

FEATURES

- **Microsoft™ Windows Vista™ Compliant**
- **Fully Differential Architecture and High PSRR Provide Excellent RF Rectification Immunity**
- **2.1-W, 1% THD+N Into 4-Ω Speakers and 85-mW, 1% THD+N Into 16-Ω Headphones From 5-V Supply**
- **DirectPath™ Headphone Amplifier Eliminates Output Capacitors ⁽¹⁾**
- **Internal 4-Step Speaker Gain Control: 10, 12, 15.6, 21.6 dB and Fixed -1.5-V/V Headphone**
- **3.3-V Low Dropout Regulator for CODEC**
- **Independent Shutdown Controls for Speaker, Headphone Amplifier, and Low Dropout Regulator (LDO)**
- **Output Short-Circuit and Thermal Protection**

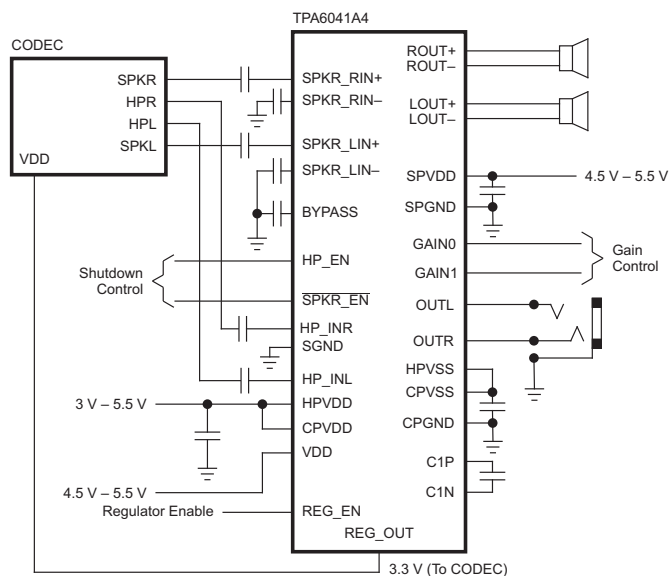
The TPA6041A4 is a stereo audio power amplifier and DirectPath™ headphone amplifier in a thermally enhanced, space-saving, 32-pin QFN package. The speaker amplifier is capable of driving 2.1 W per channel continuously into 4-Ω loads at 5 V. The headphone amplifier achieves a minimum of 85 mW at 1% THD+N from a 5-V supply. A built-in internal 4-step gain control for the speaker amplifier and a fixed -1.5 V/V gain for the headphone amplifier minimizes external components needed.

Independent shutdown control and dedicated inputs for the speaker and headphone allow the TPA6041A4 to simultaneously drive both headphones and internal speakers. Differential inputs to the speaker amplifiers offer superior power-supply and common-mode noise rejection.

- Notebook Computers
- Portable DVD

(1) US Patent Number 5289137

SIMPLIFIED APPLICATION CIRCUIT



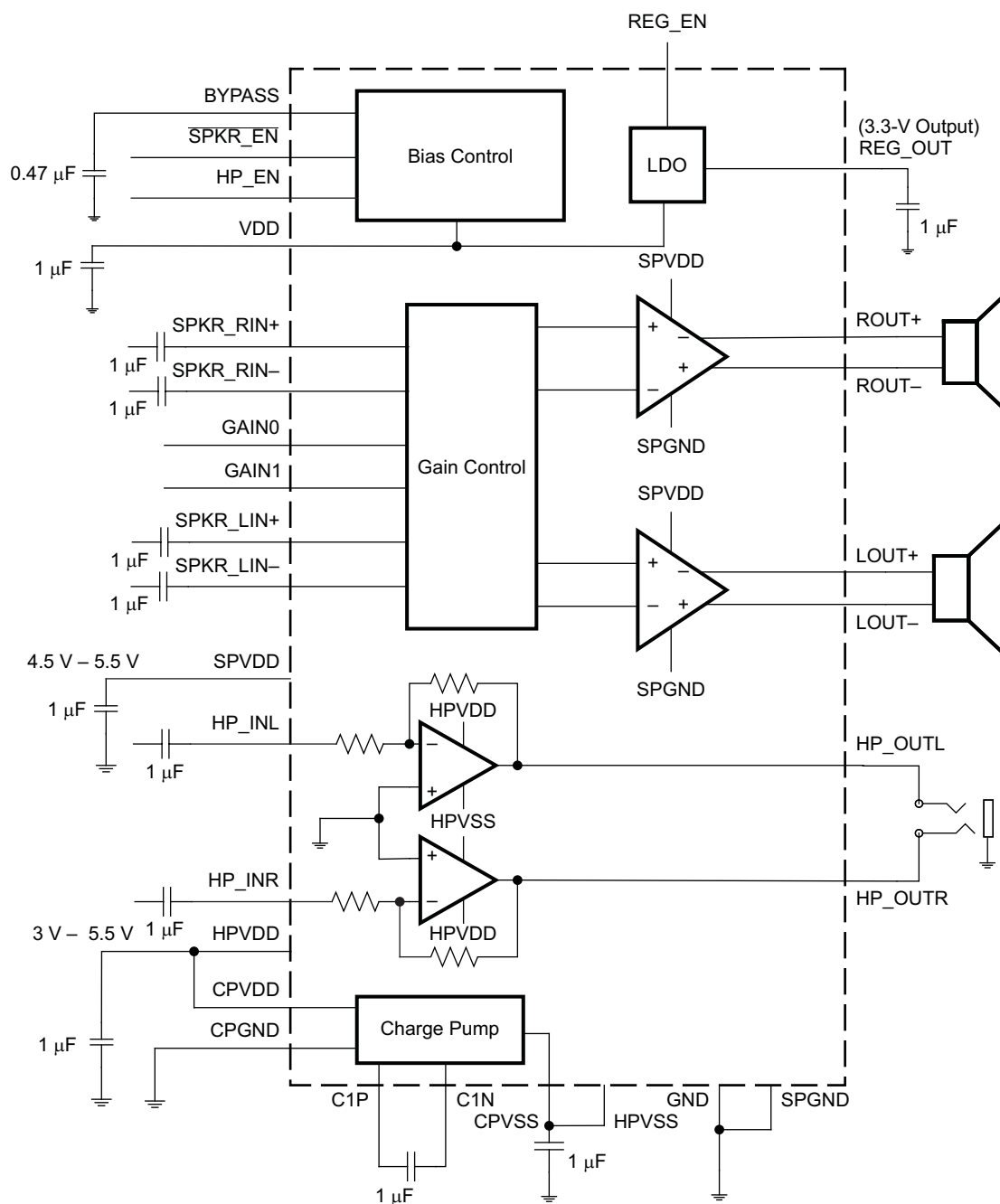
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These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

Functional Block Diagram

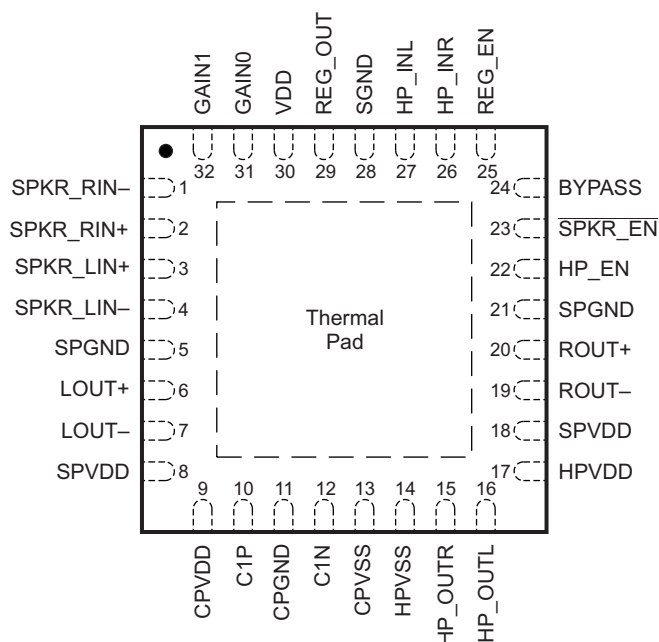


AVAILABLE PACKAGE OPTIONS

T _A	PACKAGED DEVICE ⁽¹⁾⁽²⁾ 32-Pin QFN (RHB)	SYMBOL
–40°C to 85°C	TPA6041A4RHB	RHB

- (1) The RHB package is available taped and reeled. To order a taped and reeled part, add the suffix R to the part number (e.g., TPA6041A4RHBR).
- (2) 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.

**TPA6041A4RHB
(TOP VIEW)**



TERMINAL FUNCTIONS

TERMINAL		I/O/P	DESCRIPTION
NAME	NO.		
SPKR_RIN–	1	I	Right-channel negative differential audio input for speaker amplifier
SPKR_RIN+	2	I	Right-channel positive differential audio input for speaker amplifier
SPKR_LIN+	3	I	Left-channel positive differential audio input for speaker amplifier
SPKR_LIN–	4	I	Left-channel negative differential audio input for speaker amplifier
SPGND	5, 21	P	Speaker power ground
LOUT+	6	O	Left-channel positive audio output
LOUT–	7	O	Left-channel negative audio output
SPVDD	8, 18	P	Supply voltage terminal for speaker amplifier
CPVDD	9	P	Charge pump positive supply, connect to HPVDD via star connection
C1P	10	I/O	Charge pump flying capacitor positive terminal
CPGND	11	P	Charge pump ground
C1N	12	I/O	Charge pump flying capacitor negative terminal
CPVSS	13	P	Charge pump output (negative supply for headphone amplifier), connect to HPVSS
HPVSS	14	P	Headphone amplifier negative supply, connect to CPVSS
HP_OUTR	15	O	Right-channel capacitor-free headphone output
HP_OUTL	16	O	Left-channel capacitor-free headphone output
HPVDD	17	P	Headphone amplifier supply voltage, connect to CPVDD
ROUT–	19	O	Right-channel negative audio output

TERMINAL FUNCTIONS (continued)

TERMINAL		I/O/P	DESCRIPTION
NAME	NO.		
ROUT+	20	O	Right-channel positive audio output
HP_EN	22	I	Headphone channel enable logic input; active high enable. HIGH=ENABLE.
SPKR_EN	23	I	Speaker channel enable logic input; active low enable. LOW=ENABLE.
BYPASS	24	P	Common-mode bias voltage for speaker preamplifiers
REG_EN	25	I	Enable pin (Active HIGH) for turning on/off LDO. HIGH=ENABLE
HP_INR	26	I	Headphone right-channel audio input
HP_INL	27	I	Headphone left-channel audio input
SGND	28	P	Signal ground, connect to CPGND and SPGND
REG_OUT	29	O	Regulated 3.3-V output
VDD	30	P	Positive power supply
GAIN0	31	I	Bit 0, MSB, of gain select bits
GAIN1	32	I	Bit 1, LSB, of gain select bits
Thermal Pad	Die Pad	P	Solder the thermal pad on the bottom of the QFN package to the GND plane of the PCB. It is required for mechanical stability and will enhance thermal performance.

ABSOLUTE MAXIMUM RATINGSover operating free-air temperature range (unless otherwise noted)⁽¹⁾

		VALUE	UNIT
Supply voltage	HPVDD, VDD, SPVDD, CPVDD	–0.3 to 6	V
V _I Input voltage	SPKR_LIN+, SPKR_LIN-, SPKR_RIN+, SPKR_RIN-, HP_EN, GAIN0, GAIN1, SPK_EN, REG_EN	–0.3 to 6.3	V
	HP_INL, HP_INR HP Enabled	–3.5 to 3.5	
	HP_INL, HP_INR HP not Enabled	–0.3 to 3.5	
	Continuous total power dissipation		See Dissipation Rating Table
T _A Operating free-air temperature range		–40 to 85	°C
T _J Operating junction temperature range		–40 to 150	°C
T _{stg} Storage temperature range		–65 to 150	°C
Electrostatic discharge	HBM for HP_OUTL and HP_OUTR	8	kV
Electrostatic discharge, all other pins	CDM	500	V
	HBM	2	kV

- (1) Stresses beyond those listed under *absolute maximum ratings* may cause permanent damage to the device. These are stress ratings only, and functional operations of the device at these or any other conditions beyond those indicated under *recommended operating conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

DISSIPATION RATINGS

PACKAGE ⁽¹⁾	T _A ≤ 25°C	DERATING FACTOR	T _A = 70°C	T _A = 85°C
RHB	5.06 W	40 mW/°C	4.04 W	3.23 W

- (1) The PowerPAD™ must be soldered to a thermal land on the printed-circuit board. Refer to the Texas Instruments document, PowerPAD™ Thermally Enhanced Package application report (literature number SLMA002) for more information regarding the PowerPAD™ package.

RECOMMENDED OPERATING CONDITIONS

		MIN	MAX	UNIT
Supply voltage	VDD, SPVDD	4.5	5.5	V
Supply voltage	HPVDD, CPVDD	3	5.5	V
V _{IH} High-level input voltage	SPKR_EN, HP_EN, GAIN0, GAIN1, REG_EN	2		V

RECOMMENDED OPERATING CONDITIONS (continued)

			MIN	MAX	UNIT
V _{IL}	Low-level input voltage	SPKR_EN, HP_EN, GAIN0, GAIN1, REG_EN		0.8	V
T _A	Operating free-air temperature		–40	85	°C

GENERAL DC ELECTRICAL CHARACTERISTICS

T_A = 25°C, VDD = SPVDD = HPVDD = CPVDD = 5 V (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
I _{IH}	High-level input current SPKR_EN, HP_EN, GAIN0, GAIN1, REG_EN = VDD		0.02	1	μA
I _{IL}	Low-level input current SPKR_EN, HP_EN, GAIN0, GAIN1, REG_EN = 0 V		0.02	1	μA
I _{DD(Speaker)}	Supply current, speaker amplifier ONLY enabled SPKR_EN = 0 V, HP_EN = REG_EN = 0 V		5	12	mA
I _{DD(HP)}	Supply current, headphone amplifier ONLY enabled SPKR_EN = HP_EN = 2 V, REG_EN = 0 V		7.5	14	mA
I _{DD(REG)}	Supply current, regulator ONLY enabled SPKR_EN = REG_EN = 2 V, HP_EN = 0 V		0.65	1	mA
I _{DD(SD)}	Supply current, shutdown mode SPKR_EN = 2 V, HP_EN = REG_EN = 0 V		2.5	5	μA

SPEAKER AMPLIFIER DC CHARACTERISTICS

T_A = 25°C, VDD = SPVDD = 5 V, R_L = 4 Ω, Gain = 10 dB (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
V _{OO}	Output offset voltage (measured differentially) Inputs AC-coupled to GND, Gain = 10 dB		0.5	10	mV
PSRR	Power supply rejection ratio VDD = SPVDD = 4.5 V to 5.5 V	–60	–74		dB

SPEAKER AMPLIFIER AC CHARACTERISTICS

T_A = 25°C, VDD = SPVDD = 5 V, R_L = 4 Ω, Gain = 10 dB (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
P _O	THD+N = 1%, f = 1 kHz, R _L = 8 Ω		1.3		W
	THD+N = 10%, f = 1 kHz, R _L = 8 Ω		1.6		
	THD+N = 1%, f = 1 kHz, R _L = 4 Ω		2.1		
	THD+N = 10%, f = 1 kHz, R _L = 4 Ω		2.6		
THD+N	P _O = 1 W, R _L = 8 Ω, f = 20 Hz to 20 kHz		0.06%		
	P _O = 1 W, R _L = 4 Ω, f = 20 Hz to 20 kHz		0.1%		
kSVR	f = 1 kHz, CBYPASS = 0.47 μF, R _L = 8 Ω V _{RIPPLE} = 200 mV _{PP}		–53		dB
SNR	Maximum output at THD+N <1%, f = 1 kHz, Gain = 10 dB		90		dB
Crosstalk (Left-Right; Right-Left)	f = 1 kHz, P _O = 1 W, Gain = 10 dB		–110		dB
	f = 10 kHz, P _O = 1 W, Gain = 10 dB		–100		dB
V _n	CBYPASS = 0.47 μF, f = 20 Hz to 20 kHz, Gain = 10 dB, No weighting		21		μV _{rms}
Z _I	Gain = 21.6 dB	15	20		kΩ
G	GAIN0, GAIN1 = 0.8 V	9.4	10	10.6	dB
	GAIN0 = 0.8 V; GAIN1 = 2 V	11.4	12	12.6	
	GAIN0 = 2 V, GAIN1 = 0.8 V	15	15.6	16.2	
	GAIN0, GAIN1 = 2 V	21	21.6	22.2	
Gain Matching		Channel-to Channel		0.01	dB
Start-up time from shutdown		CBYPASS = 0.47 μF		25	ms

