

PROGRAMMABLE-GAIN INSTRUMENTATION AMPLIFIERS

By David Jones (602) 746-7696 and R. Mark Stitt

The INA115 is a precision instrumentation amplifier (IA). Its gain-sense and amplifier output connections are available so that gains can be accurately set using external resistors. By adding switches or a multiplexer, you can make a precision programmable-gain IA (PGIA). Using the circuit topology shown in this bulletin, the switches are in series with op amp inputs so their resistance does not add error.

Burr-Brown offers fixed and programmable-gain IAs with amplifiers similar to the INA115. If you need a fixed gain of 100V/V, use the INA131. If you need a digitally programmable IA with decade gains of 1, 10, 100, and 1000V/V, or binary gains of 1, 2, 4, and 8V/V, use the PGA204 or PGA205.

If you need an IA with more gain steps, you can cascade two or more PGIA's. For example, if you cascade two PGA205's you will get gains of 1, 2, 4, 8, 16, 32, and 64V/V.

For other gains or gain-steps, you may want to make your own PGIA using an INA115. The circuits and equations below make it easy to design a programmable-gain IA with any gains and any number of gain steps.

MODEL	GAINS (V/V)
INA131	100
PGA204	1, 10, 100, 1000
PGA205	1, 2, 4, 8

TABLE I. Fixed and Programmable-Gain IAs.

