



# Precision LOGARITHMIC AND LOG RATIO AMPLIFIER

## FEATURES

- EASY-TO-USE COMPLETE LOG RATIO FUNCTION
- OUTPUT AMPLIFIERS FOR SCALING AND SIGNAL LOSS INDICATION
- HIGH ACCURACY: 0.15% FSO Total Error Over 6 Decades
- WIDE INPUT DYNAMIC RANGE: 6 Decades, 1nA to 1mA
- LOW QUIESCENT CURRENT: 1.25mA
- SO-14 PACKAGE

## APPLICATIONS

- ONET, OPTICAL POWER METERS
- LOG, LOG RATIO COMPUTATION: Communication, Analytical, Medical, Industrial, Test, General Instrumentation
- PHOTODIODE SIGNAL COMPRESSION AMP
- ANALOG SIGNAL COMPRESSION IN FRONT OF A/D CONVERTER
- ABSORBANCE MEASUREMENT
- OPTICAL DENSITY MEASUREMENT

## DESCRIPTION

The LOG102 is a versatile integrated circuit that computes the logarithm or log ratio of an input current relative to a reference current.

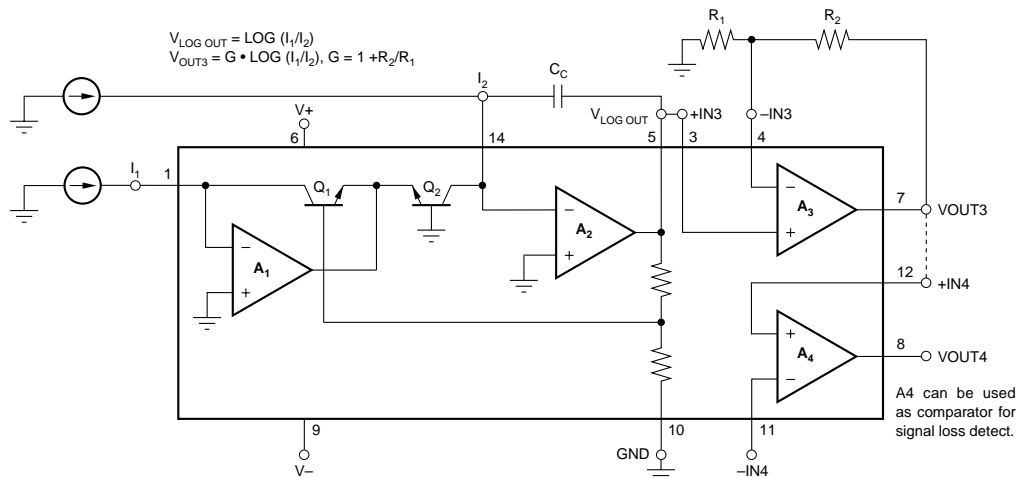
The LOG102 is tested over a wide dynamic range of input signals. In log ratio applications, a signal current can be generated by a photodiode, and a reference current from a resistor in series with a precision external voltage reference.

A3 and A4 are identical, uncommitted op amps that can be used for a variety of functions, such as filtering, offsetting, adding gain or as a comparator to detect loss of signal.

The output signal at  $V_{LOG OUT}$  is trimmed to 1V per decade of input current. It can be scaled with an output amplifier, either A3 or A4.

Low dc offset voltage and temperature drift allow accurate measurement of low-level signals over a wide environmental temperature range. The LOG102 is specified over the temperature range, 0°C to +70°C, with operation over -40°C to +85°C.

NOTE: U.S. Patent Pending.



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.

## ABSOLUTE MAXIMUM RATINGS<sup>(1)</sup>

Supply Voltage, V+ to V- .....	36V
Input Voltage .....	V- (-0.5) to V+ (+0.5V)
Input Current .....	±10mA
Output Short-Circuit <sup>(2)</sup> .....	Continuous
Operating Temperature .....	-40°C to +85°C
Storage Temperature .....	-55°C to +125°C
Junction Temperature .....	+150°C
Lead Temperature (soldering, 10s) .....	+300°C

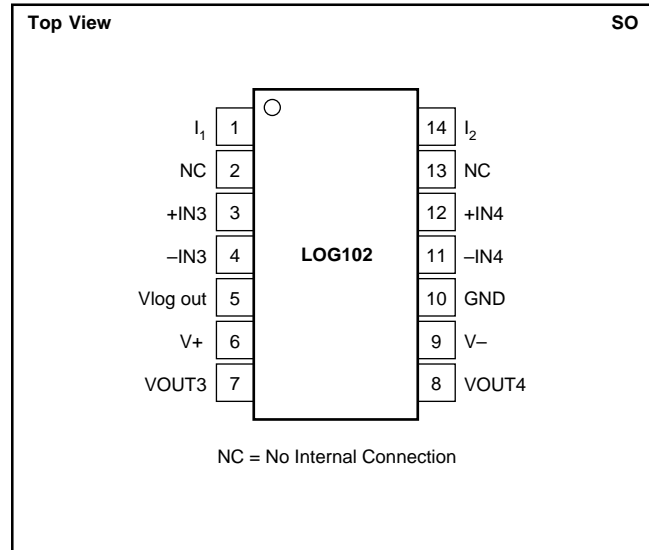
NOTES: (1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. (2) Short circuit to ground, one amplifier per package.

## 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 DESCRIPTION



## PACKAGE/ORDERING INFORMATION

PRODUCT	PACKAGE-LEAD	PACKAGE DESIGNATOR <sup>(1)</sup>	SPECIFIED TEMPERATURE RANGE	PACKAGE MARKING	ORDERING NUMBER	TRANSPORT MEDIA, QUANTITY
LOG102AID	SO-14	D	0°C to +70°C	LOG102A	LOG102AID	Rails, 58
"	"	"	"	"	LOG102AIDR	Tape and Reel, 2500

NOTES: (1) For the most current specifications and package information, refer to our web site at [www.ti.com](http://www.ti.com).

