# INA337
# INA338

SBOS248 – JUNE 2002

# Wide-Temperature, Precision INSTRUMENTATION AMPLIFIER

## FEATURES

- **PRECISION**
  - **LOW OFFSET: 100μV (max)**
  - **LOW OFFSET DRIFT: 0.4μV/°C (max)**
  - **EXCELLENT LONG-TERM STABILITY**
  - **VERY-LOW 1/f NOISE**
- **SMALL SIZE**
  - ***micro*PACKAGE: MSOP-8, MSOP-10**
- **LOW COST**

## APPLICATIONS

- **LOW-LEVEL TRANSDUCER AMPLIFIER FOR BRIDGES, LOAD CELLS, THERMOCOUPLES**
- **WIDE DYNAMIC RANGE SENSOR MEASUREMENTS**
- **HIGH-RESOLUTION TEST SYSTEMS**
- **WEIGH SCALES**
- **MULTI-CHANNEL DATA ACQUISITION SYSTEMS**
- **MEDICAL INSTRUMENTATION**
- **AUTOMOTIVE APPLICATIONS**
- **GENERAL-PURPOSE**

## DESCRIPTION

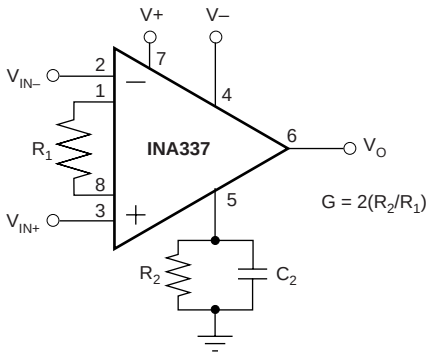
The INA337 and INA338 (with shutdown) are high temperature, high-performance, low-cost, precision instrumentation amplifiers. They are true single-supply instrumentation amplifiers with very-low DC errors and input common-mode ranges that extends beyond the positive and approaches the negative rail. These features make them suitable for applications ranging from general-purpose to high-accuracy.

Excellent long-term stability and very low 1/f noise assure low offset voltage and drift throughout the life of the product.

The INA337 (without shutdown) comes in the MSOP-8 package. The INA338 (with shutdown) is offered in MSOP-10. Both are specified over the temperature range, –40°C to +125°C.

### INA337 AND INA338 RELATED PRODUCTS

| PRODUCT | FEATURES |
|---|---|
| **INA326** | **Precision, Rail-to-Rail I/O, 2.4mA $I_Q$** |
| INA114 | 50μV $V_{OS}$, 0.5nA $I_B$, 115dB CMR, 3mA $I_Q$, 0.25μV/°C drift |
| INA118 | 50μV $V_{OS}$, 1nA $I_B$, 120dB CMR, 385μA $I_Q$, 0.5μV/°C drift |
| INA122 | 250μV $V_{OS}$, –10nA $I_B$, 85μA $I_Q$, Rail-to-Rail Output, 3μV/°C drift |
| INA128 | 50μV $V_{OS}$, 2nA $I_B$, 125dB CMR, 750μA $I_Q$, 0.5μV/°C drift |
| INA321 | 500μV $V_{OS}$, 0.5pA $I_B$, 94dB CMRR, 60μA $I_Q$, Rail-to-Rail Output |




Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

PRODUCTION DATA information is current as of publication date. Products conform to specifications per the terms of Texas Instruments standard warranty. Production processing does not necessarily include testing of all parameters.

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## PACKAGE/ORDERING INFORMATION

| PRODUCT | PACKAGE-LEAD | PACKAGE DESIGNATOR(1) | SPECIFIED TEMPERATURE RANGE | PACKAGE MARKING | ORDERING NUMBER | TRANSPORT MEDIA, QUANTITY |
|---|---|---|---|---|---|---|
| INA337 | MSOP-8 | DGK | –40°C to +125°C | BIM | INA337AIDGKT | Tape and Reel, 250 |
| " | " | " | " | " | INA337AIDGKR | Tape and Reel, 2500 |
| INA338 | MSOP-10 | DGS | –40°C to +125°C | BIL | INA338AIDGST | Tape and Reel, 250 |
| " | " | " | " | " | INA338AIDGSR | Tape and Reel, 2500 |

NOTE: (1) For the most current specifications and package information, refer to our web site at www.ti.com.

## ABSOLUTE MAXIMUM RATINGS(1)

| | |
|---|---|
| Supply Voltage | +5.5V |
| Signal Input Terminals: Voltage(2) | –0.5V to (V+) + 0.5V |
| Current(2) | ±10mA |
| Output Short-Circuit | Continuous |
| Operating Temperature Range | –40°C to +150°C |
| Storage Temperature Range | –65°C to +150°C |
| Junction Temperature | +150°C |
| Lead Temperature (soldering, 10s) | +300°C |

NOTES: (1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those specified is not implied. (2) Input terminals are diode clamped to the power-supply rails. Input signals that can swing more than 0.5V beyond the supply rails should be current limited to 10mA or less.

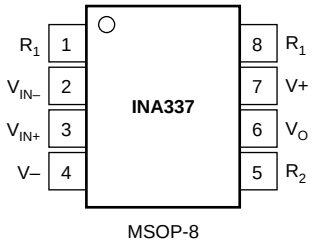
## ELECTROSTATIC DISCHARGE SENSITIVITY

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

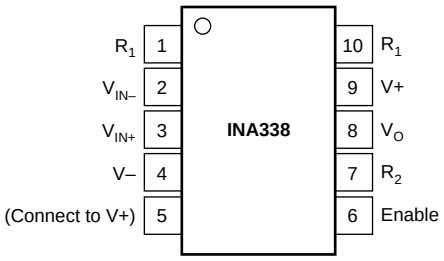
ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

## PIN CONFIGURATION

**Top View**




MSOP-8




MSOP-10

# ELECTRICAL CHARACTERISTICS: $V_S$ = +2.7V to +5.5V

## **BOLDFACE** limits apply over the specified temperature range, $T_A$ = –40°C to +125°C

At $T_A$ = +25°C, $R_L$ = 10kΩ, G = 100 ($R_1$ = 2kΩ, $R_2$ = 100kΩ), external gain set resistors, and $IA_{COMMON} = V_S/2$, with external equivalent filter corner of 1kHz filters, unless otherwise noted.

