity-gain difference amplifier with a high input common-mode voltage range of up to $\pm 275\text{V}$, but the input impedance is lower than the **INA828** device (differential = $800\text{k}\Omega$, common mode = $200\text{k}\Omega$). The **ADS86XX** family of ADCs has an integrated analog front end (AFE) and multiplexer which makes it an ideal candidate for a **PLC (analog input module)**, **protection relay**, **grid automation**, and other various industrial applications.



Specifications

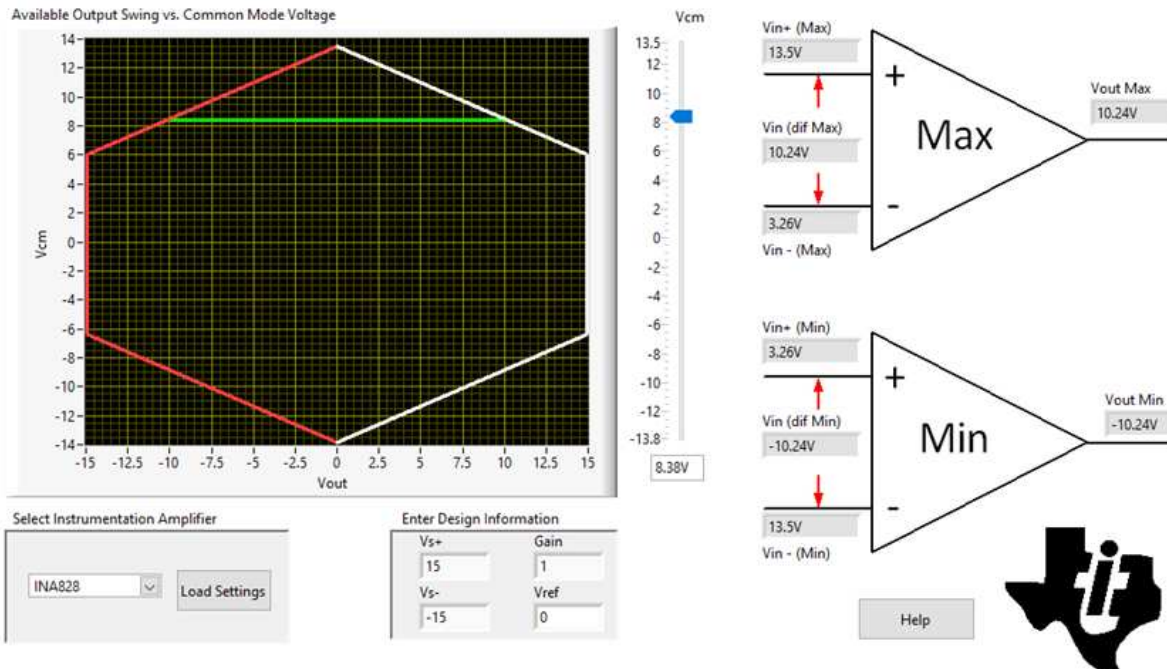
Specification	Calculated	Simulated	Measured
INA149 Common-Mode Voltage (VCM)	275V	275V	275V
INA828 Common-Mode Voltage (VCM)	8.38V	8.38V	7.5V
INA149 Integrated Noise	487 μ V	487.3 μ V	488 μ V
INA828 Integrated Noise	150 μ V	150 μ V	154 μ V

Design Notes

1. The [ADS86XX](#) family of HV SAR ADCs was selected because of the integrated analog front end and multiplexer. The integrated AFE eliminates the use of extra components to drive the ADC.
2. The [INA149](#) device was selected to provide a very high common-mode voltage ($V_{cm} = \pm 275V$).
3. Comparing the [INA828](#) device to the [INA149](#) shows that the INA828 device has high input impedance (100G Ω), and the INA149 device has lower input impedance (differential = 800k Ω , common mode = 200k Ω). Also, the INA149 device has very wide common mode ($V_{cm} = \pm 275V$) but the INA828 common mode range is limited to the supply range (for example, $\pm 15V$). In cases where high input impedance is required, the INA828 device can be used, but be careful to not violate common-mode range. Note that high input impedance is important when the sensor output impedance is high as this will create a voltage divider effect and introduce error.
4. In this example, the input signal is $\pm 10.24V$. Therefore, resistor R_g is not needed in order to set the Gain = 1 for the INA828 device. If the input signal is smaller, use the appropriate resistor value to set the gain with a proper reference voltage on reference pin to achieve an input swing that matches the input range of the ADC.
5. Check the common mode range of the instrumentation amplifier using the [Common-Mode Input Range Calculator for Instrumentation Amplifiers](#) software tool.
6. If gain is required, use 0.1% 20ppm/ $^{\circ}C$ film resistors or better for the gain setting resistor (R_g) to achieve best gain accuracy and low gain drift.

