



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: $\pm 4.5\text{V}$ to $\pm 18\text{V}$**
- **PACKAGES: SO-14 (narrow) and SO-16**

DESCRIPTION

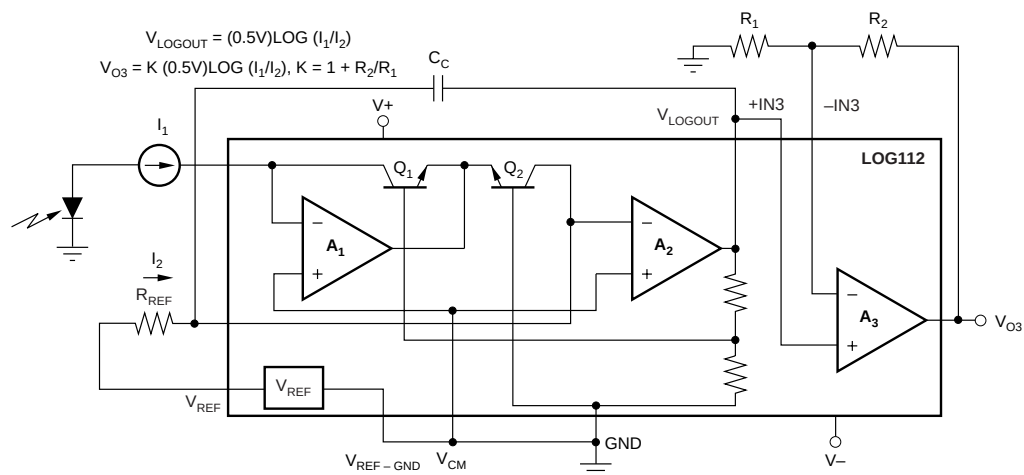
The LOG112 and LOG2112 are versatile integrated circuits that compute the logarithm or log ratio of an input current relative to a reference current. V_{LOGOUT} of the LOG112 and LOG2112 are trimmed to 0.5V per decade of input current, ensuring high precision over a wide dynamic range of input signals.

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°C to $+75^{\circ}\text{C}$.

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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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.

ABSOLUTE MAXIMUM RATINGS⁽¹⁾

Supply Voltage, V_+ to V_-	$\pm 18V$
Inputs	$\pm 18V$
Input Current	$\pm 10mA$
Output Short-Circuit Current ⁽²⁾	Continuous
Operating Temperature	$-40^{\circ}C$ to $+85^{\circ}C$
Storage Temperature	$-55^{\circ}C$ to $+125^{\circ}C$
Junction Temperature	$+150^{\circ}C$
Lead Temperature (soldering, 10s)	$+300^{\circ}C$

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.

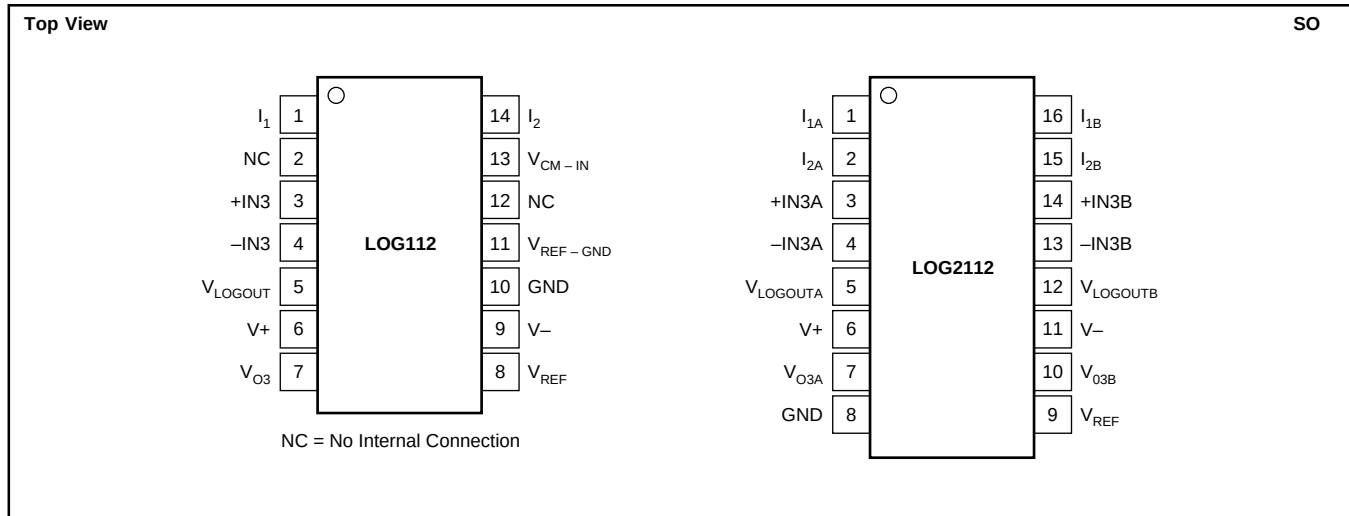
ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

PACKAGE/ORDERING INFORMATION⁽¹⁾

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.