| PARAMETER | | CONDITION | INA337AIDGK, INA338AIDGS MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|
| **INPUT** | | | | | | |
| Offset Voltage, RTI | $V_{OS}$ | $V_S$ = +5V, $V_{CM} = V_S/2$ | | ±20 | ±100 | µV |
| **Over Temperature** | | | | | **±140** | µV |
| **vs Temperature** | **$dV_{OS}/dT$** | | | **±0.1** | **±0.4** | µV/°C |
| vs Power Supply | PSR | $V_S$ = +2.7V to +5.5V, $V_{CM} = V_S/2$ | ±20 | ±3 | | µV/V |
| Long-Term Stability | | | | See Note (1) | | |
| Input Impedance, Differential | | | | $10^{10}$ \|\| 2 | | Ω \|\| pF |
| Common-Mode | | | | $10^{10}$ \|\| 14 | | Ω \|\| pF |
| **Input Voltage Range** | | | **(V–) + 0.25** | | **(V+) + 0.1** | **V** |
| Safe Input Voltage | | | (V–) –0.5 | | (V+) + 0.5 | V |
| Common-Mode Rejection | CMR | $V_S$ = +5V, $V_{CM}$ = (V–) + 0.25V to (V+) + 0.1V | 106 | 120 | | dB |
| **Over Temperature** | | | **100** | | | dB |
| **INPUT BIAS CURRENT** | | $V_{CM} = V_S/2$ | | | | |
| Bias Current | $I_B$ | $V_S$ = +5V | | ±0.2 | ±2 | nA |
| **vs Temperature** | | | | **See Typical Characteristics** | | |
| Offset Current | $I_{OS}$ | $V_S$ = +5V | | ±0.2 | ±2 | nA |
| **NOISE** | | | | | | |
| Voltage Noise, RTI | | $R_S$ = 0Ω, G = 100, $R_1$ = 2kΩ, $R_2$ = 100kΩ | | | | |
| f = 10Hz | | | | 33 | | nV/√Hz |
| f = 100Hz | | | | 33 | | nV/√Hz |
| f = 1kHz | | | | 33 | | nV/√Hz |
| f = 0.01Hz to 10Hz | | | | 0.8 | | µVp-p |
| Voltage Noise, RTI | | $R_S$ = 0Ω, G = 10, $R_1$ = 20kΩ, $R_2$ = 100kΩ | | | | |
| f = 10Hz | | | | 120 | | nV/√Hz |
| f = 100Hz | | | | 97 | | nV/√Hz |
| f = 1kHz | | | | 97 | | nV/√Hz |
| f = 0.01Hz to 10Hz | | | | 4 | | µVp-p |
| Current Noise, RTI | | | | | | |
| f = 1kHz | | | | 0.15 | | pA/√Hz |
| f = 0.01Hz to 10Hz | | | | 4.2 | | pAp-p |
| Output Ripple, $V_O$ Filtered[2] | | | | See Applications Information | | |
| **GAIN** | | | | | | |
| Gain Equation | | | | $G = 2(R_2/R_1)$ | | |
| Range of Gain | | | < 0.1 | | > 10000 | V/V |
| Gain Error[3] | | G = 10, 100, $V_S$ = +5V, $V_O$ = 0.25V to 4.925V | | 0.08 | ±0.2 | % |
| **vs Temperature** | | G = 10, 100, $V_S$ = +5V, $V_O$ = 0.25V to 4.925V | | **±6** | **±25** | ppm/°C |
| Nonlinearity | | G = 10, 100, $V_S$ = +5V, $V_O$ = 0.25V to 4.925V | | ±0.003 | ±0.01 | % of FS |
| **OUTPUT** | | | | | | |
| Voltage Output Swing from Positive Rail | | $R_L$ = 10kΩ, $V_S$ = 5V | (V+) – 0.075 | (V+) – 0.01 | | V |
| **Over Temperature** | | | **(V+) – 0.075** | | | **V** |
| Voltage Output Swing from Negative Rai | | $R_L$ = 10kΩ, $V_S$ = 5V | (V–) + 0.25 | (V+) + 0.01 | | V |
| **Over Temperature** | | | **(V–) + 0.25** | | | **V** |
| Capacitive Load Drive | | | | 500 | | pF |
| Short-Circuit Current | $I_{SC}$ | | | ±25 | | mA |
| **INTERNAL OSCILLATOR** | | | | | | |
| Frequency of Auto-Correction | | | | 90 | | kHz |
| Accuracy | | | | ±20 | | % |
| **FREQUENCY RESPONSE** | | | | | | |
| Bandwidth[4], –3dB | BW | G = 1 to 1k | | 1 | | kHz |
| Slew Rate[4] | SR | $V_S$ = 5V, All Gains, $C_L$ = 100pF | | Filter Limited | | |
| Settling Time[4], 0.1% | $t_S$ | 1kHz Filter, G = 1 to 1k, $V_O$ = 2V step, $C_L$ = 100pF | | 0.95 | | ms |
| 0.01% | | | | 1.3 | | ms |
| 0.1% | | 10kHz Filter, G = 1 to 1k, $V_O$ = 2V step, $C_L$ = 100pF | | 130 | | µs |
| 0.01% | | | | 160 | | µs |
| Overload Recovery[4] | | 1kHz Filter, 50% Output Overload, G = 1 to 1k | | 30 | | µs |
| | | 10kHz Filter, 50% Output Overload, G = 1 to 1k | | 5 | | µs |

# ELECTRICAL CHARACTERISTICS: $V_S$ = +2.7V to +5.5V (Cont.)

**BOLDFACE** limits apply over the specified temperature range, $T_A$ = –40°C to +125°C

At $T_A$ = +25°C, $R_L$ = 10kΩ, G = 100 ($R_1$ = 2kΩ, $R_2$ = 100kΩ), external gain set resistors, and $IA_{COMMON} = V_S/2$, with external equivalent filter corner of 1kHz filters, unless otherwise noted.

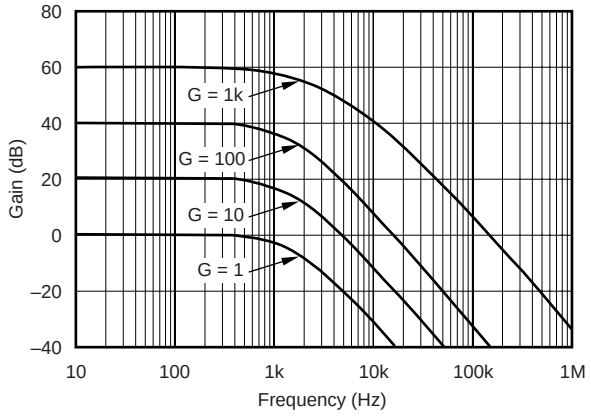
| PARAMETER | CONDITION | INA337AIDGK, INA338AIDGS MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|
| **POWER SUPPLY** | | | | | |
| Specified Voltage Range | | +2.7 | | +5.5 | V |
| Quiescent Current $I_Q$ | $I_O$ = 0, Diff $V_{IN}$ = 0V, $V_S$ = +5V | | 2.4 | 3.4 | mA |
| **Over Temperature** | | | | **3.7** | **mA** |
| **SHUTDOWN** | | | | | |
| Disable (Logic-Low Threshold) | | | | 0.25 | V |
| Enable (Logic-High Threshold) | | 1.6 | | | V |
| Enable Time[5] | | | 75 | | µs |
| Disable Time | | | 100 | | µs |
| Shutdown Current and Enable Pin Current | $V_S$ = +5V, Disabled | | 2 | 5 | µA |
| **TEMPERATURE RANGE** | | | | | |
| Specified Range | | –40 | | +125 | °C |
| Operating Range | | –40 | | +150 | °C |
| Storage Range | | –65 | | +150 | °C |
| Thermal Resistance $\theta_{JA}$ | MSOP-8 Surface-Mount | | 150 | | °C/W |

NOTES: (1) 1000-hour life test at 150°C demonstrated randomly distributed variation in the range of measurement limits—approximately 10µV. (2) See Applications Information section, Figures 1 and 2. (3) Does not include error and TCR of external gain-setting resistors. (4) Dynamic response is limited by filtering. Higher bandwidths can be achieved by adjusting the filter. (5) See Typical Characteristics, “Input Offset Voltage vs Warm-Up Time”.

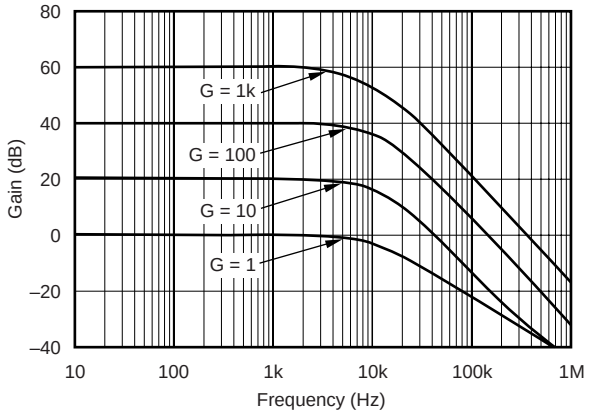
# TYPICAL CHARACTERISTICS

At $T_A$ = 25°C, $V_S$ = +5V, Gain = 100, $R_L$ = 10kΩ with external equivalent filter corner of 1kHz filters, unless otherwise noted.

