3.2W Mono Class-D Audio Power Amplifier With 12-dB Gain and Auto Short-Circuit Recovery

Check for Samples: TPA2039D1

FEATURES

- **Powerful Mono Class-D Speaker Amplifier**
  - **3.24 W (4 Ω, 5 V, 10% THDN)**
  - **2.57 W (4 Ω, 5 V, 1% THDN)**
  - **1.80 W (8 Ω, 5 V, 10% THDN)**
  - **1.46 W (8 Ω, 5 V, 1% THDN)**
- **+12 dB Fixed Gain**
- **Integrated Image Reject Filter for DAC Noise Reduction**
- **Low Output Noise of 27 μV**
- **Low Quiescent Current of 1.5 mA**
- **Differential Input Impedance of 150 kΩ**
- **Auto-Recovering Short-Circuit Protection**
- **Thermal-Overload Protection**
- **Filter-Free Mono Class-D Amp**
- **9-Ball 1,21 mm × 1,16 mm 0,4mm Pitch WCSP**

APPLICATIONS

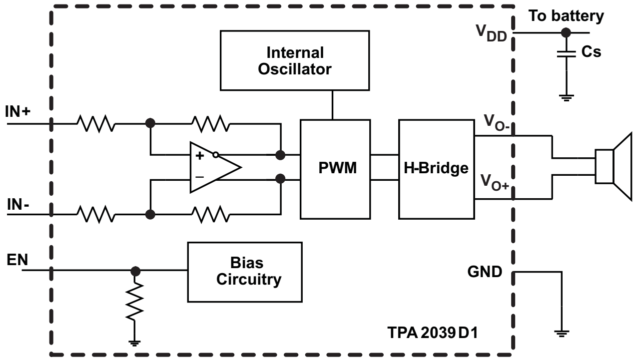
- **Wireless or Cellular Handsets and PDAs**
- **Portable Navigation Devices**
- **General Portable Audio Devices**

DESCRIPTION

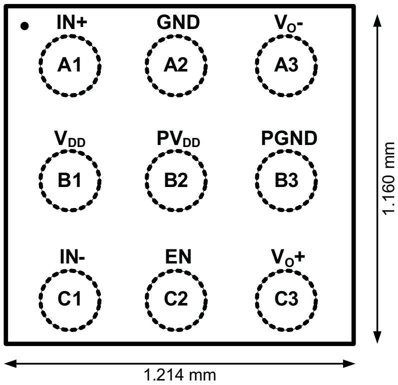
The TPA2039D1 is a 3.2 W high efficiency filter-free class-D audio power amplifier (class-D amp) with 12 dB of fixed gain in a tiny 1.21 mm x 1.16 mm wafer chip scale package (WCSP). The device requires only one external component.

Features like 93% efficiency, 1.5 mA quiescent current, 0.1 μA shutdown current, 82-dB PSRR, 27 μV output noise and improved RF immunity make the TPA2039D1 class-D amplifier ideal for cellular handsets. A fast start-up time of 4 ms with no audible pop makes the TPA2039D1 ideal for PDA and smart-phone applications.

APPLICATION CIRCUIT



TPA2039D1
9-BALL 0.4mm PITCH
WAFER CHIP SCALE PACKAGE (YFF)
(TOP VIEW OF PCB)



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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.

ORDERING INFORMATION

T_A	PACKAGED DEVICES(1)	PART NUMBER(2)	SYMBOL
—40°C to 85°C	9-ball WSCP	TPA2039D1YFFR	DAR
		TPA2039D1YFFT	DAR

(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

(2) The YFF package is only available taped and reeled. The suffix "R" indicates a reel of 3000, the suffix "T" indicates a reel of 250.

ABSOLUTE MAXIMUM RATINGS

over operating free-air temperature range, T_A = 25°C (unless otherwise noted)(1)

			VALUE	UNIT
V_{DD}, PV_{DD}	Supply voltage	In active mode	–0.3 to 6.0	V
		In shutdown mode	–0.3 to 6.0	V
V_I	Input voltage	EN, IN+, IN–	–0.3 to V_{DD} + 0.3	V
R_L	Minimum load resistance		3.2	Ω
	Output 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 85	°C

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

DISSIPATION RATINGS

PACKAGE	DERATING FACTOR(1)	T_A < 25°C	T_A = 70°C	T_A = 85°C
YFF (WCSP)	4.2 mW/°C	525 mW	336 mW	273 mW

(1) Derating factor measure with high K board.

RECOMMENDED OPERATING CONDITIONS

			MIN	MAX	UNIT
V_{DD}, PV_{DD}	Class-D supply voltage		2.5	5.5	V
V_{IH}	High-level input voltage	EN	1.3		V
V_{IL}	Low-level input voltage	EN		0.35	V
V_{IC}	Common mode input voltage range	V_{DD} = 2.5V, 5.5V, CMRR ≥ 49 dB	0.75	V_{DD}-1.1	V
T_A	Operating free-air temperature		–40	85	°C

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ELECTRICAL CHARACTERISTICS

T_A = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
$\|V_{OS}\|$	Output offset voltage (measured differentially)	V_I = 0 V, V_{DD} = 2.5 V to 5.5 V		1	10	mV
$\|I_{IH}\|$	High-level EN input current	V_{DD} = 5.5 V, V_{EN} = 5.5 V			50	μA
$\|I_{IL}\|$	Low-level EN input current	V_{DD} = 5.5 V, V_{EN} = 0 V			1	μA
$I_{(Q)}$	Quiescent current	V_{DD} = 5.5 V, no load		1.8	2.5	mA
		V_{DD} = 3.6 V, no load		1.5	2.3	
		V_{DD} = 2.5 V, no load		1.3	2.1	
$I_{(SD)}$	Shutdown current	V_{EN} = 0.35 V, V_{DD} = 3.6 V		0.1	2	μA
$R_{O,\ SD}$	Output impedance in shutdown mode	V_{EN} = 0.35 V		2		kΩ
$f_{(SW)}$	Switching frequency	V_{DD} = 2.5 V to 5.5 V	250	300	350	kHz
A_V	Gain	V_{DD} = 2.5 V to 5.5 V, R_L = no load	11.5	12	12.5	dB
R_{EN}	Resistance from EN to GND			300		kΩ
R_{IN}	Single ended input resistance	$V_{EN} \geq V_{IH}$		75		kΩ
		$V_{EN} \leq V_{IL}$		75		

