

SBOS242B – MAY 2002 – REVISED JUNE 2004

Precision LOGARITHMIC AND LOG RATIO AMPLIFIER

FEATURES

- **EASY-TO-USE COMPLETE CORE FUNCTION**
- **HIGH ACCURACY: 0.01% FSO Over 5 Decades**
- **WIDE INPUT DYNAMIC RANGE: 7.5 Decades, 100pA to 3.5mA**
- **LOW QUIESCENT CURRENT: 1mA**
- **WIDE SUPPLY RANGE: ±4.5V to ±18V**

APPLICATIONS

- **LOG, LOG RATIO COMPUTATION: Communication, Analytical, Medical, Industrial, Test, and General Instrumentation**
- **PHOTODIODE SIGNAL COMPRESSION AMPS**
- **ANALOG SIGNAL COMPRESSION IN FRONT OF ANALOG-TO-DIGITAL (A/D) CONVERTERS**

DESCRIPTION

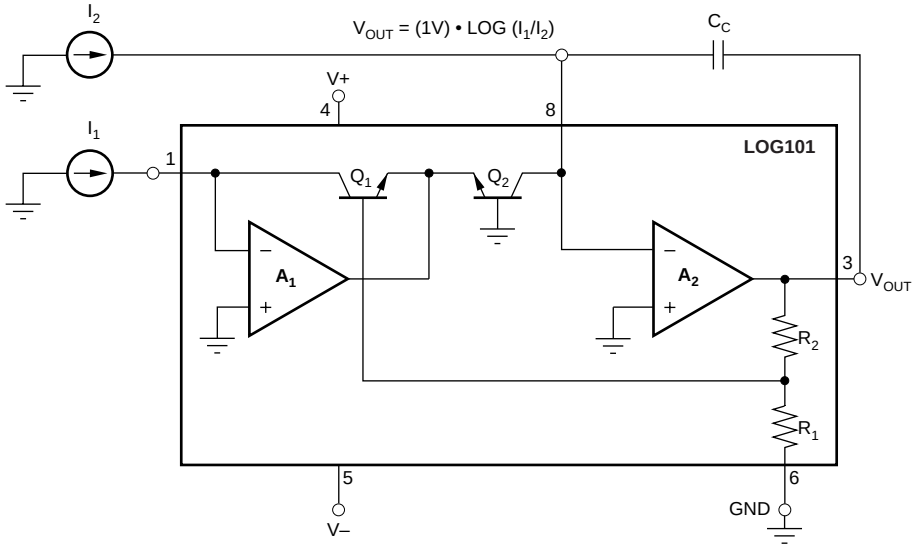
The LOG101 is a versatile integrated circuit that computes the logarithm or log ratio of an input current relative to a reference current.

The LOG101 is tested over a wide dynamic range of input signals. In log ratio applications, a signal current can come from a photodiode, and a reference current from a resistor in series with a precision external reference.

The output signal at V_{OUT} is trimmed to 1V per decade of input current allowing seven decades of input current dynamic range.

Low DC offset voltage and temperature drift allow accurate measurement of low-level signals over a wide environmental temperature range. The LOG101 is specified over the temperature range –5°C to +75°C, with operation over –40°C to +85°C.

Note: Protected under US Patent #6,667,650; other patents pending.





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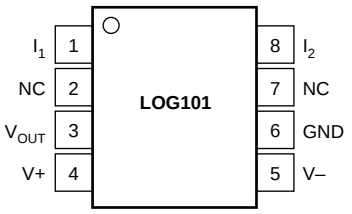
ABSOLUTE MAXIMUM RATINGS(1)

Supply Voltage, V+ to V–	36V
Input Voltage	(V–) – 0.5 to (V+) + 0.5V
Input Current	±10mA
Output Short-Circuit(2)	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.

PIN DESCRIPTION

Top View **SO**



NC = No Internal Connection

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.

PACKAGE/ORDERING INFORMATION(1)

PRODUCT	PACKAGE-LEAD	PACKAGE DESIGNATOR	SPECIFIED TEMPERATURE RANGE	PACKAGE MARKING	ORDERING NUMBER	TRANSPORT MEDIA, QUANTITY
LOG101AID	SO-8	D	–5°C to +75°C	LOG101	LOG101AID	Rails, 100
"	"	"	"	"	LOG101AIDR	Tape and Reel, 2500

NOTE: (1) For the most current package and ordering information, see the Package Option Addendum located at the end of this data sheet.

ELECTRICAL CHARACTERISTICS

Boldface limits apply over the specified temperature range, **T_A = –5°C to +75°C.**

At T_A = +25°C, V_S = ±5V, and R_{OUT} = 10kΩ, unless otherwise noted.

PARAMETER	CONDITION	LOG101AID MIN	LOG101AID TYP	LOG101AID MAX	UNITS
CORE LOG FUNCTION					
I_{IN}/V_{OUT} Equation			$V_O = (1V) \bullet \log (I_1/I_2)$		V
LOG CONFORMITY ERROR(1)					
Initial	1nA to 100µA (5 decades)		0.01	0.2	%
	100pA to 3.5mA (7.5 decades)		0.06		%
over Temperature	**1nA to 100µA (5 decades)**		0.0001		**%/°C**
	100pA to 3.5mA (7.5 decades)(2)		0.0005		**%/°C**
GAIN(3)					
Initial Value	1nA to 100µA		1		V/decade
Gain Error	1nA to 100µA		0.15	±1	%
vs Temperature	**T_{MIN} to T_{MAX}**		**0.003**	**0.01**	**%/°C**
INPUT, A1 and A2					
Offset Voltage			±0.3	±1.5	mV
vs Temperature	**T_{MIN} to T_{MAX}**		**±2**		**µV/°C**
vs Power Supply (PSRR)	V_S = ±4.5V to ±18V		5	50	µV/V
Input Bias Current			±5		pA
vs Temperature	**T_{MIN} to T_{MAX}**		**Doubles Every 10°C**		
Voltage Noise	f = 10Hz to 10kHz		3		µVrms
	f = 1kHz		30		nV/√Hz
Current Noise	f = 1kHz		4		fA/√Hz
Common-Mode Voltage Range (Positive)		(V+) – 2	(V+) – 1.5		V
(Negative)		(V–) + 2	(V–) + 1.2		V
Common-Mode Rejection Ratio (CMRR)			105		dB
OUTPUT, A2 (V_{OUT})					
Output Offset, V_{OSO}, Initial			±3	±15	mV
vs Temperature	**T_{MIN} to T_{MAX}**		**±2**		**µV/°C**
Full-Scale Output (FSO)	V_S = ±5V	(V–) + 1.2		(V+) – 1.5	V
Short-Circuit Current			±18		mA

ELECTRICAL CHARACTERISTICS (Cont.)

