High common-mode differential input voltage to ±10-V ADC input circuit

Aaron Estrada

Input	ADC Input	Digital Output ADS8688
VinDiffMin = −10.24V	CH_x = −10.24V	0000$_H$
VinDiffMax = +10.24V	CH_x = +10.24V	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 (Vcm) to a level that the ADS86XX family can accept. The ADS86XX family **cannot** support a high Vcm 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 (100GΩ), excellent DC precision, and low noise. The INA828 can accept common-mode signals in the range of its supply voltage (±15V). The INA149 device is a unity-gain difference amplifier with a high input common-mode voltage range of up to ±275V, but the input impedance is lower than the INA828 device (differential = 800kΩ, common mode = 200kΩ). 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.
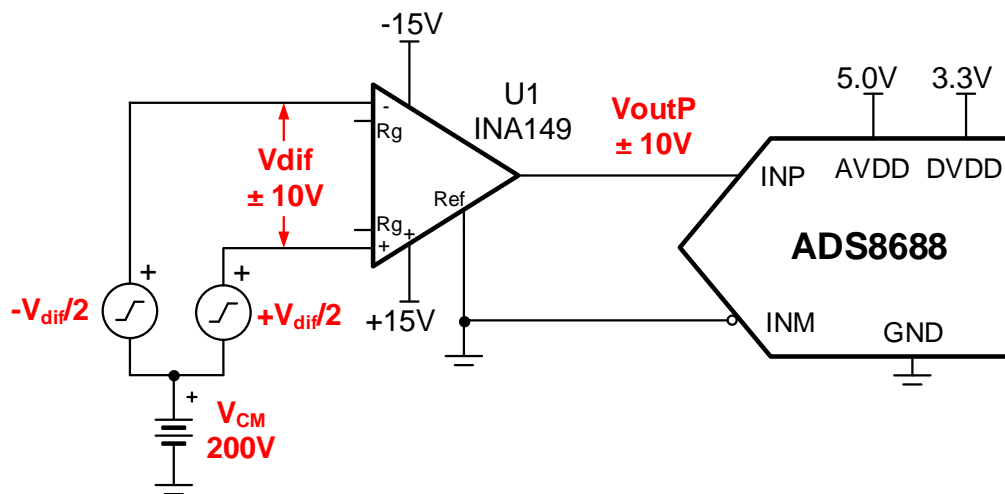
Specifications

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	487µV	487.3µV	488µV
INA828 Integrated Noise	150µV	150µV	154µV

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 (Vcm = ±275V).

3. Comparing the INA828 device to the INA149 shows that the INA828 device has high input impedance (100GΩ), and the INA149 device has lower input impedance (differential = 800kΩ, common mode = 200kΩ). Also, the INA149 device has very wide common mode (Vcm = ±275V) but the INA828 common mode range is limited to the supply range (for example, ±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 ±10.24V. Therefore, resistor Rg 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/°C film resistors or better for the gain setting resistor (Rg) to achieve best gain accuracy and low gain drift.