## ELECTRICAL CHARACTERISTICS

**Boldface** limits apply over the specified temperature range,  $T_A = 0^\circ\text{C}$  to  $+70^\circ\text{C}$ .

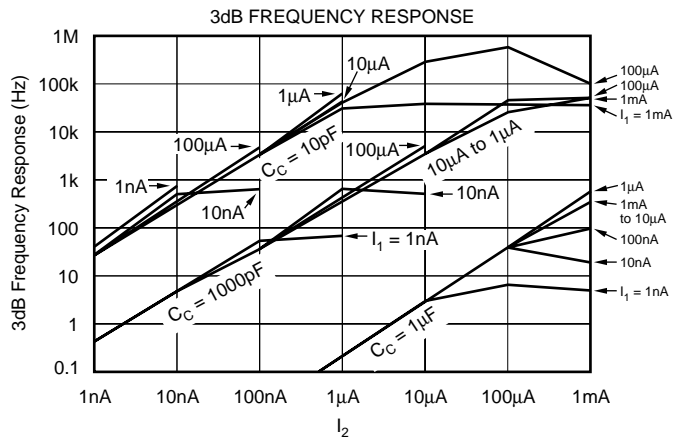
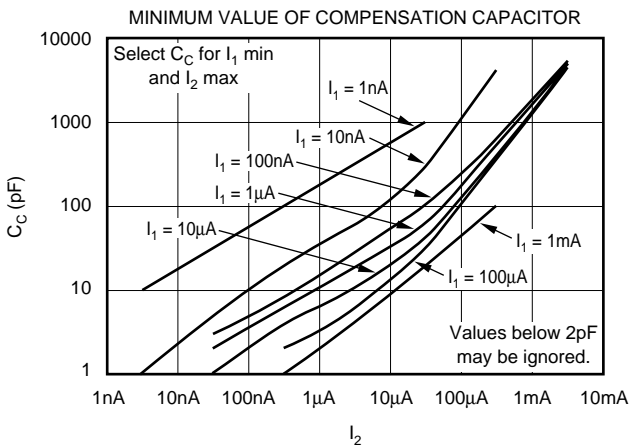
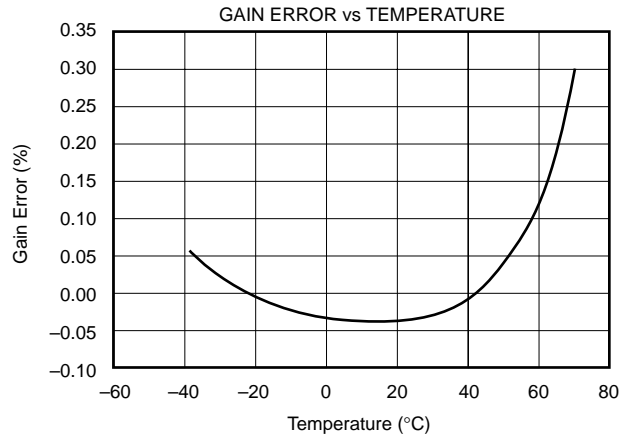
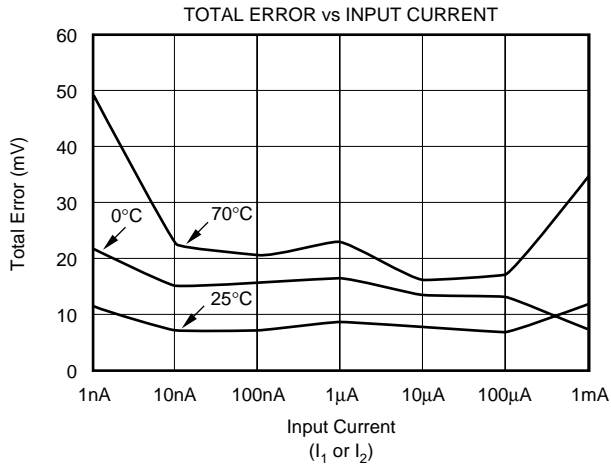
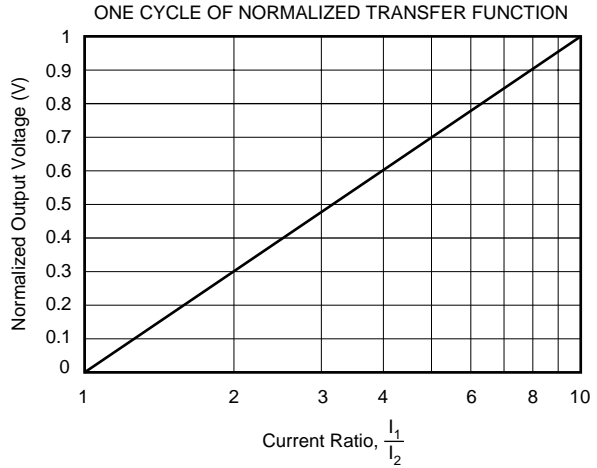
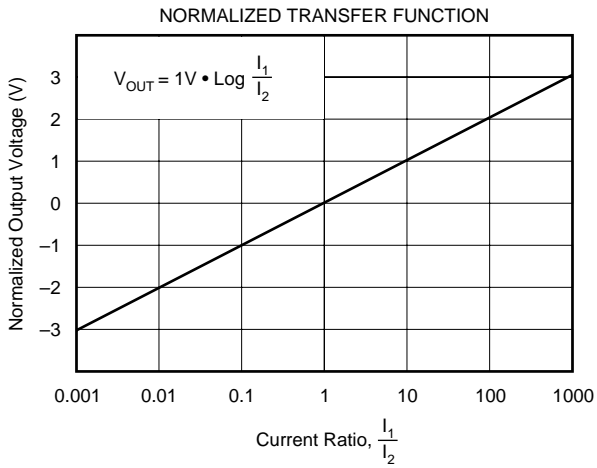
At  $T_A = +25^\circ\text{C}$ ,  $V_S = \pm 5\text{V}$ ,  $R_L = 10\text{k}\Omega$ , unless otherwise noted.

PARAMETER	CONDITION	LOG102AID			UNITS
		MIN	TYP	MAX	
<b>CORE LOG FUNCTION</b> $I_{IN}/V_{LOG\ OUT}$ Equation			$V_O = \log(I_1/I_2)$		
<b>LOG CONFORMITY ERROR<sup>(1)</sup></b> Initial	1nA to 100 $\mu$ A (5 decades) 1nA to 1mA (6 decades)		0.04 0.15	±0.3	% %
<b>over Temperature</b>	<b>1nA to 100<math>\mu</math>A (5 decades)</b> <b>1nA to 1mA (6 decades)</b>		<b>0.0002</b> <b>0.002</b>		<b>%/°C</b> <b>%/°C</b>
<b>GAIN<sup>(2)</sup></b> Initial Value	1nA to 100 $\mu$ A (5 decades)		1		V/decade
Gain Error	1nA to 100 $\mu$ A (5 decades)		0.15	±1	%
<b>vs Temperature</b>	<b><math>T_{MIN}</math> to <math>T_{MAX}</math></b>		<b>0.025</b>	<b>0.05</b>	<b>%/°C</b>
<b>INPUT, A1 and A2</b> Offset Voltage	$T_{MIN}$ to $T_{MAX}$ $V_S = \pm 4.5\text{V}$ to $\pm 18\text{V}$		±0.3 <b>±2</b>	±1.5	mV $\mu\text{V}/^\circ\text{C}$
<b>vs Temperature</b> vs Power Supply (PSRR)			5	50	$\mu\text{V}/\text{V}$
Input Bias Current	$T_{MIN}$ to $T_{MAX}$ $f = 10\text{Hz}$ to $10\text{kHz}$ $f = 1\text{kHz}$ $f = 1\text{kHz}$		±5		pA
<b>vs Temperature</b> Voltage Noise			<b>Doubles Every 10°C</b>		$\mu\text{Vrms}$
Current Noise			30		$\text{nV}/\sqrt{\text{Hz}}$
Common-Mode Voltage Range (Positive)		(V+) - 2	(V+) - 1.5		V
(Negative)		(V-) + 2	(V-) + 1.2		V
CMRR		90	105		dB
<b>OUTPUT, A2 (<math>V_{LOGOUT}</math>)</b> Output Offset, $V_{OSO}$ , Initial	$T_{MIN}$ to $T_{MAX}$ $V_S = \pm 5\text{V}$ Supplies		±3	±55	mV
<b>vs Temperature</b> Full-Scale Output (FSO)				<b>25</b>	(V+) - 1.5
Short-Circuit Current			±18		mA