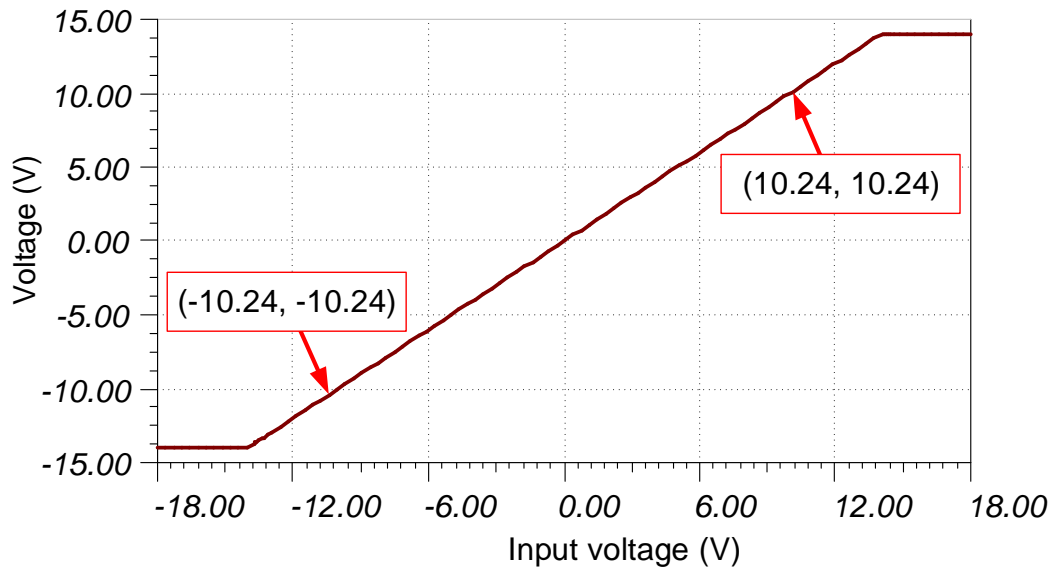
Component Selection

1. The ADS86XX can accept a single-ended input signal of $\pm 10.24\text{V}$. In this example, the input signal is $\pm 10.24\text{V}$ so no external gain set resistor is required for the INA828 device. The INA149 device is a unity gain difference amplifier so no extra components are necessary.
2. The INA828 reference voltage input is used to shift inputs to match the input range of the ADC. In this example, the ADC input range is symmetrical so the reference pin is grounded.
3. Determine if the INA828 device is violating the common-mode range by using the [Common-Mode Input Range Calculator for Instrumentation amplifiers](#). In this example, the INA828 device shows that you can achieve a maximum VCM of 8.38V with $\pm 15\text{V}$ supplies, Gain = 1, and $V_{\text{ref}} = 0\text{V}$.



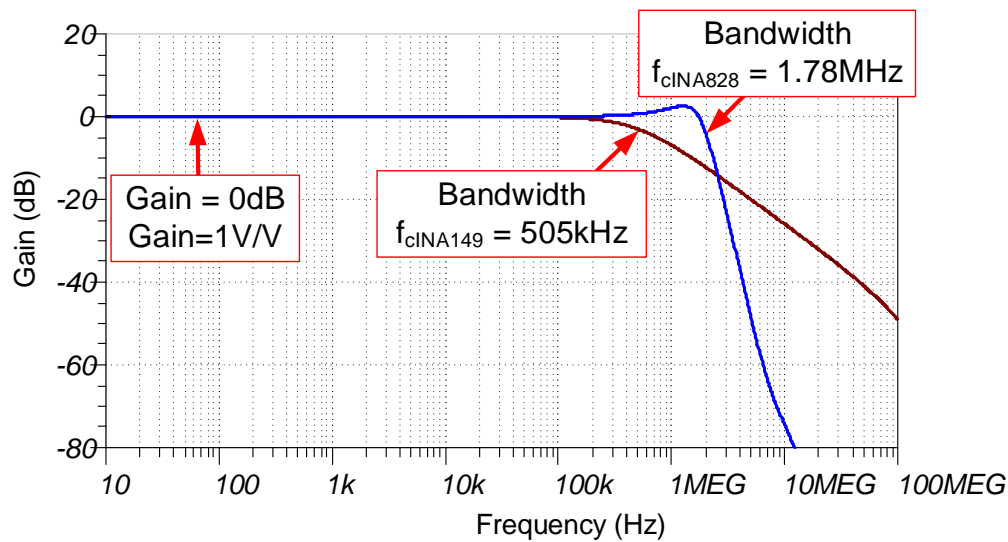
DC Transfer Characteristics

The following graphs show a linear output response for the INA149 device. The input range of the ADC is $\pm 10.24\text{V}$ so the amplifier is linear well beyond the range the ADC requires. Refer to [Determining a SAR ADC's Linear Range](#) when using instrumentation amplifiers for detailed theory on this subject.



