



# Precision LOGARITHMIC AND LOG RATIO AMPLIFIERS

## FEATURES

- EASY-TO-USE COMPLETE FUNCTION
- OUTPUT SCALING AMPLIFIER
- ON-CHIP 2.5V VOLTAGE REFERENCE
- HIGH ACCURACY: 0.2% FSO Over 5 Decades
- WIDE INPUT DYNAMIC RANGE:  
7.5 Decades, 100pA to 3.5mA
- LOW QUIESCENT CURRENT: 1.75mA
- WIDE SUPPLY RANGE:  $\pm 4.5V$  to  $\pm 18V$
- PACKAGES: SO-14 (narrow) and SO-16

## DESCRIPTION

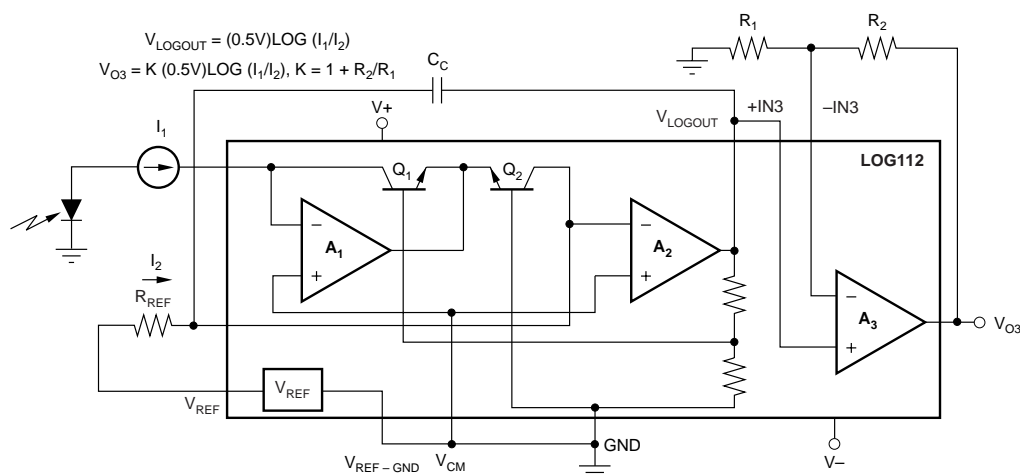
The LOG112 and LOG2112 are versatile integrated circuits that compute the logarithm or log ratio of an input current relative to a reference current.  $V_{LOGOUT}$  of the LOG112 and LOG2112 are trimmed to 0.5V per decade of input current, ensuring high precision over a wide dynamic range of input signals.

The LOG112 and LOG2112 features a 2.5V voltage reference that may be used to generate a precision current reference using an external resistor.

Low DC offset voltage and temperature drift allow accurate measurement of low-level signals over the specified temperature range of  $-5^{\circ}C$  to  $+75^{\circ}C$ .

## APPLICATIONS

- LOG, LOG RATIO:  
Communication, Analytical, Medical, Industrial,  
Test, General Instrumentation
- PHOTODIODE SIGNAL COMPRESSION AMP
- ANALOG SIGNAL COMPRESSION IN FRONT  
OF ANALOG-TO-DIGITAL (A/D) CONVERTER
- ABSORBANCE MEASUREMENT
- OPTICAL DENSITY MEASUREMENT



NOTE: Internal resistors are used to compensate gain change over temperature. The  $V_{CM}$  pin is internally connected to GND in the LOG2112.



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

Supply Voltage, V+ to V- .....	±18V
Inputs .....	±18V
Input Current .....	±10mA
Output Short-Circuit Current <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) One output 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.

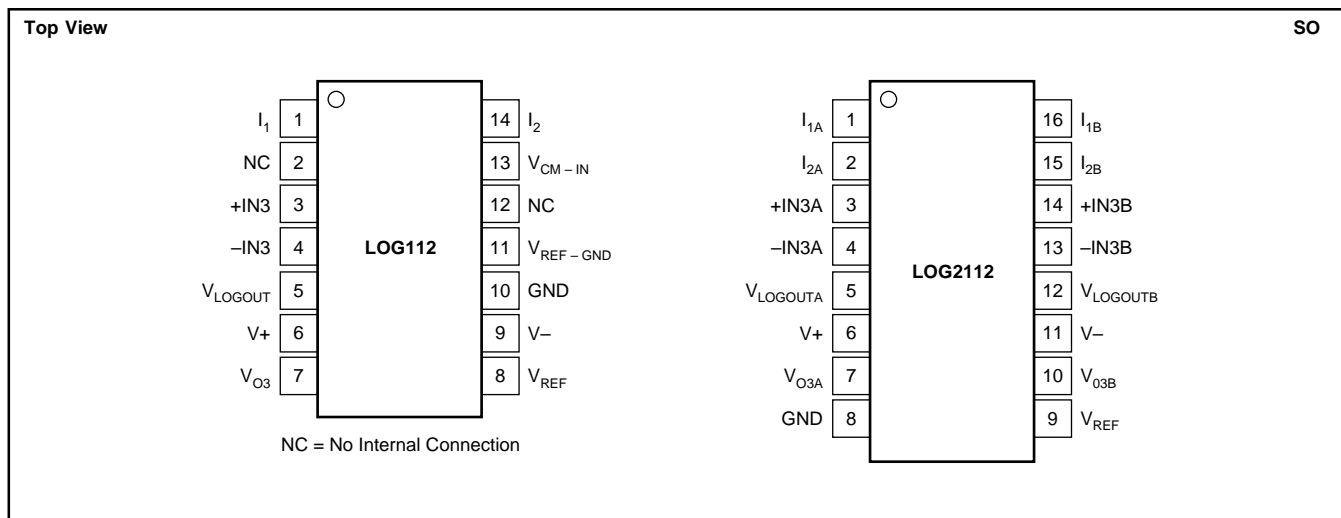
ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

## PACKAGE/ORDERING INFORMATION<sup>(1)</sup>

PRODUCT	PACKAGE-LEAD	PACKAGE DESIGNATOR	PACKAGE MARKING
LOG112	SO-14	D	LOG112A
LOG2112	SO-16	DW	LOG2112A

NOTES: (1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI website at [www.ti.com](http://www.ti.com).