Boldface limits apply over the specified temperature range, **T_A = –5°C to +75°C.**

At T_A = +25°C, V_S = ±5V, and R_L = 10kΩ, unless otherwise noted.

PARAMETER	CONDITION	LOG101AID MIN	LOG101AID TYP	LOG101AID MAX	UNITS
TOTAL ERROR[4][5]	I_1 or I_2 remains fixed while other varies.				
Initial	Min to Max				
	I_1 or I_2 = 3.5mA			±75	mV
	I_1 or I_2 = 1mA			±20	mV
	I_1 or I_2 = 100µA			±20	mV
	I_1 or I_2 = 10µA			±20	mV
	I_1 or I_2 = 1µA			±20	mV
	I_1 or I_2 = 100nA			±20	mV
	I_1 or I_2 = 10nA			±20	mV
	I_1 or I_2 = 1nA			±20	mV
	I_1 or I_2 = 350pA			±20	mV
	I_1 or I_2 = 100pA			±20	mV
vs Temperature	**I_1 or I_2 = 3.5mA**		**±1.2**		**mV/°C**
	I_1 or I_2 = 1mA		**±0.4**		**mV/°C**
	I_1 or I_2 = 100µA		**±0.1**		**mV/°C**
	I_1 or I_2 = 10µA		**±0.05**		**mV/°C**
	I_1 or I_2 = 1µA		**±0.05**		**mV/°C**
	I_1 or I_2 = 100nA		**±0.09**		**mV/°C**
	I_1 or I_2 = 10nA		**±0.2**		**mV/°C**
	I_1 or I_2 = 1nA		**±0.3**		**mV/°C**
	I_1 or I_2 = 350pA		**±0.1**		**mV/°C**
	I_1 or I_2 = 100pA		**±0.3**		**mV/°C**
vs Supply	I_1 or I_2 = 3.5mA		±3.0		mV/V
	I_1 or I_2 = 1mA		±0.1		mV/V
	I_1 or I_2 = 100µA		±0.1		mV/V
	I_1 or I_2 = 10µA		±0.1		mV/V
	I_1 or I_2 = 1µA		±0.1		mV/V
	I_1 or I_2 = 100nA		±0.1		mV/V
	I_1 or I_2 = 10nA		±0.1		mV/V
	I_1 or I_2 = 1nA		±0.25		mV/V
	I_1 or I_2 = 350pA		±0.1		mV/V
	I_1 or I_2 = 100pA		±0.1		mV/V
FREQUENCY RESPONSE, CORE LOG[6]					
BW, 3dB					
I_2 = 10nA	C_C = 4500pF		0.1		kHz
I_2 = 1µA	C_C = 150pF		38		kHz
I_2 = 10µA	C_C = 150pF		40		kHz
I_2 = 1mA	C_C = 50pF		45		kHz
Step Response					
Increasing					
I_2 = 1µA to 1mA	C_C = 150pF		11		µs
I_2 = 100nA to 1µA	C_C = 150pF		7		µs
I_2 = 10nA to 100nA	C_C = 150pF		110		µs
Decreasing					
I_2 = 1mA to 1µA	C_C = 150pF		45		µs
I_2 = 1µA to 100nA	C_C = 150pF		20		µs
I_2 = 100nA to 10nA	C_C = 150pF		550		µs
POWER SUPPLY					
Operating Range	V_S	±4.5		±18	V
Quiescent Current	I_O = 0		±1	±1.5	mA
TEMPERATURE RANGE					
Specified Range, T_{MIN} to T_{MAX}		–5		75	°C
Operating Range		–40		85	°C
Storage Range		–55		125	°C
Thermal Resistance, θ_{JA} SO-8			150		°C/W

NOTES: (1) Log Conformity Error is peak deviation from the best-fit straight line of V_{OUT} versus log (I_1/I_2) curve expressed as a percent of peak-to-peak full-scale.

(2) May require higher supply for full dynamic range.

(3) Output core log function is trimmed to 1V output per decade change of input current.

(4) Worst-case Total Error for any ratio of I_1/I_2 is the largest of the two errors, when I_1 and I_2 are considered separately.

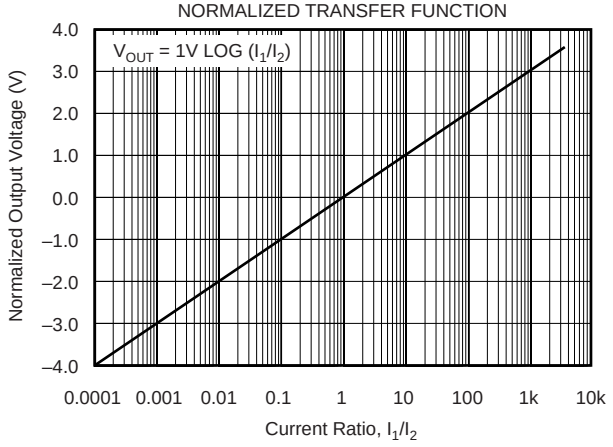
(5) Total I_1 + I_2 should be kept below 4.5mA on ±5V supply.

(6) Bandwidth (3dB) and transient response are a function of both the compensation capacitor and the level of input current.

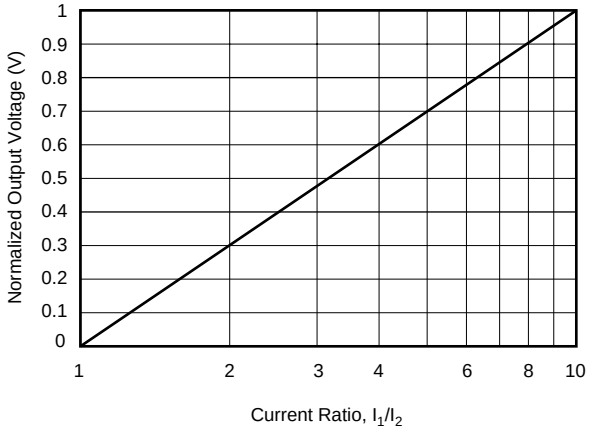
TYPICAL CHARACTERISTICS

At T_A = +25°C, V_S = ±5V, and R_L = 10kΩ, unless otherwise noted.

