

IA Parameters - Input Bias Current

TI Precision Labs – Instrumentation Amplifiers

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IA parameters – input bias current

Common application problems:

1. Sensor high output impedance processing
2. Input bias current return paths

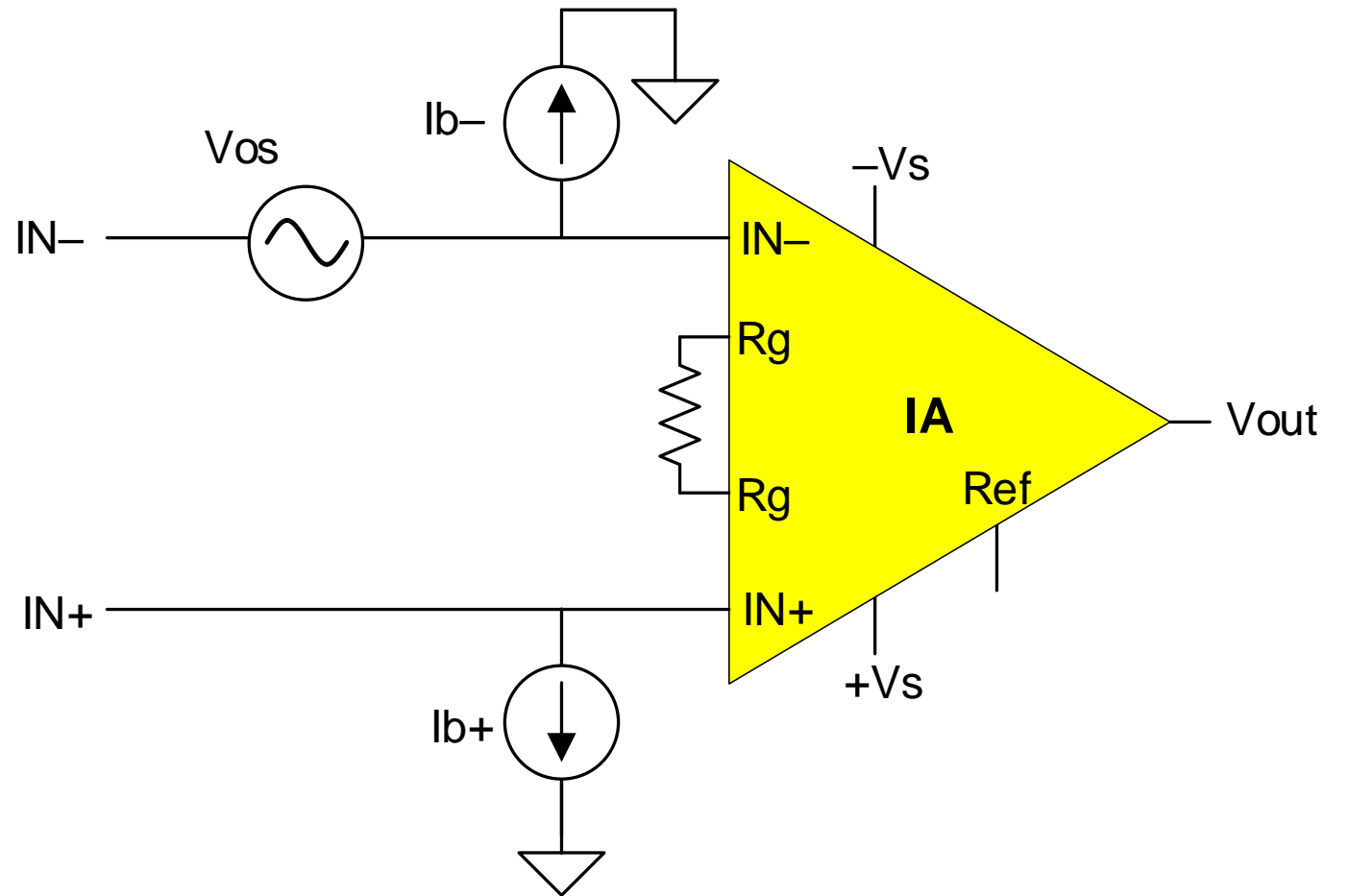
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Instrumentation amplifiers - the next level of precision signal conditioning

Integrated resistor networks maximize accuracy and space efficiency

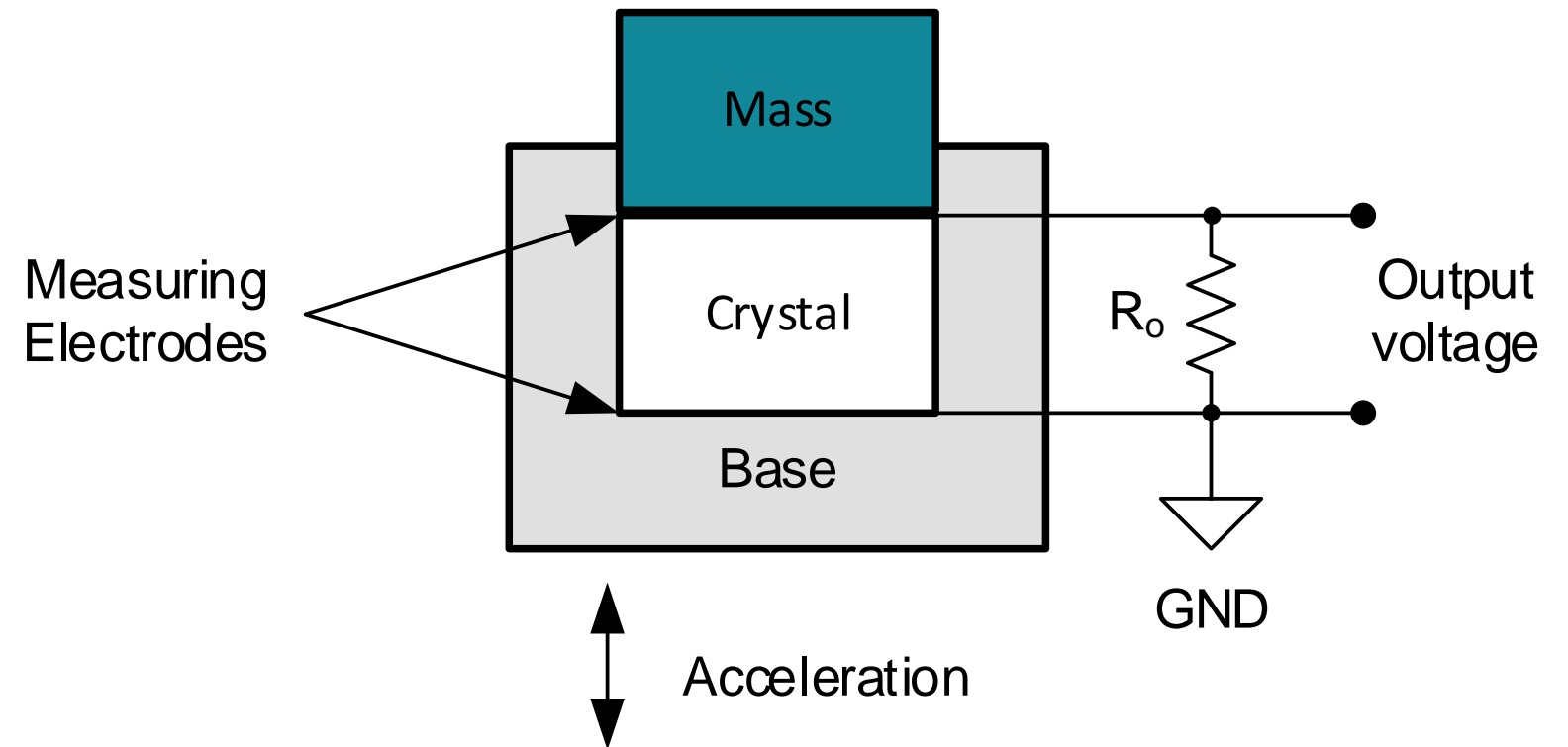
V_{os} and I_b – definition and recap

- Input bias current (I_b): current flowing into or out of the inputs of an IA. Can be modeled as a current source connected to each input.
- Input offset current (I_{os}): mismatch between I_b flowing into the two inputs of the IA
- Typical values of I_b (at room temperature):
 - Bipolar input: 1 nA to 50 nA
 - FET input: 1 pA to 50 pA
- Input offset voltage (V_{os}): differential input voltage that would have to be applied to force the IA's output to 0 V. Can be modeled as a voltage source in series with the inverting input terminal of the IA.
- Typical values of V_{os} (at room temperature): 2 mV down to 10s of μ V