PIN CONFIGURATION



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

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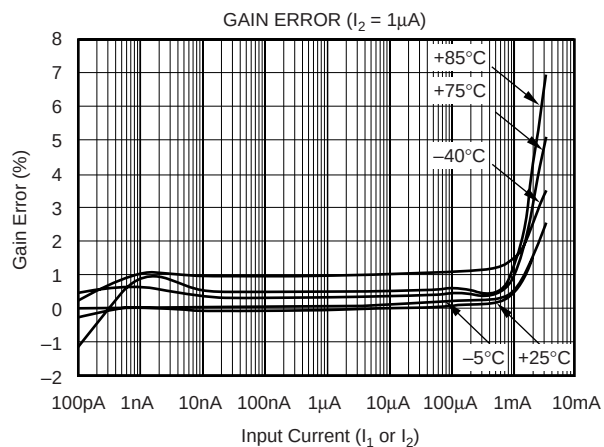
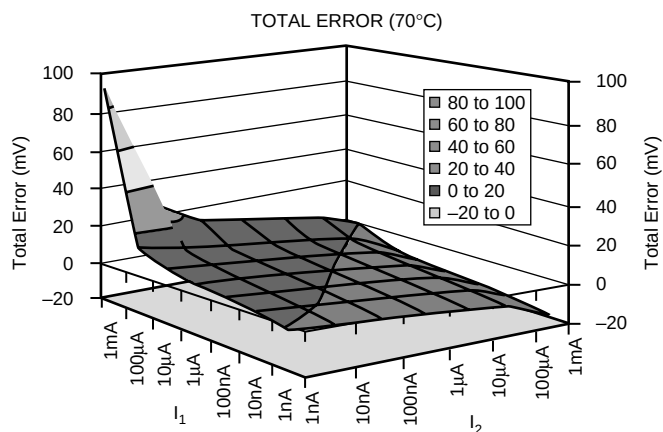
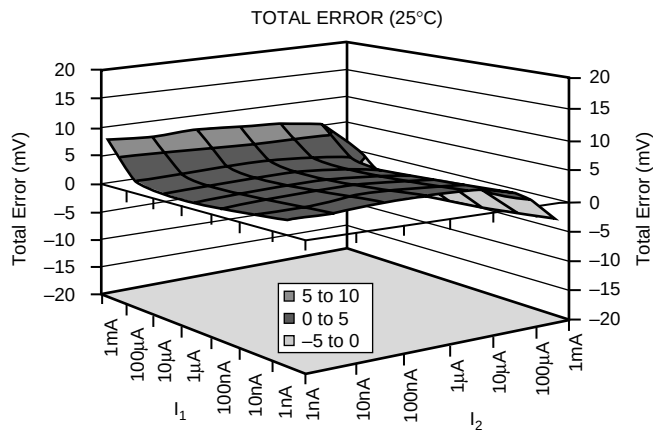
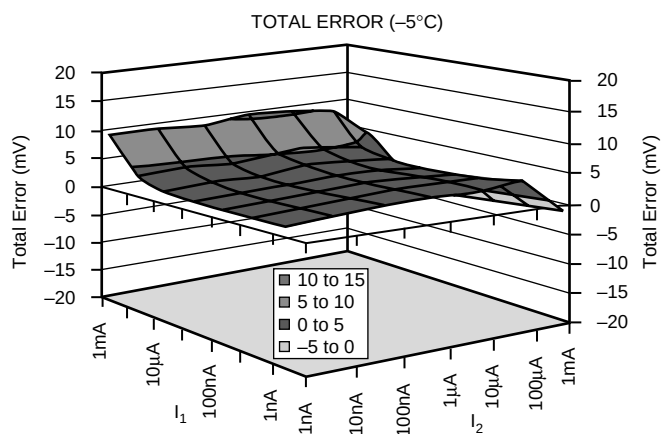
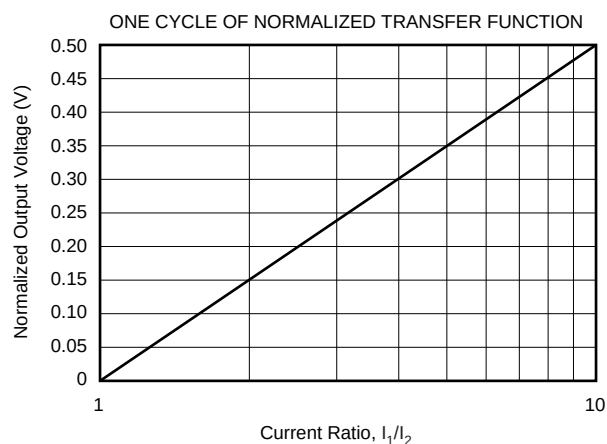
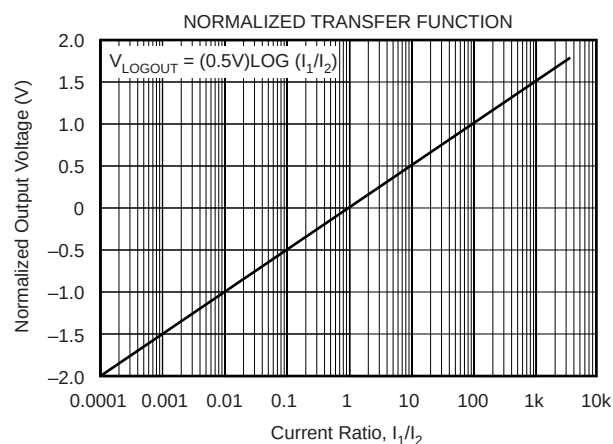
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At $T_A = +25^\circ\text{C}$, $V_S = \pm 5\text{V}$, and $R_I = 10\text{k}\Omega$, unless otherwise noted.

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.

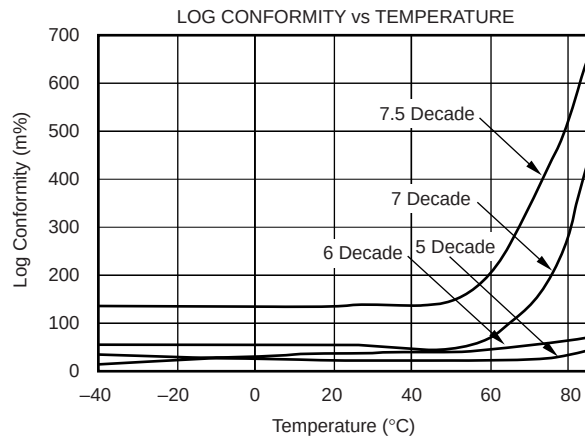
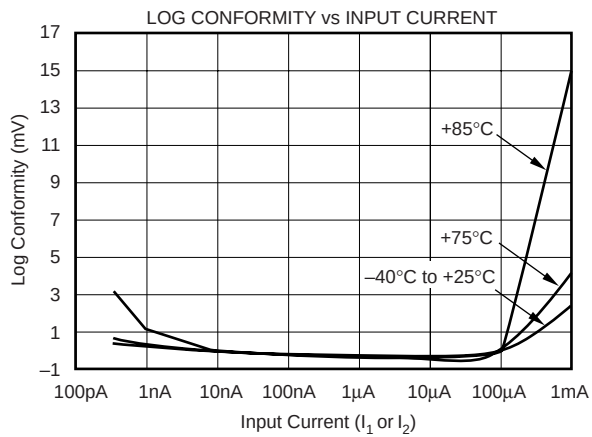
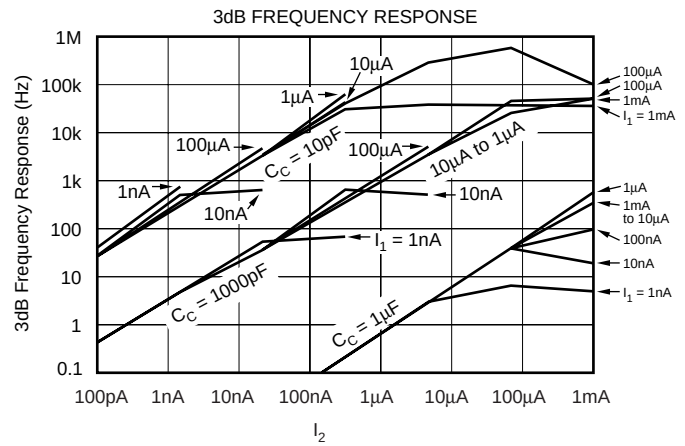
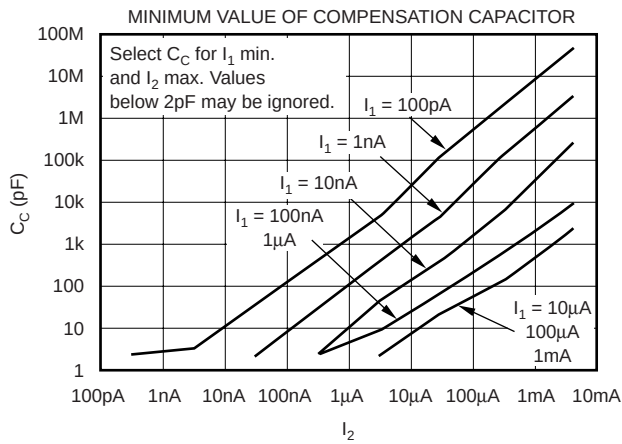
TYPICAL CHARACTERISTICS

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.