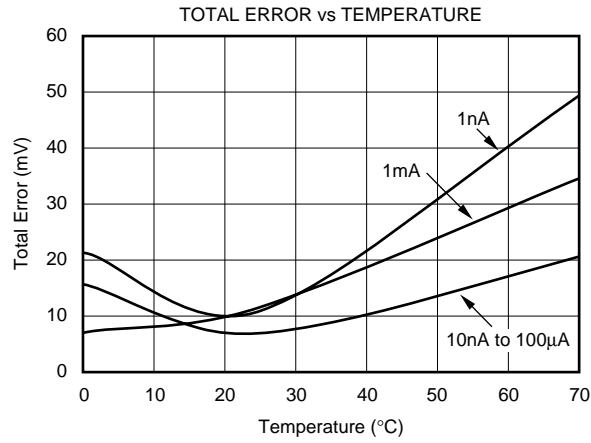
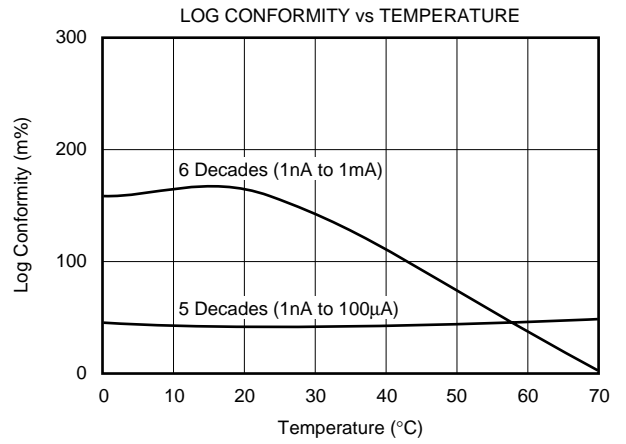
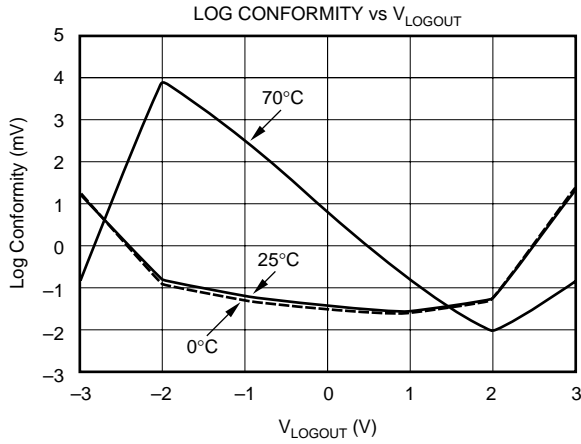
# TYPICAL CHARACTERISTICS

At  $T_A = +25^\circ\text{C}$ ,  $V_S = \pm 5\text{V}$ ,  $R_L = 10\text{k}\Omega$ , unless otherwise noted.



# TYPICAL CHARACTERISTICS (Cont.)

At  $T_A = +25^\circ\text{C}$ ,  $V_S = \pm 5\text{V}$ ,  $R_L = 10\text{k}\Omega$ , unless otherwise noted.



# APPLICATION INFORMATION

The LOG102 is a true logarithmic amplifier that uses the base-emitter voltage relationship of bipolar transistors to compute the logarithm, or logarithmic ratio of a current ratio. With two uncommitted on-chip operational amplifiers, the LOG102 provides design flexibility and simplicity.

Figure 1 shows the basic connections required for operation of the LOG102 with a gain factor. In order to reduce the influence of lead inductance of power supply lines, it is recommended that each supply be bypassed with a  $10\mu\text{F}$  tantalum capacitor in parallel with a  $1000\text{pF}$  ceramic capacitor, as shown in Figure 1. Connecting the capacitors as close to the LOG102 as possible will contribute to noise reduction as well.

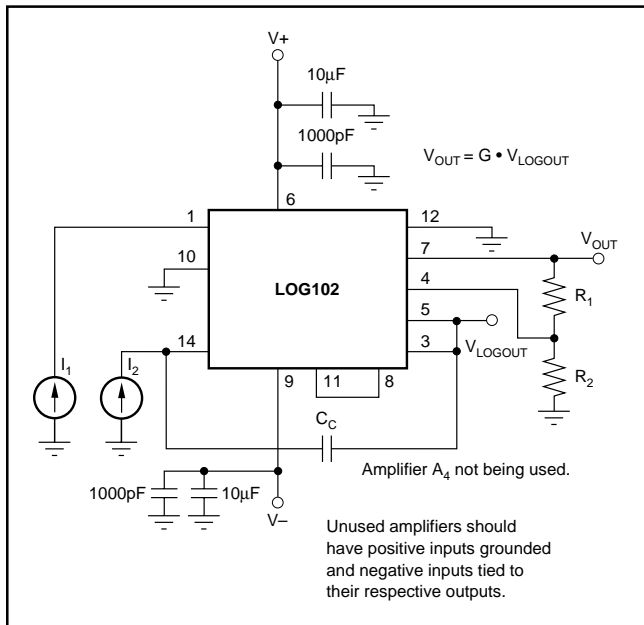


FIGURE 1. Basic Connections with Output Gain Factor of the LOG102.

## INPUT CURRENT RANGE

To maintain specified accuracy, the input current range of the LOG102 should be limited from  $1\text{nA}$  to  $1\text{mA}$ . Input currents outside of this range may compromise LOG102 performance. Input currents larger than  $1\text{mA}$  result in increased nonlinearity. An absolute maximum input current rating of  $10\text{mA}$  is included to prevent excessive power dissipation that may damage the logging transistor.

On  $\pm 5\text{V}$  supplies the total input current ( $I_1 + I_2$ ) is limited to  $1.1\text{mA}$ . Due to compliance issues internal to the LOG102, to accommodate larger total input currents, supplies should be increased.

Currents smaller than  $1\text{nA}$  will result in increased errors due the input bias currents of op amps  $A_1$  and  $A_2$  (typically  $5\text{pA}$ ). The input bias currents may be compensated for, as shown in Figure 2. The input stages of the amplifiers have FET inputs, with input bias current doubling every  $10^\circ\text{C}$ , which makes the nulling technique shown practical only where the temperature is fairly stable.

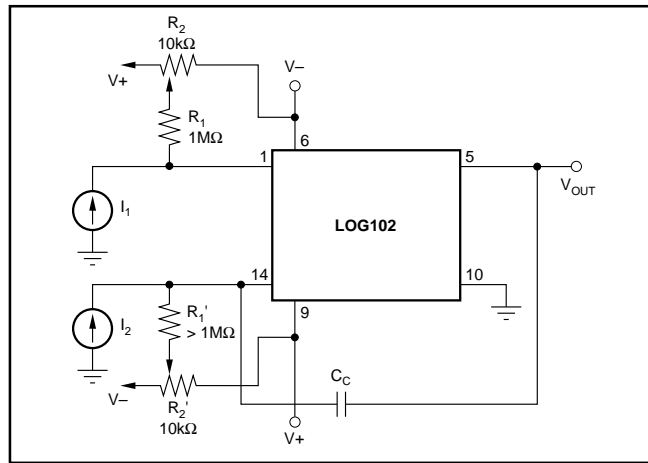


FIGURE 2. Bias Current Nulling.