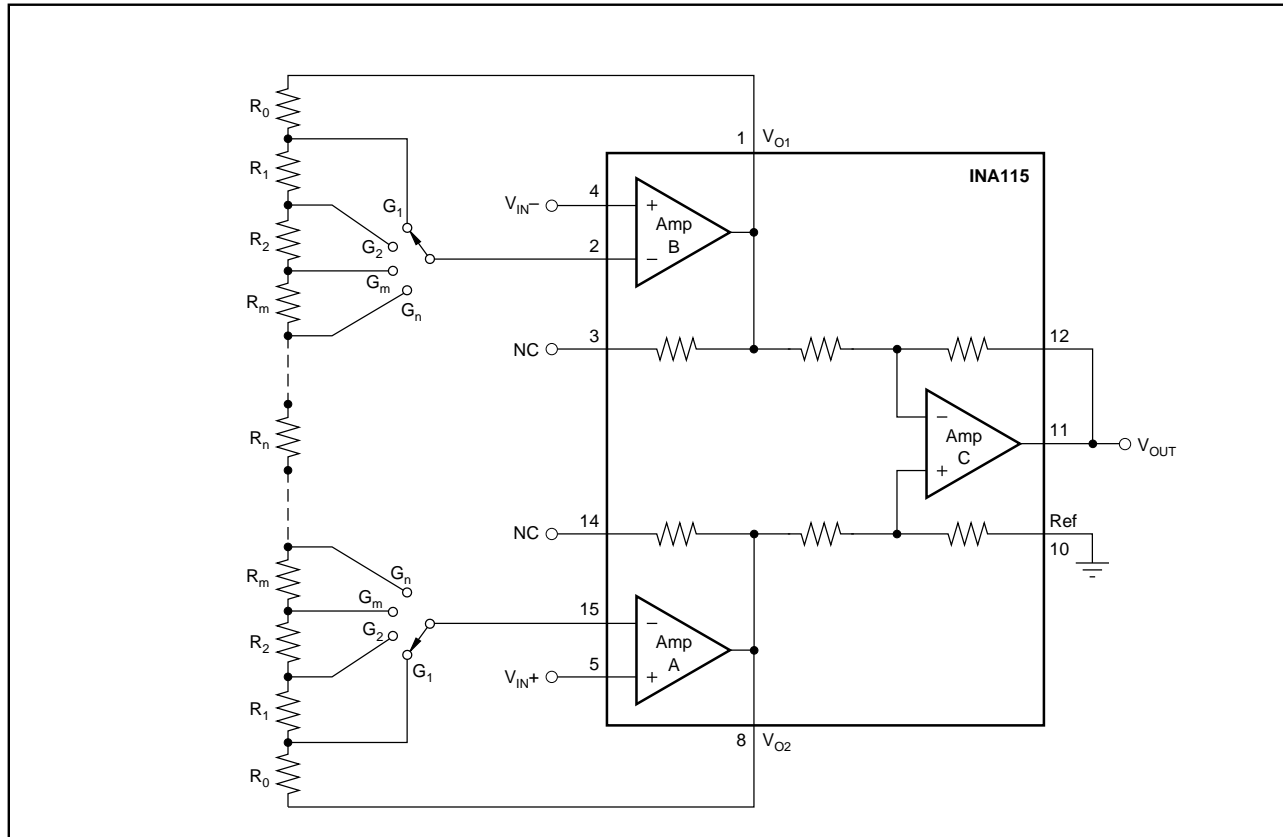


FIGURE 1. Programmable-Gain Instrumentation Amplifier with n Gain Steps and Lowest Gain > 1V/V.

If you want a PGIA with n gains and the first gain is not unity (1V/V), use the following relationships and the circuit shown in Figure 1.

RESISTOR VALUES FOR PGIA WITH n GAINS AND LOWEST GAIN > 1V/V

R_0 = Your choice (e.g. 25k Ω)

R_0 = 25k Ω when using the internal feedback resistors in the INA115 (see Figure 2)

$$R_1 = \frac{R_0 (G_1 - G_2)}{G_2 (1 - G_1)}$$

$$R_2 = \frac{G_1 R_0 (G_2 - G_3)}{G_2 G_3 (1 - G_1)}$$

⋮

$$R_m = \frac{G_1 R_0 (G_m - G_{m+1})}{G_m G_{m+1} (1 - G_1)}$$

$$R_n = \frac{2 G_1 R_0}{G_n (G_1 - 1)}$$

Where:

G_m = Intermediate gain (V/V)

G_n = Highest gain (V/V)

R_0, R_1, \dots, R_n = Resistor value per circuit diagram (Ω)

If you want to use the 25k Ω feedback resistors in the INA115 for the R_0 s, you can use the circuit shown in Figure 2. Keep in mind that the gain accuracy and gain drift will be limited by the internal feedback resistors. The 25k Ω feedback resistors have a tolerance of $\pm 0.5\%$ with a temperature coefficient of resistance drift (TCR) of up to 100ppm/ $^\circ\text{C}$. In the INA131, PGA204 and PGA205, resistor matching and TCR tracking of the resistors on the die give typical gain error and drift of 0.01% and 5ppm/ $^\circ\text{C}$.

GAINS (V/V)	R_0 (Ω)	R_1 (Ω)	R_2 (Ω)	R_3 (Ω)	R_4 (Ω)
2, 4, 8, 16	25k	12.4k	6.19k	3.09k	6.19k
10, 20, 50, 100	25k	1.4k	825	280	562
3dB, 6dB, 9dB, 12dB	25k	17.8k	12.4k	8.87k	43.2k
10, 100, 1k, 10k	100k	10k	1k	100	22.1
10, 100, 200, 500	49.9k	4.99k	280	165	221
100, 200, 400, 800	100k	511	255	127	255

NOTE: Nearest Standard 1% Resistor Values.

TABLE II. Examples of Resistor Values for Selected Gains—Figure 1 and 2 Circuits.

