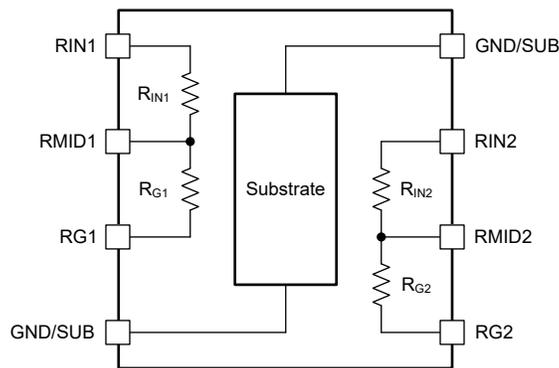


# Navigating Precision Resistor Networks



## What are matched resistor pairs?

A resistor pair is made up of two resistors connected in series making up a resistor divider. With matched pairs, each pair functions independently and is made up of an  $R_{IN}$  and an  $R_G$  with  $R_{IN1} = R_{IN2}$  and  $R_{G1} = R_{G2}$ . A tap point can be found between the resistors of each divider, labeled  $R_{MID1}$  and  $R_{MID2}$  in the [Functional Block Diagram](#). Additionally, one of the two GND pins can be used to bias the substrate for best AC performance.



**Functional Block Diagram**

To determine the value of the resistors, consider the ratio of the RES11Axx device in question. The divider ratio for a resistor pair is  $R_{IN}$  divided by  $R_G$ , where  $R_{IN}$  is fixed to 1k $\Omega$  for all RES11A-Q1 and  $R_G$  is the variable gain resistor that sets the dividing ratio. Each orderable part number (OPN) is associated with a different ratio, as noted in the [RES11A-Q1 Ratios](#) table. For example, a RES11A20 has a 1:2 ratio, thus the resistor has a 1k $\Omega$   $R_{IN}$  and a 2k $\Omega$   $R_G$ . For additional specifications see the [RES11A-Q1 Automotive, Matched, Thin-Film Resistor Dividers With 1-k \$\Omega\$  Inputs](#) data sheet.

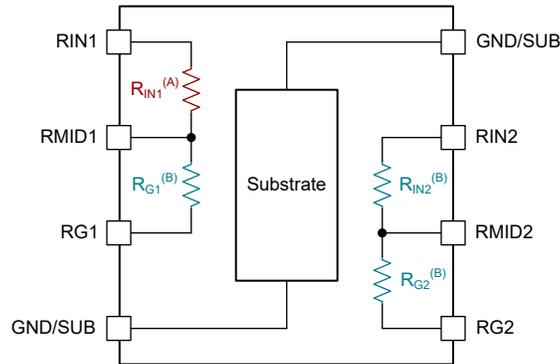
**RES11A-Q1 Ratios**

OPN	$R_{IN}$ (Nominal)	$R_G$ (Nominal)	Maximum Differential Divider Voltage ( $R_{INX}$ Pin to $R_{GX}$ Pin) <sup>1</sup>
RES11A00	1k $\Omega$	10k $\Omega$	44.7V
RES11A10	1k $\Omega$	1k $\Omega$	24.4V
RES11A15	1k $\Omega$	1.5k $\Omega$	20.3V
RES11A16	1k $\Omega$	1.667k $\Omega$	19.9V
RES11A20	1k $\Omega$	2k $\Omega$	18.3V
RES11A25	1k $\Omega$	2.5k $\Omega$	28.4V
RES11A30	1k $\Omega$	3k $\Omega$	32.5V
RES11A40	1k $\Omega$	4k $\Omega$	30.5V
RES11A50	1k $\Omega$	5k $\Omega$	29.9V
RES11A90	1k $\Omega$	9k $\Omega$	40.7V

<sup>1</sup> The maximum sustained differential voltage rating per divider is determined by a number of factors, including the maximum junction temperature and the self-heating associated with a given voltage and divider impedance. See the specifications section of the [RES11A-Q1 Automotive, Matched, Thin-Film Resistor Dividers With 1-k \$\Omega\$  Inputs](#) data sheet for more details.