## SETTING THE REFERENCE CURRENT

When the LOG102 is used to compute logarithms, either  $I_1$  or  $I_2$  can be held constant and becomes the reference current to which the other is compared.

$V_{\text{LOGOUT}}$  is expressed as:

$$V_{\text{LOGOUT}} = (1\text{V}) \cdot \log(I_1/I_2) \quad (1)$$

$I_{\text{REF}}$  can be derived from an external current source (such as shown in Figure 3), or it may be derived from a voltage source with one or more resistors. When a single resistor is used, the value may be large depending on  $I_{\text{REF}}$ . If  $I_{\text{REF}}$  is  $10\text{nA}$  and  $+2.5\text{V}$  is used:

$$R_{\text{REF}} = 2.5\text{V}/10\text{nA} = 250\text{M}\Omega$$

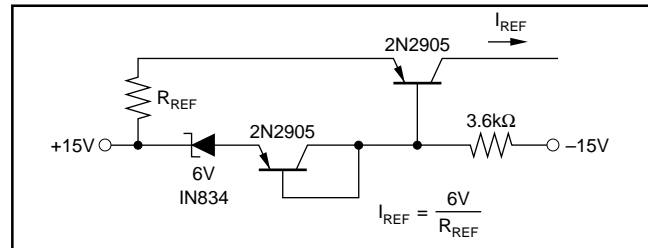


FIGURE 3. Temperature Compensated Current Source.

A voltage divider may be used to reduce the value of the resistor (as shown in Figure 4). When using this method, one must consider the possible errors caused by the amplifier's input offset voltage. The input offset voltage of amplifier  $A_1$  has a maximum value of  $1.5\text{mV}$ , making  $V_{\text{REF}}$  a suggested value of  $100\text{mV}$ .

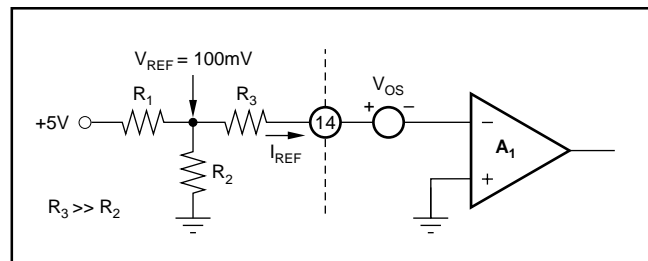


FIGURE 4. T Network for Reference Current.

Figure 5 shows a low-level current source using a series resistor. The low offset op-amp reduces the effect of the LOG102's input offset voltage.

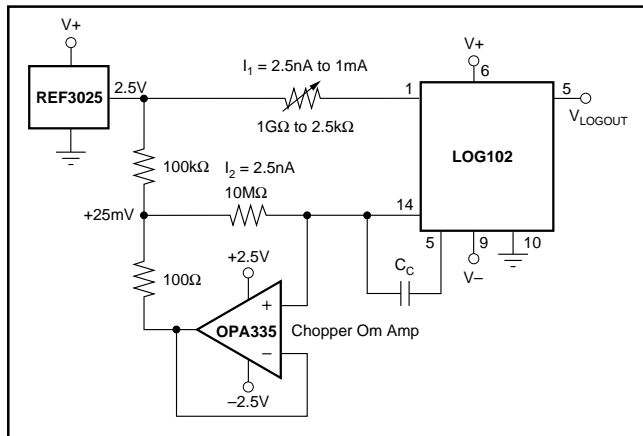


FIGURE 5. Current Source with Offset Compensation.

## FREQUENCY RESPONSE

The 3dB frequency response of the LOG102 is a function of the magnitude of the input current levels and of the value of the frequency compensation capacitor. See Typical Characteristic Curves for details.

The frequency response curves are shown for constant DC  $I_1$  and  $I_2$  with a small signal AC current on one of them.

The transient response of the LOG102 is different for increasing and decreasing signals. This is due to the fact that a log amp is a nonlinear gain element and has different gains at different levels of input signals. Smaller input currents require greater gain to maintain full dynamic range, and will slow the frequency response of the LOG102.

## FREQUENCY COMPENSATION

Frequency compensation for the LOG102 is obtained by connecting a capacitor between pins 5 and 14. The size of the capacitor is a function of the input currents, as shown in the Typical Characteristic Curves (Minimum Value of Compensation Capacitor). For any given application, the smallest value of the capacitor which may be used is determined by the maximum value of  $I_2$  and the minimum value of  $I_1$ . Larger values of  $C_C$  will make the LOG102 more stable, but will reduce the frequency response.

In an application, highest overall bandwidth can be achieved by detecting the signal level at  $V_{OUT}$ , then switching in appropriate values of compensation capacitors.

As seen on front page diagram, the voltage output of  $V_{LOGOUT}$  can be scaled by increasing or decreasing the resistor ratio connected to pins 4 and 7. The gain,  $G$ , can be set according to the following equation:

$$G = 1 + R_2/R_1 \quad (2)$$

## NEGATIVE INPUT CURRENTS

The LOG102 will function only with positive input currents (conventional current flow into pins 1 and 14). In situations where negative input currents are needed, the circuits in Figures 6, 7, 8, and 9, may be used.

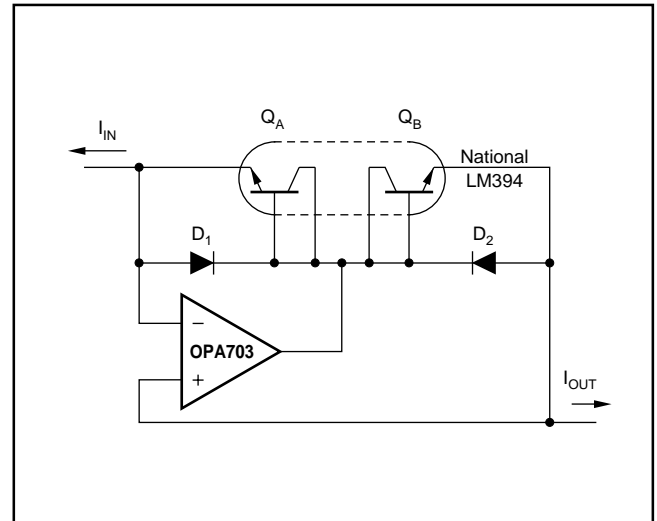


FIGURE 6. Current Inverter/Current Source.

