WIDEBAND, LOW NOISE, LOW DISTORTION FULLY DIFFERENTIAL AMPLIFIER

FEATURES

- **Fully Differential Architecture**
- **Common-Mode Input Range Includes the Negative Rail**
- **Minimum Gain of 2 V/V (6 dB)**
- **Bandwidth: 2 GHz**
- **Slew Rate: 6400 V/µs**
- **0.1% Settling Time: 2 ns**
- **HD_2: –72 dBc at 100 MHz**
- **HD_3: –79 dBc at 100 MHz**
- **OIP_2: 78 dBm at 70 MHz**
- **OIP_3: 42 dBm at 70 MHz**
- **Input Voltage Noise: 2.3 nV/$\sqrt{Hz}$ (f > 10 MHz)**
- **Noise Figure: 19.2 dB (G = 10 dB)**
- **Output Common-Mode Control**
- **5-V Power Supply Current: 39.2 mA**
- **Power-Down Capability: 0.65 mA**

APPLICATIONS

- **5-V Data-Acquisition Systems**
- **High Linearity ADC Amplifier**
- **Wireless Communication**
- **Medical Imaging**
- **Test and Measurement**

DESCRIPTION

The THS4508 is a wideband, fully-differential operational amplifier designed for single-supply 5-V data-acquisition systems. It has very low noise at 2.3 nV/$\sqrt{Hz}$, and extremely low harmonic distortion of –72 dBc HD_2 and –79 dBc HD_3 at 100 MHz with 2 V_{PP}, G = 10 dB, and 1-kΩ load. Slew rate is very high at 6400 Vµs and with settling time of 2 ns to 0.1% (2 V step) it is ideal for pulsed applications. It is designed for minimum gain of 6 dB, but is optimized for gain of 10 dB.

To allow for dc coupling to ADCs, its unique output common-mode control circuit maintains the output common-mode voltage within 5-mV offset (typical) from the set voltage, when set within 0.5 V of mid-supply. The common-mode set point is set to mid-supply by internal circuitry, which may be over-driven from an external source.

The THS4508 is a high-performance amplifier that has been optimized for use in high performance, 5-V single supply data acquisition systems. The output has been optimized for best performance with its common-mode voltages set to mid supply, and the input has been optimized for best performance with its common-mode voltage set to 0.7 V. High performance at a low power-supply voltage makes for high-performance single-supply 5-V data-acquisition systems with a minimum parts count. The combined performance of the THS4508 in a gain of 10-dB driving the ADS5500 ADC, sampling at 125 MSPS, is 82-dBc SFDR, and 68.3-dBc SNR with a –1-dBFS signal at 70 MHz.

The THS4508 is offered in a Quad 16-pin leadless QFN package (RGT), and is characterized for operation over the full industrial temperature range from –40°C to 85°C.

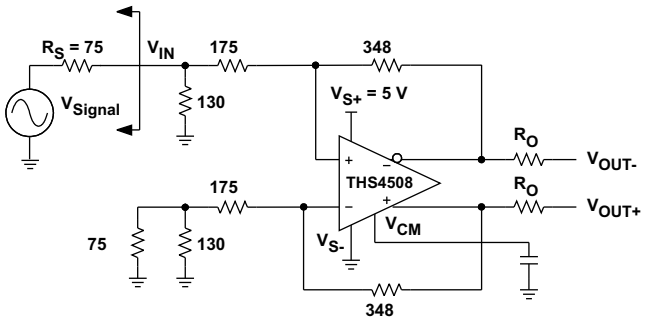

Figure 1. Video Buffer

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

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

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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.

ABSOLUTE MAXIMUM RATINGS(1)

over operating free-air temperature range (unless otherwise noted)

			UNIT
V_{SS}	Supply voltage	V_{S-} to V_{S+}	5.5 V
V_I	Input voltage		$\pm V_S$
V_{ID}	Differential input voltage		4 V
I_O	Output current		200 mA
	Continuous power dissipation		See Dissipation Rating Table
T_J	Maximum junction temperature(2)		150°C
T_J	Maximum junction temperature, continuous operation, long term reliability(3)		125°C
T_A	Operating free-air temperature range		–40°C to 85°C
T_{stg}	Storage temperature range		–65°C to 150°C
	Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds		300°C
	ESD ratings	HBM	2000
		CDM	1500
		MM	100

(1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those specified is not implied.
(2) The absolute maximum temperature under any condition is limited by the constraints of the silicon process.
(3) The maximum junction temperature for continuous operation is limited by the package constraints. Operation above this temperature may result in reduced reliability and/or lifetime of the device. The THS4508 incorporates a (QFN) exposed thermal pad on the underside of the chip. This acts as a heatsink and must be connected to a thermally dissipative plane for proper power dissipation. Failure to do so may result in exceeding the maximum junction temperature which could permanently damage the device. See TI technical brief SLMA002 and SLMA004 for more information about utilizing the QFN thermally enhanced package.

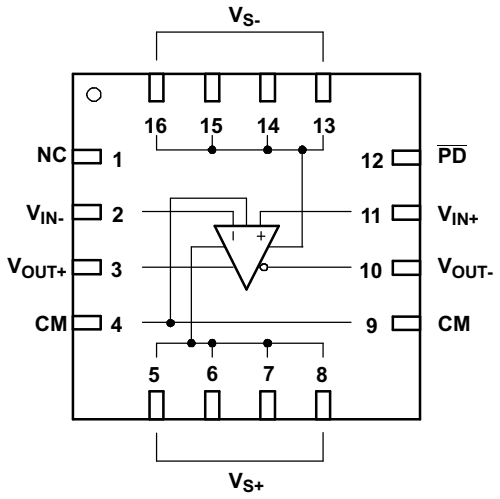
DISSIPATION RATINGS TABLE PER PACKAGE

PACKAGE(1)	θ_{JC}	θ_{JA}	POWER RATING	
			$T_A \leq 25°C$	$T_A = 85°C$
RGT (16)	2.4°C/W	39.5°C/W	2.3 W	225 mW

(1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI Web site at www.ti.com.

DEVICE INFORMATION

THS4508
(RGT PACKAGE)
(TOP VIEW)



TERMINAL FUNCTIONS

TERMINAL (RGT PACKAGE)		DESCRIPTION
NO.	NAME	
1	NC	No internal connection
2	V_{IN-}	Inverting amplifier input
3	V_{OUT+}	Noninverted amplifier output
4,9	CM	Common-mode voltage input
5,6,7,8	V_{S+}	Positive amplifier power supply input
10	V_{OUT-}	Inverted amplifier output
11	V_{IN+}	Noninverting amplifier input
12	$\overline{PD}$	Powerdown, $\overline{PD}$ = logic low puts part into low power mode, $\overline{PD}$ = logic high or open for normal operation
13,14,15,16	V_{S-}	Negative amplifier power supply input

ELECTRICAL CHARACTERISTICS; V_{S+} – $V_{S–}$ = 5 V:

Test conditions unless otherwise noted: V_{S+} = 5 V, $V_{S–}$ = 0 V, G = 10 dB, CM = open, V_O = 2 Vpp, R_F = 349 Ω, R_L = 200 Ω Differential, T = 25°C Single-Ended Input, Differential Output, Input Referenced to Ground, and Output Referenced to Mid-supply

PARAMETER	TEST CONDITIONS		MIN	TYP	MAX	UNITS	TEST LEVEL(1)
AC PERFORMANCE (Figure 44)							
Small-Signal Bandwidth	G = 6 dB, V_O = 100 mV_{PP}			2		GHz	C
	G = 10 dB, V_O = 100 mV_{PP}			1.7		GHz	
	G = 14 dB, V_O = 100 mV_{PP}			600		MHz	
	G = 20 dB, V_O = 100 mV_{PP}			300		MHz	
Gain-Bandwidth Product	G = 20 dB			3		GHz	
Bandwidth for 0.1dB flatness	G = 10 dB, V_O = 2 V_{PP}			400		MHz	
Large-Signal Bandwidth	G = 10 dB, V_O = 2 V_{PP}			1.5		GHz	
Slew Rate (Differential)	V_O = 2-V Step			6400		V/µs	
Rise Time				0.5		ns	
Fall Time				0.5		ns	
Settling Time to 0.1%				2		ns	
2nd Order Harmonic Distortion	f = 10 MHz			–104		dBc	
	f = 50 MHz			–82			
	f = 100 MHz			–69			
3rd Order Harmonic Distortion	f = 10 MHz			–105			
	f = 50 MHz			–92			
	f = 100 MHz			–81			
2nd Order Intermodulation Distortion	200 kHz tone spacing, R_L = 499 Ω	f_C = 70 MHz		–78		dBc	
		f_C = 140 MHz		–64			
3rd Order Intermodulation Distortion		f_C = 70 MHz		–95			
		f_C = 140 MHz		–78			
2nd Order Output Intercept Point	200 kHz tone spacing, R_L = 100 Ω	f_C = 70 MHz		78		dBm	
		f_C = 140 MHz		58			
3rd Order Output Intercept Point		f_C = 70 MHz		42			
		f_C = 140 MHz		35			
1-dB Compression Point(2)	f_C = 70 MHz			12.2		dBm	
	f_C = 140 MHz			10.8			
Noise Figure	50-Ω system, 10 MHz			19.2		dB	
Input Voltage Noise	f > 10 MHz			2.3		nV/√Hz	
Input Current Noise	f > 10 MHz			2.9		pA/√Hz	
DC PERFORMANCE							
Open-Loop Voltage Gain (A_{OL})				68		dB	C
Input Offset Voltage	T_A = 25°C			1	4	mV	A
	T_A = -40°C to 85°C			1	5		
Average Offset Voltage Drift				2.3		µA/°C	B
Input Bias Current	T_A = 25°C		1.75	8	15.5	µA	A
	T_A = -40°C to 85°C			8	18.5		
Average Bias Current Drift				20		nA/°C	B
Input Offset Current	T_A = 25°C			0.5	3.6	µA	A
	T_A = -40°C to 85°C			0.5	7		
Average Offset Current Drift				7		nA/°C	B

(1) Test levels: (A) 100% tested at 25°C. Overtemperature limits by characterization and simulation. (B) Limits set by characterization and simulation. (C) Typical value only for information.

(2) The 1-dB compression point is measured at the load with 50-Ω double termination. Add 3 dB to refer to amplifier output.

ELECTRICAL CHARACTERISTICS; V_{S+} – $V_{S–}$ = 5 V: (continued)

Test conditions unless otherwise noted: V_{S+} = 5 V, $V_{S–}$ = 0 V, G = 10 dB, CM = open, V_O = 2 Vpp, R_F = 349 Ω, R_L = 200 Ω Differential, T = 25°C Single-Ended Input, Differential Output, Input Referenced to Ground, and Output Referenced to Mid-supply

PARAMETER	TEST CONDITIONS		MIN	TYP	MAX	UNITS	TEST LEVEL (1)
INPUT							
Common-Mode Input Range High				2.3		V	B
Common-Mode Input Range Low				-0.3			
Common-Mode Rejection Ratio				90		dB	B
OUTPUT							
Maximum Output Voltage High	Each output with 100 Ω to mid-supply	T_A = 25°C	3.7	3.8		V	A
		T_A = -40°C to 85°C	3.6	3.8			
Minimum Output Voltage Low		T_A = 25°C		1.2	1.3		
		T_A = -40°C to 85°C		1.2	1.4		
Differential Output Voltage Swing	T_A = 25°C		4.8	5.2		V	A
	T_A = -40°C to 85°C		4.4	5.2			
Differential Output Current Drive	R_L = 10 Ω			96		mA	C
Output Balance Error	V_O = 100 mV, f = 1 MHz			-43		dB	C
Closed-Loop Output Impedance	f = 1 MHz			0.3		Ω	C
OUTPUT COMMON-MODE VOLTAGE CONTROL							
Small-Signal Bandwidth				700		MHz	C
Slew Rate				110		V/µs	
Gain				1		V/V	
Output Common-Mode Offset from CM input	1.25 V < CM < 3.5 V			5		mV	
CM Input Bias Current	1.25 V < CM < 3.5 V			±40		µA	
CM Input Voltage Range				1.25 to 3.75		V	
CM Input Impedance				32 || 1.5		kΩ || pF	
CM Default Voltage				2.5		V	
POWER SUPPLY							
Specified Operating Voltage			3.75 (3)	5	5.25	V	C
Maximum Quiescent Current	T_A = 25°C			39.2	42.5	mA	A
	T_A = -40°C to 85°C			39.2	43.5		
Minimum Quiescent Current	T_A = 25°C		35.9	39.2			
	T_A = -40°C to 85°C		35	39.2			
Power Supply Rejection (±PSRR)	To differential output			90		dB	C
POWERDOWN	Referenced to V_{S-}						
Enable Voltage Threshold	Device assured *on* above 2.1 V			> 2.1		V	C
Disable Voltage Threshold	Device assured *off* below 0.7 V			< 0.7			
Powerdown Quiescent Current	T_A = 25°C			0.65	0.9	mA	A
	T_A = -40°C to 85°C			0.65	1		
Input Bias Current	$\overline{PD}$ = $V_{S–}$			100		µA	C
Input Impedance				50 || 2		kΩ || pF	
Turn-on Time Delay	Measured to output on			55		ns	
Turn-off Time Delay	Measured to output off			10		µs	

(3) See the *Application Information* section of this data sheet for device operation with full supply voltages less than 5 V.