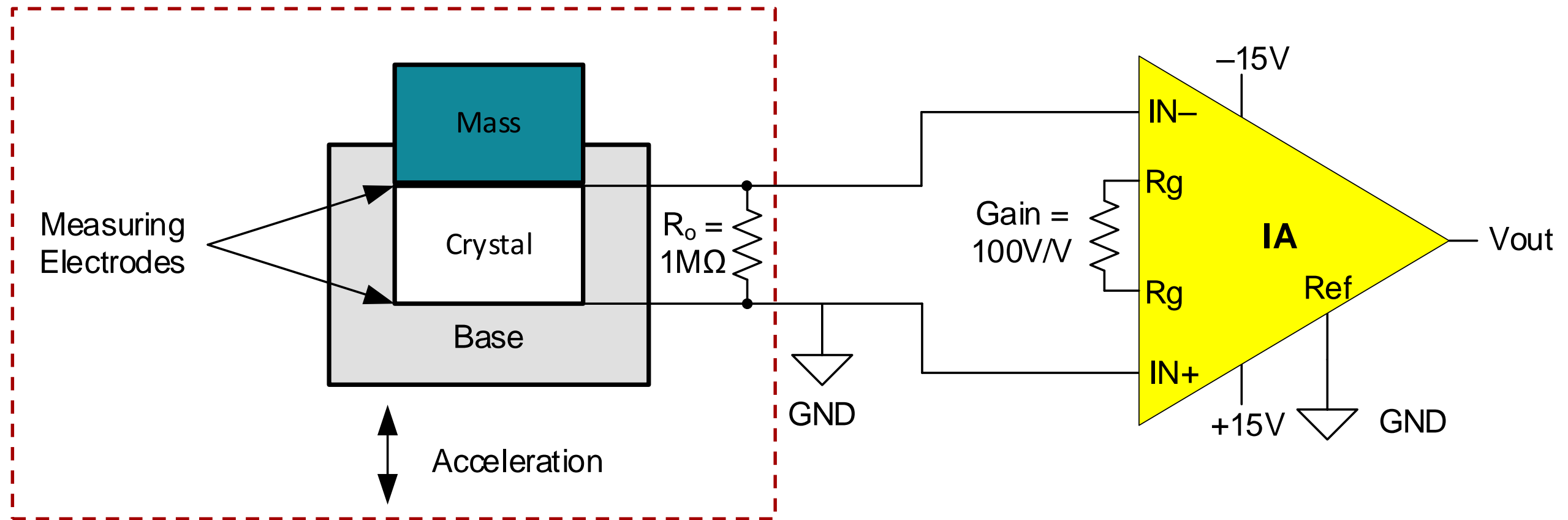
Input bias current effects – application example

- Piezoelectric accelerometer: consists of a mass attached to a piezoelectric crystal which is mounted on a base. This device measures acceleration when subjected to vibration and produces a voltage output.
- Applications which employ piezoelectric accelerometers:
 - dynamic response testing,
 - shock and vibration isolation,
 - auto chassis structural testing,
 - structural analysis,
 - reactors,
 - control systems and
 - materials evaluation



Piezoelectric accelerometer – IA processing

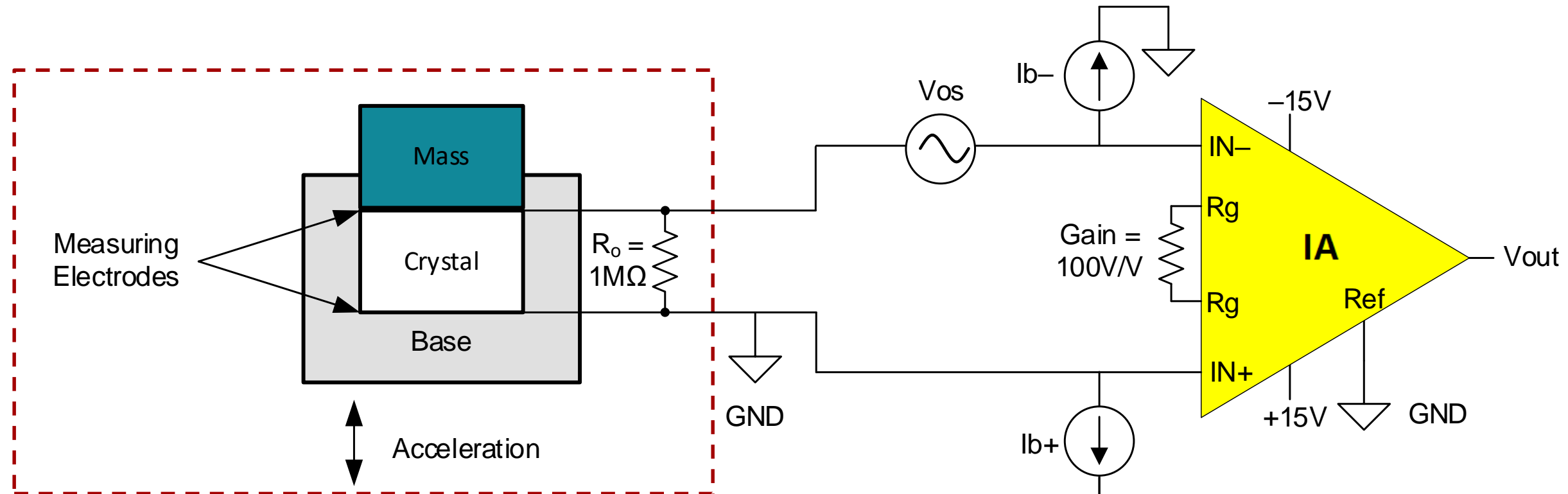
Piezoelectric accelerometer preamp circuit to convert acceleration to a potential:



Assume IA input bias current = $2.5 \mu A$ and the gain of the circuit is 100 V/V

Piezoelectric accelerometer – IA processing

Piezoelectric accelerometer preamp circuit to convert acceleration to a potential



$$V_{OS(Ib-)} = I_{b-} \times R_o,$$

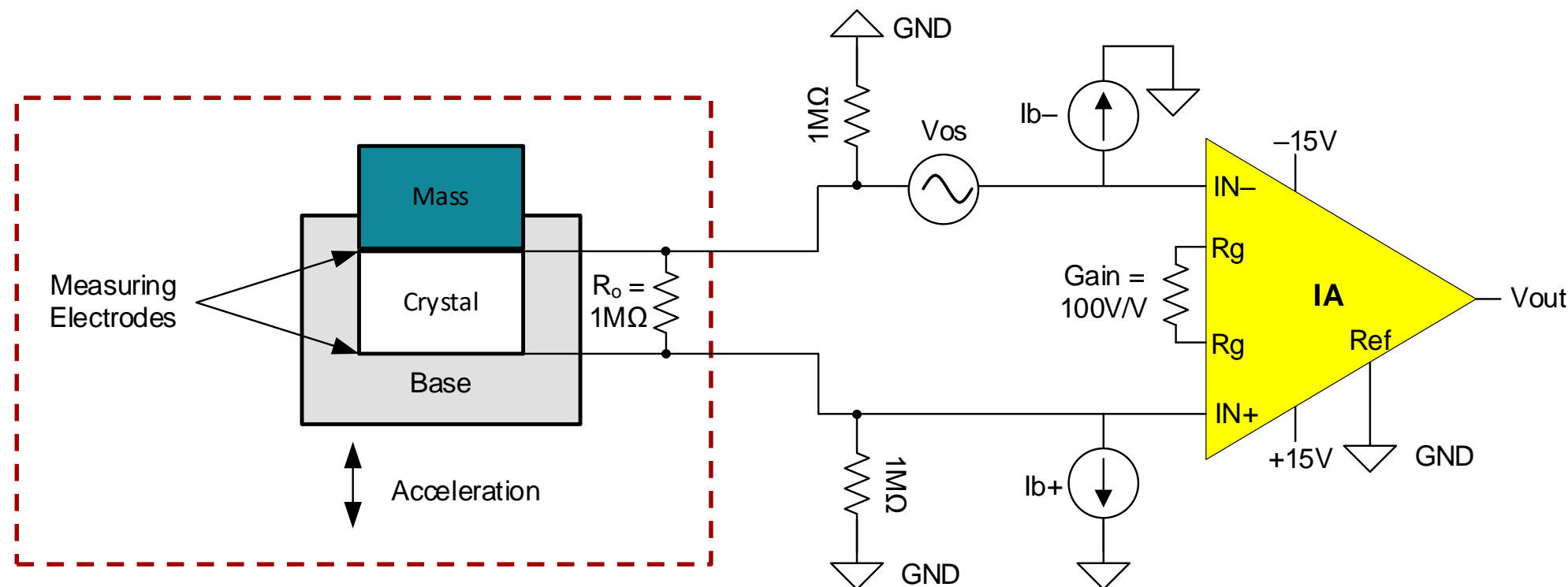
where I_{b-} is 2.5 μ A and R_o is 1 M Ω

$$V_{OS(Ib-)} = 2.5 \text{ V}$$

$$V_{out} = V_{OS(Ib-)} \times \text{Gain} = 2.5 \text{ V} \times 100 \text{ V/V} = 250 \text{ V (impossible due to 15 V supply voltage)}$$