## Ratio Tolerance vs Initial Tolerance

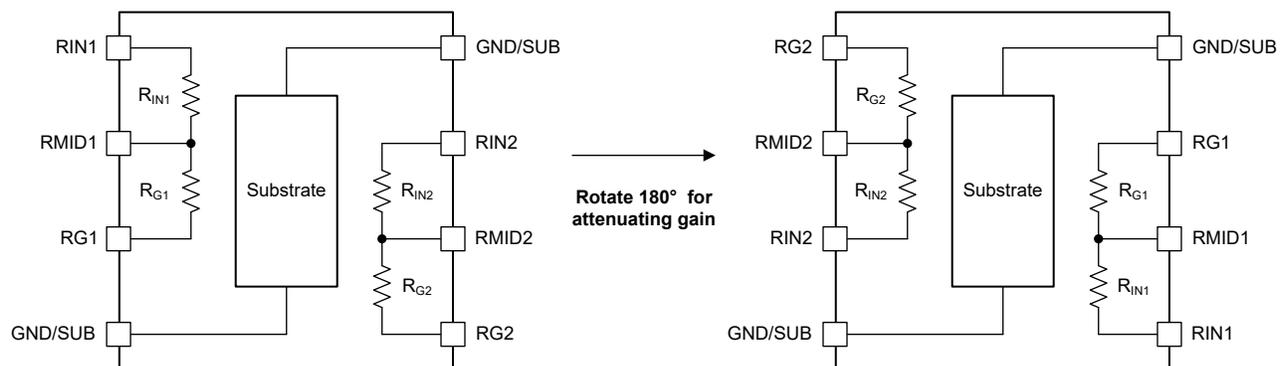
The RES11A-Q1 features a  $\pm 0.05\%$  maximum ratio tolerance ( $t_{D1}$  and  $t_{D2}$ ) meaning that the ratio of  $R_{IN1}:R_{G1}$  and  $R_{IN2}:R_{G2}$  are at most 0.05% off of the specified ratio values at a room temperature of 25°C. The initial tolerance ( $t_{abs}$ ) of 14% refers to the part-to-part variation of the individual resistors to the nominal or printed resistance. The four resistors within the device track each other much more closely, with a typical absolute error span of 235 ppm. This means a RES11A-Q1 (which has a nominal  $R_{IN1}$  of 1k $\Omega$ ) can have an  $R_{IN1}$  value as high as 1140 $\Omega$ ; however, because of the maximum ratio tolerance specification this means all other resistors ( $R_{IN2}$ ,  $R_{G1}$ ,  $R_{G2}$ ) have values approximately 14% above the nominal values of these resistors.



**Figure 2. Resistor Ratio Matching**

## Considerations for use

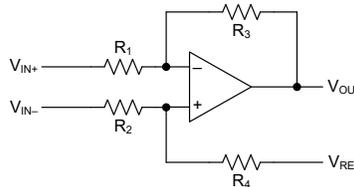
- Connect only one of the two GND pins to a low-impedance ground or bias point. Float the other pin to avoid the formation of current return paths through the device substrate. See the [RES11A-Q1](#) data sheet for more information.
- The RES11A-Q1 is AEC-Q200 Grade 1 qualified and has an operating temperature range of  $-40^{\circ}\text{C}$  to  $125^{\circ}\text{C}$ , desirable for industrial and automotive applications. AEC-Q200 is the worldwide standard for stress and temperature resistance that all passive electric components must meet to be qualified for use in the automotive industry. Pair the RES11A-Q1 with AEC-Q100 active components (amplifiers, comparators, ADC, DAC, and so forth) for a full automotive qualified design.
- Though labeled  $R_{INX}$  and  $R_{GX}$  there is no requirement for the direction of current flow. The RES11A can be rotated  $180^{\circ}$  for an attenuating gain configuration. With  $R_{GX}$  used as the input and  $R_{INX}$  as the output the divider ratio becomes inverted. For example, a RES11A-Q1 with a nominal resistance ratio of 1:2 has a 1:0.5 ratio when  $R_{GX}$  is used as the input.