TYPICAL CHARACTERISTICS

TYPICAL AC PERFORMANCE: V_{S+} – V_{S-} = 5 V

Test conditions unless otherwise noted: V_{S+} = 5 V, V_{S-} = 0 V, G = 10 dB, CM = open, V_O = 2 V_{PP}, R_F = 349 Ω, R_L = 200 Ω Differential, Single-Ended Input, Input Referenced to Ground and Output Referenced to Midrail

Small-Signal Frequency Response			Figure 2
Large Signal Frequency Response			Figure 3
Harmonic Distortion	HD_2, G = 6 dB, V_{OD} = 2 V_{PP}	vs Frequency	Figure 4
	HD_3, G = 6 dB, V_{OD} = 2 V_{PP}	vs Frequency	Figure 5
	HD_2, G = 10 dB, V_{OD} = 2 V_{PP}	vs Frequency	Figure 6
	HD_3, G = 10 dB, V_{OD} = 2 V_{PP}	vs Frequency	Figure 7
	HD_2, G = 14 dB, V_{OD} = 2 V_{PP}	vs Frequency	Figure 8
	HD_3, G = 14 dB, V_{OD} = 2 V_{PP}	vs Frequency	Figure 9
	HD_2, G = 10 dB	vs Output voltage	Figure 10
	HD_3, G = 10 dB	vs Output voltage	Figure 11
	HD_2, G = 10 dB	vs CM input voltage	Figure 12
	HD_3, G = 10 dB	vs CM input voltage	Figure 13
Intermodulation Distortion	IMD_2, G = 6 dB, V_{OD} = 2 V_{PP}	vs Frequency	Figure 14
	IMD_3, G = 6 dB, V_{OD} = 2 V_{PP}	vs Frequency	Figure 15
	IMD_2, G = 10 dB, V_{OD} = 2 V_{PP}	vs Frequency	Figure 16
	IMD_3, G = 10 dB, V_{OD} = 2 V_{PP}	vs Frequency	Figure 17
	IMD_2, G = 14 dB, V_{OD} = 2 V_{PP}	vs Frequency	Figure 18
	IMD_3, G = 14 dB, V_{OD} = 2 V_{PP}	vs Frequency	Figure 19
Output Intercept Point	OIP_2	vs Frequency	Figure 20
	OIP_3	vs Frequency	Figure 21
S-Parameters		vs Frequency	Figure 22
Transition Rate		vs Output Voltage	Figure 23
Transient Response			Figure 24
Settling Time			Figure 25
0.1 dB Flatness			Figure 26
Rejection Ratio		vs Frequency	Figure 27
Output Impedance		vs Frequency	Figure 28
Overdrive Recovery			Figure 29
Output Voltage Swing		vs Load Resistance	Figure 30
Turn-Off Time			Figure 31
Turn-On Time			Figure 32
Input Offset Voltage		vs Input Common-Mode Voltage	Figure 33
Open Loop Gain		vs Frequency	Figure 34
Input Referred Noise		vs Frequency	Figure 35
Noise Figure		vs Frequency	Figure 36
Quiescent Current		vs Supply Voltage	Figure 37
Output Balance Error		vs Frequency	Figure 38
CM Input Impedance		vs Frequency	Figure 39
CM Small-Signal Frequency Response			Figure 40
CM Input Bias Current		vs CM Input Voltage	Figure 41
Differential Output Offset Voltage		vs CM Input Voltage	Figure 42
Output Common-Mode Offset		vs CM Input Voltage	Figure 43

SMALL-SIGNAL FREQUENCY RESPONSE

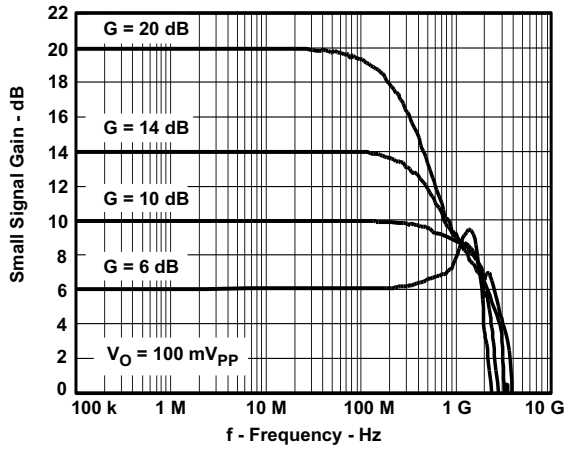


Figure 2.

LARGE-SIGNAL FREQUENCY RESPONSE

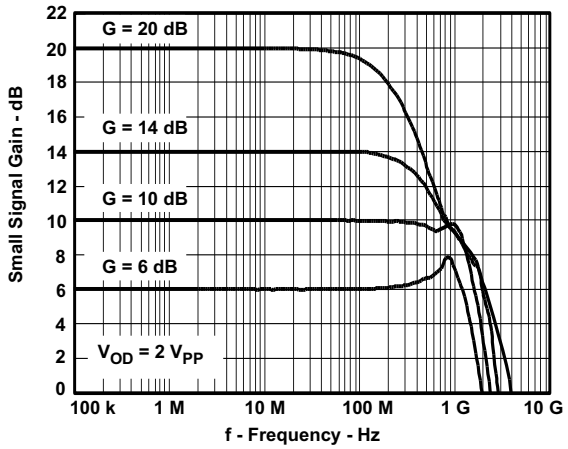


Figure 3.

HD_2 vs FREQUENCY

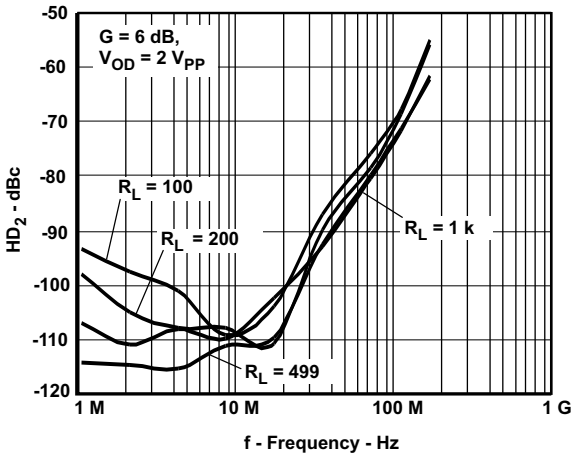


Figure 4.

HD_3 vs FREQUENCY

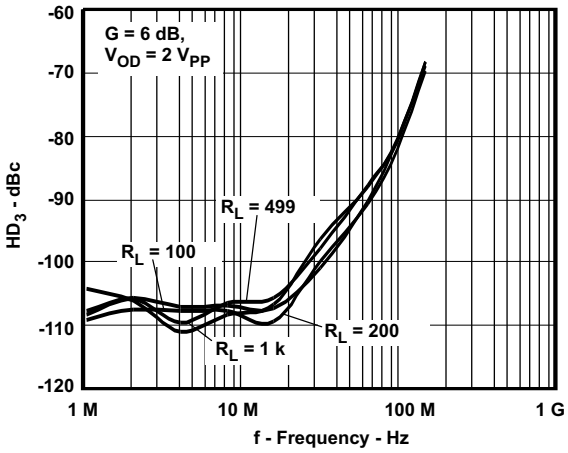


Figure 5.

HD_2 vs FREQUENCY

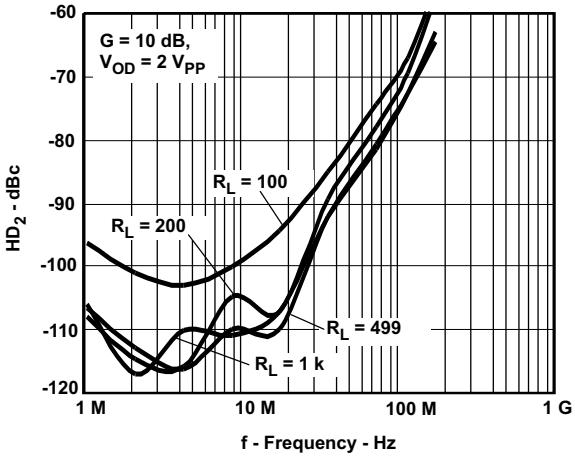
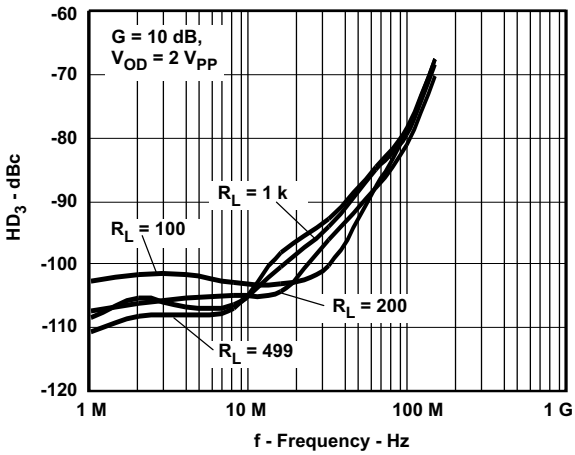


Figure 6.

HD_3 vs FREQUENCY



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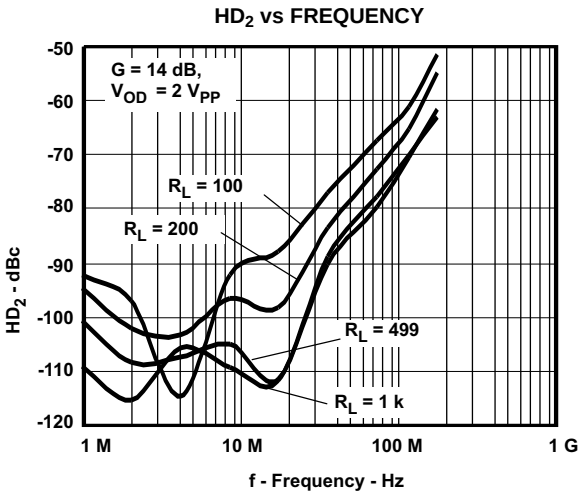


Figure 8.

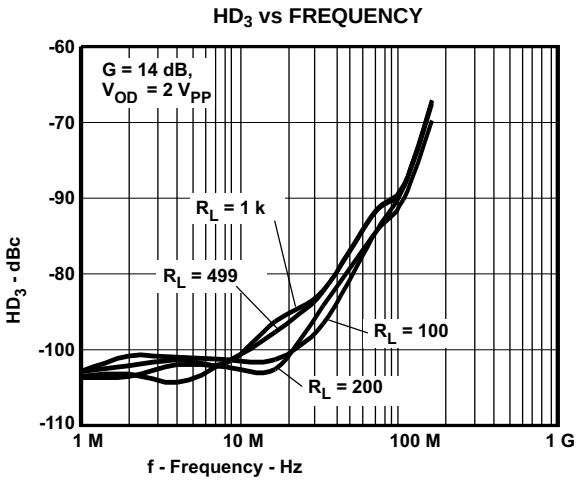
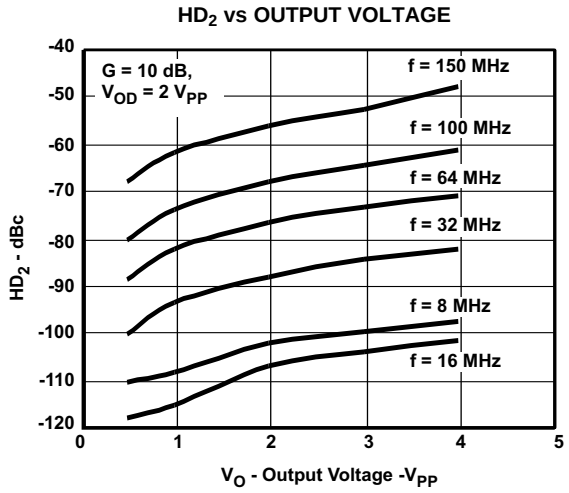


Figure 9.



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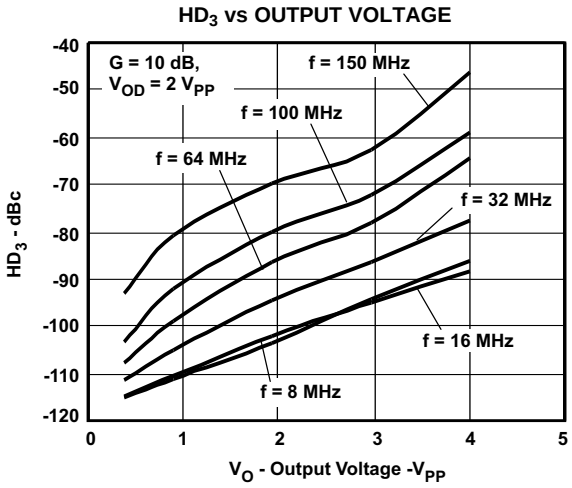

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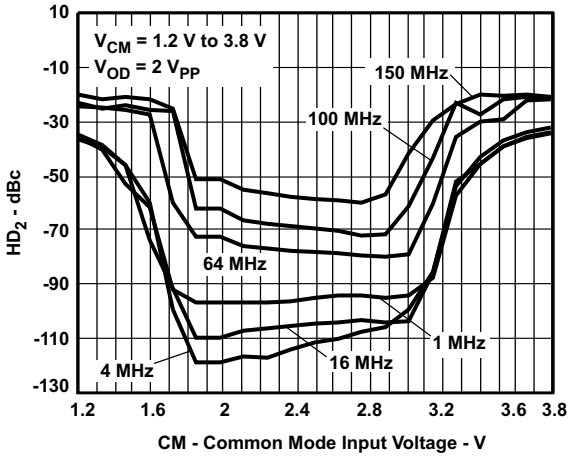