Component Selection

1. The ADS86XX can accept a single-ended input signal of ±10.24V. In this example, the input signal is ±10.24V 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 ±15V supplies, Gain = 1, and Vref = 0V.
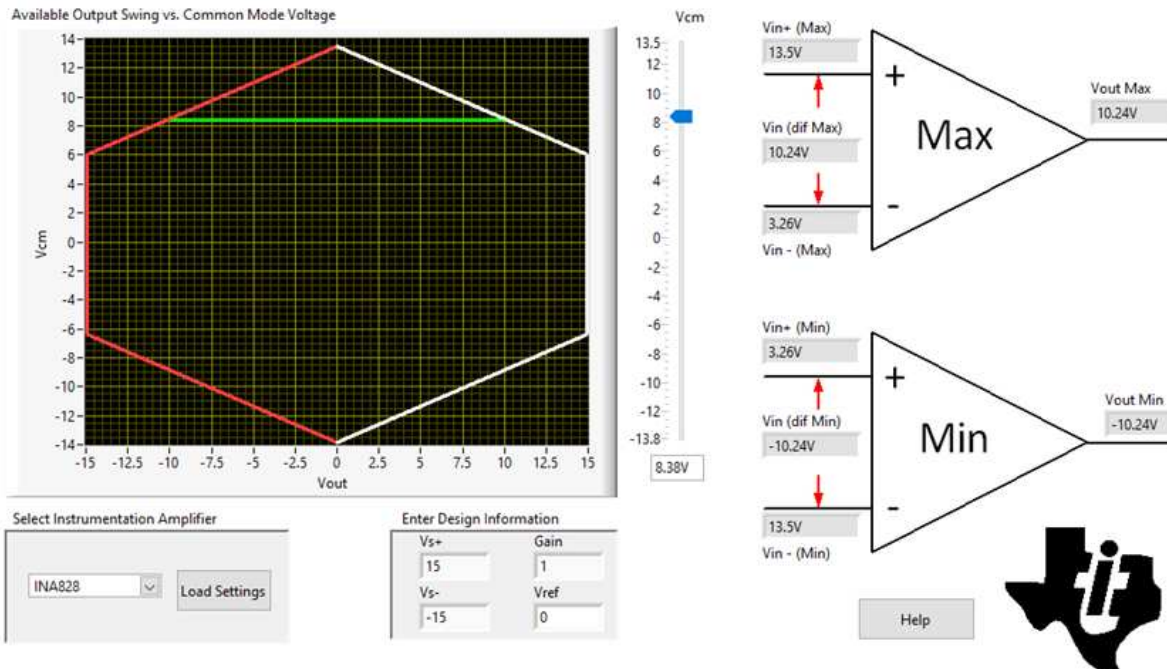
DC Transfer Characteristics

The following graphs show a linear output response for the INA149 device. The input range of the ADC is ±10.24V 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.
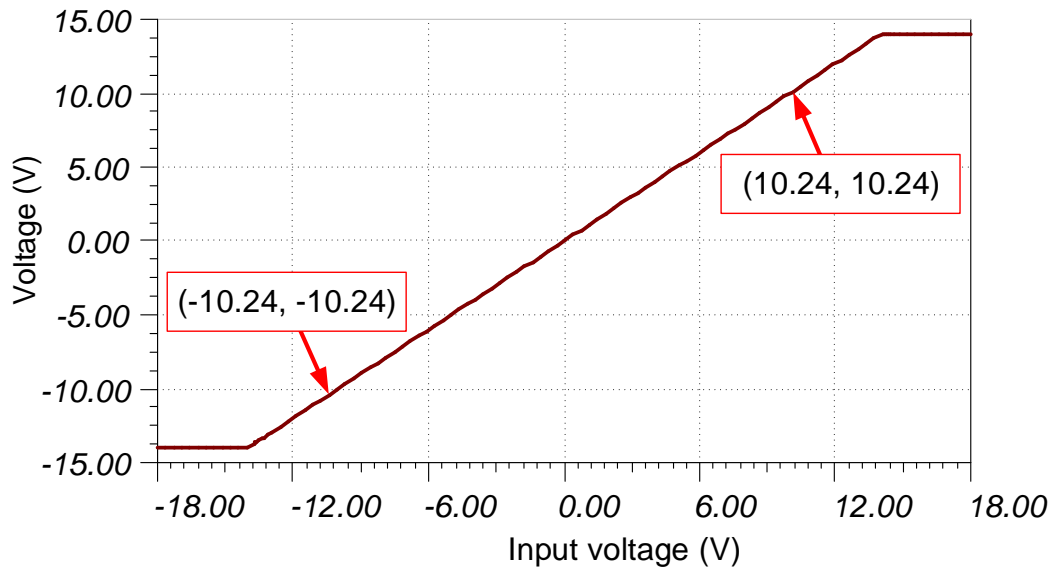