HEADPHONE AMPLIFIER DC ELECTRICAL CHARACTERISTICS
 $T_A = 25^\circ\text{C}$, $\text{HPVDD} = \text{CPVDD} = \text{VDD} = 5\text{ V}$, $R_L = 16\ \Omega$ (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
$ V_{OS} $ Output offset voltage	Inputs grounded		1	3	mV
PSRR Power supply rejection ratio	HPVDD = 4.5 V to 5.5 V	-75	-100		dB

HEADPHONE AMPLIFIER AC CHARACTERISTICS
 $T_A = 25^\circ\text{C}$, $\text{HPVDD} = 5\text{ V}$, $R_L = 16\ \Omega$ (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
P_O Output power (outputs in phase)	THD+N = 10%, $R_L = 16\ \Omega$, $f = 1\text{ kHz}$		200		mW
	THD+N = 10%, $R_L = 32\ \Omega$, $f = 1\text{ kHz}$		100		
THD+N Total harmonic distortion plus noise	$P_O = 85\text{ mW}$, $f = 20\text{ Hz to }20\text{ kHz}$, $R_L = 16\ \Omega$		0.03%		
	$P_O = 50\text{ mW}$, $f = 20\text{ Hz to }20\text{ kHz}$, $R_L = 32\ \Omega$		0.04%		
Dynamic Range with Signal Present	A-Weighted, $f = 20\text{ Hz to }20\text{ kHz}$		-100		dB FS
kSVR Supply ripple rejection ratio	$f = 1\text{ kHz}$, 200-mV _{PP} ripple		-60		dB
Crosstalk	$P_O = 35\text{ mW}$, $f = 20\text{ Hz to }20\text{ kHz}$		-80		dB
SNR Signal-to-noise ratio	Maximum output at THD+N 1%, $f = 1\text{ kHz}$		95		dB
V_n Noise output voltage	$f = 20\text{ Hz to }20\text{ kHz}$, No weighting		20		μV_{rms}
Z_i Input Impedance		15	20		k Ω
Gain Closed-loop voltage gain	$R_L = 16\ \Omega$	-1.45	-1.5	-1.55	V/V
Start-up time from shutdown			5		ms

LDO CHARACTERISTICS
 $T_A = 25^\circ\text{C}$, $\text{VDD} = 5\text{ V}$ (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_I Input voltage	V_{DD}	4.5		5.5	V
I_O Continuous output current		120			mA
V_O Output voltage	$0 < I_O < 120\text{ mA}$; $4.9\text{ V} < V_{in} < 5.5\text{ V}$	3.2	3.3	3.4	V
Line regulation	$I_L = 5\text{ mA}$; $4.9\text{ V} < V_{in} < 5.5\text{ V}$		1.8	10	mV
Load regulation	$I_L = 0 - 120\text{ mA}$, $V_{in} = 5\text{ V}$		0.13	0.23	mV/ mA
Power supply ripple rejection	$V_{DD} = 4.9\text{ V}$, $I_L = 10\text{ mA}$ $f = 100\text{ Hz}$		-46		dB

TYPICAL CHARACTERISTICS

Default graph conditions: $V_{CC} = 5\text{ V}$, Freq = 1 kHz, AES17 Filter.

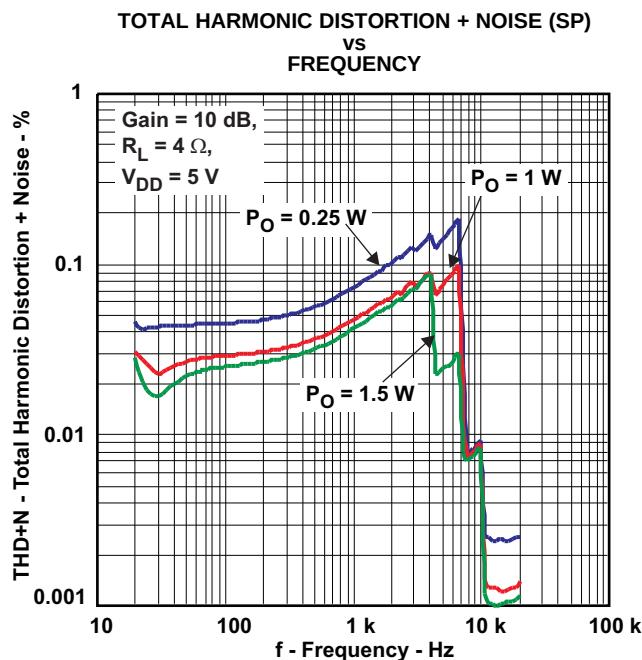


Figure 1.

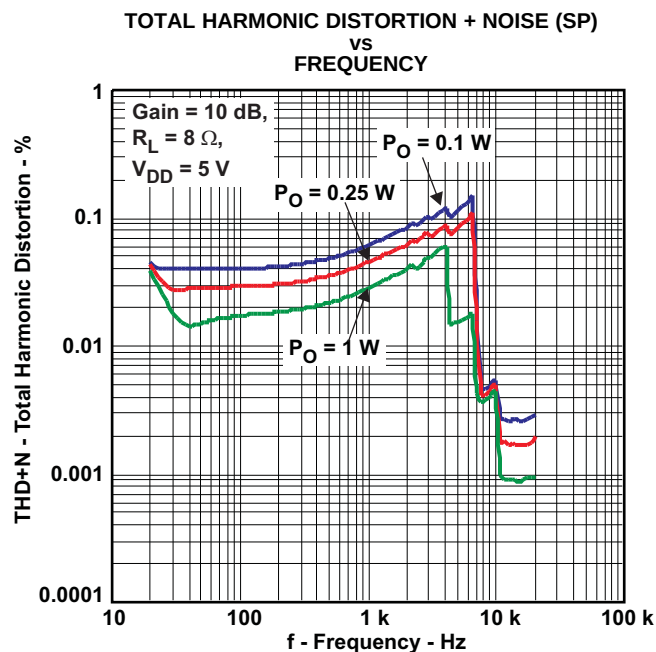


Figure 2.

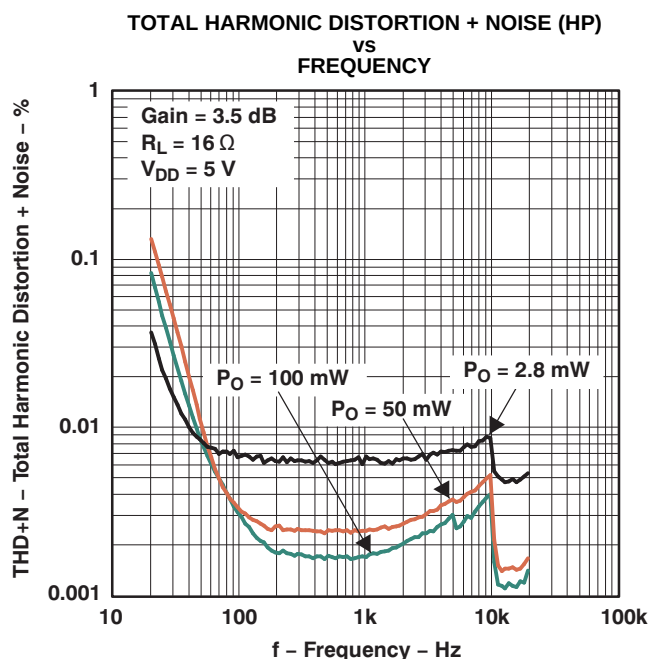


Figure 3.

G003

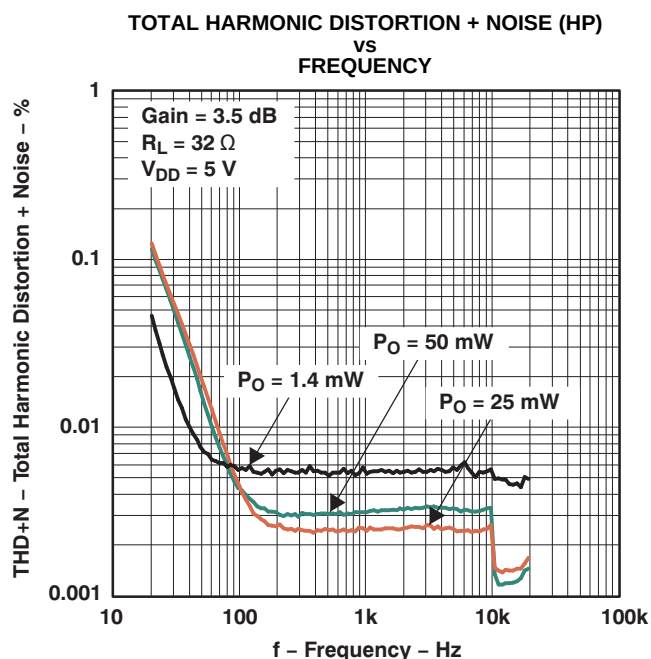


Figure 4.

G004

TYPICAL CHARACTERISTICS (continued)

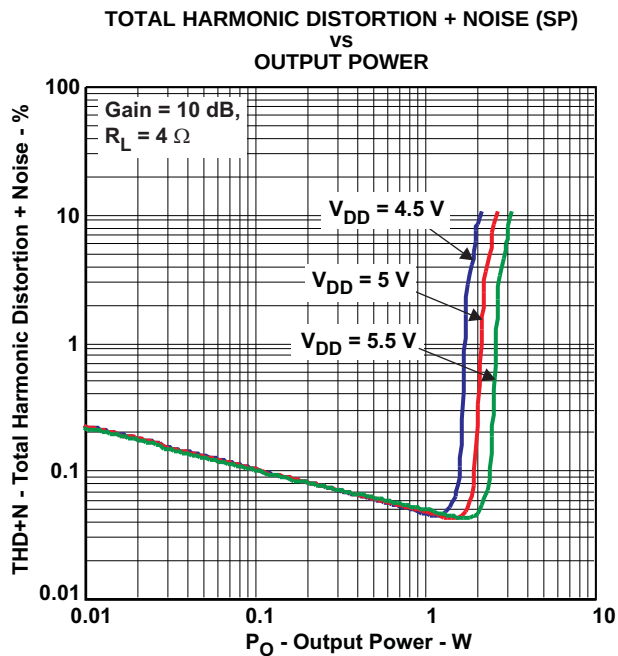


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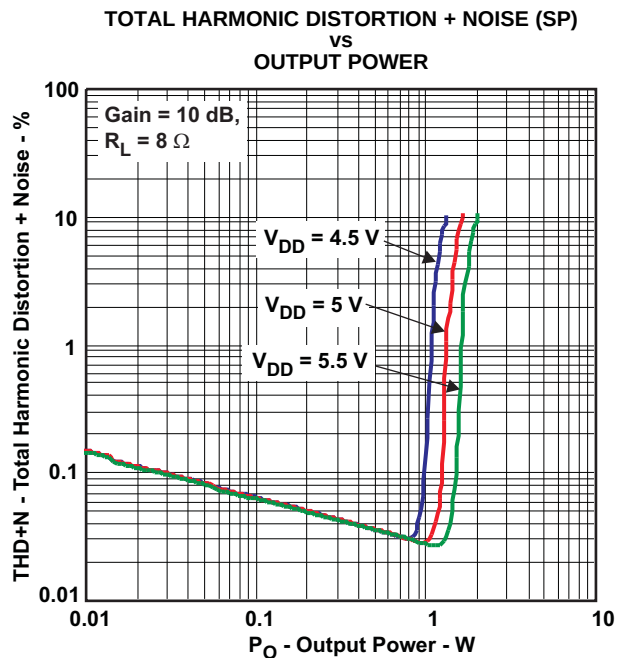


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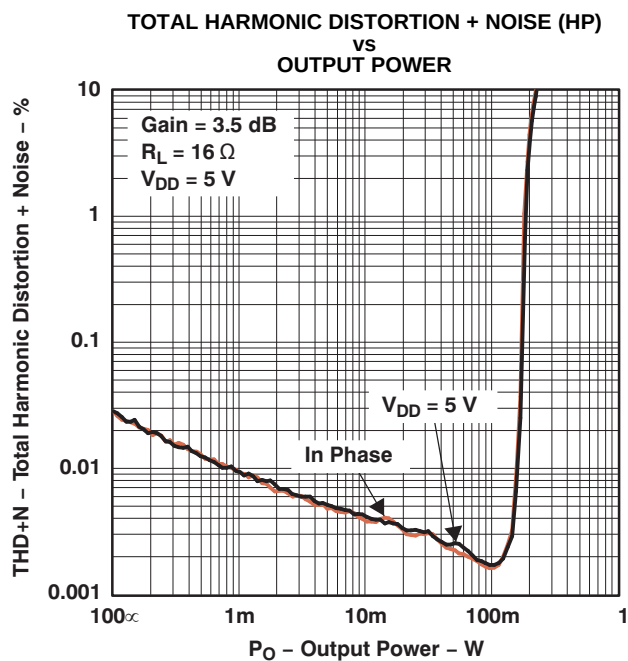


Figure 7.

G007

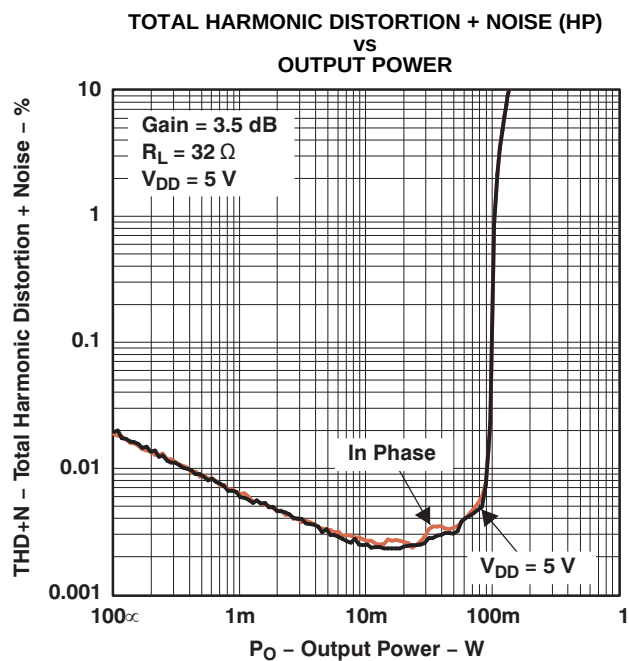


Figure 8.