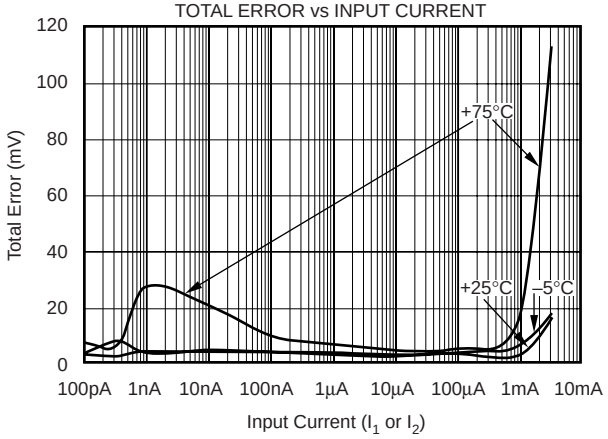
NORMALIZED TRANSFER FUNCTION



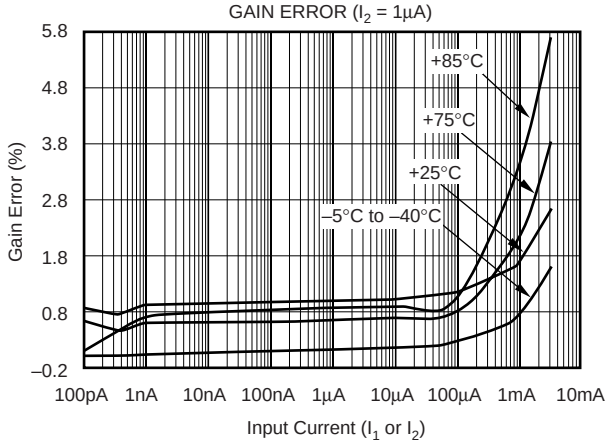
ONE CYCLE OF NORMALIZED TRANSFER FUNCTION



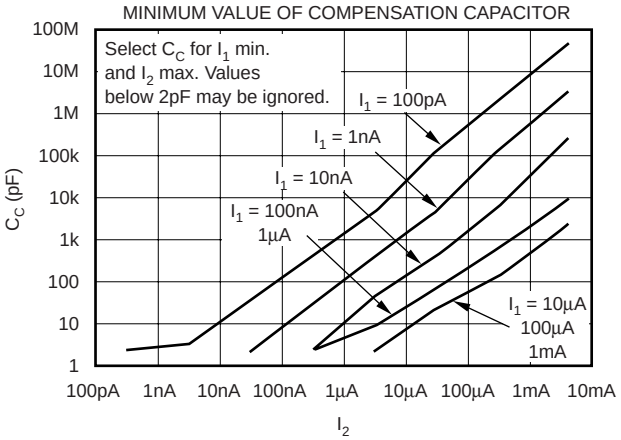
TOTAL ERROR vs INPUT CURRENT



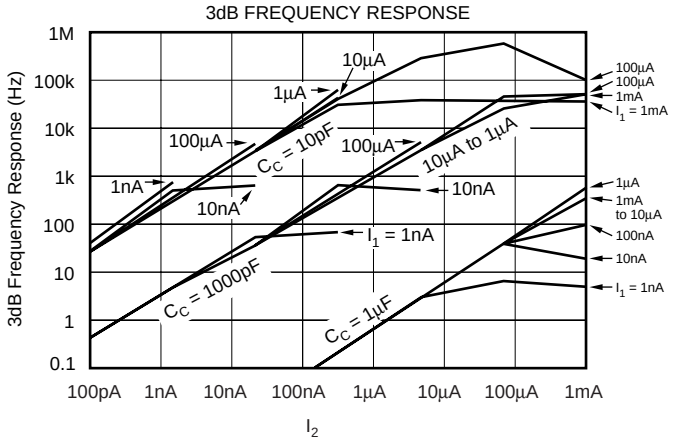
GAIN ERROR (I_2 = 1µA)



MINIMUM VALUE OF COMPENSATION CAPACITOR

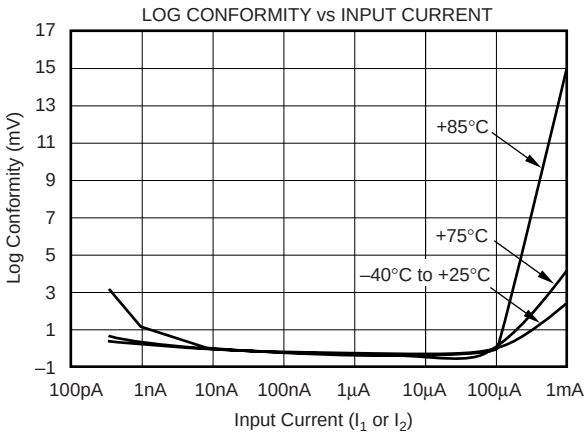


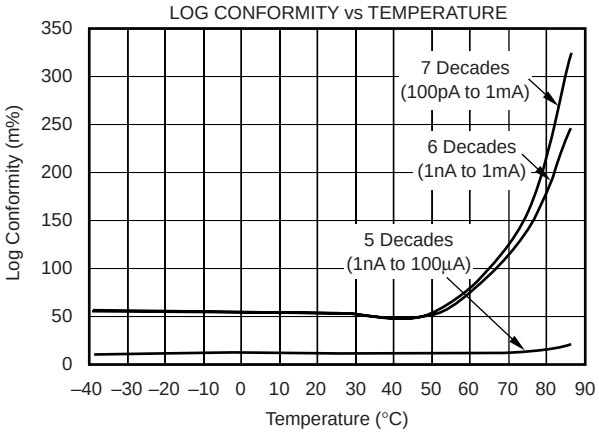
3dB FREQUENCY RESPONSE



TYPICAL CHARACTERISTICS (Cont.)

At T_A = +25°C, V_S = ±5V, and R_L = 10kΩ, unless otherwise noted.





APPLICATION INFORMATION

The LOG101 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.

Figure 1 shows the basic connections required for operation of the LOG101. In order to reduce the influence of lead inductance of power-supply lines, it is recommended that each supply be bypassed with a 10µF tantalum capacitor in parallel with a 1000pF ceramic capacitor, as shown in Figure 1. Connecting the capacitors as close to the LOG101 as possible will contribute to noise reduction as well.

