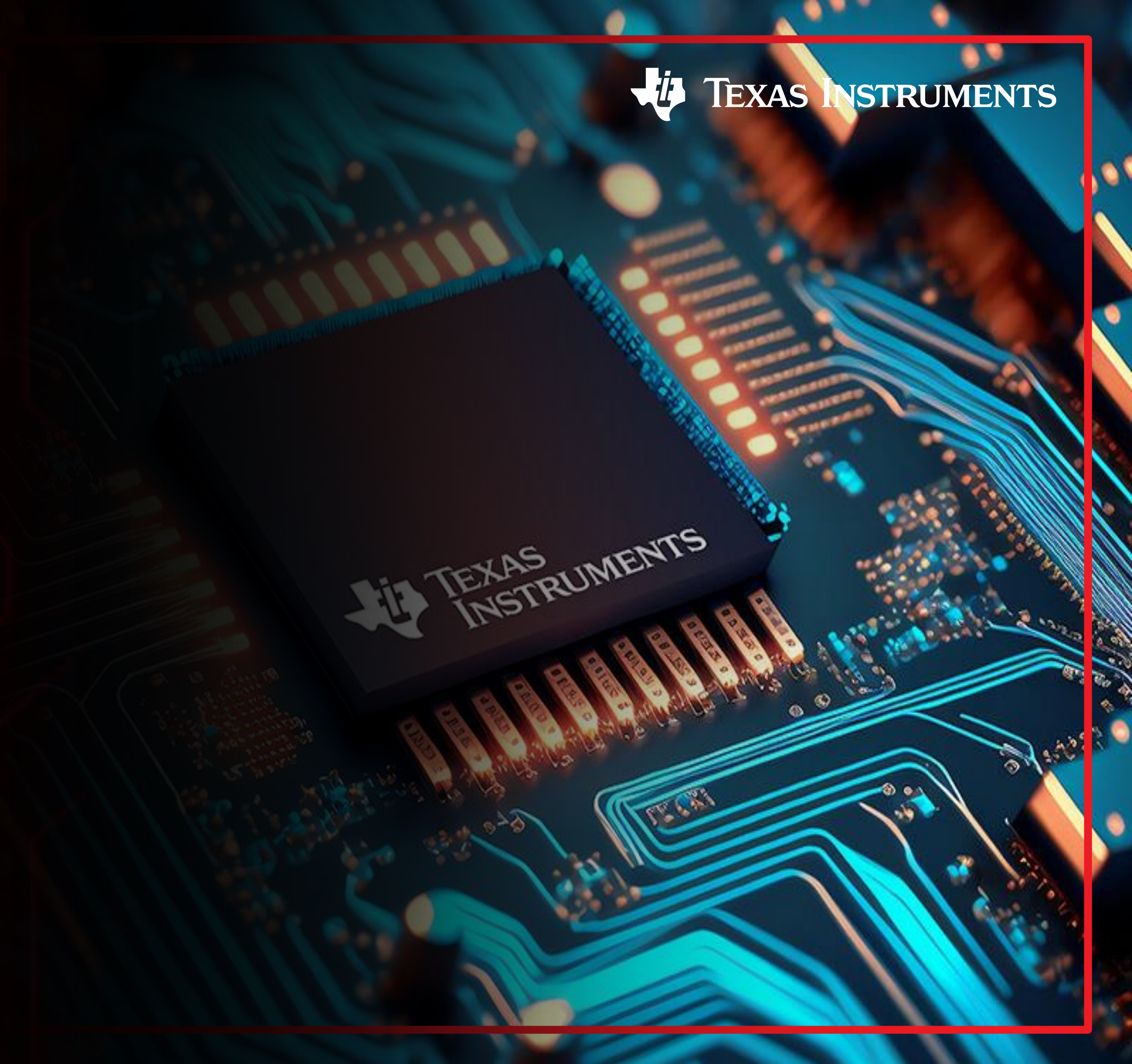
New Product Update

Interface your signals using TI's next-generation of cost-optimized Difference Amps



Pradeep Jacob & Jacob Nogaj

General Purpose Amplifiers

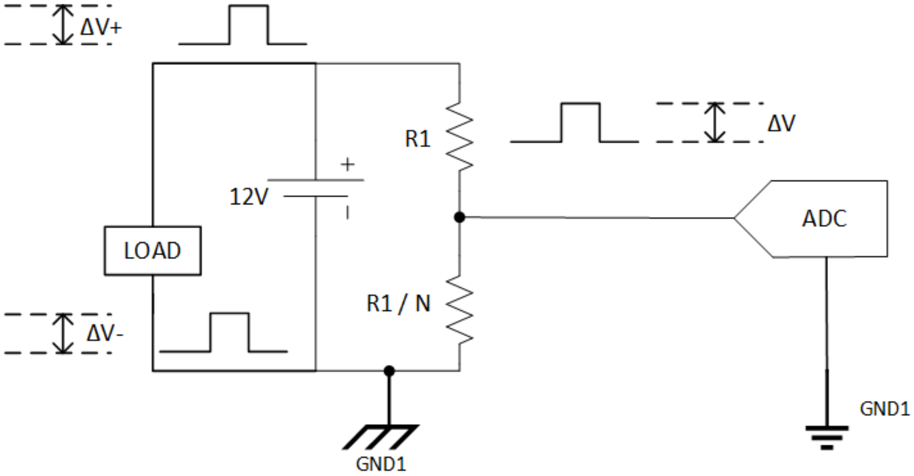
Agenda

- Application Scenarios
- Why Difference Amps?
- Why INA500?
- Application Design with INA500
- Packages, Gain Options & HV Voltage version
- How to get started?