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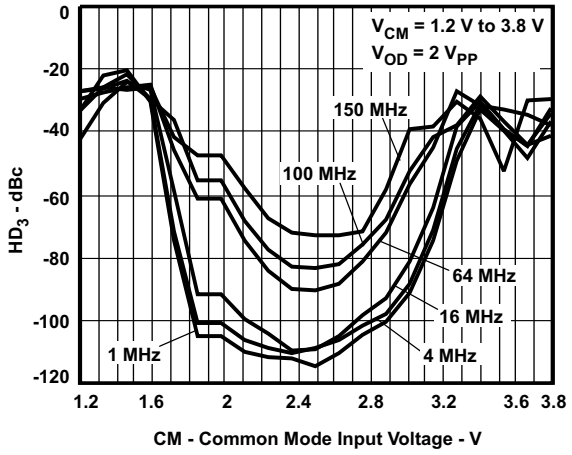

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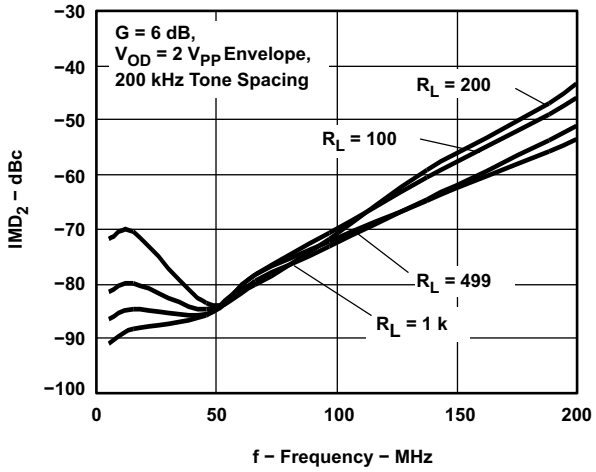

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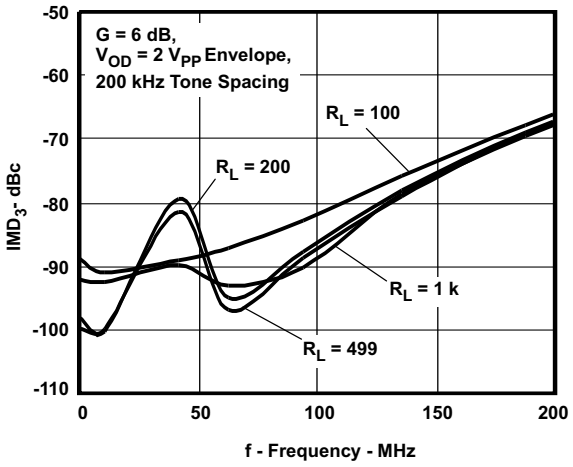

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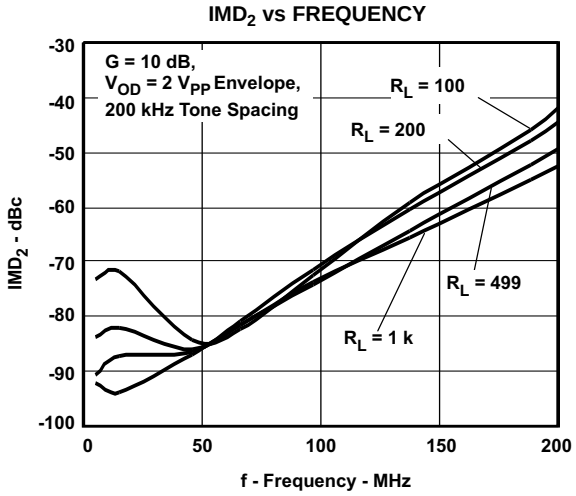


Figure 16.

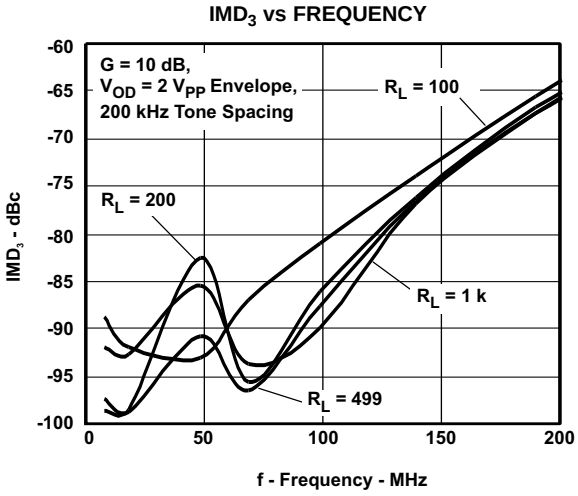


Figure 17.

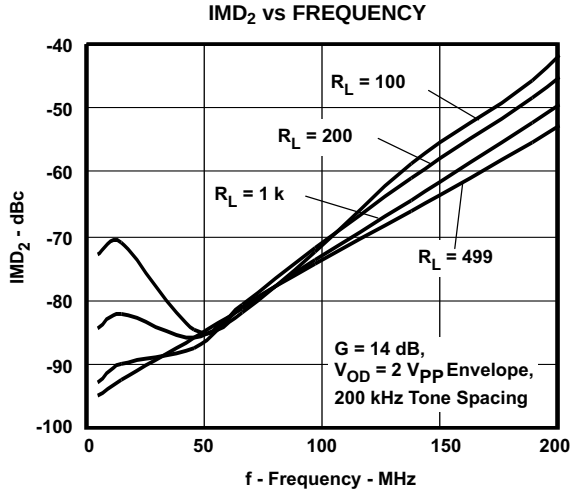


Figure 18.

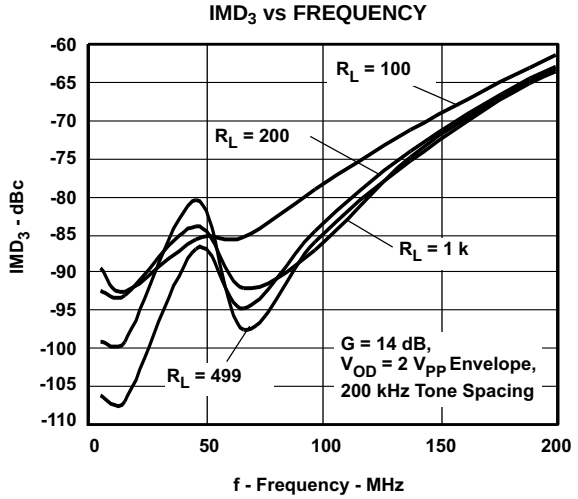
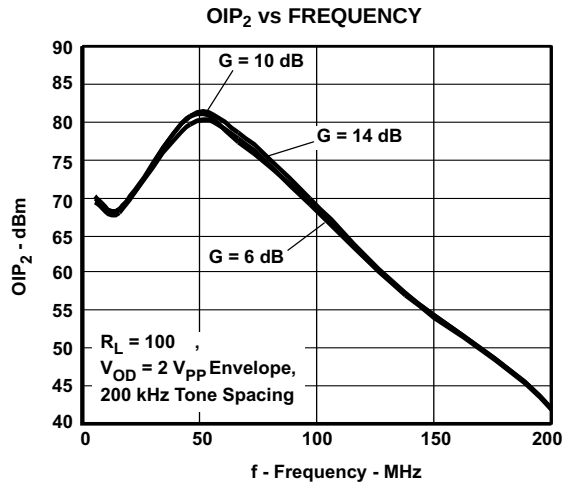


Figure 19.



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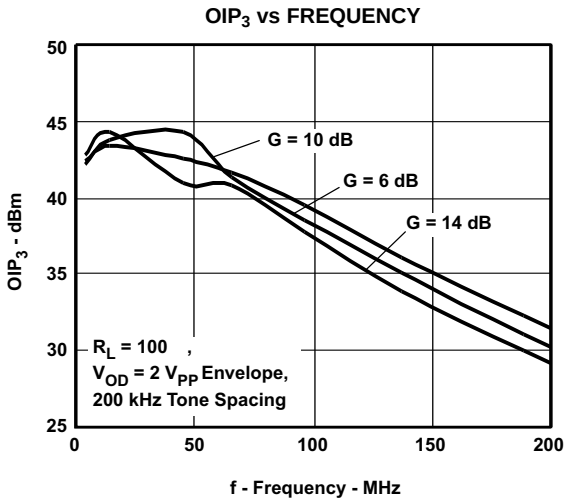
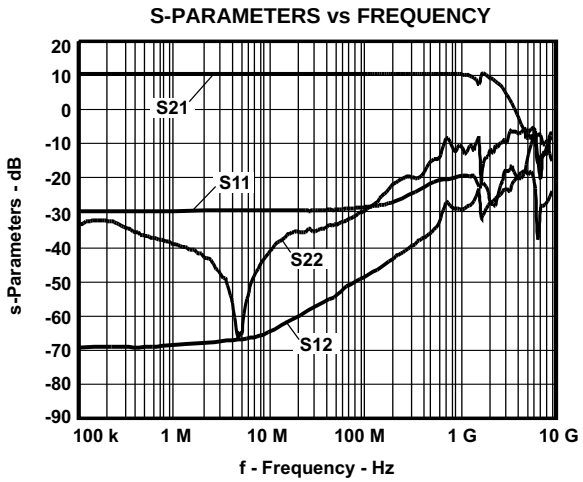


Figure 21.



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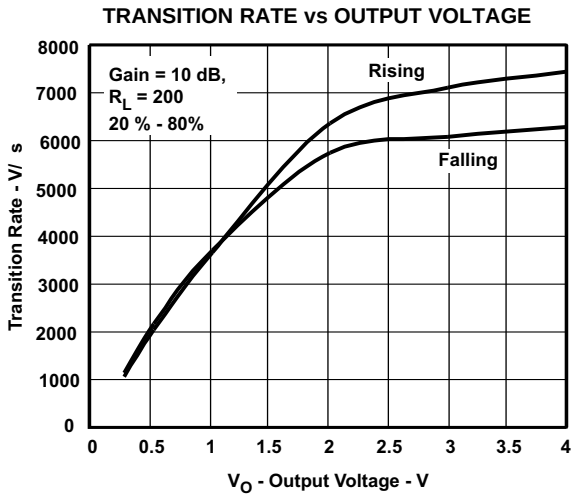

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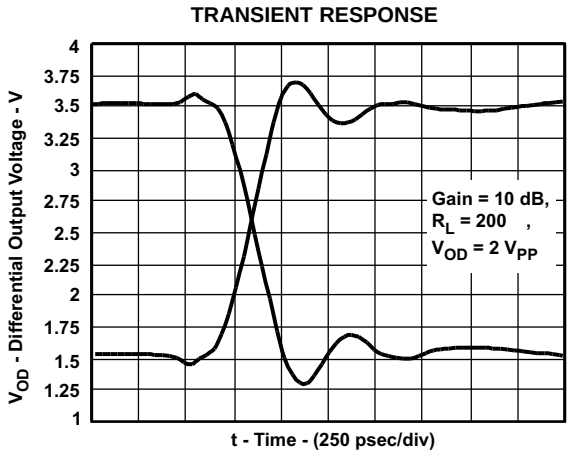

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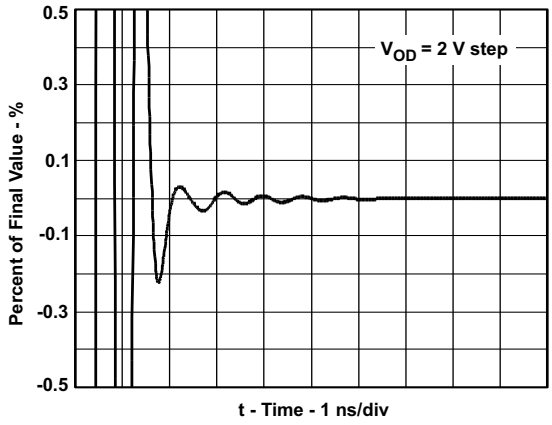

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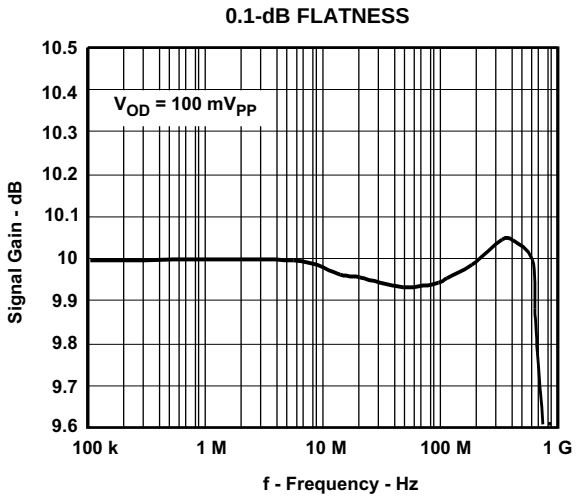

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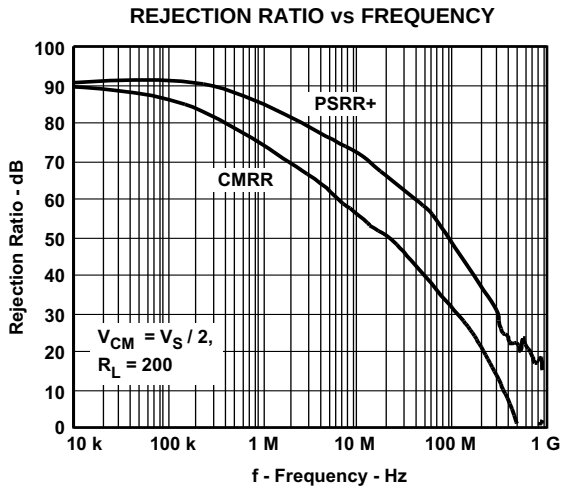

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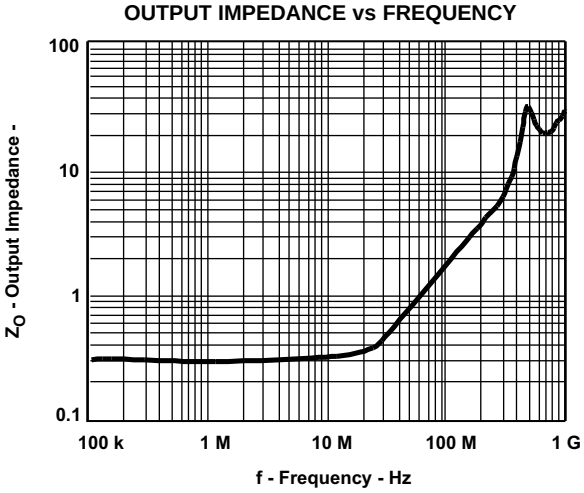
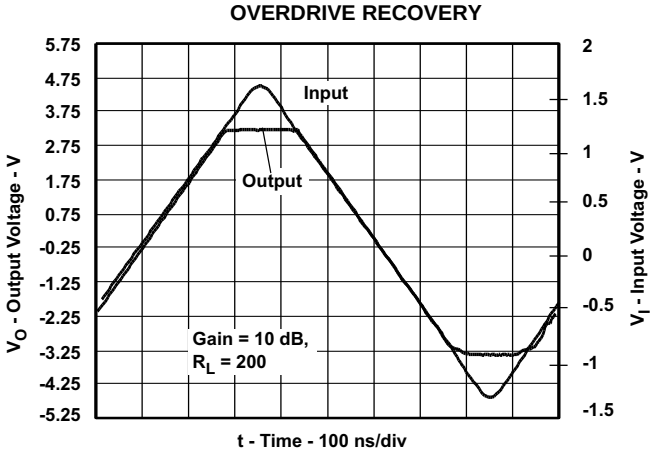


Figure 28.