OPERATING CHARACTERISTICS

V_{DD} = 3.6 V, T_A = 25°C, R_L = 8 Ω (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
P_O	Output power	THD + N = 10%, f = 1 kHz, R_L = 4 Ω	V_{DD} = 5 V		3.24		W
			V_{DD} = 3.6 V		1.62		
			V_{DD} = 2.5 V		0.70		
		THD + N = 1%, f = 1 kHz, R_L = 4 Ω	V_{DD} = 5 V		2.57		W
			V_{DD} = 3.6 V		1.32		
			V_{DD} = 2.5 V		0.57		
		THD + N = 10%, f = 1 kHz, R_L = 8 Ω	V_{DD} = 5 V		1.80		W
			V_{DD} = 3.6 V		0.91		
			V_{DD} = 2.5 V		0.42		
		THD + N = 1%, f = 1 kHz, R_L = 8 Ω	V_{DD} = 5 V		1.46		W
			V_{DD} = 3.6 V		0.74		
			V_{DD} = 2.5 V		0.33		
V_n	Noise output voltage	V_{DD} = 3.6 V, Inputs AC grounded with C_I = 2μF, f = 20 Hz to 20 kHz	A-weighting		27		$μV_{RMS}$
			No weighting		36		
THD+N	Total harmonic distortion plus noise	V_{DD} = 5.0 V, P_O = 1.0 W, f = 1 kHz, R_L = 8 Ω			0.12%		
		V_{DD} = 3.6 V, P_O = 0.5 W, f = 1 kHz, R_L = 8 Ω			0.05%		
		V_{DD} = 2.5 V, P_O = 0.2 W, f = 1 kHz, R_L = 8 Ω			0.05%		
		V_{DD} = 5.0 V, P_O = 2.0 W, f = 1 kHz, R_L = 4 Ω			0.32%		
		V_{DD} = 3.6 V, P_O = 1.0 W, f = 1 kHz, R_L = 4 Ω			0.11%		
		V_{DD} = 2.5 V, P_O = 0.4 W, f = 1 kHz, R_L = 4 Ω			0.12%		
PSRR	AC power supply rejection ratio	V_{DD} = 3.6 V, Inputs AC grounded with C_I = 2 μF, 200 mV_{pp} ripple, f = 217 Hz			82		dB
CMRR	Common mode rejection ratio	V_{DD} = 3.6 V, V_{IC} = 1 V_{PP}, f = 217 Hz			77		dB
T_{SU}	Startup time from shutdown	V_{DD} = 3.6 V			4		ms

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OPERATING CHARACTERISTICS (continued)

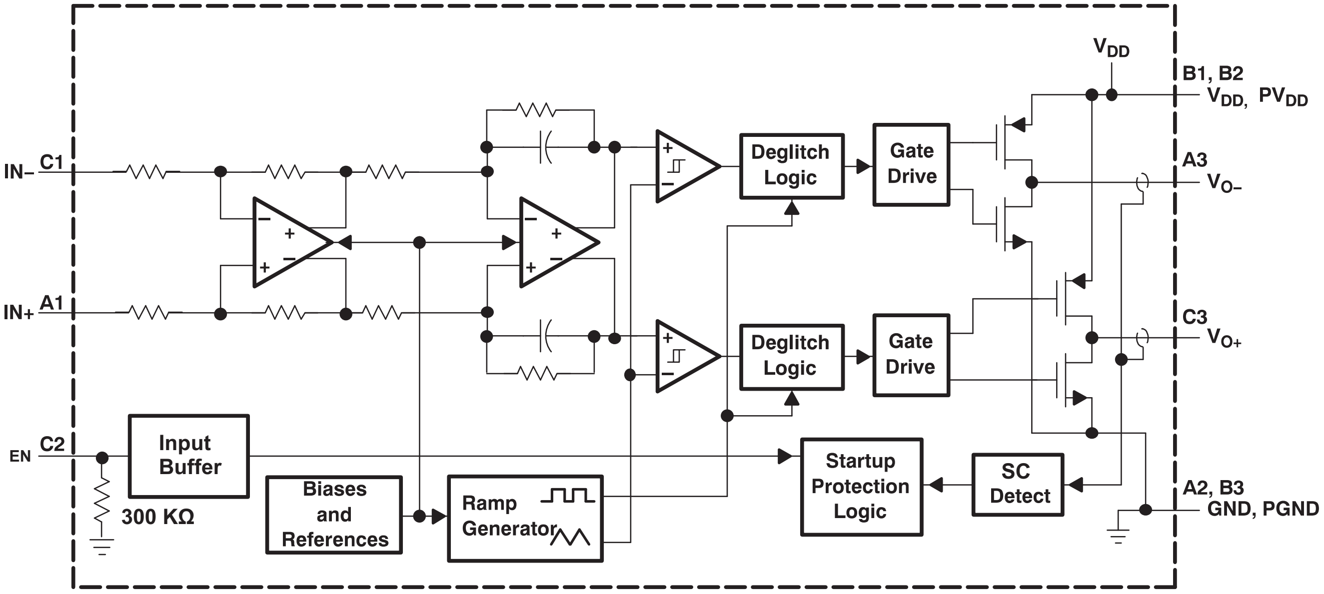
V_{DD} = 3.6 V, T_A = 25°C, R_L = 8 Ω (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
I_{SC}	Short circuit protection threshold	V_{DD} = 3.6 V, V_{O+} shorted to VDD		2		A
		V_{DD} = 3.6 V, V_{O-} shorted to VDD		2		
		V_{DD} = 3.6 V, V_{O+} shorted to GND		2		
		V_{DD} = 3.6 V, V_{O-} shorted to GND		2		
		V_{DD} = 3.6 V, V_{O+} shorted to V_{O-}		2		
T_{AR}	Time for which output is disabled after a short circuit event, after which auto-recovery trials are continuously made	V_{DD} = 2.5 V to 5.5 V		100		ms

Terminal Functions

TERMINAL		I/O	DESCRIPTION
NAME	WCSP BALL		
IN–	C1	I	Negative differential audio input.
IN+	A1	I	Positive differential audio input.
V_{O-}	A3	O	Negative BTL audio output.
V_{O+}	C3	O	Positive BTL audio output.
GND	A2	I	Analog ground terminal. Must be connected to same potential as PGND using a direct connection to a single point ground.
PGND	B3	I	High-current Analog ground terminal. Must be connected to same potential as GND using a direct connection to a single point ground.
V_{DD}	B1	I	Power supply terminal. Must be connected to same power supply as PV_{DD} using a direct connection. Voltage must be within values listed in Recommended Operating Conditions table.
PV_{DD}	B2	I	High-current Power supply terminal. Must be connected to same power supply as V_{DD} using a direct connection. Voltage must be within values listed in Recommended Operating Conditions table.
EN	C2	I	Enable terminal. Connect to Logic High voltage to enable device, Logic Low voltage to disable (shutdown).

FUNCTIONAL BLOCK DIAGRAM



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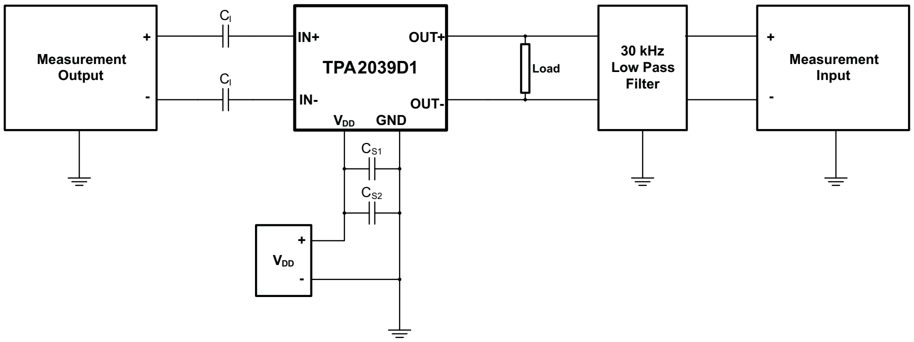
TEST SETUP FOR GRAPHS



1. C_I was shorted for any common-mode input voltage measurement. All other measurements were taken with C_I = 0.1-μF (unless otherwise noted).
2. C_{S1} = 0.1μF is placed very close to the device. The optional C_{S2} = 10μF is used for datasheet graphs.
3. The 30-kHz low-pass filter is required even if the analyzer has an internal low-pass filter. An RC low-pass filter (1kΩ, 4700pF) is used on each output for the data sheet graphs.