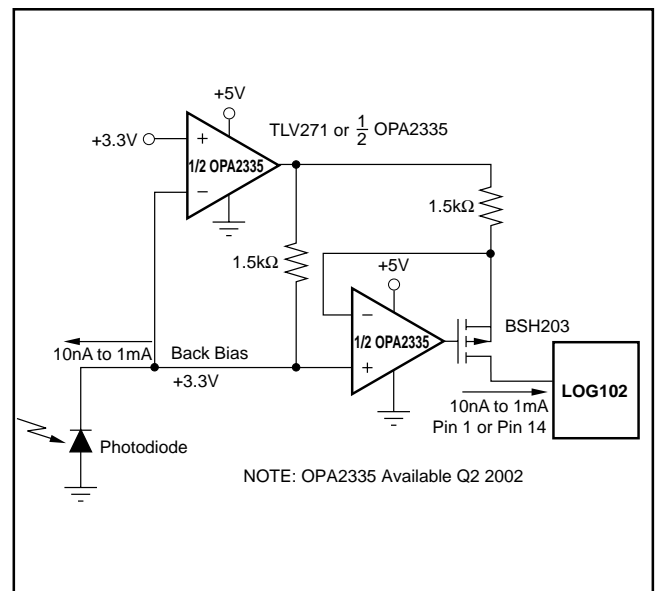


FIGURE 7. Precision Current Inverter/Current Source.

## VOLTAGE INPUTS

The LOG102 gives the best performance with current inputs. Voltage inputs may be handled directly with series resistors, but the dynamic input range is limited to approximately three decades of input voltage by voltage noise and offsets. The transfer function of equation (14) applies to this configuration.

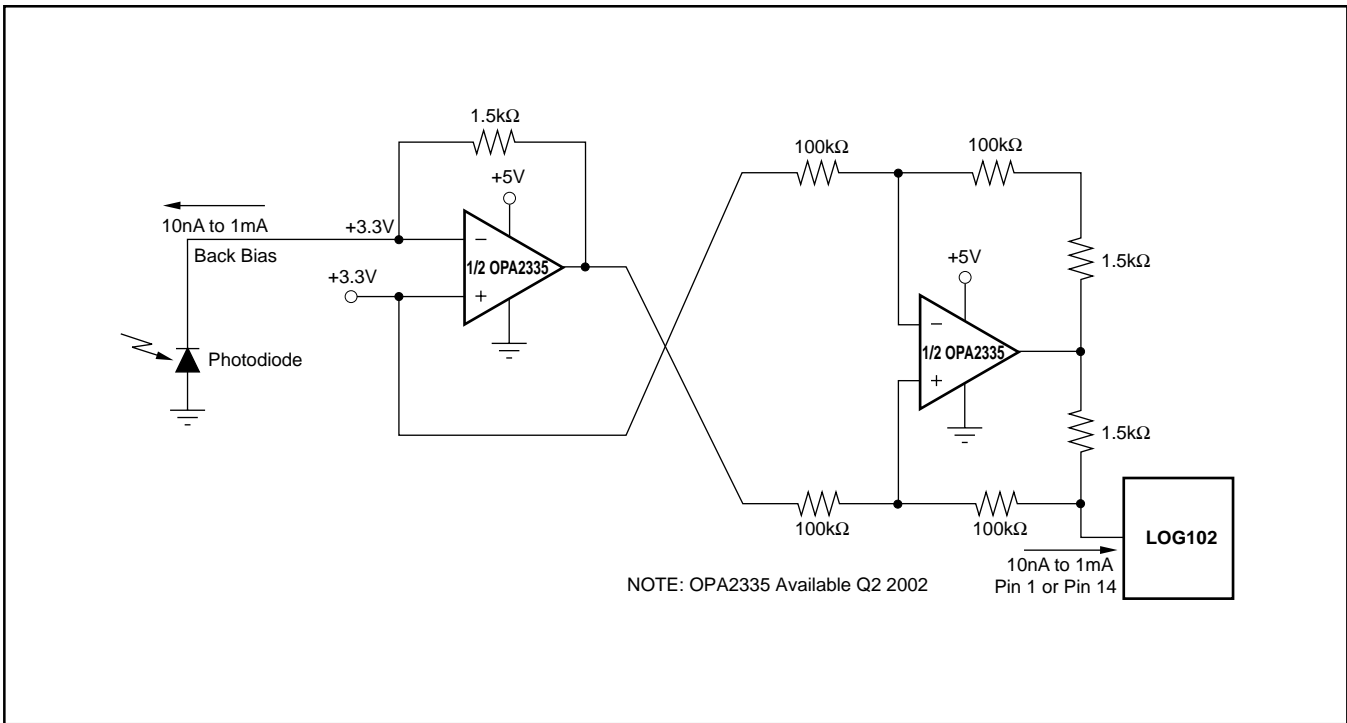


FIGURE 8. Precision Current Inverter/Current Source.

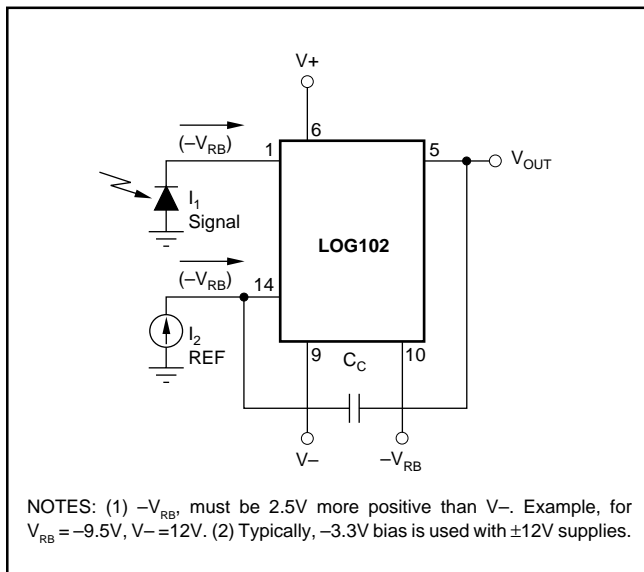


FIGURE 9. Reverse Biased Photodiode Using Pin 10 on LOG102.

## DATA COMPRESSION

In many applications the compressive effects of the logarithmic transfer function are useful. For example, a LOG102 preceding a 12-bit Analog-to-Digital (A/D) converter can produce the dynamic range equivalent to a 20-bit converter.

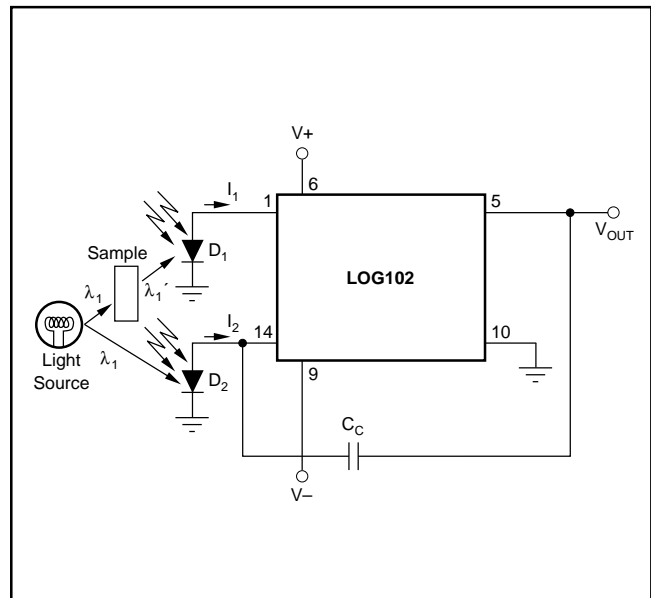


FIGURE 10. Absorbance Measurement.