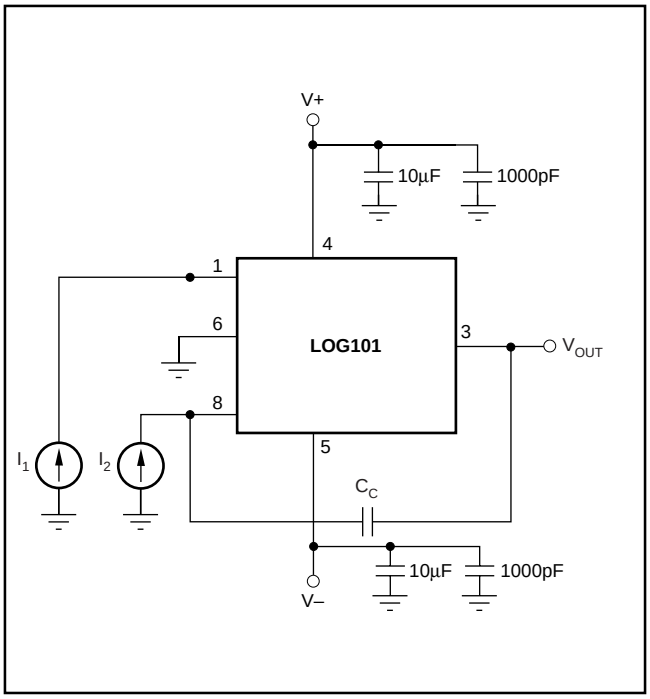


FIGURE 1. Basic Connections of the LOG101.

INPUT CURRENT RANGE

To maintain specified accuracy, the input current range of the LOG101 should be limited from 100pA to 3.5mA. Input currents outside of this range may compromise LOG101 performance. Input currents larger than 3.5mA result in increased nonlinearity. An absolute maximum input current rating of 10mA is included to prevent excessive power dissipation that may damage the logging transistor.

On ±5V supplies, the total input current (I_1 + I_2) is limited to 4.5mA. Due to compliance issues internal to the LOG101, to accommodate larger total input currents, supplies should be increased.

Currents smaller than 100pA will result in increased errors due to the input bias currents of op amps A_1 and A_2 (typically 5pA). 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°C, which makes the nulling technique shown practical only where the temperature is fairly stable.

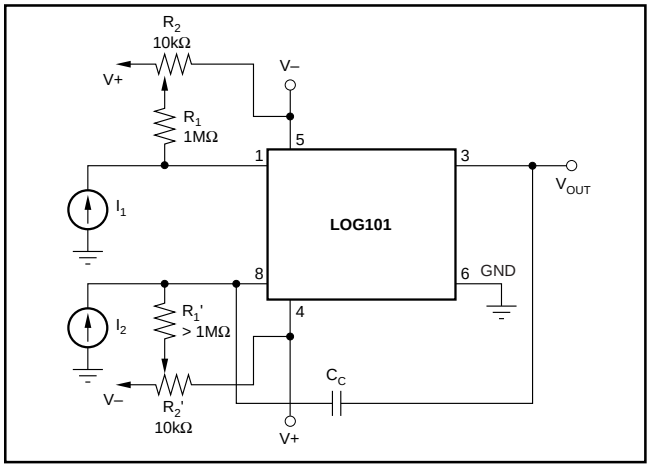


FIGURE 2. Bias Current Nulling.

SETTING THE REFERENCE CURRENT

When the LOG101 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_{OUT} is expressed as:

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

I_{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_{REF}. If I_{REF} is 10nA and +2.5V is used:

$$R_{REF} = 2.5V/10nA = 250M\Omega \quad (2)$$

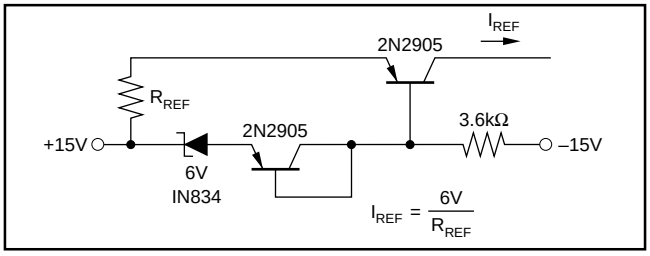


FIGURE 3. Temperature Compensated Current Source.

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 1.5mV, making V_{REF} a suggested value of 100mV.

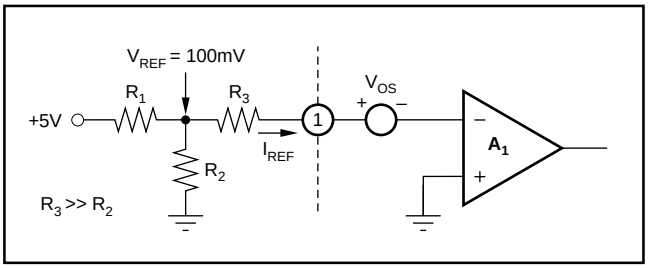


FIGURE 4. T Network for Reference Current.

Figure 5 shows a low-level current source using a series resistor. The low offset op-amp reduces the effect of the LOG101's input offset voltage.

FREQUENCY RESPONSE

The frequency response curve seen in the Typical Characteristic Curves is shown for constant DC I_1 and I_2 with a small signal AC current on one input.

The 3dB frequency response of the LOG101 is a function of the magnitude of the input current levels and of the value of the frequency compensation capacitor. See Typical Characteristic Curve "3dB Frequency Response" for details.

The transient response of the LOG101 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

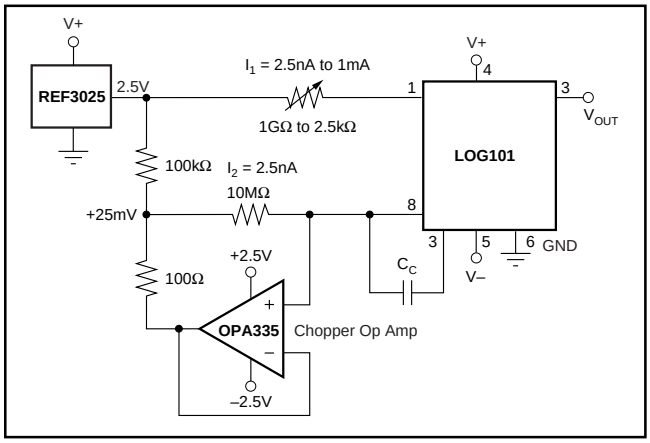


FIGURE 5. Current Source with Offset Compensation.

at different levels of input signals. Smaller input currents require greater gains to maintain full dynamic range, and will slow the frequency response of the LOG101.