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TYPICAL CHARACTERISTICS

V_{DD} = 3.6 V, C_I = 0.1 µF, C_{S1} = 0.1 µF, C_{S2} = 10 µF, T_A = 25°C, R_L = 8 Ω (unless otherwise noted)

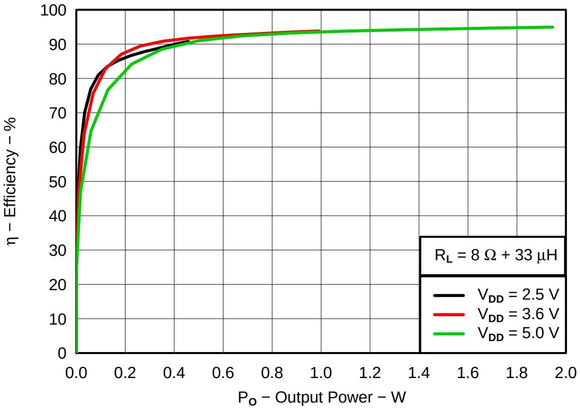
EFFICIENCY
vs OUTPUT POWER

Figure 1.

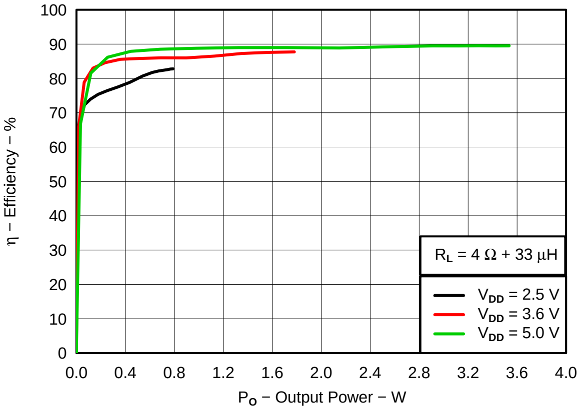
EFFICIENCY
vs OUTPUT POWER

Figure 2.

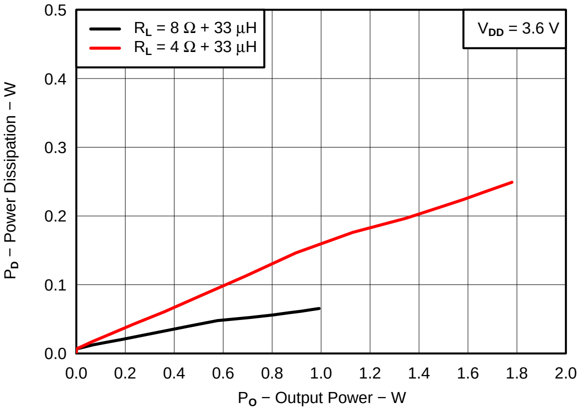
POWER DISSIPATION
vs OUTPUT POWER

Figure 3.

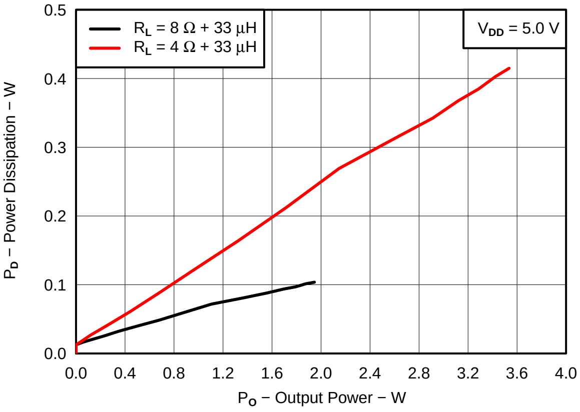
POWER DISSIPATION
vs OUTPUT POWER

Figure 4.

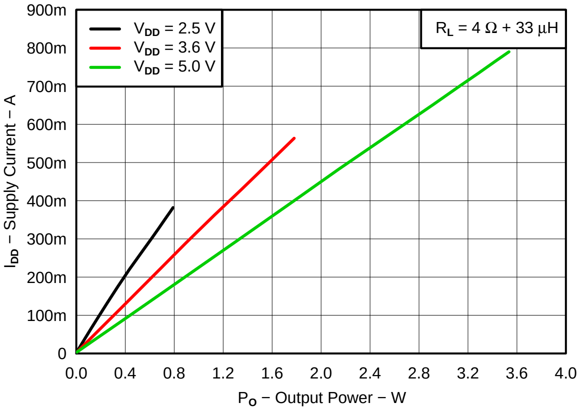
SUPPLY CURRENT
vs OUTPUT POWER

Figure 5.

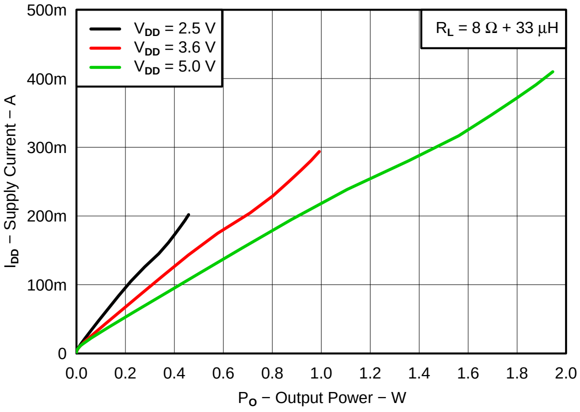
SUPPLY CURRENT
vs OUTPUT POWER

Figure 6.

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TYPICAL CHARACTERISTICS (continued)

V_{DD} = 3.6 V, C_I = 0.1 μF, C_{S1} = 0.1 μF, C_{S2} = 10 μF, T_A = 25°C, R_L = 8 Ω (unless otherwise noted)

SUPPLY CURRENT vs SUPPLY VOLTAGE

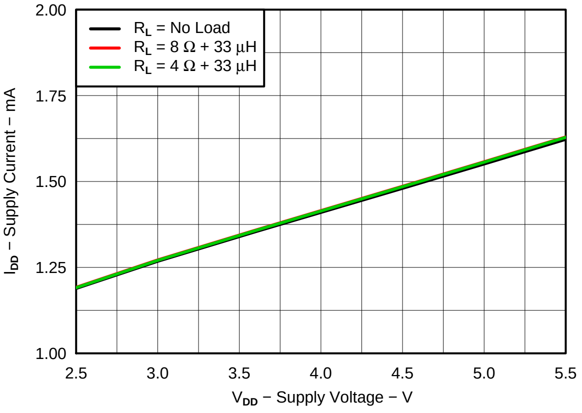

Figure 7.