G008

TYPICAL CHARACTERISTICS (continued)

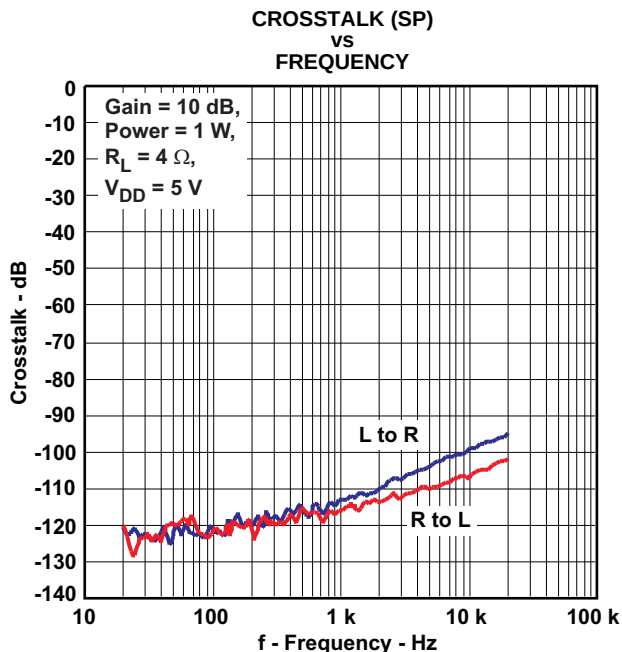


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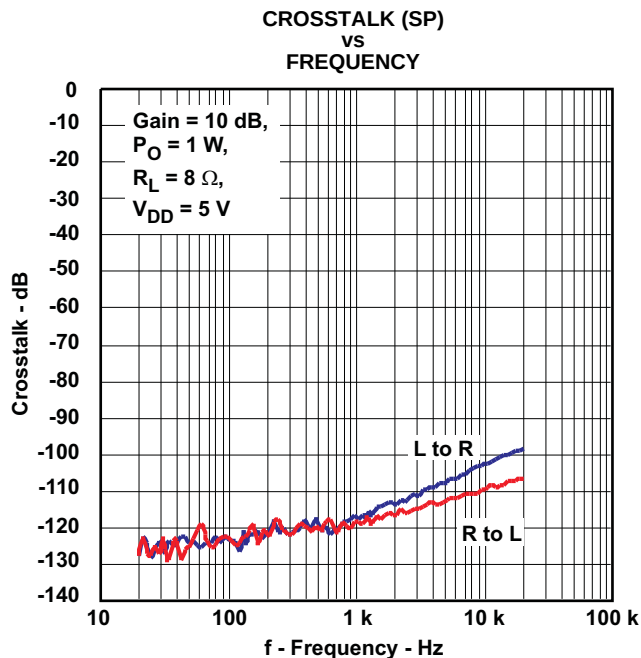


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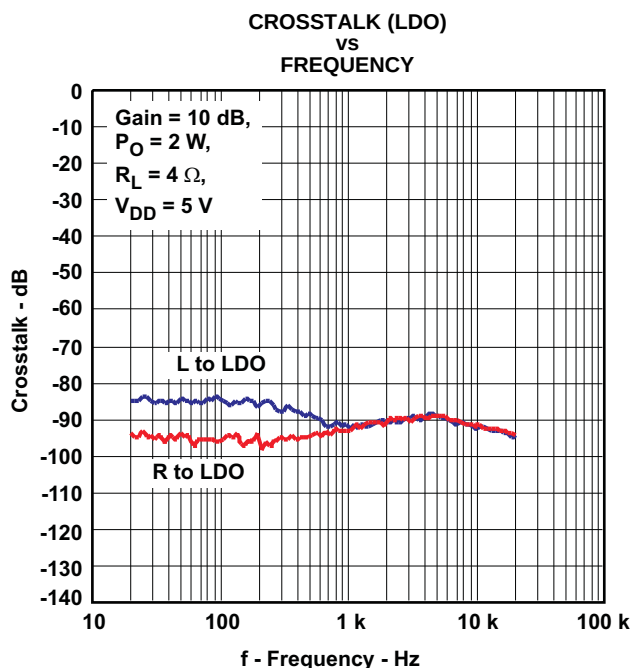


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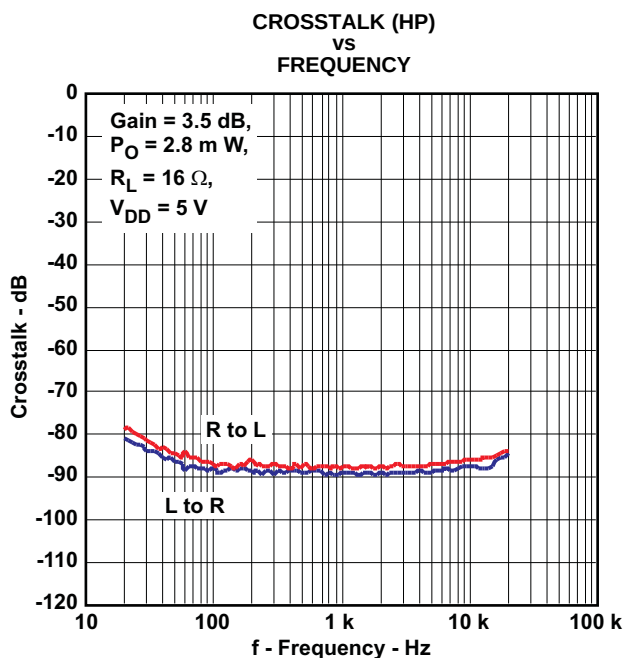


Figure 12.

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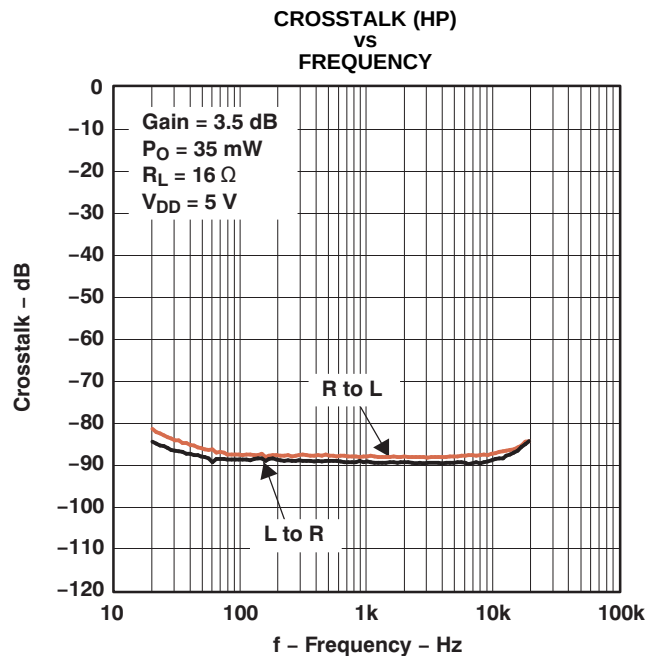


Figure 13.

G012

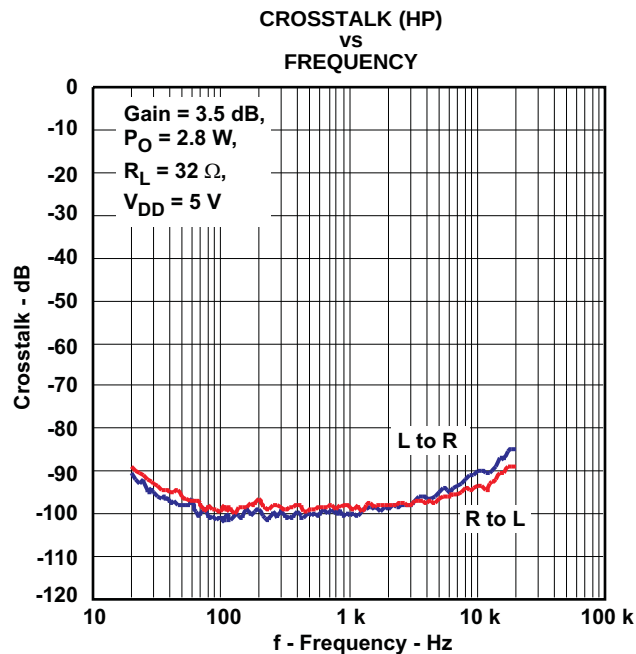


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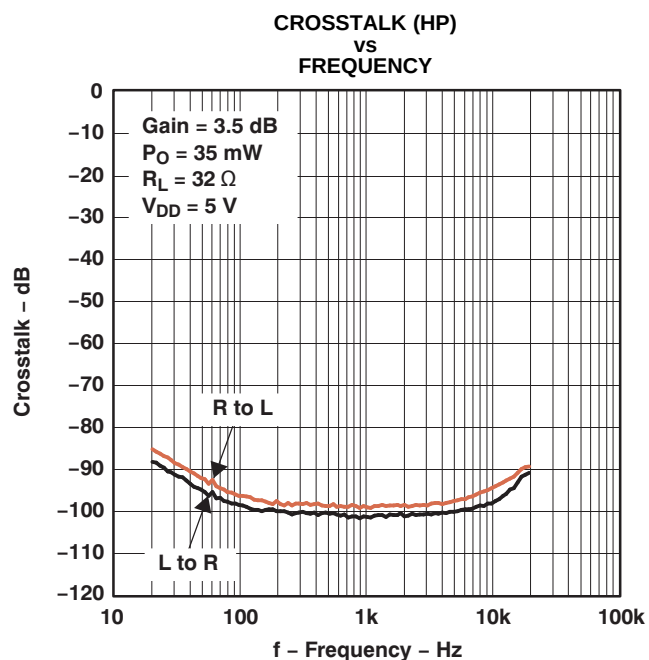


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G013

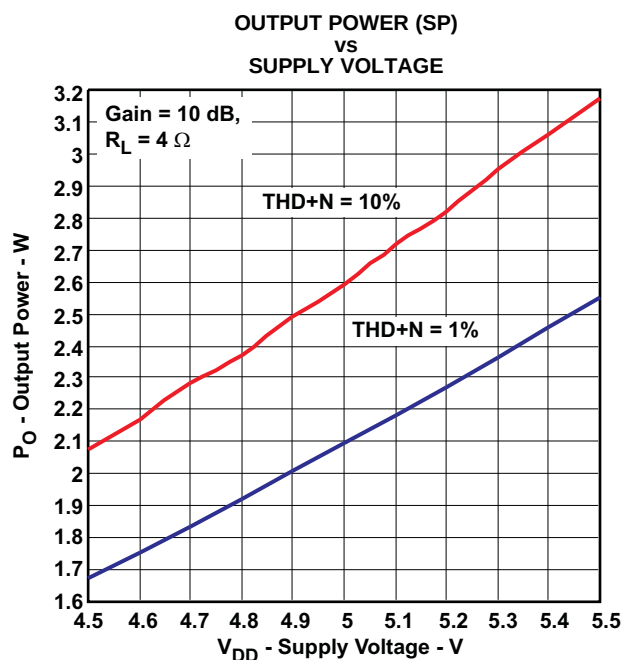


Figure 16.

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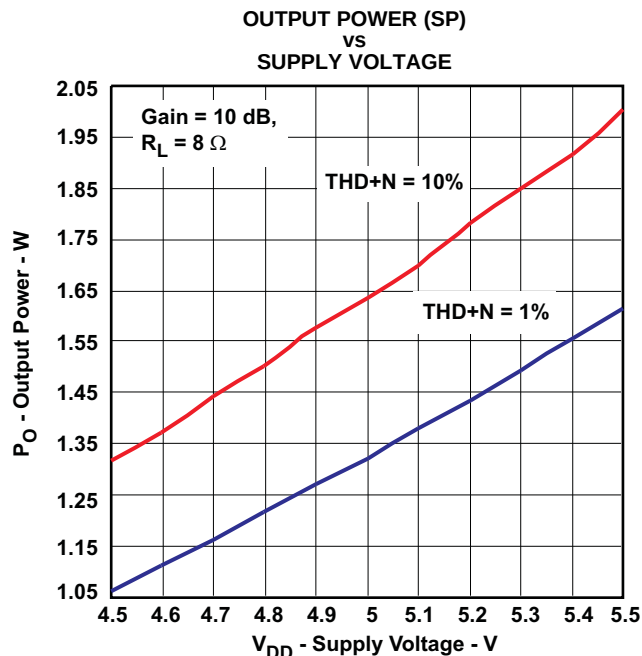


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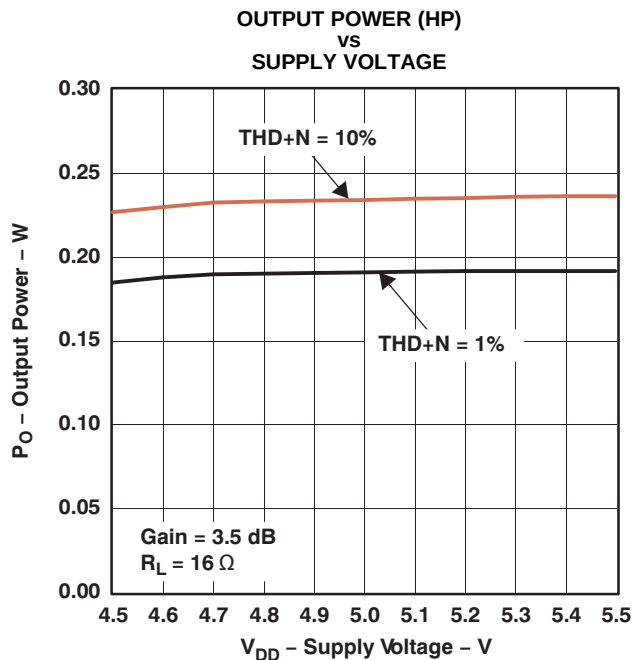


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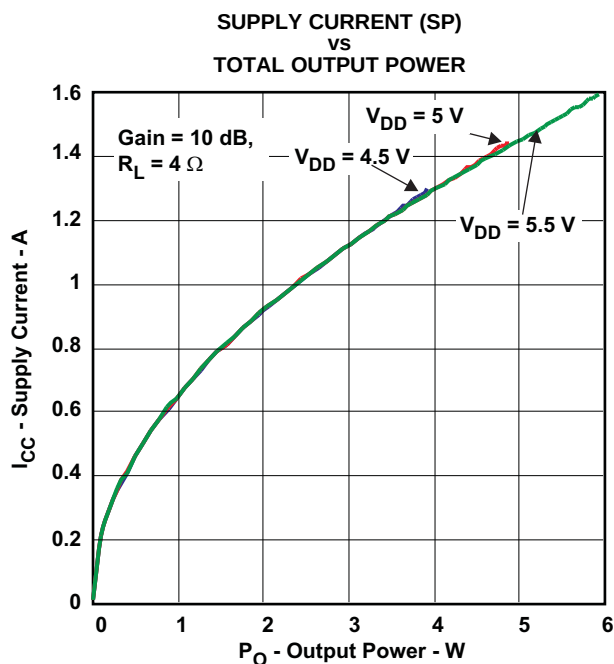


Figure 19.

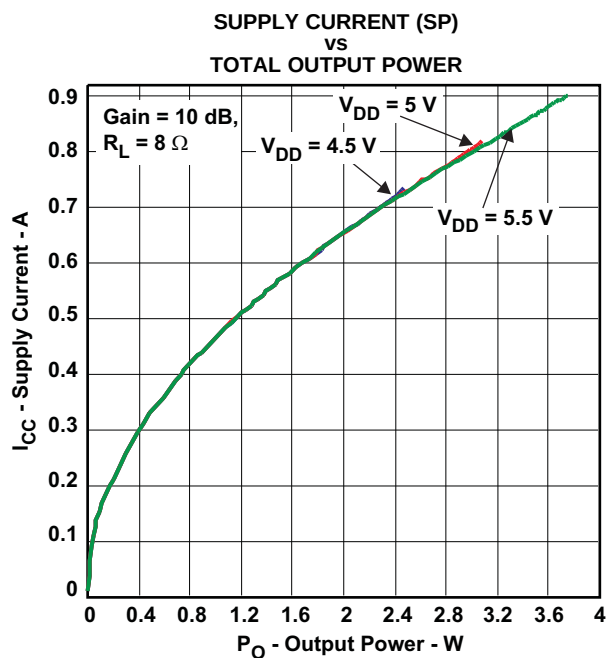


Figure 20.

