

±150V Common-Mode Difference Amplifiers for Voltage and High-Side Current Sensing in GEO and LEO Platforms



For decades, aerospace and defense engineers have relied on discrete component designs for radiation-hardened designs due to the lack of practical integrated alternatives. The [INA1H94-SP](#) and [INA1H94-SEP](#) help bridge the gap for engineers creating robust radiation-hardened designs such as [battery management systems](#) for both GEO and LEO systems while also reducing weight, bill of materials (BOM) size, and improving accuracy.

Higher Voltage Trends in the Space Market

As the space industry pushes for the commercialization of space travel, more vehicles are being launched into space every day. Each of these space vehicles, including satellites, rovers, and probes, all come equipped with solar-powered batteries. There are various types of battery topologies used to create a battery pack; when considering which battery technology to implement, engineers must evaluate different performance specifications such as energy density, cycle life and self-discharge rate. These specifications are all key because monitoring the voltage of each individual battery cell is critical in providing the state of health of the battery. The most common battery pack topology, lithium-ion, is composed of multiple 3.6V commercially available off-the-shelf batteries (COTS) in series, and can range from 28V up to 120V. Due to pushes for longer space mission durations and lessening the launch weight of space vehicles, there is an emerging trend of higher voltage battery packs. Additionally, this increase in bus voltages calls for radiation-hardened devices that can take an input up to 120V (with additional margin) in applications such as in-line current sensing for motor control systems.

Why an Integrated Difference Amplifier?

Integrated difference amplifiers offer designers the opportunity to explore remarkable methods of voltage and current sensing, providing performance benefits compared to the discrete implementation. An integrated difference amplifier offers improved precision and accuracy without requiring expensive, high-tolerance resistors (typically $<\pm 0.1\%$ tolerance). Aside from accuracy, difference amplifiers are inherently able to extend the common-mode voltage range beyond the amplifier supply rails while maintaining an excellent common-mode rejection ratio (CMRR), which is challenging to accomplish with discrete resistors without tight matching. [Table 1](#) below compares key parameters between the INA1H94-SP, INA1H94-SEP, and a discrete difference amplifier.

Table 1. Integrated vs. Discrete - Electrical Performance Comparison

	INA1H94-SP	INA1H94-SEP	Discrete Unity-Gain Difference Amplifier Using 0.1% Resistors
Common-Mode Voltage	±150V		(V-) to (V+) - 1.5V
Common-Mode Rejection Ratio (min)	84dB		Approximately 54dB
Resistor Drift (ppm/°C) (max)	10		Approximately 100
Gain Drift (max)	0.047%	0.067%	>1%

Reducing Size, Weight, and Component Count with Integrated Difference Amplifiers

Anywhere weight can be reduced translates to reduced spending in launch cost. Traditional amplifier designs for radiation-hardened systems, regardless of mission type, have long been constrained to using ceramic packaging, which is generally large and heavy. This new line of integrated difference amplifiers is available in ceramic and space-enhanced plastic for GEO and LEO missions, respectively, to help reduce the amount of weight on existing systems. [Figure 1](#) compares the size of the SOIC-8 space-enhanced plastic packaging (INA1H94-SEP), hermetically-sealed HKX-8 package (INA1H94-SP), and a quad-channel amplifier in the ceramic CDIP-14 packaging (LM124AQML-SP).

