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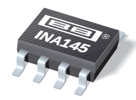


# INA145

For most current data sheet and other product information, visit www.burr-brown.com

# Programmable Gain DIFFERENCE AMPLIFIER

## FEATURES

- DIFFERENTIAL GAIN = 1V/V TO 1000V/V: Set with External Resistors
- LOW QUIESCENT CURRENT: 570μA
- WIDE SUPPLY RANGE:
  Single Supply: 4.5V to 36V
  Dual Supplies: ±2.25V to ±18V
- HIGH COMMON-MODE VOLTAGE:
  +8V at $V_S$ = +5V
  ±28V at $V_S$ = ±15V
- LOW GAIN ERROR: 0.01%
- HIGH CMR: 86dB
- SO-8 PACKAGE

## APPLICATIONS

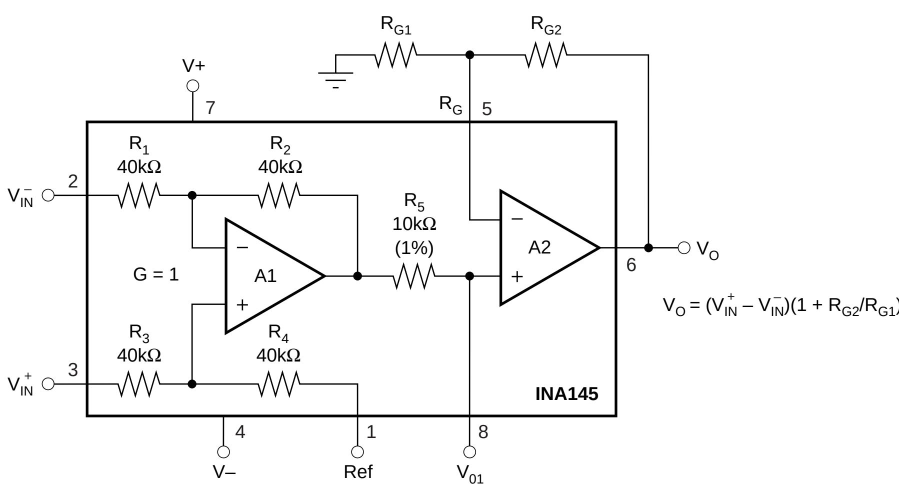
- CURRENT SHUNT MEASUREMENTS
- SENSOR AMPLIFIER
- DIFFERENTIAL LINE RECEIVER
- BATTERY POWERED SYSTEMS

## DESCRIPTION

The INA145 is a precision, unity-gain difference amplifier consisting of a precision op amp and on-chip precision resistor network. Two external resistors set the gain from 1V/V to 1000V/V. The input common-mode voltage range extends beyond the positive and negative rails.

On-chip precision resistors are laser-trimmed to achieve accurate gain and high common-mode rejection. Excellent TCR tracking of these resistors assures continued high precision over temperature.

The INA145 is available in the SO-8 surface-mount package specified for the extended industrial temperature range, –40°C to +85°C.

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Twx: 910-952-1111 • Internet: http://www.burr-brown.com/ • Cable: BBRCORP • Telex: 066-6491 • FAX: (520) 889-1510 • Immediate Product Info: (800) 548-6132

 PDS-1567B Printed in U.S.A. March, 2000

# SPECIFICATIONS: $V_S$ = ±2.25V to ±18V

**Boldface** limits apply over the specified temperature range, **$T_A$ = –40°C to +85°C**

At $T_A$ = +25°C, G = 1, $R_L$ = 10kΩ connected to ground and ref pin connected to ground unless otherwise noted.

| PARAMETER | | CONDITION | INA145UA MIN | INA145UA TYP | INA145UA MAX | UNITS |
|---|---|---|---|---|---|---|
| **OFFSET VOLTAGE, $V_O$** | | RTI(1, 2) | | | | |
| Input Offset Voltage | $V_{OS}$ | $V_{CM} = V_O$ = 0V | | ±0.2 | ±1 | mV |
| **vs Temperature** | **$\Delta V_{OS}/\Delta T$** | | | **See Typical Curve** | | |
| vs Power Supply | PSRR | $V_S$ = ±1.35V to ±18V | | ±20 | ±60 | µV/V |
| vs Time | | | | ±0.3 | | µV/mo |
| Offset Voltage, $V_{01}$ | | RTI(1, 2) | | ±0.4 | | mV |
| **INPUT VOLTAGE RANGE** | | | | | | |
| Common-Mode Voltage Range | $V_{CM}$ | ($V_{IN}$+) – ($V_{IN}$–) = 0V, $V_O$ = 0V | 2(V–) | | 2(V+) –2 | V |
| Common-Mode Rejection | CMRR | $V_{CM}$ = 2(V–) to 2(V+) – 2V, $R_S$ = 0Ω | 76 | 86 | | dB |
| **Over Temperature** | | $V_S$ = ±15V | **70** | **80** | | dB |
| **INPUT BIAS CURRENT(2)** | | $V_{CM} = V_S/2$ | | | | |
| Bias Current | $I_B$ | | | ±50 | | nA |
| Offset Current | $I_{OS}$ | | | ±5 | | nA |
| **INPUT IMPEDANCE** | | | | | | |
| Differential (non-inverting input) | | | | 80 | | kΩ |
| Differential (inverting input) | | | | 27 | | kΩ |
| Common-Mode | | | | 40 | | kΩ |
| **NOISE** | | RTI(1, 3) | | | | |
| Voltage Noise, f = 0.1Hz to 10Hz | | | | 2 | | µVp-p |
| Voltage Noise Density, f = 1kHz | $e_n$ | | | 90 | | nV/√Hz |
| **GAIN** | | | | G = 1 to 1000 | | |
| Gain Equation | | | | G = 1 + $R_{G2}/R_{G1}$ | | V/V |
| Initial(1) | | | | 1 | | V/V |
| Gain Error | | $R_L$ = 100kΩ, $V_O$ = (V–)+0.15 to (V+)–1, G = 1 | | ±0.01 | ±0.1 | % |
| **vs Temperature** | | **$R_L$ = 100kΩ, $V_O$ = (V–)+0.25 to (V+)–1, G = 1** | | **±2** | **±10** | ppm/°C |
| | | $R_L$ = 10kΩ, $V_O$ = (V–)+0.3 to (V+)–1.25, G = 1 | | ±0.01 | ±0.1 | % |
| **vs Temperature** | | **$R_L$ = 10kΩ, $V_O$ = (V–)+0.5 to (V+)–1.25, G = 1** | | **±2** | **±10** | ppm/°C |
| Nonlinearity | | $R_L$ = 10kΩ, $V_O$ = (V–)+0.3 to (V+)–1.25, G = 1 | | ±0.0002 | ±0.005 | % of FS |
| **FREQUENCY RESPONSE** | | | | | | |
| Small Signal Bandwidth | | G = 1 | | 500 | | kHz |
| | | G = 10 | | 50 | | kHz |
| Slew Rate | | | | 0.45 | | V/µs |
| Settling Time, 0.1% | | G = 1, 10V Step | | 40 | | µs |
| 0.01% | | G = 1, 10V Step | | 90 | | µs |
| Overload Recovery | | 50% Input Overload | | 40 | | µs |
| **OUTPUT, $V_O$** | | | | | | |
| Voltage Output | | $R_L$ = 100kΩ, G = 1 | (V–) + 0.15 | | (V+) – 1 | V |
| **Over Temperature** | | **$R_L$ = 100kΩ, G = 1** | **(V–) + 0.25** | | **(V+) – 1** | V |
| | | $R_L$ = 10kΩ, G = 1 | (V–) + 0.3 | | (V+) – 1.25 | V |
| **Over Temperature** | | **$R_L$ = 10kΩ, G = 1** | **(V–) + 0.5** | | **(V+) – 1.25** | V |
| Short-Circuit Current | | Continuous to Common | | ±15 | | mA |
| Capacitive Load | | Stable Operation | | 1000 | | pF |
| **POWER SUPPLY** | | | | | | |
| Specified Voltage Range, Dual Supplies | | | ±2.25 | | ±18 | V |
| Operating Voltage Range | | | ±1.35 | | ±18 | V |
| Quiescent Current | | $V_{IN}$ = 0, $I_O$ = 0 | | ±570 | ±700 | µA |
| **Over Temperature** | | | | | **±800** | µA |
| **TEMPERATURE RANGE** | | | | | | |
| Specified Range | | | –40 | | +85 | °C |
| Operating Range | | | –55 | | +125 | °C |
| Storage Range | | | –55 | | +125 | °C |
| Thermal Resistance | $\theta_{JA}$ | | | 150 | | °C/W |

