Analog Engineer's Circuit: Data Converters

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Circuit for driving a high-voltage SAR with an instrumentation amplifier

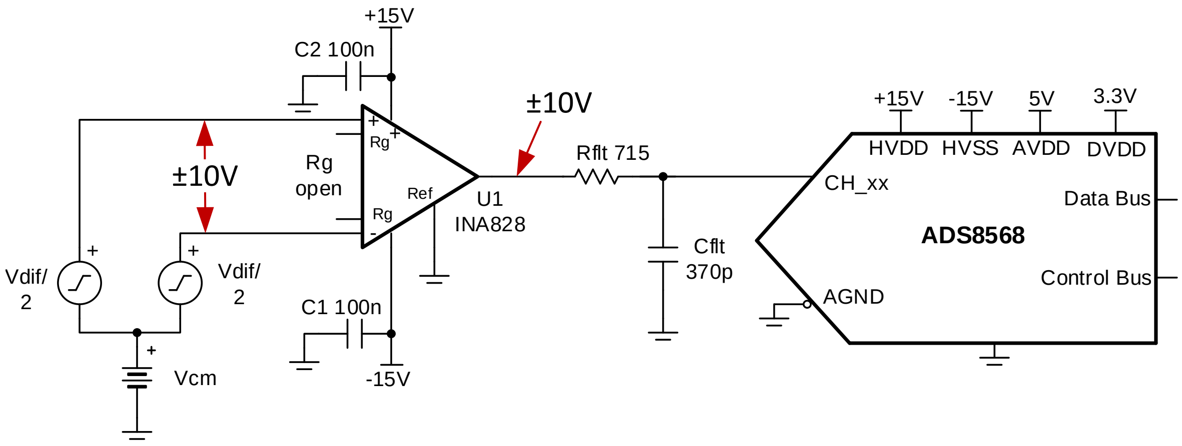
Dale Li

Input	**ADC Input**	**Digital Output ADS7042**
–10V	–10V	8000H
+10V	+10V	7FFFH

Power Supplies				
AVDD	**DVDD**	**V_{ref}**	**V_{cc}**	**V_{ee}**
5.0V	3.0V	5.0V	+15V	–15V

Design Description

Instrumentation amplifiers are optimized for low noise, low offset, low drift, high CMRR and high accuracy. The INA828 instrumentation amplifier preforms a differential to single-ended conversion for a ±10-V range. The INA828 has excellent DC performance (that is, offset, drift), as well as good bandwidth. The ADS8568 is ideally suited to work with the INA828 as the ADC can be configured for a ±10-V single-ended input. To achieve the best settling, limit the sampling rate to 200kSPS or lower. For higher sampling rates see *Driving High-Voltage SAR ADC with a Buffered Instrumentation Amplifier*. Also, this design example uses unity gain (G=1) to translate a ±10-V differential input signal to a ±10-V single-ended output. For smaller input signals or higher gains, see *Circuit for Driving an ADC with an Instrumentation Amplifier in High Gain*. This circuit implementation is applicable to *Industrial Transportation* and *Analog Input Modules* that require precision signal-processing and data-conversion.



Specifications

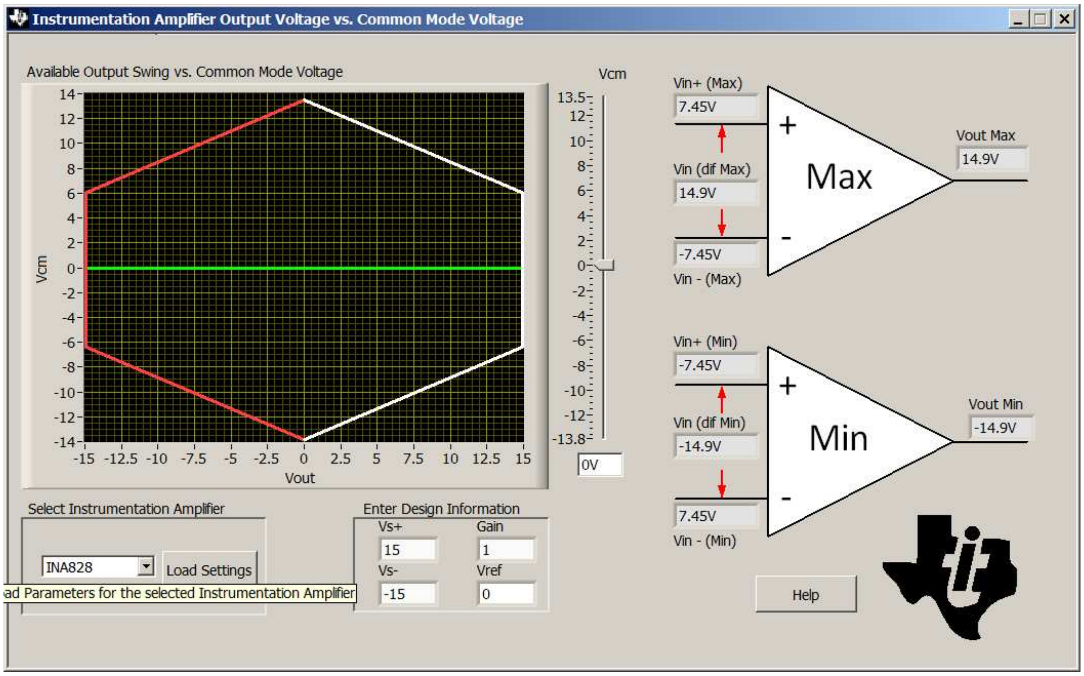
Specification	Goal	Calculated	Simulated
Transient Settling Error	< 1/2 LSB (±152µV)	NA	–105µV
Noise	< 20µV	103µV	86.6µV