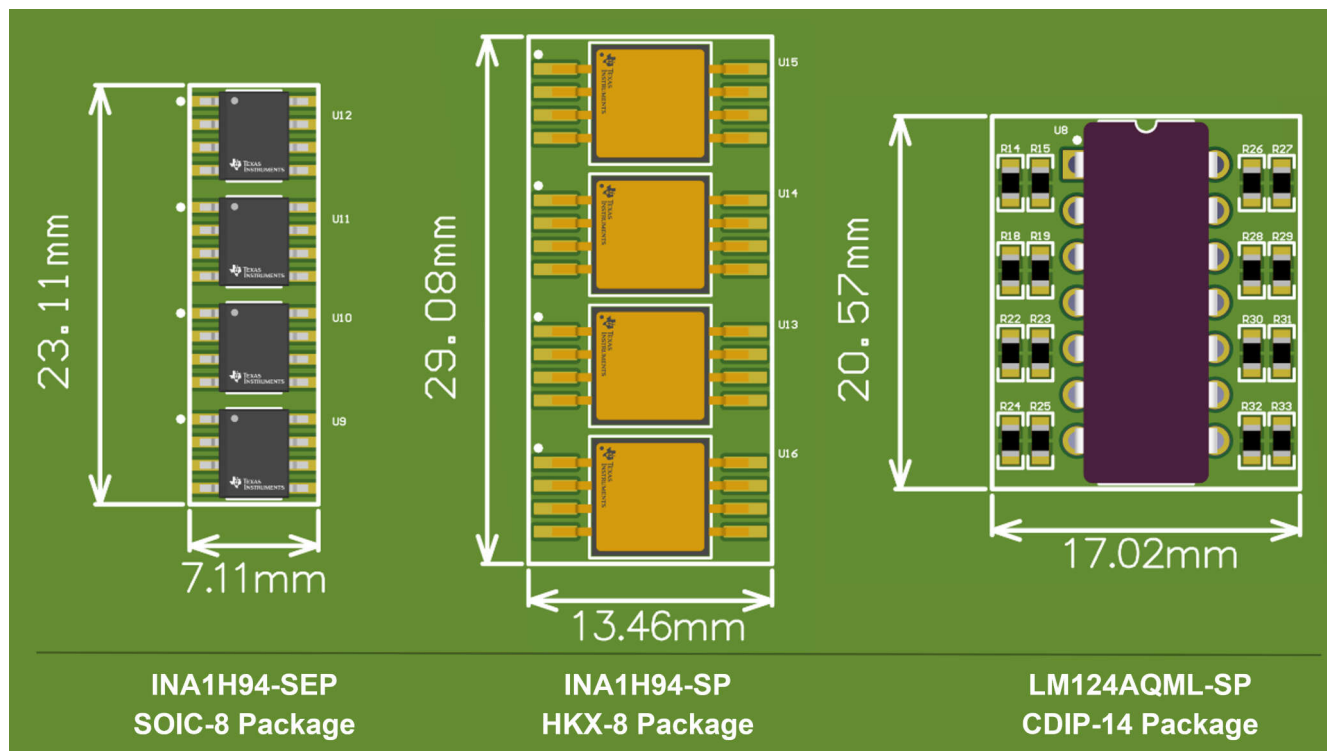


Figure 1. Size Comparison Between INA1H94-SEP, INA1H94-SP & LM124AQML-SP

[Table 2](#) provides a fair comparison of size, weight, and BOM between a traditional quad-channel amplifier design and four INA1H94 (-SP & -SEP) devices (providing equivalent four-channel monitoring capability) for GEO and LEO missions. Despite using four individual devices, the integrated difference amplifier designs provide significant advantages in size, weight, and BOM.

Table 2. Integrated versus Discrete - Size, Weight, and BOM Comparison

	INA1H94-SEP	INA1H94-SP	Amplifier + 0603 Resistors
Package Outline	SOIC-8	HKX-8	CDIP-14
Size (mm ²)	164.3*	391.4*	Approximately 350
Mass (mg)	370*	1,700*	4,850
Component Count	4	4	20+

Serial Battery Stack Voltage Monitoring

To monitor the state of health of the battery pack, an INA1H94-SP or INA1H94-SEP can be used for voltage sensing of each individual COTS battery. Most commonly, engineers either use a voltage divider or create a discrete difference amplifier design. Each of these implementations come with a unique set of challenges.

Using a single voltage divider to monitor the positive terminal of the battery solely shows the voltage output of that particular node, but not provide information on the voltage of the battery, as the reference is unknown. By using a difference amplifier, accurate determination of the voltage of each individual battery becomes possible;

however, mismatches in the discrete implementation can degrade CMRR performance, as mentioned earlier. Figure 2 shows the INA1H94-SP being used for serial battery voltage monitoring of a 33.6V battery pack.