Application scenarios

1. **Voltage Monitoring**
   a. Battery Voltage → **0-5V** to **0-2.5V | ±5V** to **0-2.5V**
   b. Power Rails – LDO, Buck, Boost etc. → **0-12V** to **0-3V**
2. **Level Translation**
   a. Ground Isolation → **0-5V** to **0-5V**
   b. Single Ended to Single Ended (Attenuation) → **0-5V** to **0-2.5V**
   c. Differential to Single Ended → **±10V** to **0-5V**

1a. Battery monitoring | Discrete implementation (1)



With Superposition :

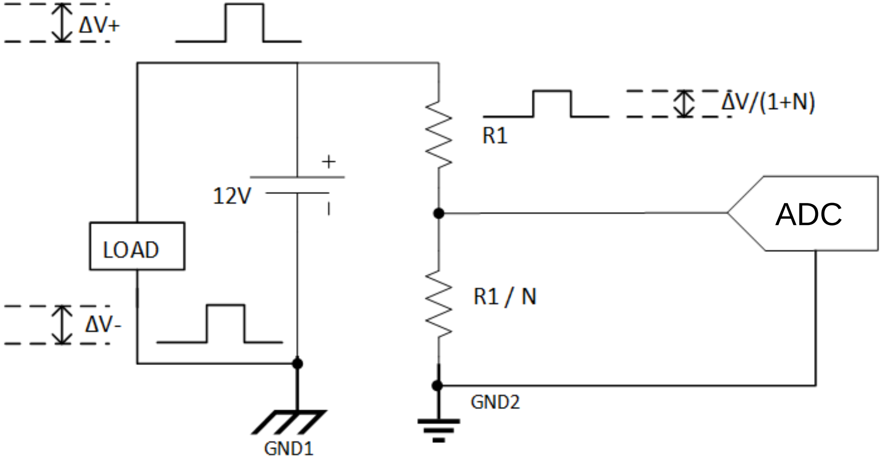
$$V_{ADC_{\Delta V+}} = (\Delta V+) * \frac{\frac{R1}{N}}{R1 + \frac{R1}{N}} \qquad V_{ADC\_\Delta V-} = (\Delta V-) * \frac{R1}{R1 + \frac{R1}{N}}$$

$$V_{ADC} = (\Delta V+) * \frac{\frac{R1}{N}}{R1 + \frac{R1}{N}} + (\Delta V-) * \frac{R1}{R1 + \frac{R1}{N}}$$

$$(\Delta V) = (\Delta V+) = (\Delta V-)$$

$$V_{ADC} = [\Delta V] * \frac{R1 + \frac{R1}{N}}{R1 + \frac{R1}{N}} = [\Delta V]$$

1a. Battery monitoring | Discrete implementation (2)



With Superposition :

$$V_{ADC_{\Delta V+}} = (\Delta V+) * \frac{\frac{R1}{N}}{R1 + \frac{R1}{N}}$$

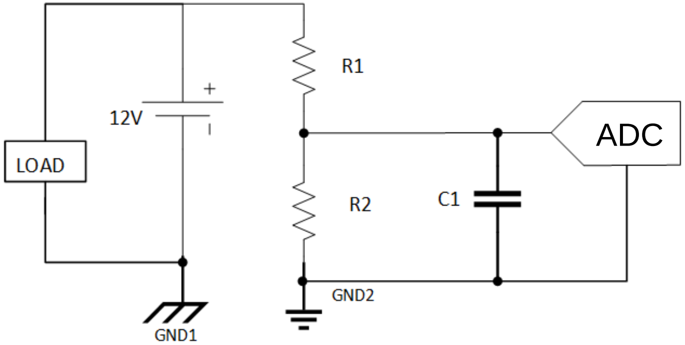
$$V_{ADC} = (\Delta V+) * \frac{\frac{1}{N}}{\frac{1+N}{N}}$$

$$(\Delta V) = \ (\Delta V+) = (\Delta V-)$$

$$V_{ADC} = [\Delta V +] * \frac{1}{1+N}$$

1a. Battery monitoring | Discrete implementation

Resistor Value (Power vs Bandwidth Trade-off)