SUPPLY CURRENT vs EN VOLTAGE

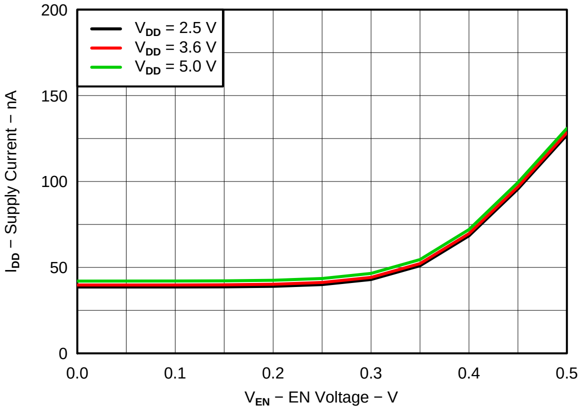

Figure 8.

OUTPUT POWER vs LOAD RESISTANCE

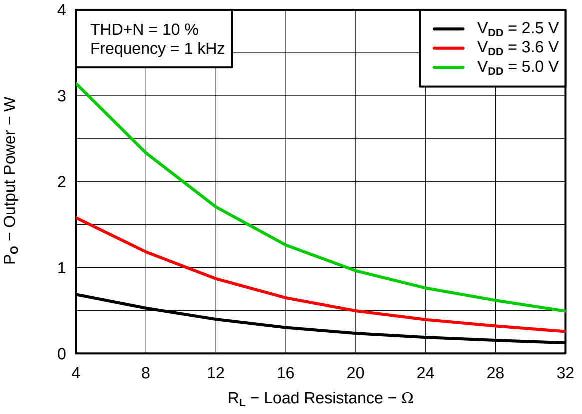

Figure 9.

OUTPUT POWER vs LOAD RESISTANCE

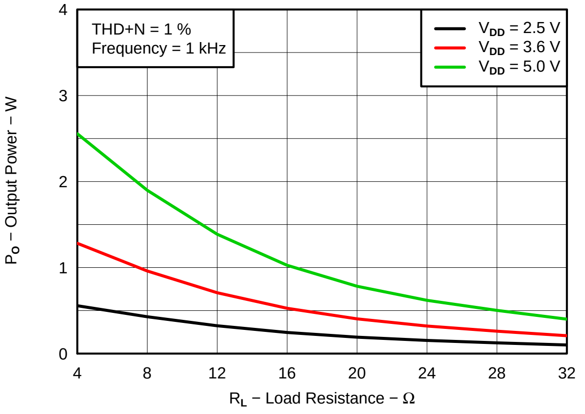

Figure 10.

OUTPUT POWER vs SUPPLY VOLTAGE

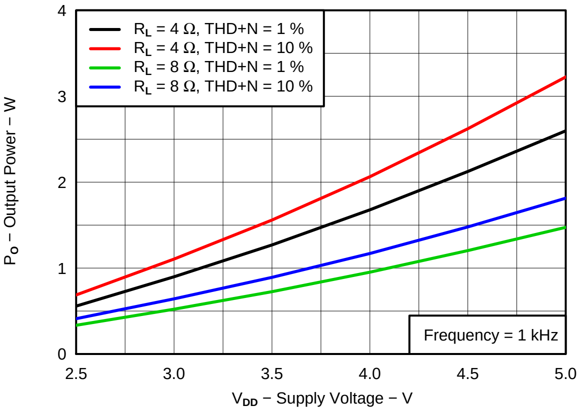

Figure 11.

THD + NOISE vs OUTPUT POWER

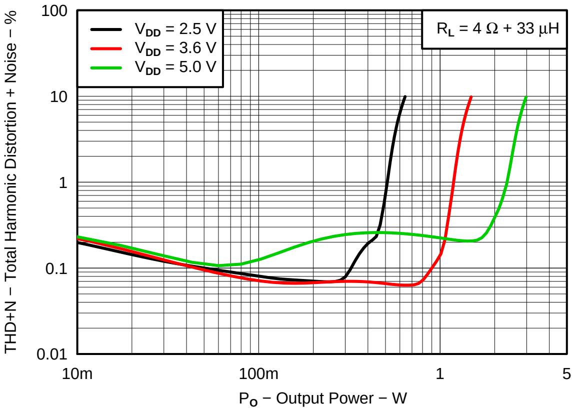

Figure 12.

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TYPICAL CHARACTERISTICS (continued)

V_{DD} = 3.6 V, C_I = 0.1 µF, C_{S1} = 0.1 µF, C_{S2} = 10 µF, T_A = 25°C, R_L = 8 Ω (unless otherwise noted)

THD + NOISE vs OUTPUT POWER

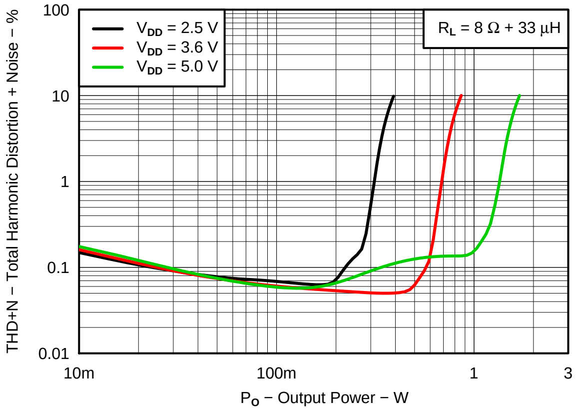

Figure 13.

THD + NOISE vs FREQUENCY

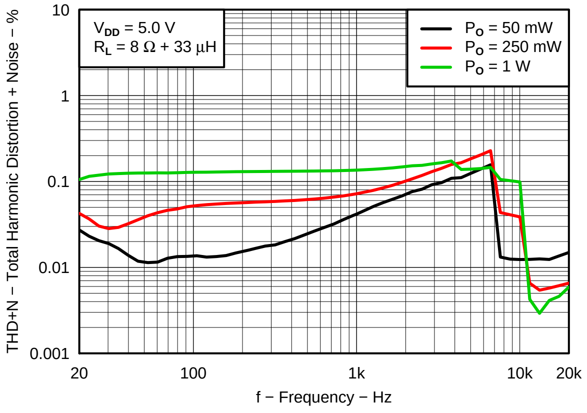

Figure 14.

THD + NOISE vs FREQUENCY

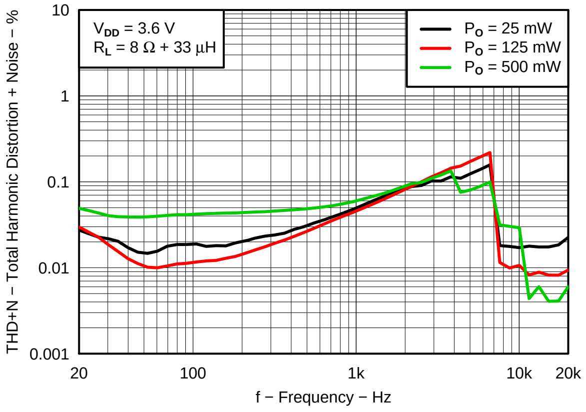

Figure 15.

THD + NOISE vs FREQUENCY

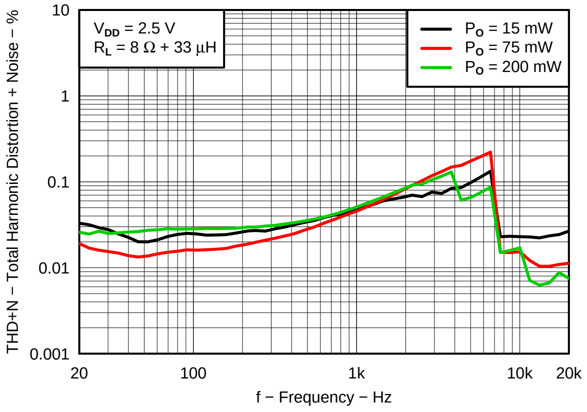

Figure 16.