## APPLICATION CIRCUITS

### LOG RATIO

One of the more common uses of log ratio amplifiers is to measure absorbance. A typical application is shown in Figure 10.

$$\text{Absorbance of the sample is } A = \log \lambda_1' / \lambda_1 \quad (3)$$

$$\text{If } D_1 \text{ and } D_2 \text{ are matched } A \propto (1V) \log I_1 / I_2 \quad (4)$$

## INSIDE THE LOG102

Using the base-emitter voltage relationship of matched bipolar transistors, the LOG102 establishes a logarithmic function of input current ratios. Beginning with the base-emitter voltage defined as

$$V_{BE} = V_T \ln \frac{I_C}{I_S} \quad \text{where: } V_T = \frac{kT}{q} \quad (1)$$

$k$  = Boltzman's constant =  $1.381 \cdot 10^{-23}$

$T$  = Absolute temperature in degrees Kelvin

$q$  = Electron charge =  $1.602 \cdot 10^{-19}$  Coulombs

$I_C$  = Collector current

$I_S$  = Reverse saturation current

From the circuit in Figure 11, we see that

$$V_L = V_{BE1} - V_{BE2} \quad (2)$$

Substituting (1) into (2) yields

$$V_L = V_{T1} \ln \frac{I_1}{I_{S1}} - V_{T2} \ln \frac{I_2}{I_{S2}} \quad (3)$$

If the transistors are matched and isothermal and  $V_{T1} = V_{T2}$ , then (3) becomes:

$$V_L = V_{T1} \left[ \ln \frac{I_1}{I_S} - \ln \frac{I_2}{I_S} \right] \quad (4)$$

$$V_L = V_T \ln \frac{I_1}{I_2} \quad \text{and since} \quad (5)$$

$$\ln x = 2.3 \log_{10} x \quad (6)$$

$$V_L = n V_T \log \frac{I_1}{I_2} \quad (7)$$

$$\text{where } n = 2.3 \quad (8)$$

also

$$V_{OUT} = V_L \frac{R_1 + R_2}{R_1} \quad (9)$$

$$= \log \frac{I_1}{I_2} \quad (10)$$

or 
$$V_{OUT} = \frac{R_1 + R_2}{R_1} n V_T \log \frac{I_1}{I_2} \quad (11)$$

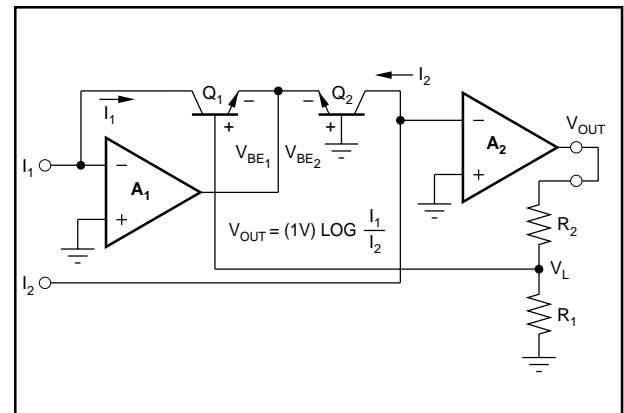


FIGURE 11. Simplified Model of Log Amplifier.

It should be noted that the temperature dependence associated with  $V_T = kT/q$  is internally compensated on the LOG102 by making  $R_1$  a temperature sensitive resistor with the required positive temperature coefficient.

### USING A LARGER REFERENCE VOLTAGE REDUCES OFFSET ERRORS

Using a larger reference voltage to create the reference current minimizes errors due to the LOG102's input offset voltage. Maintaining an increasing output voltage as a function of increasing photodiode current is also important in many optical sensing applications. All zeros from the A/D converter output represent zero or low scale photodiode current. Inputting the reference current into  $I_1$ , and designing

$I_{REF}$  such that it is as large or larger than the expected maximum photodiode current is accomplished using this requirement. The LOG102 configured with the reference current connecting  $I_1$  and the photodiode current connecting to  $I_2$  is shown in Figure 12.  $A_3$  is configured as a level shifter with inverting gain and is used to scale the photodiode current directly into the A/D input voltage range.

The wide dynamic range of the LOG102 is useful for measuring avalanche photodiode current (APD) (see Figure 13).

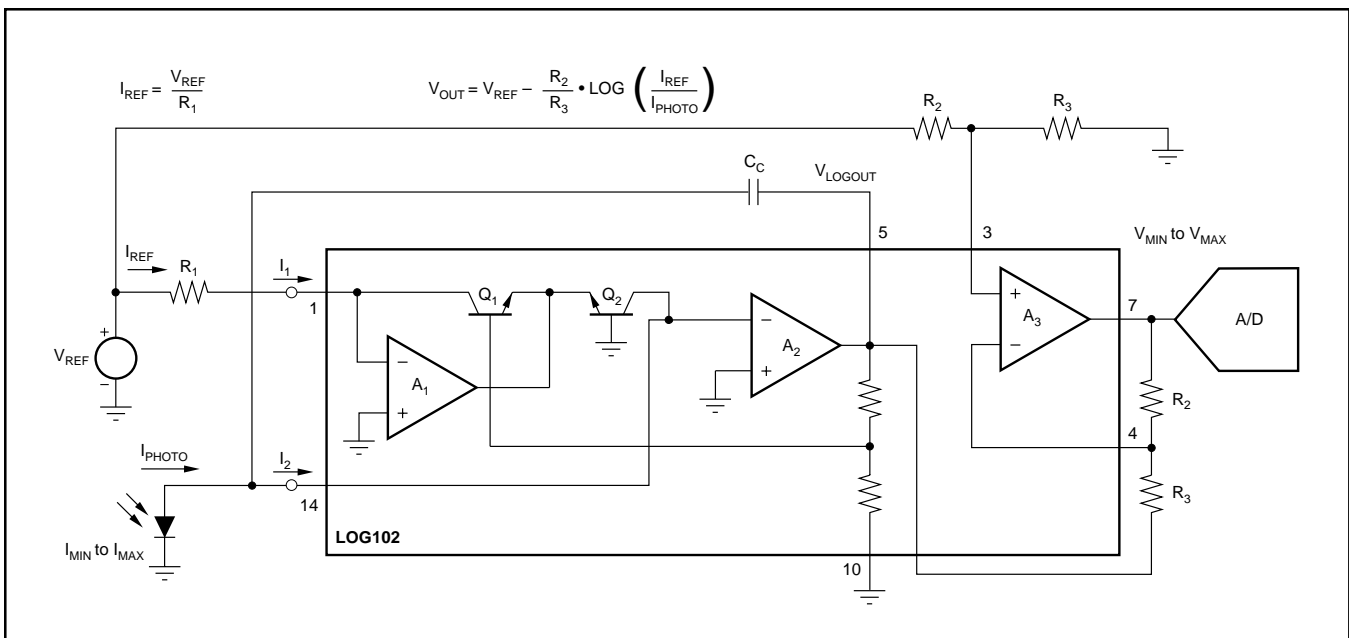


FIGURE 12. Technique for Using Full-Scale Reference Current Such that  $V_{OUT}$  Increases with Increasing Photodiode Current.