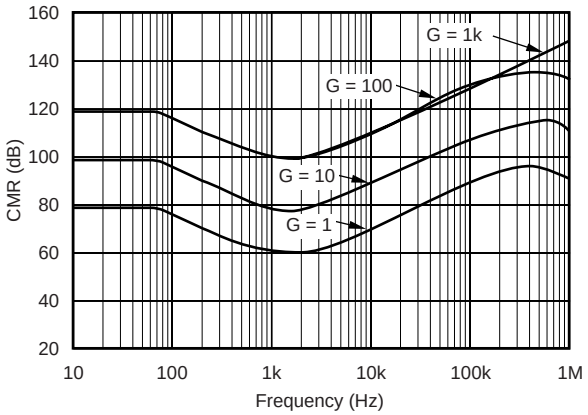
GAIN vs FREQUENCY
1kHz FILTER



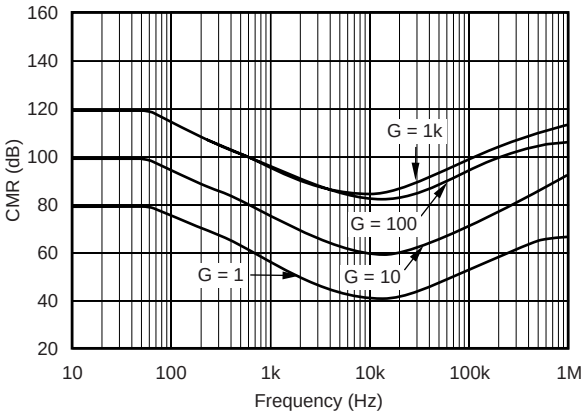

GAIN vs FREQUENCY
10kHz FILTER



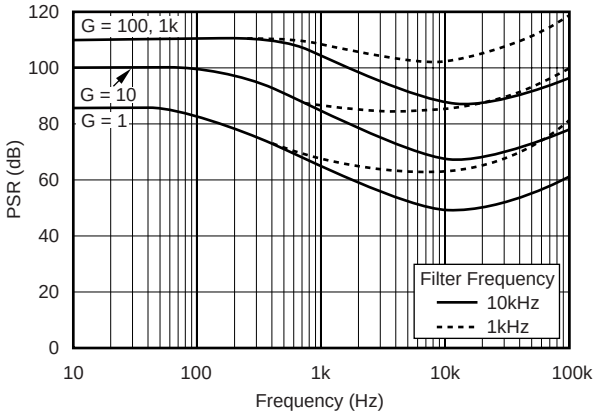

CMR vs FREQUENCY
1kHz FILTER



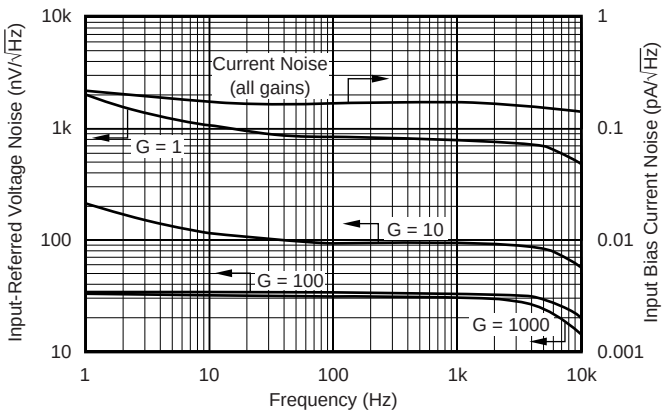

CMR vs FREQUENCY
10kHz FILTER




POWER-SUPPLY REJECTION vs FREQUENCY



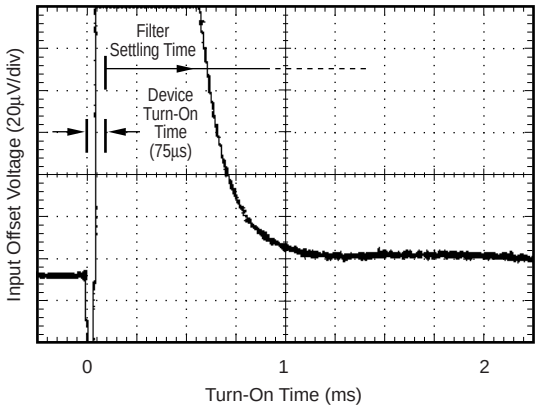

INPUT-REFERRED VOLTAGE NOISE AND
INPUT BIAS CURRENT NOISE vs FREQUENCY
10kHz Filter



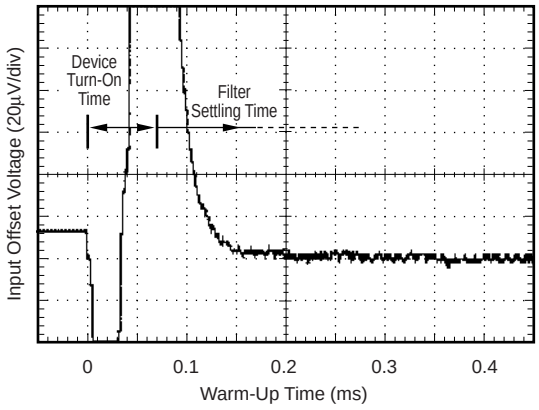
# TYPICAL CHARACTERISTICS (Cont.)

At $T_A$ = 25°C, $V_S$ = +5V, Gain = 100, $R_L$ = 10kΩ with external equivalent filter corner of 1kHz filters, unless otherwise noted.

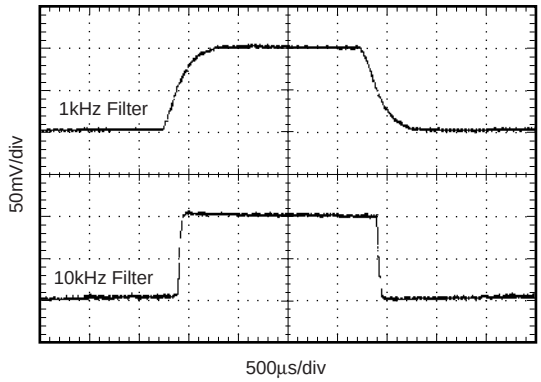
INPUT OFFSET VOLTAGE vs TURN-ON TIME
1kHz FILTER, G = 100



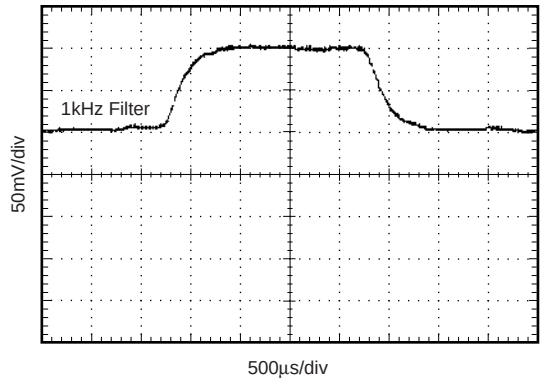

INPUT OFFSET VOLTAGE vs WARM-UP TIME
10kHz FILTER, G = 100



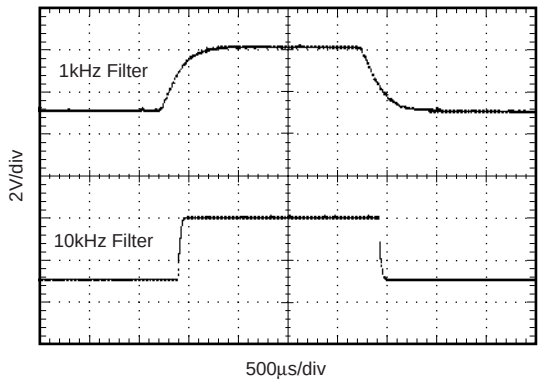

SMALL-SIGNAL RESPONSE
G = 1, 10, AND 100



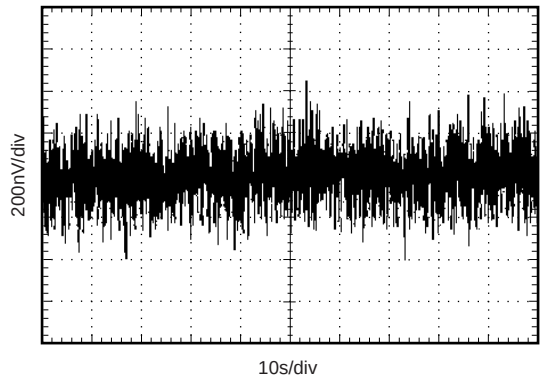

SMALL-SIGNAL STEP RESPONSE
G = 1000




LARGE-SIGNAL RESPONSE
G = 1 TO 1000



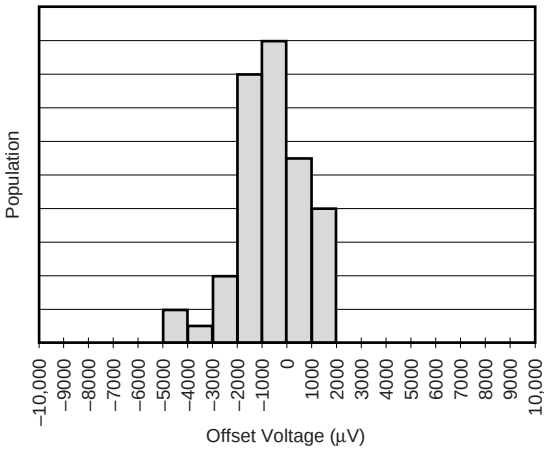

0.01Hz TO 10Hz VOLTAGE NOISE



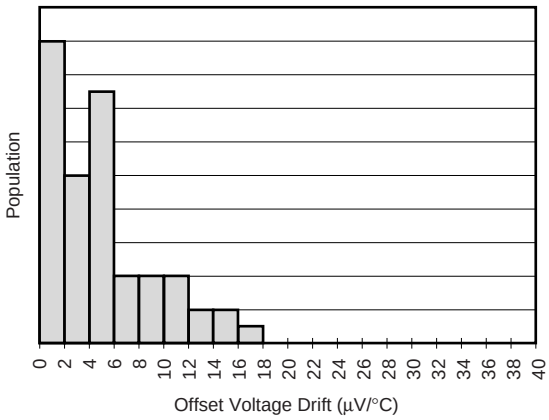
# TYPICAL CHARACTERISTICS (Cont.)