IA processing – cancel I_b error effects

- Idea: balance IA inputs so that $V_{OS(Ib-)} = V_{OS(Ib+)}$



- Input offset current: I_{OS} = difference between the input bias current at the non-inverting terminal (I_{b+}) and the input bias current at the inverting terminal (I_{b-}) of the instrumentation amplifier.
- Assume input offset current of this IA to be $I_{OS} = 30 \text{ nA}$

IA processing – cancel I_b error effects

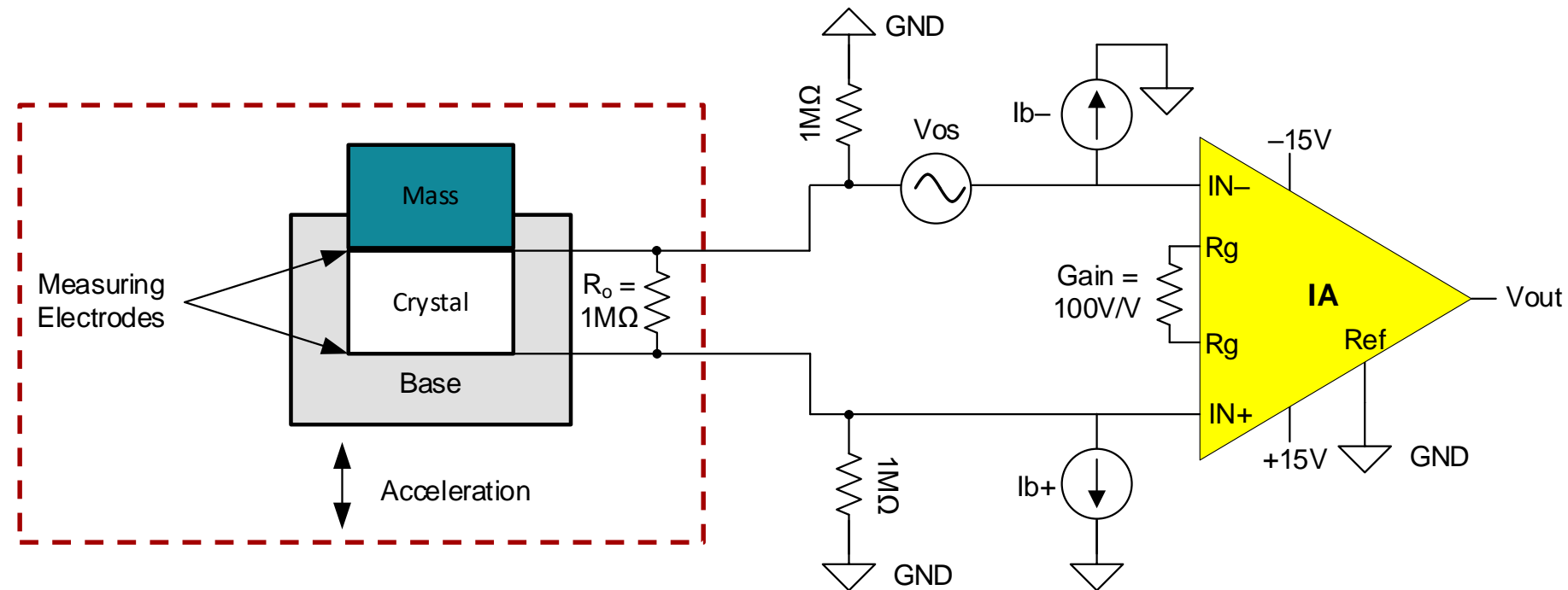
Idea: balance IA inputs so that $V_{OS(Ib-)} = V_{OS(Ib+)}$

Input offset current: $I_{OS} = I_{b+} - I_{b-} = 30 \text{ nA}$

$I_{b-} = 2.5 \text{ } \mu\text{A}$, $I_{OS} = 30 \text{ nA}$, so $I_{b+} = 2.5 \text{ } \mu\text{A} + 30 \text{ nA} = 2.53 \text{ } \mu\text{A}$

$V_{OS(Ib-)} = 2.5 \text{ V}$, $V_{OS(Ib+)} = 2.53 \text{ } \mu\text{A} \times 1 \text{ M}\Omega = 2.53 \text{ V} \rightarrow \Delta V_{OS} = 30 \text{ mV}$

$V_{out} = \Delta V_{OS} \times \text{Gain} = 30 \text{ mV} \times 100 \text{ V/V} = 3 \text{ V}$



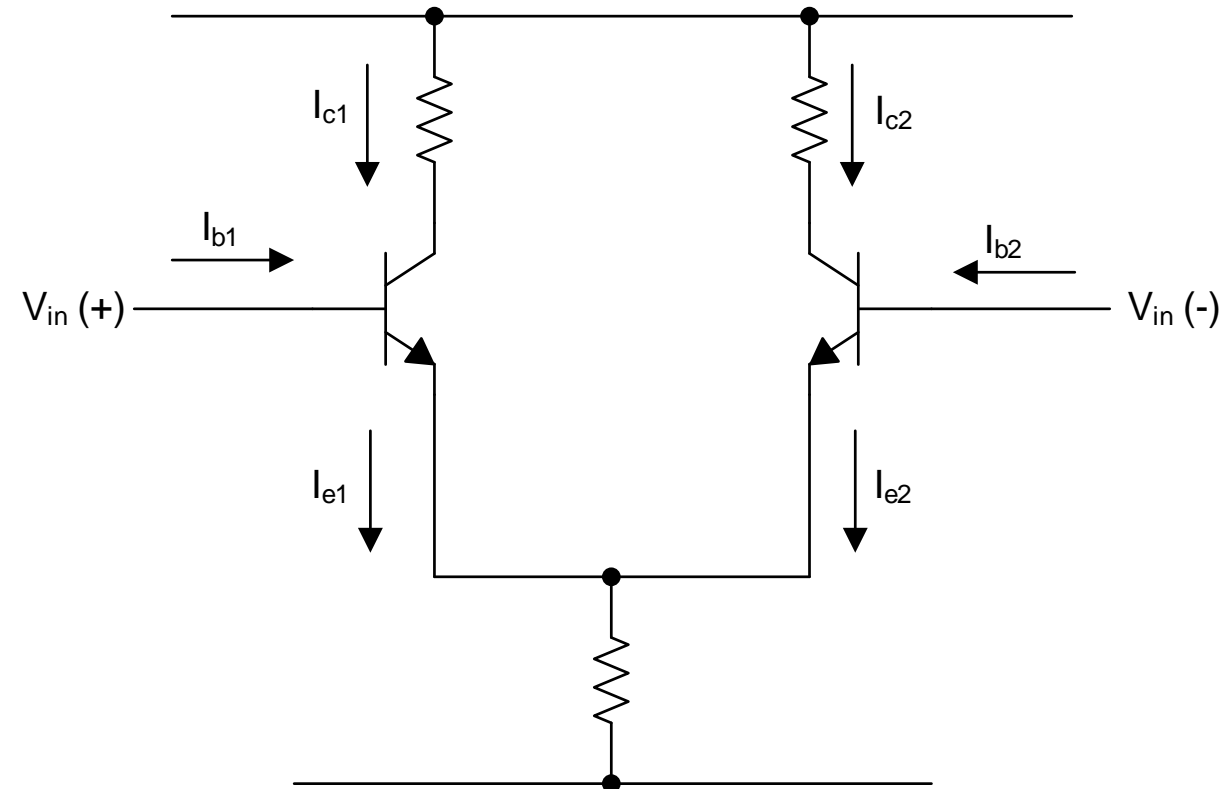
High impedance IA processing – solution

- Idea: Pick a low I_b IA
- Typical values of input bias current (at room temperature):
 - Bipolar input: 1 nA to 50 nA
 - FET input: 1 pA to 50 pA

Part number	Input technology	Input bias current (typ, max)
INA121	FET	4 pA, 50 pA
INA331	FET	0.5 pA, 10 pA
INA111	FET	2 pA, 20 pA
INA827	Bipolar	35 nA, 50 nA

Super- β input amplifiers

- $\beta = I_c / I_b$
- Traditional bipolar transistor β : 50 to 200
 - If $\beta = 100$ and $I_c = 10 \mu\text{A}$, then $I_b = 100 \text{ nA}$
- Transistors with super- β technology > 1000
 - If $\beta = 1000$ and $I_c = 10 \mu\text{A}$, then $I_b = 10 \text{ nA}$
 - Typical I_b for super- β input IAs: 0.1 nA to 5 nA



<https://www.ti.com/lit/an/sboa305/sboa305.pdf>

Application Brief
Super-beta Input Amplifiers: Features and Benefits
 TEXAS INSTRUMENTS

David Hess, Software Development and Design Services

Introduction
 Texas Instruments (TI) new generation of bipolar amplifiers are built on a precision complementary bipolar semiconductor technology that incorporates super-beta bipolar transistors. Super-beta transistors are optimized for high current gain (> 1000) which allow them to deliver a high base current and still maintain high linearity and low distortion.