THD + NOISE vs FREQUENCY

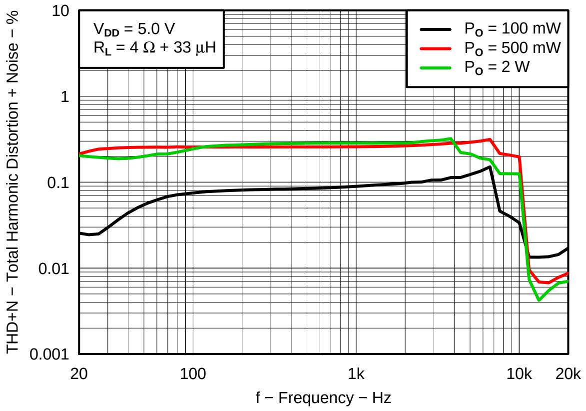

Figure 17.

THD + NOISE vs FREQUENCY

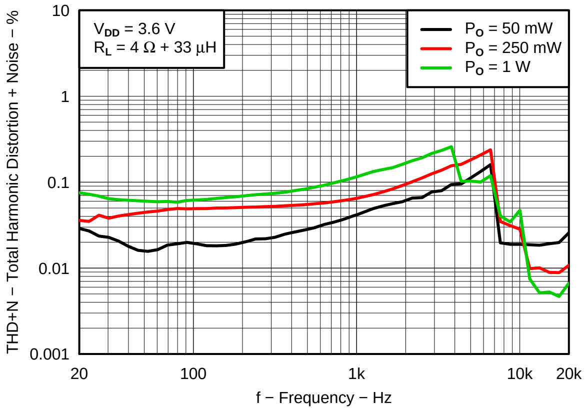

Figure 18.

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TYPICAL CHARACTERISTICS (continued)

V_{DD} = 3.6 V, C_I = 0.1 µF, C_{S1} = 0.1 µF, C_{S2} = 10 µF, T_A = 25°C, R_L = 8 Ω (unless otherwise noted)

THD + NOISE vs FREQUENCY

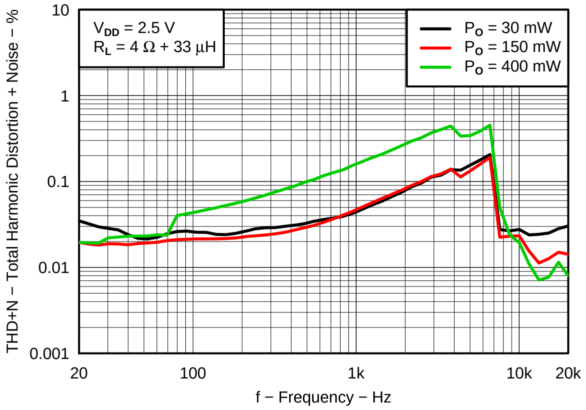

Figure 19.

THD + NOISE vs COMMON MODE INPUT VOLTAGE

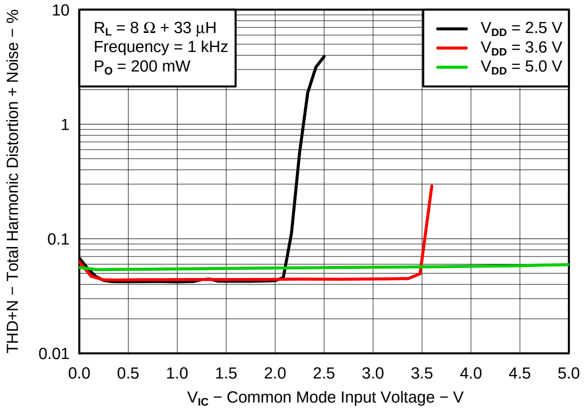

Figure 20.

POWER SUPPLY REJECTION RATIO vs FREQUENCY

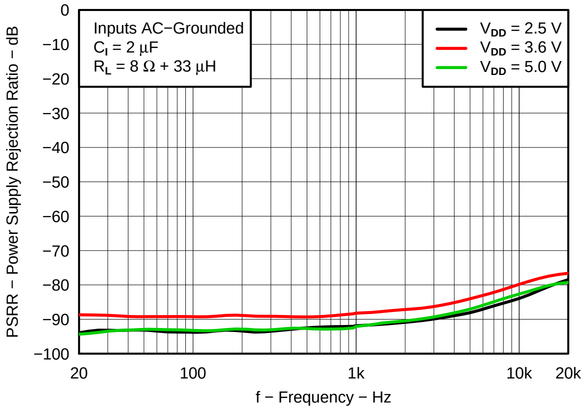

Figure 21.

POWER SUPPLY REJECTION RATIO vs FREQUENCY

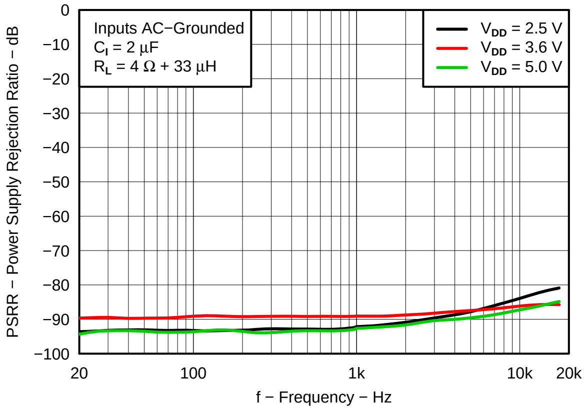

Figure 22.

POWER SUPPLY REJECTION RATIO vs COMMON MODE INPUT VOLTAGE

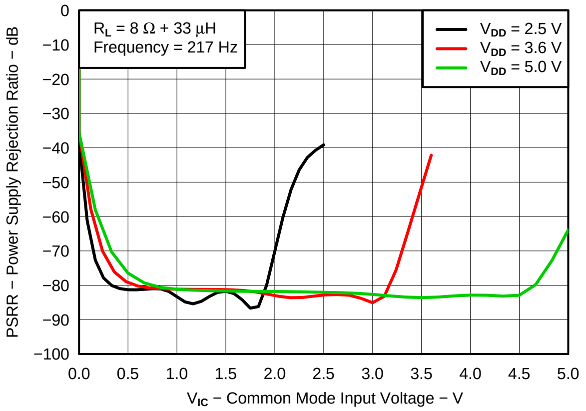

Figure 23.

COMMON MODE REJECTION RATIO vs FREQUENCY

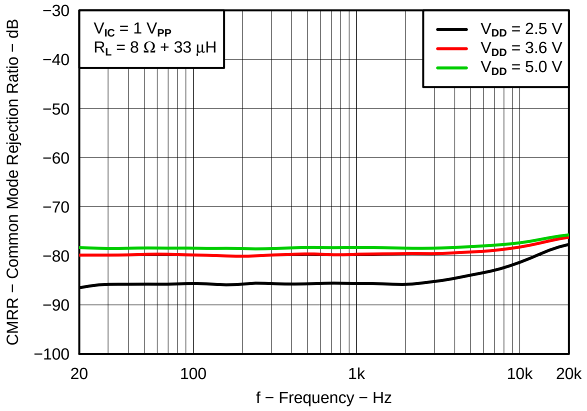

Figure 24.