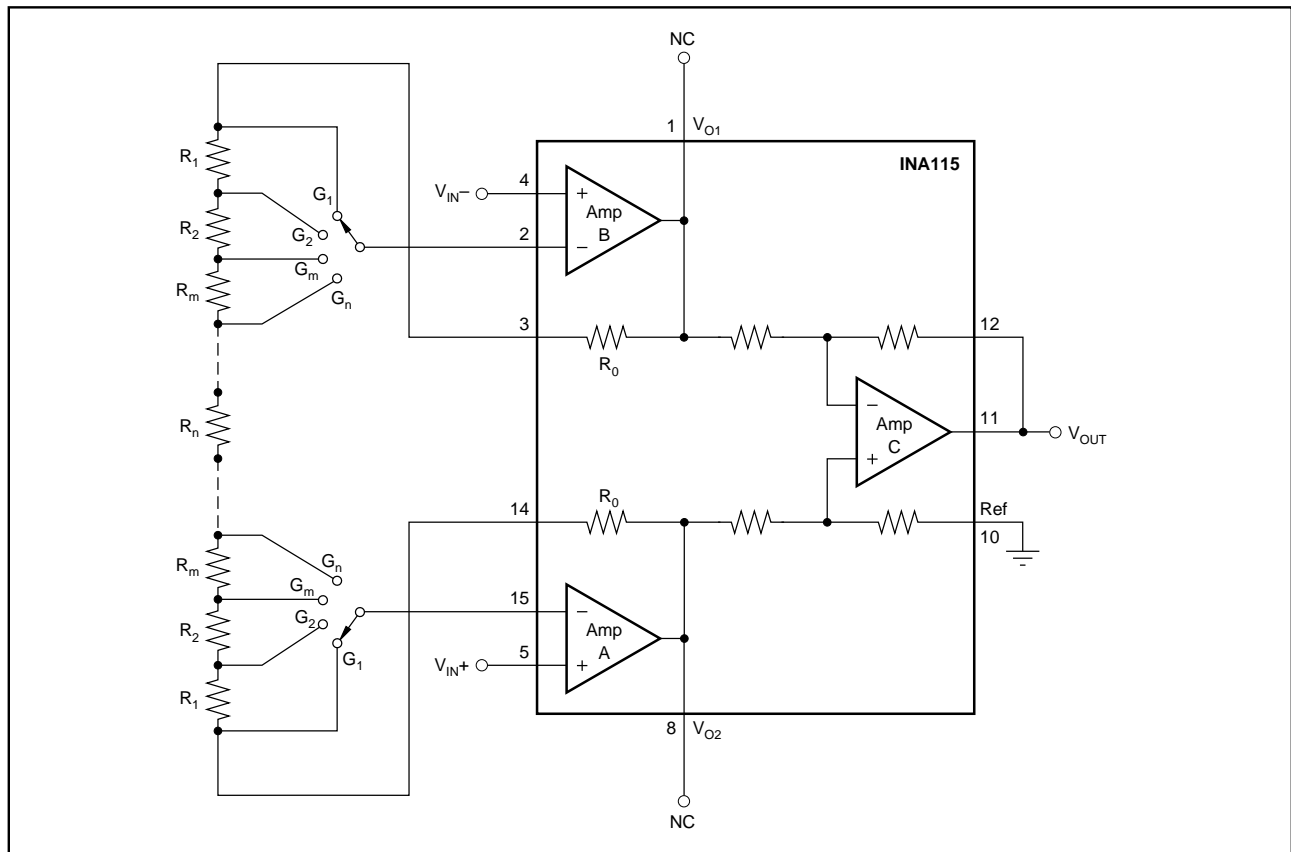


FIGURE 2. Programmable-Gain Instrumentation Amplifier with n Gain Steps and Lowest Gain > 1V/V. This circuit uses the 25k Ω feedback resistor in the INA115 for R_0 of Figure 1.

If you want a PGIA with n gains and the first gain is unity (1V/V), use the following relationships and the circuit shown in Figure 3.

RESISTOR VALUES FOR PGIA WITH n GAINS AND LOWEST GAIN = 1V/V

$$R_0 = 0$$

$R_1 =$ Your choice (e.g. 25k Ω)

$R_1 = 25k\Omega$ when using the internal feedback resistors in the INA115 (see Figure 4)

$$R_2 = \frac{R_1 (G_2 - G_3)}{G_3 (1 - G_2)}$$

$$R_3 = \frac{G_2 R_1 (G_3 - G_4)}{G_3 G_4 (1 - G_2)}$$

⋮

$$R_m = \frac{G_2 R_1 (G_m - G_{m+1})}{G_m G_{m+1} (1 - G_2)}$$

$$R_n = \frac{2 G_2 R_1}{G_n (G_2 - 1)}$$

Where:

$G_m =$ Intermediate gain (V/V)

$G_n =$ Highest gain (V/V)

$R_0, R_1, \dots, R_n =$ Resistor value per circuit diagram (Ω)

If you want to use the 25k Ω feedback resistors in the INA115 for the R_1 s, you can use the circuit shown in Figure 4. Keep in mind the gain accuracy and gain drift limitations discussed previously.

An actual example of a four-gain digitally programmable IA is shown in Figure 5. It uses a four-channel differential multiplexer (MUX) for gain switching.