TYPICAL CHARACTERISTICS (continued)

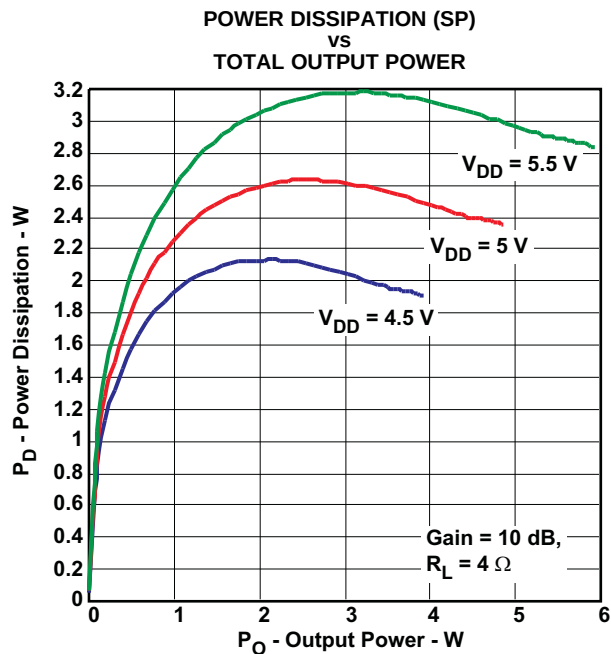


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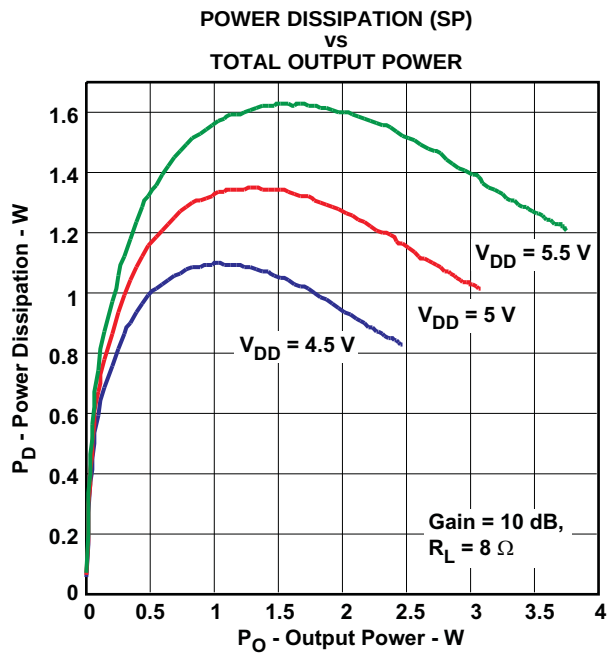


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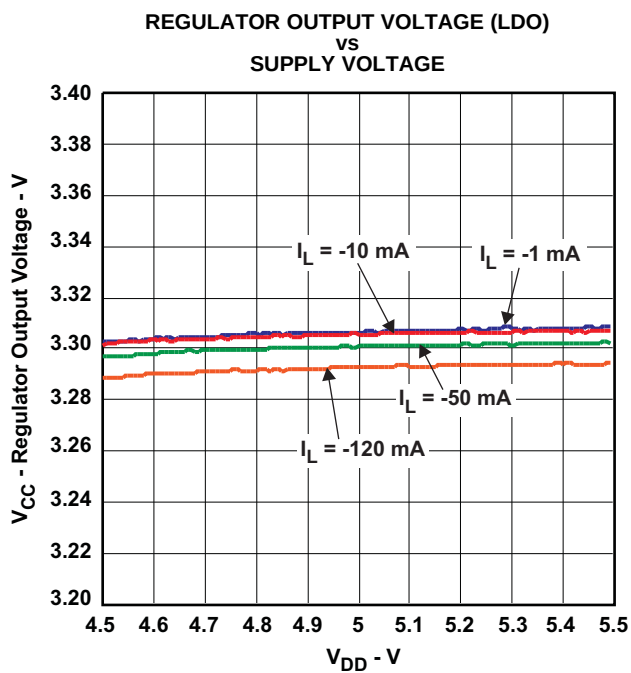


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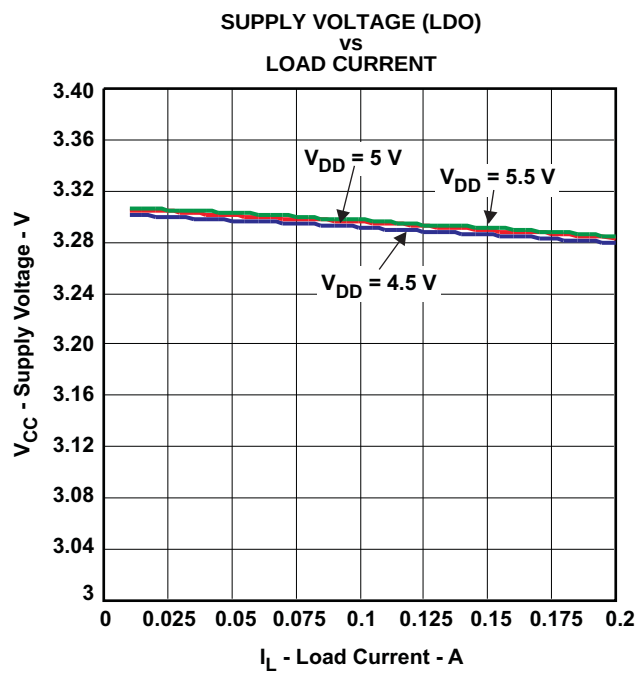


Figure 24.

TYPICAL CHARACTERISTICS (continued)

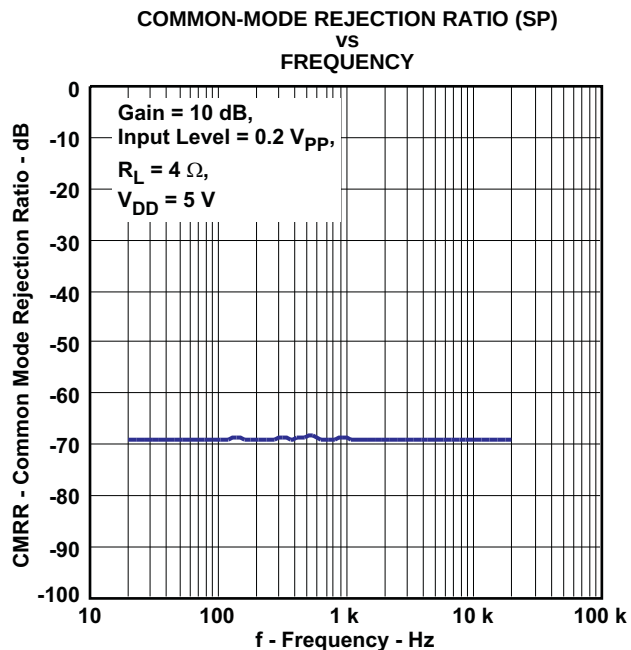


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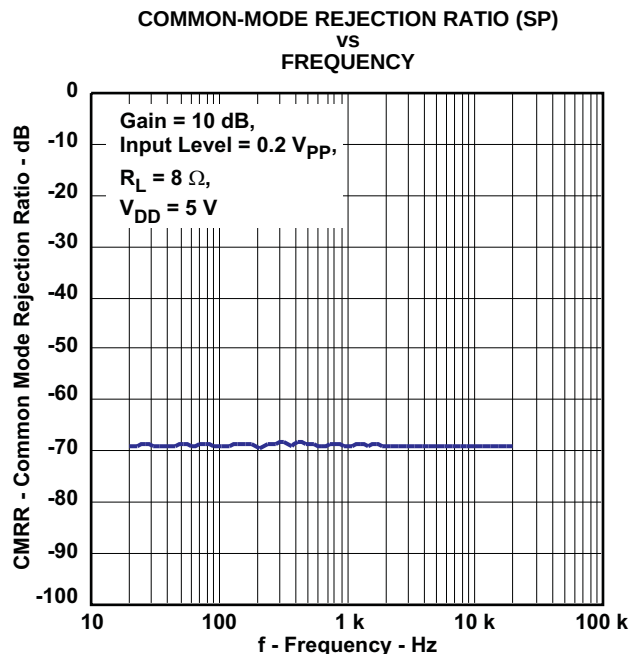


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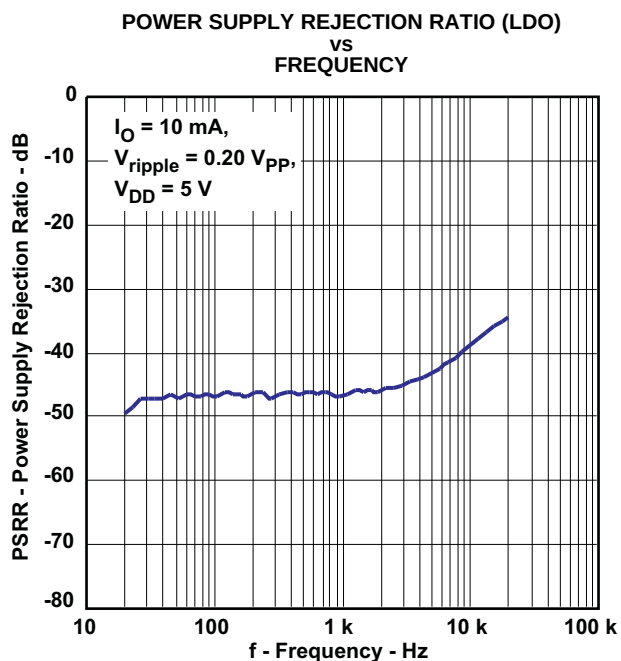


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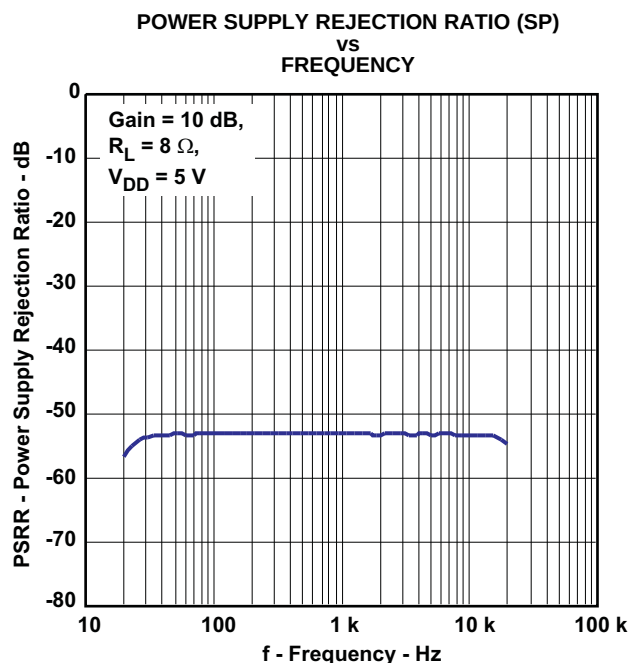


Figure 28.

TYPICAL CHARACTERISTICS (continued)

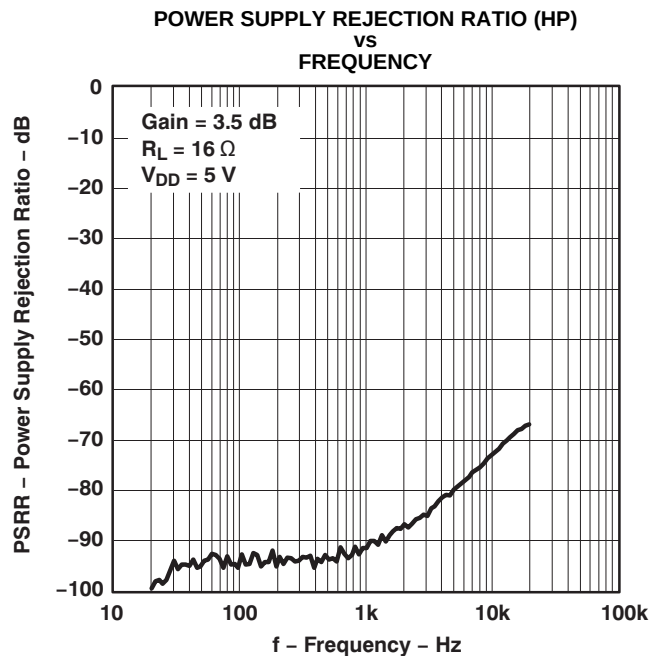


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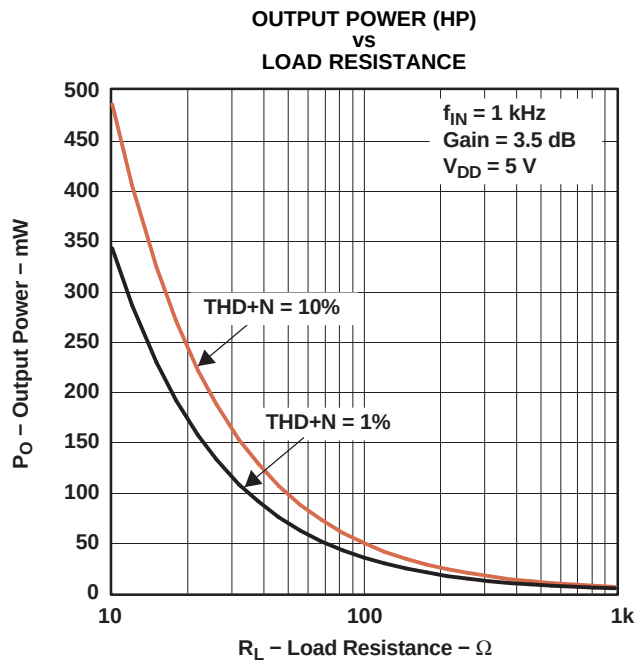


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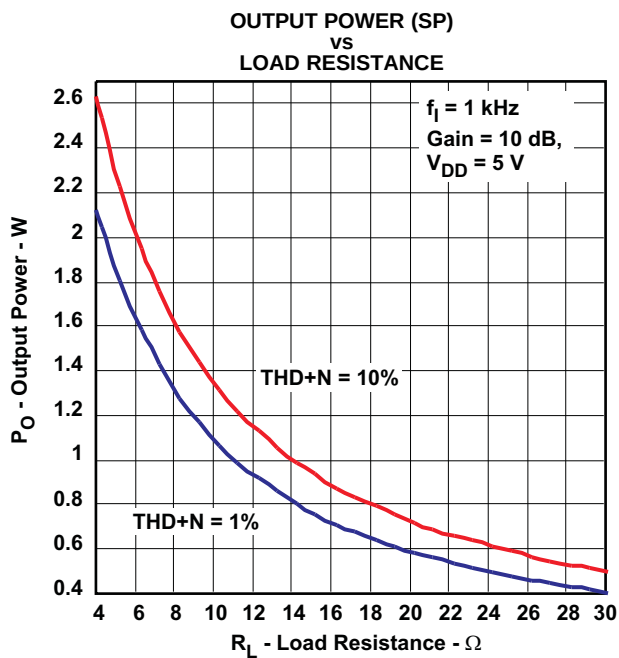


Figure 31.

TYPICAL CHARACTERISTICS (continued)

SPEAKER SHUTDOWN - 8 Ω - 10 dB

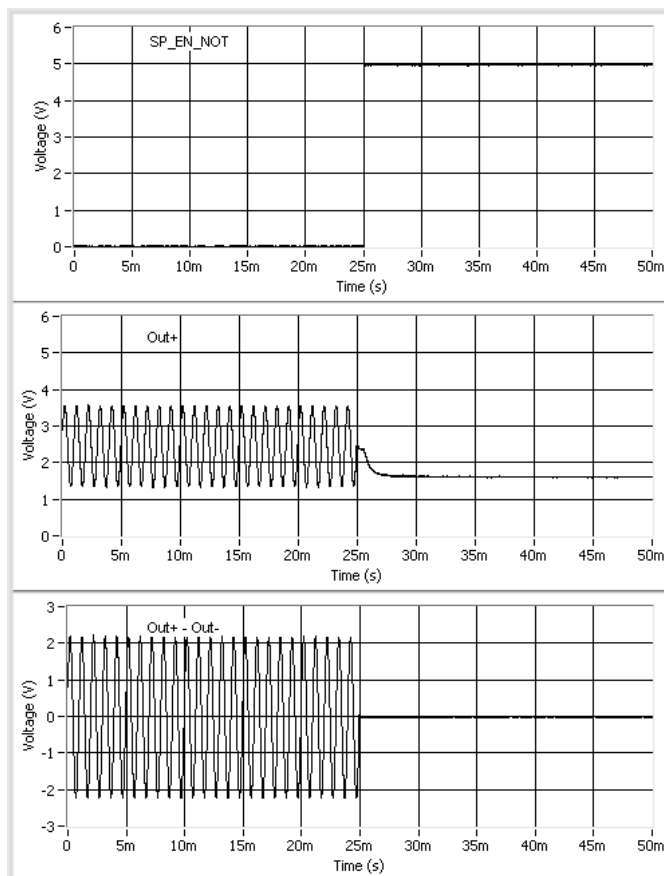


Figure 32.