NOTES: (1) Referred to input pins ($V_{IN}$+ and $V_{IN}$–), Gain = 1V/V. Specified with 10kΩ in feedback of A2. (2) Input offset voltage specification includes effects of amplifier's input bias and offset currents. (3) Includes effects of input bias current noise and thermal noise contribution of resistor network.

# SPECIFICATIONS: $V_S$ = +5V Single Supply

## **Boldface** limits apply over the specified temperature range, **$T_A$ = –40°C to +85°C**

At $T_A$ = +25°C, G = 1, $R_L$ = 10kΩ connected to ground and ref pin connected to 2.5V unless otherwise noted.

| PARAMETER | | CONDITION | INA145UA MIN | INA145UA TYP | INA145UA MAX | UNITS |
|---|---|---|---|---|---|---|
| **OFFSET VOLTAGE, $V_O$** | | RTI(1, 2) | | | | |
| Input Offset Voltage | $V_{OS}$ | $V_{CM}$ = $V_O$ = 2.5V | | ±0.35 | ±1 | mV |
| **vs Temperature** | **$\Delta V_{OS}/\Delta T$** | | | **See Typical Curve** | | |
| vs Power Supply Rejection Ratio | PSRR | $V_S$ = ±1.35V to ±18V | | ±20 | ±60 | µV/°C |
| vs Time | | | | ±0.3 | | µV/mo |
| Offset Voltage, $V_{01}$ | | RTI(1, 2) | | ±0.55 | | mV |
| **INPUT VOLTAGE RANGE** | | | | | | |
| Common-Mode Voltage Range(3) | $V_{CM}$ | $V_{IN}$+ – $V_{IN}$– = 0V, $V_O$ = 2.5V | –2.5 | | 5.5 | V |
| Common-Mode Rejection Ratio | CMRR | $V_{CM}$ = –2.5V to +5.5V, $R_S$ = 0Ω | 76 | 86 | | dB |
| **Over Temperature** | | | | **80** | | dB |
| **INPUT BIAS CURRENT(2)** | | | | | | |
| Bias Current | $I_B$ | | | ±50 | | nA |
| Offset Current | $I_{OS}$ | | | ±5 | | nA |
| **INPUT IMPEDANCE** | | | | | | |
| Differential (non-inverting input) | | | | 80 | | kΩ |
| Differential (inverting input) | | | | 27 | | kΩ |
| Common-Mode | | | | 40 | | kΩ |
| **NOISE** | | RTI(1, 4) | | | | |
| Voltage Noise, f = 0.1Hz to 10Hz | | | | 2 | | µVp-p |
| Voltage Noise Density, f = 1kHz | $e_n$ | | | 90 | | nV/√Hz |
| **GAIN** | | | | G = 1 to 1000 | | V/V |
| Gain Equation | | | | G = 1 + $R_{G2}/R_{G1}$ | | V/V |
| Initial(1) | | | | 1 | | V/V |
| Gain Error | | $R_L$ = 100kΩ, $V_O$ = 0.15V to 4V, G = 1 | | ±0.01 | ±0.1 | % |
| **vs Temperature** | | **$R_L$ = 100kΩ, $V_O$ = 0.25V to 4V, G = 1** | | **±2** | **±10** | ppm/°C |
| | | $R_L$ = 10kΩ, $V_O$ = 0.3V to 3.75V, G = 1 | | ±0.01 | ±0.1 | % |
| **vs Temperature** | | **$R_L$ = 10kΩ, $V_O$ = 0.5V to 3.75V, G = 1** | | **±2** | **±10** | ppm/°C |
| Nonlinearity | | $R_L$ = 10kΩ, $V_O$ = +0.3 to +3.75, G = 1 | | ±0.001 | ±0.005 | % of FS |
| **FREQUENCY RESPONSE** | | | | | | |
| Small Signal Bandwidth | | G = 0.1 | | 500 | | kHz |
| | | G = 1 | | 50 | | kHz |
| Slew Rate | | | | 0.45 | | V/µs |
| Settling Time, 0.1% | | G = 1, 10V Step | | 40 | | µs |
| 0.01% | | G = 1, 10V Step | | 90 | | µs |
| Overload Recovery | | 50% Input Overload | | 40 | | µs |
| **OUTPUT, $V_O$** | | | | | | |
| Voltage Output | | $R_L$ = 100kΩ, G = 1 | 0.15 | | 4 | V |
| **Over Temperature** | | **$R_L$ = 100kΩ, G = 1** | **0.25** | | **4** | V |
| | | $R_L$ = 10kΩ, G = 1 | 0.3 | | 3.75 | V |
| **Over Temperature** | | **$R_L$ = 10kΩ, G = 1** | **0.5** | | **3.75** | V |
| Short-Circuit Current | | Continuous to Common | | ±15 | | mA |
| Capacitive Load | | Stable Operation | | 1000 | | pF |
| **POWER SUPPLY** | | | | | | |
| Specified Voltage Range, Single Supply | | | +4.5 | | +36 | V |
| Operating Voltage Range | | | +2.7 | | +36 | V |
| Quiescent Current | | $V_{IN}$ = 0, $I_O$ = 0 | | 550 | 700 | µA |
| **Over Temperature** | | | | | **800** | µA |
| **TEMPERATURE RANGE** | | | | | | |
| Specified Range | | | –40 | | +85 | °C |
| Operating Range | | | –55 | | +125 | °C |
| Storage Range | | | –55 | | +125 | °C |
| Thermal Resistance | $\theta_{JA}$ | | | 150 | | °C/W |

NOTES: (1) Referred to input pins ($V_{IN}$+ and $V_{IN}$–), Gain = 1V/V. Specified with 10kΩ in feedback of A2. (2) Input offset voltage specification includes effects of amplifier's input bias and offset currents. (3) Common-mode voltage range with single supply is 2(V+) – 2V – $V_{REF}$ to –$V_{REF}$. (4) Includes effects of input current noise and thermal noise contribution of resistor network.