Why do we care about base current?
 In an amplifier, base current of the input transistors translates to input base current (I_b). Traditional bipolar amplifiers have higher base current and, therefore, require more base current to drive the input signal. The higher I_b may be suitable for high source impedance applications.

What is super-beta?
 The beta (β) of a transistor is a measure of current gain. In the case of the transistor, collector current (I_c) is the base current (I_b), as shown in Equation 1:

$$\beta = I_c / I_b$$

The β value is used for a given transistor and operating condition. Figure 1 shows a simplified amplifier input stage using bipolar transistors.

What are the benefits of lower I_b?
 Lower I_b translates to lower input current noise. The relationship between I_b and current noise is best described in Equation 2. The current noise (I_n) of a bipolar amplifier is given by:

$$I_n = \sqrt{2qI_b}$$

where q is the elementary charge (1.6 x 10⁻¹⁹ C), I_b is the base current (I_b) of a bipolar amplifier, and I_n is the current noise.

Figure 1. Simplified amplifier input stage
 The value of β for traditional bipolar transistors typically ranges from 100 to 200 which may lead to a relatively high current for a given collector current. For example, a transistor with a β value of 100 and I_c of 10 μA will require 100 nA of I_b.

Equation 2. Current noise (I_n)
 $I_n = \sqrt{2qI_b}$

Super- β input amplifiers – benefits

- Low input bias current \rightarrow suitable for high source impedance applications
- Low current noise \rightarrow suitable for precision applications where current noise combines with input impedance to produce a DC offset voltage error ($i_n \times R_{in}$)
- Preserve low voltage noise and 1/f noise \rightarrow suitable for high precision applications across all frequency ranges

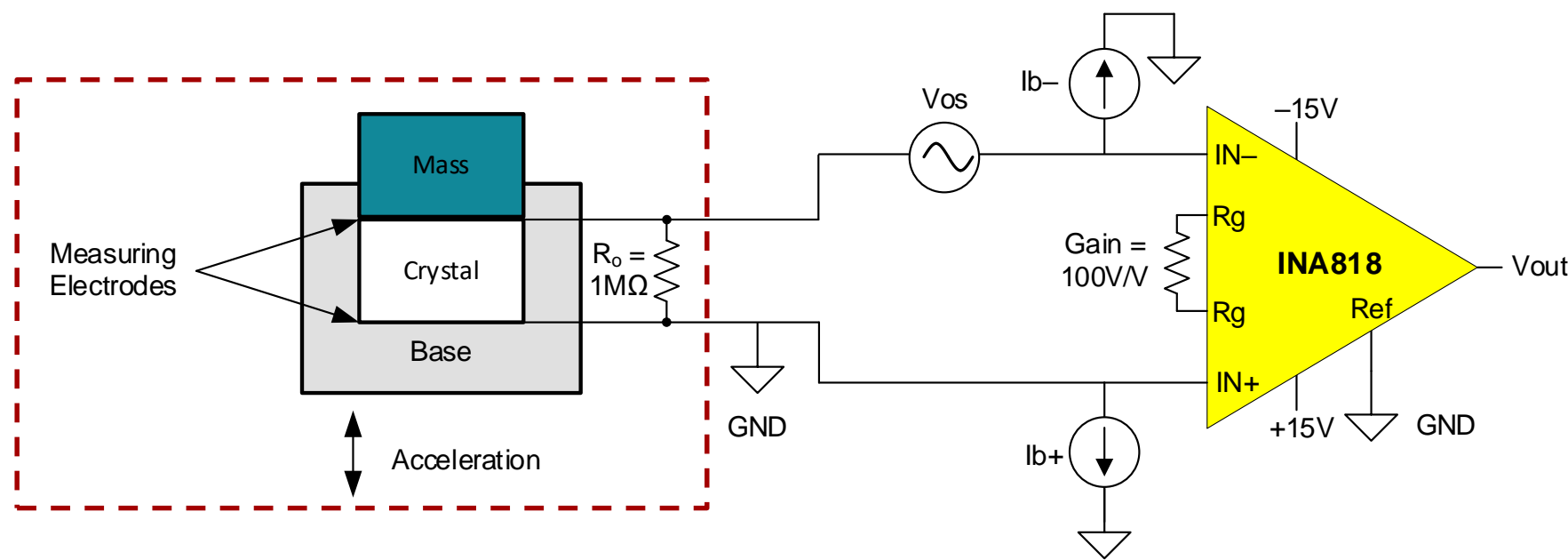
Device	Attribute	I_B (nA)	i_n (pA _{pp})
INA818 (super-beta)	Typical	0.15	4.7
	Maximum	0.50	-
INA118 (traditional)	Typical	1.00	80.0
	Maximum	5.00	-

Super- β input IA	Input bias current (max)
INA818	0.5nA
INA819	0.5nA
INA821	0.5nA
INA828	0.6nA

Browse TI's super-beta portfolio on [ti.com/inas](https://www.ti.com/inas)

Example revisit – piezoelectric accelerometer

- Piezoelectric accelerometer preamp circuit to convert acceleration to a potential



Summary of accelerometer example:

- Take 1: IA with 2.5 μA of I_b :
output limited to 15 V supply
- Take 2: Balance IA inputs:
3 V error
- Take 3: use IA with super- β inputs:
15 mV error

$$V_{OS(Ib-)} = I_{b-} \times R_o,$$

where I_{b-} is 0.15 nA and R_o is 1 M Ω

$$V_{OS(ib-)} = 0.00015 \text{ V}$$

$$V_{out} = V_{OS(ib-)} \times \text{Gain} = 0.00015 \text{ V} \times 100 \text{ V/V} = 15 \text{ mV}$$

IA parameters – input bias current

Common application problems:

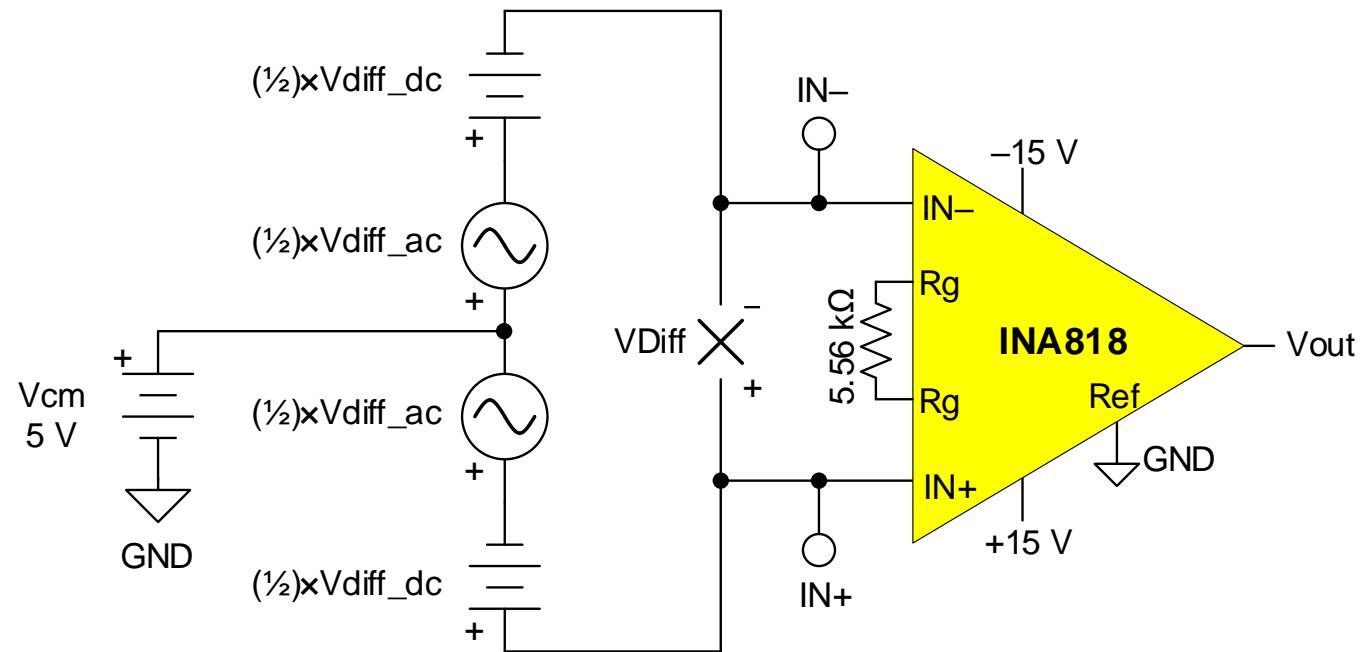
1. Sensor high output impedance processing
2. Input bias current return paths