SPEAKER STARTUP - 8 Ω - 10 dB

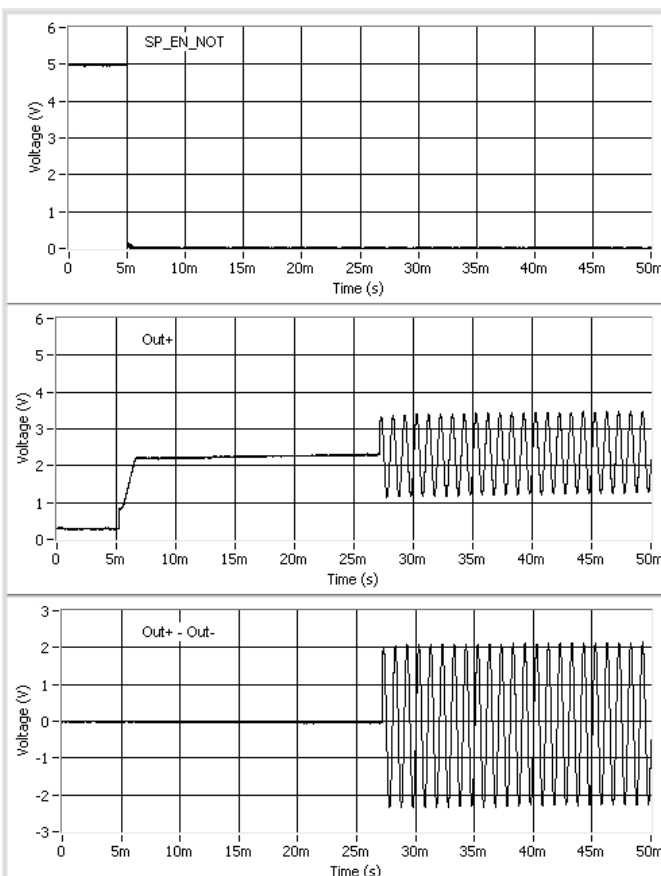


Figure 33.

LDO SHUTDOWN - 120 mA

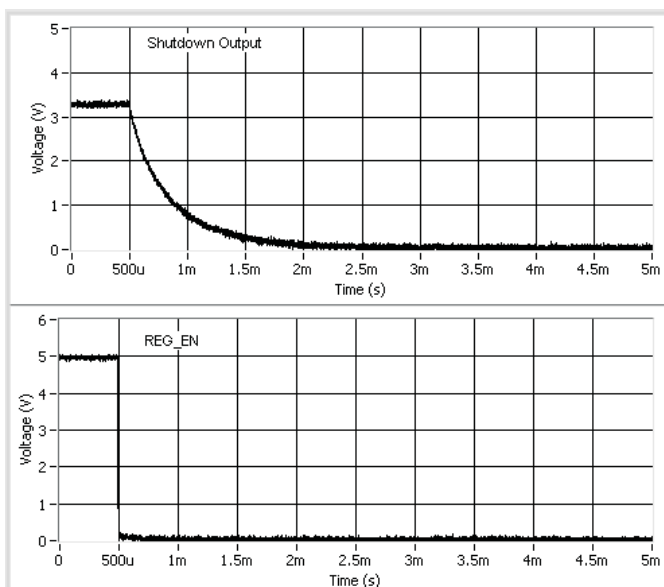


Figure 34.

LDO STARTUP - 120 mA

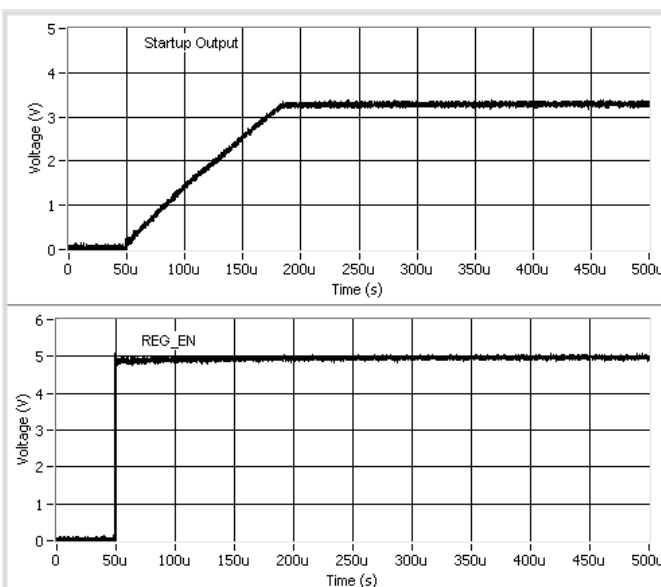
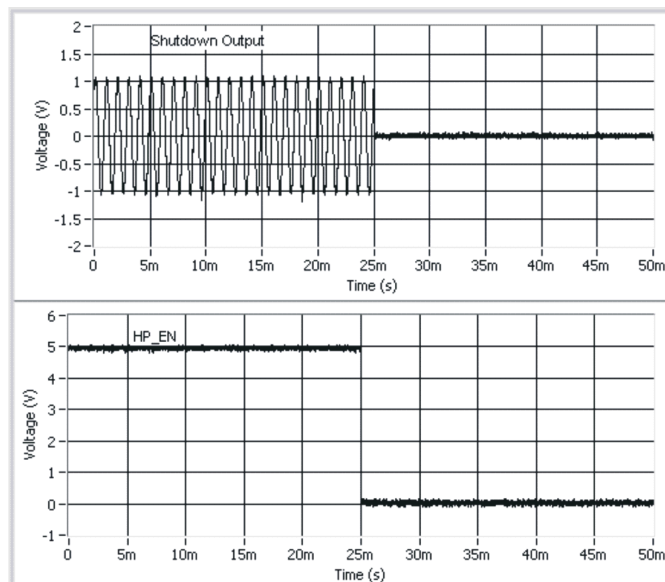
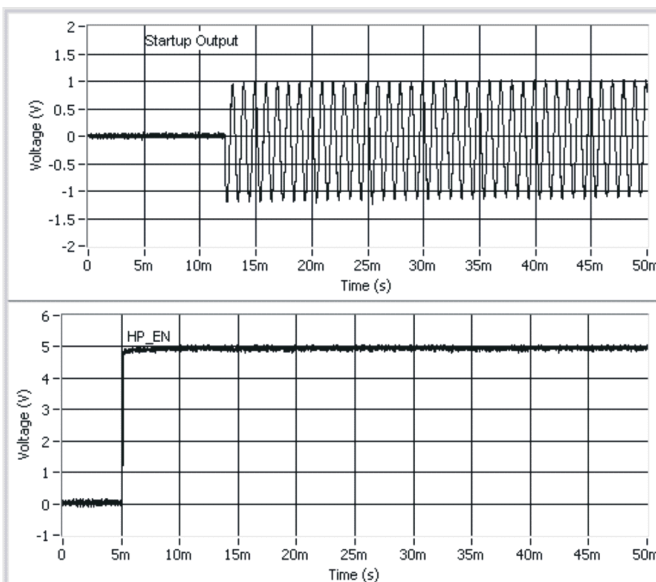


Figure 35.

TYPICAL CHARACTERISTICS (continued)**HP SHUTDOWN - 32 Ω** **Figure 36.****HP STARTUP - 32 Ω** **Figure 37.**

APPLICATION INFORMATION

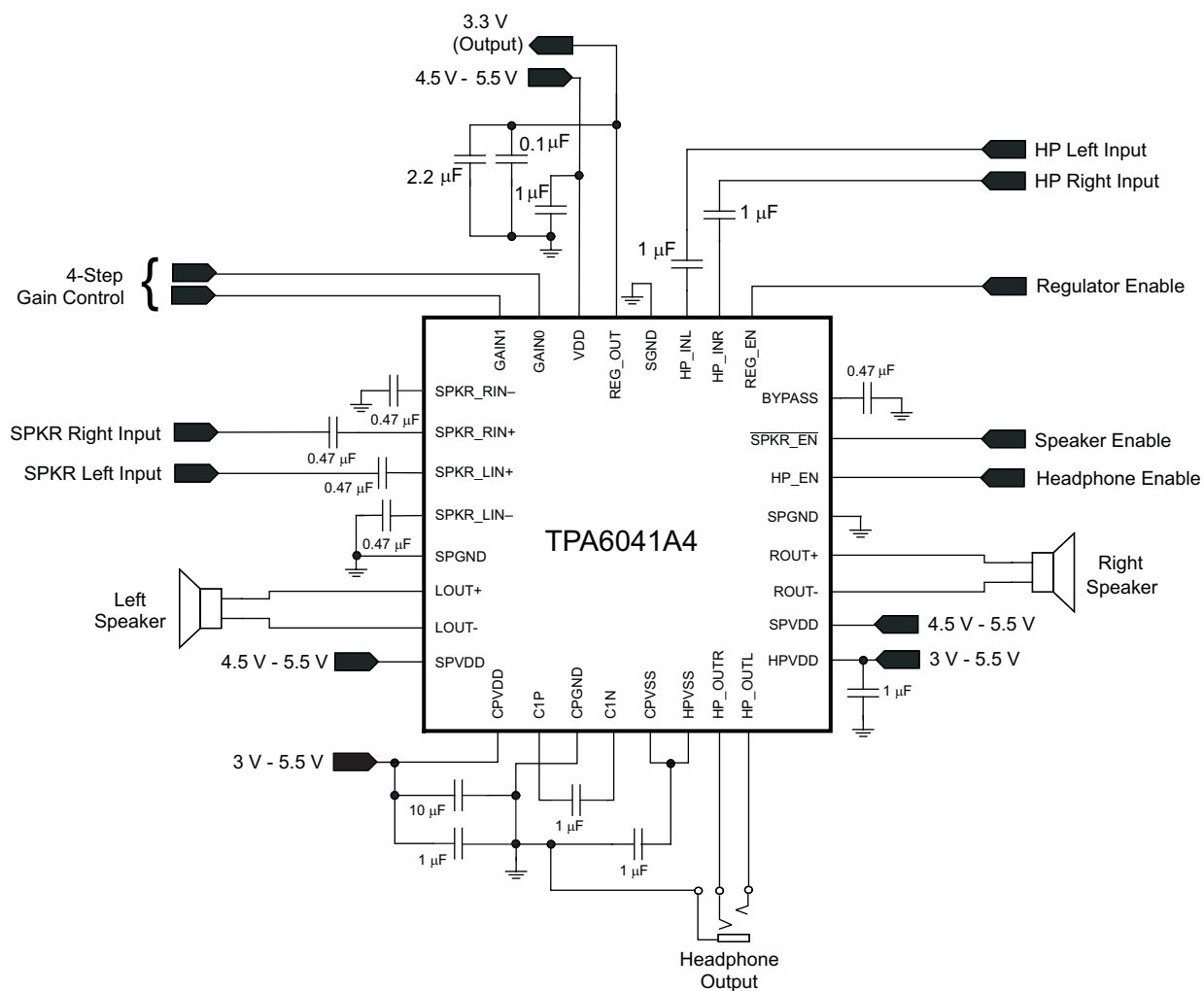


Figure 38. Single-Ended Input Application Circuit

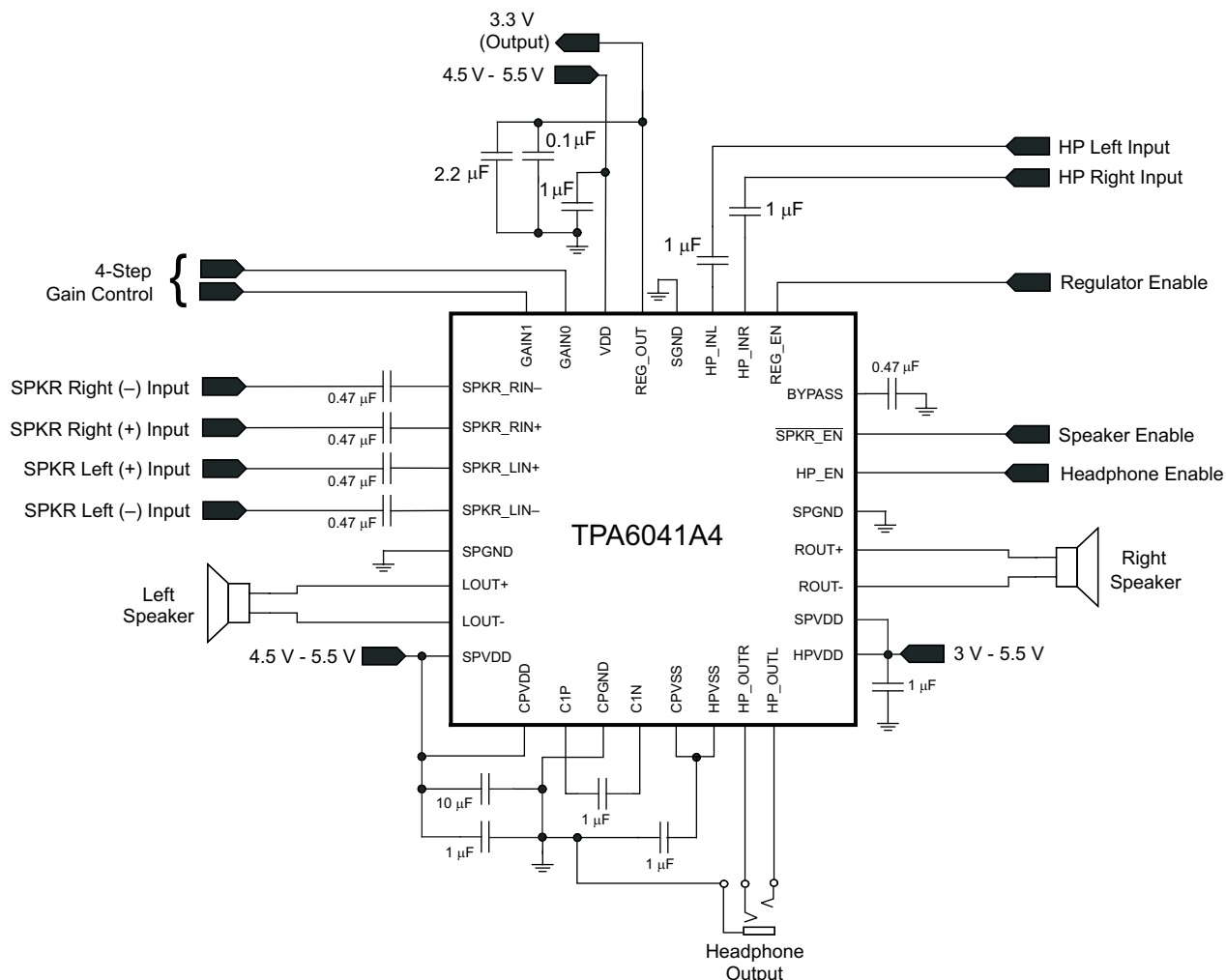


Figure 39. Differential Input Application Circuit

Power Enable Modes

The TPA6041A4 allows disable of any or all of the main circuit blocks when not in use in order to reduce operating power to an absolute minimum. The `SPKR_EN` control can be used to disable the speaker amplifier while the `HP_EN` can be used separately to turn off the headphone amplifier. The LDO also has an independent power control, `REG_EN`. With all circuit blocks disabled, the supply current in shutdown mode is only 5 μA . See the General DC Electrical Characteristics for operating currents with each circuit block operating independently.