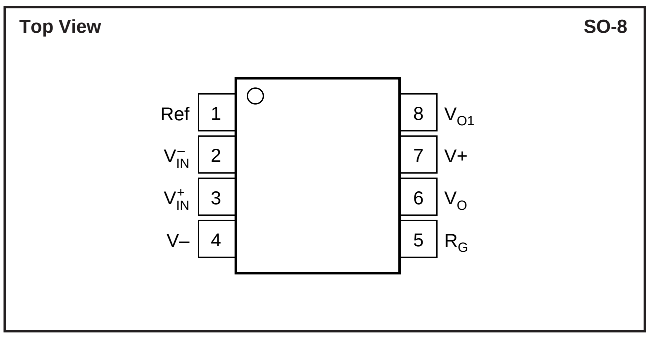
# AMPLIFIER A1, A2 PERFORMANCE

**Boldface** limits apply over the specified temperature range, **$T_A$ = –40°C to +85°C**

At $T_A$ = +25°C, G = 1, $R_L$ = 10kΩ connected to ground and ref pin connected to ground unless otherwise noted.

| PARAMETER | | CONDITION | INA145UA MIN | INA145UA TYP | INA145UA MAX | UNITS |
|---|---|---|---|---|---|---|
| **OFFSET VOLTAGE, $V_O$** | | RTI[1, 2] | | | | |
| Input Offset Voltage | $V_{OS}$ | $V_S$ = ±15V, $V_{CM}$ = $V_O$ = 0V | | ±0.5 | | mV |
| **vs Temperature** | **$\Delta V_{OS}/\Delta T$** | | | **±1** | | μV/°C |
| **INPUT VOLTAGE RANGE** | | | | | | |
| Common-Mode Voltage Range | $V_{CM}$ | $V_{IN}$+ – $V_{IN}$– = 0V, $V_O$ = 0V | | (V–) to (V+) –1 | | V |
| Common-Mode Rejection Ratio | CMRR | $V_{CM}$ = (V–) to (V+) –1 | | 90 | | dB |
| **OPEN-LOOP GAIN** | | | | | | |
| Open Loop Gain | $A_{OL}$ | | | 110 | | dB |
| **INPUT BIAS CURRENT[2]** | | | | | | |
| Bias Current | $I_B$ | | | ±50 | | nA |
| Offset Current | $I_{OS}$ | | | ±5 | | nA |
| **RESISTOR AT A1 OUTPUT, $V_{O1}$** | | | | | | |
| Initial | | | | 10 | | kΩ |
| Error | | | | ±0.2 | | % |
| Temperature Drift Coefficient | | | | ±50 | | ppm/°C |

## PIN CONFIGURATION




## ABSOLUTE MAXIMUM RATINGS[1]

| | |
|---|---|
| Supply Voltage, V+ to V– | 36V |
| Signal Input Terminals, Voltage | ±80V |
| Current | ±1mA |
| Output Short Circuit (to ground) | Continuous |
| Operating Temperature | –55°C to +125°C |
| Storage Temperature | –55°C to +150°C |
| Junction Temperature | +150°C |
| Lead Temperature (soldering, 10s) | +240°C |

NOTE: (1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability.

## ELECTROSTATIC DISCHARGE SENSITIVITY

This integrated circuit can be damaged by ESD. Burr-Brown recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

## PACKAGE/ORDERING INFORMATION

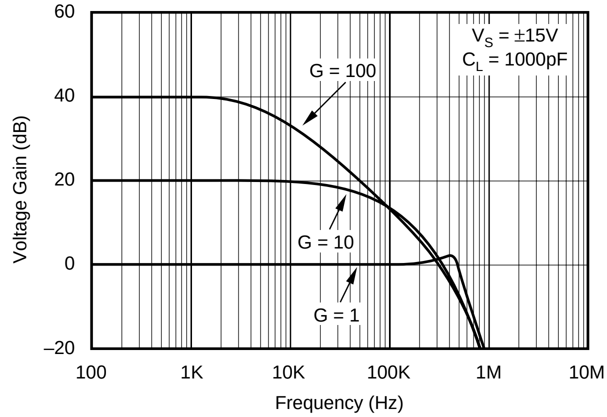
| PRODUCT | PACKAGE | PACKAGE DRAWING NUMBER | SPECIFIED TEMPERATURE RANGE | PACKAGE MARKING | ORDERING NUMBER[1] | TRANSPORT MEDIA |
|---|---|---|---|---|---|---|
| INA145UA | SO-8 | 182 | –40°C to +85°C | INA145UA | INA145UA | Rails |
| " | " | " | " | " | INA145UA/2K5 | Tape and Reel |

NOTE: (1) Models with a slash (/) are available only in Tape and Reel in the quantities indicated (e.g., /2K5 indicates 2500 devices per reel). Ordering 2500 pieces of "INA145UA/2K5" will get a single 2500-piece Tape and Reel.

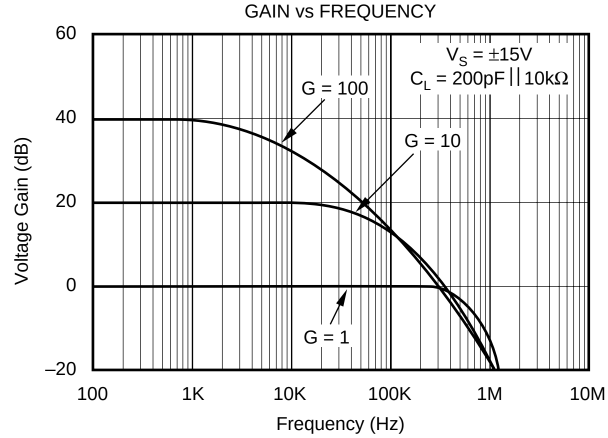
# TYPICAL PERFORMANCE CURVES

At $T_A = +25°C$, $V_S = ±15V$, G = 1, $R_L = 10kΩ$ connected to ground and Ref pin connected to ground, unless otherwise noted.