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Importance of input bias current return paths

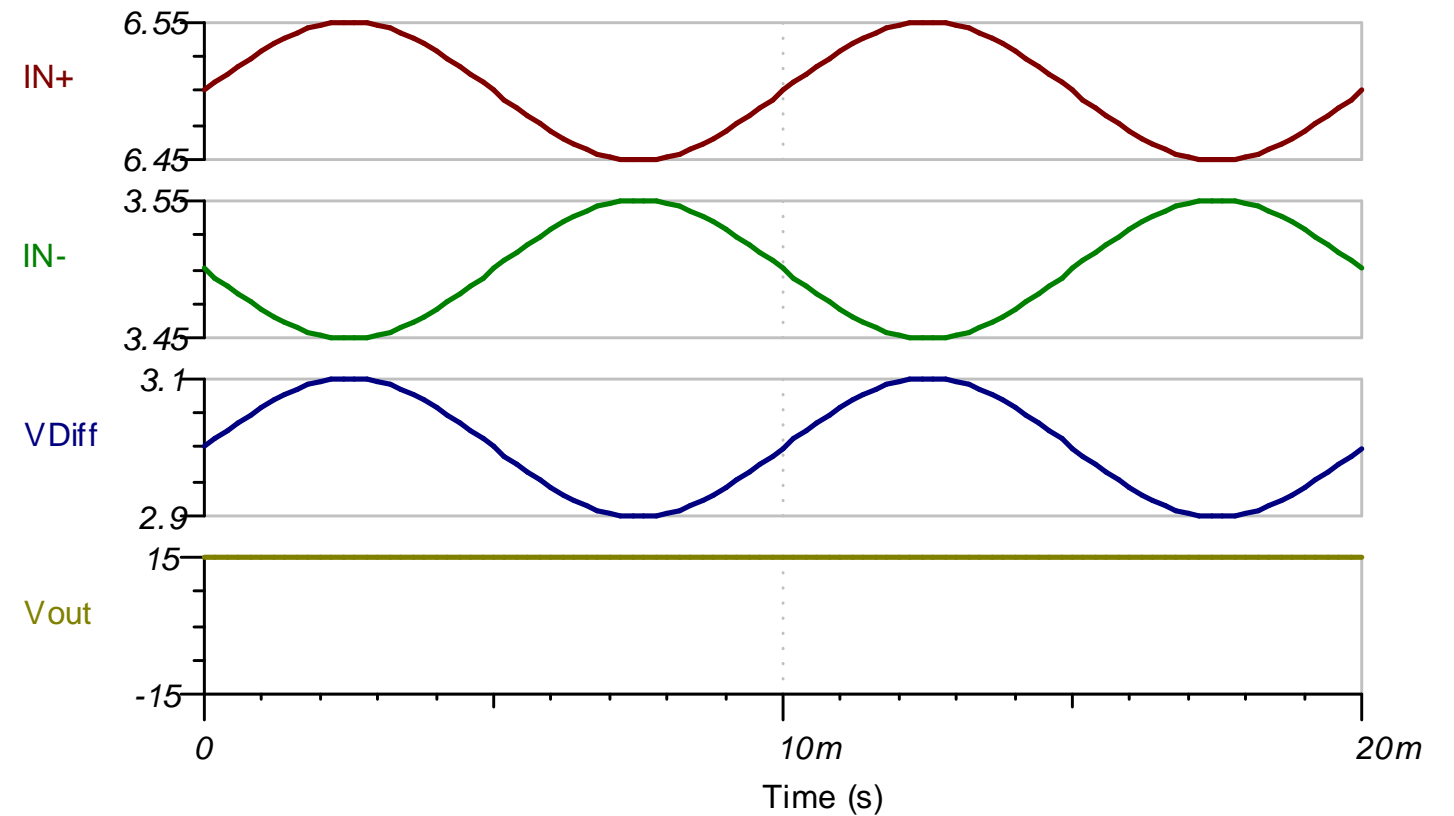
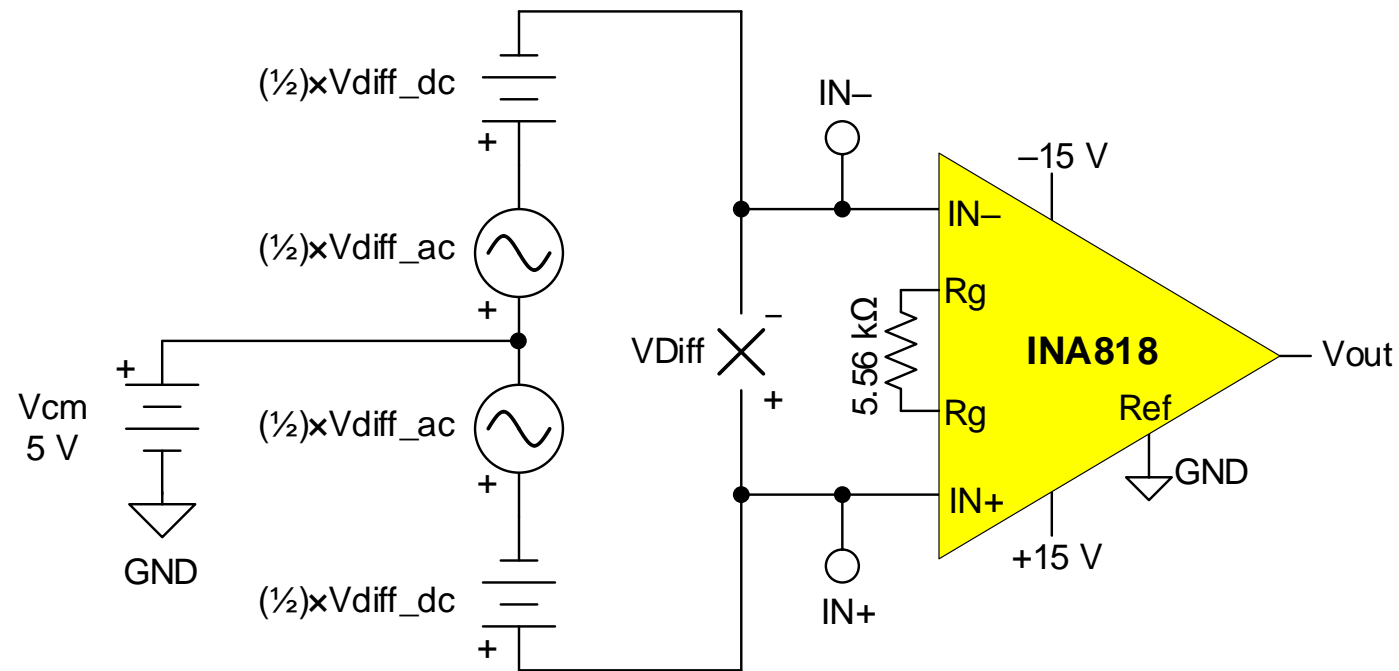


- Input: 100-Hz sine wave with an amplitude of 100 mV in the presence of a 5 V common-mode voltage and a 3 V dc voltage.
- Desired $V_{out} = \pm 1$ V signal
- Calculate gain:

$$\begin{aligned} \text{Gain} &= V_{out} / V_{in} \\ &= 1 \text{ V} / 100 \text{ mV} \\ &= 10 \text{ V/V} \end{aligned}$$

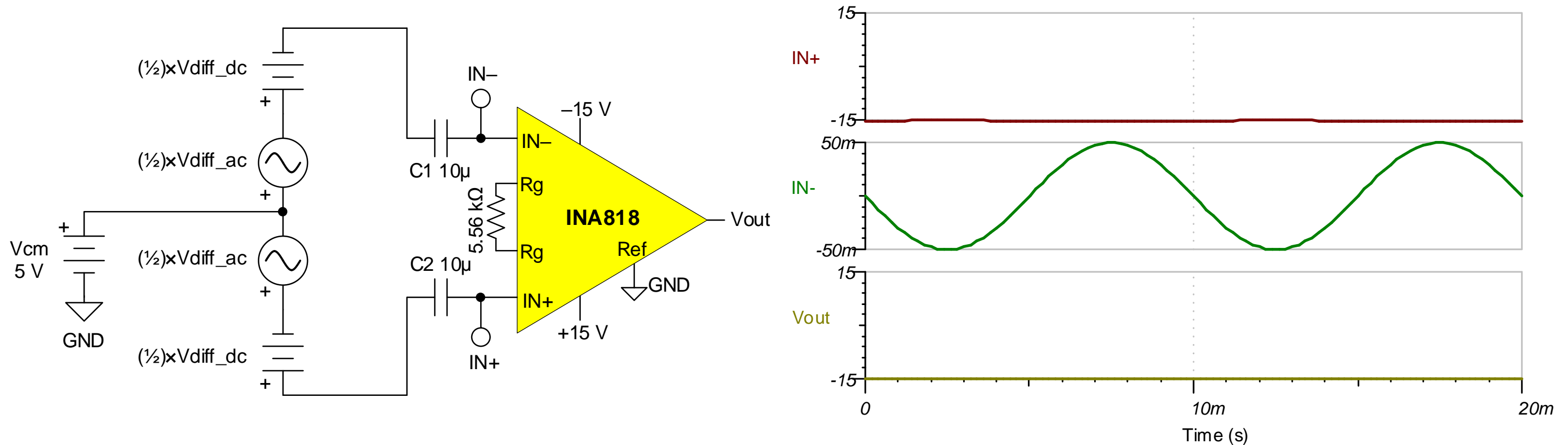
I_b return paths – transient analysis

- IA rejected the 5 V common mode signal but the 3 V dc voltage summed with the differential voltage \rightarrow Vdiff curve
- Vout saturated to the positive power supply rail