## PIN CONFIGURATION



# ELECTRICAL CHARACTERISTICS

**Boldface** limits apply over the specified temperature range,  $T_A = -5^{\circ}\text{C}$  to  $+75^{\circ}\text{C}$ .

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

PARAMETER	CONDITION	LOG112, LOG2112			UNITS
		MIN	TYP	MAX	
<b>CORE LOG FUNCTION</b> $V_{IN}/V_{OUT}$ Equation		$V_{LOGOUT} = (0.5\text{V})\text{LOG}(I_1/I_2)$			V
<b>LOG CONFORMITY ERROR<sup>(1)</sup></b> Initial	1nA to 100µA (5 decades) 100pA to 3.5mA (7.5 decades)		0.01 0.13	0.2	% %
<b>over Temperature</b>	<b>1nA to 100µA (5 decades)</b> <b>100pA to 3.5mA (7.5 decades)</b>		0.0001 0.005		<b>%/°C</b> <b>%/°C</b>
<b>GAIN<sup>(2)</sup></b> Initial Value	1nA to 100µA		0.5		V/decade
Gain Error	1nA to 100µA		0.10	±1	%
<b>vs Temperature</b>	<b><math>T_{MIN}</math> to <math>T_{MAX}</math></b>		<b>0.003</b>	<b>0.01</b>	<b>%/°C</b>
<b>INPUT, <math>A_{1A}</math> and <math>A_{1B}</math>, <math>A_{2A}</math>, <math>A_{2B}</math></b> Offset Voltage	$T_{MIN}$ to $T_{MAX}$ $V_S = \pm 4.5\text{V}$ to $\pm 18\text{V}$		±0.3	±1.5	mV
<b>vs Temperature</b>			±2		µV/°C
vs Power Supply (PSRR)			5	20	µV/V
Input Bias Current			±5		pA
<b>vs Temperature</b>	<b><math>T_{MIN}</math> to <math>T_{MAX}</math></b> f = 10Hz to 10kHz	<b>Doubles Every 10°C</b>	3		µVrms
Voltage Noise	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)			10		µV/V
<b>OUTPUT, (<math>V_{LOG OUT}</math>) <math>A_{2A}</math>, <math>A_{2B}</math></b> Output Offset, $V_{OSO}$ , Initial	$T_{MIN}$ to $T_{MAX}$ $V_S = \pm 5\text{V}$		±3	±15	mV
<b>vs Temperature</b>			±10		µV/°C
Full-Scale Output (FSO)		(V-) + 1.2		(V+) - 1.5	V
Short-Circuit Current			±18		mA
<b>TOTAL ERROR<sup>(3)(4)</sup></b> Initial	$I_1$ or $I_2$ remains fixed while other varies. Min to Max $I_1$ or $I_2 = 5\text{mA}$ ( $V_S \geq \pm 6\text{V}$ ) $I_1$ or $I_2 = 3.5\text{mA}$ $I_1$ or $I_2 = 1\text{mA}$ $I_1$ or $I_2 = 100\mu\text{A}$ $I_1$ or $I_2 = 10\mu\text{A}$ $I_1$ or $I_2 = 1\mu\text{A}$ $I_1$ or $I_2 = 100\text{nA}$ $I_1$ or $I_2 = 10\text{nA}$ $I_1$ or $I_2 = 1\text{nA}$ $I_1$ or $I_2 = 350\text{pA}$ $I_1$ or $I_2 = 100\text{pA}$			±150	mV
<b>vs Temperature</b>			±1.2	±75	mV
	<b><math>I_1</math> or <math>I_2 = 3.5\text{mA}</math></b>		±20	mV	
	<b><math>I_1</math> or <math>I_2 = 1\text{mA}</math></b>		±20	mV	
	<b><math>I_1</math> or <math>I_2 = 100\mu\text{A}</math></b>		±20	mV	
	<b><math>I_1</math> or <math>I_2 = 10\mu\text{A}</math></b>		±20	mV	
	<b><math>I_1</math> or <math>I_2 = 1\mu\text{A}</math></b>		±20	mV	
	<b><math>I_1</math> or <math>I_2 = 100\text{nA}</math></b>		±20	mV	
	<b><math>I_1</math> or <math>I_2 = 10\text{nA}</math></b>		±20	mV	
	<b><math>I_1</math> or <math>I_2 = 1\text{nA}</math></b>		±20	mV	
	<b><math>I_1</math> or <math>I_2 = 350\text{pA}</math></b>		±20	mV	
	<b><math>I_1</math> or <math>I_2 = 100\text{pA}</math></b>		±20	mV	
<b>vs Supply</b>	<b><math>I_1</math> or <math>I_2 = 3.5\text{mA}</math></b>		±3.0	mV/V	
	<b><math>I_1</math> or <math>I_2 = 1\text{mA}</math></b>		±0.1	mV/V	
	<b><math>I_1</math> or <math>I_2 = 100\mu\text{A}</math></b>		±0.1	mV/V	
	<b><math>I_1</math> or <math>I_2 = 10\mu\text{A}</math></b>		±0.1	mV/V	
	<b><math>I_1</math> or <math>I_2 = 1\mu\text{A}</math></b>		±0.1	mV/V	
	<b><math>I_1</math> or <math>I_2 = 100\text{nA}</math></b>		±0.1	mV/V	
	<b><math>I_1</math> or <math>I_2 = 10\text{nA}</math></b>		±0.1	mV/V	
	<b><math>I_1</math> or <math>I_2 = 1\text{nA}</math></b>		±0.25	mV/V	
	<b><math>I_1</math> or <math>I_2 = 350\text{pA}</math></b>		±0.1	mV/V	
	<b><math>I_1</math> or <math>I_2 = 100\text{pA}</math></b>		±0.1	mV/V	

NOTES: (1) Log Conformity Error is the peak deviation from the best-fit-straight line of  $V_O$  versus  $\text{LOG}(I_1/I_2)$  curve expressed as a percent of peak-to-peak full-scale output. K, scale factor, equals 0.5V output per decade of input current. (2) Scale factor of core log function is trimmed to 0.5V output per decade change of input current. (3) Worst-case Total Error for any ratio of  $I_1/I_2$ , as the largest of the two errors, when  $I_1$  and  $I_2$  are considered separately. (4) Total Error includes offset voltage, bias current, gain, and log conformity. (5) Bandwidth (3dB) and transient response are a function of both the compensation capacitor and the level of input current.

# ELECTRICAL CHARACTERISTICS (Cont.)

**Boldface** limits apply over the specified temperature range,  $T_A = -5^\circ\text{C}$  to  $+75^\circ\text{C}$ .

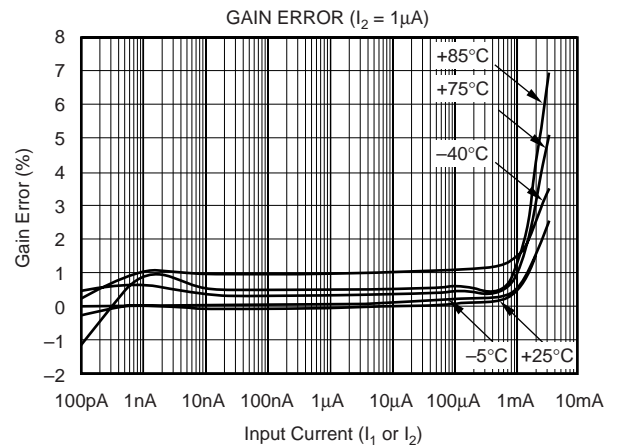
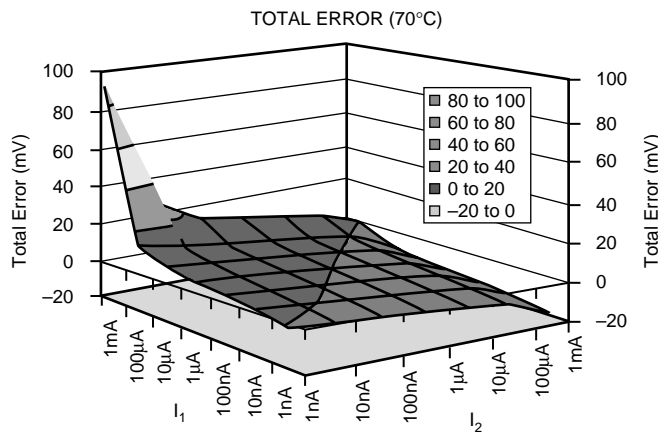
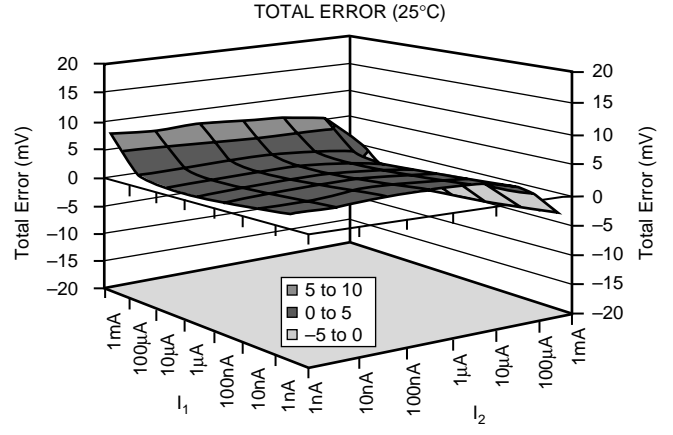
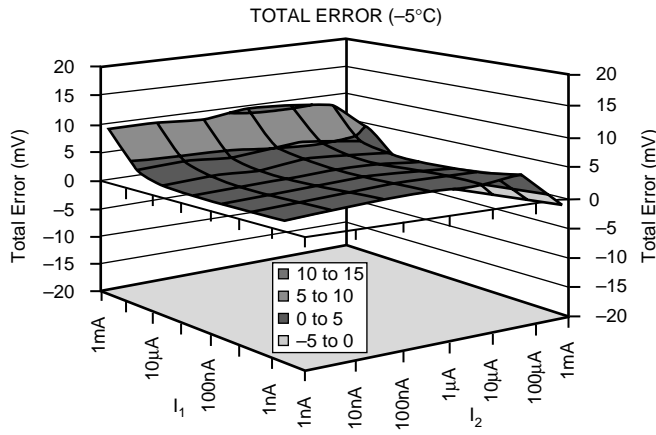
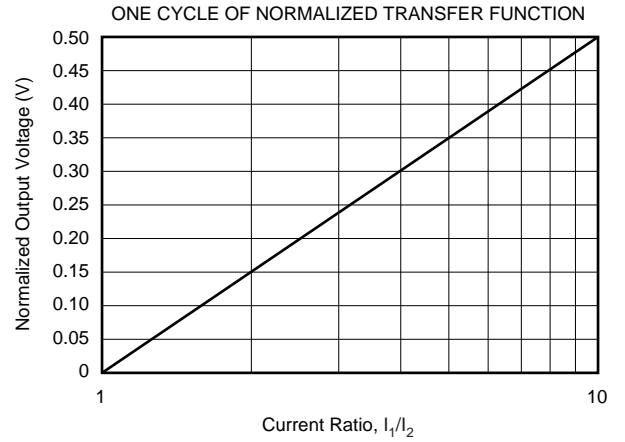
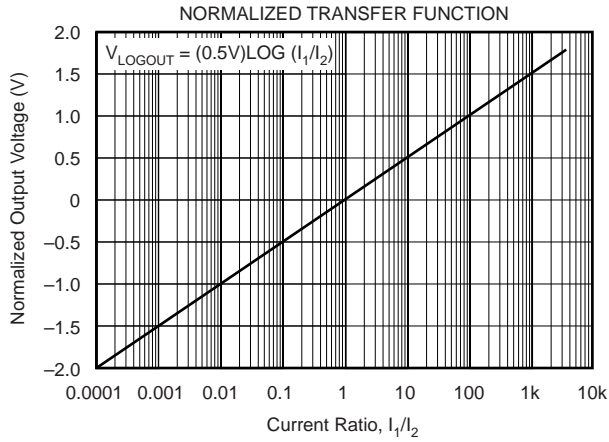
At  $T_A = +25^\circ\text{C}$ ,  $V_S = \pm 5\text{V}$ , and  $R_L = 10\text{k}\Omega$ , unless otherwise noted.