Design Notes

1. The bandwidth of instrumentation amplifiers is typically not enough to drive SAR data converters at higher data rate. In this example, the sampling rate is reduced from 510kSPS to 200kSPS to achieve good settling. For full sampling rate see *Driving High-Voltage SAR ADC with a Buffered Instrumentation Amplifier*.
2. Check the common mode and output range of the instrumentation amplifier using the *Common-Mode Input Range Calculator for Instrumentation Amplifiers* software tool.
3. Use a COG type capacitor for C_{filt} to minimize distortion.
4. The *Precision Labs* video series covers methods for selecting the charge bucket circuit C_{flt} and R_{flt}. See the *Introduction to SAR ADC Front-End Component Selection* for details on this subject.

Component Selection

1. The ADS8568 can accept a ±10-V single-ended input signal. The INA828 is used to translate a ±10-V differential signal to a ±10-V single-ended signal. So the INA828 is in unity gain for this example, and no external gain set resistor R_g is needed. See *Circuit for Driving an ADC with an Instrumentation Amplifier in High Gain* in cases where the input signal range is small and gain is required.
2. The INA826 reference voltage (V_{ref}) input is used to shift asymmetrical input ranges to match the input range of the ADC. In this case the input range is symmetrical so the V_{ref} pin is grounded (V_{ref} = 0V). See *Circuit for Driving an ADC with an Instrumentation Amplifier in High Gain* for an example where the V_{ref} pin is used to adjust asymmetrical input signals.
3. Use the *Common-Mode Input Range Calculator for Instrumentation Amplifiers* to determine if the INA828 is violating the common-mode range. The common-mode calculator in the following figure indicates that the output swing is ±14.9V for a 0-V common mode input.