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TYPICAL CHARACTERISTICS (continued)

V_{DD} = 3.6 V, C_I = 0.1 µF, C_{S1} = 0.1 µF, C_{S2} = 10 µF, T_A = 25°C, R_L = 8 Ω (unless otherwise noted)

COMMON MODE REJECTION RATIO vs COMMON MODE INPUT VOLTAGE

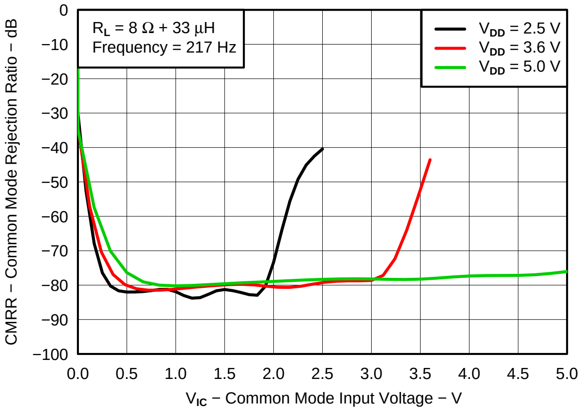

Figure 25.

GSM POWER SUPPLY REJECTION vs TIME

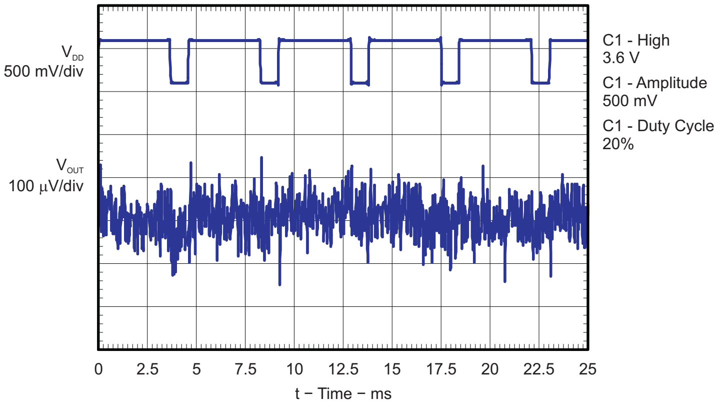

Figure 26.

GSM POWER SUPPLY REJECTION vs FREQUENCY

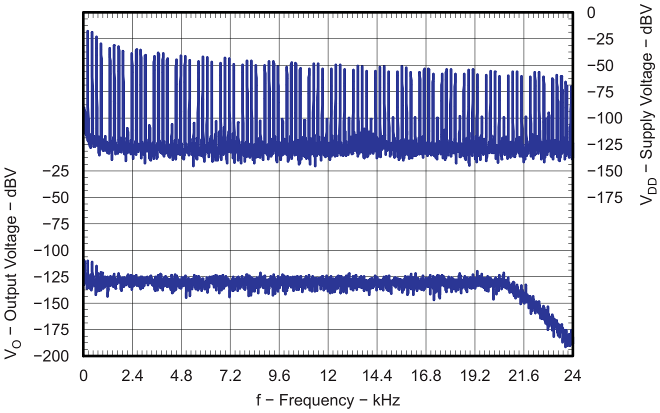

Figure 27.

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APPLICATION INFORMATION

SHORT CIRCUIT AUTO-RECOVERY

When a short-circuit event occurs, the TPA2039D1 goes to shutdown mode and activates the integrated auto-recovery process whose aim is to return the device to normal operation once the short-circuit is removed. This process repeatedly examines (once every 100ms) whether the short-circuit condition persists, and returns the device to normal operation immediately after the short-circuit condition is removed. This feature helps protect the device from large currents and maintain a good long-term reliability.

INTEGRATED IMAGE REJECT FILTER FOR DAC NOISE REJECTION

In applications which use a DAC to drive Class-D amplifiers, out-of-band noise energy present at the DAC's image frequencies fold back into the audio-band at the output of the Class-D amplifier. An external low-pass filter is often placed between the DAC and the Class-D amplifier in order to attenuate this noise.

The TPA2039D1 has an integrated Image Reject Filter with a low-pass cutoff frequency of 130 kHz, which significantly attenuates this noise. Depending on the system noise specification, the integrated Image Reject Filter may help eliminate external filtering, thereby saving board space and component cost.

COMPONENT SELECTION

Figure 28 shows the TPA2039D1 typical schematic with differential inputs, while Figure 29 shows the TPA2039D1 with differential inputs and input capacitors. Figure 30 shows the TPA2039D1 with a single-ended input.

Decoupling Capacitors (C_{S1}, C_{S2})

The TPA2039D1 is a high-performance class-D audio amplifier that requires adequate power supply decoupling to ensure the efficiency is high and total harmonic distortion (THD) is low. For higher frequency transients, spikes, or digital hash on the line, a good low equivalent-series-resistance (ESR) ceramic capacitor C_{S1} = 0.1µF , placed as close as possible to the device V_{DD} lead works best. Placing C_{S1} close to the TPA2039D1 is important for the efficiency of the class-D amplifier, because any resistance or inductance in the trace between the device and the capacitor can cause a loss in efficiency. For filtering lower-frequency noise signals, a 10 µF or greater capacitor (C_{S2}) placed near the audio power amplifier would also help, but it is not required in most applications because of the high PSRR of this device. Typically, the smaller the capacitor's case size, the lower the inductance and the closer it can be placed to the TPA2039D1. X5R and X7R dielectric capacitors are recommended for both C_{S1} and C_{S2}.

Input Capacitors (C_I)

The TPA2039D1 does not require input coupling capacitors if the design uses a differential source that is biased within the common-mode input voltage range. That voltage range is listed in the Recommended Operating Conditions table. If the input signal is not biased within the recommended common-mode input range, such as in needing to use the input as a high pass filter, shown in Figure 29, or if using a single-ended source, shown in Figure 30, input coupling capacitors are required. The same value capacitors should be used on both IN+ and IN– for best pop performance. The 3-dB high-pass cutoff frequency f_C of the filter formed by the input coupling capacitor C_I and the input resistance R_I (typically 75 kΩ) of the TPA2039D1 is given by Equation 1:

$$f_C = \frac{1}{(2\pi R_I C_I)} \tag{1}$$

The value of the input capacitor is important to consider as it directly affects the bass (low frequency) performance of the circuit. Speaker response may also be taken into consideration when setting the corner frequency using input capacitors. Solving for the input coupling capacitance, we get:

$$C_I = \frac{1}{(2\pi R_I f_C)} \tag{2}$$

If the corner frequency is within the audio band, the capacitors should have a tolerance of ±10% or better, because any mismatch in capacitance causes an impedance mismatch at the corner frequency and below.

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For a flat low-frequency response, use large input coupling capacitors (0.1 μF or larger). X5R and X7R dielectric capacitors are recommended.