PARAMETER	CONDITION	LOG112, LOG2112			UNITS	
		MIN	TYP	MAX		
<b>FREQUENCY RESPONSE, CORE LOG<sup>(5)</sup></b> BW, 3dB $I_2 = 10\text{nA}$ $I_2 = 1\mu\text{A}$ $I_2 = 10\mu\text{A}$ $I_2 = 1\text{mA}$ Step Response Increasing $I_1 = 10\text{nA}$ to $100\text{nA}$ $I_1 = 1\mu\text{A}$ to $100\mu\text{A}$ $I_1 = 1\mu\text{A}$ to $1\text{mA}$ Decreasing $I_1 = 100\text{nA}$ to $10\text{nA}$ $I_1 = 100\mu\text{A}$ to $1\mu\text{A}$ $I_1 = 1\text{mA}$ to $1\mu\text{A}$ Increasing $I_2 = 10\text{nA}$ to $100\text{nA}$ $I_2 = 1\mu\text{A}$ to $100\mu\text{A}$ $I_2 = 1\mu\text{A}$ to $1\text{mA}$ Decreasing $I_2 = 100\text{nA}$ to $10\text{nA}$ $I_2 = 100\mu\text{A}$ to $1\mu\text{A}$ $I_2 = 1\text{mA}$ to $1\mu\text{A}$	$C_C = 4500\text{pF}$ $C_C = 150\text{pF}$ $C_C = 150\text{pF}$ $C_C = 50\text{pF}$		0.1 38 40 45		kH kH kH kHz	
	$C_C = 120\text{pF}$ , $I_2 = 31.6\text{nA}$		1.1		ms	
	$C_C = 375\text{pF}$ , $I_2 = 10\mu\text{A}$		1.6		$\mu\text{s}$	
	$C_C = 950\text{pF}$ , $I_2 = 31.6\mu\text{A}$		1.5		$\mu\text{s}$	
	$C_C = 120\text{pF}$ , $I_2 = 31.6\text{nA}$		2.1		ms	
	$C_C = 375\text{pF}$ , $I_2 = 10\mu\text{A}$		31.2		$\mu\text{s}$	
	$C_C = 950\text{pF}$ , $I_2 = 31.6\mu\text{A}$		39		$\mu\text{s}$	
	$C_C = 125\text{pF}$ , $I_1 = 31.6\text{nA}$		2.6		ms	
	$C_C = 750\text{pF}$ , $I_1 = 10\mu\text{A}$		113		$\mu\text{s}$	
	$C_C = 10.5\text{nF}$ , $I_1 = 31.6\mu\text{A}$		1.2		ms	
	$C_C = 125\text{pF}$ , $I_1 = 31.6\text{nA}$		630		$\mu\text{s}$	
	$C_C = 750\text{pF}$ , $I_1 = 10\mu\text{A}$		6.6		$\mu\text{s}$	
$C_C = 10.5\text{nF}$ , $I_1 = 31.6\mu\text{A}$		13.3		$\mu\text{s}$		
<b>OP AMP, A3</b> Input Offset Voltage <b>vs Temperature</b> vs Supply Input Bias Current Input Offset Current Input Voltage Range Input Noise, $f = 0.1\text{Hz}$ to $10\text{Hz}$ $f = 1\text{kHz}$ Open-Loop Voltage Gain Gain-Bandwidth Product Slew Rate Settling Time, 0.01% Rated Output Short-Circuit Current	$T_{\text{MIN}}$ to $T_{\text{MAX}}$ $V_S = \pm 4.5\text{V}$ to $\pm 18\text{V}$		+250 <b><math>\pm 2</math></b> 5 -10 <b><math>\pm 0.5</math></b>	$\pm 1000$ 50	$\mu\text{V}$ <b><math>\mu\text{V}/^\circ\text{C}</math></b> $\mu\text{V}/\text{V}$ nA nA V $\mu\text{V}_{\text{pp}}$ $\text{nV}/\sqrt{\text{Hz}}$ dB MHz V/ $\mu\text{s}$ $\mu\text{s}$ V mA	
	$G = -1$ , 3V Step, $C_L = 100\text{pF}$	(V-)	1 28 88 1.4 0.5 16	(V+) - 1.5		
		(V-) + 1.5	<b><math>\pm 4</math></b>	(V+) - 0.9		
	<b>VOLTAGE REFERENCE</b> Bandgap Voltage Error, Initial vs Temperature vs Supply vs Load Short-Circuit Current	$T_{\text{MIN}}$ to $T_{\text{MAX}}$ $V_S = \pm 4.5\text{V}$ to $\pm 18\text{V}$ $I_{\text{LOAD}} = 10\text{mA}$		2.5 $\pm 0.05$ $\pm 25$ $\pm 10$ $\pm 600$ 16	$\pm 0.5$	V % $\text{ppm}/^\circ\text{C}$ $\text{ppm}/\text{V}$ $\text{ppm}/\text{mA}$ mA
	<b>POWER SUPPLY</b> Operating Range Quiescent Current LOG112 LOG2112	$V_S$ $I_O = 0$	$\pm 4.5$		$\pm 18$	V mA mA
				$\pm 1.25$ $\pm 2.5$	$\pm 1.75$ $\pm 3.5$	
	<b>TEMPERATURE RANGE</b> Specified Range, $T_{\text{MIN}}$ to $T_{\text{MAX}}$ Operating Range Storage Range Thermal Resistance, $\theta_{\text{JA}}$ SO-14 SO-16		-5 -40 -55		75 85 125	$^\circ\text{C}$ $^\circ\text{C}$ $^\circ\text{C}$ $^\circ\text{C}/\text{W}$ $^\circ\text{C}/\text{W}$
				110 80		

NOTES: (1) Log Conformity Error is the peak deviation from the best-fit-straight line of  $V_O$  vs  $\text{LOG}(I_1/I_2)$  curve expressed as a percent of peak-to-peak full-scale output. K, scale factor, equals 0.5V output per decade of input current. (2) Scale factor of core log function is trimmed to 0.5V output per decade change of input current. (3) Worst-case Total Error for any ratio of  $I_1/I_2$ , as the largest of the two errors, when  $I_1$  and  $I_2$  are considered separately. (4) Total Error includes offset voltage, bias current, gain, and log conformity. (5) Bandwidth (3dB) and transient response are a function of both the compensation capacitor and the level of input current.