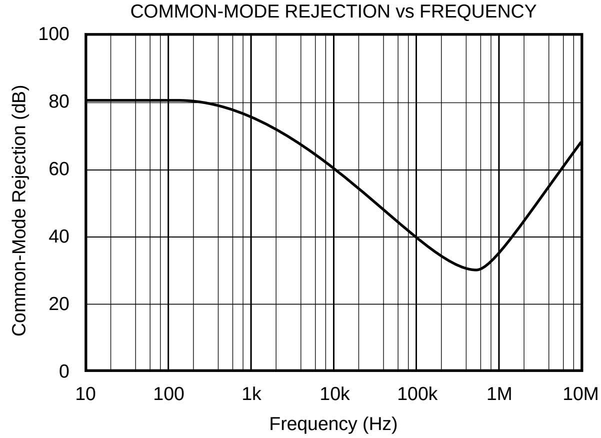
GAIN vs FREQUENCY



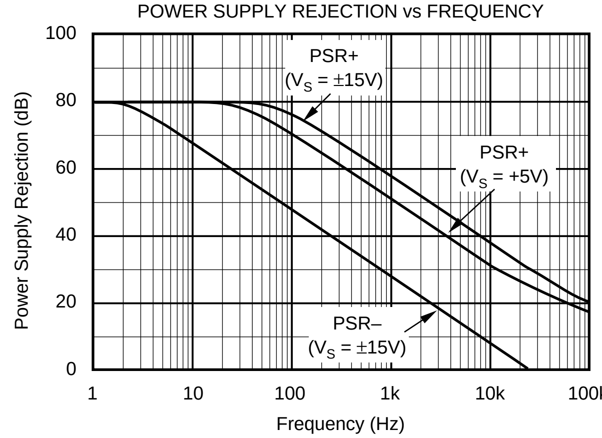

GAIN vs FREQUENCY



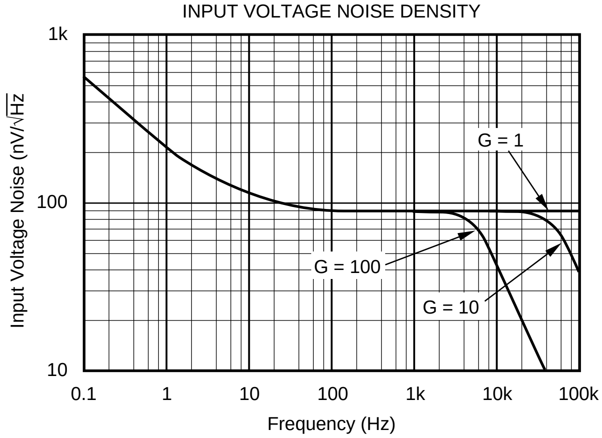

COMMON-MODE REJECTION vs FREQUENCY



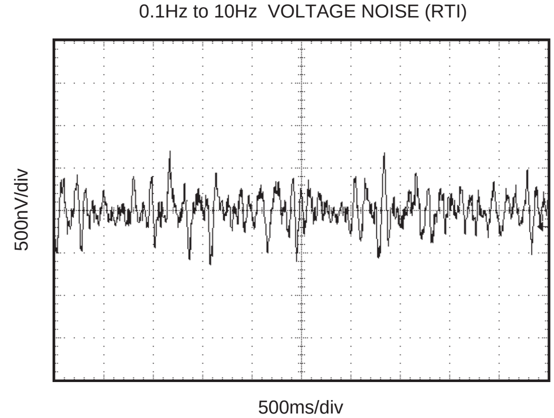

POWER SUPPLY REJECTION vs FREQUENCY




INPUT VOLTAGE NOISE DENSITY

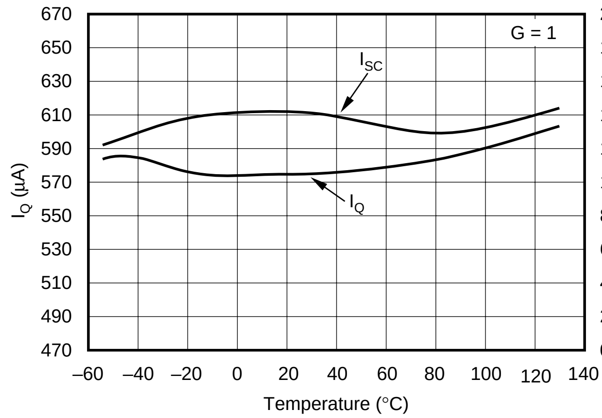



0.1Hz to 10Hz VOLTAGE NOISE (RTI)

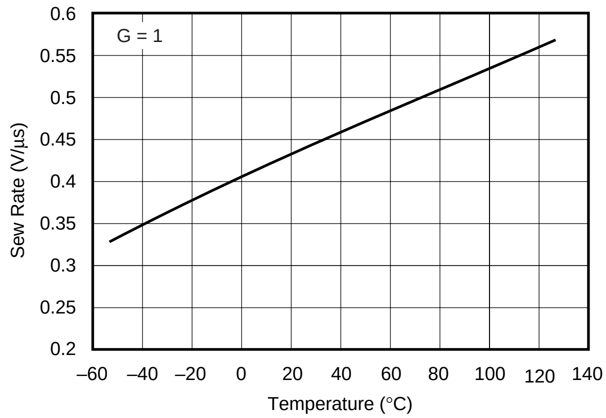


At $T_A$ = +25°C, $V_S$ = ±15V, G = 1, $R_L$ = 10kΩ connected to ground and Ref pin connected to ground, unless otherwise noted.

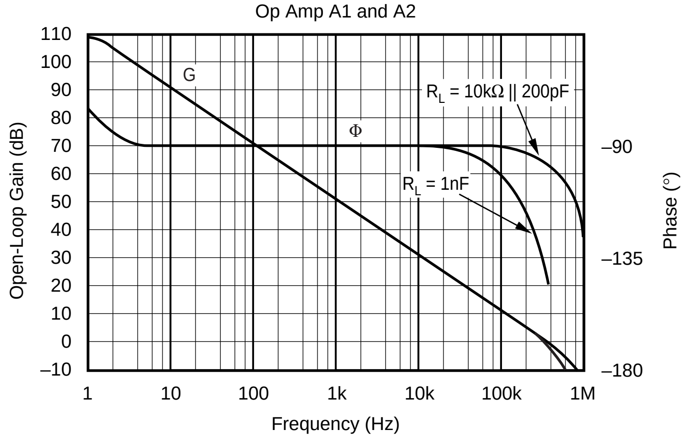
QUIESCENT CURRENT AND SHORT-CIRCUIT CURRENT vs TEMPERATURE



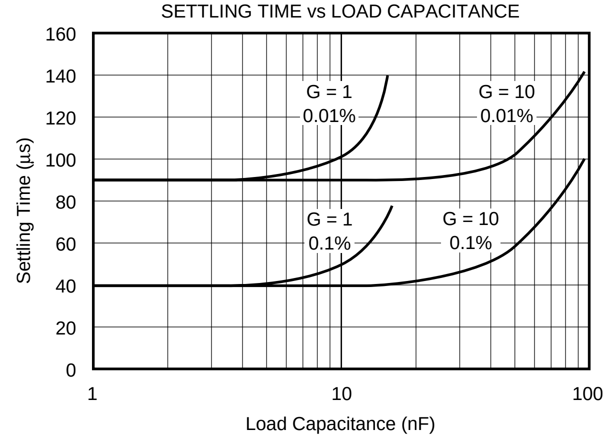

SLEW RATE vs TEMPERATURE



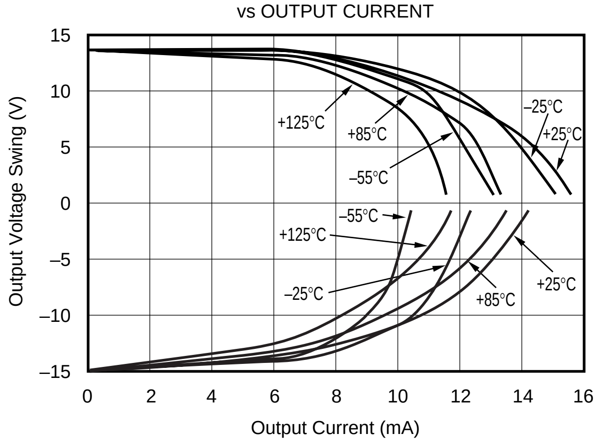

GAIN AND PHASE vs FREQUENCY
Op Amp A1 and A2



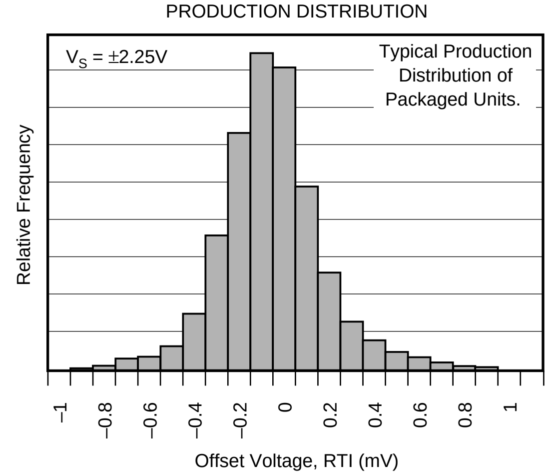

SETTLING TIME vs LOAD CAPACITANCE




MAXIMUM OUTPUT VOLTAGE SWING vs OUTPUT CURRENT



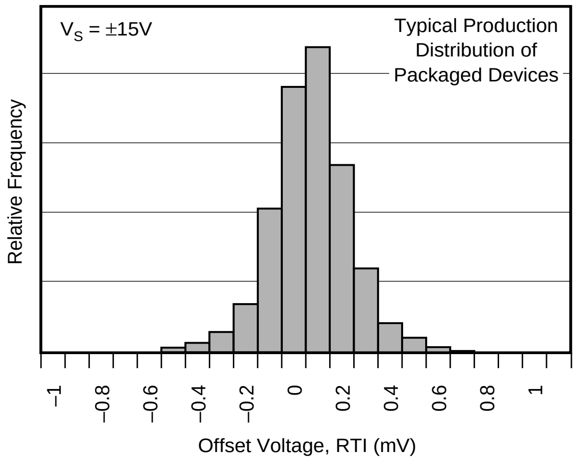

OFFSET VOLTAGE PRODUCTION DISTRIBUTION



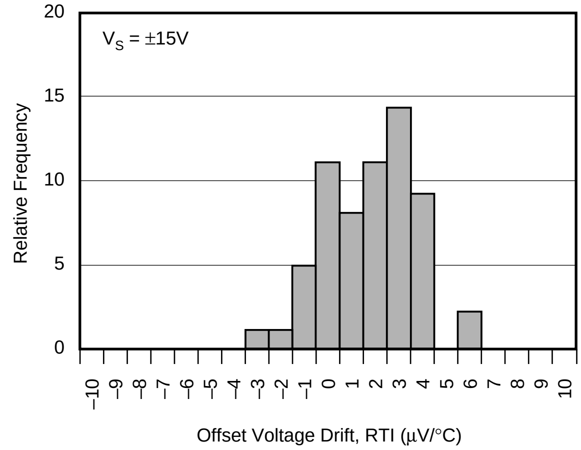
# TYPICAL PERFORMANCE CURVES (Cont.)