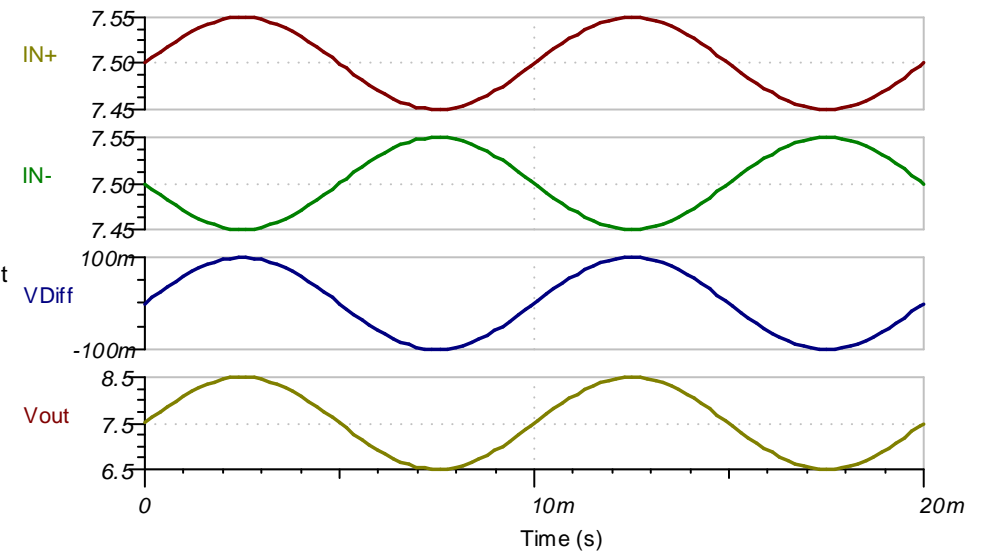
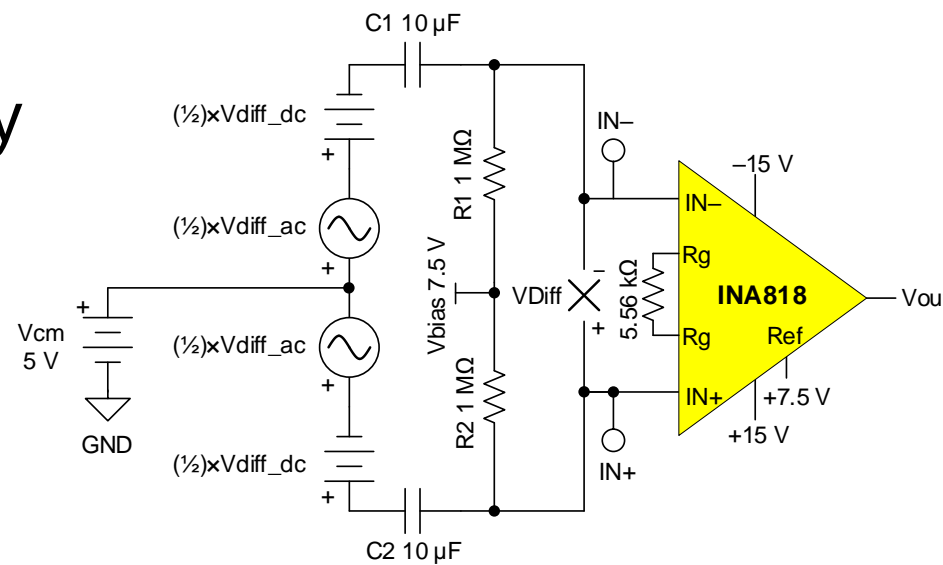
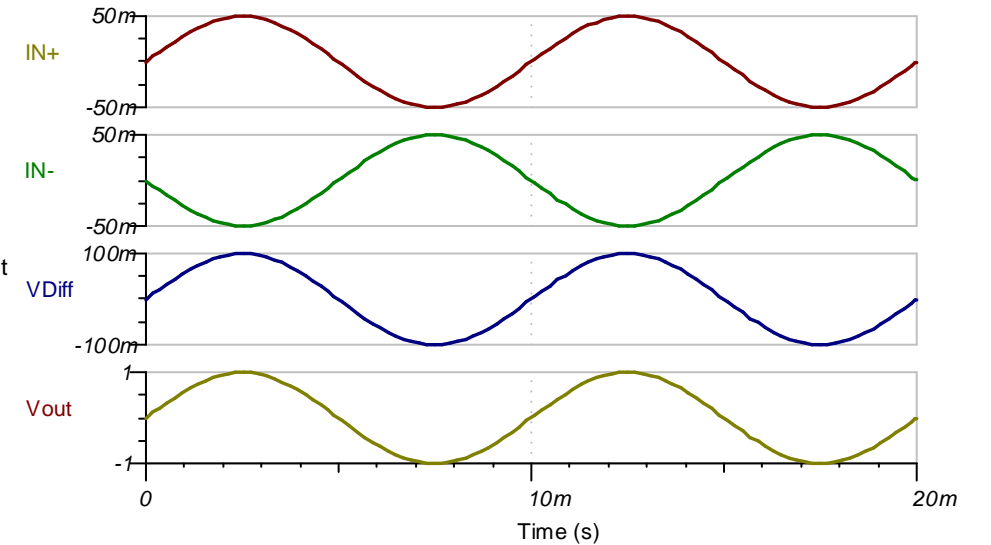
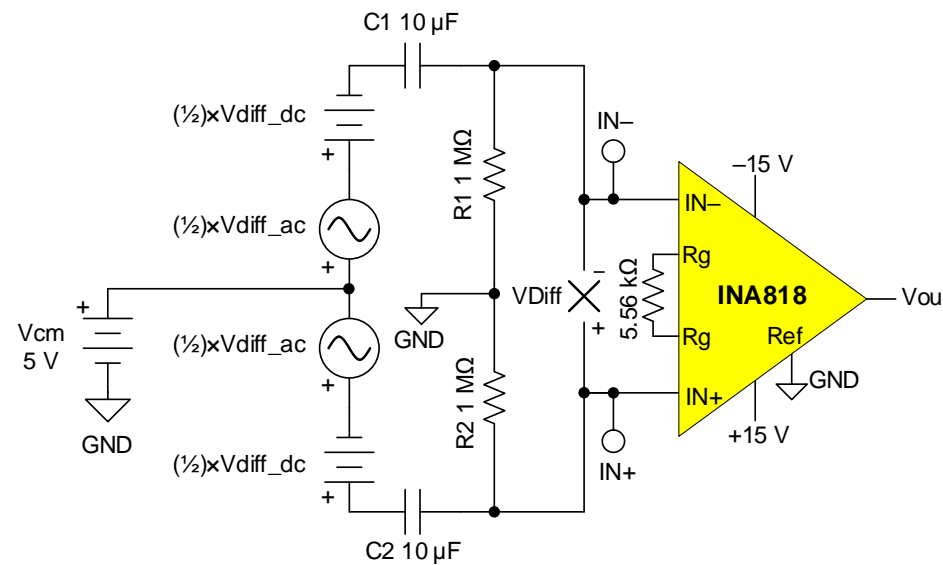
AC coupling – common mistake

- Incorrect ac-coupled circuit by adding a capacitor in series with each IA input terminal, without providing a path for the input bias current $\rightarrow I_b$ of the IA will charge the capacitor until the output is saturated