At $T_A$ = 25°C, $V_S$ = +5V, Gain = 100, $R_L$ = 10kΩ with external equivalent filter corner of 1kHz filters, unless otherwise noted.

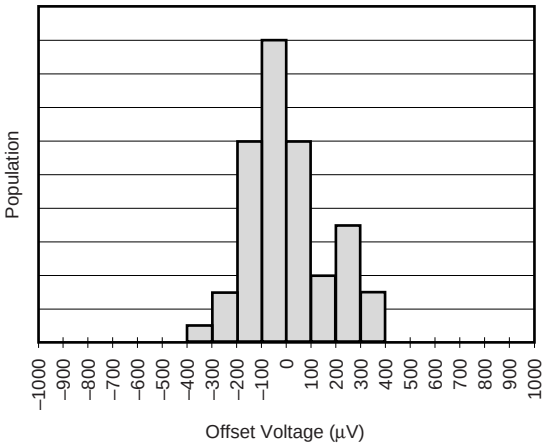
OFFSET VOLTAGE PRODUCTION DISTRIBUTION
G = 1



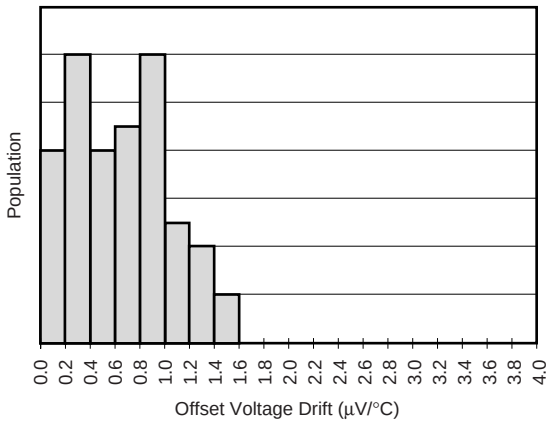

OFFSET VOLTAGE DRIFT PRODUCTION DISTRIBUTION
G = 1



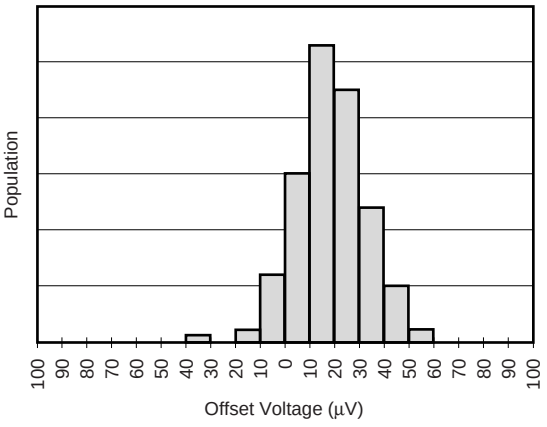

OFFSET VOLTAGE PRODUCTION DISTRIBUTION
G = 10



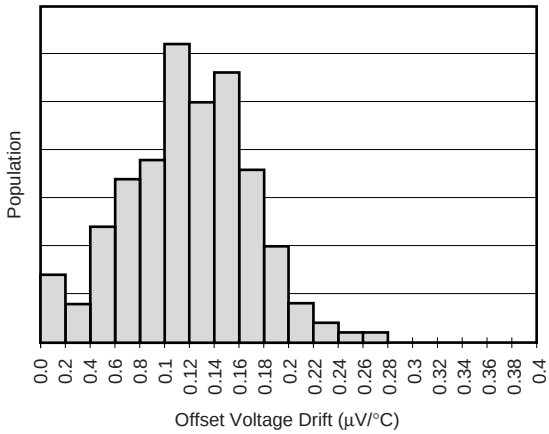

OFFSET VOLTAGE DRIFT PRODUCTION DISTRIBUTION
G = 10




OFFSET VOLTAGE PRODUCTION DISTRIBUTION
G = 100 and 1000



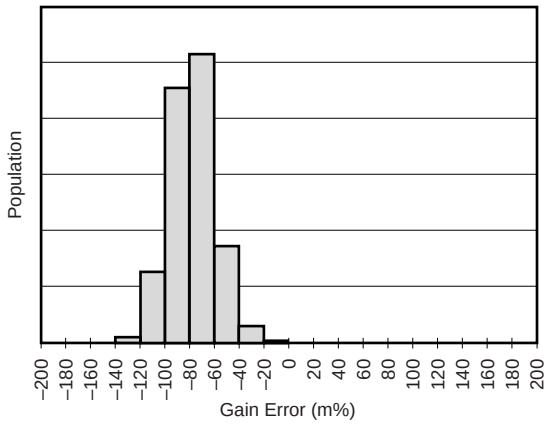

OFFSET VOLTAGE DRIFT PRODUCTION DISTRIBUTION
G = 100 and 1000



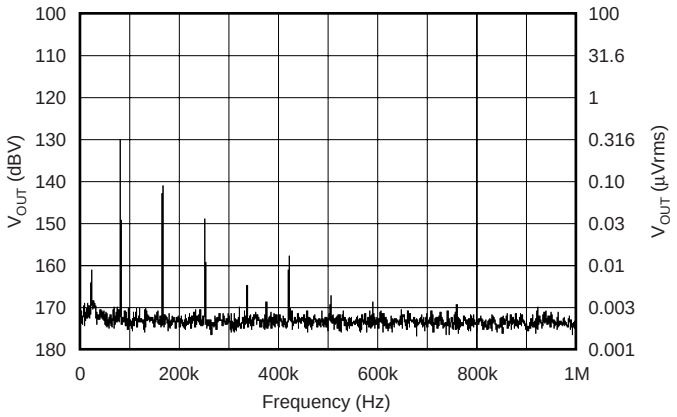
# TYPICAL CHARACTERISTICS (Cont.)

At $T_A$ = 25°C, $V_S$ = +5V, Gain = 100, $R_L$ = 10kΩ with external equivalent filter corner of 1kHz filters, unless otherwise noted.