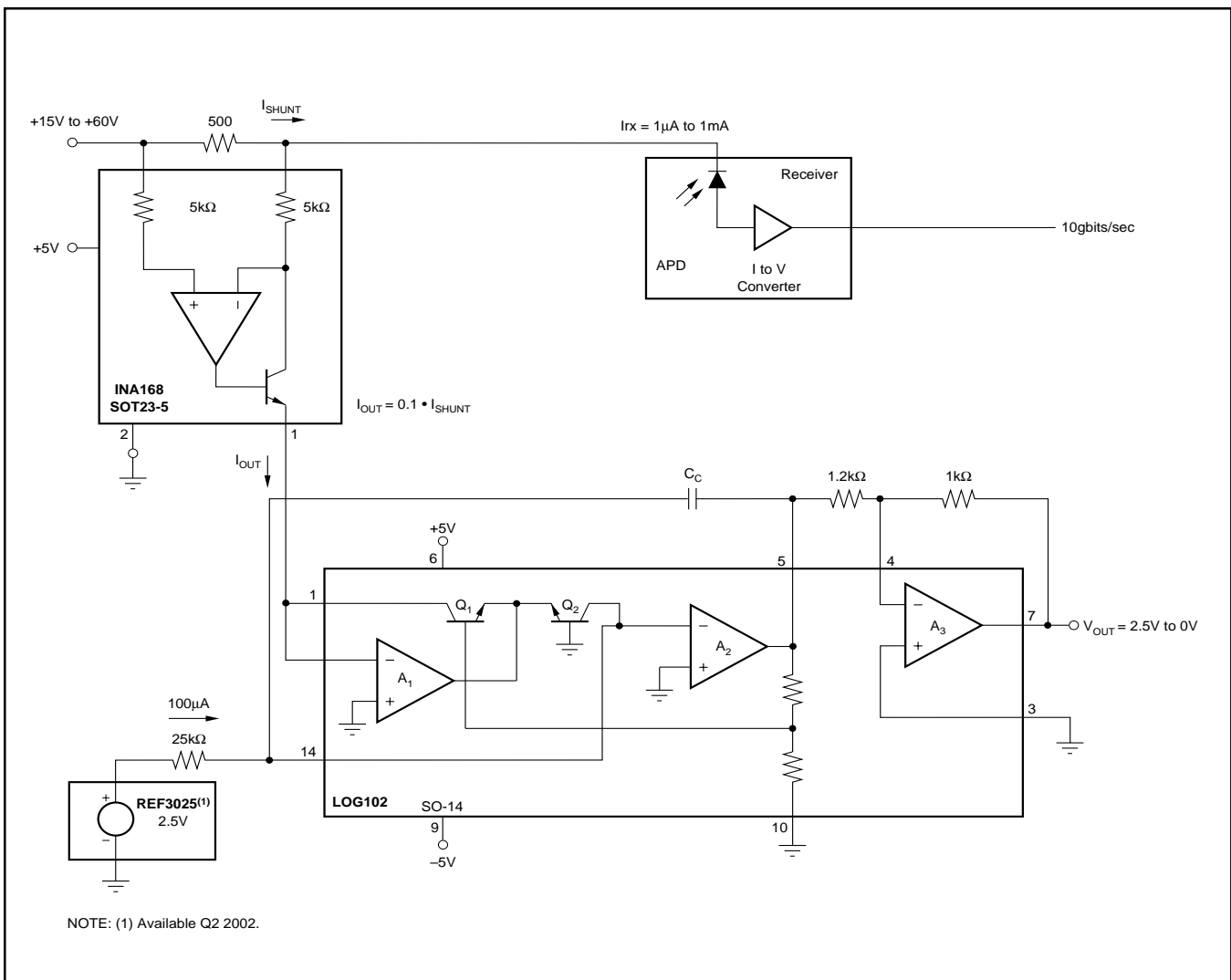


FIGURE 13. High Side Shunt for Avalanche Photodiode (APD) Measures 3-Decades of APD Current.

# DEFINITION OF TERMS

## TRANSFER FUNCTION

The ideal transfer function is:

$$V_{OUT} = 1V \cdot \log I_1/I_2 \quad (5)$$

Figure 14 shows the graphical representation of the transfer over valid operating range for the LOG102.

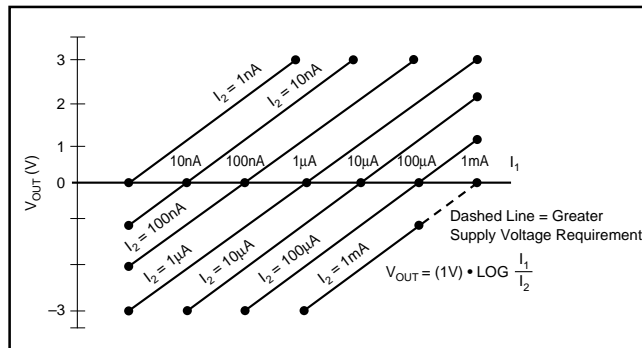


FIGURE 14. Transfer Function with Varying  $I_2$  and  $I_1$ .

## ACCURACY

Accuracy considerations for a log ratio amplifier are somewhat more complicated than for other amplifiers. This is because the transfer function is nonlinear and has two inputs, each of which can vary over a wide dynamic range. The accuracy for any combination of inputs is determined from the total error specification.

## TOTAL ERROR

The total error is the deviation (expressed in mV) of the actual output from the ideal output of  $V_{OUT} = 1V \cdot \log(I_1/I_2)$ .

Thus,

$$V_{OUT} (ACTUAL) = V_{OUT} (IDEAL) \pm \text{Total Error.} \quad (5)$$

It represents the sum of all the individual components of error normally associated with the log amp when operated in the current input mode. The worst-case error for any given ratio of  $I_1/I_2$  is the largest of the two errors when  $I_1$  and  $I_2$  are considered separately; and is shown in Table I. Temperature can affect total error.

$I_2$ (maximum error) <sup>(1)</sup>	$I_1$ (maximum error) <sup>(1)</sup>		
	10nA (30mV)	100nA (25mV)	1µA (20mV)
100nA (25mV)	30mV	25mV	25mV
1µA (20mV)	30mV	25mV	20mV
10µA (25mV)	30mV	25mV	25mV

NOTE: (1) Maximum errors are in parenthesis.

TABLE I.  $I_1/I_2$  and Maximum Errors.

## ERRORS RTO AND RTI

As with any transfer function, errors generated by the function itself may be Referred-to-Output (RTO) or Referred-to-Input (RTI). In this respect, log amps have a unique property:

Given some error voltage at the log amp's output, that error corresponds to a constant percent of the input regardless of the actual input level.

## LOG CONFORMITY

For the LOG102, log conformity is calculated the same as linearity and is plotted  $I_1/I_2$  on a semi-log scale. In many applications, log conformity is the most important specification. This is true because bias current errors are negligible (1pA compared to input currents of 1nA and above) and the scale factor and offset errors may be trimmed to zero or removed by system calibration. This leaves log conformity as the major source of error.

Log conformity is defined as the peak deviation from the best fit straight line of the  $V_{OUT}$  versus  $\log(I_1/I_2)$  curve. This is expressed as a percent of ideal full-scale output. Thus, the nonlinearity error expressed in volts over m decades is:

$$V_{OUT} (NONLIN) = 1V/\text{dec} \cdot 2Nm \text{ V} \quad (6)$$

where N is the log conformity error, in percent.