Vcm: 0V

Vin+ (Max): 7.45V

Vin (dif Max): 14.9V

Vin - (Max): -7.45V

Vout Max: 14.9V

Vin+ (Min): -7.45V

Vin (dif Min): -14.9V

Vin - (Min): 7.45V

Vout Min: -14.9V

Select Instrumentation Amplifier: INA828 | Load Settings

ad Parameters for the selected Instrumentation Amplifier

Enter Design Information

Vs+: 15

Gain: 1

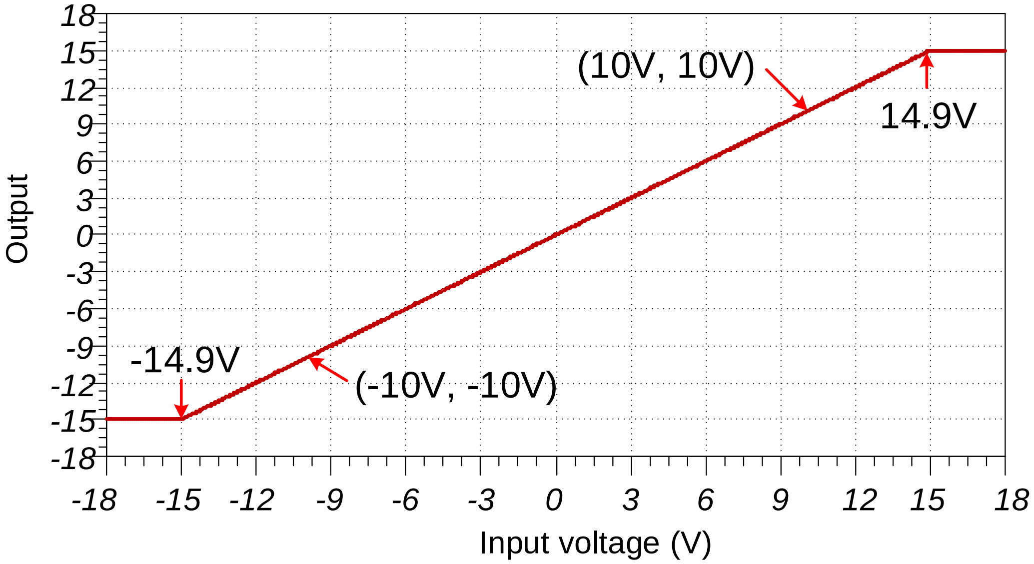
Vs-: -15

Vref: 0

4. Find the value for C_{filt}, and R_{filt} using TINA SPICE and the methods described in *Introduction to SAR ADC Front-End Component Selection*. The value of R_{filt} and C_{filt} shown in this document will work for these circuits; however, if you use different amplifiers you will have to use TINA SPICE to find new values.

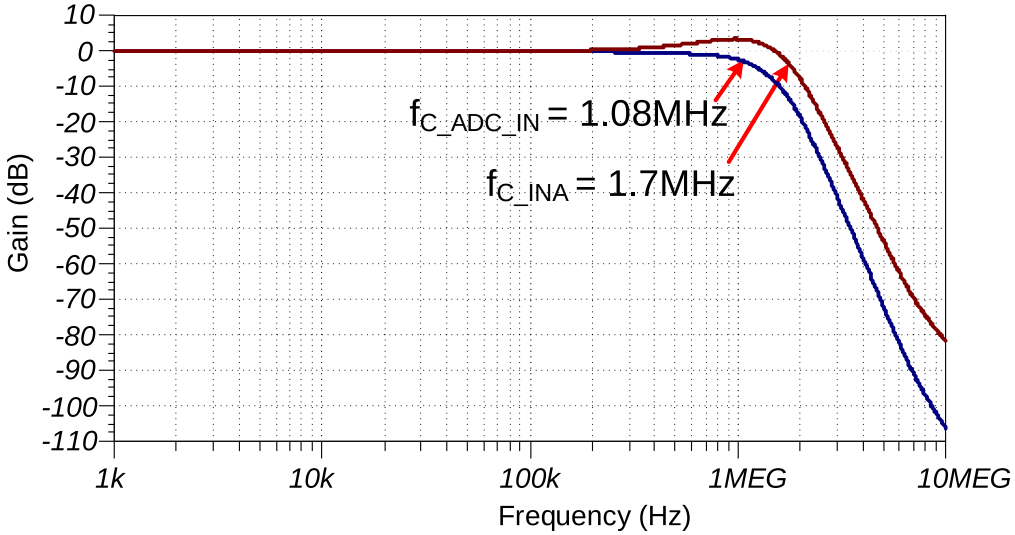
DC Transfer Characteristics

The following graph shows a linear output response for inputs from differential –14.9V to +14.9V. The input range of the ADC is ±10V, so the amplifiers are linear well beyond the required range. See *Determining a SAR ADC's Linear Range when using Instrumentation Amplifiers* for detailed theory on this subject. The full-scale range (FSR) of the ADC falls within the linear range of the instrumentation amplifier.