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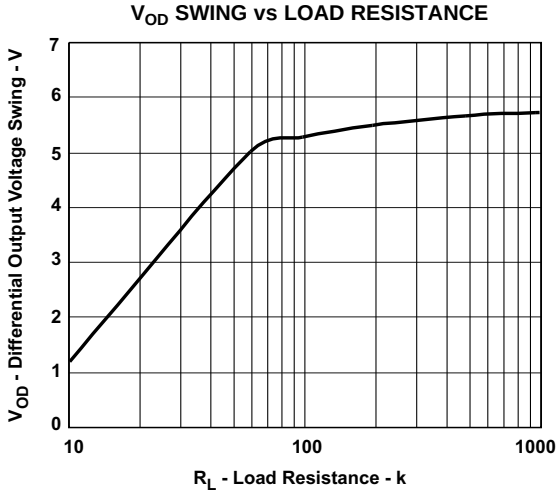

Figure 30.

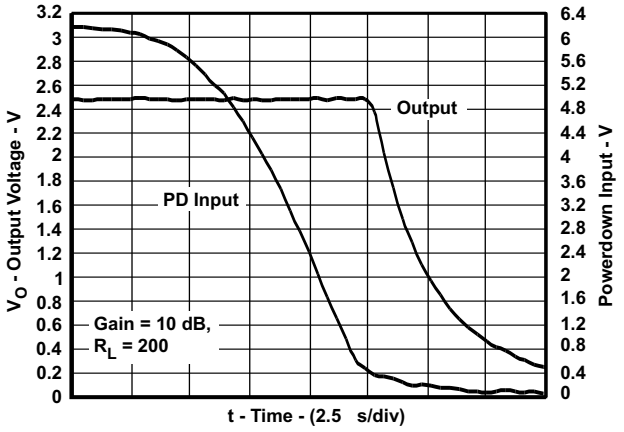

Figure 31.

TURN-ON TIME

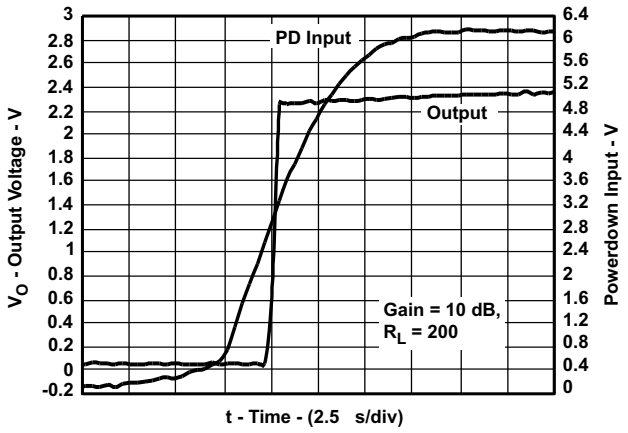

Figure 32.

INPUT OFFSET VOLTAGE vs CM INPUT VOLTAGE

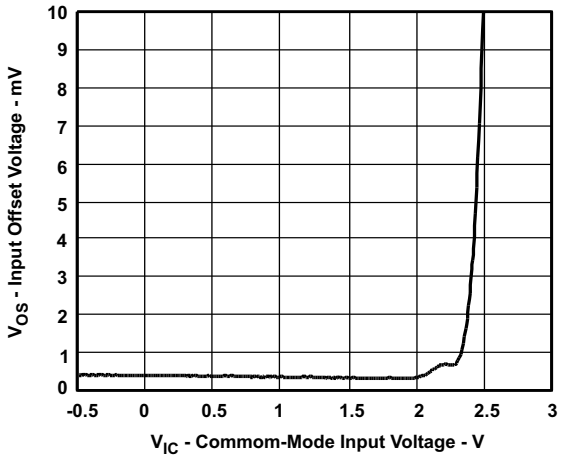

Figure 33.

OPEN LOOP GAIN AND PHASE vs FREQUENCY

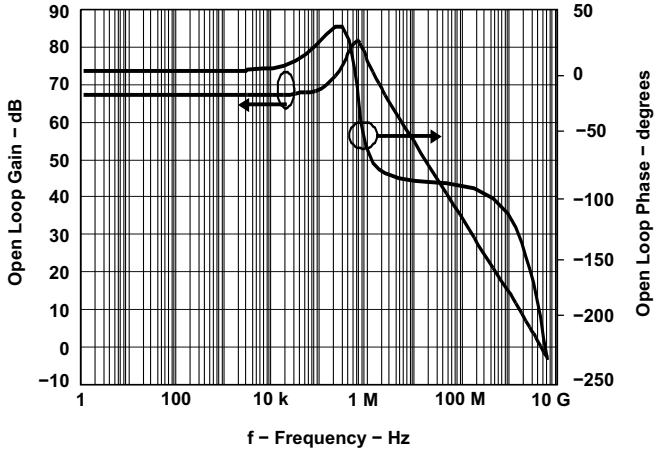

Figure 34.

INPUT REFERRED NOISE vs FREQUENCY

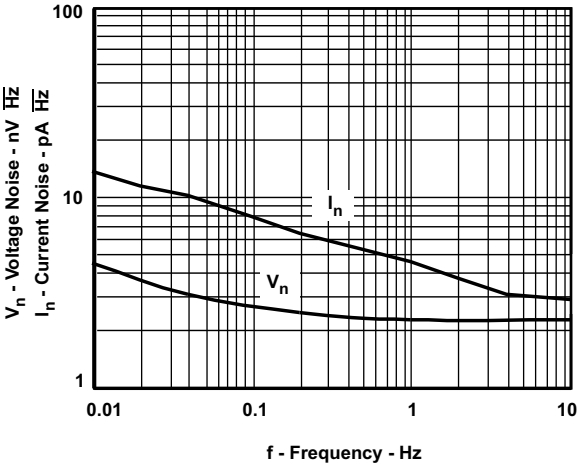

Figure 35.

NOISE FIGURE vs FREQUENCY

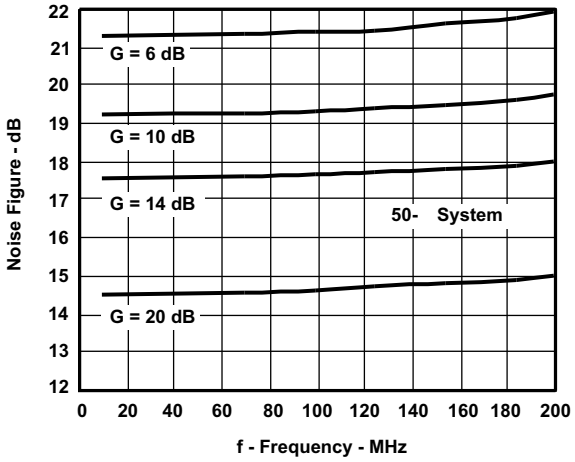

Figure 36.

QUIESCENT CURRENT vs SUPPLY VOLTAGE

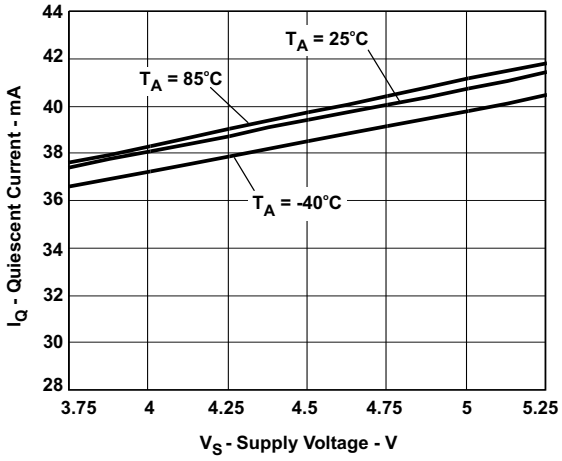

Figure 37.

OUTPUT BALANCE ERROR vs FREQUENCY

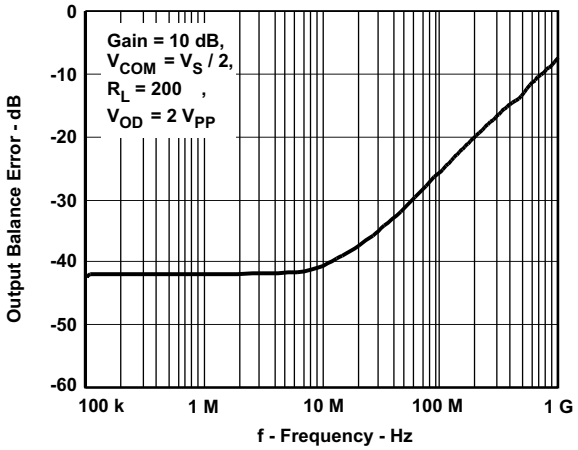

Figure 38.

CM INPUT IMPEDANCE vs FREQUENCY

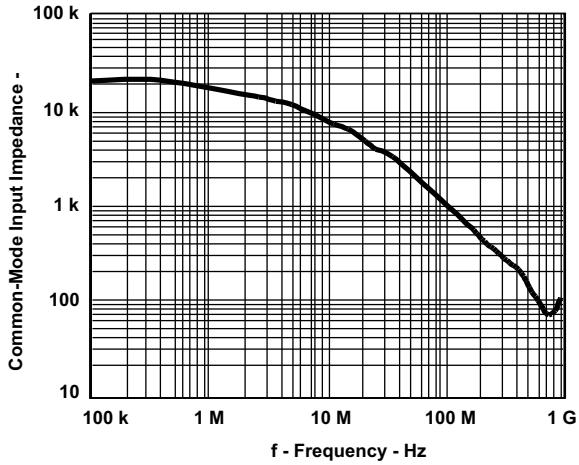

Figure 39.

CM SMALL SIGNAL FREQUENCY RESPONSE

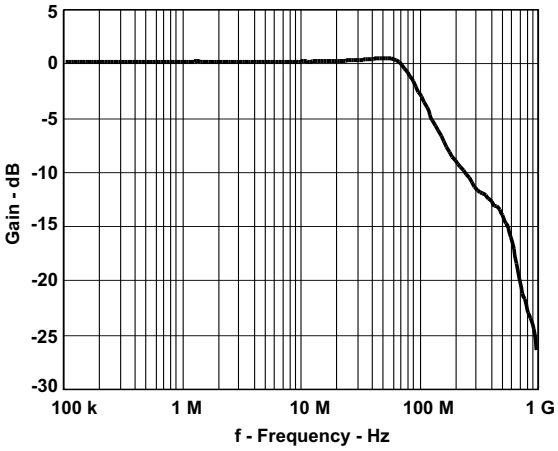

Figure 40.

CM BIAS CURRENT vs CM INPUT VOLTAGE

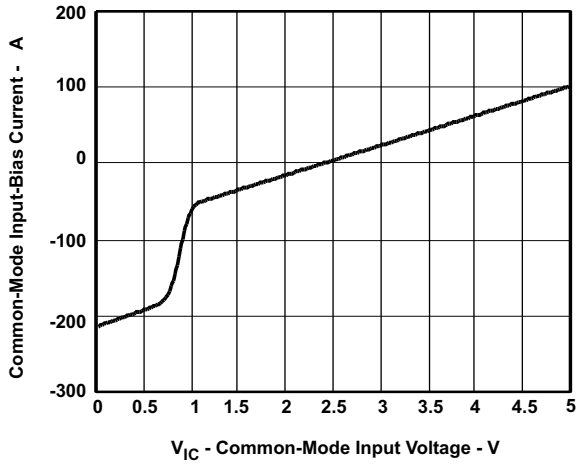

Figure 41.

V_{OD} OFFSET VOLTAGE vs CM INPUT VOLTAGE

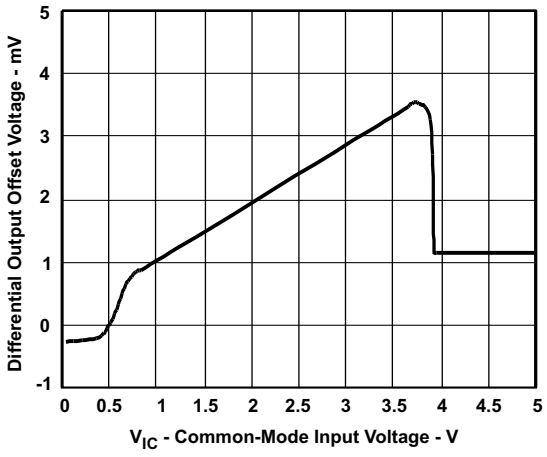

Figure 42.