Speaker Amplifier Description

The speaker amplifier is capable of driving 2.1 W/ch of continuous RMS power into a 4- Ω load at 5 V. An internal 4-step control allows variation of the gain from 10 dB to 21.6 dB.

Fully Differential Amplifier

The TPA6041A4 speaker amplifier is a fully differential amplifier with differential inputs and outputs. The fully differential architecture consist of a differential amplifier and a common mode amplifier. The differential amplifier ensures that the amplifier outputs a differential voltage that is equal to the differential input times the gain. The common-mode voltage at the output is biased around $V_{DD}/2$ regardless of the common-mode voltage at the input.

One of the primary advantages of the fully differential amplifier is improved RF immunity. GSM handsets save power by turning on and off the RF transmitter at a rate of 217 Hz. The transmitted signal is picked up on input and output traces. The fully differential amplifier cancels the signal and others of this type much better than typical audio amplifiers.

Gain Setting via GAIN0 and GAIN1 Inputs

The gain of the TPA6041A4 is set by two terminals, GAIN0 and GAIN1. The gains listed in Table 1 are realized by changing the taps on the input resistors and feedback resistors inside the amplifier. This causes the input impedance (Z_i) to vary as a function of the gain setting.

Gain Setting

GAIN1	GAIN0	AMPLIFIER GAIN (dB)	INPUT IMPEDANCE (k Ω)
		TYPICAL	TYPICAL
0	0	10	78
0	1	12	65
1	0	15.6	46
1	1	21.6	20

Input Capacitor, C_i

The input capacitor allows the amplifier to bias the input signal to the proper dc level for proper operation. In this case, the input capacitor, C_i , and the input impedance of the amplifier, R_i , form a high-pass filter with the corner frequency determined in Equation 1. Figure 40 shows how the input capacitor and the input resistor within the amplifier interact.

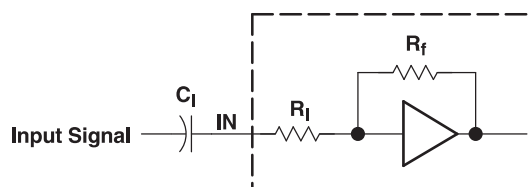
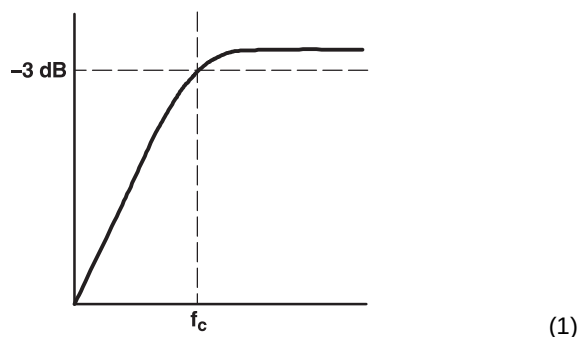


Figure 40. Input Resistor and Input Capacitor

$$f_{c(\text{highpass})} = \frac{1}{2\pi R_i C_i} \quad (1)$$



The value of C_i is important to consider as it directly affects the low-frequency, or bass, performance of the circuit. Furthermore, the input impedance changes with a change in volume. The higher the volume, the lower the input impedance is. To determine the appropriate capacitor value, reconfigure Equation 1 into Equation 2. The value of the input resistor, R_i , can be determined from Equation 2.

$$C_i = \frac{1}{2\pi R_i f_c} \quad (2)$$

Low-leakage tantalum or ceramic capacitors are recommended. When polarized capacitors are used, the positive side of the capacitor should face the amplifier input in most applications as the dc level there is held at $V_{CC}/2$, which is likely higher than the source dc level. Note that it is important to confirm the capacitor polarity in each specific application. Recommended capacitor values are between 0.1 μF and 1 μF .

Windows Vista™ Premium Mobile Mode Specifications

Device Type	Requirement	Windows Premium Mobile Vista Specifications	TPA6041A4 Typical Performance
Analog Speaker Line Jack ($R_L = 10\text{ k}\Omega$, FS = 0.707 Vrms)	THD+N	$\leq -65\text{ dB FS [20 Hz, 20 kHz]}$	$-88\text{ dB FS [20 Hz, 20 kHz]}$
	Dynamic Range with Signal Present	$\leq -80\text{ dB FS A-Weight}$	$-88\text{ dB FS A-Weight}$
	Line Output Crosstalk	$\leq -60\text{ dB [20 Hz, 20 kHz]}$	$-105\text{ dB [20 Hz, 20 kHz]}$
Analog Headphone Out Jack ($R_L = 32\Omega$, FS = 0.300 Vrms)	THD+N	$\leq -45\text{ dB FS [20 Hz, 20 kHz]}$	$-88\text{ dB FS [20 Hz, 20 kHz]}$
	Dynamic Range with Signal Present	$\leq -80\text{ dB FS A-Weight}$	$-89\text{ dB FS A-Weight}$
	Headphone Output Crosstalk	$\leq -60\text{ dB [20 Hz, 20 kHz]}$	$-100\text{ dB [20 Hz, 20 kHz]}$

Bridge-Tied Load Versus Single-Ended Mode

Figure 41 shows a Class-AB audio power amplifier (APA) in a bridge-tied-load (BTL) configuration. The TPA6041A4 speaker amplifier consists of two Class-AB differential amplifiers per channel driving the positive and negative terminals of the load. Specifically, differential drive means that as one side of the amplifier (the positive terminal, for example) is slewing up, the other side is slewing down, and vice versa. This doubles the voltage swing across the load as opposed to a ground-referenced load, or a single-ended load. Power is proportional to the square of the voltage. Plugging $2 \times V_{O(PP)}$ into the power equation yields $4 \times$ the output power from the same supply rail and load impedance as would have been obtained with a ground-referenced load (see Equation 3).

$$V_{(RMS)} = \frac{V_{O(PP)}}{2\sqrt{2}}$$

$$\text{Power} = \frac{V_{(RMS)}^2}{R_L}$$

(3)

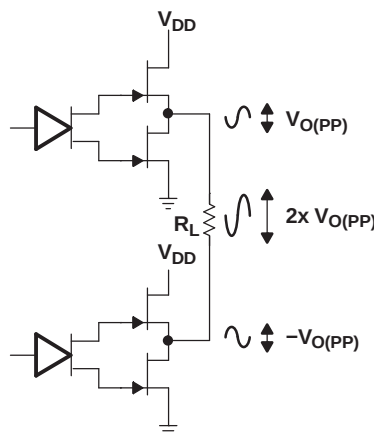


Figure 41. Differential Output Configuration

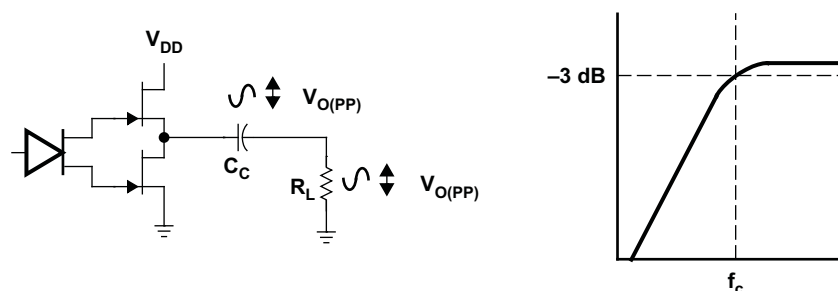


Figure 42. Single-Ended Configuration and Frequency Response

Bridge-tying the outputs in a typical computer audio, LCD TV, or multimedia LCD monitor application drastically increases output power. For example, if an amplifier in a single-ended configuration was capable of outputting a maximum of 250 mW for a given load with a supply voltage of 12 V, then that same amplifier would be able to output 1 W of power in a BTL configuration with the same supply voltage and load. In addition to the increase in output power, the BTL configuration does not suffer from the same low-frequency issues that plague the single-ended configuration. In a BTL configuration, there is no need for an output capacitor to block dc, so no unwanted filtering occurs. In addition, the BTL configuration saves money and space, as the dc-blocking capacitors needed for single-ended operation are large and expensive. For example, with an 8-Ω load in SE operation, the user needs a 1000-μF capacitor to obtain a cutoff frequency below 20 Hz. This capacitor is expensive and large.

Headphone Amplifier Description

The headphone amplifier has a fixed gain of -1.5 V/V. It uses single-ended (SE) inputs. The DirectPath™ amplifier architecture operates from a single supply but makes use of an internal charge pump to provide a negative voltage rail. Combining the user-provided positive rail and the negative rail generated by the IC, the device operates in what is effectively a split supply mode. The output voltages are now centered at zero volts with the capability to swing to the positive rail or negative rail. The DirectPath™ amplifier requires no output dc blocking capacitors and does not place any voltage on the sleeve. The block diagram and waveform of [Figure 43](#) illustrate the ground-referenced headphone architecture. This is the architecture of the TPA6041A4.

Single-supply headphone amplifiers typically require dc-blocking capacitors. The capacitors are required because most headphone amplifiers have a dc bias on the outputs pin. If the dc bias is not removed, the output signal is severely clipped, and large amounts of dc current rush through the headphones, potentially damaging them. The left-side drawing in [Figure 43](#) illustrates the conventional headphone amplifier connection to the headphone jack and output signal.

DC blocking capacitors are often large in value. The headphone speakers (typical resistive values of 16 Ω or 32 Ω) combine with the dc blocking capacitors to form a high-pass filter. [Equation 4](#) shows the relationship between the load impedance (R_L), the capacitor (C_O), and the cutoff frequency (f_c).

$$f_c = \frac{1}{2\pi R_L C_O} \quad (4)$$

C_O can be determined using [Equation 5](#), where the load impedance and the cutoff frequency are known.

$$C_O = \frac{1}{2\pi R_L f_c} \quad (5)$$

If f_c is low, the capacitor must then have a large value because the load resistance is small. Large capacitance values require large package sizes. Large package sizes consume PCB area, stand high above the PCB, increase cost of assembly, and can reduce the fidelity of the audio output signal.

Two different headphone amplifier applications are available that allow for the removal of the output dc blocking capacitors. The capacitor-less amplifier architecture is implemented in the same manner as the conventional amplifier with the exception of the headphone jack shield pin. This amplifier provides a reference voltage, which is connected to the headphone jack shield pin. This is the voltage on which the audio output signals are centered. This voltage reference is half of the amplifier power supply to allow symmetrical swing of the output voltages. Do not connect the shield to any GND reference, or large currents will result. The scenario can happen if, for example, an accessory other than a floating GND headphone is plugged into the headphone connector. See the second block diagram and waveform in [Figure 43](#).

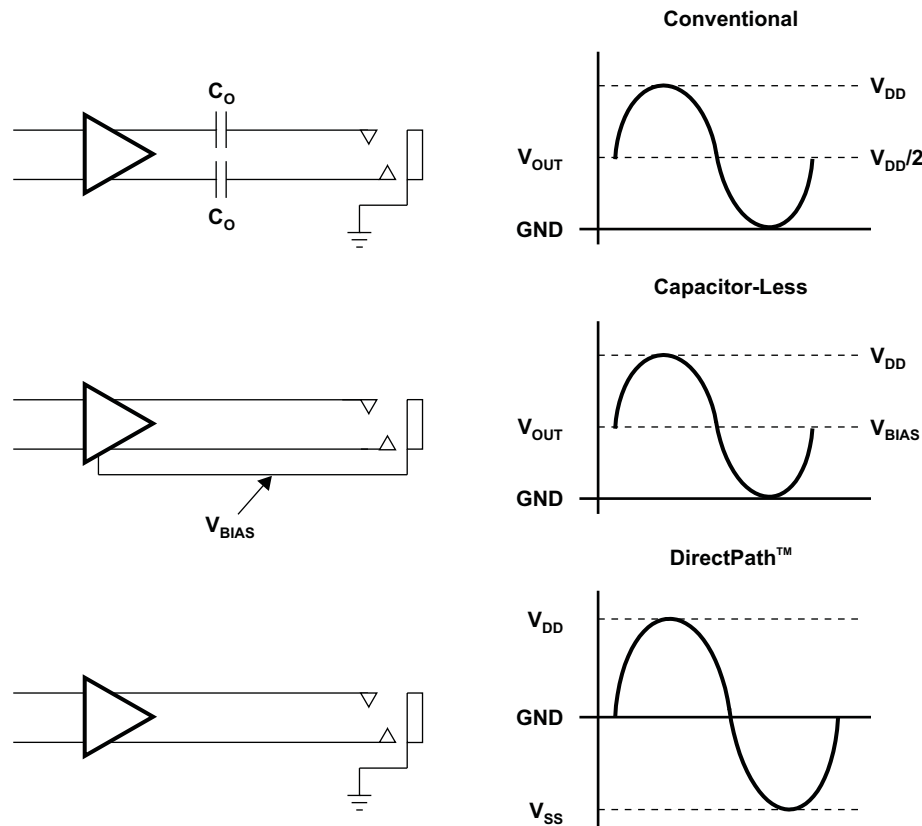


Figure 43. Amplifier Applications

Input-Blocking Capacitors

DC input-blocking capacitors block the dc portion of the audio source and allow the inputs to properly bias. Maximum performance is achieved when the inputs of the TPA6041A4 are properly biased. Performance issues such as pop are optimized with proper input capacitors.

The dc input-blocking capacitors can be removed, provided the inputs are connected differentially and within the input common-mode range of the amplifier, the audio signal does not exceed ± 3 V, and pop performance is sufficient.

C_{IN} is a theoretical capacitor used for mathematical calculations only. Its value is the series combination of the dc input-blocking capacitors, $C_{(DCINPUT-BLOCKING)}$. Use Equation 6 to determine the value of $C_{(DCINPUT-BLOCKING)}$. For example, if C_{IN} is equal to 0.22 μ F, then $C_{(DCINPUT-BLOCKING)}$ is equal to about 0.47 μ F.

$$C_{IN} = \frac{1}{2} C_{(DCINPUT-BLOCKING)} \quad (6)$$

The two $C_{(DCINPUT-BLOCKING)}$ capacitors form a high-pass filter with the input impedance of the TPA6041A4. Use Equation 6 to calculate C_{IN} , then calculate the cutoff frequency using C_{IN} and the differential input impedance of the TPA6041A4, R_{IN} , using Equation 7. Note that the differential input impedance changes with gain. See Figure 39 for input impedance values. The frequency and/or capacitance can be determined when one of the two values are given.

$$f_{C_{IN}} = \frac{1}{2\pi R_{IN} C_{IN}} \quad \text{or} \quad C_{IN} = \frac{1}{2\pi f_{C_{IN}} R_{IN}} \quad (7)$$

If a high-pass filter with a -3-dB point of no more than 20 Hz is desired over all gain settings, the minimum impedance would be used in the Equation 7. The minimum input impedance for TPA6041A4 is 20 kΩ. The capacitor value by Equation 7 would be 0.399 μF. However, this is C_{IN} , and the desired value is for $C_{(DCINPUT-BLOCKING)}$. Multiplying C_{IN} by 2 yields 0.80 μF, which is close to the standard capacitor value of 1 μF. Place 1-μF capacitors at each input terminal of the TPA6041A4 to complete the filter.

Charge Pump Flying Capacitor and CPVSS Capacitor

The charge pump flying capacitor serves to transfer charge during the generation of the negative supply voltage. The CPVSS capacitor must be at least equal to the flying capacitor in order to allow maximum charge transfer. Low ESR capacitors are an ideal selection, and a value of 1 μF is typical.