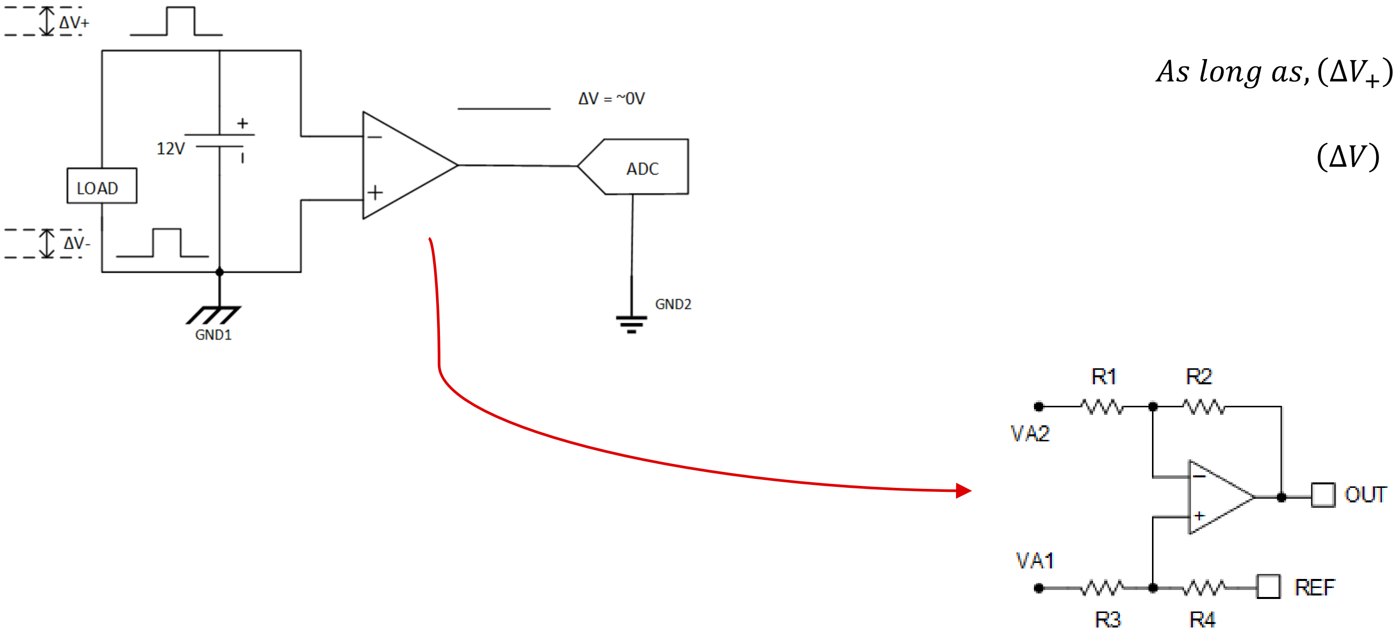


$$V_{ADC} = (V_{BAT}) * \frac{R1}{R1 + R2} * \frac{1}{(1 + S * C1 * \frac{R1 * R2}{R1 + R2})}$$

R_1	R_2	$I_Q = \frac{12V}{R_1 + R_2}$	$R_{eq} = \frac{12V}{R_1 + R_2}$	$C_1 = 10*C_{SH}$	$\tau = R_{eq} * C_1$	10-bit Settling time t = 7τ	1ksps sampling time
120-kΩ	40-kΩ	75µA	30-kΩ	0.5nF	30µs	105µs	160µs (ADS7041 | 10-bit 1ksps ADC)
500-kΩ	125-kΩ	19µA	100-kΩ	0.5nF	100µs	350µs	
1-MΩ	250-kΩ	10µA	200-kΩ	0.5nF	200µs	700µs	

1a. Battery monitoring | INA500 implementation

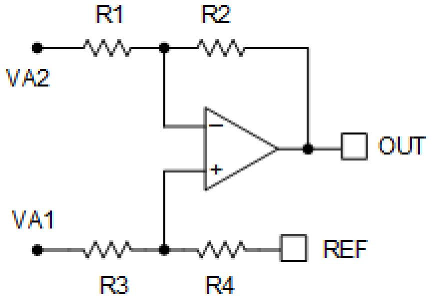
Difference Amp Implementation



$$As\ long\ as, (\Delta V_+) = (\Delta V_-) = (\Delta V)$$

$$(\Delta V) \cong 0V$$

Difference amps & why to use them?



- **Rejects the input common-mode signal** (average voltage of two input pins)
  - Eliminates ground bounce & Provides ground isolation
  - Key spec : Common-mode rejection ratio (CMRR)
- **Applies gain to the input differential** (voltage difference between two input pins)
  - Provides the ability to attenuate or gain the differential
  - Key spec : Gain Error (GE) & Gain Error Drift
- **Places gained input differential on an output common-mode** (reference voltage)
  - Enables level translation

$$\boldsymbol{V_{OUT} = VRE_F + G_{DM-ideal} * (VA1 - VA2)}$$

$$Differential\ Gain = G_{DM-ideal} = \frac{R2}{R1} = \frac{R4}{R3}$$

$$Common - mode\ gain = G_{CM-ideal} = 0$$

$$CMRR(dB) = |20 * log_{10}\left(\frac{G_{CM-real}}{G_{DM-ideal}}\right)|$$

$$GE = \frac{G_{DM-ideal} - G_{DM-real}}{G_{DM-ideal}} * 100$$

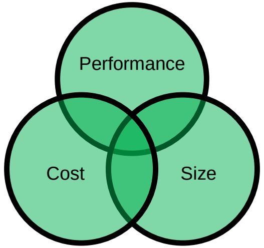
$$\boldsymbol{V_{OUT} = VRE_F + G_{DM-real} * (VA1 - VA2) + \frac{(\frac{VA1 + VA2}{2})}{CMRR\ in\ V/V}}$$

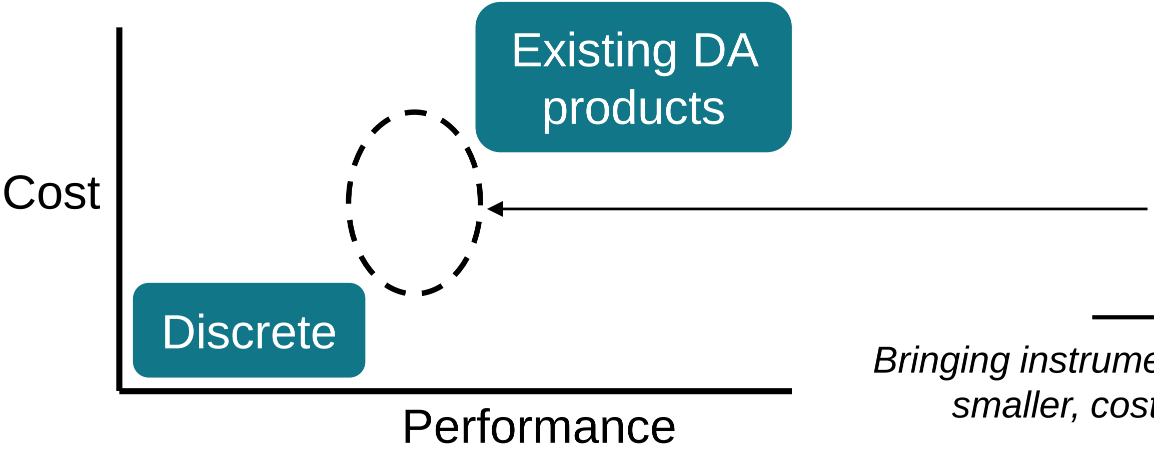
Difference amplifier | Discrete implementation