V_{OC} OFFSET VOLTAGE vs CM INPUT VOLTAGE

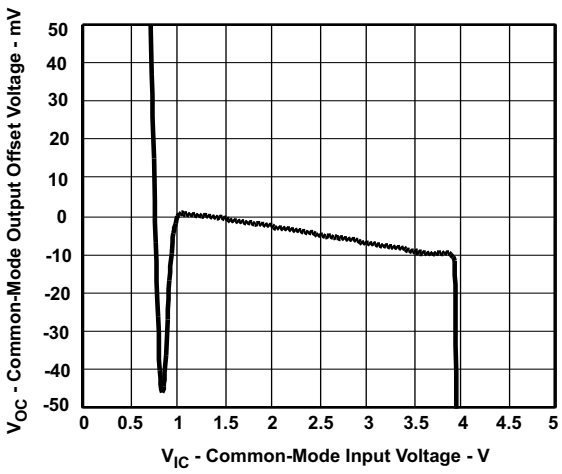

Figure 43.

TEST CIRCUITS

The THS4508 is tested with the following test circuits built on the EVM. For simplicity, the power supply decoupling is not shown – see the layout in the application information section for recommendations. Depending on the test conditions, component values are changed per the following tables, or as otherwise noted. The signal generators used are ac coupled 50-Ω sources and a 0.22-µF capacitor and a 49.9-Ω resistor to ground are inserted across R_{IT} on the alternate input to balance the circuit.

Table 1. Gain Component Values

GAIN	R_F	R_G	R_{IT}
6 dB	348 Ω	165 Ω	61.9 Ω
10 dB	348 Ω	100 Ω	69.8 Ω
14 dB	348 Ω	56.2 Ω	88.7 Ω
20 dB	348 Ω	16.5 Ω	287 Ω

Note the gain setting includes 50-Ω source impedance. Components are chosen to achieve gain and 50-Ω input termination.

Table 2. Load Component Values

R_L	R_O	R_{OT}	Atten.
100 Ω	25 Ω	open	6 dB
200 Ω	86.6 Ω	69.8 Ω	16.8 dB
499 Ω	237 Ω	56.2 Ω	25.5 dB
1k Ω	487 Ω	52.3 Ω	31.8 dB

Note the total load includes 50-Ω termination by the test equipment. Components are chosen to achieve load and 50-Ω line termination through a 1:1 transformer.

Due to the voltage divider on the output formed by the load component values, the amplifier's output is attenuated. The column *Atten* in Table 2 shows the attenuation expected from the resistor divider. When using a transformer at the output as shown in Figure 45, the signal will see slightly more loss, and these numbers will be approximate.

Frequency Response

The circuit shown in Figure 44 is used to measure the frequency response of the circuit.

A network analyzer is used as the signal source and as the measurement device. The output impedance of the network analyzer is 50 Ω. R_{IT} and R_G are chosen to impedance match to 50 Ω, and to maintain the proper gain. To balance the amplifier, a 0.22-µF capacitor and 49.9-Ω resistor to ground are inserted across R_{IT} on the alternate input.

The output is probed using a high-impedance differential probe across the 100-Ω resistor. The gain is referred to the amplifier output by adding back the 6-dB loss due to the voltage divider on the output.

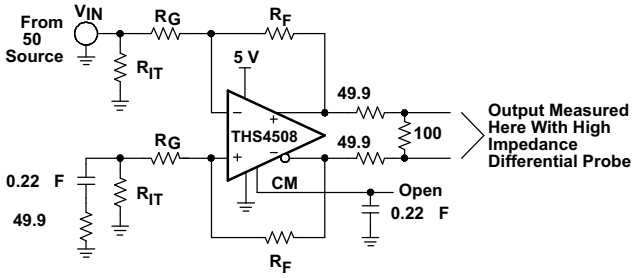

Figure 44. Frequency Response Test Circuit

Distortion and 1 db Compression

The circuit shown in Figure 45 is used to measure harmonic distortion, intermodulation distortion, and 1-db compression point of the amplifier.

A signal generator is used as the signal source and the output is measured with a spectrum analyzer. The output impedance of the signal generator is 50 Ω. R_{IT} and R_G are chosen to impedance-match to 50 Ω, and to maintain the proper gain. To balance the amplifier, a 0.22-µF capacitor and 49.9-Ω resistor to ground are inserted across R_{IT} on the alternate input.

A low-pass filter is inserted in series with the input to reduce harmonics generated at the signal source. The level of the fundamental is measured, then a high-pass filter is inserted at the output to reduce the fundamental so that it does not generate distortion in the input of the spectrum analyzer.

The transformer used in the output to convert the signal from differential to single ended is an ADT1-1WT. It limits the frequency response of the circuit so that measurements cannot be made below approximately 1 MHZ.

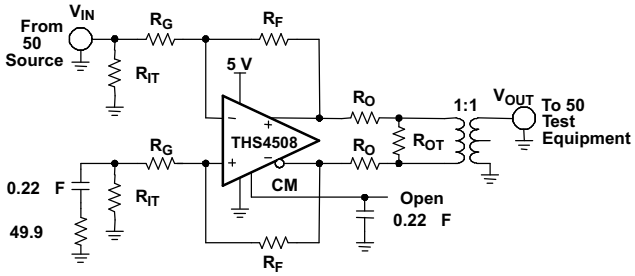

Figure 45. Distortion Test Circuit

The 1-dB compression point is measured with a spectrum analyzer with 50-Ω double termination or

100-Ω termination as shown in Table 2. The input power is increased until the output is 1 dB lower than expected. The number reported in the table data is the power delivered to the spectrum analyzer input. Add 3 dB to refer to the amplifier output.

S-Parameter, Slew Rate, Transient Response, Settling Time, Output Impedance, Overdrive, Output Voltage, and Turn-On/Off Time

The circuit shown in Figure 46 is used to measure s-parameters, slew rate, transient response, settling time, output impedance, overdrive recovery, output voltage swing, and turn-on/turn-off times of the amplifier. For output impedance, the signal is injected at V_{OUT} with V_{IN} left open and the drop across the 49.9 Ω resistor is used to calculate the impedance seen looking into the amplifier's output.

Because S_{21} is measured single-ended at the load with 50-Ω double termination, add 12 dB to refer to the amplifier's output as a differential signal.

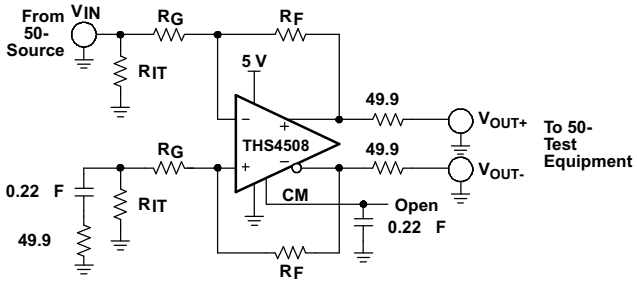

Figure 46. S-Parameter, SR, Transient Response, Settling Time, Z_O, Overdrive Recovery, V_{OUT} Swing, and Turn-on/off Test Circuit

CM Input

The circuit shown in Figure 47 is used to measure the frequency response and input impedance of the CM input. Frequency response is measured single-ended at V_{OUT+} or V_{OUT-} with the input injected at V_{IN}, R_{CM} = 0 Ω and R_{CMT} = 49.9 Ω. The input impedance is measured with R_{CM} = 49.9 Ω with R_{CMT} = open, and calculated by measuring the voltage drop across R_{CM} to determine the input current.

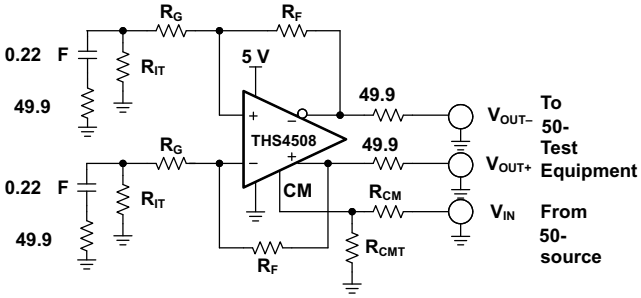

Figure 47. CM Input Test Circuit

CMRR and PSRR

The circuit shown in Figure 48 is used to measure the CMRR and PSRR of V_{S+} and V_{S-}. The input is switched appropriately to match the test being performed.

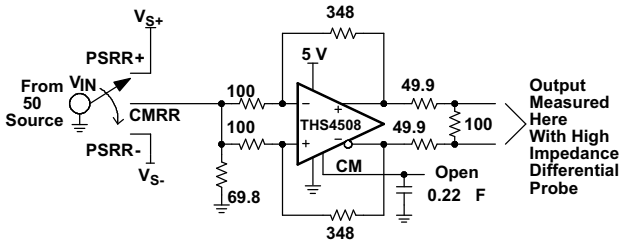

Figure 48. CMRR and PSRR Test Circuit

APPLICATION INFORMATION

APPLICATIONS

The following circuits show application information for the THS4508. For simplicity, power supply decoupling capacitors are not shown in these diagrams. For more detail on the use and operation of fully differential operational amplifiers, refer to application report *Fully-Differential Amplifiers* (SLOA054) .

Differential Input to Differential Output Amplifier

The THS4508 is a fully differential operational amplifier, and can be used to amplify differential input signals to differential output signals. A basic block diagram of the circuit is shown in Figure 49 (CM input not shown). The gain of the circuit is set by R_F divided by R_G.

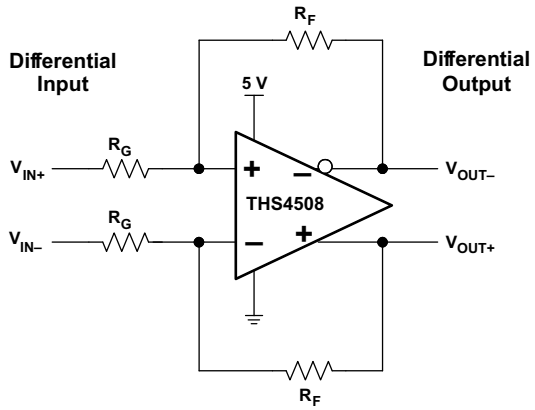

Figure 49. Differential Input to Differential Output Amplifier

Depending on the source and load, input and output termination can be accomplished by adding R_{IT} and R_O.

Single-Ended Input to Differential Output Amplifier

The THS4508 can be used to amplify and convert single-ended input signals to differential output signals. A basic block diagram of the circuit is shown in Figure 50 (CM input not shown). The gain of the circuit is again set by R_F divided by R_G.

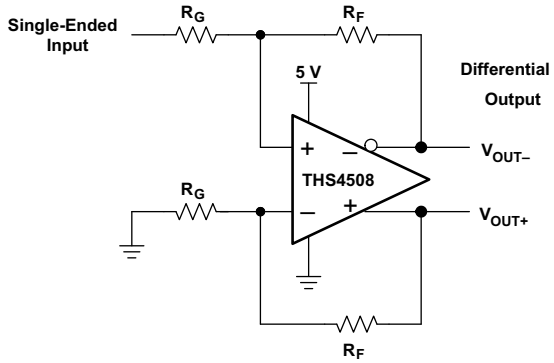

Figure 50. Single-Ended Input to Differential Output Amplifier

Input Common-Mode Voltage Range

The input common-model voltage of a fully differential operational amplifier is the voltage at the (+) and (–) input pins of the operational amplifier.

It is important to not violate the input common-mode voltage range (V_{ICR}) of the operational amplifier. Assuming the operational amplifier is in linear operation the voltage across the input pins is only a few millivolts at most. So finding the voltage at one input pin determines the input common-mode voltage of the operational amplifier.

Treating the negative input as a summing node, the voltage is given by Equation 1:

$$V_{IC} \quad V_{OUT} \quad \frac{R_G}{R_G \quad R_F} \quad V_{IN} \quad \frac{R_F}{R_G \quad R_F} \tag{1}$$

To determine the V_{ICR} of the operational amplifier, the voltage at the negative input is evaluated at the extremes of V_{OUT+}.

As the gain of the operational amplifier increases, the input common-mode voltage becomes closer and closer to the input common-mode voltage of the source.

Setting the Output Common-Mode Voltage

The output common-mode voltage is set by the voltage at the CM pin(s). The internal common-mode control circuit maintains the output common-mode voltage within 5-mV offset (typical) from the set voltage, when set within 0.5 V of mid-supply. If left unconnected, the common-mode set point is set to mid-supply by internal circuitry, which may be over-driven from an external source. Figure 51 is representative of the CM input. The internal CM circuit has about 700 MHz of –3-dB bandwidth, which

is required for best performance, but it is intended to be a dc-bias input pin. Bypass capacitors are recommended on this pin to reduce noise at the output. The external current required to overdrive the internal resistor divider is given by Equation 2:

$$I_{EXT} \quad \frac{2V_{CM} \quad V_S \quad V_S}{50\ k} \tag{2}$$

where V_{CM} is the voltage applied to the CM pin, and V_{S+} ranges from 3.75 V to 5 V, and V_{S-} is 0 V (ground).