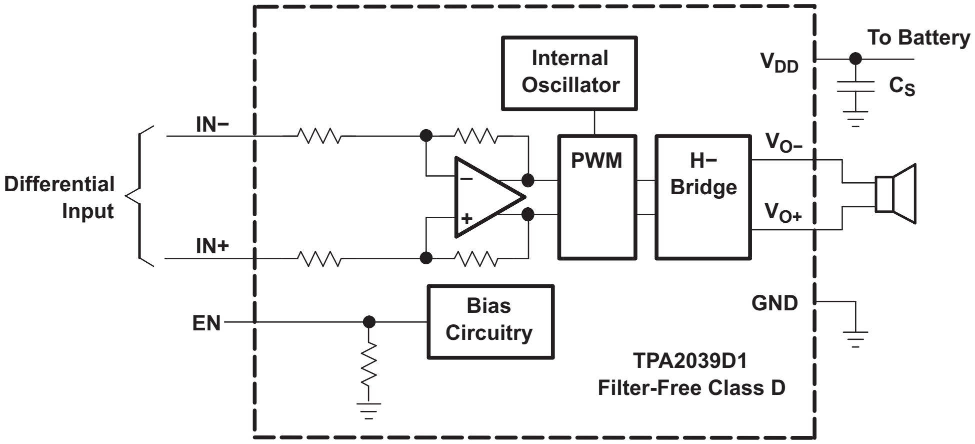

Figure 28. Typical TPA2039D1 Application Schematic With DC-coupled Differential Input

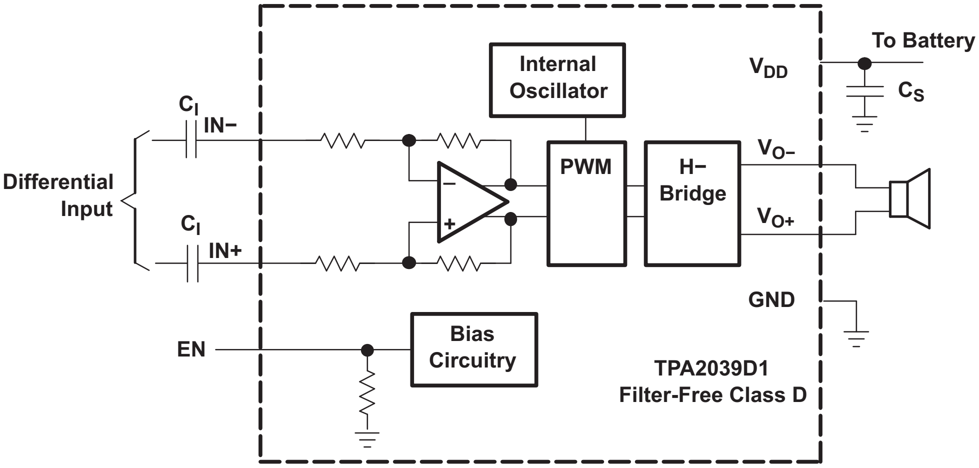

Figure 29. TPA2039D1 Application Schematic With Differential Input and Input Capacitors

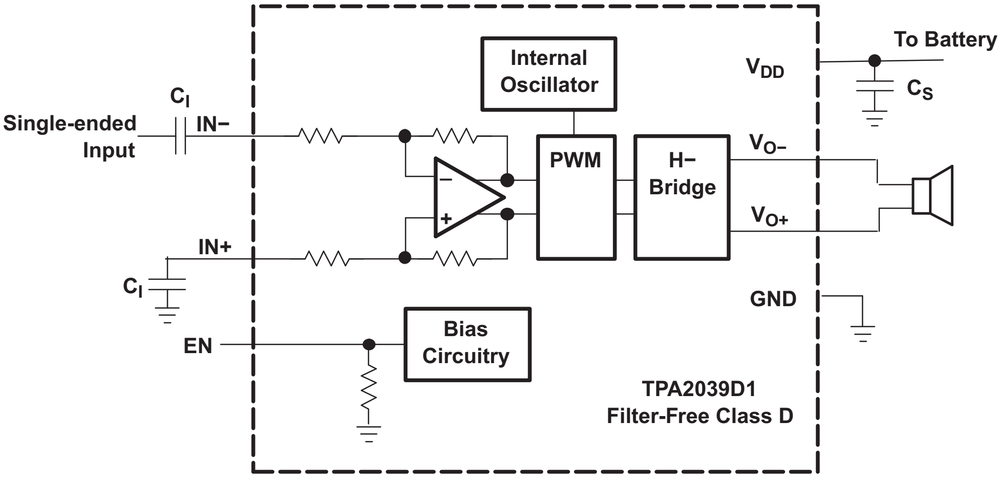

Figure 30. TPA2039D1 Application Schematic With Single-Ended Input

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EFFICIENCY AND THERMAL INFORMATION

The maximum ambient operating temperature of the TPA2039D1 depends on the load resistance, power supply voltage and heat-sinking ability of the PCB system. The derating factor for the YFF package is shown in the dissipation rating table. Converting this to θ_{JA}:

$$\theta_{JA} = \frac{1}{\text{Derating Factor}} \tag{3}$$

Given θ_{JA} (from the Package Dissipation ratings table), the maximum allowable junction temperature (from the Absolute Maximum ratings table), and the maximum internal dissipation (from Power Dissipation vs Output Power figures) the maximum ambient temperature can be calculated with the following equation. Note that the units on these figures are Watts RMS. Because of crest factor (ratio of peak power to RMS power) from 9–15 dB, thermal limitations are not usually encountered.

$$T_A\text{Max} = T_J\text{Max} - \theta_{JA}P_{Dmax} \tag{4}$$

The TPA2039D1 is designed with thermal protection that turns the device off when the junction temperature surpasses 150°C to prevent damage to the IC. Note that the use of speakers less resistive than 4-Ω (typ) is not advisable. Below 4-Ω (typ) the thermal performance of the device dramatically reduces because of increased output current and reduced amplifier efficiency. The Absolute Maximum rating of 3.2-Ω covers the manufacturing tolerance of a 4-Ω speaker and speaker impedance decrease due to frequency. θ_{JA} is a gross approximation of the complex thermal transfer mechanisms between the device and its ambient environment. If the θ_{JA} calculation reveals a potential problem, a more accurate estimate should be made.

WHEN TO USE AN OUTPUT FILTER

Design the TPA2039D1 without an Inductor / Capacitor (LC) output filter if the traces from the amplifier to the speaker are short. Wireless handsets and PDAs are great applications for this class-D amplifier to be used without an output filter.

The TPA2039D1 does not require an LC output filter for short speaker connections (approximately 100 mm long or less). A ferrite bead can often be used in the design if failing radiated emissions testing without an LC filter; and, the frequency-sensitive circuit is greater than 1 MHz. If choosing a ferrite bead, choose one with high impedance at high frequencies, but very low impedance at low frequencies. The selection must also take into account the currents flowing through the ferrite bead. Ferrites can begin to loose effectiveness at much lower than rated current values. See the TPA2039D1 EVM User's Guide for components used successfully by TI.

Figure 31 shows a typical ferrite-bead output filter.