Resistor Mismatch	Gain Error (%)	Gain Error Drift (ppm/C)	Resistor CMRR (dB)	Resistor Cost ($) Lowest from DigiKey	Total 4 Resistor Cost ($)	Total Cost = Res + 1CH Amp ($0.09)	Precision Bits (N) = CMRR / 6
5%	7.5%	100	22.5	0.00070	0.003	$0.093	3.7
1%	1.5%	100	36.4	0.00070	0.003	$0.093	6.1
0.5%	0.75%	100	42.5	0.00286	0.011	$0.101	7.1
0.1%	0.15%	50	56.5	0.01940	0.078	$0.168	9.4
0.05%	0.075%	50	62.5	0.04360	0.175	$0.265	10.4
0.01%	0.015%	25	76.4	0.38800	1.552	NA	12.7

***Resistor cost is lowest cost from DigiKey for 0402 type resistors**

Why INA500 ? - good cost, better performance, best size





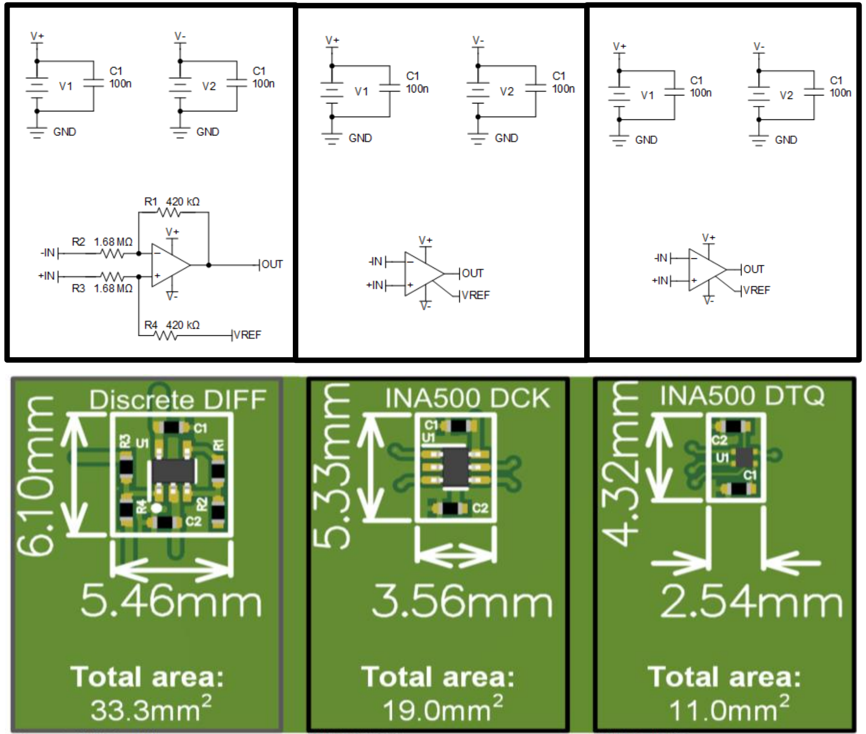
Bringing instrumentation amp performance to smaller, cost-optimized applications

Key specs	Discrete 1%	INA500	Discrete 0.1%	Existing DAs
1KU Price	~$0.093	$0.145	~$0.168	> $0.400
Max gain error	~1.5%	0.1%	~0.15%	< 0.05%
Max gain drift	~200-100ppm/°C	1ppm/°C	~100-50ppm/°C	< 0.5ppm/°C
Min CMRR	~36dB	75dB	~56dB	> 85dB

INA500 size comparison vs Discrete solution

Discrete BOM:

- 1.5 x 2.1mm SC70 DCK
- 4 Resistors
- 2 Decoupling Capacitors
- Total area = 33.3mm^2



Discrete DIFF Amplifier INA500xIDCK INA500xIDTQ

INA500 BOM Standard Package:

- 1.5 x 2.1mm SC70 DCK
- 2 Decoupling Capacitors
- Total area = 19mm^2

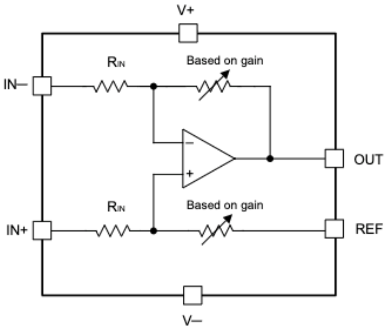
INA500 BOM Small Package:

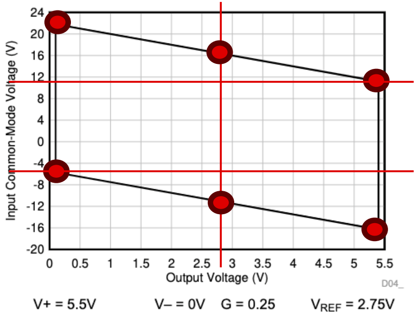
- 1 x 1mm X2QFN DTQ
- 2 Decoupling Capacitors
- Total area = 11mm^2