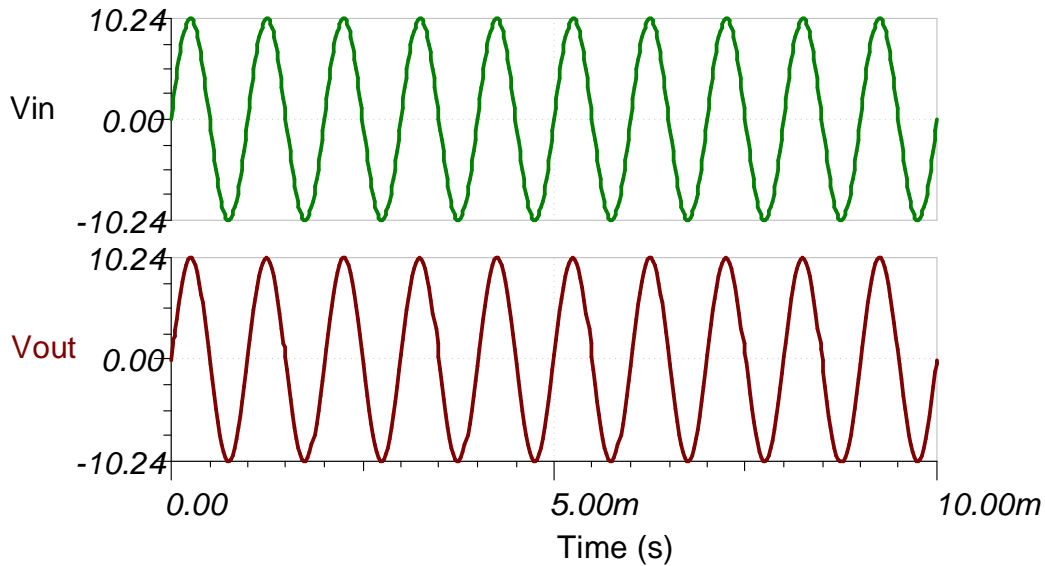
AC Transfer Characteristics

The simulated bandwidth for the INA149 device is 505kHz at gain = 1V/V, or 0dB. The simulated bandwidth for the INA828 device is 1.78MHz at a gain of 0dB. Both of the simulated bandwidths closely match their respective data sheets. See [Amplifier Bandwidth Video Series](#) for more details on this subject.

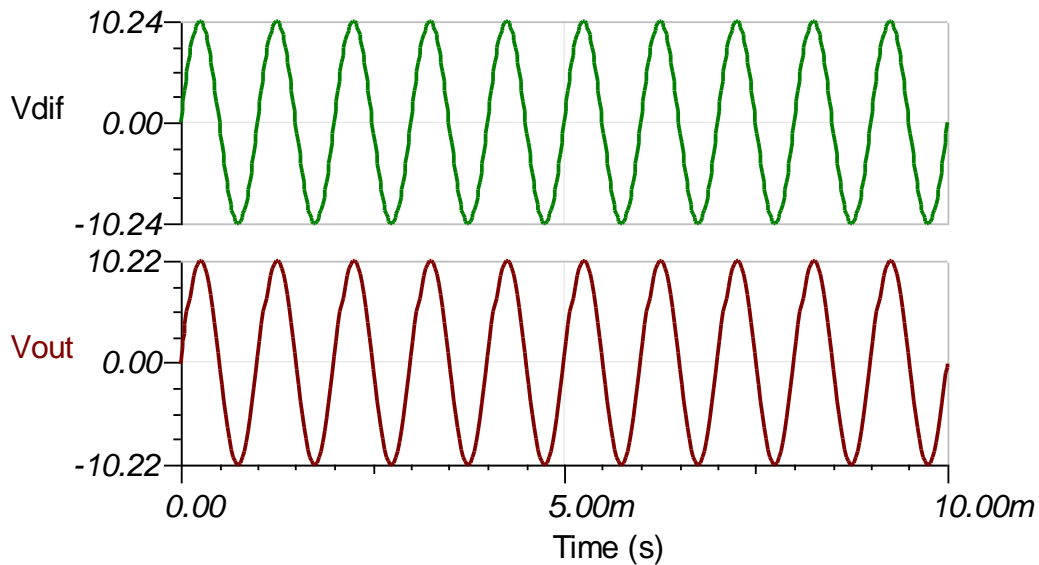


Transient ADC Input Settling Simulation

The INA149 device was simulated with a $\pm 10.24\text{-V}$ differential input and a 275-V common-mode voltage. The following TINA simulation shows the differential input as well as the single-ended output for the INA149 device. The device has no issue with a common-mode voltage of 200V .