FREQUENCY COMPENSATION

Frequency compensation for the LOG101 is obtained by connecting a capacitor between pins 3 and 8. 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 LOG101 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.

NEGATIVE INPUT CURRENTS

The LOG101 will function only with positive input currents (conventional current flows into pins 1 and 8). In situations where negative input currents are needed, the circuits in Figures 6, 7, and 8 may be used.

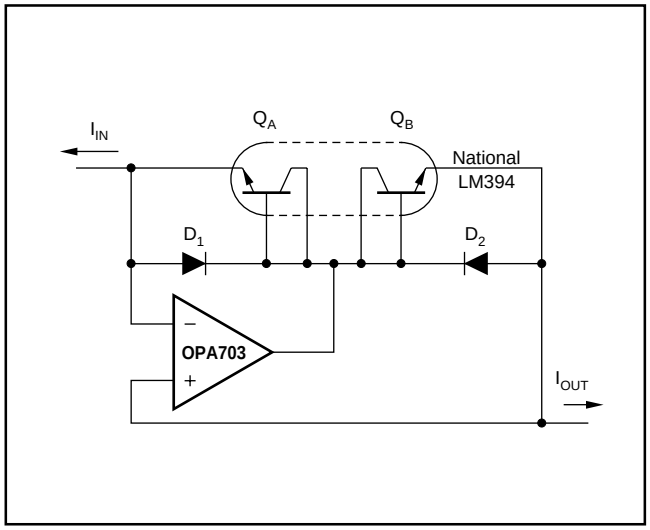


FIGURE 6. Current Inverter/Current Source.

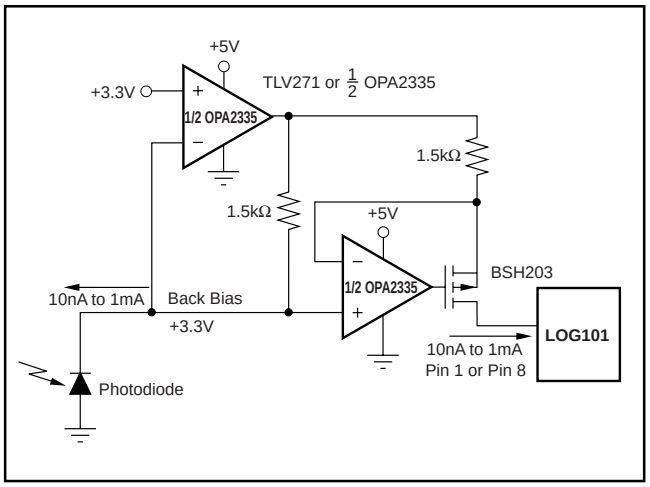


FIGURE 7. Precision Current Inverter/Current Source.

VOLTAGE INPUTS

The LOG101 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 (13) applies to this configuration.

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 9.

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

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

DATA COMPRESSION

In many applications the compressive effects of the logarithmic transfer function are useful. For example, a LOG101 preceding a 12-bit Analog-to-Digital (A/D) converter can produce the dynamic range equivalent to a 20-bit converter.

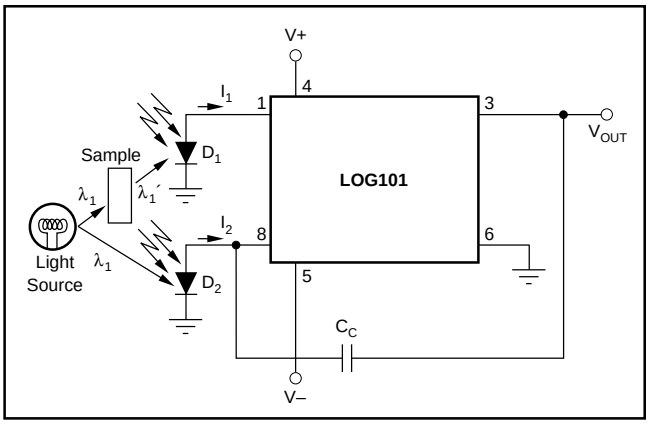


FIGURE 9. Absorbance Measurement.

OPERATION ON SINGLE SUPPLY

Many applications do not have the dual supplies required to operate the LOG101. Figure 10 shows the LOG101 configured for operation with a single +5V supply.

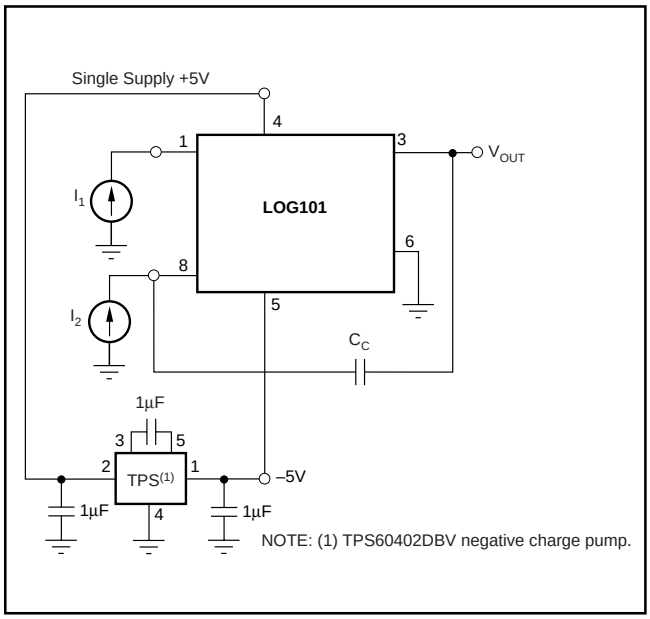


FIGURE 10. Single +5V Power-Supply Operation.