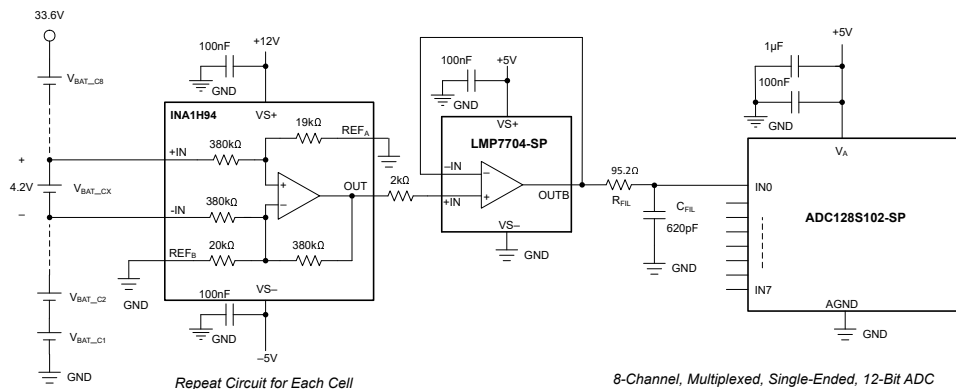


Figure 2. Single-Cell Voltage Monitoring with INA1H94-SP

For battery packs of 48V and above, discrete designs typically require devices with isolation to protect the inputs of operational amplifiers from high common-mode voltages. The $\pm 150\text{V}$ common-mode voltage range of the INA1H94-SP and INA1H94-SEP allows direct interfacing to any cell within the battery pack without additional isolation circuitry. In discrete designs, individual resistor tolerance compound, increasing overall gain error and drift over temperature. When using typical 1% tolerance resistors, a discrete difference amplifier implementation can lower accuracy compared to an integrated design with matched thin-film resistor networks.

High-Side Current Sensing

The INA1H94-SP is also a practical device for high-side current sensing to detect load shorts to ground due to the wide input common-mode voltage range of $\pm 150\text{V}$ as systems trend towards 120V bus voltages. Because the INA1H94-SP has a differential gain of one, using an operational amplifier such as the OPA4H199-SP is recommended when sensing across a small sense resistor. This approach minimizes power dissipation while scaling the output to the full scale range of the analog-to-digital converter (ADC), such as the ADC128S102QML-SP as shown in Figure 3.

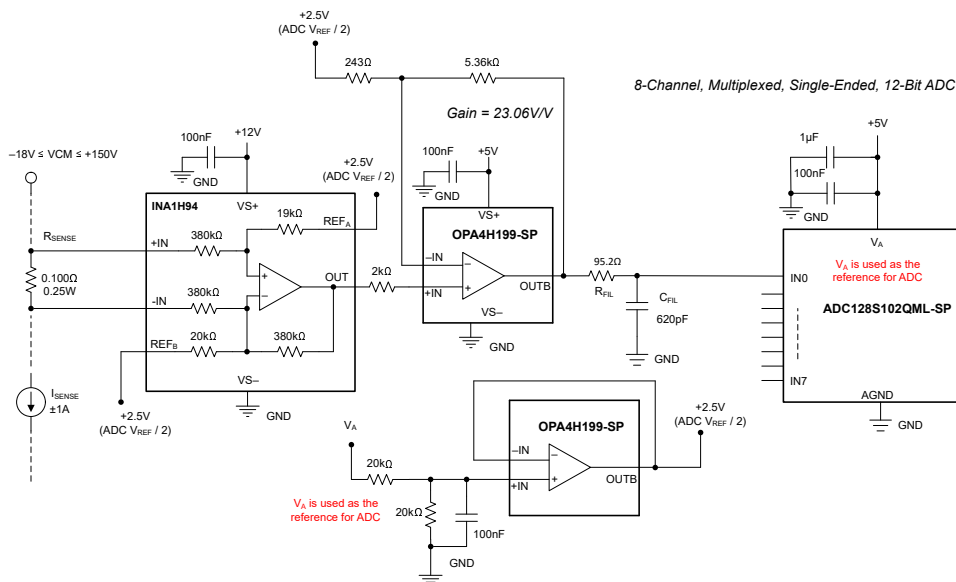


Figure 3. High-Side Current Sensing with INA1H94-SP/-SEP, Unipolar Supply

In the circuit example in Figure 3, the INA1H94 is powered with a unipolar supply of +12V (VS+) and GND (VS-). To allow headroom, the difference amplifier reference voltage is set above GND where the REF_A and REF_B pins are set to the mid-supply of the ADC at 2.5V. The OPA4H199-SP is configured in a non-inverting gain

configuration supporting a gain of approximately 23.05V/V, with the operational amplifier gain resistor network also referred to 2.5V (ADC mid-scale). This circuit supports a common-mode voltage range from +150V to -18V at the inputs of the difference amplifier and an input differential voltage of $\pm 100\text{mV}$ across the 100m Ω shunt resistor. The resulting values allow for monitoring a current of $\pm 1\text{A}$ across the sense resistor.