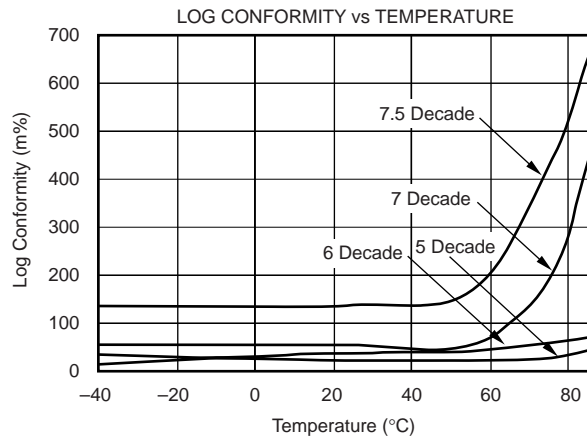
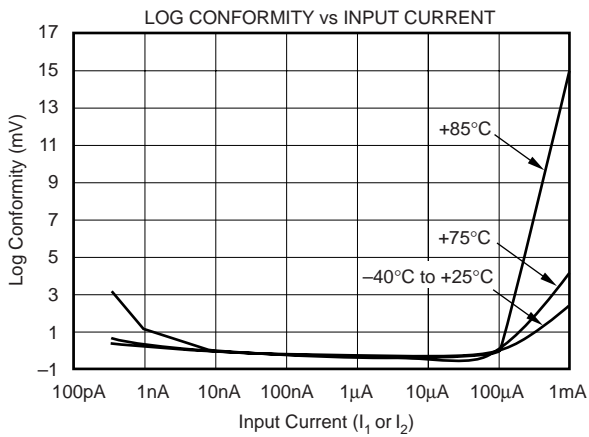
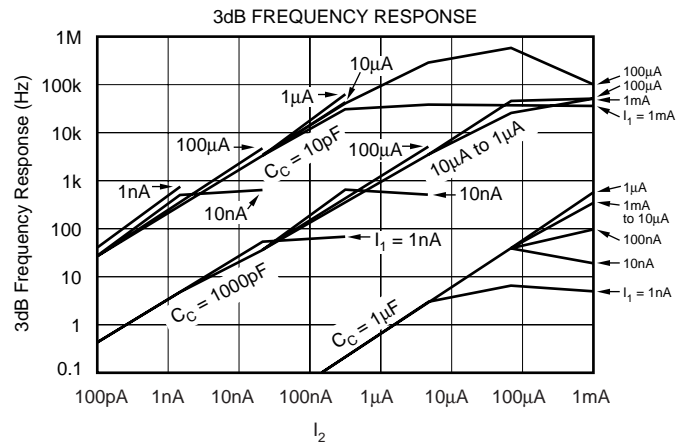
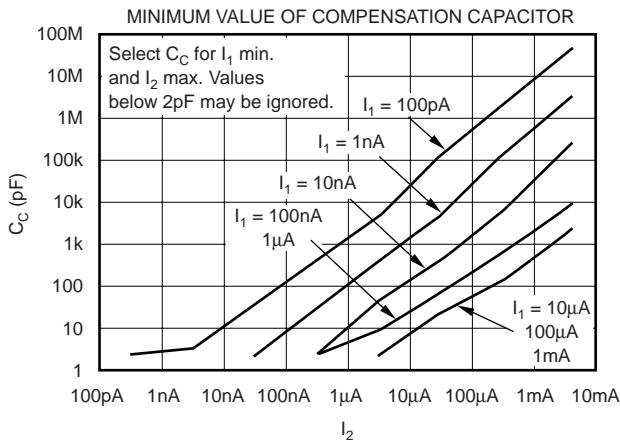
# TYPICAL CHARACTERISTICS

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



# TYPICAL CHARACTERISTICS (Cont.)

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



# APPLICATION INFORMATION

The LOG112 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 and Figure 2 show the basic connections required for operation of the LOG112 and LOG2112. 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 and Figure 2. Connecting the capacitors as close to the LOG112 and LOG2112 as possible will contribute to noise reduction as well.

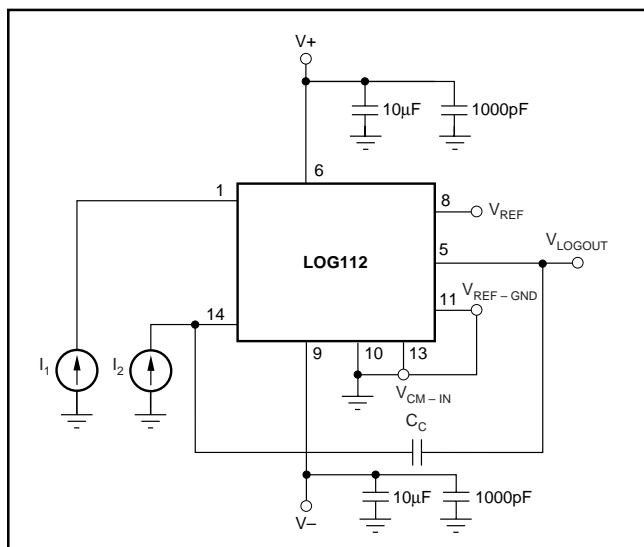


FIGURE 1. Basic Connections of the LOG112.

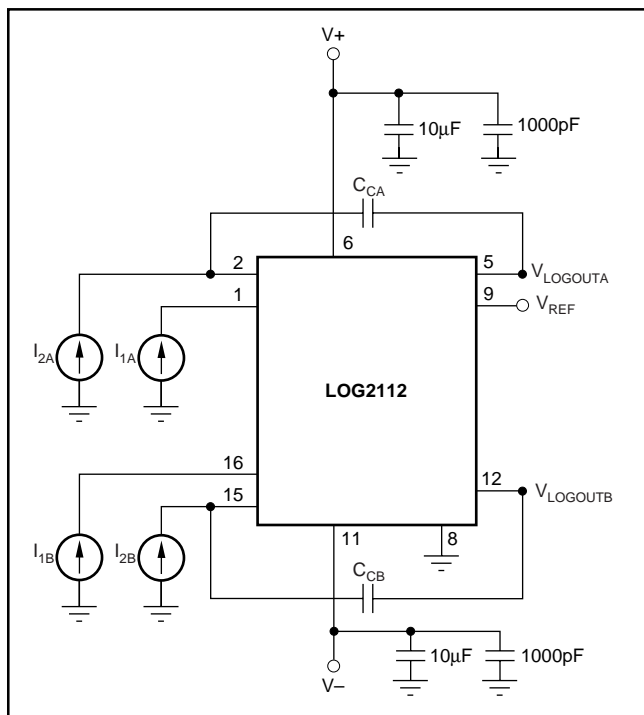


FIGURE 2. Basic Connections of the LOG2112.

## INPUT CURRENT RANGE

To maintain specified accuracy, the input current range of the LOG112 and LOG2112 should be limited from 100pA to 3.5mA. Input currents outside of this range may compromise the LOG112 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 input transistor.

On ±5V supplies, the total input current ( $I_1 + I_2$ ) is limited to 4.5mA. Due to compliance issues internal to the LOG112 and LOG2112, to accommodate larger total input currents, supplies should be increased.

## SETTING THE REFERENCE CURRENT

When the LOG112 and LOG2112 are used to compute logarithms, either  $I_1$  or  $I_2$  can be held constant to become the reference current to which the other is compared.