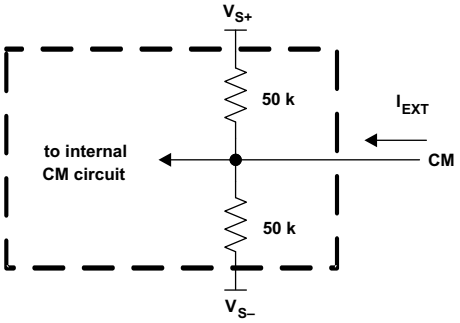

Figure 51. CM Input Circuit

Device Operation with Single Power Supplies Less than 5 V

The THS4508 is optimized to work in systems using a 5-V single supply, and the characterization data presented in this data sheet was taken with 5-V single-supply inputs. For ac-coupled systems or dc-coupled systems operating with supplies less than 5 V and greater than 3.75 V, the amplifier input common-mode range is maximized by adding pull-down resistors at the device inputs. The pull-down resistors provide additional loading at the input, and lower the common-mode voltage that is fed back into the device input through resistor R_F. Figure 52 shows the circuit configuration for this mode of operation where R_{PD} is added to the dc-coupled circuit to avoid violating the V_{ICR} of the operational amplifier. Note R_S and R_{IT} are added to the alternate input from the signal input to balance the amplifier. One resistor that is equal to the combined value $R_I = R_G + R_S||R_{IT}$ can be placed at the alternate input.

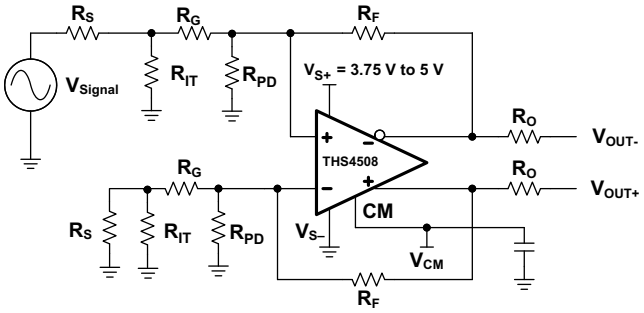

Figure 52. THS4508 DC Coupled Single-Source Supply Range From 3.75 V to 5 V With R_{PD} Used To Set V_{IC}

Note that in Figure 52, the source is referenced to ground as is the input termination resistor R_{IT}. The proper value of resistance to add can be calculated from Equation 3:

$$R_{PD} \quad \frac{1}{\frac{1}{R_F} \quad \frac{1.6}{\frac{V_S}{2} \quad 1.6} \quad \frac{1}{R_I}} \tag{3}$$

where $R_I = R_G + R_S||R_{IT}$.

V_{S+} is the power-supply voltage, R_F is the feedback resistance, R_G is the gain-setting resistance, R_S is the signal source resistance, and R_{IT} is the termination resistance.

Table 3 is a modification of Table 1 to add the proper values with R_{PD} assuming V_{S+} = 3.75 V, a dc-coupled 50-Ω source impedance, and setting the output common-mode voltage to mid-supply.

Table 3. R_{PD} Values for Various Gains, V_{S+} = 3.75 V, DC-coupled Signal Source

Gain	R_F	R_G	R_{IT}	R_{PD}
6 dB	348 Ω	169 Ω	64.9 Ω	86.6 Ω
10 dB	348 Ω	102 Ω	78.7 Ω	110 Ω
14 dB	348 Ω	61.9 Ω	115 Ω	158 Ω
20 dB	348 Ω	40.2 Ω	221 Ω	226 Ω

If the signal originates from an ac-coupled 50-Ω source (see Figure 53), the equivalent dc-source resistance is an open circuit and $R_I = R_G + R_{IT}$. Table 4 is a modification of Table 1 to add the proper values with R_{PD} assuming V_{S+} = 3.75 V, an ac-coupled 50-Ω source impedance, and setting the output common-mode voltage to mid-supply.

Table 4. R_{PD} Values for Various Gains, V_{S+} = 3.75 V, AC-coupled Signal Source

Gain	R_F	R_G	R_{IT}	R_{PD}
6 dB	348 Ω	169 Ω	64.9 Ω	80.6 Ω
10 dB	348 Ω	102 Ω	78.7 Ω	90.9 Ω
14 dB	348 Ω	61.9 Ω	115 Ω	90.9 Ω
20 dB	348 Ω	40.2 Ω	221 Ω	77.6 Ω

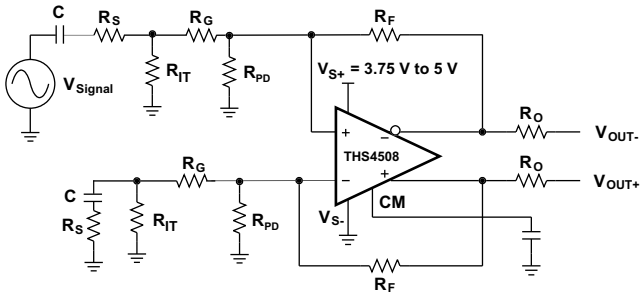

Figure 53. THS4508 AC Coupled Single-Source Supply Range From 3.75 V to 5 V With R_{PD} Used To Set V_{IC}

Video Buffer

Figure 54 shows a possible application of the THS4508 as a dc-coupled video buffer with a gain of 2. Figure 55 shows a plot of the Y' signal originating from a HDTV 720p video system. The input signal includes a 3-level sync (minimum level at -0.3 V), and the portion of the video signal with maximum amplitude of 0.7 V. Although the buffer draws its power from a 5-V single-ended power supply, internal level shifters allow the buffer to support input signals which are as much as -0.3 V below ground. This allows maximum design flexibility while maintaining a minimum parts count. Figure 56 shows the differential output of the buffer. Note that the dc-coupled amplifier can introduce a dc offset on a signal applied at its input

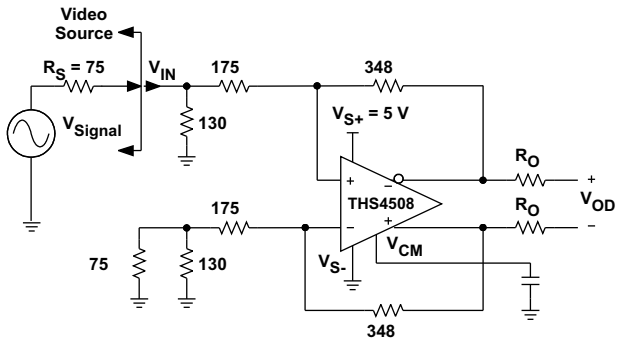

Figure 54. Single-Supply Video Buffer, Gain = 2

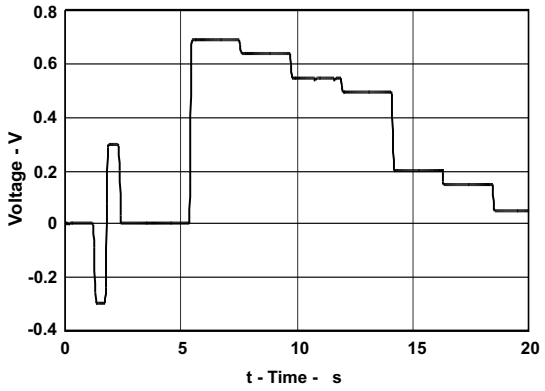

Figure 55. Y' Signal With 3-Level Sync and Video Signal

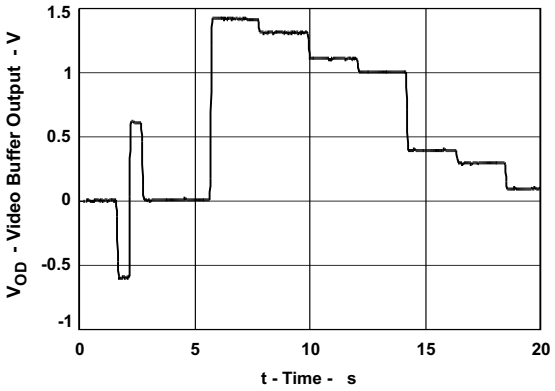

Figure 56. Video Buffer Differential Output Signal

THS4508 + ADS5500 Combined Performance

The THS4508 is designed to be a high performance drive amplifier for high performance data converters like the ADS5500 14-bit 125-MSPS ADC. Figure 57 shows a circuit combining the two devices, and Figure 58 shows the combined SNR and SFDR performance versus frequency with –1 dBFS input signal level sampling at 125 MSPS. The THS4508 amplifier circuit provides 10 dB of gain, and converts the single-ended input signal to a differential output signal. The default common-mode output of the THS4508 (2.5 V) is not compatible with the required common-mode input of the ADS5500 (1.55 V), so dc-blocking capacitors are added (0.22 µF). Note that a biasing circuit (not shown in Figure 57) is needed to provide the required common-mode, dc-input for the ADS5500. The 100-Ω resistors and 2.7-pF capacitor between the THS4508 outputs and ADS5500 inputs along with the input capacitance of the ADS5500 limit the bandwidth of the signal to 115 MHz (–3 dB). For testing, a signal generator is used for the signal source. The generator is an ac-coupled 50-Ω source. A band-pass filter is inserted in series with the input to reduce harmonics and noise from the signal

source. Input termination is accomplished via the 69.8-Ω resistor and 0.22-µF capacitor to ground in conjunction with the input impedance of the amplifier circuit. A 0.22-µF capacitor and 49.9-Ω resistor is inserted to ground across the 69.8-Ω resistor and 0.22-µF capacitor on the alternate input to balance the circuit. Gain is a function of the source impedance, termination, and 348-Ω feedback resistor. See Table 1 for component values to set proper 50-Ω termination for other common gains.

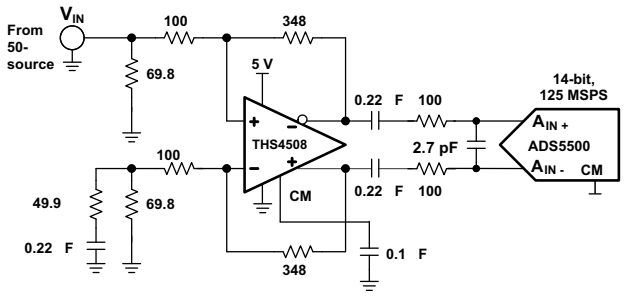

Figure 57. THS4508 + ADS5500 Circuit

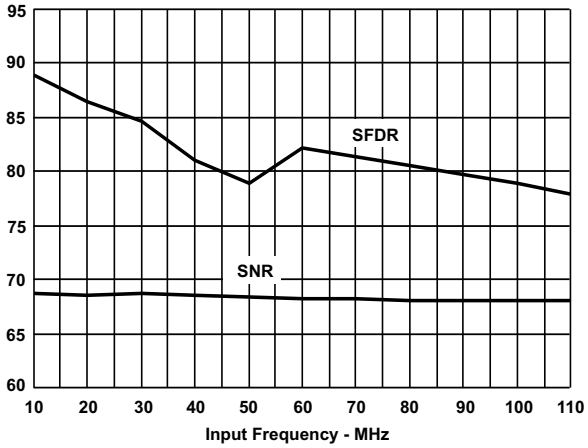

Figure 58. THS4508 + ADS5500 SFDR and SNR Performance versus Frequency

THS4508 + ADS5424 Combined Performance

Figure 59 shows the THS4508 driving the ADS5424 ADC, and Figure 60 shows their combined SNR and SFDR performance versus frequency with –1 dBFS input signal level and sampling at 80 MSPS.

As before, the THS4508 amplifier provides 10 dB of gain, converts the single-ended input to differential, and sets the proper input common-mode voltage to the ADS5424. Input termination and circuit testing is the same as described above for the THS4508 + ADS5500 circuit.

The 225-Ω resistors and 2.7-pF capacitor between the THS4508 outputs and ADS5424 inputs (along with the input capacitance of the ADC) limit the bandwidth of the signal to about 100 MHz (-3 dB).

When the THS4508 is operated from a single power supply with V_{S+} = 5 V and V_{S-} = ground, the 2.5-V output common-mode voltage is compatible with the recommended value of the ADS5424 input common-mode voltage (2.4 V).

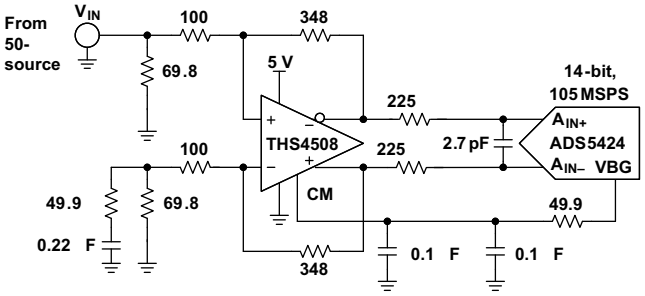

Figure 59. THS4508 + ADS5424 Circuit

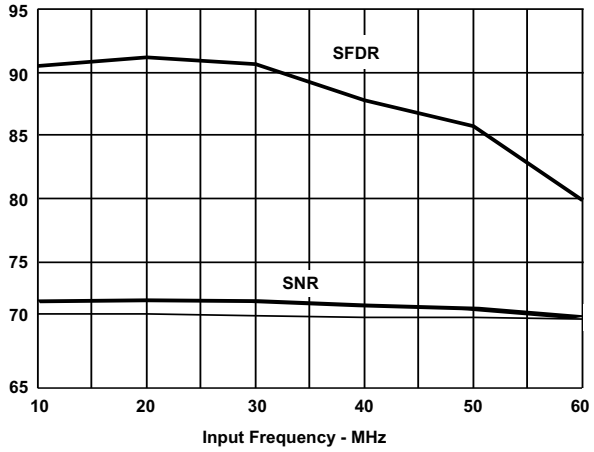

Figure 60. THS4508 + ADS5424 SFDR and SNR Performance vs Frequency

Layout Recommendations

It is recommended to follow the layout of the external components near the amplifier, ground plane construction, and power routing of the EVM as closely as possible. General guidelines are:

1. Signal routing should be direct and as short as possible into and out of the operational amplifier circuit.
2. The feedback path should be short and direct avoiding vias.
3. Ground or power planes should be removed from directly under the amplifier's input and output pins.
4. An output resistor is recommended on each output, as near to the output pin as possible.
5. Two 10-µF and two 0.1-µF power-supply decoupling capacitors should be placed as near to the power-supply pins as possible.
6. Two 0.1-µF capacitors should be placed between the CM input pins and ground. This limits noise coupled into the pins. One each should be placed to ground near pin 4 and pin 9.
7. It is recommended to split the ground pane on layer 2 (L2) as shown below and to use a solid ground on layer 3 (L3). A single-point connection should be used between each split section on L2 and L3.
8. A single-point connection to ground on L2 is recommended for the input termination resistors R1 and R2. This should be applied to the input gain resistors if termination is not used.
9. The THS4508 recommended PCB footprint is shown in Figure 61.