INA500 consumes **67% less space** than traditional discrete difference amplifier solutions

Difference amp | Inputs beyond supplies

- **INA500** is fault tolerant well beyond the supply voltage (No damage but saturated outputs)
  - Positive side : (V+) + 30V
  - Negative side : (V-) – 25V





- INA500's valid common-mode range for linear operation depends on,
  - Gain option chosen (G)
  - Positive power supply voltage (V+)
  - Negative power supply voltage (V-)
  - Reference voltage (V_{REF})

$$V_{CM\_MAX} = V(+)\left(1+\frac{1}{G}\right) - V_{REF} * \left(\frac{1}{G}\right)$$

$$V_{CM\_MIN} = V(-)\left(1+\frac{1}{G}\right) - V_{REF} * \left(\frac{1}{G}\right)$$

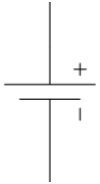
Application design with INA500

Now, lets consider a popular use case scenario of **Battery Monitoring (Battery Testers)**

- **Battery Voltage Range : 0V to 5V**
- **Overvoltage Range : ±0.5V**
- **Reverse Polarity Range : −5V to 0V**
- **Total Input Voltage Range : -5.5V to 5.5V**

Problem : Interface **-5.5V** to **5.5V Battery** voltage into a **0** to **5.5V ADC** inside a Micro-controller

11V$_{PP}$ differential with V$_{CM}$ of 0V

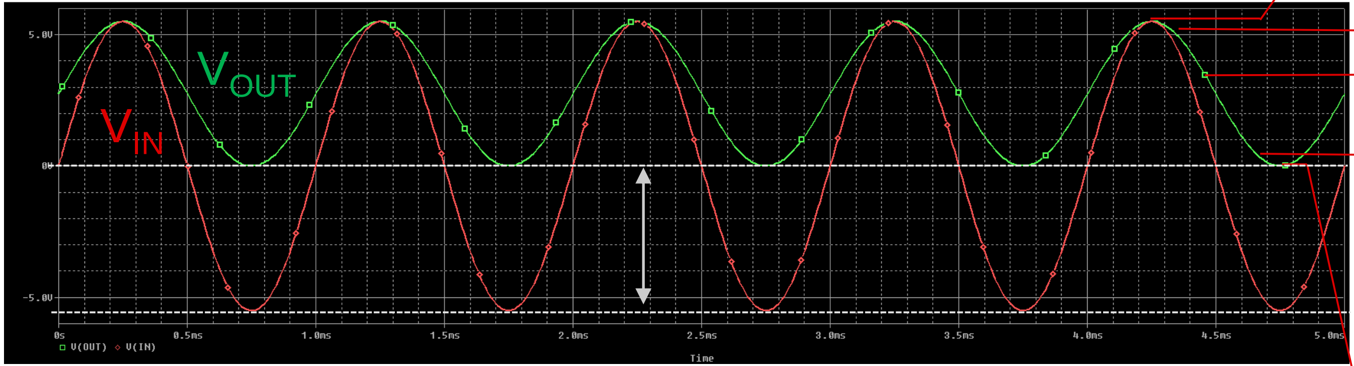


Input Voltage (Battery)	Output Voltage (V)
5.5	5.5
5	5.25
0	2.75
-5	0.25
-5.5	0

5.5V$_{PP}$ differential with V$_{CM}$ of 2.75V

$$Gain = \frac{5.5V_{pp}}{11V_{pp}} = 0.5 \qquad V(+) = 5.5V, V(-) = 0V, VREF = 2.75V$$