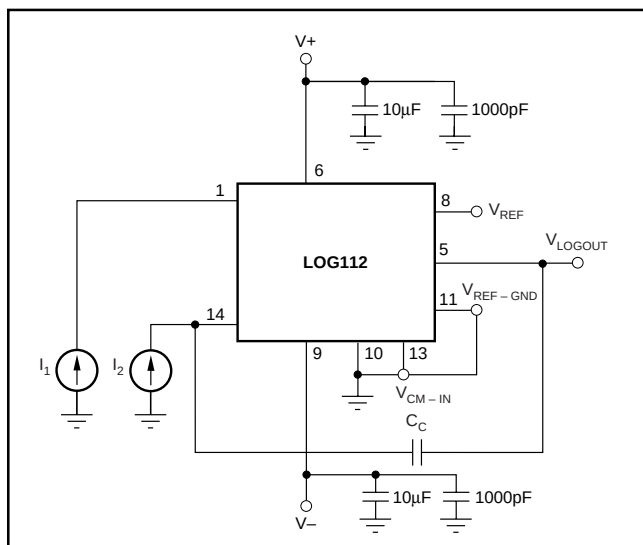


FIGURE 1. Basic Connections of the LOG112.

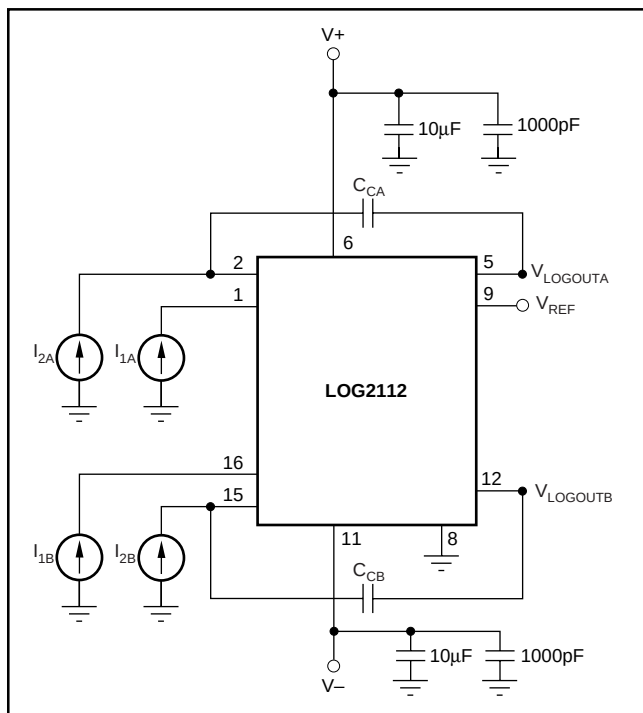


FIGURE 2. Basic Connections of the LOG2112.

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:

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

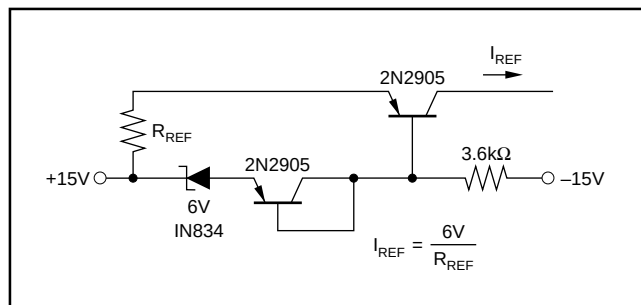


FIGURE 3. Temperature Compensated Current Source.

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.

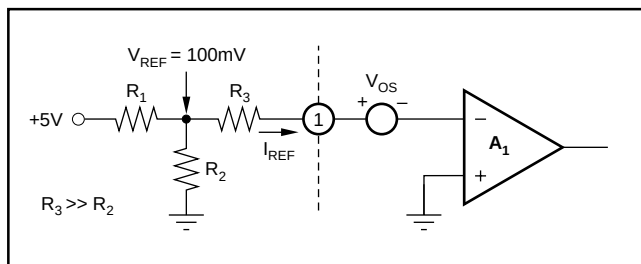


FIGURE 4. T Network for Reference Current.

The diagram shows a precision current source circuit. A 100kΩ resistor is connected between V_{REF} (pin 8) and a node labeled $I_1 = 2.5\text{nA to } 1\text{mA}$. A 100Ω resistor is connected between this node and the non-inverting input (+) of the OPA335. The OPA335 is configured as a voltage follower, with its output connected to its inverting input (-). The OPA335 is powered by +2.5V and -2.5V supplies. A 1MΩ resistor is connected between the output of the OPA335 and the input of the LOG112 (pin 14). The LOG112 is powered by V_{REF} (pin 8), V_+ (pin 6), and V_- (pin 9). A capacitor C_C is connected between the input (pin 14) and output (pin 5) of the LOG112. The output of the LOG112 (pin 5) is labeled V_{LOGOUT} . The LOG112 also has a pin 10 connected to GND.

FREQUENCY RESPONSE

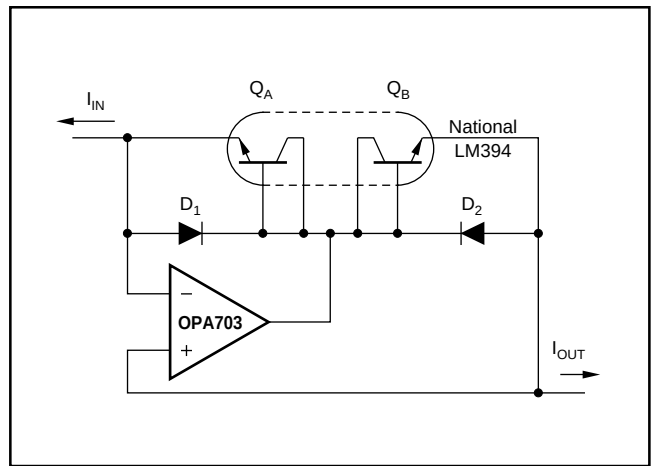
The 3dB frequency response of the LOG112 and LOG2112 are a function of the magnitude of the input current levels and of the value of the frequency compensation capacitor. See Typical Characteristic curve, *3dB Frequency Response* for details.

FREQUENCY COMPENSATION

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.



The diagram shows a two-stage circuit. The first stage is a transimpedance amplifier using an OPA2335 op-amp. Its non-inverting input (+) is connected to a +3.3V bias source. Its inverting input (-) is connected to a photodiode (represented by a triangle pointing to ground) and a feedback resistor of 1kΩ. The output of the first op-amp is connected to the gate of a BSH203 MOSFET through a 1.5kΩ resistor. The MOSFET's source is connected to ground, and its drain is connected to a second OPA2335 op-amp. This second op-amp is configured as a voltage follower, with its non-inverting input (+) connected to the MOSFET drain and its output (-) connected to the MOSFET gate. The output of the second op-amp is connected to a LOG112 device. A note specifies that the +3.3V bias is an arbitrary AC level < 5V that also appears on the -IN of the first op-amp, applying a reverse bias to the photodiode.