$V_{LOGOUT}$  is expressed as:

$$V_{LOGOUT} = (0.5V) \text{LOG} (I_1/I_{REF}) \quad (1)$$

$I_{REF}$  can be derived from an external current source (such as that 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:

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

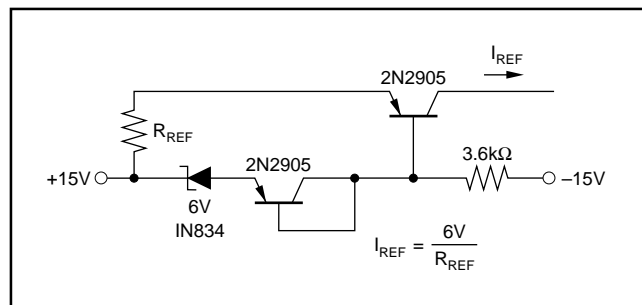


FIGURE 3. Temperature Compensated Current Source.

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.

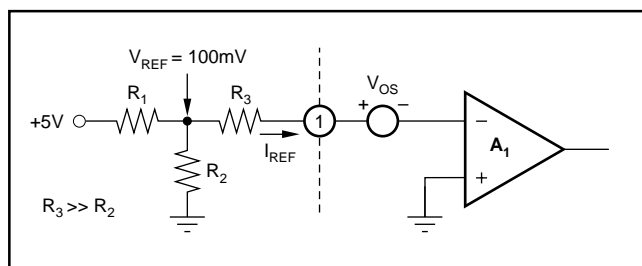


FIGURE 4. T Network for Reference Current.

Figure 5 shows a low-level current source using a series resistor. The low offset op amp reduces the effect of the LOG112 and LOG2112's input offset voltage.

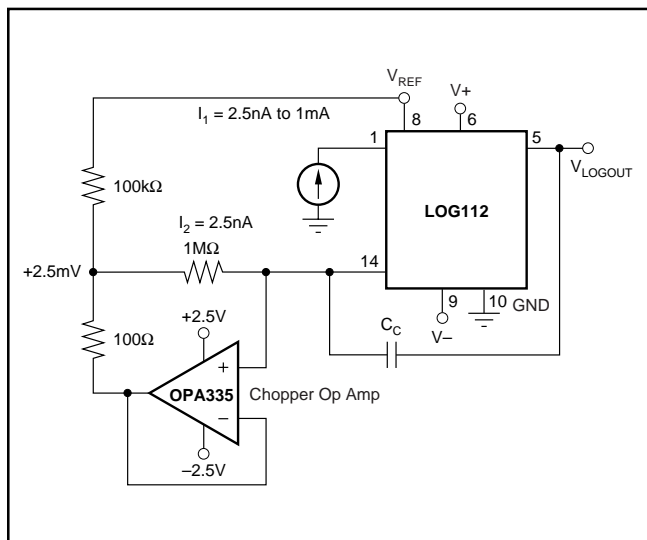


FIGURE 5. Current Source with Offset Compensation.

## FREQUENCY RESPONSE

The frequency response curves seen in the Typical Characteristic curves are shown for constant DC  $I_1$  and  $I_2$  with a small-signal AC current on one input.

The 3dB frequency response of the LOG112 and LOG2112 are 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 LOG112 and LOG2112 are 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 LOG112 and LOG2112.

## FREQUENCY COMPENSATION

Frequency compensation for the LOG112 is obtained by connecting a capacitor between pins 5 and 14. Frequency compensation for the LOG2112 is obtained by connecting a capacitor between pins 2 and 5, or 15 and 12. 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  $C_C$  make the LOG112 and LOG2112 more stable, but 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 LOG112 and LOG2112 function only with positive input currents (conventional current flows into input current pins). In situations where negative input currents are needed, the circuits in Figures 6, 7, and 8 may be used.

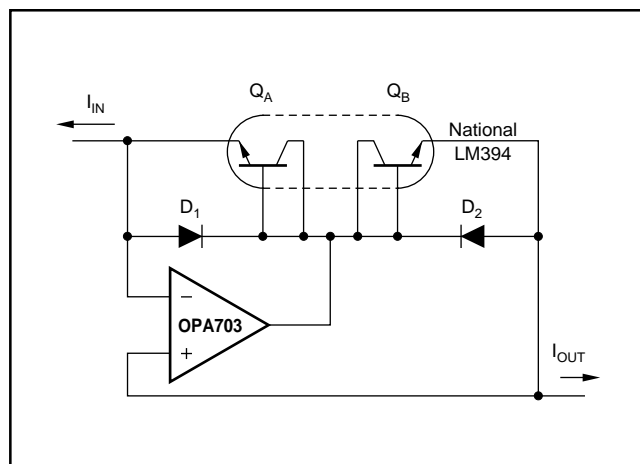
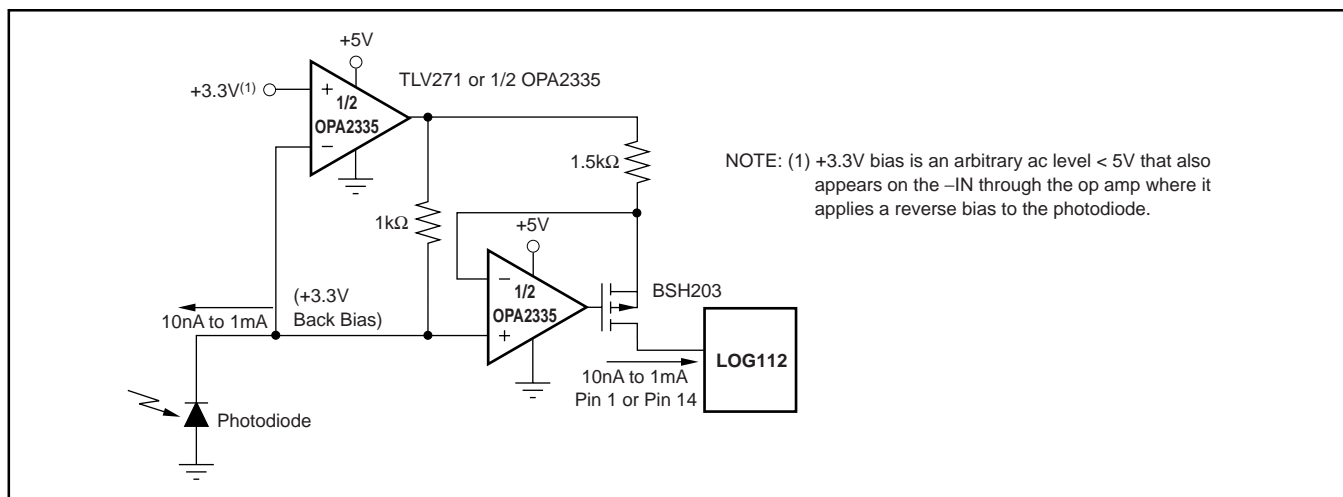


FIGURE 6. Current Inverter/Current Source.



NOTE: (1) +3.3V bias is an arbitrary ac level < 5V that also appears on the -IN through the op amp where it applies a reverse bias to the photodiode.

FIGURE 7. Precision Current Inverter/Current Source.



## VOLTAGE INPUTS

The LOG112 and LOG2112 give the best performances 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.

## ACHIEVING HIGHER ACCURACY WITH HIGHER INPUT CURRENTS

As input current to the LOG112 increases, output accuracy degrades. For a 4.5mA input current on  $\pm 5V$  supplies and a 10mA input current on  $\pm 12V$  supplies, total output error can be between 15% and 25%. Applying a common-mode volt-

age to  $V_{CM}$  of at least +1V and up to 2.5V, brings the log transistors out of saturation and reduces output error to approximately 10%. To avoid forward biasing a photodiode, return the cathode to the  $V_{CM}$  pin, as shown in Figure 9. To reverse bias the photodiode, apply a more positive voltage to the cathode than the anode.

## APPLICATION CIRCUITS

### LOG RATIO

One of the more common uses of log ratio amplifiers is to measure absorbance. See Figure 10 for a typical application.