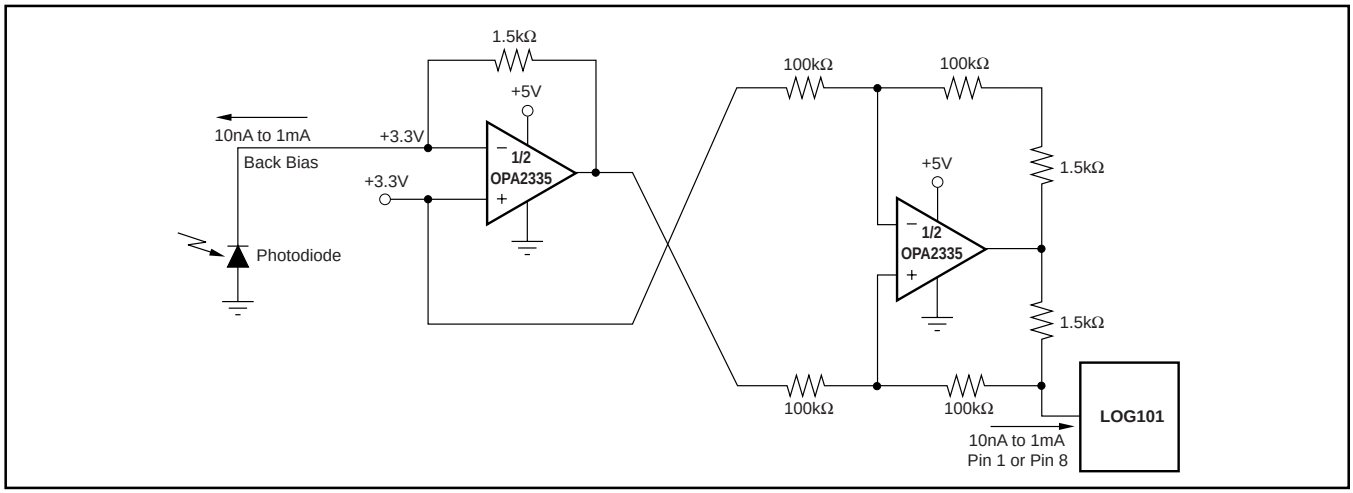


FIGURE 8. Precision Current Inverter/Current Source.

INSIDE THE LOG101

Using the base-emitter voltage relationship of matched bipolar transistors, the LOG101 establishes a logarithmic function of input current ratios. Beginning with the base-emitter voltage defined as:

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

k = Boltzman's constant = 1.381 • 10^{-23}

T = Absolute temperature in degrees Kelvin

q = Electron charge = 1.602 • 10^{-19} Coulombs

I_C = Collector current

I_S = Reverse saturation current

From the circuit in Figure 11, we see that:

$$V_L = V_{BE_1} - V_{BE_2} \tag{2}$$

Substituting (1) into (2) yields:

$$V_L = V_{T_1} \ln \frac{I_1}{I_{S_1}} - V_{T_2} \ln \frac{I_2}{I_{S_2}} \tag{3}$$

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

$$V_L = V_{T_1} \left[\ln \frac{I_1}{I_S} - \ln \frac{I_2}{I_S} \right] \tag{4}$$

$$V_L = V_T \ln \frac{I_1}{I_2} \text{ and since} \tag{5}$$

$$\ln x = 2.3 \log_{10} x \tag{6}$$

$$V_L = n\, V_T \log \frac{I_1}{I_2} \tag{7}$$

where n = 2.3 (8)

also

$$V_{OUT} = V_L \frac{R_1 + R_2}{R_1} \tag{9}$$

$$V_{OUT} = \frac{R_1 + R_2}{R_1} n\, V_T \log \frac{I_1}{I_2} \tag{10}$$

or

$$V_{OUT} = (1V) \bullet \log \frac{I_1}{I_2} \tag{11}$$

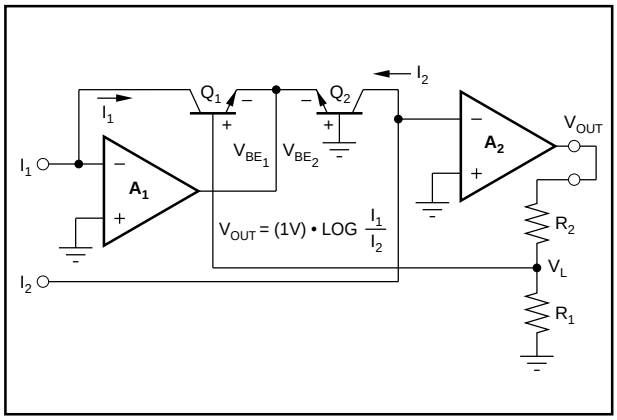


FIGURE 11. Simplified Model of a Log Amplifier.

It should be noted that the temperature dependance associated with $V_T = kT/q$ is internally compensated on the LOG101 by making R_1 a temperature sensitive resistor with the required positive temperature coefficient.

DEFINITION OF TERMS

TRANSFER FUNCTION

The ideal transfer function is:

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

Figure 12 shows the graphical representation of the transfer over valid operating range for the LOG101.

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.

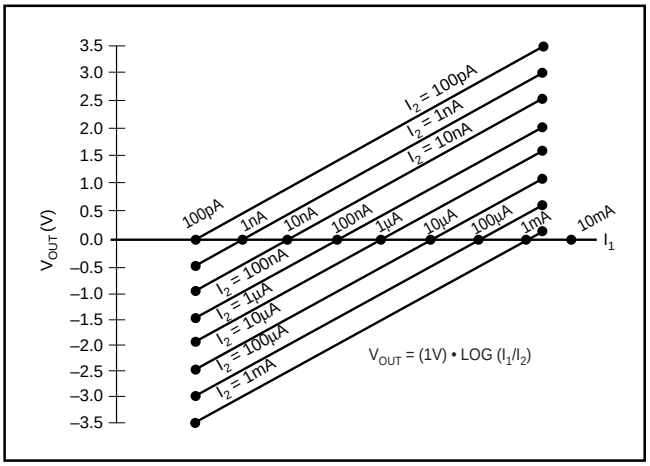


FIGURE 12. Transfer Function with Varying I_2 and I_1.

TOTAL ERROR

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

Thus,

$$V_{OUT(ACTUAL)} = V_{OUT(IDEAL)} \pm \text{Total Error.} \quad (6)$$

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. Temperature can affect total error.

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.

USING A LARGER REFERENCE VOLTAGE REDUCES OFFSET ERRORS

Using a larger reference voltage to create the reference current minimizes errors due to the LOG101'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 LOG101 configured with the reference current connecting I_1 and the photodiode current connecting to I_2 is shown in Figure 13. The OPA703 is configured as a level shifter with inverting gain and is used to scale the photodiode current directly into the A/D converter input voltage range.

The wide dynamic range of the LOG101 is also useful for measuring avalanche photodiode current (APD) (see Figure 14).

LOG CONFORMITY

For the LOG101, 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 because bias current errors are negligible (5pA compared to input currents of 100pA 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:

$$V_{OUT(NONLIN)} = 1V/\text{dec} \bullet 2NmV \quad (7)$$

where N is the log conformity error, in percent.