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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.

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

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

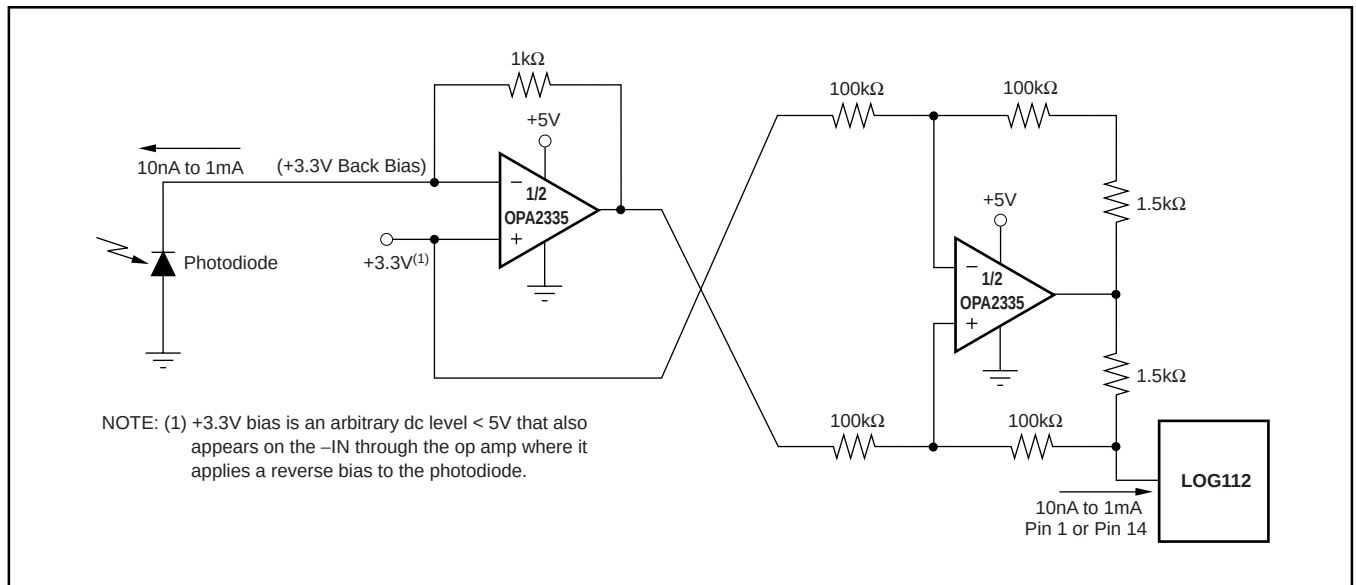


FIGURE 8. Precision Current Inverter/Current Source.

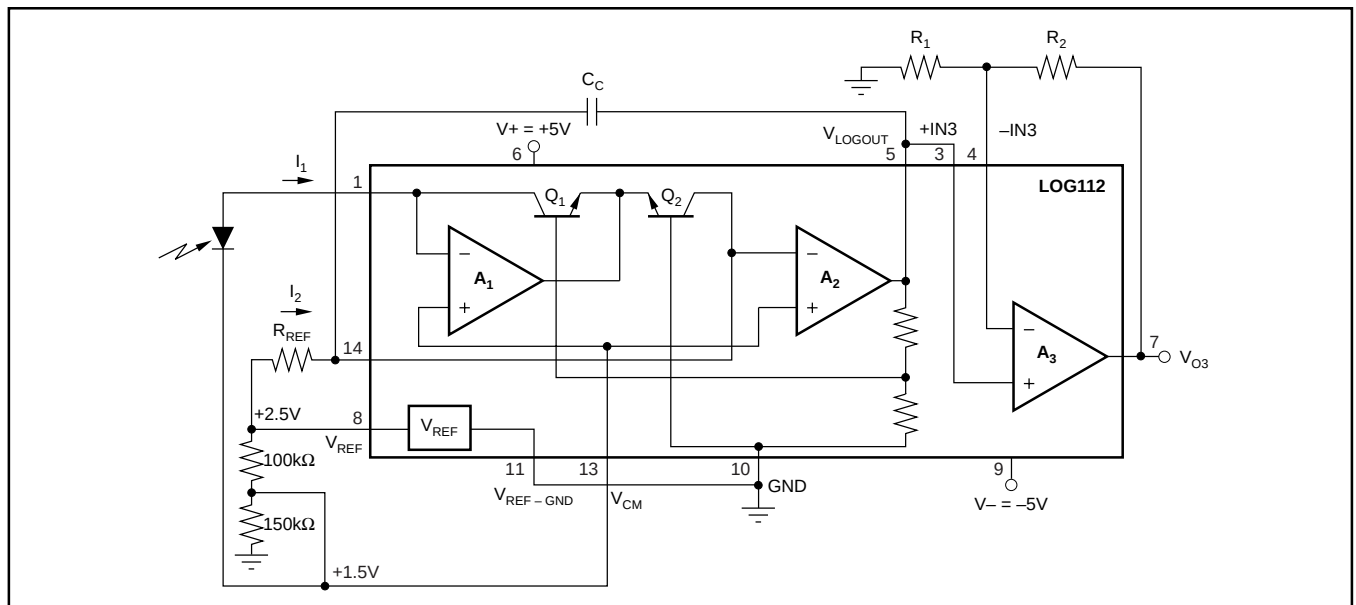


FIGURE 9. Extending Input Current Level and Improving Accuracy by Applying a Common-Mode Voltage.

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.

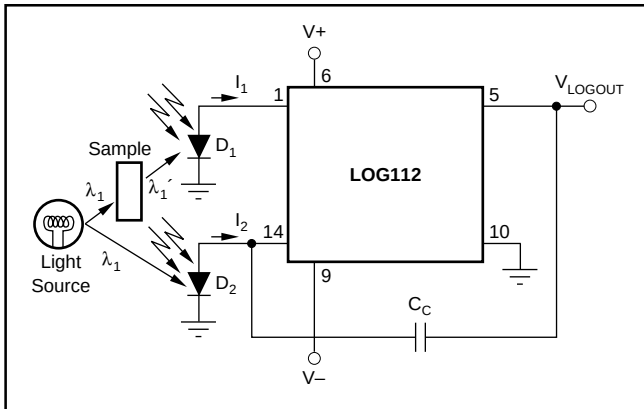


FIGURE 10. Absorbance Measurement.

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.