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

$$\text{If } D_1 \text{ and } D_2 \text{ are matched } A \propto (0.5V) \log I_1 / I_2 \quad (4)$$

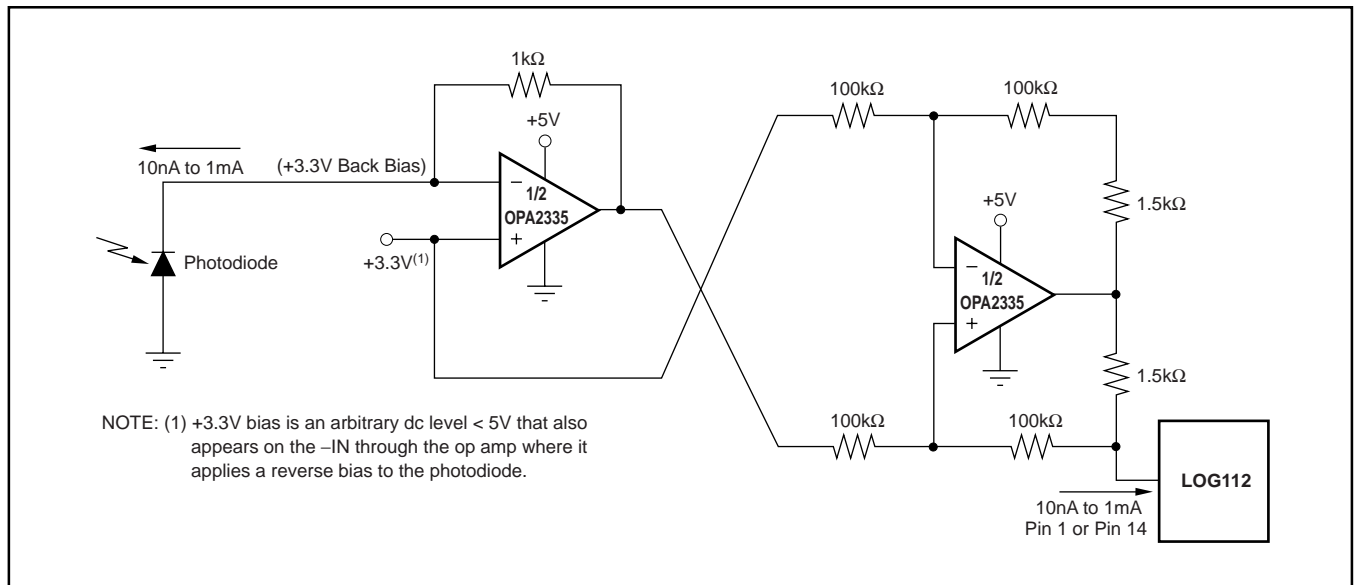


FIGURE 8. Precision Current Inverter/Current Source.

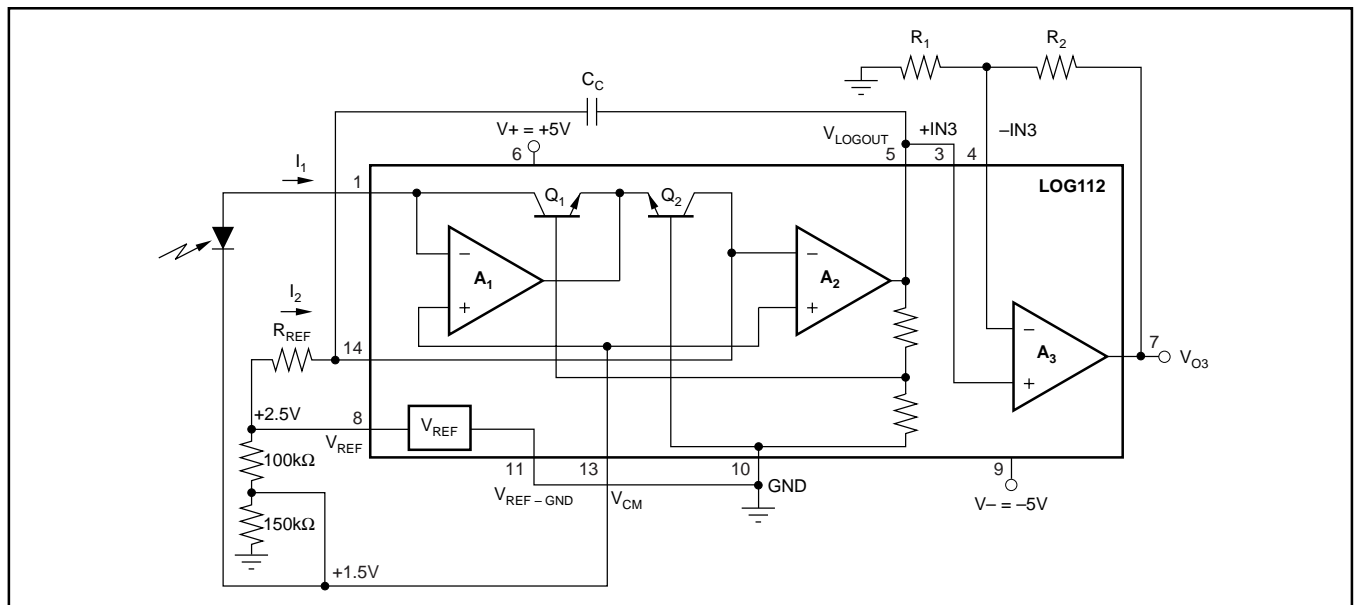


FIGURE 9. Extending Input Current Level and Improving Accuracy by Applying a Common-Mode Voltage.

## DATA COMPRESSION

In many applications, the compressive effects of the logarithmic transfer function are useful. For example, a LOG112 preceding a 12-bit A/D converter can produce the dynamic range equivalent to a 20-bit converter.

## OPERATION ON SINGLE SUPPLY

Many applications do not have the dual supplies required to operate the LOG112 and LOG2112. Figure 11 shows the LOG112 and LOG2112 configured for operation with a single +5V supply.

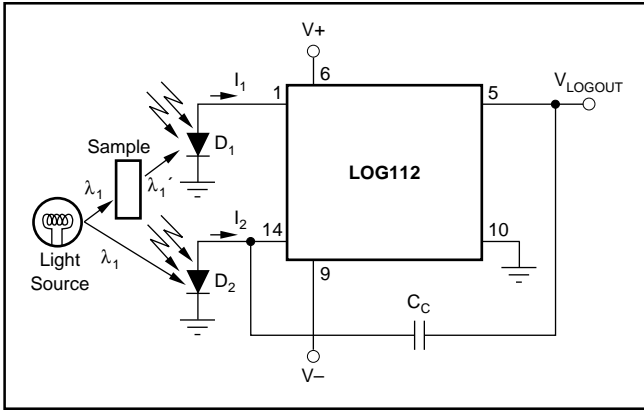


FIGURE 10. Absorbance Measurement.

## MEASURING AVALANCHE PHOTODIODE CURRENT

The wide dynamic range of the LOG112 and LOG2112 is useful for measuring avalanche photodiode current (APD), as shown in Figure 12.

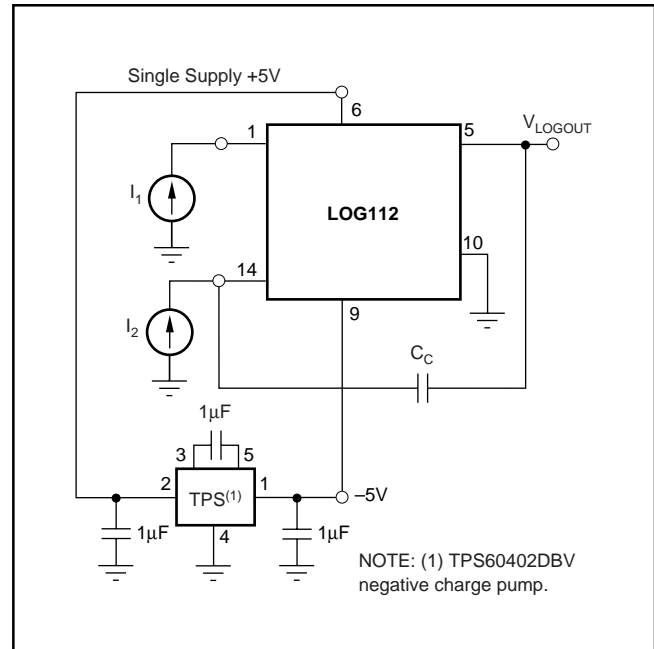


FIGURE 11. Single +5V Power-Supply Operation.