## INDIVIDUAL ERROR COMPONENTS

The ideal transfer function with current input is:

$$V_{OUT} = (1V) \cdot \log \frac{I_1}{I_2} \quad (7)$$

The actual transfer function with the major components of error is:

$$V_{OUT} = (1V) (1 \pm \Delta K) \log \frac{I_1 - I_{B1}}{I_2 - I_{B2}} \pm 2Nm \pm V_{OS \text{ OUT}} \quad (8)$$

The individual component of error is:

$\Delta K$  = gain accuracy (0.3%, typ), as specified in specification table.

$I_{B1}$  = bias current of  $A_1$  (5pA, typ)

$I_{B2}$  = bias current of  $A_2$  (5pA, typ)

N = log conformity error (0.04%, 0.15%, typ)

0.04% for n = 5, 0.15% for n = 6

$V_{OS \text{ OUT}}$  = output offset voltage (1mV, typ)

n = number of decades over which N is specified:

Example: what is the error when

$$I_1 = 1\mu\text{A} \text{ and } I_2 = 100\text{nA} \quad (9)$$

$$V_{OUT} = (1 \pm 0.003) \log \frac{10^{-6} - 5 \cdot 10^{-12}}{10^{-7} - 5 \cdot 10^{-12}} \pm (2)(0.0004)5 \pm 0.3\text{mV}$$

$$\approx 1.003 \log \frac{10^{-6}}{10^{-7}} + 0.004 + 0.003 \quad (10)$$

$$= 1.003 (1) + 0.004 + 0.0003 \quad (11)$$

$$= 1.0073V \quad (12)$$

Since the ideal output is 1.000V, the error as a percent of reading is

$$\% \text{ error} = \frac{0.0073}{1} \bullet 100\% = 0.73\% \quad (13)$$

For the case of voltage inputs, the actual transfer function is

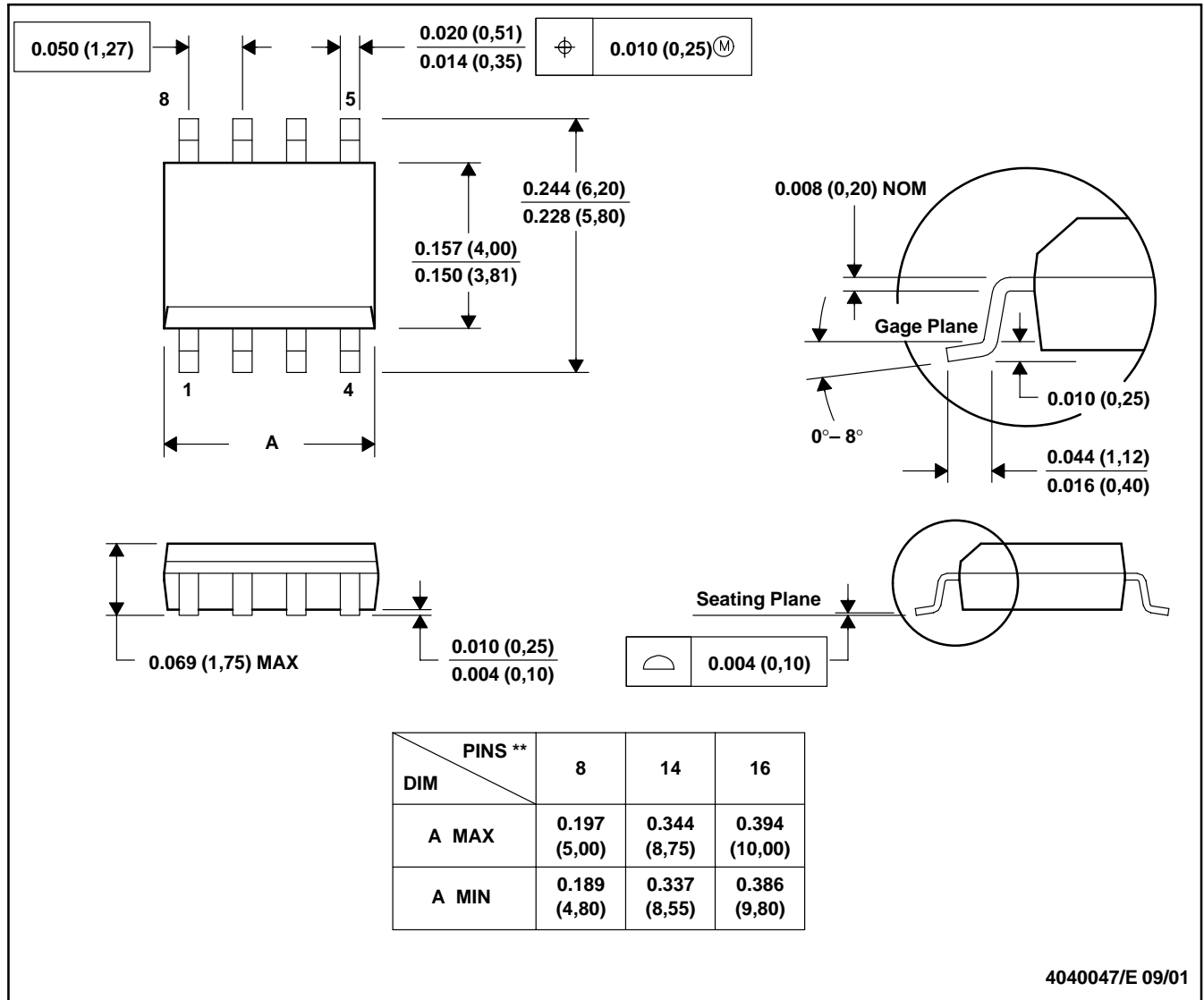
$$V_{OUT} = (1V)(1 \pm \Delta K) \log \frac{\frac{V_1 - I_{B1} \pm \frac{E_{OS1}}{R_1}}{\frac{V_2 - I_{B2} \pm \frac{E_{OS2}}{R_2}}{\pm 2Nn \pm V_{OS OUT}}}} \quad (14)$$

Where  $\frac{E_{OS1}}{R_1}$  and  $\frac{E_{OS2}}{R_2}$  are considered to be zero for large values of resistance from external input current sources. (15)

D (R-PDSO-G\*\*)

PLASTIC SMALL-OUTLINE PACKAGE

8 PINS SHOWN



- NOTES: A. All linear dimensions are in inches (millimeters).  
 B. This drawing is subject to change without notice.  
 C. Body dimensions do not include mold flash or protrusion, not to exceed 0.006 (0,15).  
 D. Falls within JEDEC MS-012

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## PACKAGING INFORMATION

ORDERABLE DEVICE	STATUS(1)	PACKAGE TYPE	PACKAGE DRAWING	PINS	PACKAGE QTY
LOG102AID	ACTIVE	SOIC	D	14	58
LOG102AIDR	ACTIVE	SOIC	D	14	2500

(1) The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBSOLETE:** TI has discontinued the production of the device.

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Mailing Address: Texas Instruments  
Post Office Box 655303 Dallas, Texas 75265

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