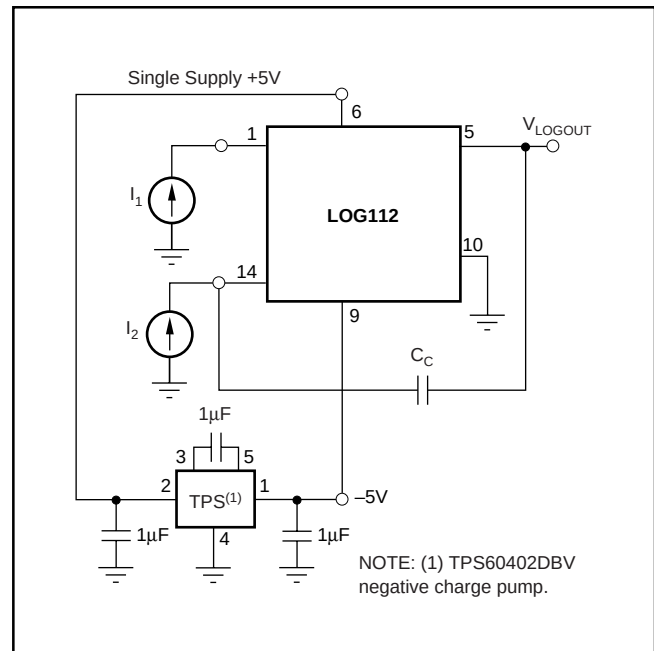


FIGURE 11. Single +5V Power-Supply Operation.

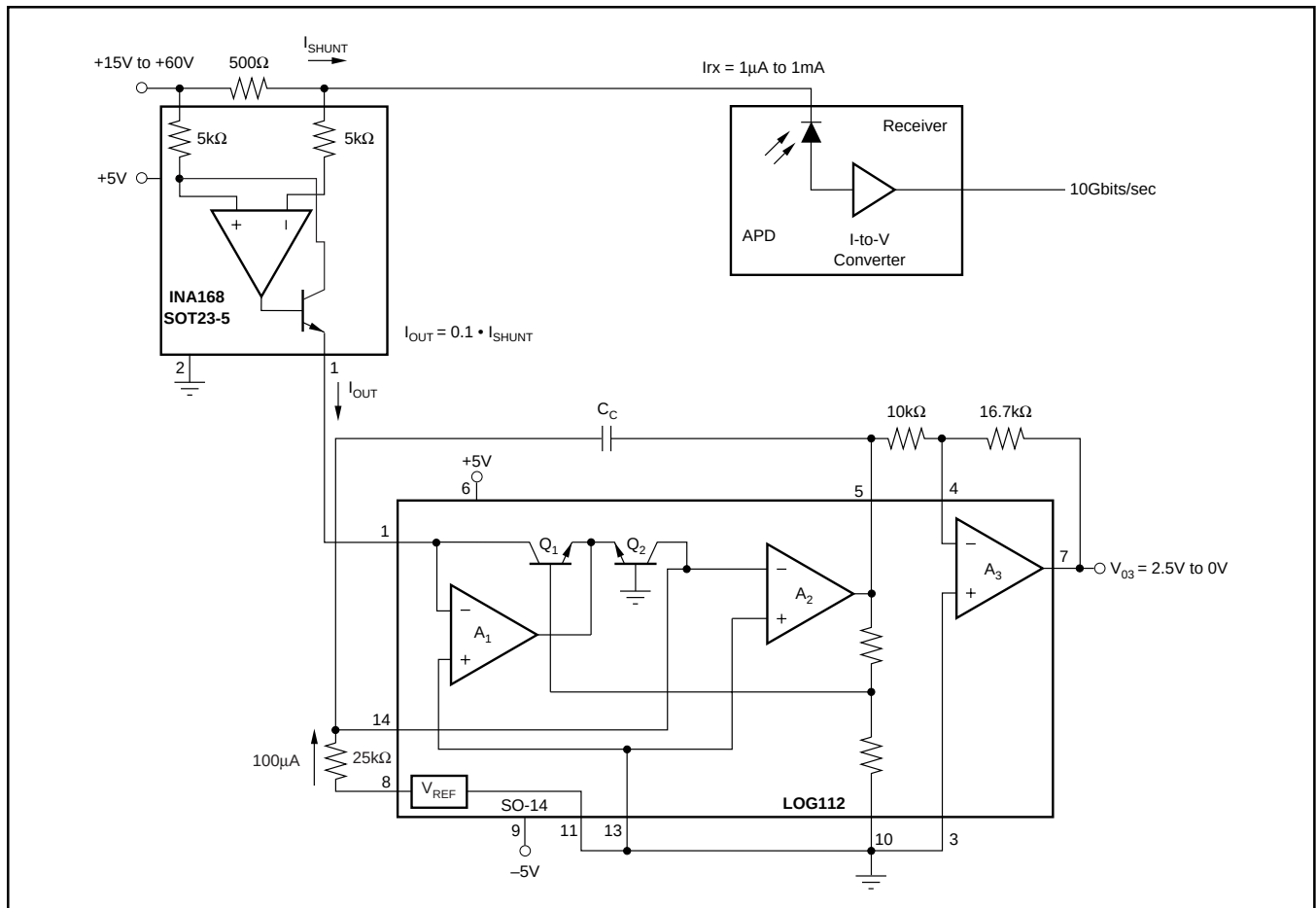


FIGURE 12. High-Side Shunt for APD Measures 3 Decades of APD Current.

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:

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

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

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

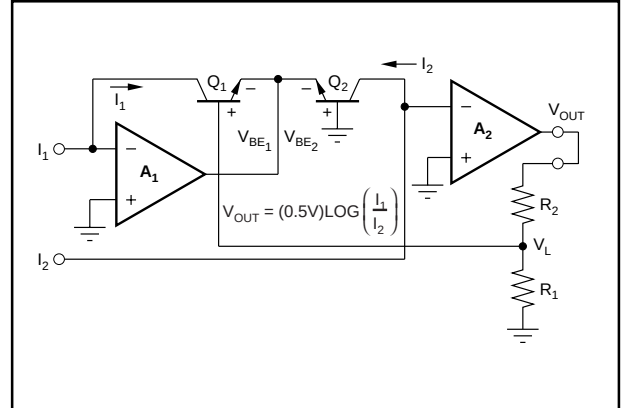


FIGURE 13. Simplified Model of a Log Amplifier.

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 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,

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

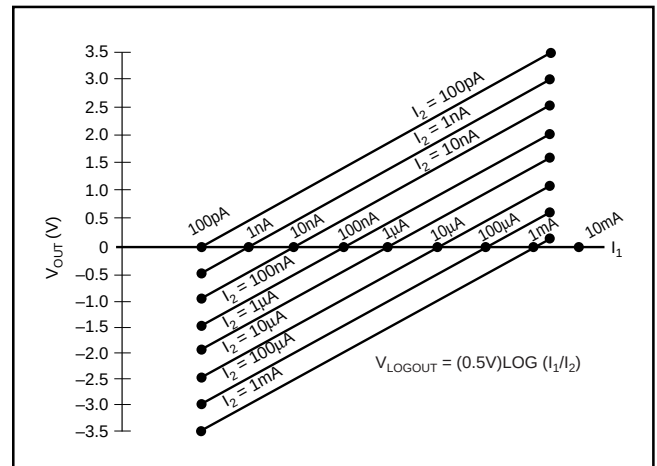


FIGURE 14. Transfer Function with Varying I_2 and I_1 .

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_{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:

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

where N is the log conformity error, in percent.