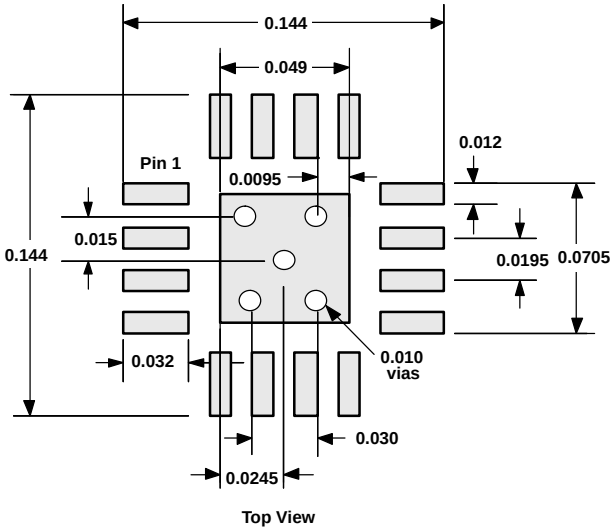

Figure 61. QFN Etch and Via Pattern

THS4508 EVM

Figure 62 is the THS4508 EVAL1 EVM schematic, layers 1 through 4 of the PCB are shown in Figure 63 through Figure 66 , and Table 5 is the bill of material for the EVM as supplied from TI.

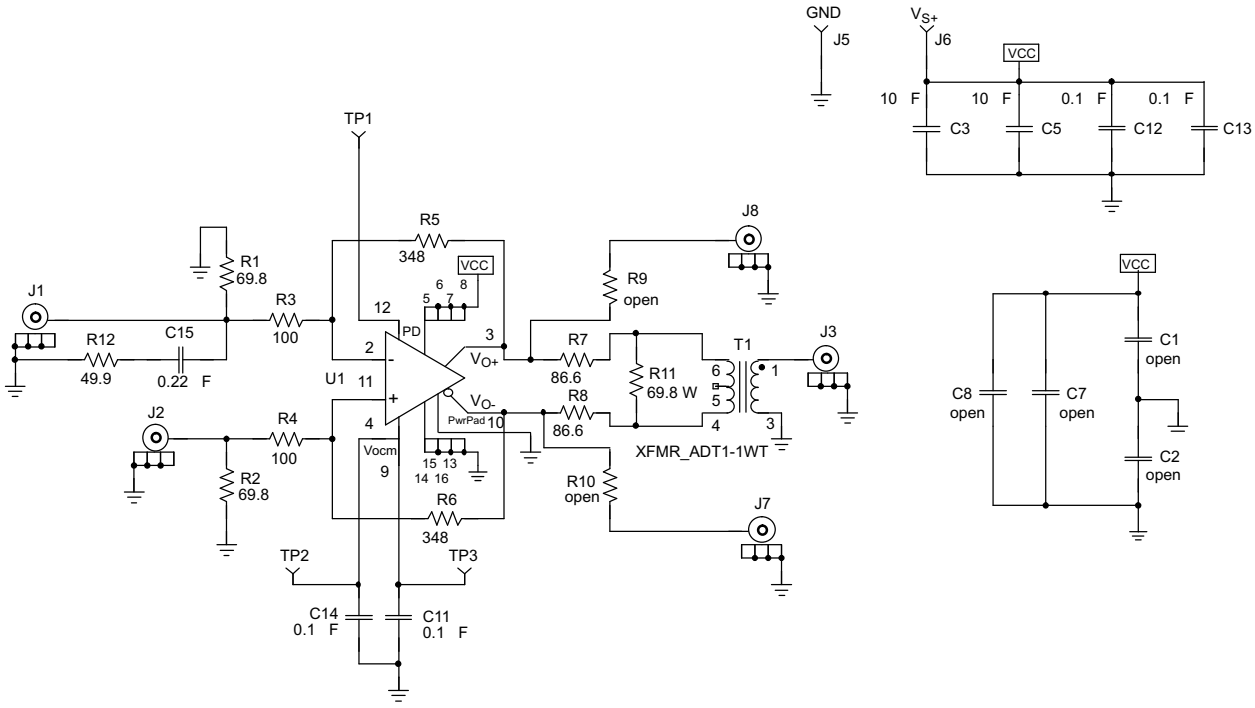

Figure 62. THS4508 EVAL1 EVM Schematic

Table 5. THS4508RGT EVM Bill of Materials

ITEM	DESCRIPTION	SMD SIZE	REFERENCE DESIGNATOR	PCB QTY	MANUFACTURER'S PART NUMBER(1)
1	CAP, 10.0 µF, Ceramic, X5R, 6.3V	0805	C3, C5	2	(AVX) 08056D106KAT2A
2	CAP, 0.1 µF, Ceramic, X5R, 10V	0402	C11, C12, C13, C14	4	(AVX) 0402ZD104KAT2A
3	CAP, 0.22 µF, Ceramic, X5R, 6.3V	0402	C15	1	(AVX) 04026D224KAT2A
4	OPEN	0402	C1, C2, C7, C8, C9, C10	6	
5	OPEN	0402	R9, R10	2	
6	Resistor, 49.9 Ω, 1/16W, 1%	0402	R12	1	(KOA) RK73H1ETTP49R9F
8	Resistor, 69.8 Ω, 1/16W, 1%	0402	R1, R2, R11	3	(KOA) RK73H1ETTP69R8F
9	Resistor, 86.6 Ω, 1/16W, 1%	0402	R7, R8	2	(KOA) RK73H1ETTP86R6F
10	Resistor, 100 Ω, 1/16W, 1%	0402	R3, R4	2	(KOA) RK73H1ETTP1000F
11	Resistor, 348 Ω, 1/16W, 1%	0402	R5, R6	2	(KOA) RK73H1ETTP3480F
12	Resistor, 0 Ω, 5%	0805	C4, C6	2	(KOA) RK73Z2ATTD
13	Transformer, RF		T1	1	(MINI-CIRCUITS) ADT1-1WT
14	Jack, banana receptance, 0.25" diameter hole		J5, J6	2	(HH SMITH) 101
15	OPEN		J1, J7, J8	3	
16	Connector, edge, SMA PCB Jack		J2, J3	2	(JOHNSON) 142-0701-801
17	Test point, Red		TP1, TP2, TP3	3	(KEYSTONE) 5000
18	IC, THS4508		U1	1	(TI) THS4508RGT
19	Standoff, 4-40 HEX, 0.625" length			4	(KEYSTONE) 1808
20	SCREW, PHILLIPS, 4-40, 0.250"			4	SHR-0440-016-SN
21	Printed circuit board			1	(TI) EDGE# 6468901

(1) The manufacturer's part numbers were used for tesr purposes only.

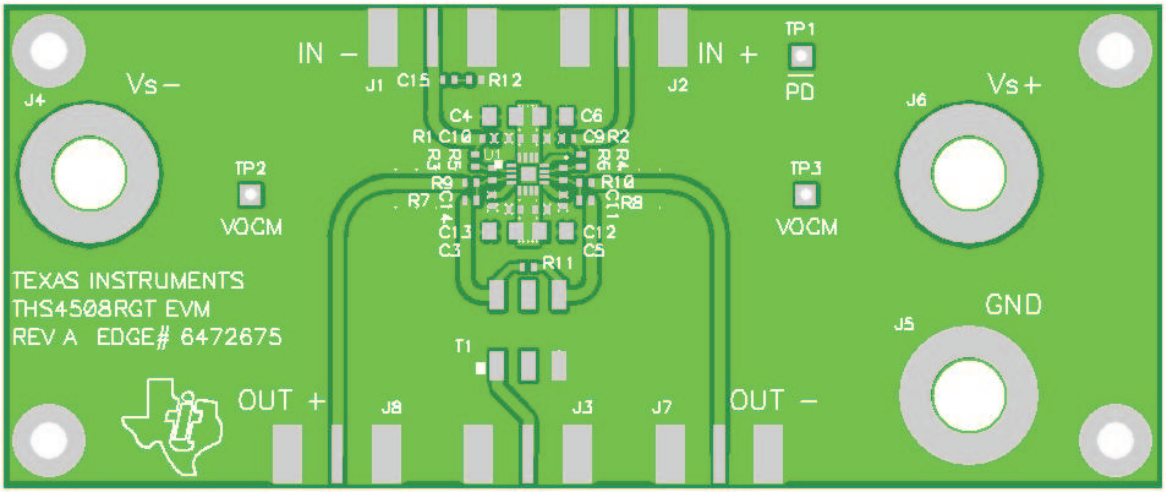

Figure 63. THS4508 EVM Top Layer

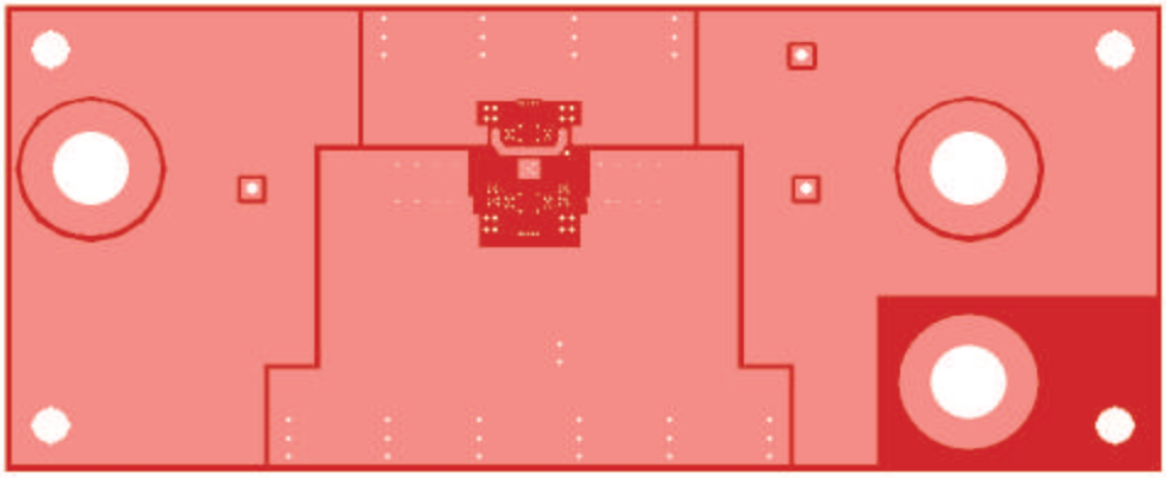

Figure 64. THS4508 EVM Layer 1

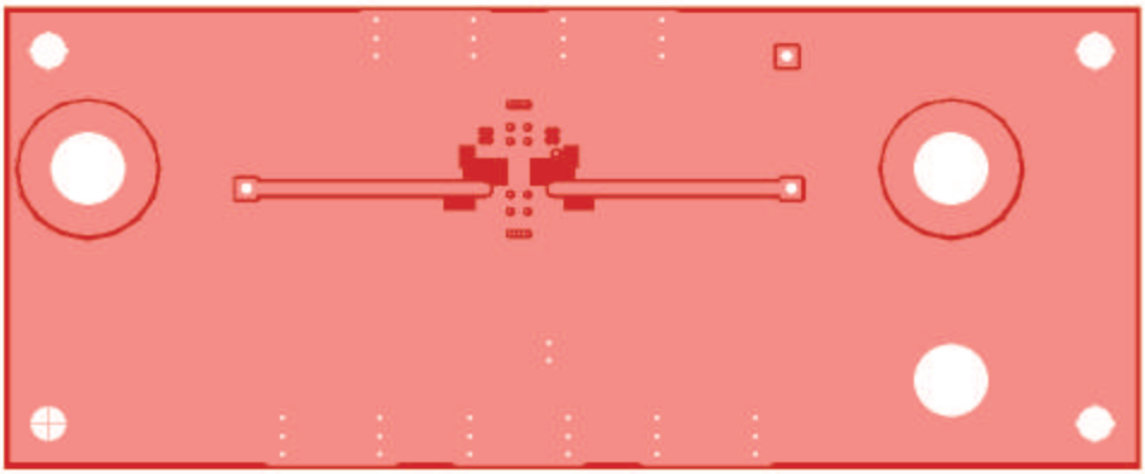

Figure 65. THS4508 EVM Layer 2

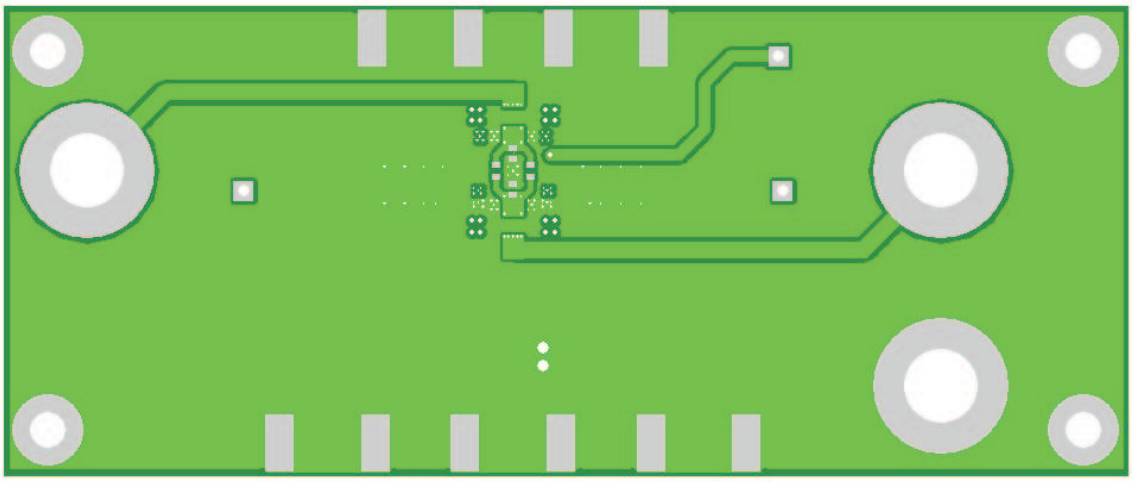

Figure 66. THS4508 EVM Bottom Layer

EVM WARNINGS AND RESTRICTIONS

It is important to operate this EVM within the input and output voltage ranges as specified in the table provided below.