GAINS (V/V)	R_0 (Ω)	R_1 (Ω)	R_2 (Ω)	R_3 (Ω)	R_4 (Ω)
1, 2, 4, 8	0	25k	12.4k	6.19k	12.4k
1, 8, 64, 512	0	25k	3.09	392	113
1, 2, 5, 10	0	25k	15k	4.99k	10k
1, 10, 100, 1k	0	49.9k	4.99k	499	110
1, 10, 100, 200	0	20k	2k	110	221
0dB, 3dB, 6dB, 9dB	0	24.9k	17.8k	12.4k	60.4k

NOTE: Nearest Standard 1% Resistor Values.

TABLE III. Examples of Resistor Values for Selected Gains— Figure 3 and 4 Circuits.

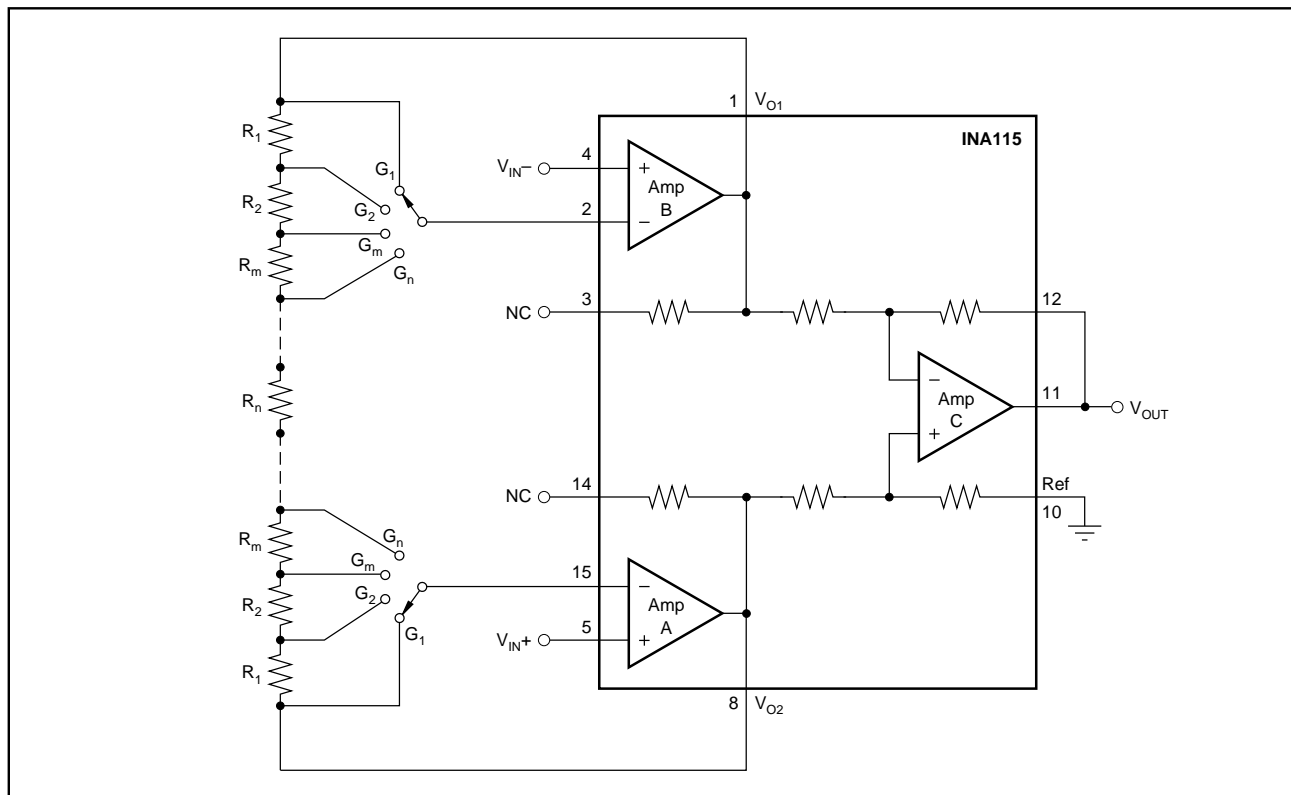


FIGURE 3. Programmable-Gain Instrumentation Amplifier with n Gain Steps and Lowest Gain = 1V/V.