INDIVIDUAL ERROR COMPONENTS

The ideal transfer function with current input is:

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

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

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

The individual component of error is:

ΔK = 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_{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)

$$V_{\text{LOGOUT}} = (0.5 \pm 0.001) \log \left(\frac{10^{-6} - 5 \cdot 10^{-12}}{10^{-7} - 5 \cdot 10^{-12}} \right) \pm (2)(0.0001)5 \pm 3.0\text{mV} \\ = 0.505\text{V}$$

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

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

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

(13)

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

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/Ball Finish	MSL Peak Temp ⁽³⁾
LOG112AID	ACTIVE	SOIC	D	14	50	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
LOG112AIDE4	ACTIVE	SOIC	D	14	50	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
LOG112AIDR	ACTIVE	SOIC	D	14	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
LOG112AIDRE4	ACTIVE	SOIC	D	14	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
LOG2112AIDW	ACTIVE	SOIC	DW	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
LOG2112AIDWE4	ACTIVE	SOIC	DW	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
LOG2112AIDWR	ACTIVE	SOIC	DW	16	1000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
LOG2112AIDWRE4	ACTIVE	SOIC	DW	16	1000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR

⁽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⁾ Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

TBD: The Pb-Free/Green conversion plan has not been defined.

Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

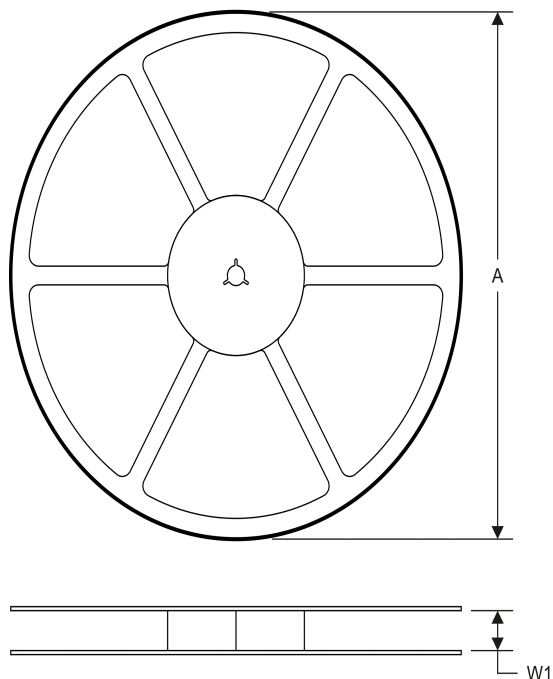
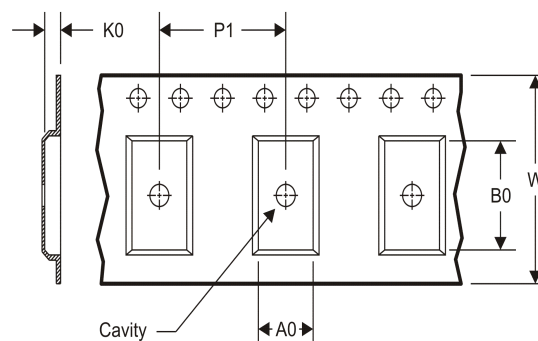
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

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

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TAPE AND REEL INFORMATION
REEL DIMENSIONS

TAPE DIMENSIONS


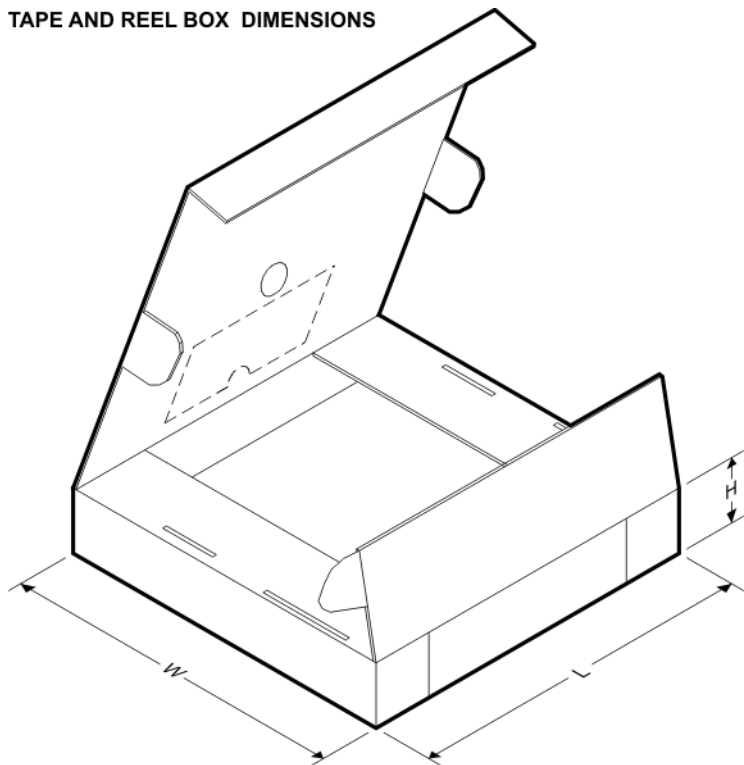
A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