AC Transfer Characteristics

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.
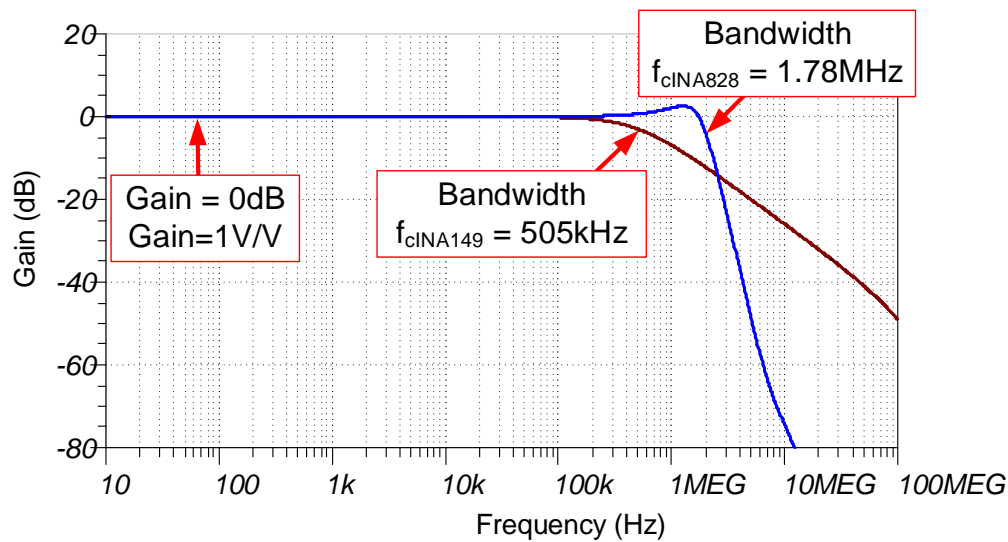
Transient ADC Input Settling Simulation

The INA149 device was simulated with a ±10.24-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.
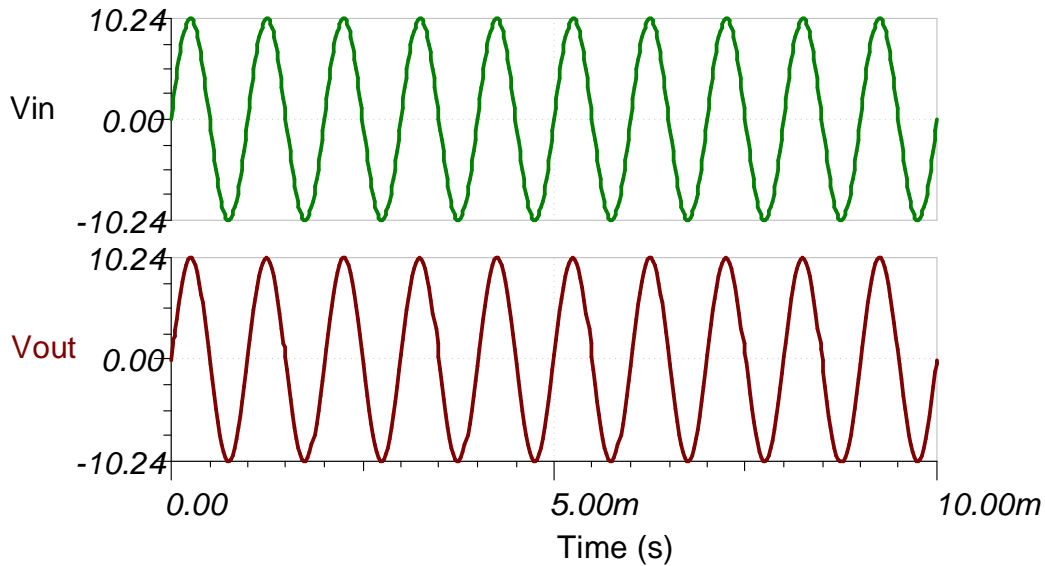
The INA828 device was simulated with a ±10.24-V differential input and a 7.75-V common-mode voltage. The following TINA simulation shows the differential input as well as the single-ended output for the INA828 device.
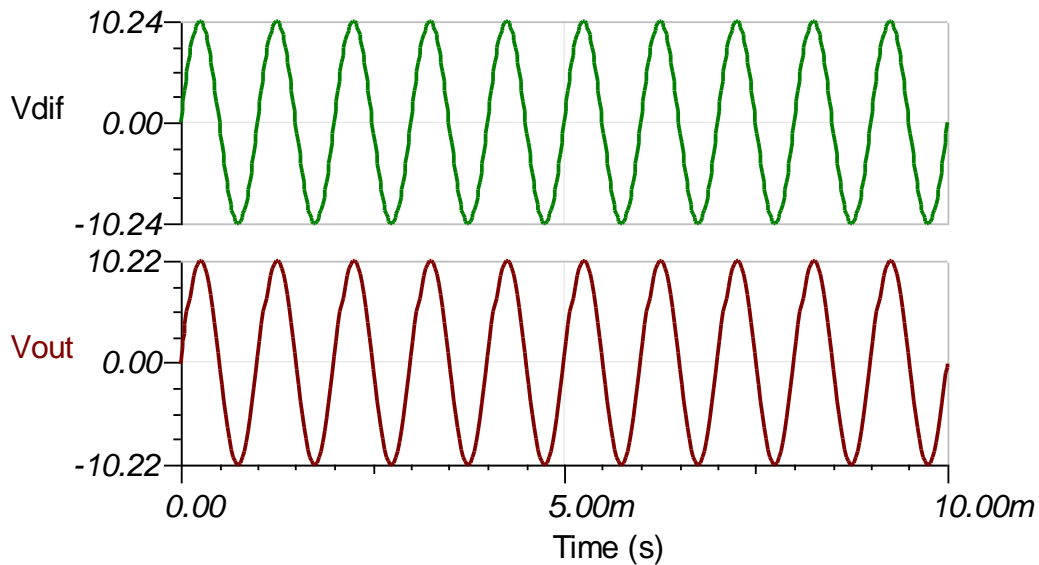
Noise Simulation