INDIVIDUAL ERROR COMPONENTS

The ideal transfer function with current input is:

$$V_{OUT} = (1V) \bullet \log \frac{I_1}{I_2} \quad (8)$$

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

$$V_{OUT} = (1V)(1 \pm \Delta K) \log \frac{I_1 - I_{B1}}{I_2 - I_{B2}} \pm 2Nm \pm V_{OSO} \quad (9)$$

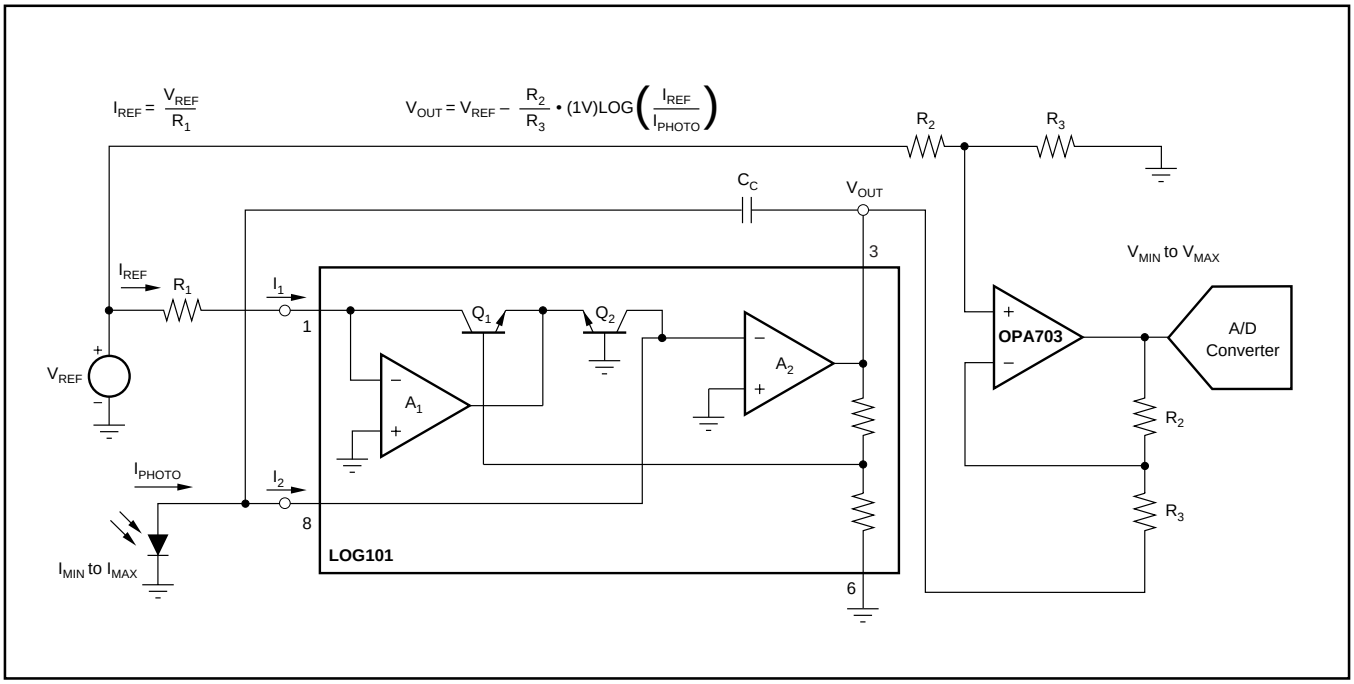


FIGURE 13. Technique for Using Full-Scale Reference Current Such that V_{OUT} Increases with Increasing Photodiode Current.