TAPE AND REEL INFORMATION

*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

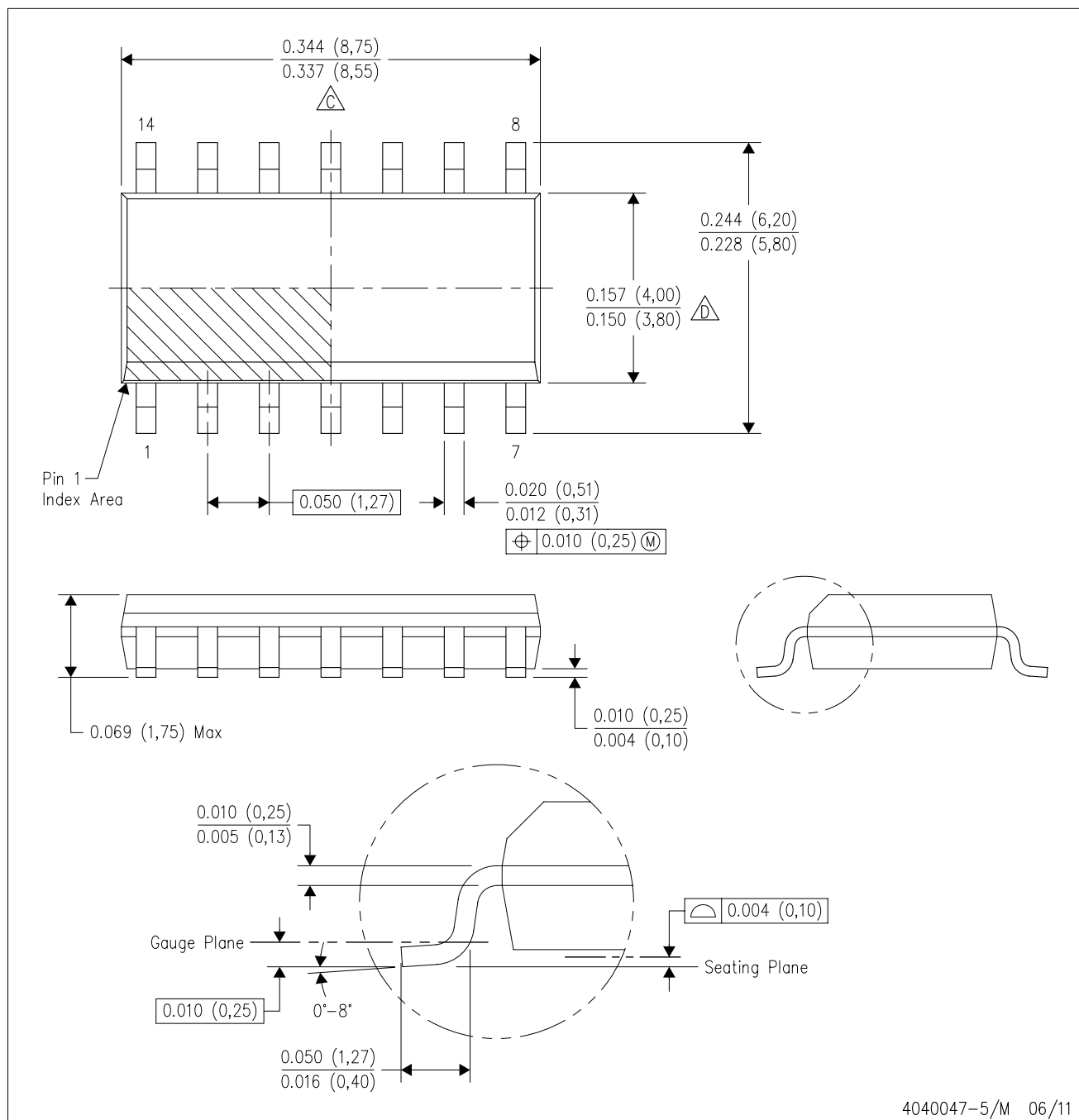


*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LOG112AIDR	SOIC	D	14	2500	367.0	367.0	38.0
LOG2112AIDWR	SOIC	DW	16	1000	367.0	367.0	38.0

D (R-PDSO-G14)

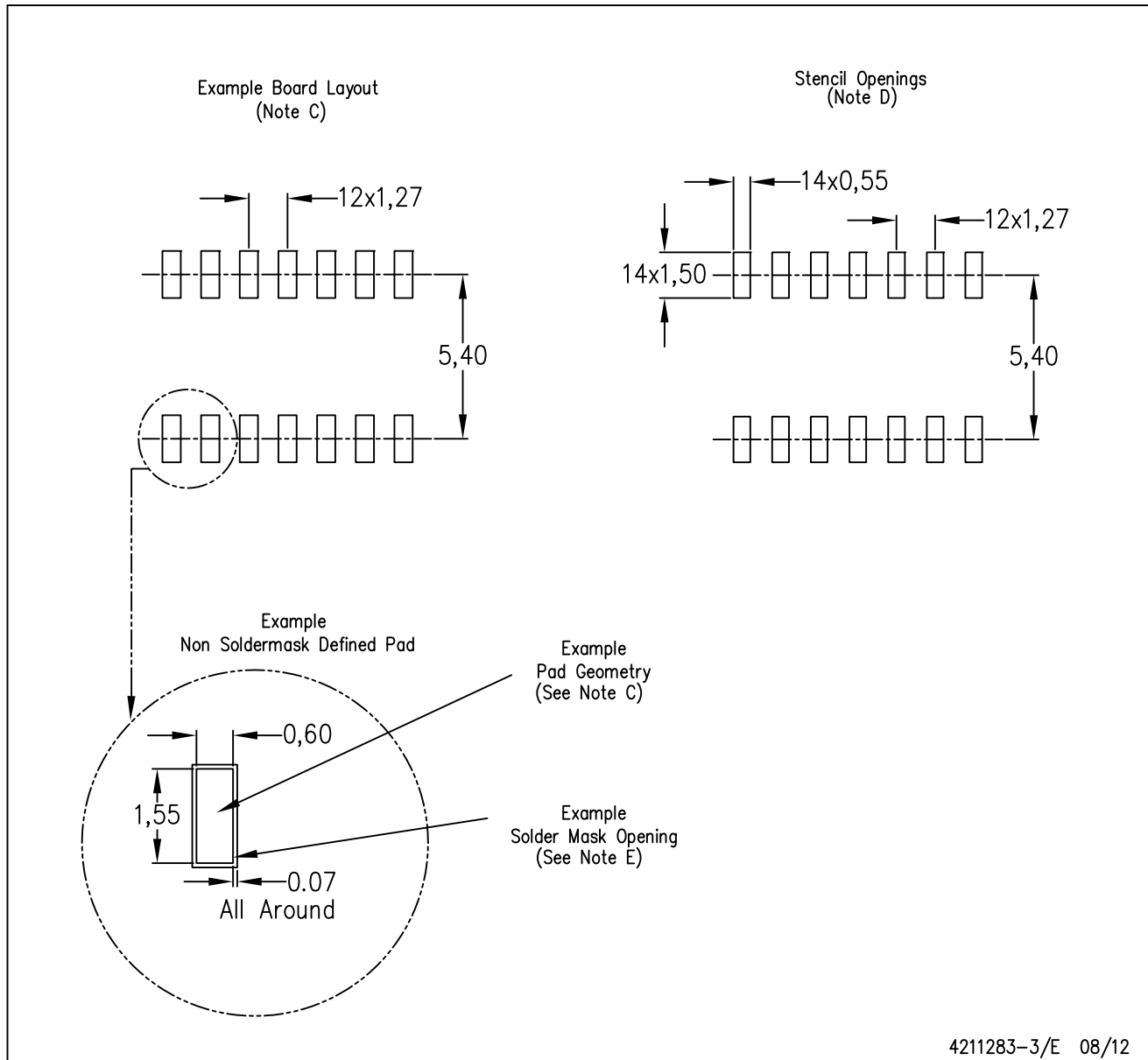
PLASTIC SMALL OUTLINE



4040047-5/M 06/11

D (R-PDSO-G14)