1a. Battery Monitor



V_{OUT} ~ 5.50V

Overvoltage

V_{OUT} = 5.25V

Battery Voltage

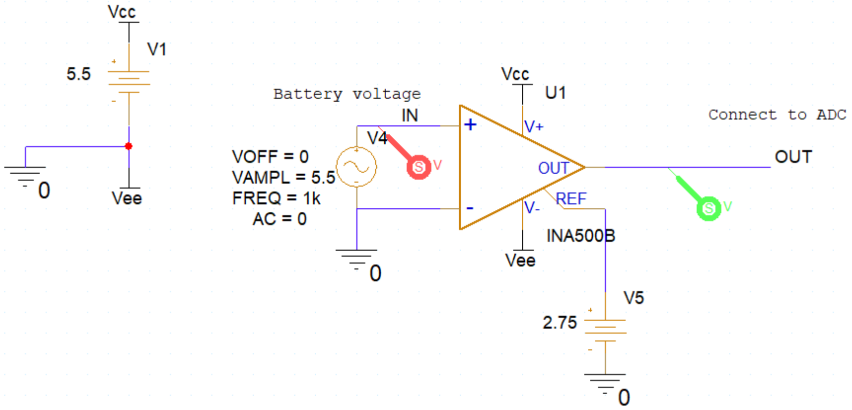
V_{OUT} = 2.75V

Reverse Battery Voltage

V_{OUT} = 0.25V

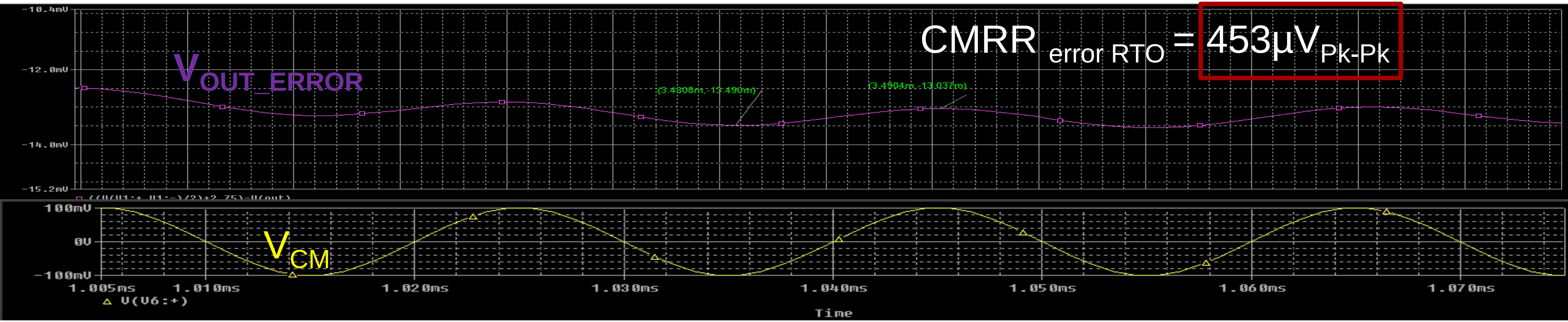
Overvoltage

V_{OUT} ~ 0.00V

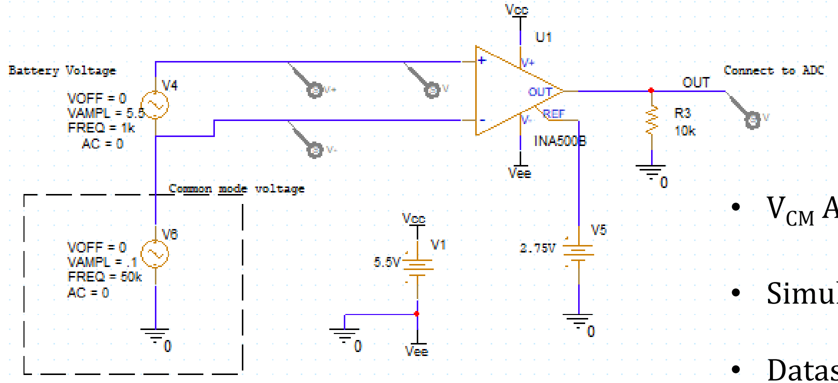


Input Voltage (Battery)	Output Voltage (V)
5.5	5.5
5	5.25
0	2.75
-5	0.25
-5.5	0

1a. Battery Monitor with AC V_{CM} shift



$CMRR_{\text{error RTO}} = \boxed{453\mu V_{Pk\text{-}Pk}}$



Ground Bounce : 50kHz, $200mV_{PK=PK}$ Sine Wave

- $V_{CM}\ \text{Attenuation} = \frac{0.45mV}{200mV} = \frac{0.002265V}{V}$
- $\text{Simulated} = |20{*}\log(0.002265)| = 53\text{dB}$
- Datasheet plot (measured) = 55dB

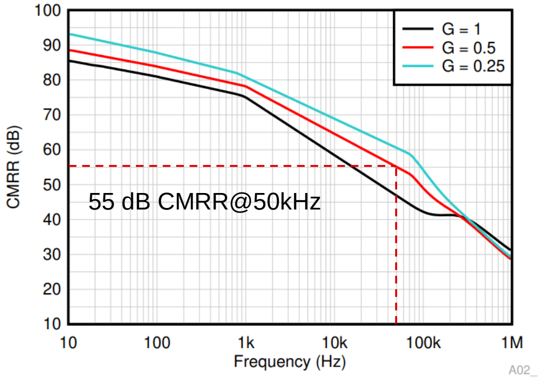


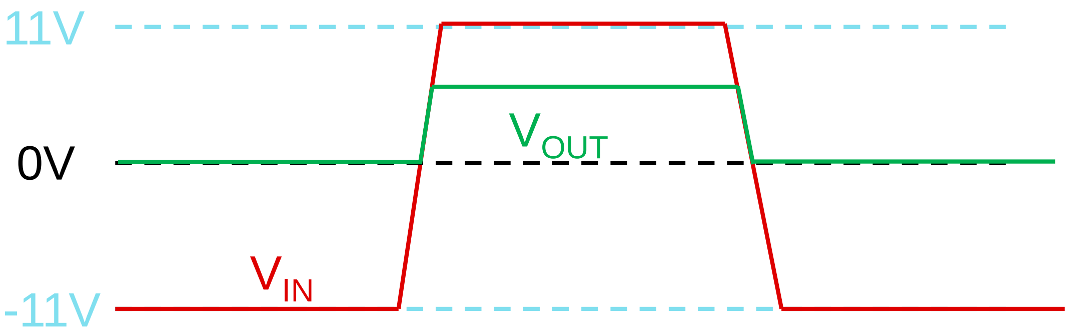
Figure 6-36. CMRR (Referred to Output) vs Frequency

2c. Level translation (differential to single-ended)

- **Input Voltage Range : -10V to 10V**
- **Overvoltage Range : ±1V**

- **Total Input Voltage Range : -11V to 11V**
- **Output Voltage Range : 0 to 5.5V**

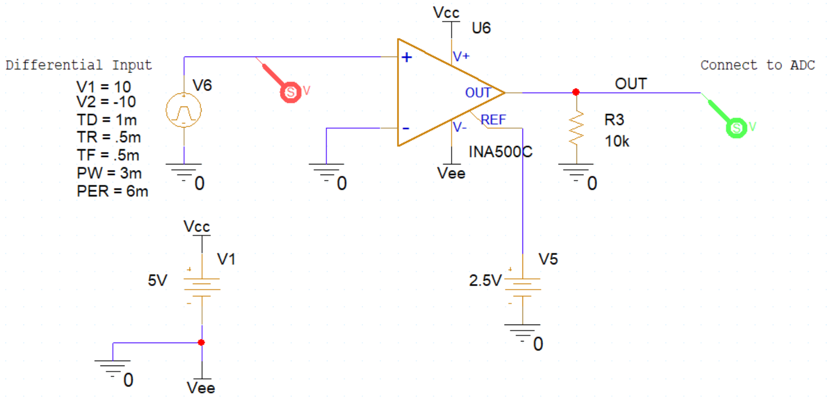
Problem : Convert high amplitude differential signal into low amplitude single ended signal