The INA828 device was simulated with a $\pm 10.24\text{-V}$ differential input and a 7.75-V common-mode voltage. The following TINA simulation shows the differential input as well as the single-ended output for the INA828 device.



Noise Simulation

The section provides simplified noise calculations for the INA149 and INA828 devices. The simulated results closely match the calculated results. Refer to [Op Amps: Noise 4](#) for detailed theory on amplifier noise calculations, and [Calculating Total Noise for ADC Systems](#) for data converter noise.

INA149 integrated noise:

$$E_{n\text{INA149}} = e_{ni} \sqrt{f_c \cdot K_n} = (550 \text{ nV}/\sqrt{\text{Hz}}) \sqrt{505 \text{ kHz} \cdot 1.57} = 489 \mu\text{Vrms}$$

INA828 integrated noise:

$$E_{n\text{INA828}} = \text{Gain} \sqrt{e_{ni}^2 + e_{no}^2} \sqrt{f_c \cdot K_n} = (1) \sqrt{(7 \text{ nV}/\sqrt{\text{Hz}})^2 + (90 \text{ nV}/\sqrt{\text{Hz}})^2} \sqrt{1.78 \text{ MHz} \cdot 1.57} = 151 \mu\text{Vrms}$$

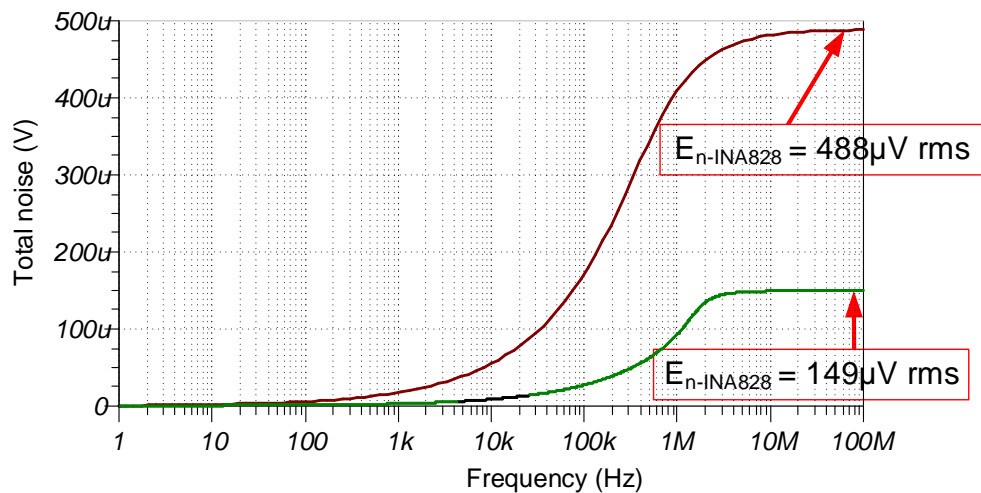
The ADS8688 device has an internal second-order 15-kHz LPF. This filter will reduce the noise from the instrumentation amplifiers significantly.

INA149 integrated noise:

$$E_{n\text{INA149}} = e_{ni} \sqrt{f_c \cdot K_n} = (550 \text{ nV}/\sqrt{\text{Hz}}) \sqrt{15 \text{ kHz} \cdot 1.22} = 74.4 \mu\text{Vrms}$$

INA828 integrated noise:

$$E_{n\text{INA828}} = \text{Gain} \sqrt{e_{ni}^2 + e_{no}^2} \sqrt{f_c \cdot K_n} = (1) \sqrt{(7 \text{ nV}/\sqrt{\text{Hz}})^2 + (90 \text{ nV}/\sqrt{\text{Hz}})^2} \sqrt{15 \text{ kHz} \cdot 1.22} = 12.2 \mu\text{Vrms}$$



Design Featured Devices

Device	Key Features	Link	Other Possible Devices
ADS86XX	16-Bit Resolution, 4-,8-Channel MUX, SPI, 500ksps sample rate, on-chip 4.096V Reference	http://www.ti.com/product/ADS8688	http://www.ti.com/adcs
INA149	500kHz BW, Very High VCM, excellent nonlinearity	http://www.ti.com/product/INA149	http://www.ti.com/amplifier-circuit/op-amps/fully-differential/overview.html
INA828	2MHz BW, Low Power 12nV/√Hz noise	http://www.ti.com/product/INA828	http://www.ti.com/inas

Design References

See [Analog Engineer's Circuit Cookbooks](#) for TI's comprehensive circuit library.

Link to Key Files

TINA source files – <http://www.ti.com/lit/zip/sbac224>.

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