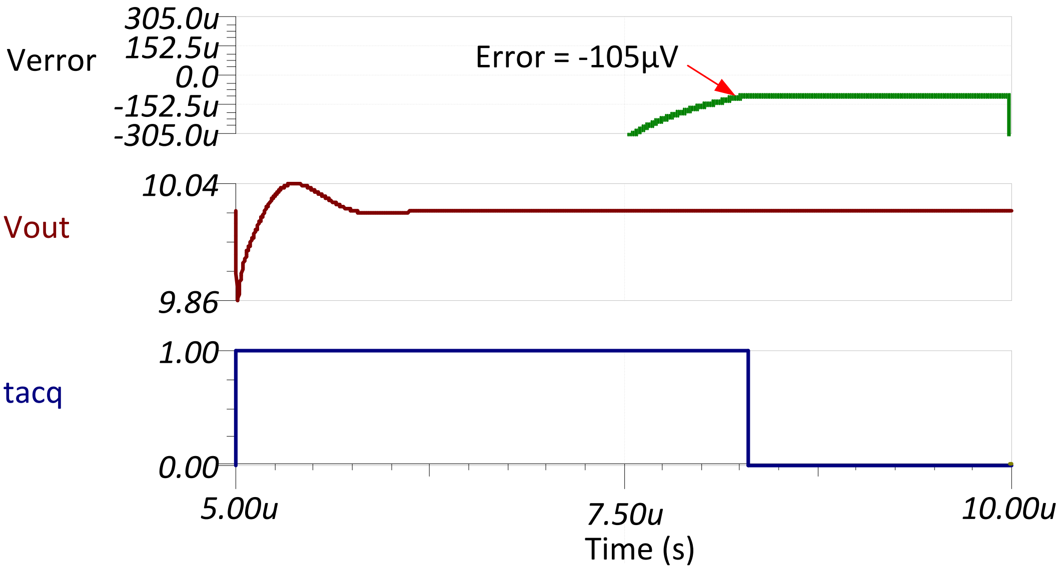
AC Transfer Characteristics

The bandwidth for this circuit is simulated to be 446.75kHz and the gain is 0dB.



Transient ADC Input Settling Simulation (200kSPS)

The following simulation shows settling to a 10-V DC input signal with INA828 and ADS8568. This type of simulation shows that the sample and hold kickback circuit is properly selected to within ½ of a LSB (152µV) at 200kSPS sampling rate on ADS8568. See the *ADC Front End Component Selection* video series for detailed theory on this subject.



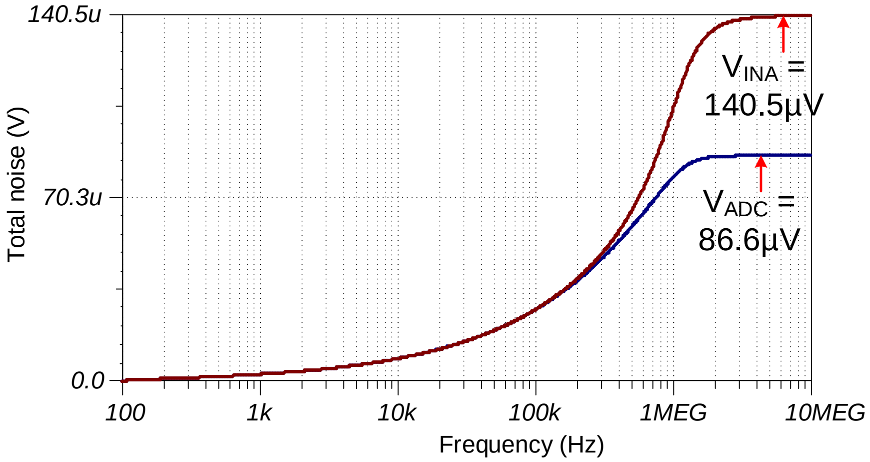
Noise

This section shows a simplified noise calculation for a rough estimate. The bandwidth estimate was taken from the TINA simulation, and the noise density values are from the *INA828 50-µV Offset, 7-nV/√Hz Noise, Low-Power, Precision Instrumentation Amplifier* data sheet. The Kn factor of 1.22 is used because the filter is second order (the INA and output filter both have a pole).

$$E_{n-ADC} = Gain \cdot \sqrt{e_{ni}^2 + \left(\frac{e_{no}}{Gain}\right)^2} \cdot \sqrt{K_n \cdot f_c}$$

$$E_{n-ADC} = 1 \cdot \sqrt{\left(7nV/\sqrt{Hz}\right)^2 + \left(\frac{90nV/\sqrt{Hz}}{1}\right)^2} \cdot \sqrt{1.22 \cdot 1.08MHz} = 103\mu Vrms$$

Note that simulated and calculated are close but not exact (simulated = 86.6µV, calculated = 103µV). The difference is because the INA has gain peaking and the filter order is approximated as two but in reality the INA and filter poles are not exactly aligned.



Design Featured Devices

Device	Key Features	Link	Other Possible Devices
ADS8860	16-bit resolution, SPI, 1MSPS sample rate, single-ended input, Vref input range 2.5 V to 5.0 V	http://www.ti.com/product/ADS8860	http://www.ti.com/adcs
INA826	Bandwidth 1MHz (G=1), low noise 18nV/$\sqrt{Hz}$, low offset ±40µV, low offset drift ±0.4µV/ºC, low gain drift 0.1ppm/ºC. (Typical values)	http://www.ti.com/product/INA826	http://www.ti.com/inas

Design References

See *Analog Engineer's Circuit Cookbooks* for TI's comprehensive circuit library.

Link to Key Files

Source files for this circuit - http://www.ti.com/lit/zip/SBAC217.

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