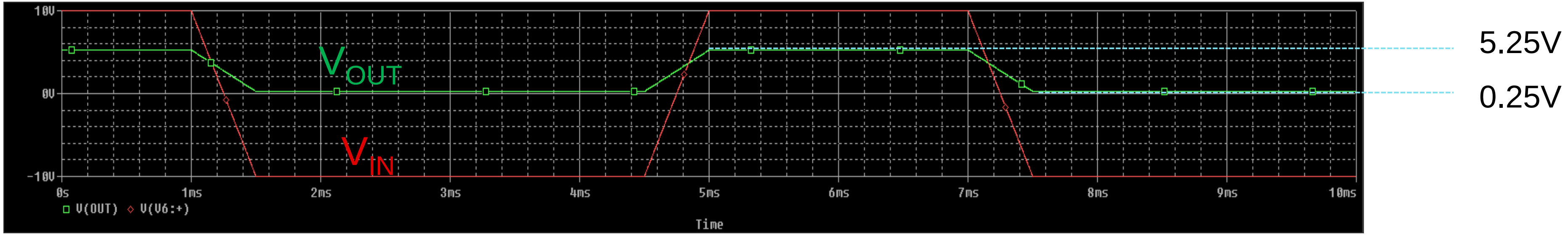
Input Voltage	Output Voltage (V)
11	5.50
10	5.25
5	4.0
0	2.75
-5	1.5
-10	0.25
-11	0

$$Gain = \frac{5.5V_{pp}}{22V_{pp}} = 0.25 \qquad V(+) = 5.5V, V(-) = 0V, VREF = 2.75V$$

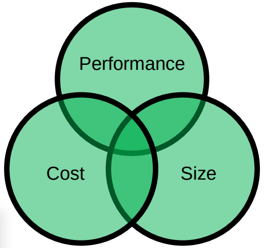
2c. Level translation G = 0.25



Input Voltage	Output Voltage (V)
11	5.50
10	5.25
5	4.0
0	2.75
-5	1.5
-10	0.25
-11	0



Better than discrete "difference amps"



1MΩ Input Impedance with lower power

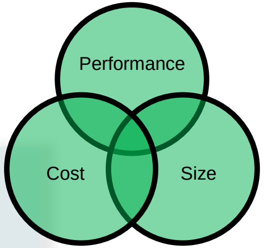
Funnel Difference Amplifier

INA500 (LV)

1.8V – 5.5V

PART NUMBER	VERSION	GAIN	PACKAGE	PACKAGE SIZE
INA500	A	1	DCK (SC70-6) DBV (SOT-23-6) DTQ (X2SON-6)*	2.1mm x 1.25mm 2.9mm x 2.8mm 1.0mm x 0.8mm
	B	½		
	C	¼		

Better than discrete “difference amps”



1MΩ Input Impedance with lower power

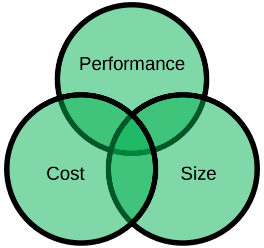
Funnel Difference Amplifier

INA500 (LV)

1.8V – 5.5V

GENERIC PART NUMBER	ORDERABLE PART NUMBER	GAIN OPTION	PACKAGE
INA500	INA500AIDBVR	1	2.9 x 2.8mm (DBV)
	INA500AIDCKR		2.1 x 1.25mm (DCK)
	INA500AIDTQR		1.0 x 0.8mm (DTQ)
	INA500BIDBVR	½	2.9 x 2.8mm (DBV)
	INA500BIDCKR		2.1 x 1.25mm (DCK)
	INA500BIDTQR		1.0 x 0.8mm (DTQ)
	INA500CIDBVR	¼	2.9 x 2.8mm (DBV)
	INA500CIDCKR		2.1 x 1.25mm (DCK)
	INA500CIDTQR		1.0 x 0.8mm (DTQ)

Better than discrete “difference amps”



1MΩ Input Impedance with lower power

Funnel Difference Amplifier

INA500 (LV)

1.8V – 5.5V

INA600 (HV)

2.7V – 40V

Evaluate Today!

Samples Available 4Q24

PART NUMBER	VERSION	GAIN	PACKAGE	PACKAGE SIZE
INA500	A	1	DCK (SC70-6) DBV (SOT-23-6) DTQ (X2SON-6)*	2.1mm x 1.25mm 2.9mm x 2.8mm 1.0mm x 0.8mm
	B	½		
	C	¼		

INA500: Micro-power Small size LV Difference Amplifier

125 kHz GBW | 75 dB Min CMRR | 0.05 % Max Gain Error | 1.7 V to 5.5 V | Up to 27V V_{CM}

Released

Features:

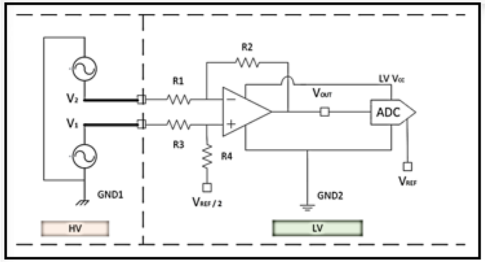
Supply Voltage	**1.7 V to 5.5 V**
Integrated Gain Options	**1/4, 1/2, 1**
>1 MΩ Input Impedance & **27V V_{CM}** (G = 1/4) **at 5.5V V_S**	
High CMRR	**75 dB (min)**
Low Gain Error	**0.05 % (max)**
Low Offset / Drift	1 - 4 mV (max), 2 - 8 µV/℃ (typ)
Low Quiescent Current	13.5 µA (typ)
Gain Bandwidth product (G = 1)	125 kHz
Stable for Caps up to 100pF with resistive output impedance	

Benefits

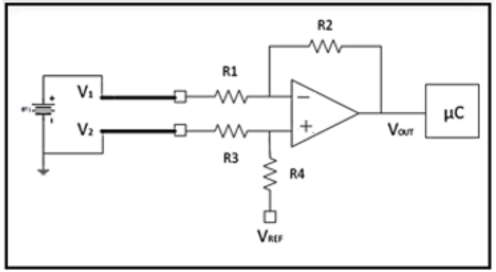
- **1 MΩ Input impedance** for easy interface to standard analog input module signals (0 to 10V, -5V to 5V and 0 to 5V)
- **Integrated Gain options** for easy interface to 2.5V / 5V ADC full scale
- **Good CMRR and Gain Error** to enable DC Precision using precision matched thin film resistors
- **Low Offset & Drift** for precision signal sense and amplification which can be further calibrated out to maximize dynamic range
- **Resistive open loop output impedance** and Stable for cap loads
- **EMI filtering** on inputs and power supply results in high EMIRR for better performance in noisy environments

Sectors / End Equipment / Applications

- Analog input module
- Battery voltage / current sense and monitoring
- Signal level translation
- Differential to single ended conversion
- Audio mic preamplifiers



PLC AIN Module : Signal Level Translation



12V Battery Voltage Sensing

INA600: Micro-Power HV Difference Amplifier

125 kHz GBW | 85 dB Min CMRR | 0.1 % Max Gain Error | 1.5 mV Max Offset | 2.7 V to 40 V

Samples 4Q24

Features:

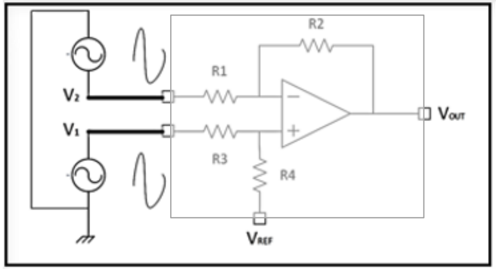
- **Supply Voltage** **2.7 V to 40 V**
- **1 MΩ High R_{IN}** & **VCM** of **-30 to 85V** (±15 to 42.5V) for V_S of 9 to 40V (±4.5 to 20V)
- **Integrated Gain Options** **1/16, 1/12, 1/10, 1/5**
- **High CMRR** **85 dB (min)**
- **Low Gain Error** **0.1 % (max)**
- Low Offset / Drift 1.5 mV (max), 1 µV/℃ (typ)
- Low Quiescent Current 65 µA (typ)
- Gain Bandwidth product (G = 1) 125 kHz
- Stable for Caps up to 100pF with resistive output impedance

Benefits

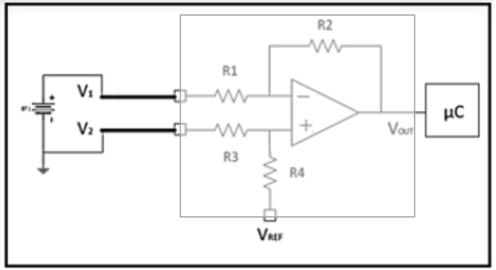
- **1 MΩ Input impedance** for easy interface to standard analog input module signals (-10V to 10V, -5V to 5V & 0 to 10V) with **heavy VCM disturbance**
- **Integrated Gain options** for easy interface to 2.5V / 5V ADC full scale
- **Good CMRR and Gain Error** to enable DC Precision using precision matched thin film resistors
- **Low Offset & Drift** for precision signal sense and amplification which can be further calibrated out to maximize dynamic range
- **Resistive open loop output impedance** and Stable for cap loads
- **EMI filtering** on inputs and power supply results in high EMIRR for better performance in noisy environments

Sectors / End Equipment / Applications

- Analog input module
- Battery Test & Measurement (V / I sense and monitoring)
- Signal level translation
- Differential to single ended conversion
- Grid Infrastructure



Analog Input Module : VCM Rejection up to ± 30V



12V / 40V Battery Voltage Sensing

Texas Instruments

Getting started

You can start evaluating this device leveraging the following:

Content type	Content title	Link to content or more details
Product folder	INA500 product folder	https://www.ti.com/product/INA500
Samples	Sampling page for INA500 A/B/C	https://www.ti.com/product/INA500#order-quality
Technical blog content or white paper	Product Overview: • Small-Size INA500x Versus Discrete Difference Amps	https://www.ti.com/lit/ab/sbat022/sbat022.pdf
Selection and design tools and models	• Reference Design • Spice models	INA500A Reference Design INA500B Reference Design INA500C Reference Design https://www.ti.com/product/INA500#design-development
Development tool or evaluation kit	DIP-ADAPTER-EVM DIY-AMP-EVM	https://www.ti.com/tool/DIP-ADAPTER-EVM https://www.ti.com/tool/DIYAMP-EVM

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TEXAS INSTRUMENTS

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Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265

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