Decoupling Capacitors

The TPA6041A4 is a DirectPath™ headphone amplifier that requires adequate power supply decoupling to ensure that the noise and total harmonic distortion (THD) are as low as possible. To filter high-frequency transients, spikes, and digital hash on the power line, use good low equivalent-series-resistance (ESR) ceramic capacitors, typically 1 μF. Find the smallest package possible, and place as close as possible to the device V_{DD} lead. Placing the decoupling capacitors close to the TPA6041A4 is important for the performance of the amplifier. Use a 10 μF or greater capacitor near the TPA6041A4 to filter lower frequency noise signals; however, the high PSRR of the TPA6041A4 makes the 10-μF capacitor unnecessary in most applications.

Midrail Bypass Capacitor, C_{BYPASS}

The midrail bypass capacitor, C_{BYPASS} , has several important functions. During start-up or recovery from shutdown mode, C_{BYPASS} determines the rate at which the amplifier starts up. A 1-μF capacitor yields a start-up time of approximately 30 ms. C_{BYPASS} also reduces the noise coupled into the output signal by the power supply. This improves the power supply ripple rejection (PSRR) of the amplifier. Ceramic or polyester capacitors with low ESR and values in the range of 0.47 μF to 1 μF are recommended.

LOW DROPOUT REGULATOR (LDO) DESCRIPTION

The TPA6041A4 contains a 3.3-V output low dropout regulator (LDO) capable of providing a maximum of 120 mA with a drop of less than 150 mV from the 5-V supply. This can be used to power an external CODEC. A 10-μF decoupling capacitor is recommended at the output of the LDO as well as 0.1-μF capacitor to filter high-frequency noise from the supply line.

LAYOUT RECOMMENDATIONS

Solder the exposed thermal pad (metal pad on the bottom of the part) on the TPA6041A4 QFN package to a pad on the PCB.

It is important to keep the TPA6041A4 external components close to the body of the amplifier to limit noise pickup. One should lay out the differential input leads symmetrical and close together to take advantage of the inherent common mode rejection of the TPA6041A4. The layout of the TPA6041A4 evaluation module (EVM) is a good example of component placement and the layout files are available at www.ti.com.

PACKAGING INFORMATION

Orderable part number	Status (1)	Material type (2)	Package Pins	Package qty Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
TPA6041A4RHBR	Active	Production	VQFN (RHB) 32	3000 LARGE T&R	Yes	NIPDAU NIPDAU	Level-3-260C-168 HR	-40 to 85	TPA 6041A4
TPA6041A4RHBR.B	Active	Production	VQFN (RHB) 32	3000 LARGE T&R	Yes	NIPDAU	Level-3-260C-168 HR	-40 to 85	TPA 6041A4

⁽¹⁾ **Status:** For more details on status, see our [product life cycle](#).

⁽²⁾ **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

⁽³⁾ **RoHS values:** Yes, No, RoHS Exempt. See the [TI RoHS Statement](#) for additional information and value definition.

⁽⁴⁾ **Lead finish/Ball material:** Parts 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.

⁽⁵⁾ **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

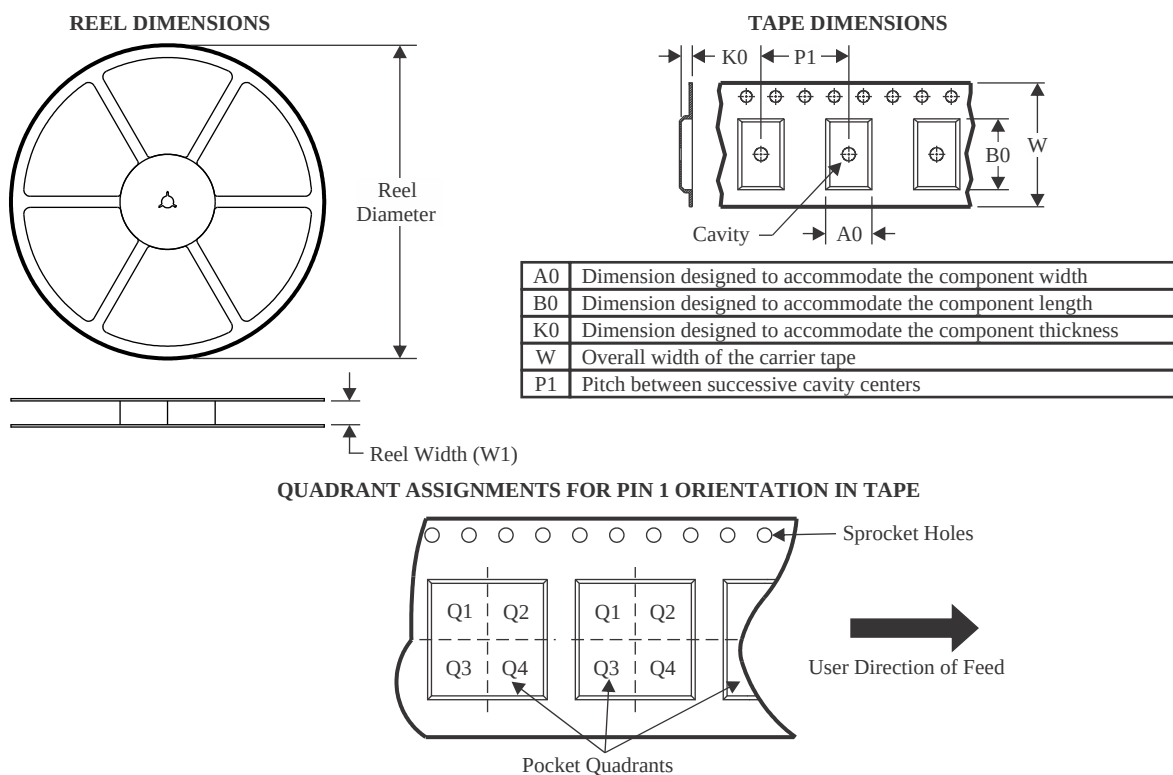
⁽⁶⁾ **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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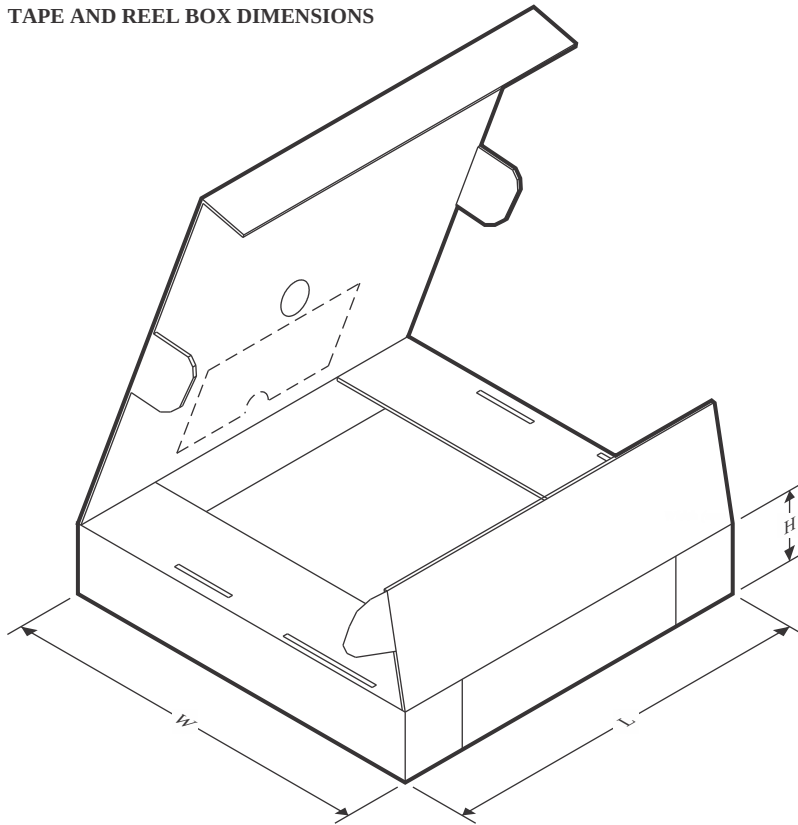
TAPE AND REEL INFORMATION



*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
TPA6041A4RHBR	VQFN	RHB	32	3000	330.0	12.4	5.3	5.3	1.1	8.0	12.0	Q2

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPA6041A4RHBR	VQFN	RHB	32	3000	346.0	346.0	33.0

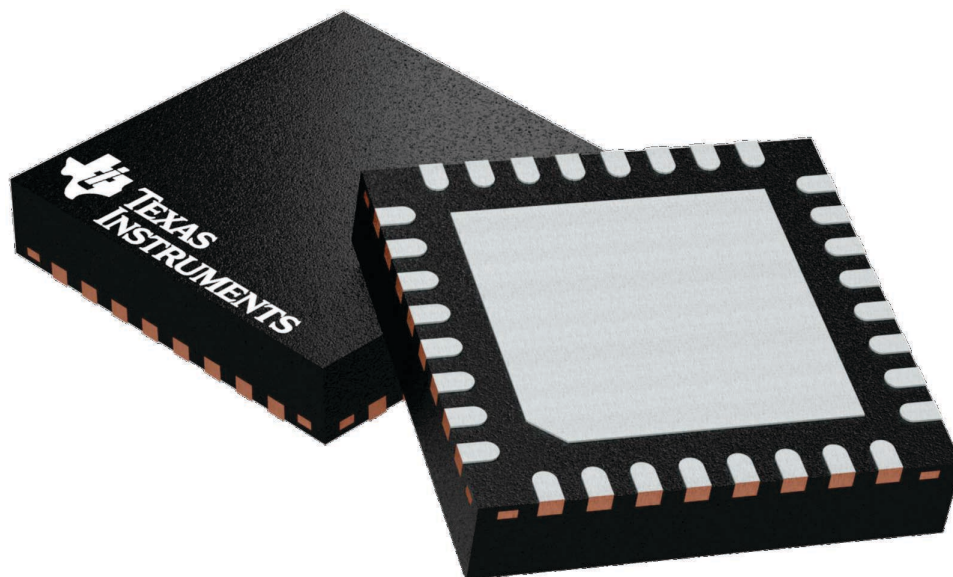
GENERIC PACKAGE VIEW

RHB 32

VQFN - 1 mm max height

5 x 5, 0.5 mm pitch

PLASTIC QUAD FLATPACK - NO LEAD

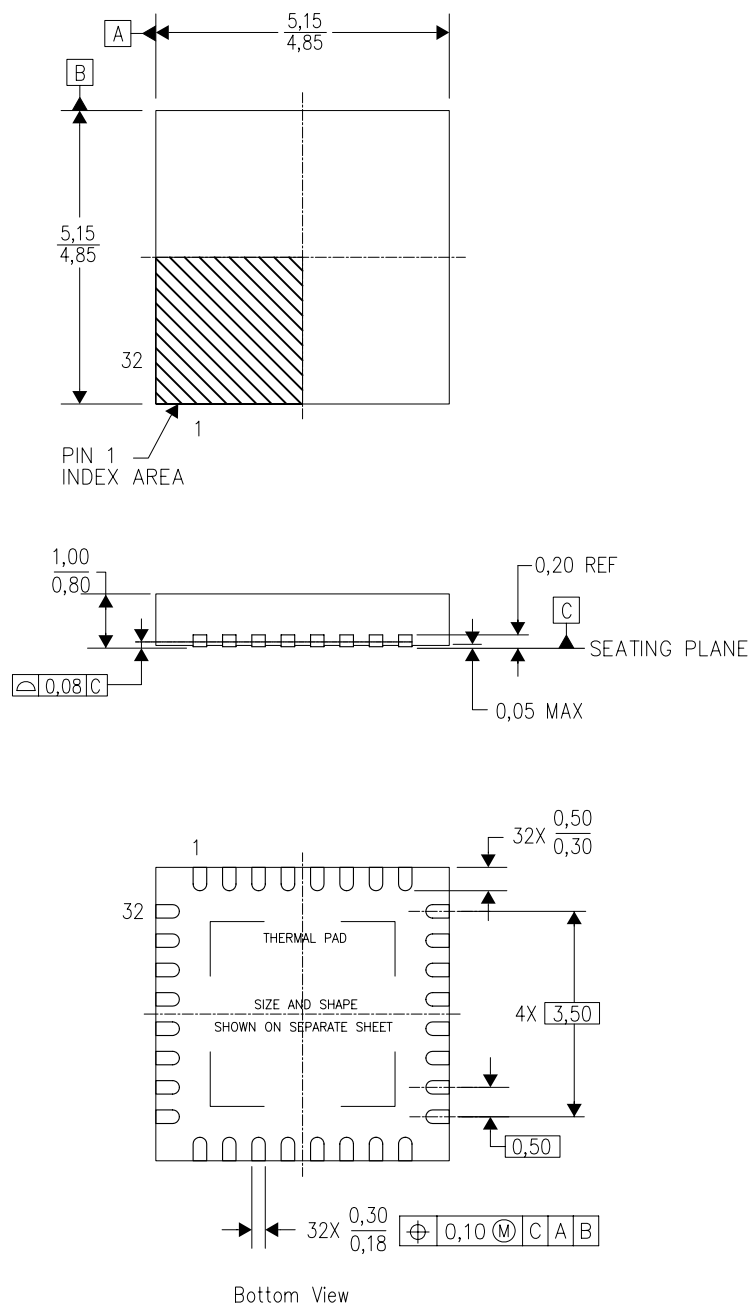


Images above are just a representation of the package family, actual package may vary.
Refer to the product data sheet for package details.

4224745/A

RHB (S-PVQFN-N32)

PLASTIC QUAD FLATPACK NO-LEAD



4204326/D 06/11

- 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. QFN (Quad Flatpack No-Lead) Package configuration.
 - D. The package thermal pad must be soldered to the board for thermal and mechanical performance.
 - E. See the additional figure in the Product Data Sheet for details regarding the exposed thermal pad features and dimensions.
 - F. Falls within JEDEC MO-220.

RHB (S-PVQFN-N32)

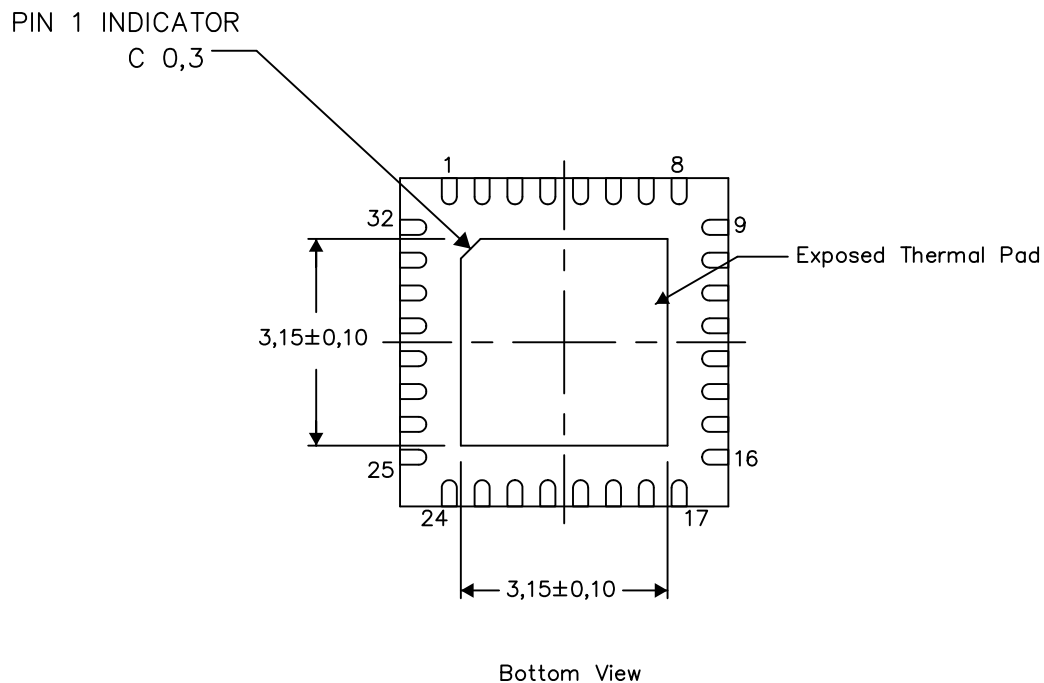
PLASTIC QUAD FLATPACK NO-LEAD

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 the appropriate copper plane shown in the electrical schematic for the device, or alternatively, can be attached to 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, QFN/SON PCB Attachment, Texas Instruments Literature No. SLUA271. This document is available at www.ti.com.