Input Range, V_{S+} to V_{S-}	**3.0 V to 6.0 V**
Input Range, V_I	3.0 V to 6.0 V NOT TO EXCEED V_{S+} or V_{S-}
Output Range, V_O	3.0 V to 6.0 V NOT TO EXCEED V_{S+} or V_{S-}

Exceeding the specified input range may cause unexpected operation and/or irreversible damage to the EVM. If there are questions concerning the input range, please contact a TI field representative prior to connecting the input power.

Applying loads outside of the specified output range may result in unintended operation and/or possible permanent damage to the EVM. Please consult the product data sheet or EVM user's guide (if user's guide is available) prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative.

During normal operation, some circuit components may have case temperatures greater than 30°C. The EVM is designed to operate properly with certain components above 50°C as long as the input and output ranges are maintained. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors. These types of devices can be identified using the EVM schematic located in the material provided. When placing measurement probes near these devices during operation, please be aware that these devices may be very warm to the touch.

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PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)
THS4508RGTR	ACTIVE	QFN	RGT	16	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
THS4508RGTRG4	ACTIVE	QFN	RGT	16	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
THS4508RGTT	ACTIVE	QFN	RGT	16	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
THS4508RGTTG4	ACTIVE	QFN	RGT	16	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR

(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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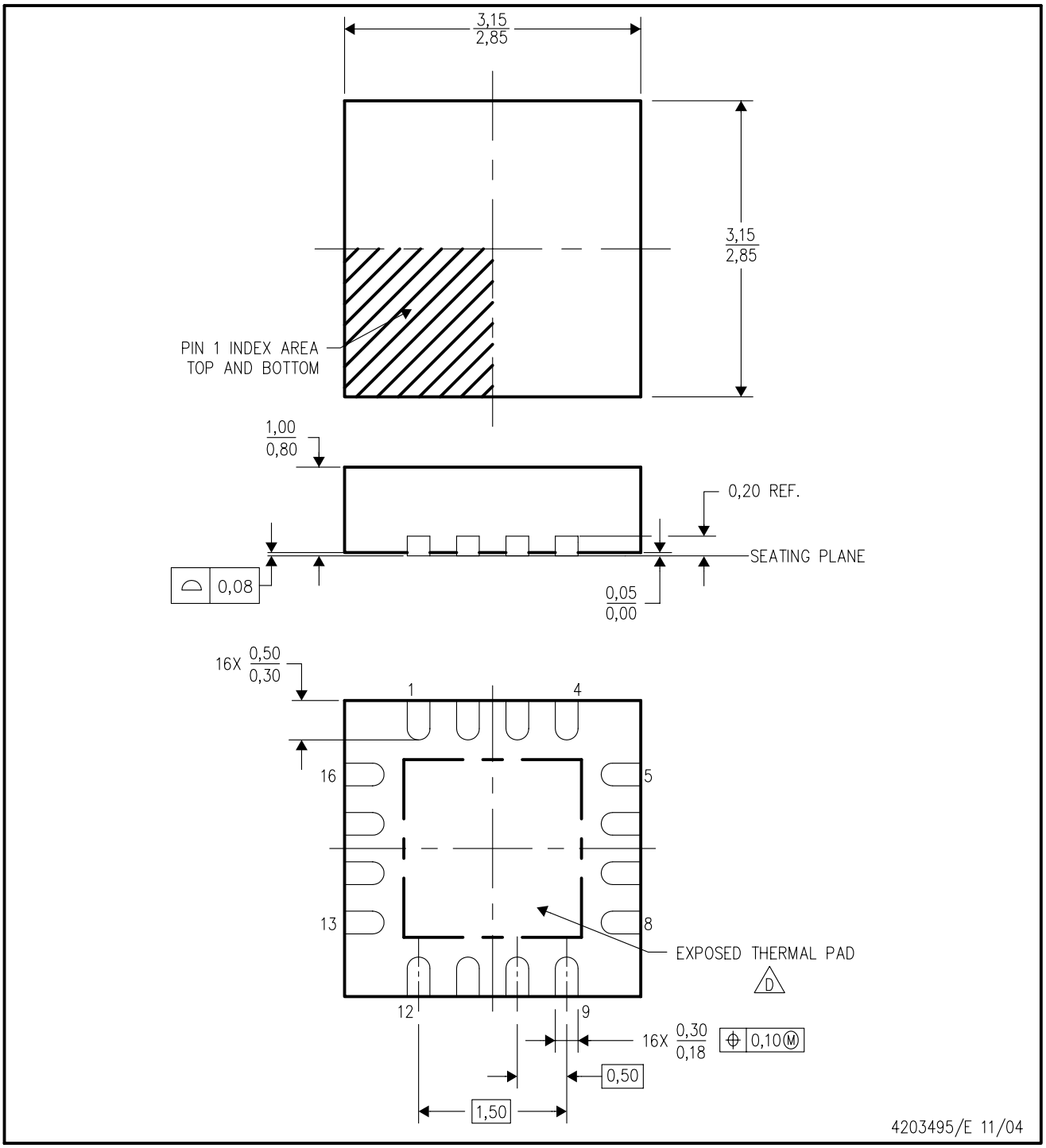
RGT (S–PQFP–N16) PLASTIC QUAD FLATPACK



NOTES:
A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M–1994.
B. This drawing is subject to change without notice.
C. Quad Flatpack, No–leads (QFN) package configuration.
D. The package thermal pad must be soldered to the board for thermal and mechanical performance. See the Product Data Sheet for details regarding the exposed thermal pad dimensions.
E. Falls within JEDEC MO–220.

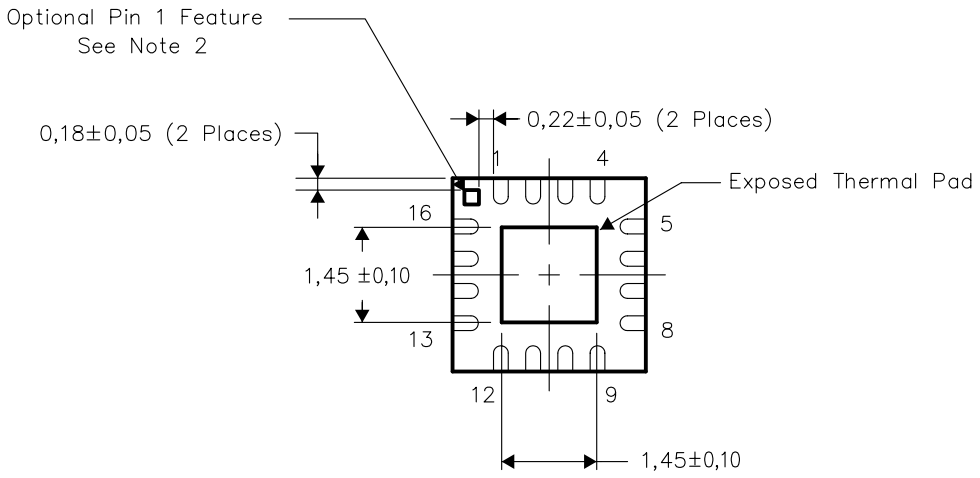
THERMAL PAD MECHANICAL DATA
RGT (S–PQFP–N16)

THERMAL INFORMATION

This package incorporates an exposed thermal pad that is designed to be attached directly to an external heatsink. The thermal pad must be soldered directly to the printed circuit board (PCB). After soldering, the PCB can be used as a heatsink. In addition, through the use of thermal vias, the thermal pad can be attached directly to a ground or power plane (whichever is applicable), or alternatively, a special heatsink structure designed into the PCB. This design optimizes the heat transfer from the integrated circuit (IC).

For information on the Quad Flatpack No–Lead (QFN) package and its advantages, refer to Application Report, Quad Flatpack No–Lead Logic Packages, Texas Instruments Literature No. SCBA017. This document is available at www.ti.com.

The exposed thermal pad dimensions for this package are shown in the following illustration.

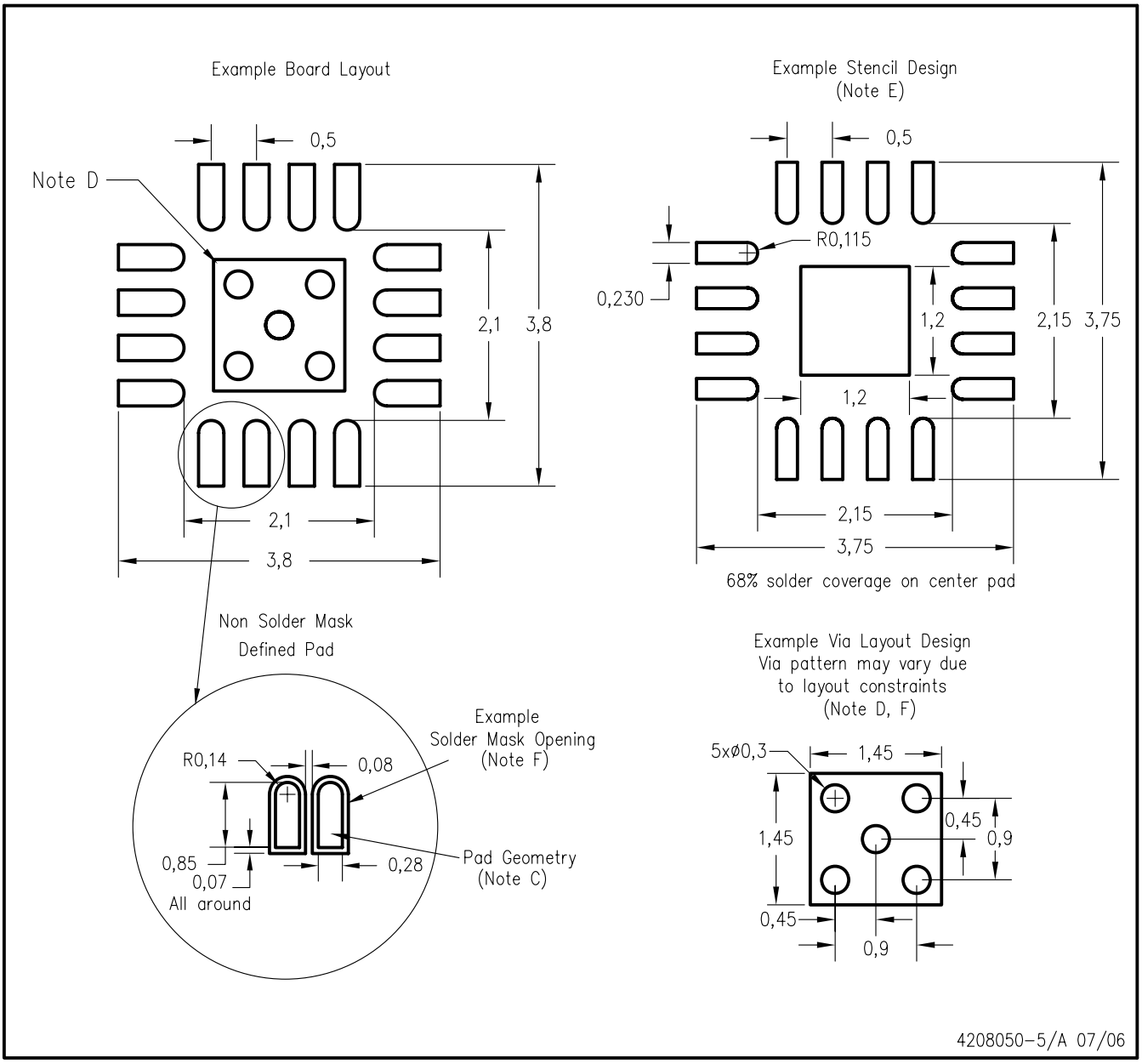


Bottom View

Exposed Thermal Pad Dimensions

NOTES:
1) All linear dimensions are in millimeters
2) The Pin 1 Identification mark is an optional feature that may be present on some devices In addition, this Pin 1 feature if present is electrically connected to the center thermal pad and therefore should be considered when routing the board layout.

RGT (S–PQFP–N16)



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. This package is designed to be soldered to a thermal pad on the board. Refer to Application Note, Quad Flat–Pack Packages, Texas Instruments Literature No. SCBA017, SLUA271, and also the Product Data Sheets for specific thermal information, via requirements, and recommended board layout. These documents are available at www.ti.com <http://www.ti.com>.
E. 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 stencil design considerations.
F. Customers should contact their board fabrication site for minimum solder mask web tolerances between signal pads.

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