**Figure 3. Attenuating Gain Configuration**

## Importance of Matched Resistors For Maximizing CMRR in Discrete Amplifier Implementations

Consider a standard differential amplifier as [Figure 3](#) shows. When simplified to  $R_1 = R_2$ , and  $R_3 = R_4$ , CMRR can be expressed as  $CMRR(dB) = 20 \times \log\left[\frac{1 + R_3 / R_1}{(4T / 100)}\right]$  where T is resistor tolerance in percent. This means CMRR is expected to be only 54dB in a unity gain configuration ( $R_1 = R_3$ ) with unmatched 0.1% tolerance resistors. If both divider ratios are matched to a 0.05% ratio tolerance then the value for T in this formula is 0.025% resulting in an improved CMRR of 66dB. See the application information section in the [RES11A-Q1](#) data sheet to learn more about how this number is calculated. An operational amplifier has infinite CMRR, which is a specification pertaining to the amount of the common mode signal present at the output of an amplifier. Ultimately, CMRR is a factor impacting the output signal noise. Learn more about CMRR with the [Common-mode rejection ratio](#) TI Precision Labs video on this topic.



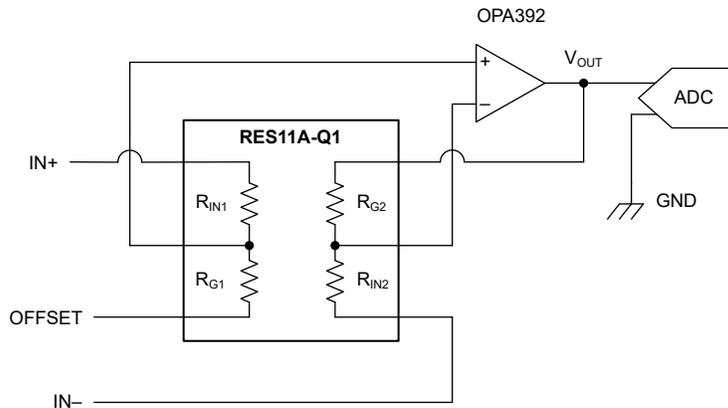
**Figure 4. Standard Differential Amplifier**

## Discrete Implementations of Difference and Instrumentation Amplifiers

### Difference Amplifier

Utilizing an operational amplifier such as the OPA392 and a single RES11A-Q1 in the [Difference Amplifier Configuration](#) yields a differential amplifier topology including differential inputs and a single-ended output. The gain of the amplifier can be calculated by the formula in [Equation 1](#).