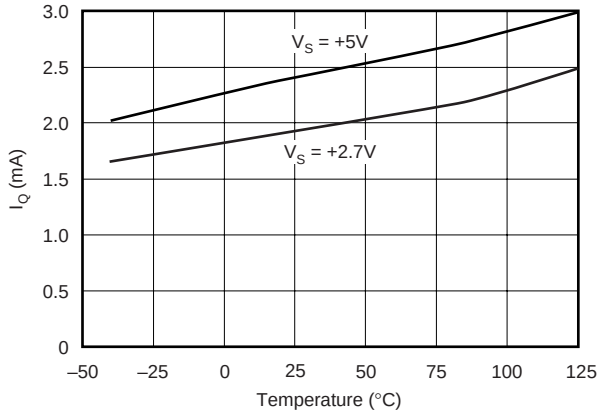
GAIN ERROR PRODUCTION DISTRIBUTION



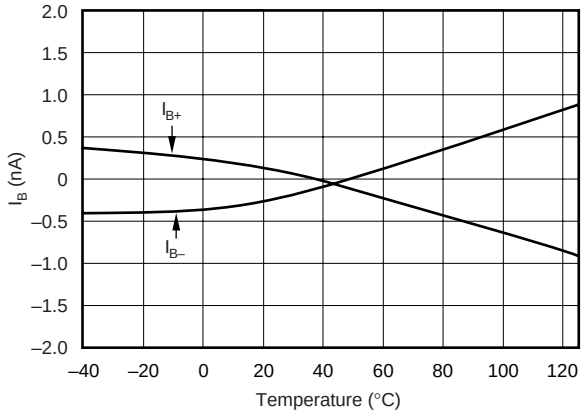

INPUT-REFERRED RIPPLE SPECTRUM
G = 100



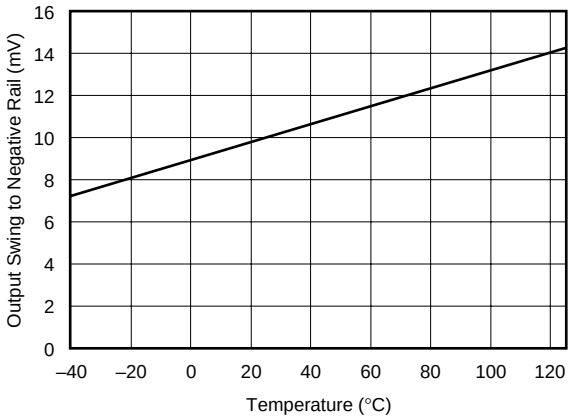

QUIESCENT CURRENT vs TEMPERATURE




INPUT BIAS CURRENT vs TEMPERATURE




OUTPUT SWING TO THE NEGATIVE RAIL
vs TEMPERATURE



# APPLICATIONS INFORMATION

Figure 1 shows the basic connections required for operation of the INA337. A 0.1µF capacitor, placed close to and across the power-supply pins is strongly recommended for highest accuracy. $R_oC_o$ is an output filter that minimizes auto-correction circuitry noise. This output filter may also serve as an anti-aliasing filter ahead of an Analog-to-Digital (A/D) converter. It is also optional based on desired precision.

The output reference terminal is taken at the low side of $R_2$ ($IA_{COMMON}$).

The INA337 uses a unique internal topology to achieve excellent common-mode rejection (CMR). Unlike conventional instrumentation amplifiers, CMR is not affected by resistance in the reference connections. See “Inside the INA337” for further detail. To achieve best high-frequency CMR, minimize capacitance on pins 1 and 8.

## SETTING THE GAIN

The INA337 is a 2-stage amplifier with each stage gain set by $R_1$ and $R_2$, respectively (see Figure 4, “Inside the INA337", for details.) Overall gain is described by the equation:

$$G = \frac{2R_2}{R_1} \quad (1)$$

The stability and temperature drift of the external gain-setting resistors will affect gain by an amount that can be directly inferred from the gain equation (1).

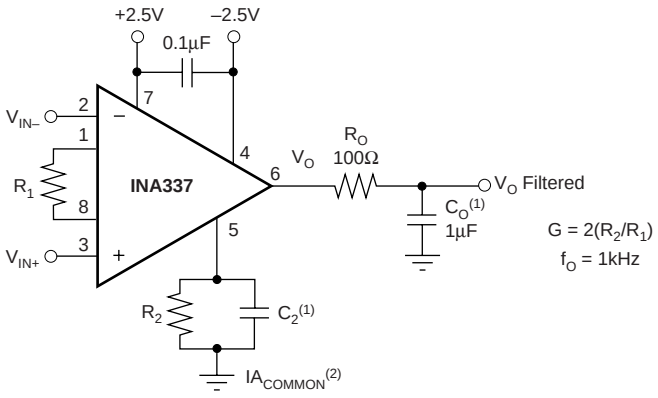
Resistor values for commonly used gains are shown in Figure 1. Gain-set resistor values for best performance are different for +5V single-supply and for ±2.5V dual-supply operation. Optimum value for $R_1$ can be calculated by:

$$R_1 = V_{IN,\ MAX}/12.5\mu A \quad (2)$$

where $R_1$ must be no less than 2kΩ.

### Dual-Supply Operation

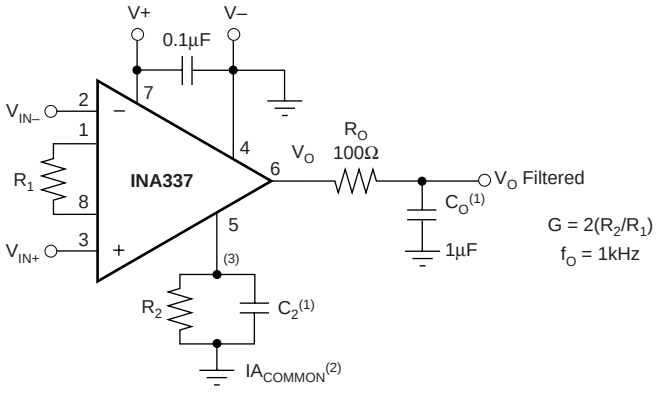
| DESIRED GAIN | $R_1$ (Ω) | $R_2$ \|\| $C_2$ (Ω \|\| nF) |
|---|---|---|
| 0.1 | 400k | 20k \|\| 5 |
| 0.2 | 400k | 40k \|\| 2.5 |
| 0.5 | 400k | 100k \|\| 1 |
| 1 | 200k | 100k \|\| 1 |
| 2 | 100k | 100k \|\| 1 |
| 5 | 40k | 100k \|\| 1 |
| 10 | 20k | 100k \|\| 1 |
| 20 | 10k | 100k \|\| 1 |
| 50 | 4k | 100k \|\| 1 |
| 100 | 2k | 100k \|\| 1 |
| 200 | 2k | 200k \|\| 0.5 |
| 500 | 2k | 500k \|\| 0.2 |
| 1000 | 2k | 1M \|\| 0.1 |
| 2000 | 2k | 2M \|\| 0.05 |
| 5000 | 2k | 5M \|\| 0.02 |
| 10000 | 2k | 10M \|\| 0.01 |




NOTES: (1) $C_2$ and $C_O$ combine to form a 2-pole response that is –3dB at 1kHz. Each individual pole is at 1.5kHz. (2) Output voltage is referenced to $IA_{COMMON}$ (see text).

### Single-Supply Operation

| DESIRED GAIN | $R_1$ (Ω) | $R_2$ \|\| $C_2$ (Ω \|\| nF) |
|---|---|---|
| 0.1 | 400k | 20k \|\| 5 |
| 0.2 | 400k | 40k \|\| 2.5 |
| 0.5 | 400k | 100k \|\| 1 |
| 1 | 400k | 200k \|\| 0.5 |
| 2 | 200k | 200k \|\| 0.5 |
| 5 | 80k | 200k \|\| 0.5 |
| 10 | 40k | 200k \|\| 0.5 |
| 20 | 20k | 200k \|\| 0.5 |
| 50 | 8k | 200k \|\| 0.5 |
| 100 | 4k | 200k \|\| 0.5 |
| 200 | 2k | 200k \|\| 0.5 |
| 500 | 2k | 500k \|\| 0.2 |
| 1000 | 2k | 1M \|\| 0.1 |
| 2000 | 2k | 2M \|\| 0.05 |
| 5000 | 2k | 5M \|\| 0.02 |
| 10000 | 2k | 10M \|\| 0.01 |




NOTES: (1) $C_2$ and $C_O$ combine to form a 2-pole response that is –3dB at 1kHz. Each individual pole is at 1.5kHz. (2) Output voltage is referenced to $IA_{COMMON}$ (see text). (3) Output pedestal required for measurement near zero (see Figure 6).

FIGURE 1. Basic Connections. NOTE: Connections for INA338 differ—see Pin Configuration for detail.

Following this design procedure for $R_1$ produces the maximum possible input stage gain for best accuracy and lowest noise.

Circuit layout and supply bypassing can affect performance. Minimize the stray capacitance on pins 1 and 8. Use recommended supply bypassing, including a capacitor directly from pin 7 to pin 4 (V+ to V–), even with dual (split) power supplies (see Figure 1).

## DYNAMIC PERFORMANCE

The typical characteristic “Gain vs Frequency” shows that the INA337 has nearly constant bandwidth regardless of gain. This results from the bandwidth limiting from the recommended filters.

## NOISE PERFORMANCE

Internal auto-correction circuitry eliminates virtually all 1/f noise (noise that increases at low frequency) in gains of 100 or greater. Noise performance is affected by gain-setting resistor values. Follow recommendations in the “Setting Gain” section for best performance.

Total noise is a combination of input stage noise and output stage noise. When referred to the input, the total mid-band noise is:

$$V_N = 33nV / \sqrt{Hz} + \frac{800nV / \sqrt{Hz}}{G} \qquad (3)$$

The output noise has some 1/f components that affect performance in gains less than 10. See typical characteristic “Input-Referred Voltage Noise vs Frequency.”