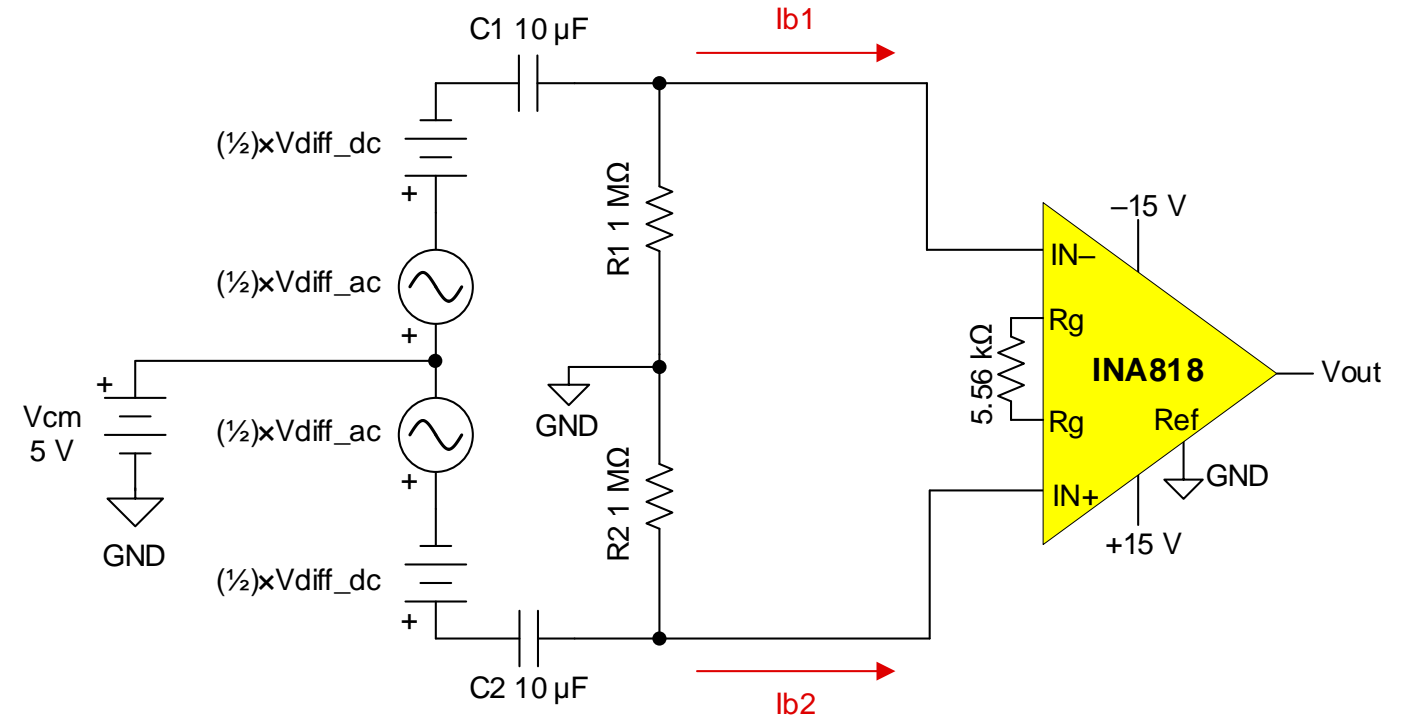
AC coupling – proposed solution

- **Proposed solution:** connect a resistor from each IA input to system ground or other bias voltage
- **Warning:** Vref and Vbias must be able to sink and source current; using an LDO may be unacceptable because an LDO can only source current. A buffer or a voltage reference is usually needed.



Component selection and trade-offs

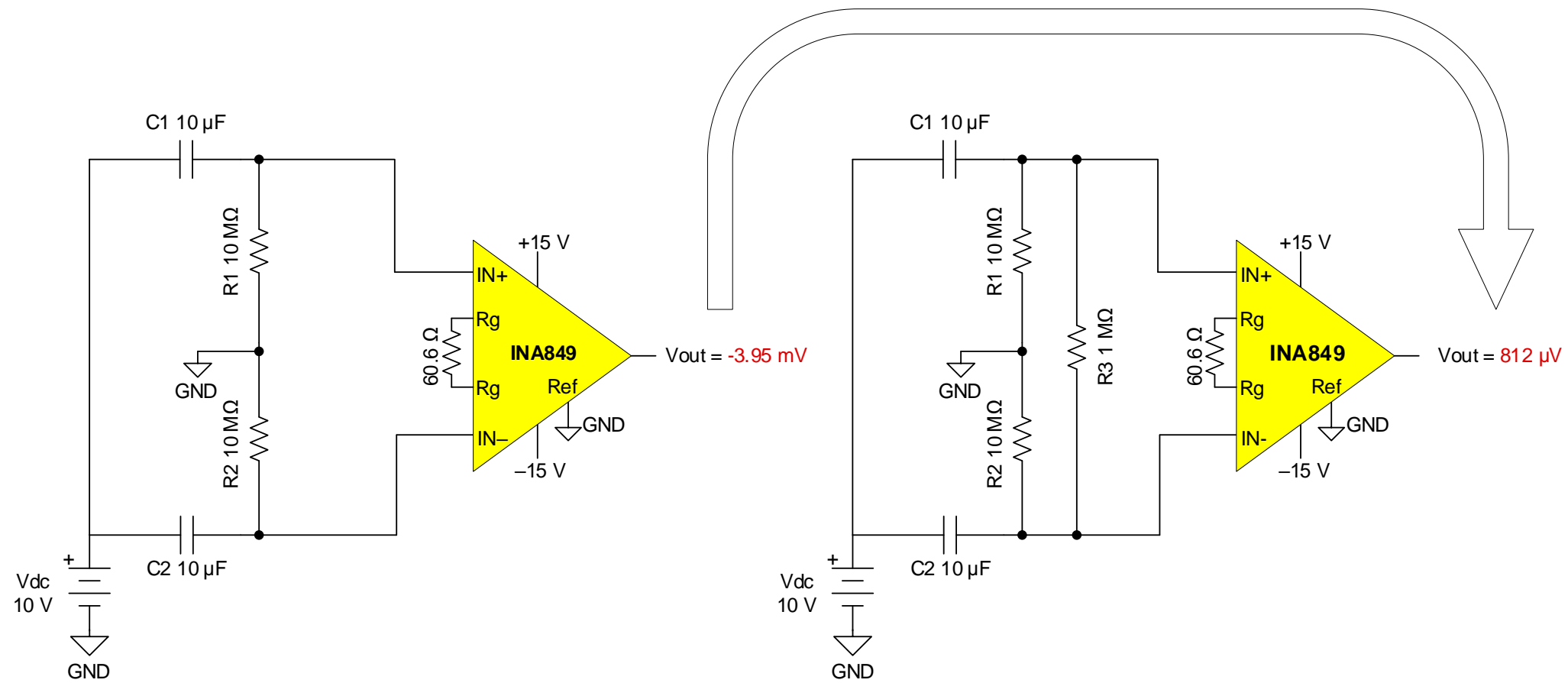
- Adding resistors and capacitors → increased noise, offset and limited board space
- Typical resistor values for R1 and R2; 100 kΩ to 1 MΩ
- I_b flows into these input impedances and produces V_{OS} adding to overall system error
- Precision: R1 must match R2 and C1 must match C2 to preserve CMRR



$$V_{OS(Ib)} = (I_{b1} \times R_1) - (I_{b2} \times R_2)$$

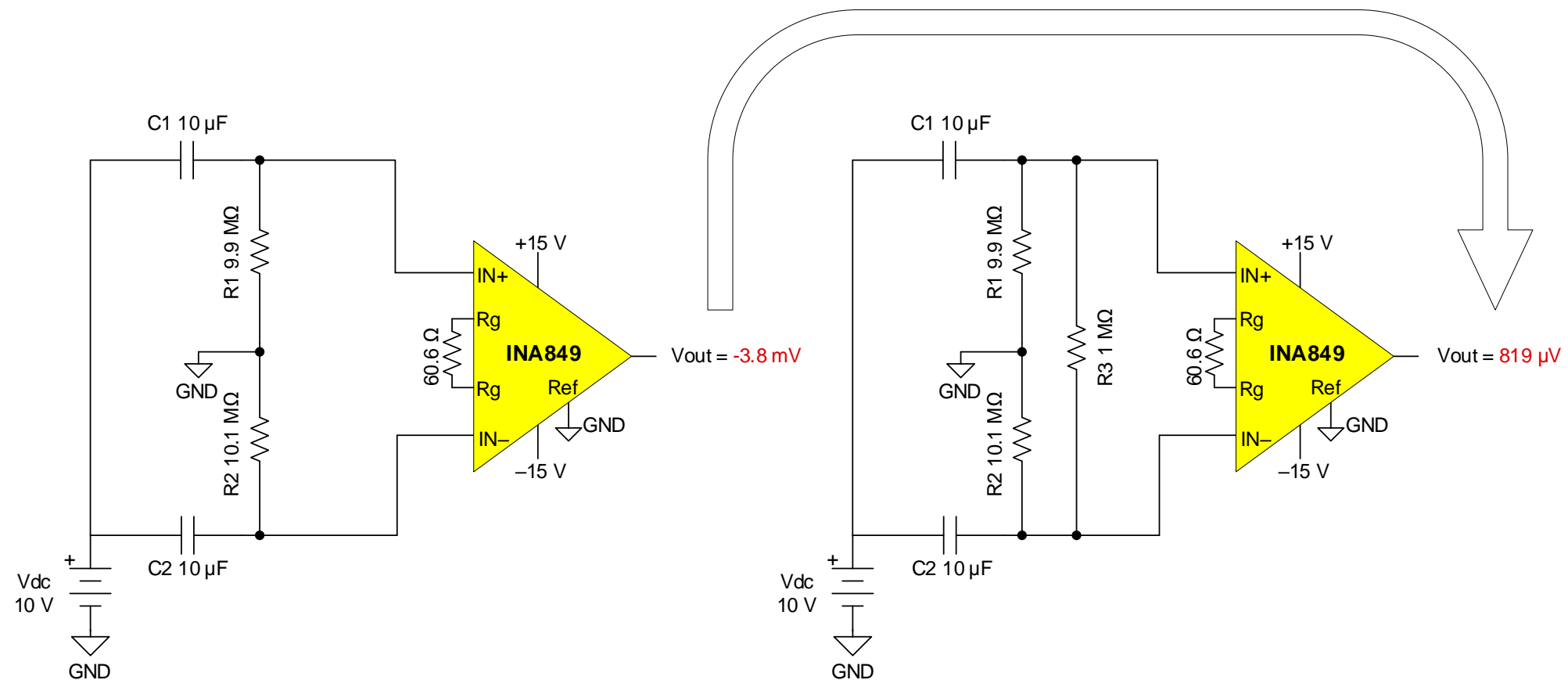
Component selection – increasing precision