At $T_A$ = +25°C, $V_S$ = ±15V, G = 1, $R_L$ = 10kΩ connected to ground and Ref pin connected to ground, unless otherwise noted.

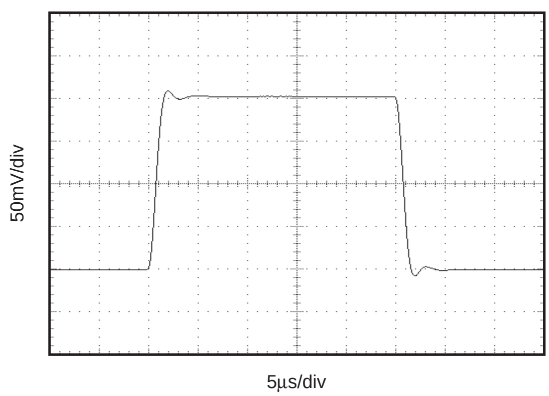
OFFSET VOLTAGE
PRODUCTION DISTRIBUTION



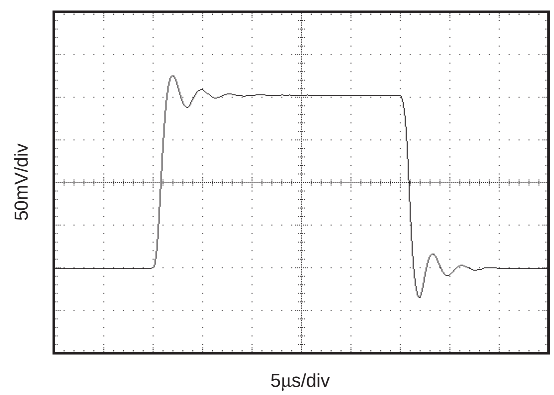

OFFSET VOLTAGE DRIFT
PRODUCTION DISTRIBUTION



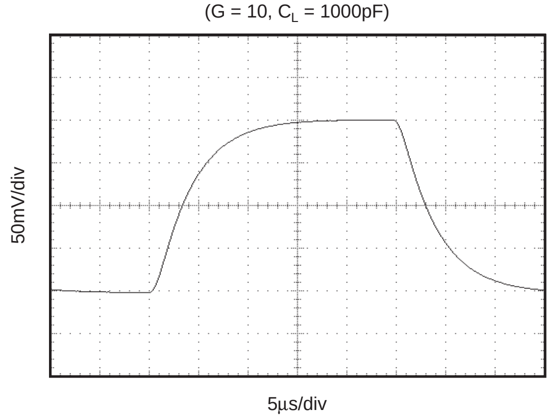

SMALL-SIGNAL STEP RESPONSE
(G = 1, $R_L$ = 10kΩ, $C_L$ = 200pF)



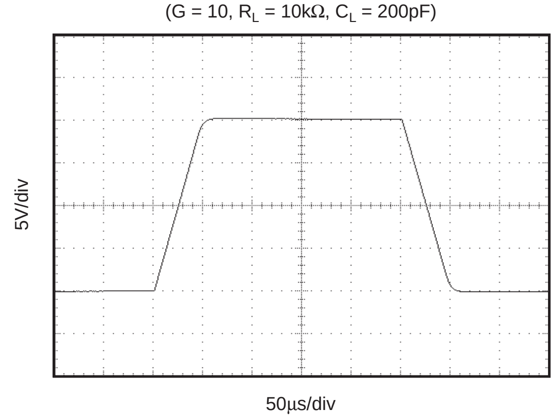

SMALL-SIGNAL STEP RESPONSE
(G = 1, $C_L$ = 1000pF)




SMALL-SIGNAL STEP RESPONSE
(G = 10, $C_L$ = 1000pF)




LARGE-SIGNAL STEP RESPONSE
(G = 10, $R_L$ = 10kΩ, $C_L$ = 200pF)



# APPLICATION INFORMATION

The INA145 is a programmable gain difference amplifier consisting of a gain of 1 difference amplifier and a programmable-gain output buffer stage. Basic circuit connections are shown in Figure 1. Power supply bypass capacitors should be connected close to pins 4 and 7, as shown. The amplifier is programmable in the range of G = 1 to G = 1000 with two external resistors.

The output of A1 is connected to the noninverting input of A2 through a 10kΩ resistor which is trimmed to ±1% absolute accuracy. The A2 input is available for applications such as a filter or a precision current source. See application figures for examples.

## OPERATING VOLTAGE

The INA145 is fully specified for supply voltages from ±2.25V to ±18V, with key parameters guaranteed over the temperature range –40°C to +85°C. The INA145 can be operated with single or dual supplies, with excellent performance. Parameters that vary significantly with operating voltage, load conditions, or temperature are shown in the typical performance curves.

## SETTING THE GAIN

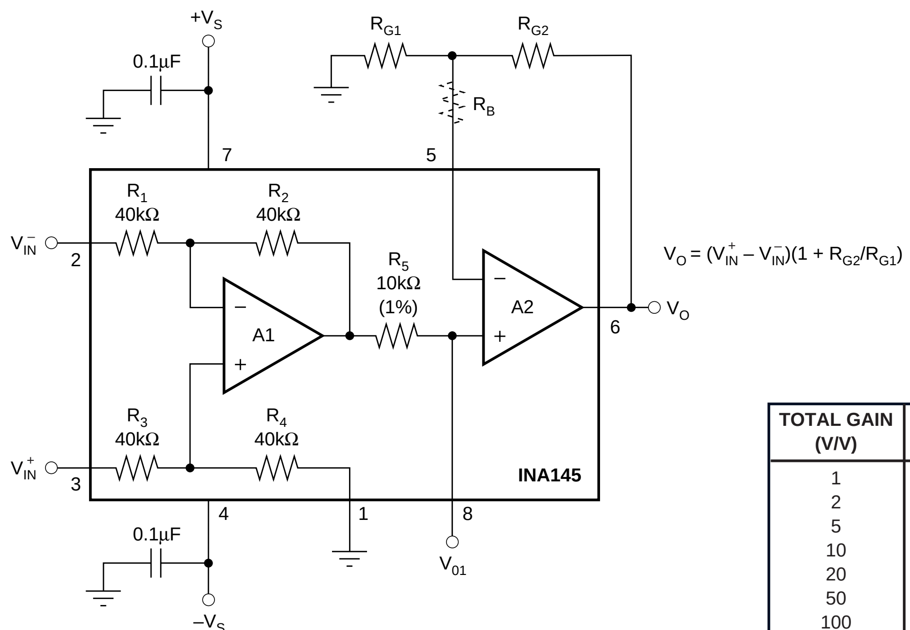
The gain of the INA145 is set by using two external resistors, $R_{G1}$ and $R_{G2}$, according to the equation:

$$G = 1 + R_{G2}/R_{G1}$$

For a total gain of 1, A2 is connected as a buffer amplifier with no $R_{G1}$. A feedback resistor, $R_{G2}$ = 10kΩ, should be used in the buffer connection. This provides bias current cancellation (in combination with internal $R_5$) to assure specified offset voltage performance. Commonly used values are shown in the table of Figure 1. Resistor values for other gains should be chosen to provide a 10kΩ parallel resistance.