High-frequency noise is created by internal auto-correction circuitry and is highly dependent on the filter characteristics chosen. This may be the dominant source of noise visible when viewing the output on an oscilloscope. Low cutoff frequency filters will provide lowest noise. Figure 2 shows the typical noise performance as a function of cutoff frequency.

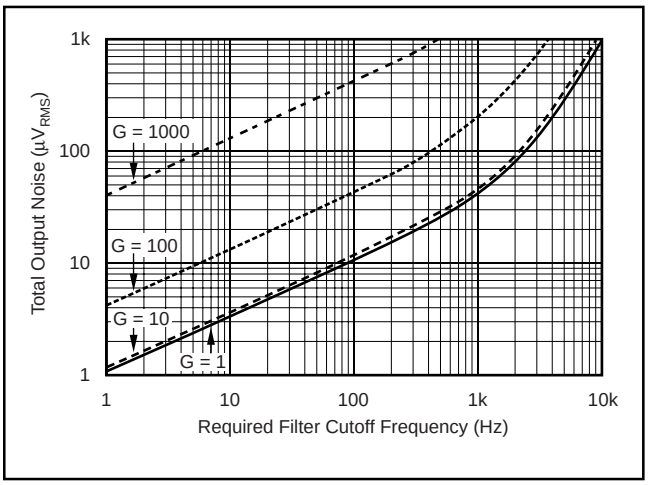



FIGURE 2. Total Output Noise vs Filter Cutoff Frequency.

Applications sensitive to the spectral characteristics of high-frequency noise may require consideration of the spurious frequencies generated by internal clocking circuitry. “Spurs” occur at approximately 90kHz and its harmonics (see typical characteristic “Input Referred Ripple”) which may be reduced by additional filtering below 1kHz.

Insufficient filtering at pin 5 can cause nonlinearity with large output voltage swings (very near the supply rails). Noise must be sufficiently filtered at pin 5 so that noise peaks do not “hit the rail” and change the average value of the signal. Figure 2 shows guidelines for filter cutoff frequency.

## HIGH-FREQUENCY NOISE

$C_2$ and $C_O$ form filters to reduce internally generated auto-correction circuitry noise. Filter frequencies can be chosen to optimize the tradeoff between noise and frequency response of the application, as shown in Figure 2. The cutoff frequencies of the filters are generally set to the same frequency. Figure 2 shows the typical output noise for four gains as a function of the –3dB cutoff frequency of each filter response. Small signals may exhibit the addition of internally generated auto-correction circuitry noise at the output. This noise, combined with broadband noise, becomes most evident in higher gains with filters of wider bandwidth.

## INPUT BIAS CURRENT RETURN PATH

The input impedance of the INA337 is extremely high—approximately $10^{10}\Omega$. However, a path must be provided for the input bias current of both inputs. This input bias current is approximately ±0.2nA. High input impedance means that this input bias current changes very little with varying input voltage.

Input circuitry must provide a path for this input bias current for proper operation. Figure 3 shows provisions for an input bias current path in a thermocouple application. Without a bias current path, the inputs will float to an undefined potential and the output voltage may not be valid.

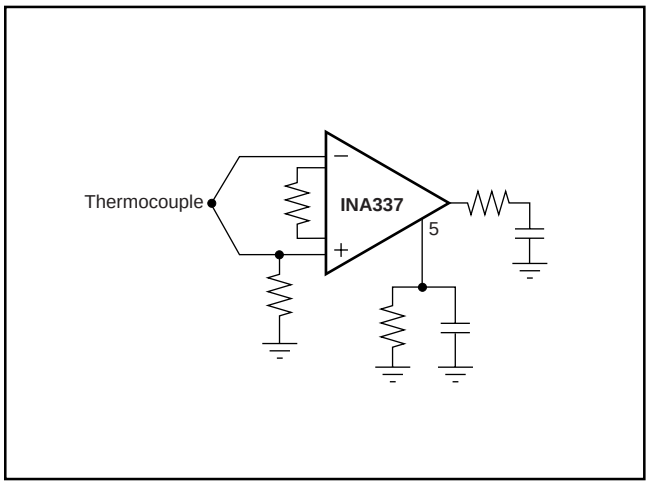



FIGURE 3. Providing Input Bias Current Return Path.

## INPUT AND OUTPUT VOLTAGE

The INA337 and INA338 feature nearly rail-to-rail input behavior, with the linear input voltage range extending from 0.25V above the negative rail to 0.1V above the positive rail. The output is able to swing to within 0.25V of the negative rail and 0.075V of the positive rail. See Typical Characteristics Curve “Output Swing to the Negative Rail” for additional detail.

## INPUT PROTECTION

The inputs of the INA337 are protected with internal diodes connected to the power-supply rails. These diodes will clamp the applied signal to prevent it from damaging the input circuitry. If the input signal voltage can exceed the power supplies by more than 0.5V, the input signal current should be limited to less than 10mA to protect the internal clamp diodes. This can generally be done with a series input resistor. Some signal sources are inherently current-limited and do not require limiting resistors.

# INSIDE THE INA337

The INA337 uses a new, unique internal circuit topology that provides near rail-to-rail input. Unlike other instrumentation amplifiers, it can linearly process inputs from 0.25V above the negative rail to 0.1V beyond the positive rail. Conventional instrumentation amplifier circuits cannot deliver such performance, even if rail-to-rail op amps are used.

The ability to reject common-mode signals is derived in most instrumentation amplifiers through a combination of amplifier CMR and accurately matched resistor ratios. The INA337 converts the input voltage to a current. Current-mode signal processing provides rejection of common-mode input voltage and power-supply variation without accurately matched resistors.

The topology of the INA337 avoids aliasing issues that appear in instrumentation amplifiers that use sampled data techniques.

A simplified diagram shows the basic circuit function. The differential input voltage, $(V_{IN}+) – (V_{IN}–)$ is applied across $R_1$. The signal-generated current through $R_1$ comes from A1 and A2’s output stages. A2 combines the current in $R_1$ with a mirrored replica of the current from A1. The resulting current in A2’s output and associated current mirror is two times the current in $R_1$. This current flows in (or out) of pin 5 into $R_2$. The resulting gain equation is:

$$G = \frac{2R_2}{R_1}$$

Amplifiers A1, A2 and their associated mirrors are powered from internal charge-pumps that provide voltage supplies that are beyond the positive negative supply. As a result, the voltage developed on $R_2$ can actually swing 100mV *above* the positive power-supply rail. A3 provides a buffered output of the voltage on $R_2$. A3’s input stage is also operated from the charge-pumped power supplies for true rail-to-rail operation.

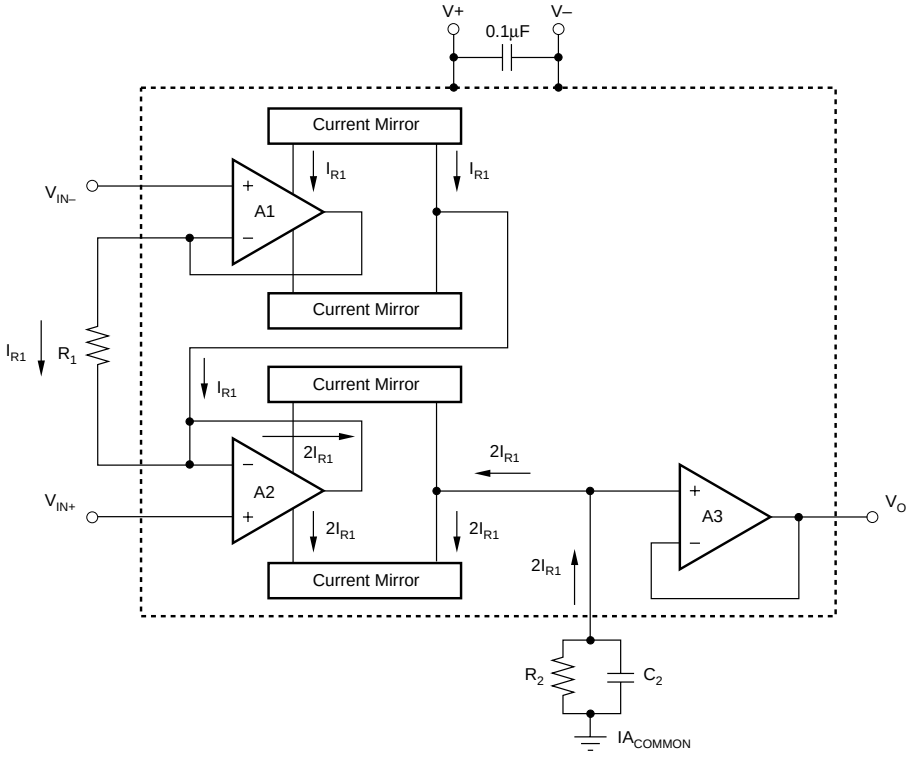



FIGURE 4. Simplified Circuit Diagram.