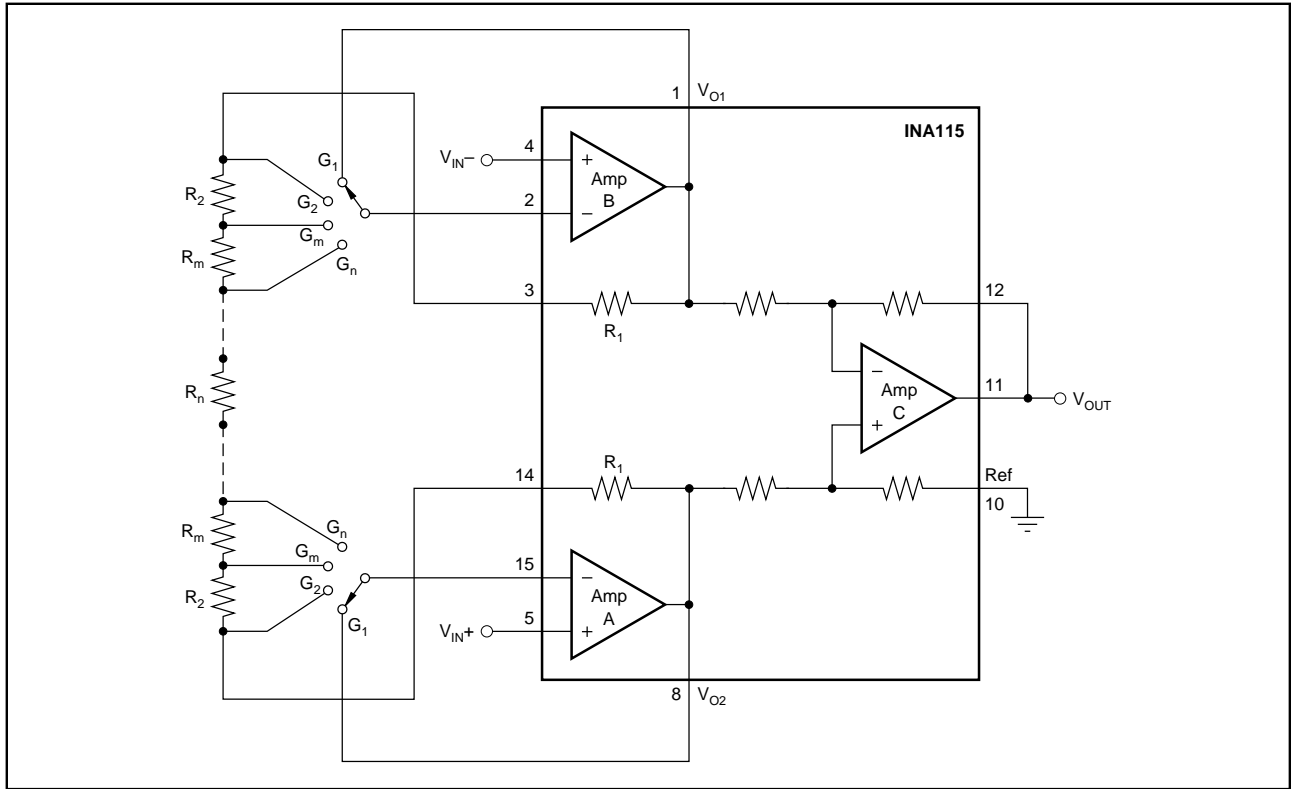


FIGURE 4. Programmable-Gain Instrumentation Amplifier with n Gain Steps and Lowest Gain = 1V/V. This circuit uses the 25kΩ feedback resistor in the INA115 for R_1 of Figure 3.