$$G = R_G / R_{IN} \tag{1}$$

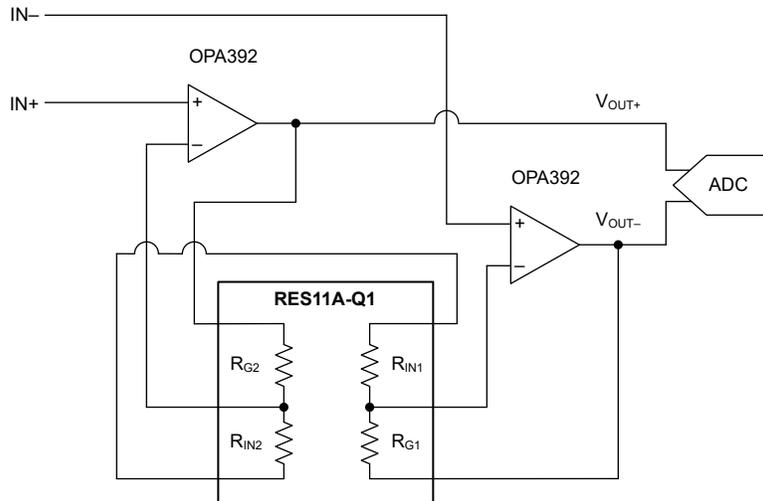


**Figure 5. Difference Amplifier Configuration**

### Instrumentation Amplifier

Utilizing two operational amplifiers such as OPA392 and a single RES11A-Q1 in the [Instrumentation Amplifier Configuration](#) yields an instrumentation amplifier topology with two high-impedance inputs and differential output. In some cases, a weak path for input bias current is needed<sup>2</sup>. The gain of the amplifier is calculated using [Equation 2](#).

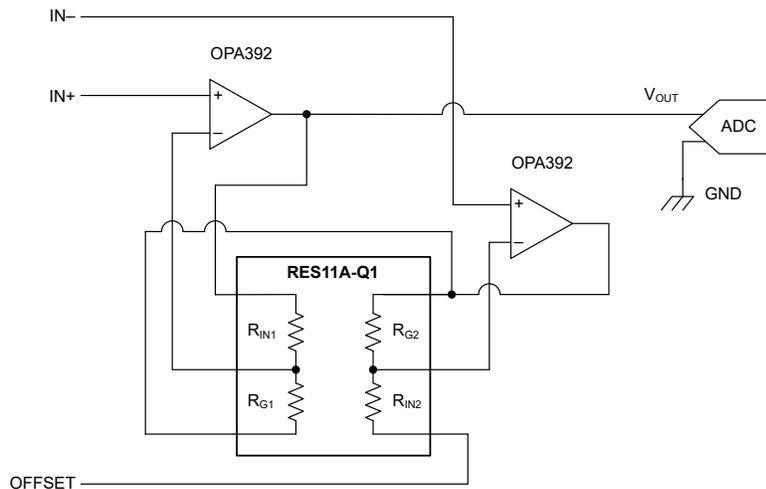
$$G = 1 + R_G / R_{IN} \tag{2}$$



**Figure 6. Instrumentation Amplifier Configuration With Differential Output**

Utilizing two operational amplifiers such as OPA392 and a single RES11A-Q1 as illustrated in [Figure 6](#) yields an instrumentation amplifier topology with two high-impedance differential inputs, one single-ended output, and a reference input. It is important to simulate the design to check that the input common mode ranges and output swings meet the requirements of the desired application. The gain of the amplifier is calculated with [Equation 3](#).

$$G = 1 + R_{IN} / R_G \tag{3}$$



**Figure 7. Instrumentation Amplifier Configuration With Reference Input**

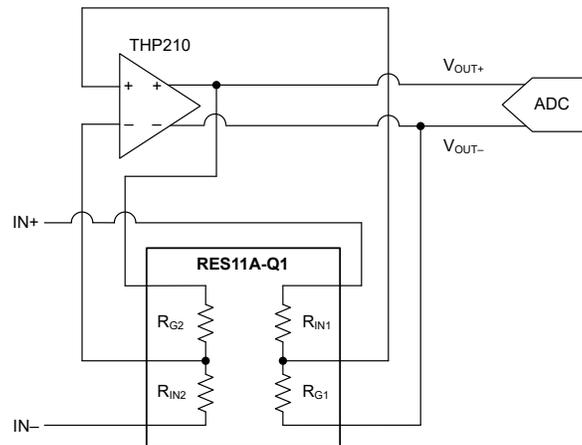
<sup>2</sup> See the [Importance of Input Bias Current Return Paths in Instrumentation Amplifier Applications](#) application note for applications such as AC-coupled measurements or thermocouple measurements.

### Fully-Differential Amplifier

A fully-differential amplifier requires resistors to set the gain as [Figure 7](#) illustrates. The ratio between these resistors determines the gain, thus matching is important to make sure the circuit behaves as intended. [Equation 4](#) shows the formula for gain in this configuration.

$$G = R_G / R_{IN}$$

(4)



**Figure 8. Fully-Differential Amplifier Configuration**

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