- Add a third resistor between IA inputs: one-tenth the value of the other two
- Adding a third resistor between the inputs of the IA reduces the overall input impedance, which results in less system error at the output.



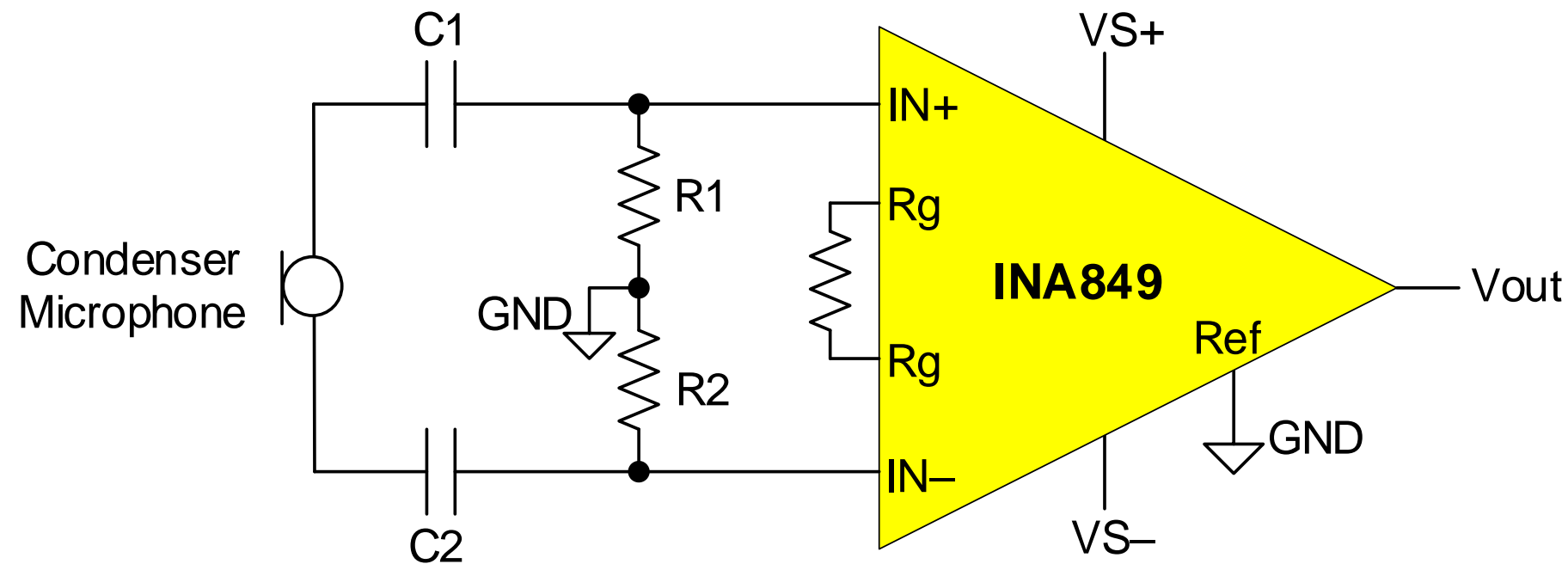
Resistor selection – tolerance

- Advantage of third resistor: Resistors cannot be perfectly matched, they are rated according to tolerance. Adding a third resistor can allow a designer to use lower tolerance resistors
- Disadvantage of third resistor: reduces the overall impedance



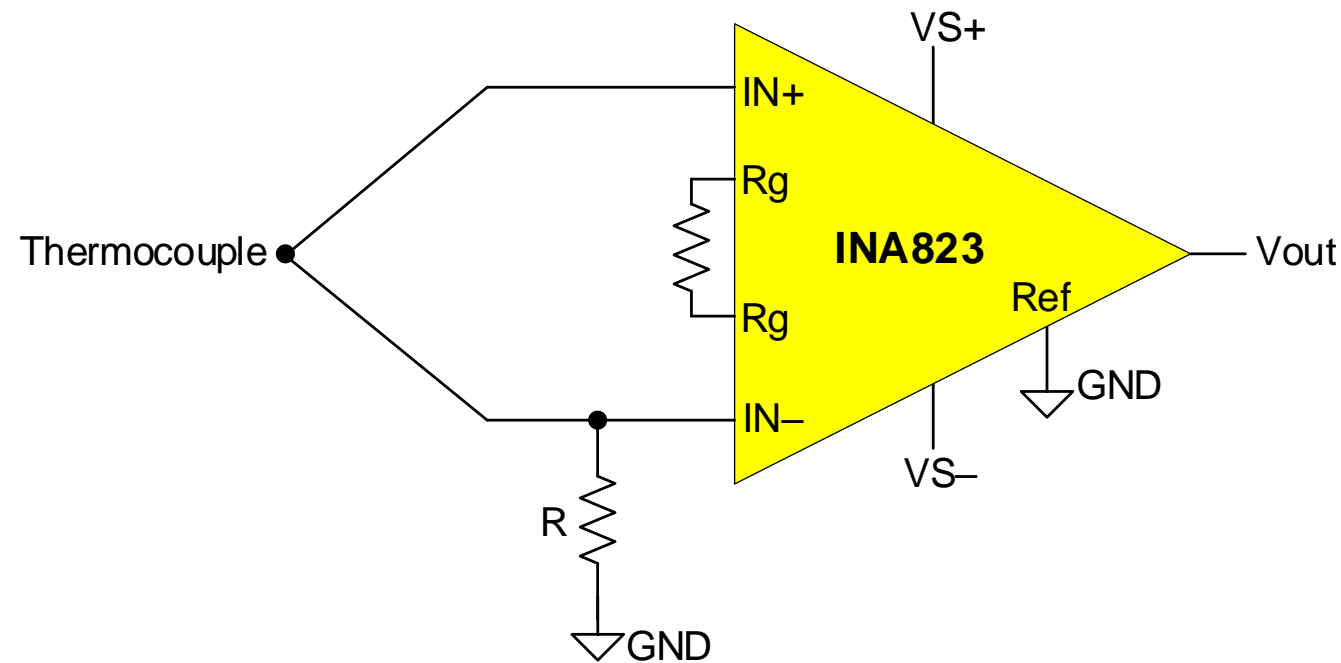
Application example – mic preamp

- 2 terminal electret microphone
- Microphone parameters determine the required biasing resistors
- Warning: do not use biasing resistors low enough to load the microphone and cause distortion, and large enough to induce excessive thermal noise.



Application example – thermocouple

- Thermocouple: temperature measurement that produces a small-signal dc signal
- The thermocouple has a low output impedance; therefore, two biasing resistors are not required. One biasing resistor can provide the necessary path to ground without creating a large offset error due to I_b .



Input bias current – summary

- Input bias current, I_b : Current flowing in to, or out of, the inputs of the IA
 - Combines with input impedance to create additional offset error:
 - Typical I_b for CMOS input: 1pA to 50pA
 - Typical I_b for traditional bipolar input: 1nA to 50nA
 - Typical I_b super- β bipolar input: 0.1nA to 5nA
 - Design with precision:
 - Provide a dc path to ground in dc or ac applications

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Thanks for your time!

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