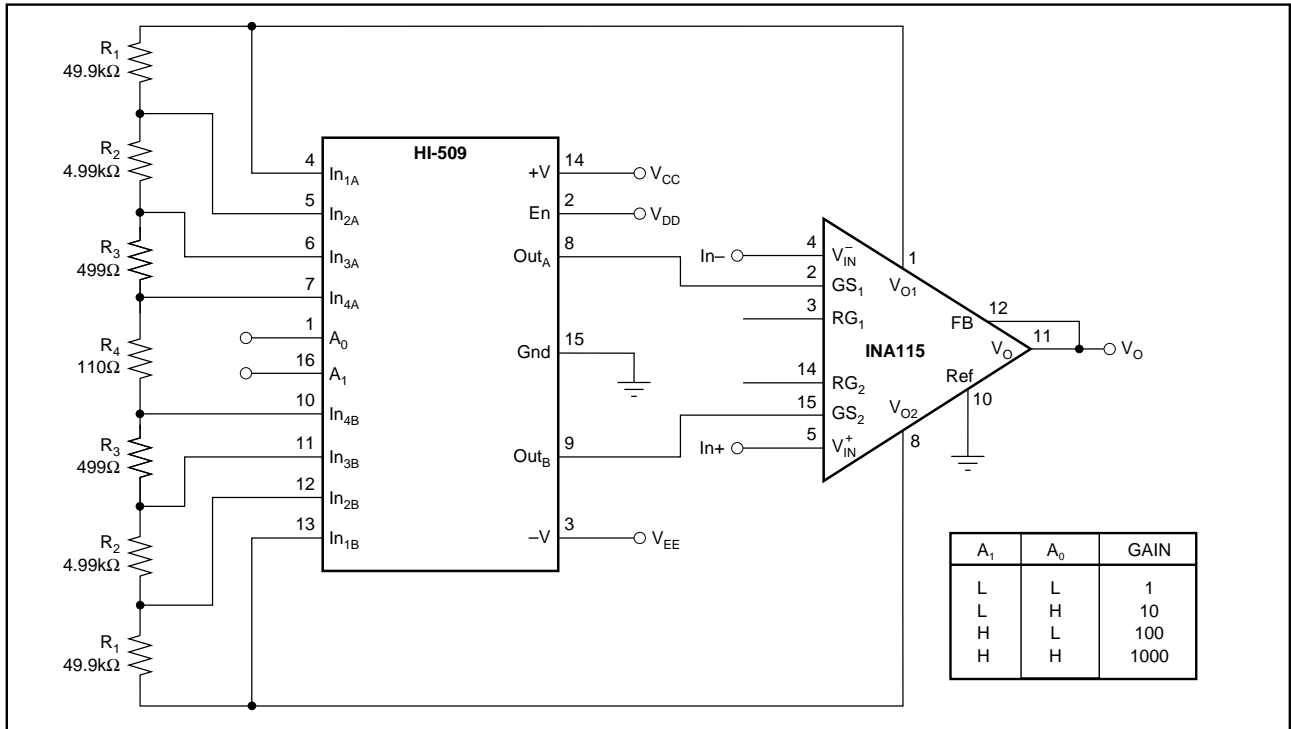


FIGURE 5. Programmable-Gain Instrumentation Amplifier Example with Four Gain Steps and Lowest Gain = 1V/V.

The information provided herein is believed to be reliable; however, BURR-BROWN assumes no responsibility for inaccuracies or omissions. BURR-BROWN assumes no responsibility for the use of this information, and all use of such information shall be entirely at the user's own risk. Prices and specifications are subject to change without notice. No patent rights or licenses to any of the circuits described herein are implied or granted to any third party. BURR-BROWN does not authorize or warrant any BURR-BROWN product for use in life support devices and/or systems.

IMPORTANT NOTICE

Texas Instruments and its subsidiaries (TI) reserve the right to make changes to their products or to discontinue any product or service without notice, and advise customers to obtain the latest version of relevant information to verify, before placing orders, that information being relied on is current and complete. All products are sold subject to the terms and conditions of sale supplied at the time of order acknowledgment, including those pertaining to warranty, patent infringement, and limitation of liability.

TI warrants performance of its semiconductor products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are utilized to the extent TI deems necessary to support this warranty. Specific testing of all parameters of each device is not necessarily performed, except those mandated by government requirements.

Customers are responsible for their applications using TI components.

In order to minimize risks associated with the customer's applications, adequate design and operating safeguards must be provided by the customer to minimize inherent or procedural hazards.

TI assumes no liability for applications assistance or customer product design. TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right of TI covering or relating to any combination, machine, or process in which such semiconductor products or services might be or are used. TI's publication of information regarding any third party's products or services does not constitute TI's approval, warranty or endorsement thereof.