## COMMON-MODE RANGE

The input resistors of the INA145 provides an input common-mode range that extends well beyond the power supply rails. Exact range depends on the power supply voltage and the voltage applied to the Ref terminal (pin 1). To assure proper operation, the voltage at the non-inverting input of A1 (an internal node) must be within its linear operating range. Its voltage is determined by the simple 1:1 voltage divider between pin 3 and pin 1. This voltage must be between V– and (V+) – 1V.




| | | STANDARD 1% RESISTORS | | |
|---|---|---|---|---|
| TOTAL GAIN (V/V) | A2 GAIN (V/V) | $R_{G1}$ (W) | $R_{G2}$ (W) | $R_B$ (W) |
| 1 | 1 | (None) | 10k | — |
| 2 | 2 | 20k | 20k | — |
| 5 | 5 | 12.4k | 49.9k | — |
| 10 | 10 | 11.0k | 100k | — |
| 20 | 20 | 10.5k | 200k | — |
| 50 | 50 | 10.2k | 499k | — |
| 100 | 100 | 10.2k | 1M | — |
| 200 | 200 | 499 | 100k | 9.53k |
| 500 | 500 | 100 | 49.9k | 10k |
| 1000 | 1000 | 100 | 100k | 10k |

FIGURE 1. Basic Circuit Connections.

## OFFSET TRIM

The INA145 is laser-trimmed for low offset voltage and drift. Most applications require no external offset adjustment. Figure 2 shows an optional circuit for trimming the offset voltage. A voltage applied to the Ref terminal will be summed with the output signal. This can be used to null offset voltage. To maintain good common-mode rejection, the source impedance of a signal applied to the Ref terminal should be less than 10Ω and a resistor added to the positive input terminal should be 10 times that, or 100Ω. Alternatively, the trim voltage can be buffered with an op amp such as the OPA277.

## INPUT IMPEDANCE

The input impedance of the INA145 is determined by the input resistor network and is approximately 40kΩ. The source impedance at the two input terminals must be nearly equal to maintain good common-mode rejection. A 5Ω mismatch in impedance between the two inputs will cause the typical common-mode rejection to be degraded to approximately 72dB. Figure 7 shows a common application measuring power supply current through a shunt resistor. The source impedance of the shunt resistor, $R_S$, is balanced by an equal compensation resistor, $R_C$.

Source impedances greater than 300Ω are not recommended, even if they are perfectly matched. Internal resistors are laser trimmed for accurate ratios, not to absolute values. Adding equal resistors greater than 300Ω can cause a mismatch in the total resistor ratios, degrading CMR.

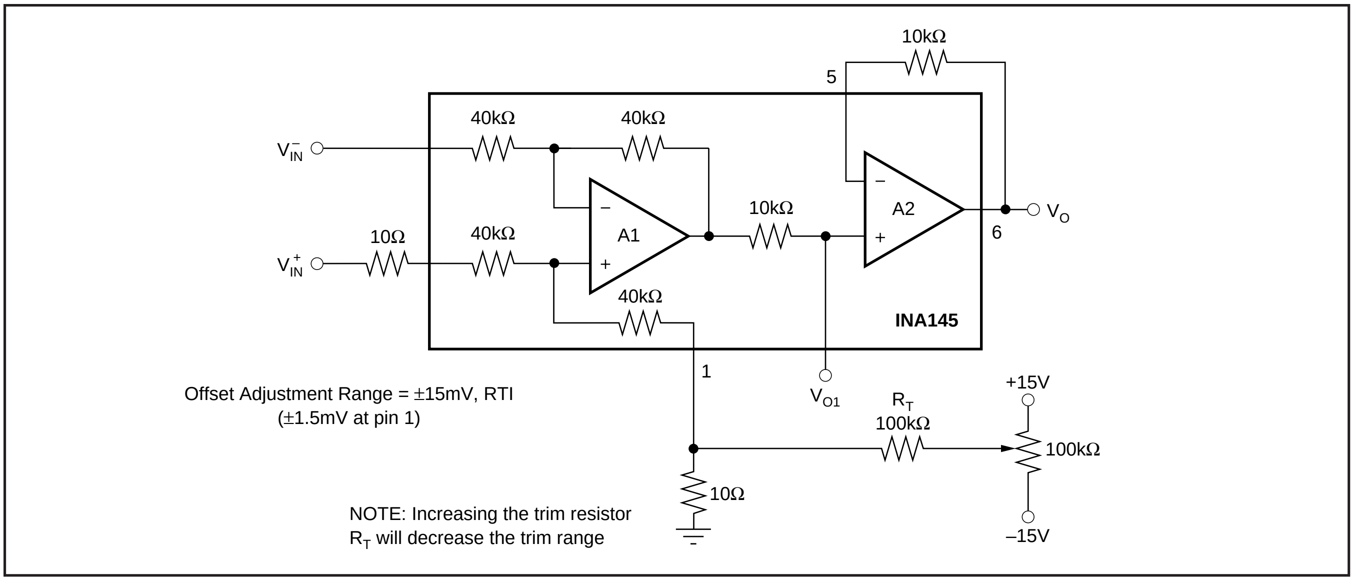
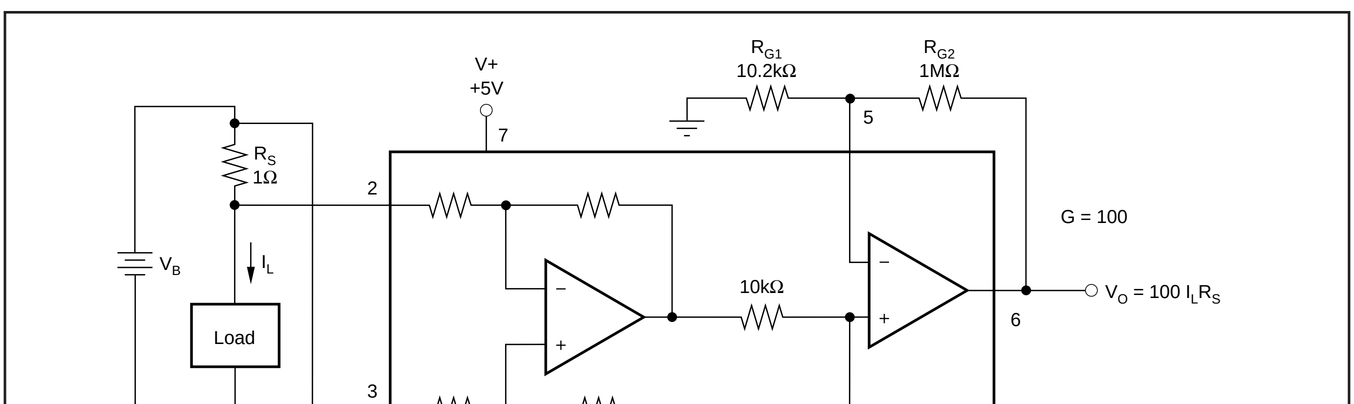



FIGURE 2. Optional Offset Trim Circuit.




| V+ | Max $V_B$ |
|---|---|
| +5V | 8V |
| +7V | 12V |
| +10V | 18V |
| +15V | 28V |

FIGURE 3. Measuring Current with Shunt Resistor.