For systems that require a wider common-mode voltage, use a bipolar supply to extend the negative common-mode voltage as shown in [Figure 4](#).

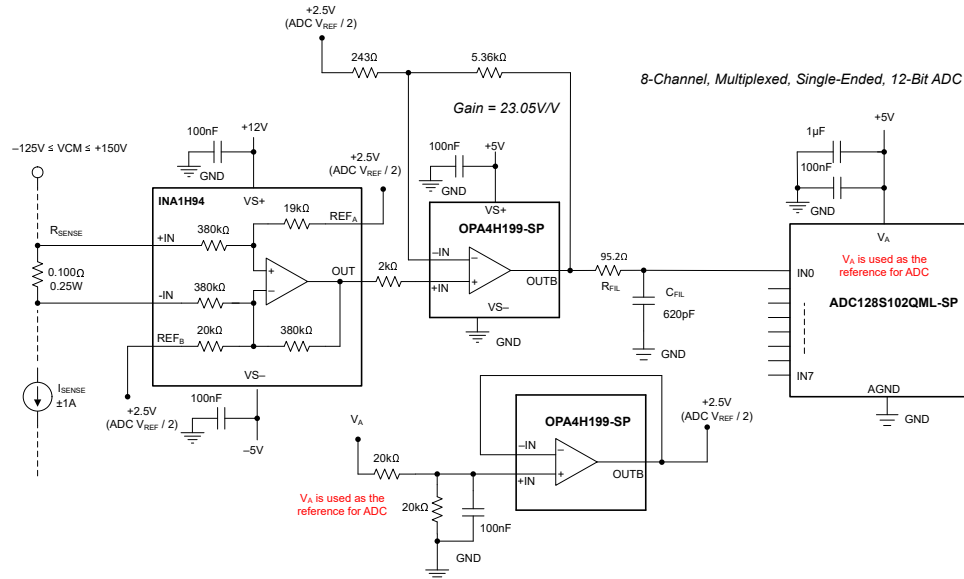


Figure 4. High-Side Current Sensing with INA1H94-SP/-SEP, Bipolar Supply

The INA1H94-SP/-SEP is a difference amplifier, where the input common-mode voltage range, differential input voltage range, and linear output voltage range is a function of the positive (V_+) and negative (V_{S-}) voltage supplies, as well as the reference voltage potential REF_A and REF_B . To verify and simulate with other component values that match your system requirements, please refer to the [INA1H94-SP/-SEP Difference Amplifier Input/Output Range Finder Tool](#) to verify the input common-mode range of the device.

[Table 3](#) shows how adding a negative power rail substantially extends the common-mode voltage of the INA1H94 to -140V.

	Unipolar Supply	Bipolar Supply
Supply Voltage	$VS_+ = +12\text{V}, VS_- = \text{GND}$	$VS_+ = +12\text{V}, VS_- = -5\text{V}$
Reference Voltage	$REF_A = REF_B = 2.5$	$REF_A = REF_B = 2.5$
Common-Mode Range	$-18\text{V} < V_{CM} < +150\text{V}$	$-140\text{V} < V_{CM} < +150\text{V}$
Differential Input Range	$\pm 100\text{mV}$	$\pm 100\text{mV}$
Shunt Resistor	100m Ω	100m Ω
Input Current Range	$\pm 1\text{A}$	$\pm 1\text{A}$
OPA4H199 Output	$+0.194 < V_O < 4.806\text{V}$	$+0.194 < V_O < 4.806\text{V}$

Learn More

- Texas Instruments, [Radiation-Hardened Battery Management System](#), reference design
- Texas Instruments, [Optimizing CMRR in Differential Amplifier Circuits With Precision Matched Resistor Divider Pairs](#), application note

EVM, Tools and Samples Order Info

- Test out the performance of the INA1H94-SP with engineering models (INA1H94HKX/EM) [available on TI.com!](#)
- [INA1H94-SP/-SEP Input/Output Voltage Range Finder tool](#)

- [INA1H94-SP Datasheet](#)
- [INA1H94-SEP Datasheet](#)
- [INA1H94-SP Evaluation Module](#)
- [INA1H94-SP Evaluation Module User's Guide](#)

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