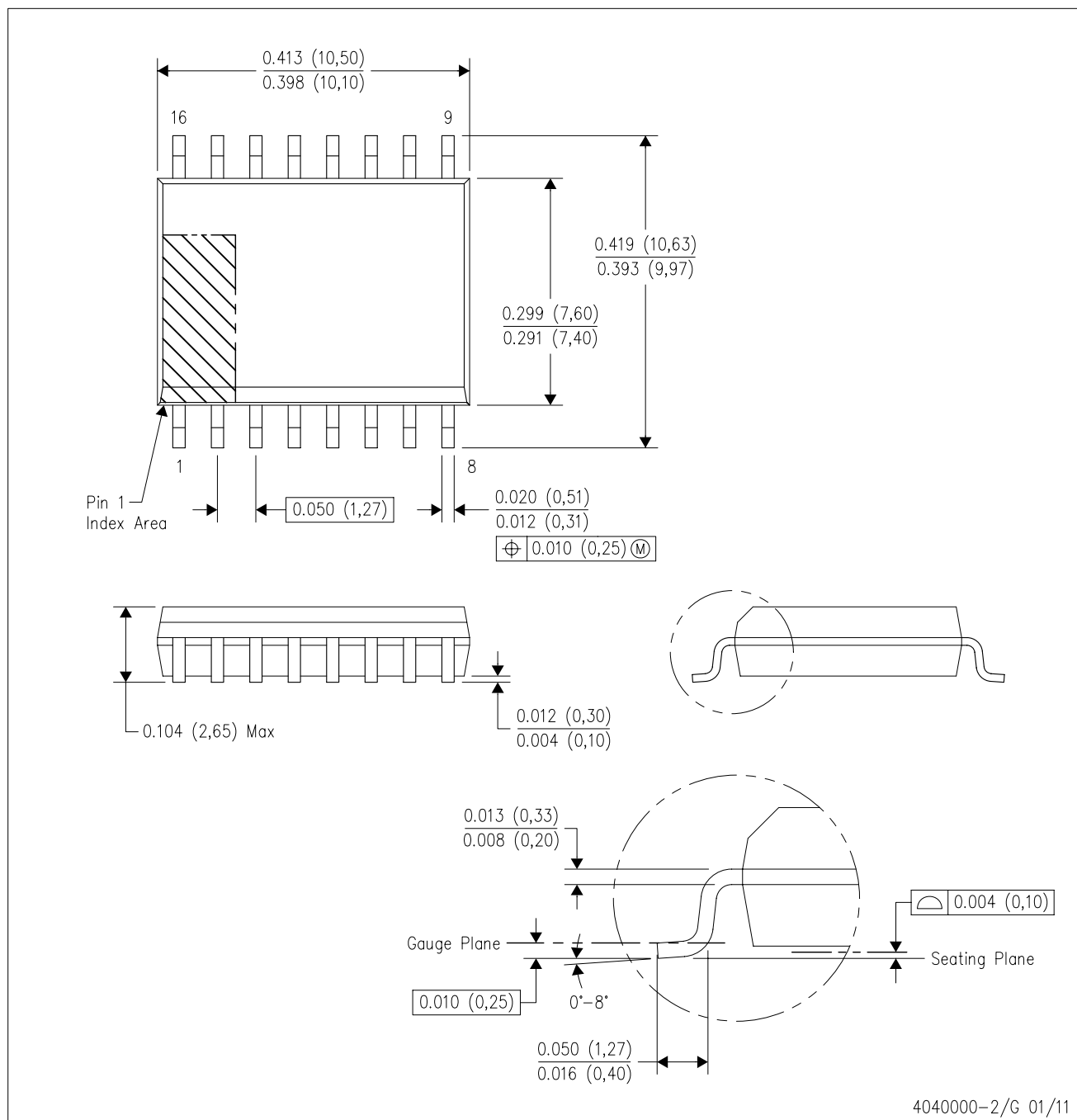
PLASTIC SMALL OUTLINE



- NOTES:
- A. All linear dimensions are in millimeters.
 - B. This drawing is subject to change without notice.
 - C. Publication IPC-7351 is recommended for alternate designs.
 - D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
 - E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

DW (R-PDSO-G16)

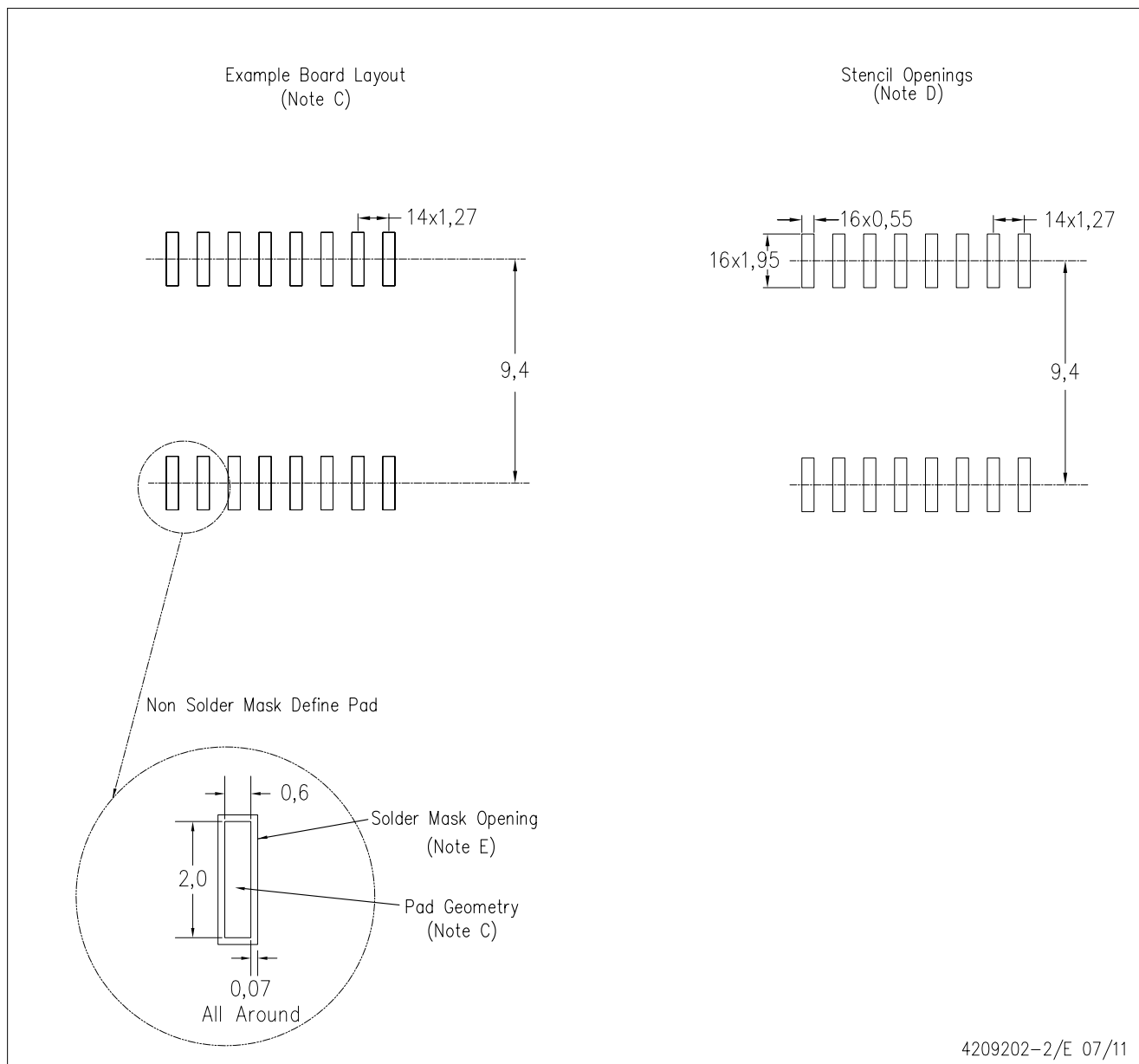
PLASTIC SMALL OUTLINE



- NOTES:
- A. All linear dimensions are in inches (millimeters). Dimensioning and tolerancing per ASME Y14.5M-1994.
 - 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-013 variation AA.

DW (R-PDSO-G16)

PLASTIC SMALL OUTLINE



- NOTES:
- A. All linear dimensions are in millimeters.
 - B. This drawing is subject to change without notice.
 - C. Refer to IPC7351 for alternate board design.
 - D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525
 - E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

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