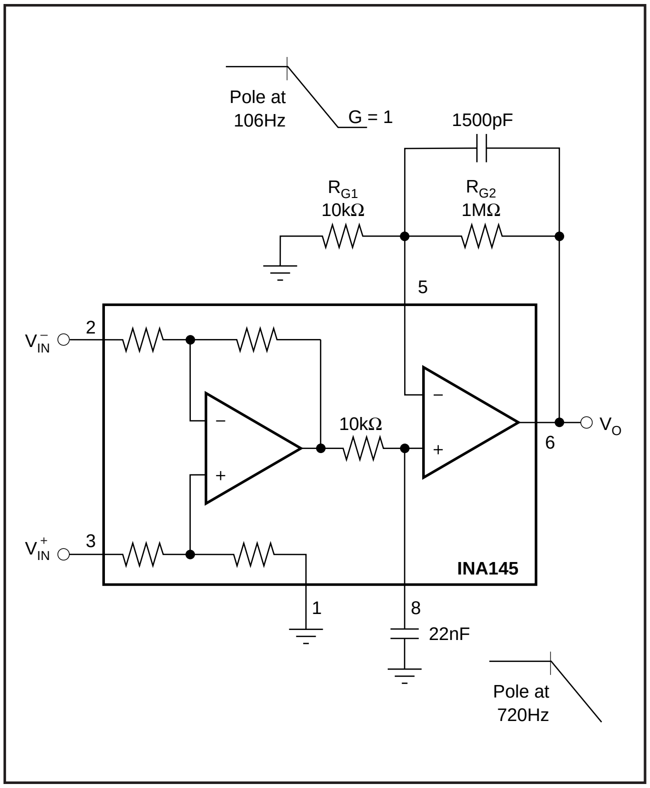



FIGURE 4. Noise Filtering.

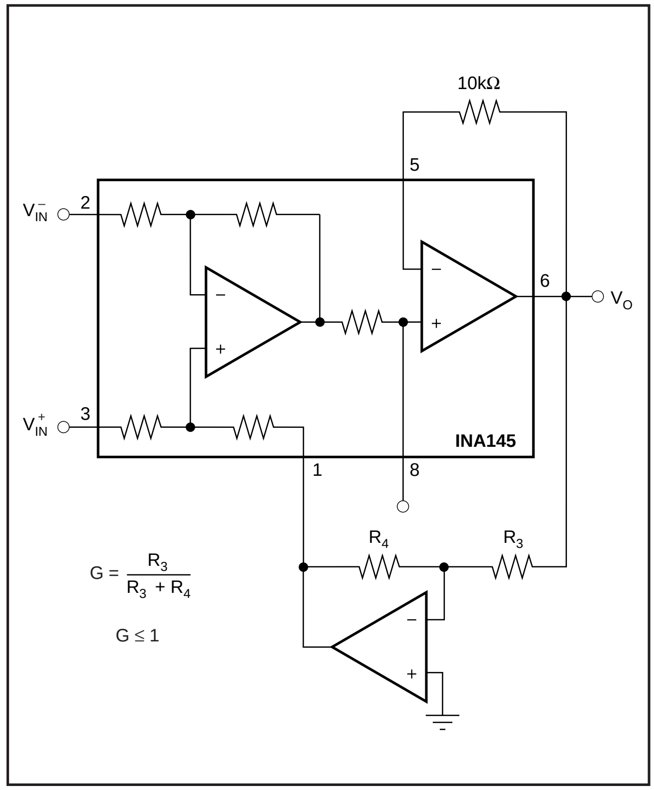



FIGURE 5. Creating Gains Less Than Unity.

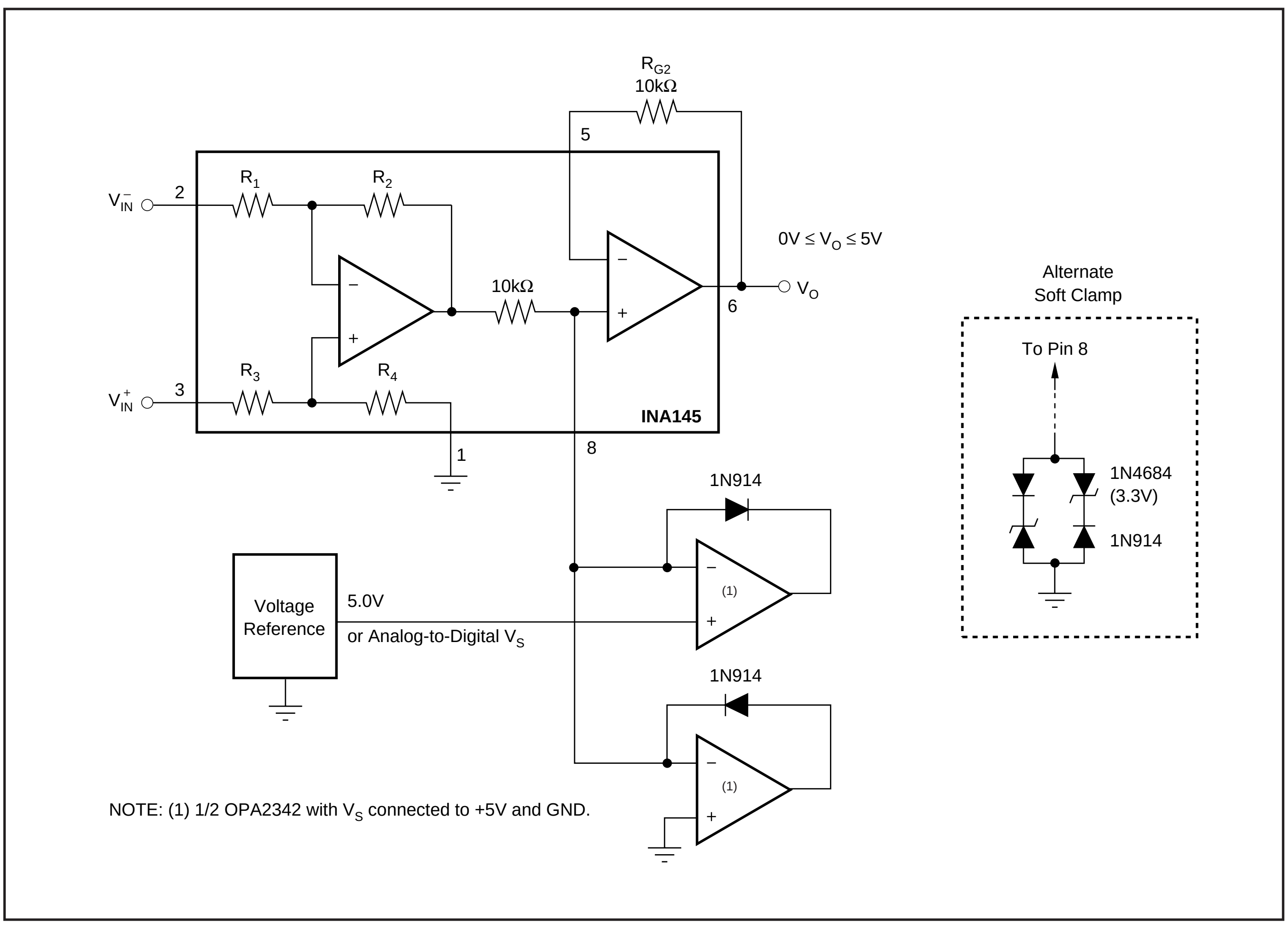



FIGURE 6. Clamp Circuits.