## FILTERING

Filtering can be adjusted through selection of $R_2C_2$ and $R_OC_O$ for the desired tradeoff of noise and bandwidth. Adjustment of these components will result in more or less ripple due to auto-correction circuitry noise and will also affect broadband noise. Filtering limits slew rate, settling time, and output overload recovery time.

It is generally desirable to keep the resistance of $R_O$ relatively low to avoid DC gain error created by the subsequent stage loading. This may result in relatively high values for $C_O$ to produce the desired filter response. The impedance of $R_OC_O$ can be scaled higher to produce smaller capacitor values if the load impedance is very high.

Certain capacitor types greater than 0.1µF may have dielectric absorption effects that can significantly increase settling time in high-accuracy applications (settling to 0.01%). Polypropylene, polystyrene, and polycarbonate types are generally good. Certain "high-K" ceramic types may produce slow settling "tails." Settling time to 0.1% is not generally affected by high-K ceramic capacitors. Electrolytic types are not recommended for $C_2$ and $C_O$.

## INA338 ENABLE FUNCTION

The INA338 can be enabled by applying a logic "High" voltage level to the Enable pin. Conversely, a logic "Low" voltage level will disable the amplifier, reducing its supply current from 2.4mA to typically 2µA. For battery-operated applications, this feature may be used to greatly reduce the average current and extend battery life. This pin should be connected to a valid high or low voltage or driven, not left open circuit. The Enable pin can be modeled as a CMOS input gate as in Figure 5.

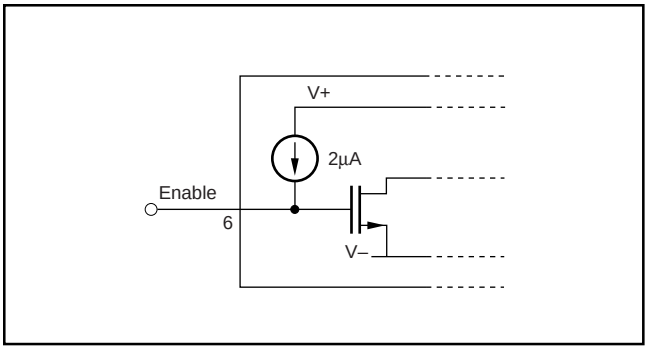



FIGURE 5. Enable Pin Model.

The enable time following shutdown is 75µs plus the settling time due to filters (see Typical Characteristics, "Input Offset Voltage vs Warm-up Time"). Disable time is 100µs. This allows the INA338 to be operated as a "gated" amplifier, or to have its output multiplexed onto a common output bus. When disabled, the output assumes a high-impedance state.

## INA338 PIN 5

Pin 5 of the INA338 should be connected to V+ to ensure proper operation.

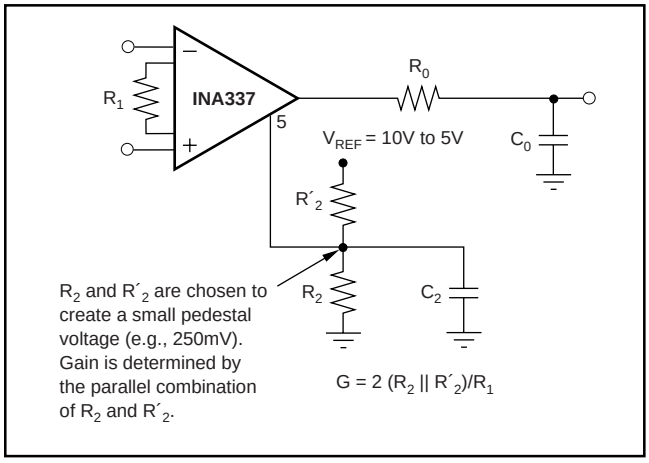



FIGURE 6. Output Range Pedestal.

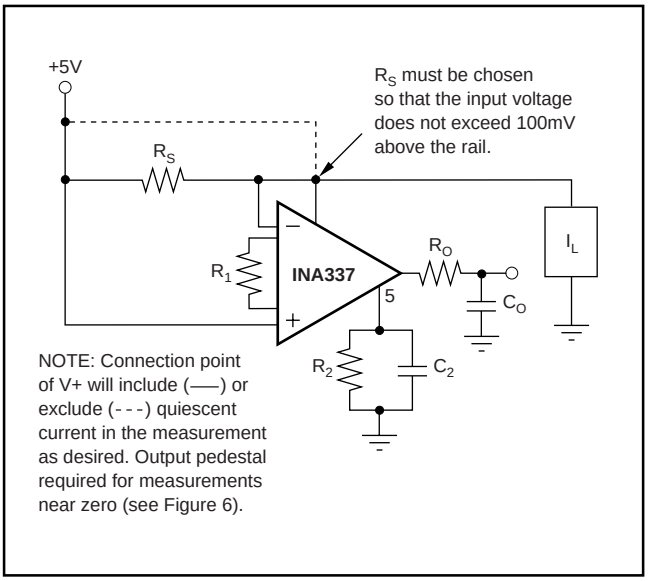



FIGURE 7. High-Side Shunt Measurement of Current Load.

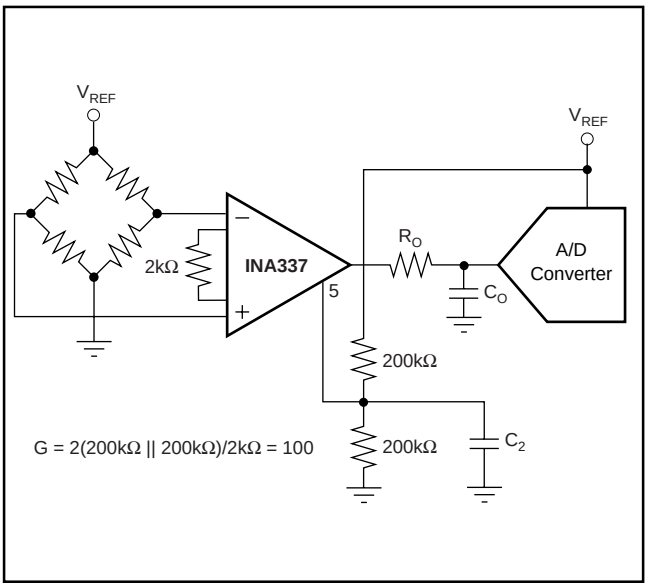
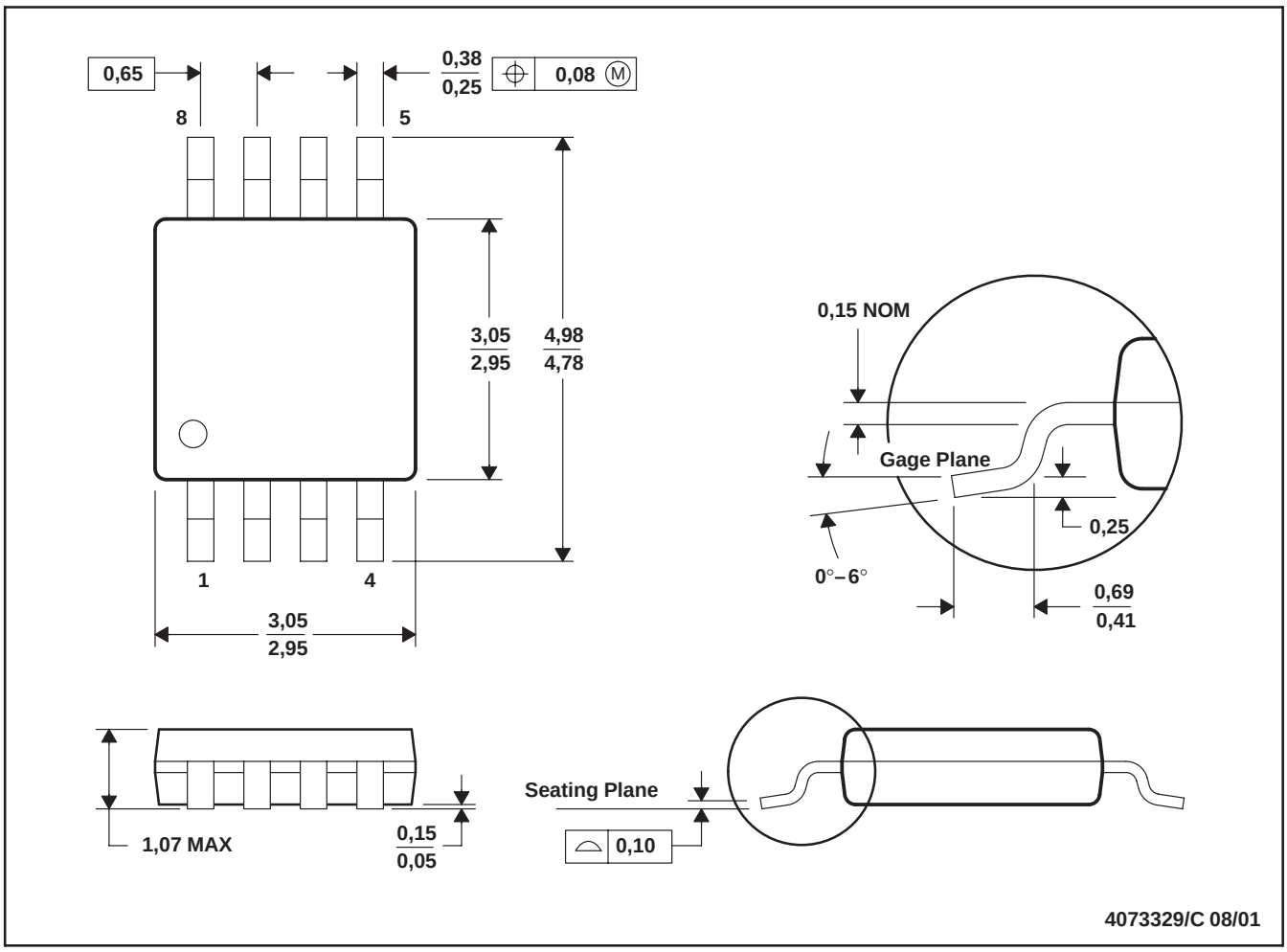