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



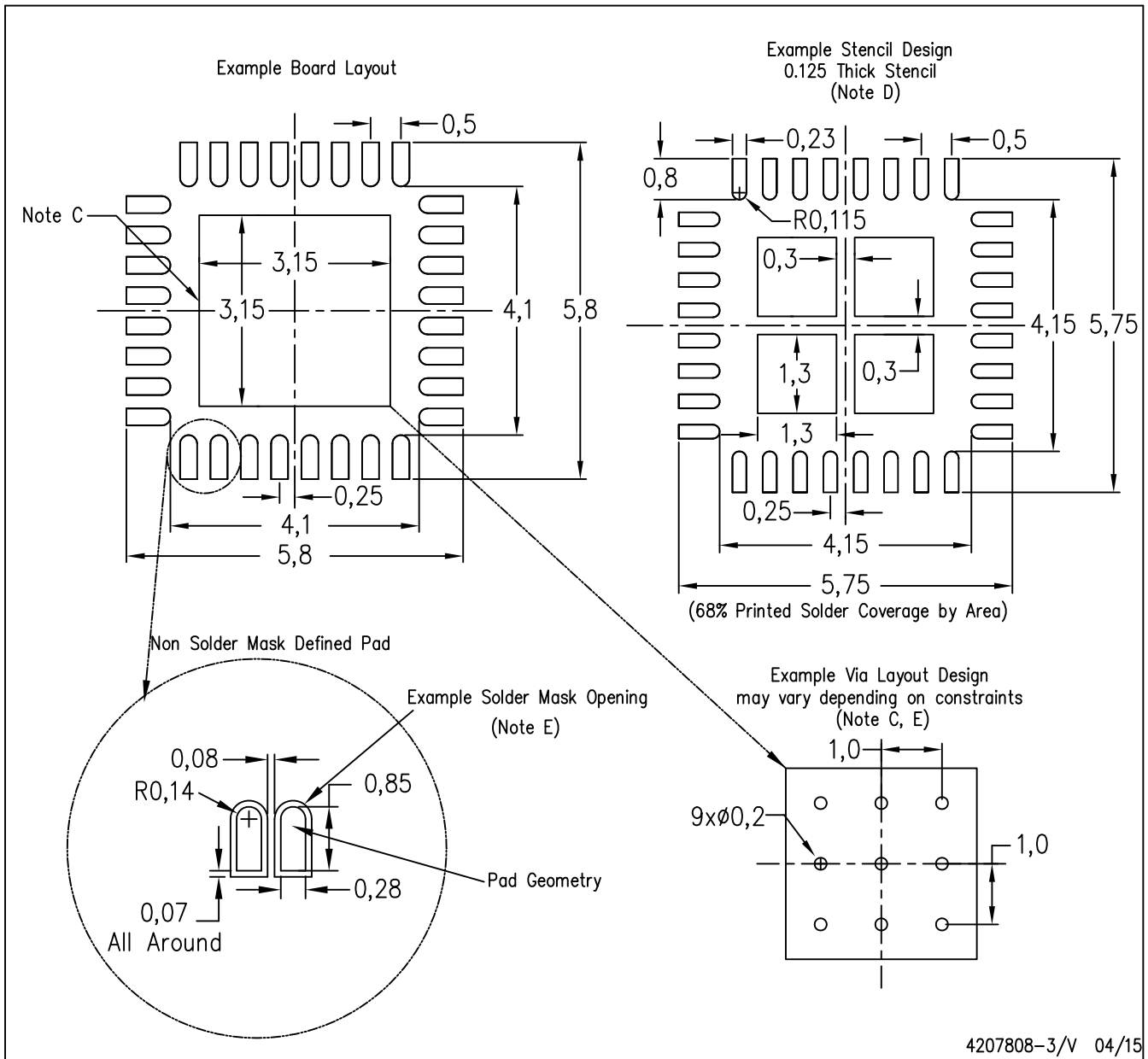
Exposed Thermal Pad Dimensions

4206356-3/AC 05/15

NOTE: A. All linear dimensions are in millimeters

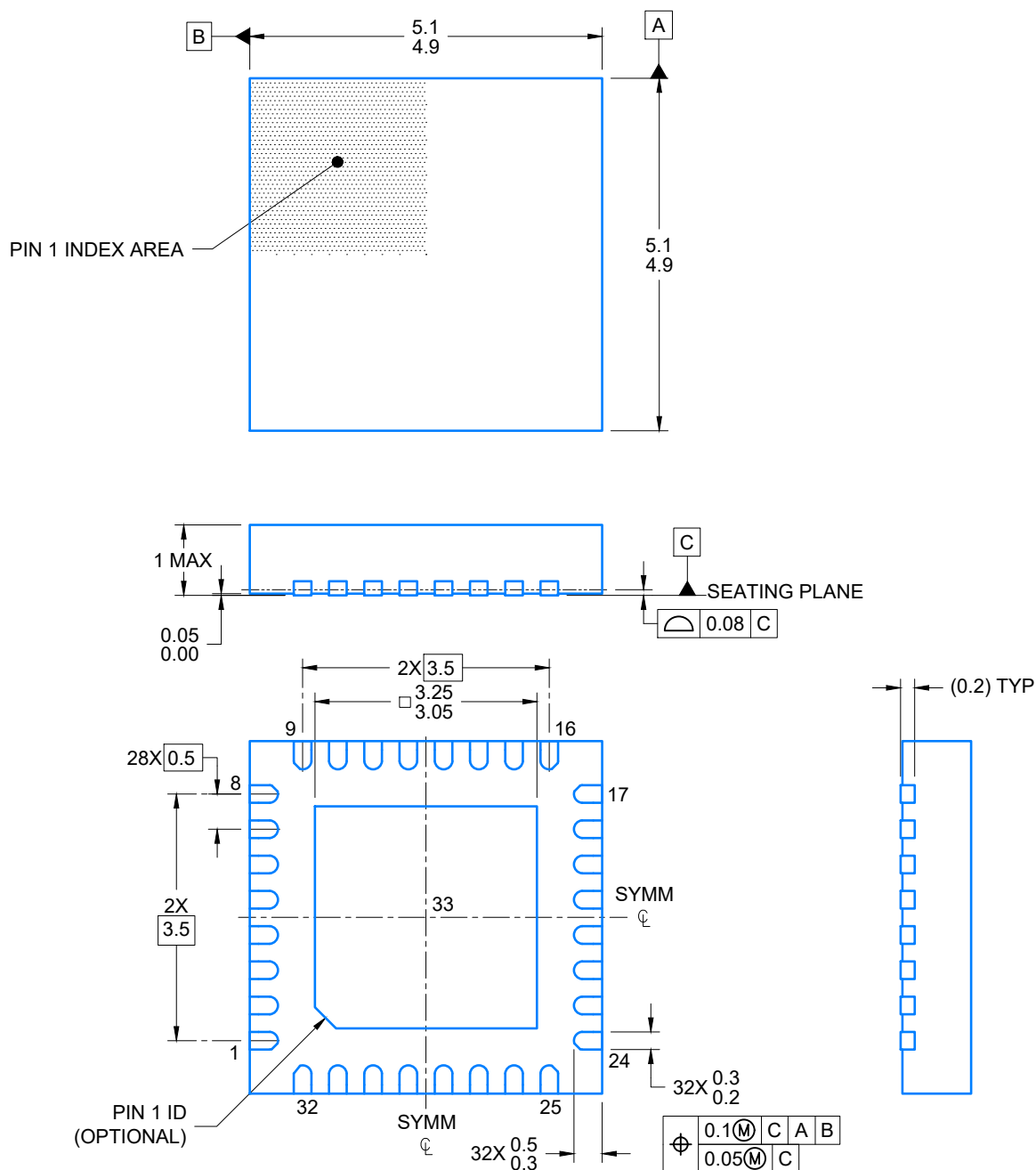
RHB (S-PVQFN-N32)

PLASTIC QUAD FLATPACK NO-LEAD



4207808-3/V 04/15

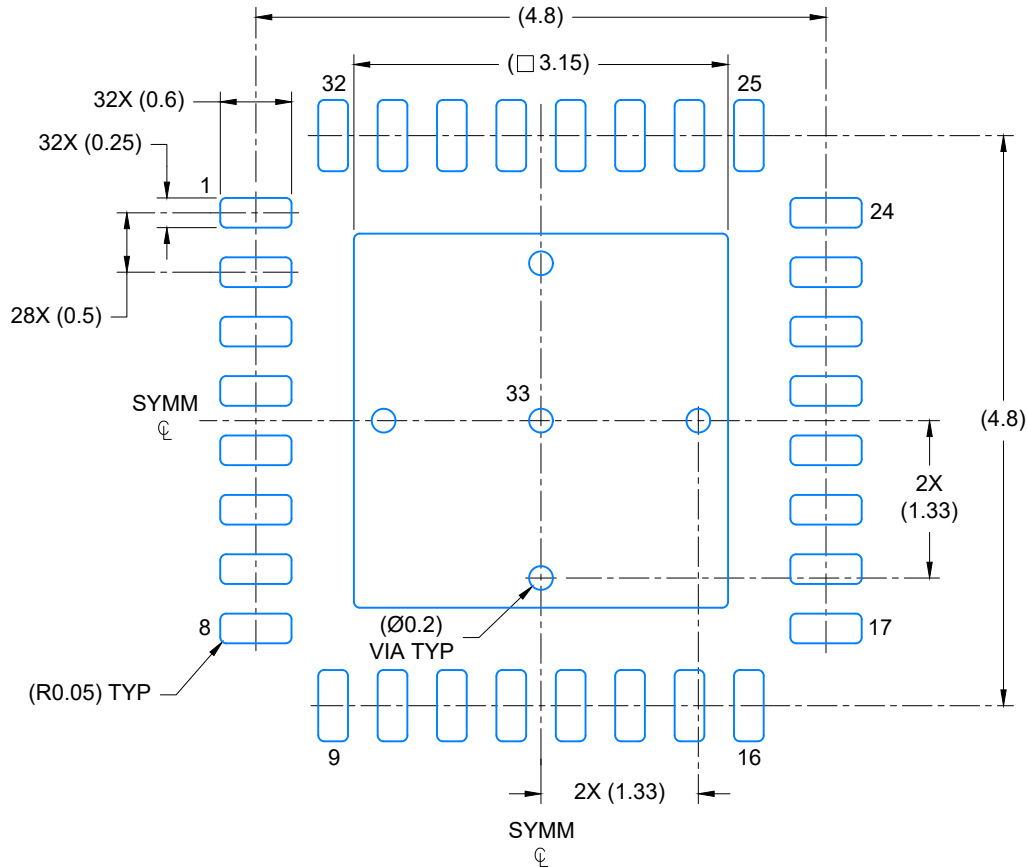
- NOTES:
- All linear dimensions are in millimeters.
 - This drawing is subject to change without notice.
 - This package is designed to be soldered to a thermal pad on the board. Refer to Application Note, Quad Flat-Pack Packages, Texas Instruments Literature No. SLUA271, and also the Product Data Sheets for specific thermal information, via requirements, and recommended board layout. These documents are available at www.ti.com <<http://www.ti.com>>.
 - 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.
 - Customers should contact their board fabrication site for recommended solder mask tolerances and via tenting recommendations for any larger diameter vias placed in the thermal pad.



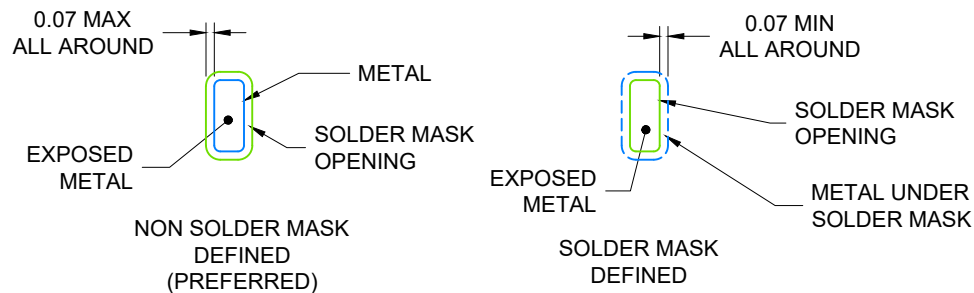
4228523/A 02/2022

NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for optimal thermal and mechanical performance.



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE: 15X

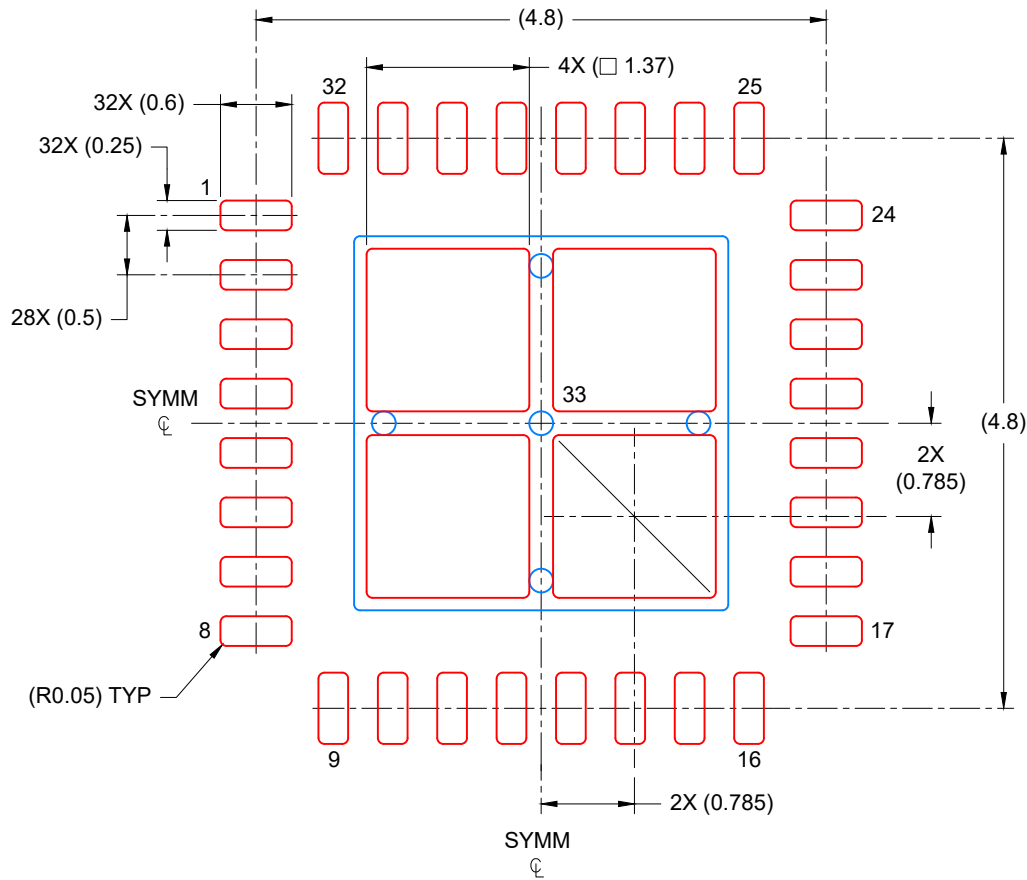


SOLDER MASK DETAILS

4228523/A 02/2022

NOTES: (continued)

- This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/slue271).
- Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.



SOLDER PASTE EXAMPLE
 BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD
 75% PRINTED COVERAGE BY AREA
 SCALE: 15X

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NOTES: (continued)

- Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

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