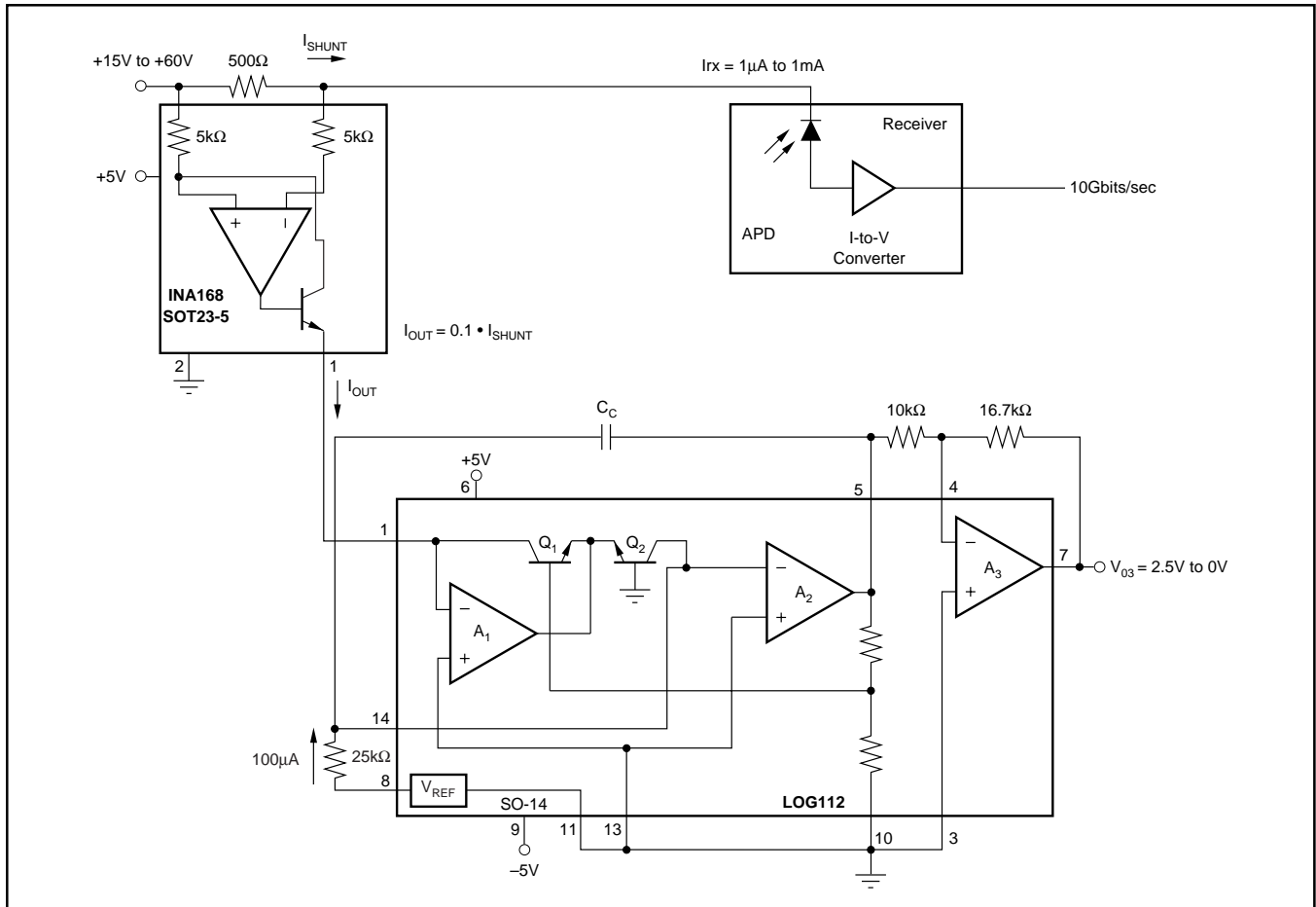


FIGURE 12. High-Side Shunt for APD Measures 3 Decades of APD Current.

# INSIDE THE LOG112

Using the base-emitter voltage relationship of matched bipolar transistors, the LOG112 establishes a logarithmic function of input current ratios. Beginning with the base-emitter voltage defined as:

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

$k$  = Boltzmann'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 12:

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

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

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

$$V_{OUT} = \frac{R_1 + R_2}{R_1} n V_T \log \frac{I_1}{I_2} \quad (10)$$

or

$$V_{OUT} = (0.5V) \text{LOG} \left( \frac{I_1}{I_2} \right) \quad (11)$$

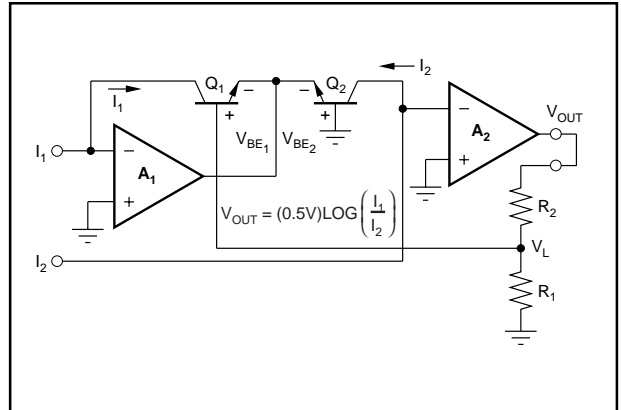


FIGURE 13. Simplified Model of a Log Amplifier.

NOTE:  $R_1$  is a metal resistor used to compensate for gain over temperature.

## DEFINITION OF TERMS

### TRANSFER FUNCTION

The ideal transfer function is:

$$V_{\text{LOGOUT}} = (0.5V) \text{LOG} (I_1/I_2)$$

Figure 14 shows the graphical representation of the transfer function over valid operating range for the LOG112 and LOG2112.

### 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  $V_{\text{LOGOUT}} = (0.5V) \text{LOG} (I_1/I_2)$ .

Thus,

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

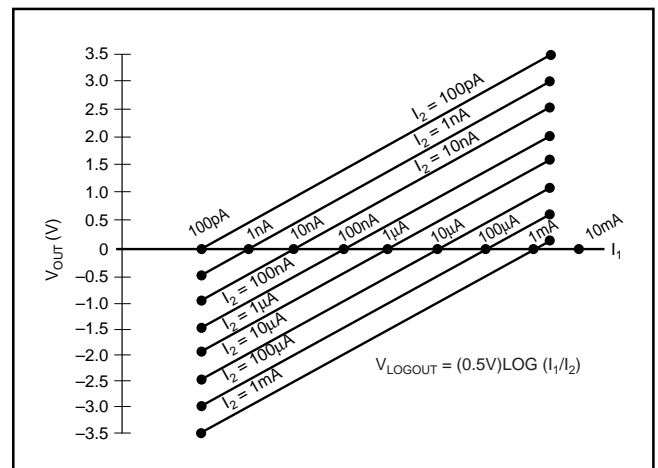


FIGURE 14. Transfer Function with Varying  $I_2$  and  $I_1$ .

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 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 LOG112 and LOG2112, 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 (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  $V_{\text{LOGOUT}}$  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:

$$V_{\text{LOGOUT (NONLIN)}} = 0.5V/\text{dec} \cdot 2NmV \quad (7)$$

where  $N$  is the log conformity error, in percent.