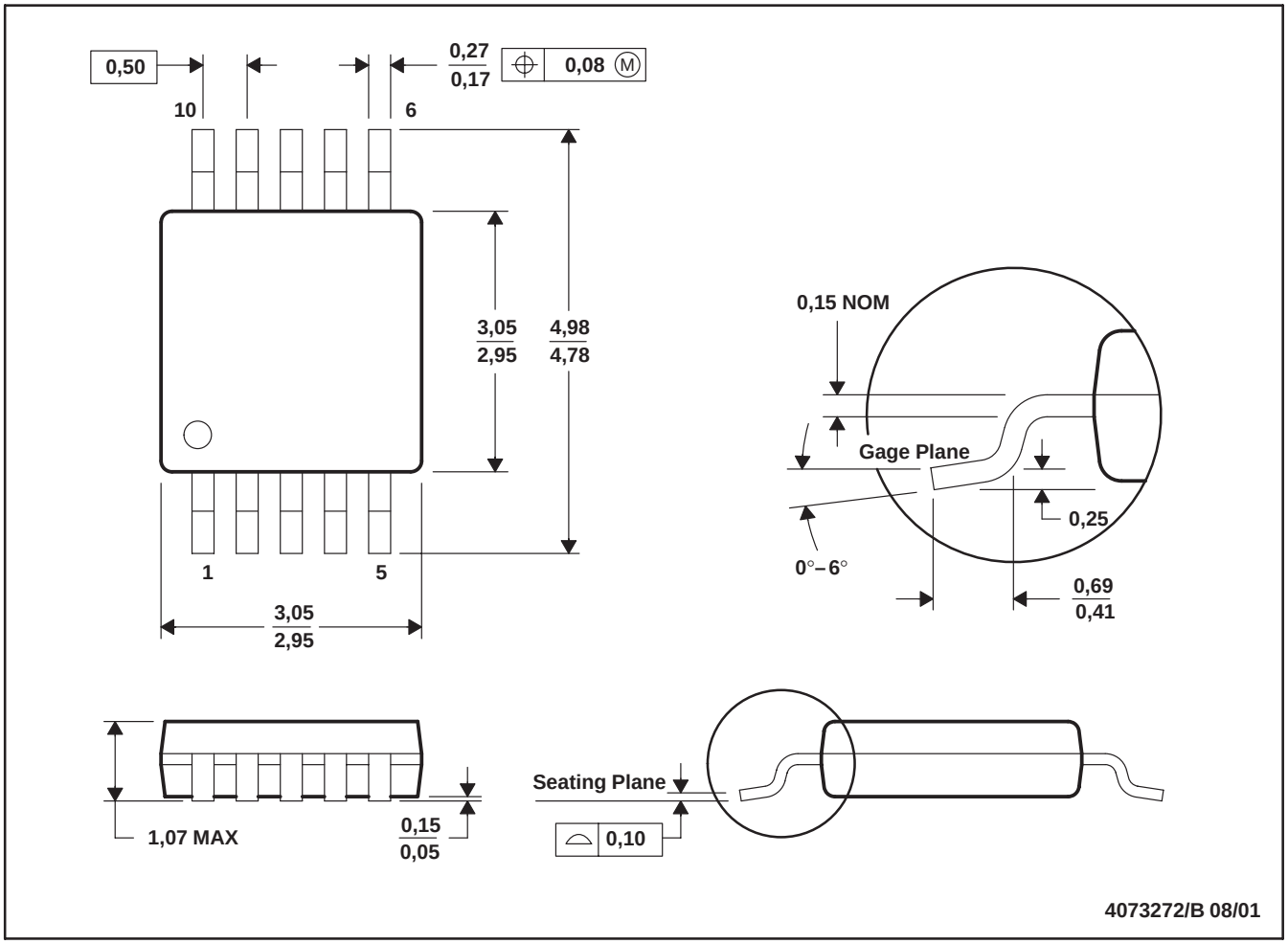

FIGURE 8. Output Referenced to $V_{REF}/2$.

**DGK (R-PDSO-G8)** **PLASTIC SMALL-OUTLINE PACKAGE**




NOTES: A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion.
D. Falls within JEDEC MO-187

**DGS (S-PDSO-G10)** **PLASTIC SMALL-OUTLINE PACKAGE**




NOTES: A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion.
A. Falls within JEDEC MO-187

## PACKAGING INFORMATION

| Orderable part number | Status (1) | Material type (2) | Package \| Pins | Package qty \| Carrier | RoHS (3) | Lead finish/ Ball material (4) | MSL rating/ Peak reflow (5) | Op temp (°C) | Part marking (6) |
|---|---|---|---|---|---|---|---|---|---|
| INA337AIDGKR | Active | Production | VSSOP (DGK) \| 8 | 2500 \| LARGE T&R | Yes | Call TI \| Nipdauag | Level-2-260C-1 YEAR | -40 to 125 | BIM |
| INA337AIDGKR.B | Active | Production | VSSOP (DGK) \| 8 | 2500 \| LARGE T&R | Yes | Call TI | Level-2-260C-1 YEAR | -40 to 125 | BIM |
| INA337AIDGKT | Active | Production | VSSOP (DGK) \| 8 | 250 \| SMALL T&R | Yes | Call TI \| Nipdauag | Level-2-260C-1 YEAR | -40 to 125 | BIM |
| INA337AIDGKT.B | Active | Production | VSSOP (DGK) \| 8 | 250 \| SMALL T&R | Yes | Call TI | Level-2-260C-1 YEAR | -40 to 125 | BIM |
| INA338AIDGST | Active | Production | VSSOP (DGS) \| 10 | 250 \| SMALL T&R | Yes | Call TI \| Nipdauag | Level-2-260C-1 YEAR | -40 to 125 | BIL |
| INA338AIDGST.B | Active | Production | VSSOP (DGS) \| 10 | 250 \| SMALL T&R | Yes | Call TI | Level-2-260C-1 YEAR | -40 to 125 | BIL |

(1) **Status:** For more details on status, see our product life cycle.

(2) **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

(3) **RoHS values:** Yes, No, RoHS Exempt. See the TI RoHS Statement for additional information and value definition.

(4) **Lead finish/Ball material:** Parts may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

(5) **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

(6) **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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