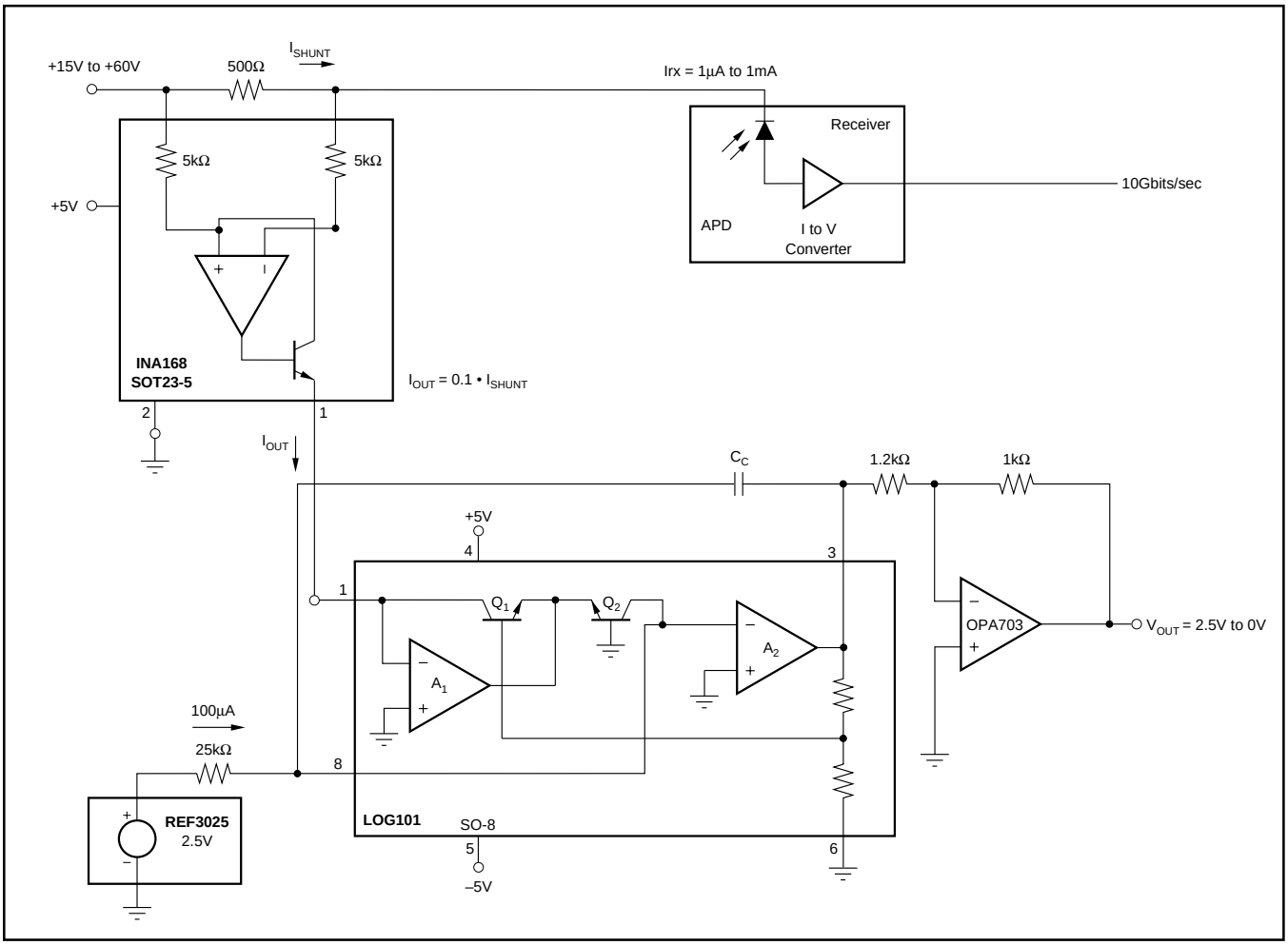


FIGURE 14. High Side Shunt for Avalanche Photodiode (APD) Measures 3-Decades of APD Current.

The individual component of error is:

ΔK = gain accuracy (0.15%, typ), as specified in the specification table.

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

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

N = log conformity error (0.01%, 0.06%, typ)

0.01% for n = 5, 0.06% for n = 7

V_{OSO} = output offset voltage (3mV, typ)

n = number of decades over which N is specified:

Example: what is the error when

$$I_1 = 1\mu A \text{ and } I_2 = 100nA \quad (10)$$

$$V_{OUT} = (1 \pm 0.0015)\log\frac{10^{-6} - 5 \bullet 10^{-12}}{10^{-7} - 5 \bullet 10^{-12}} \pm (2)(0.0001)5 \pm 3.0mV$$

$$= 1.005055V \quad (11)$$

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

$$\% \text{ error} = \frac{0.005055}{1} \bullet 100\% = 0.5\% \quad (12)$$

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

$$V_{OUT} = (1V)(1 \pm \Delta K)\log\frac{\frac{V_1}{R_1} - I_{B_1} \pm \frac{E_{OS_1}}{R_1}}{\frac{V_2}{R_2} - I_{B_2} \pm \frac{E_{OS_2}}{R_2}} \pm 2Nn \pm V_{OSO} \quad (13)$$

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.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)
LOG101AID	ACTIVE	SOIC	D	8	100	None	CU SNPB	Level-3-235C-168 HR
LOG101AIDR	ACTIVE	SOIC	D	8	2500	None	CU SNPB	Level-3-235C-168 HR

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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.

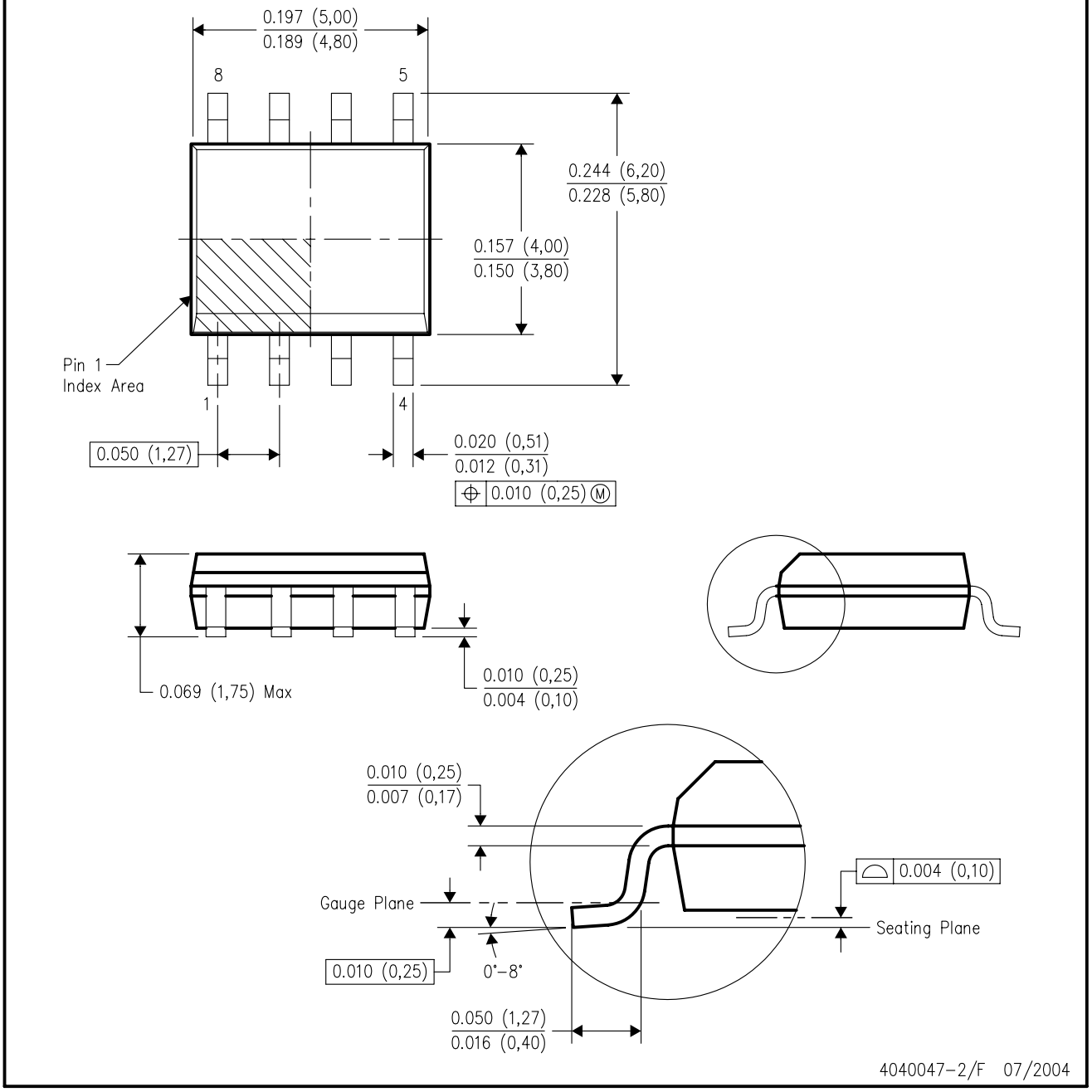
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None: Not yet available Lead (Pb-Free).
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(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDECindustry standard classifications, and peak solder temperature.

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D (R–PDSO–G8) PLASTIC SMALL–OUTLINE PACKAGE



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 variation AA.

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