## INDIVIDUAL ERROR COMPONENTS

The ideal transfer function with current input is:

$$V_{\text{LOGOUT}} = (0.5V)\text{LOG}\left(\frac{I_1}{I_2}\right) \quad (8)$$

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

$$V_{\text{LOGOUT}} = (0.5V)(1 \pm \Delta K) \log\left(\frac{I_1 - I_{B1}}{I_2 - I_{B2}}\right) \pm Nm \pm V_{\text{OSO}} \quad (9)$$

The individual component of error is:

$\Delta K$  = gain error (0.10%, 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%, 0.13%, typ)

0.01% for  $m = 5$ , 0.13% for  $m = 7.5$

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

$m$  = number of decades over which  $N$  is specified

For example, what is the error when:

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

(11)

$$V_{\text{LOGOUT}} = (0.5 \pm 0.001) \log\left(\frac{10^{-6} - 5 \cdot 10^{-12}}{10^{-7} - 5 \cdot 10^{-12}}\right) \pm (2)(0.0001)5 \pm 3.0\text{mV}$$

$$= 0.505V$$

Since the ideal output is 0.5V, the error as a percent of the reading is:

$$\% \text{ error} = \frac{0.505V}{0.5} \cdot 100\% = 1.01\% \quad (12)$$

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

(13)

$$V_{\text{LOGOUT}} = (0.5V)(1 \pm \Delta K) \log\left(\frac{\frac{V_1 - I_{B1} \pm \frac{E_{\text{OS1}}}{R_1}}{R_1}}{\frac{V_2 - I_{B2} \pm \frac{E_{\text{OS2}}}{R_2}}{R_2}}\right) \pm Nm \pm V_{\text{OSO}}$$

Where  $\frac{E_{\text{OS1}}}{R_1}$  and  $\frac{E_{\text{OS2}}}{R_2}$  (offset error) 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 finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LOG112AID	ACTIVE	SOIC	D	14	50	RoHS & Green	NIPDAU	Level-3-260C-168 HR	-40 to 85	LOG112A	<a href="#">Samples</a>
LOG112AIDR	ACTIVE	SOIC	D	14	2500	RoHS & Green	NIPDAU	Level-3-260C-168 HR	-40 to 85	LOG112A	<a href="#">Samples</a>
LOG2112AIDW	ACTIVE	SOIC	DW	16	40	RoHS & Green	NIPDAU	Level-3-260C-168 HR	-40 to 85	LOG2112A	<a href="#">Samples</a>
LOG2112AIDWR	ACTIVE	SOIC	DW	16	1000	RoHS & Green	NIPDAU	Level-3-260C-168 HR	-40 to 85	LOG2112A	<a href="#">Samples</a>

(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.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".

**RoHS Exempt:** TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.

**Green:** TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "-" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead finish/Ball material - Orderable Devices 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.

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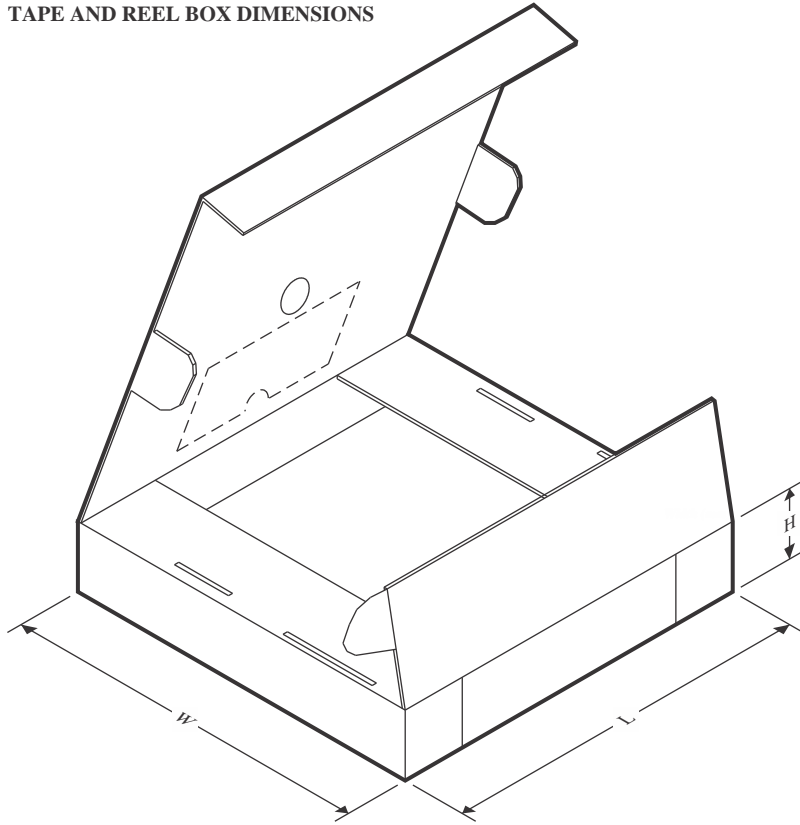
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**TAPE AND REEL INFORMATION**

**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**


\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LOG112AIDR	SOIC	D	14	2500	330.0	16.4	6.5	9.0	2.1	8.0	16.0	Q1
LOG2112AIDWR	SOIC	DW	16	1000	330.0	16.4	10.75	10.7	2.7	12.0	16.0	Q1

**TAPE AND REEL BOX DIMENSIONS**


\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LOG112AIDR	SOIC	D	14	2500	356.0	356.0	35.0
LOG2112AIDWR	SOIC	DW	16	1000	356.0	356.0	35.0



**TUBE**


\*All dimensions are nominal

Device	Package Name	Package Type	Pins	SPQ	L (mm)	W (mm)	T (μm)	B (mm)
LOG112AID	D	SOIC	14	50	506.6	8	3940	4.32
LOG2112AIDW	DW	SOIC	16	40	507	12.83	5080	6.6



# D0014A

# PACKAGE OUTLINE

## SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



4220718/A 09/2016

### NOTES:

1. All linear dimensions are in millimeters. Dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm, per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.43 mm, per side.
5. Reference JEDEC registration MS-012, variation AB.

# EXAMPLE BOARD LAYOUT

D0014A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



LAND PATTERN EXAMPLE  
SCALE:8X



SOLDER MASK DETAILS

4220718/A 09/2016

NOTES: (continued)

- 6. Publication IPC-7351 may have alternate designs.
- 7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

# EXAMPLE STENCIL DESIGN

D0014A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



SOLDER PASTE EXAMPLE  
BASED ON 0.125 mm THICK STENCIL  
SCALE:8X

4220718/A 09/2016

NOTES: (continued)

8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

## GENERIC PACKAGE VIEW

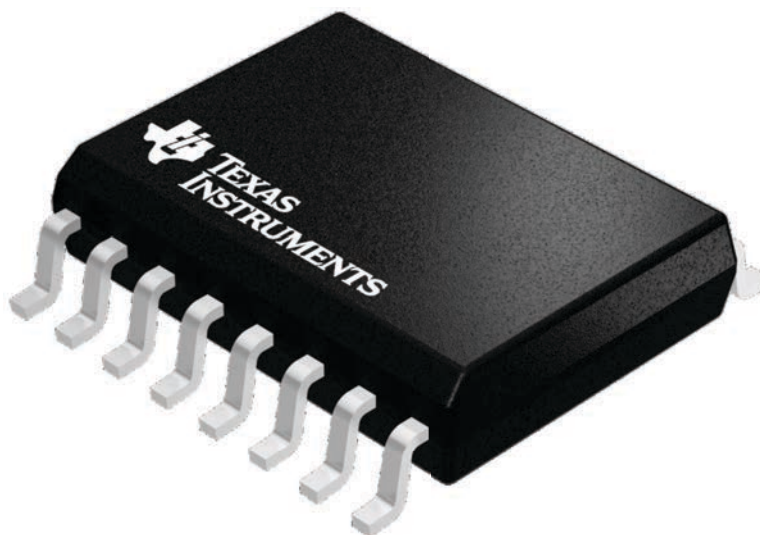
**DW 16**

**SOIC - 2.65 mm max height**

7.5 x 10.3, 1.27 mm pitch

SMALL OUTLINE INTEGRATED CIRCUIT

This image is a representation of the package family, actual package may vary.  
Refer to the product data sheet for package details.



4224780/A



# DW0016A

# PACKAGE OUTLINE SOIC - 2.65 mm max height

SOIC



4220721/A 07/2016

## NOTES:

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5. Reference JEDEC registration MS-013.

# EXAMPLE BOARD LAYOUT

DW0016A

SOIC - 2.65 mm max height

SOIC



LAND PATTERN EXAMPLE  
SCALE:7X



SOLDER MASK DETAILS

4220721/A 07/2016

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.

7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

# EXAMPLE STENCIL DESIGN

DW0016A

SOIC - 2.65 mm max height

SOIC



SOLDER PASTE EXAMPLE  
BASED ON 0.125 mm THICK STENCIL  
SCALE:7X

4220721/A 07/2016

NOTES: (continued)

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9. Board assembly site may have different recommendations for stencil design.



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