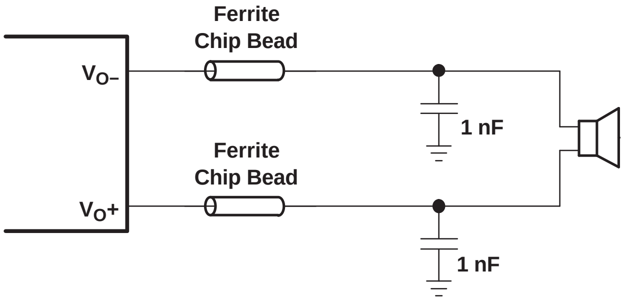

Figure 31. Typical Ferrite Chip Bead Filter

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PRINTED CIRCUIT BOARD LAYOUT

In making the pad size for the WCSP balls, it is recommended that the layout use nonsolder mask defined (NSMD) land. With this method, the solder mask opening is made larger than the desired land area, and the opening size is defined by the copper pad width. Figure 32 shows the appropriate diameters for a WCSP layout.

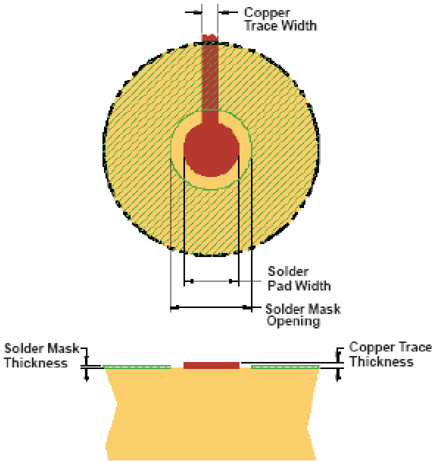

Figure 32. Land Pattern Image and Dimensions

SOLDER PAD DEFINITIONS	COPPER PAD	SOLDER MASK OPENING[5]	COPPER THICKNESS	STENCIL OPENING[6][7]	STENCIL THICKNESS
Nonsolder mask defined (NSMD)	0.23 mm	0.310 mm	1 oz max (0.032 mm)	0.275 mm x 0.275 mm Sq. (rounded corners)	0.1 mm thick

1. Circuit traces from NSMD defined PWB lands should be 75 μm to 100 μm wide in the exposed area inside the solder mask opening. Wider trace widths reduce device stand off and impact reliability.
2. Best reliability results are achieved when the PWB laminate glass transition temperature is above the operating the range of the intended application.
3. Recommend solder paste is Type 3 or Type 4.
4. For a PWB using a Ni/Au surface finish, the gold thickness should be less 0.5 mm to avoid a reduction in thermal fatigue performance.
5. Solder mask thickness should be less than 20 μm on top of the copper circuit pattern
6. Best solder stencil performance is achieved using laser cut stencils with electro polishing. Use of chemically etched stencils give inferior solder paste volume control.
7. Trace routing away from WCSP device should be balanced in X and Y directions to avoid unintentional component movement due to solder wetting forces.

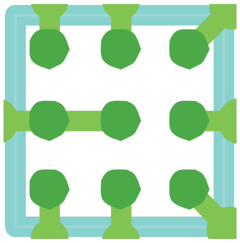

Figure 33. Layout Snapshot

An on-pad via is not required to route the middle ball B2 (PV_{DD}) of the TPA2039D1. Just short ball B2 (PV_{DD}) to ball B1 (V_{DD}) and connect both to the supply trace as shown in Figure 33. This simplifies board routing and saves manufacturing cost.

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Package Dimensions

D	E
Max = 1244µm	Max = 1190µm
Min = 1184µm	Min = 1130µm

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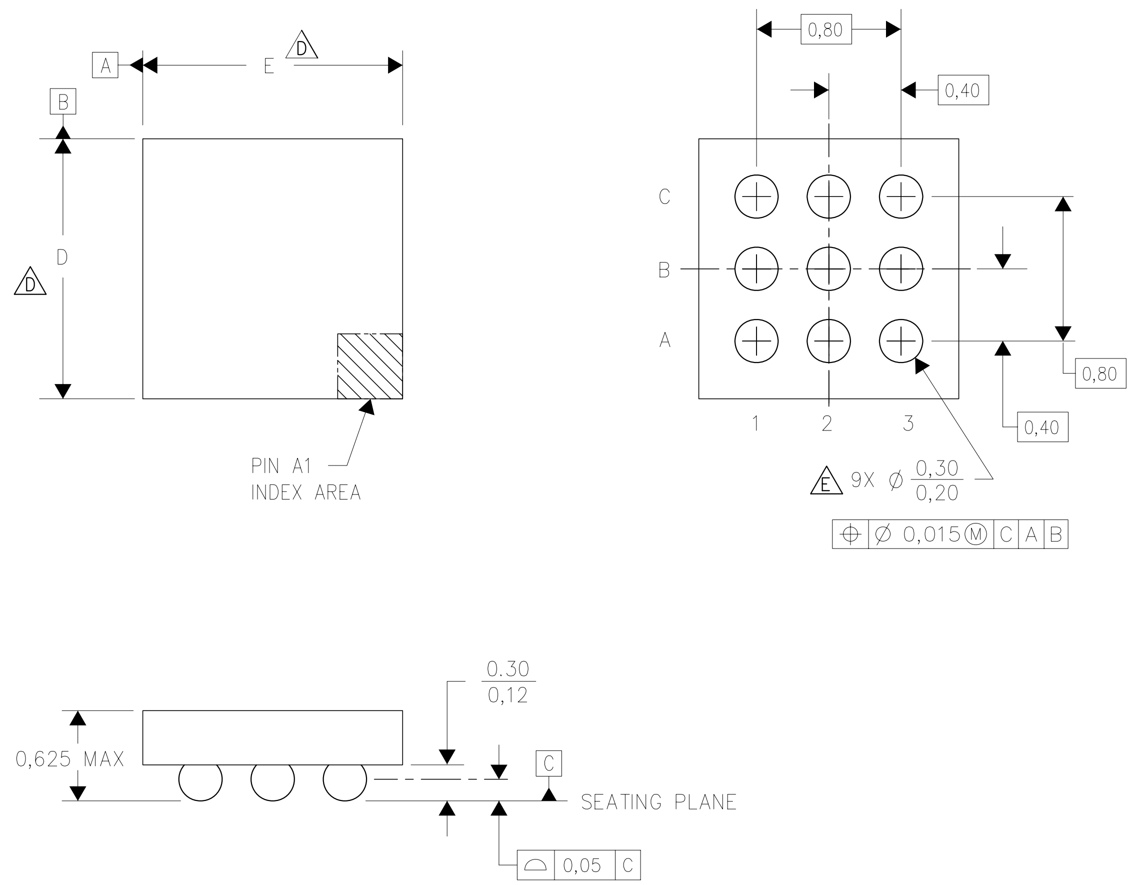
YFF (S-XBGA-N9) DIE-SIZE BALL GRID ARRAY



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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. NanoFree™ package configuration.
- D. Devices in YFF package can have dimensions D ranging from 1.16 to 1.85 mm and dimension E ranging from 1.16 to 1.85 mm. To determine the exact package size of a particular device, refer to the device datasheet or contact a local TI representative.
- E. Reference Product Data Sheet for array population. 3 x 3 matrix pattern is shown for illustration only.
- F. This package contains Pb-free balls.

NanoFree is a trademark of Texas Instruments.

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