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:

$$E_{nINA149} = e_{ni}\sqrt{f_c \cdot K_n} = \left(550\,nV/\sqrt{Hz}\right)\sqrt{505kHz \cdot 1.57} = 489\mu Vrms$$

INA828 integrated noise:

$$E_{nINA828} = Gain\sqrt{e_{ni}{}^2 + e_{no}{}^2}\sqrt{f_c \cdot K_n} = (1)\sqrt{(7\,nV/\sqrt{Hz})^2 + \left(90\,nV/\sqrt{Hz}\right)^2}\sqrt{1.78MHz \cdot 1.57} = 151\mu Vrms$$

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:

$$E_{nINA149} = e_{ni}\sqrt{f_c \cdot K_n} = \left(550\,nV/\sqrt{Hz}\right)\sqrt{15kHz \cdot 1.22} = 74.4\mu Vrms$$

INA828 integrated noise:

$$E_{nINA828} = Gain\sqrt{e_{ni}{}^2 + e_{no}{}^2}\sqrt{f_c \cdot K_n} = (1)\sqrt{(7\,nV/\sqrt{Hz})^2 + \left(90\,nV/\sqrt{Hz}\right)^2}\sqrt{15kHz \cdot 1.22} = 12.2\mu Vrms$$
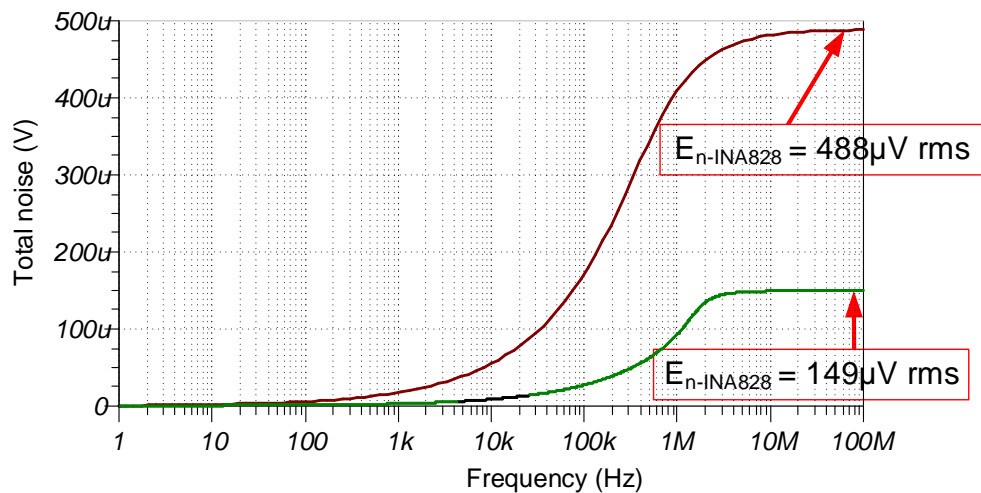
Design Featured Devices

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 Power12nV/√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.

IMPORTANT NOTICE AND DISCLAIMER