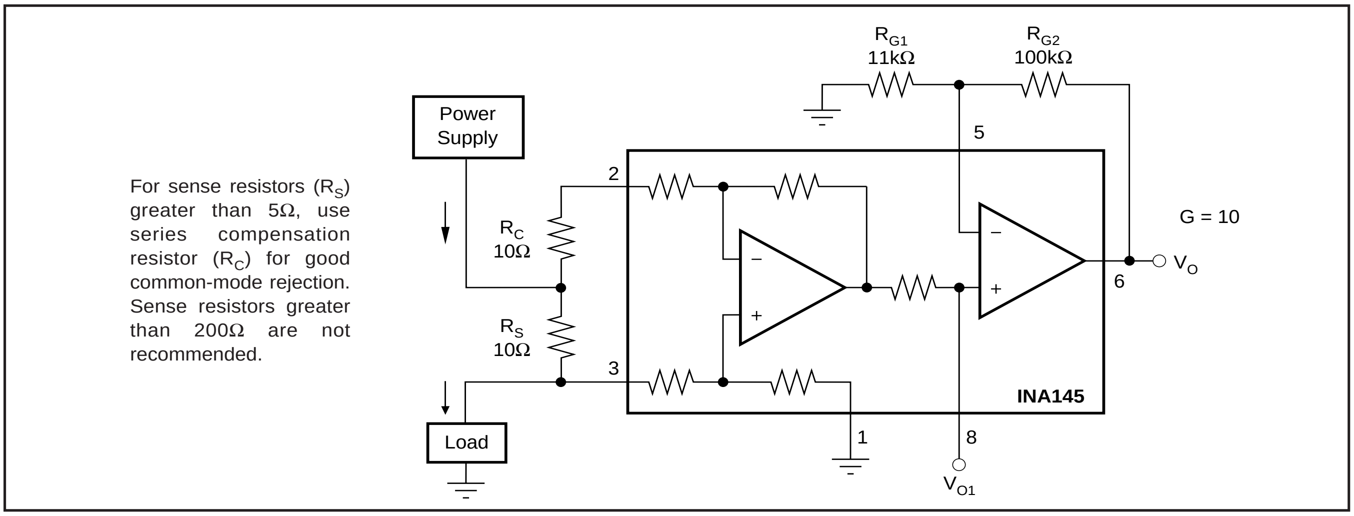



FIGURE 7. Current Monitor, G = 1.

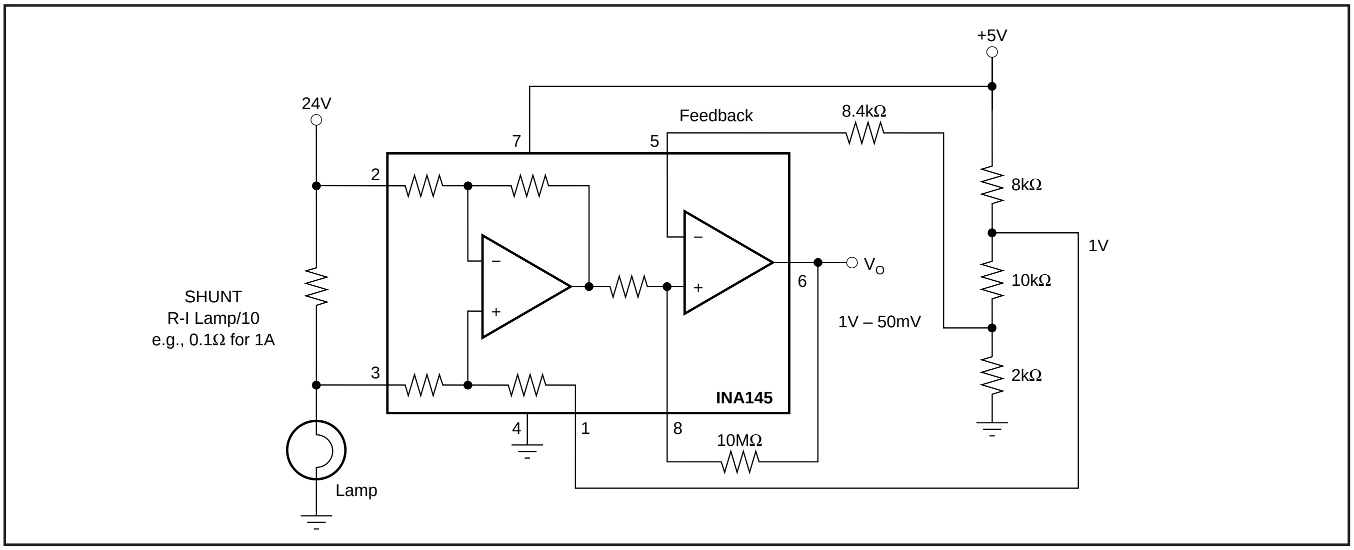



FIGURE 8. Comparator Output with Optional Hysteresis Application to Sense Lamp Burn-Out.

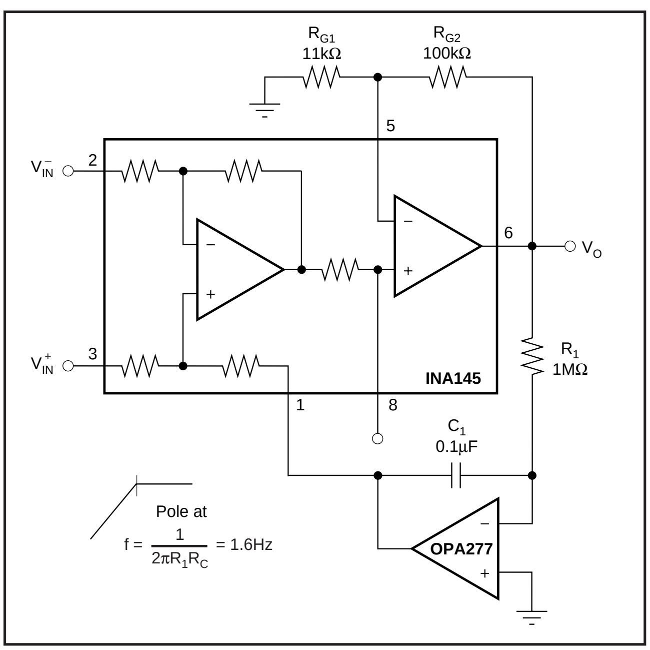



FIGURE 9. AC Coupling (DC Restoration).

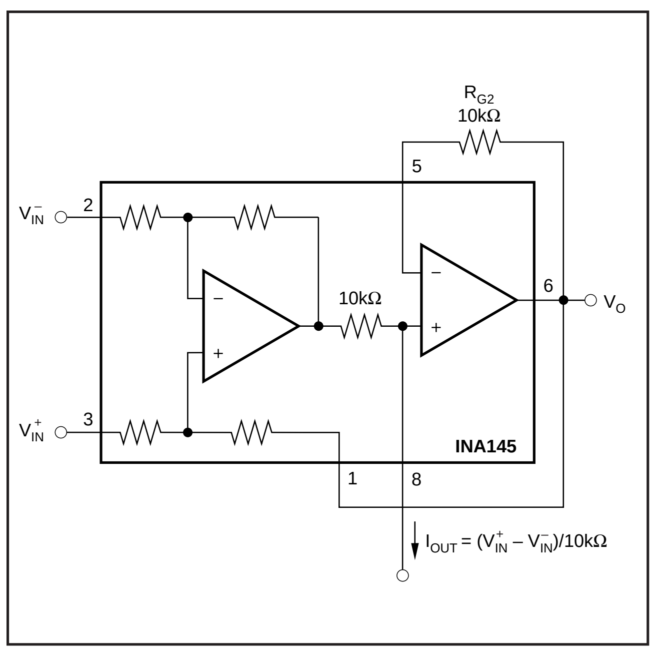



FIGURE 10. Precision Current Source.