

# TPA2015D1 2-W Constant Output Power Class-D Audio Amplifier With Adaptive Boost Converter and Battery Tracking SpeakerGuard™ AGC

## 1 Features

- Built-In SpeakerGuard™ Automatic Gain Control (AGC) with Enhanced Battery Tracking
  - Limits Battery Current Consumption
  - Prevents Audio Clipping
- 2 W into 8  $\Omega$  Load From 3.6 V Supply (6% THD)
- Integrated Adaptive Boost Converter
  - Increases Efficiency at Low Output Power
- Low Quiescent Current of 1.7 mA from 3.6 V
- Operates From 2.5 V to 5.2 V
- Thermal and Short-Circuit Protection with Auto Recovery
- Three Gain Settings: 6 dB, 15.5 dB, and 20 dB
- Independent Control for Boost and Class-D
- Pin-to-Pin Compatible with TPA2013D1
- Available in 1.954 mm  $\times$  1.954 mm 16-ball DSBGA Package

## 2 Applications

- Cell Phones, PDA, GPS
- Portable Electronics and Speakers

## 3 Description

The TPA2015D1 is a high efficiency Class-D audio power amplifier with battery-tracking SpeakerGuard™ AGC technology and an integrated adaptive boost converter that enhances efficiency at low output power. It drives up to 2 W into an 8  $\Omega$  speaker (6% THD). With 85% typical efficiency, the TPA2015D1 helps extend battery life when playing audio.

The built-in boost converter generates a 5.5 V supply voltage for the Class-D amplifier. This provides a louder audio output than a stand-alone amplifier directly connected to the battery. The SpeakerGuard™ AGC adjusts the Class-D gain to limit battery current and prevent heavy clipping.

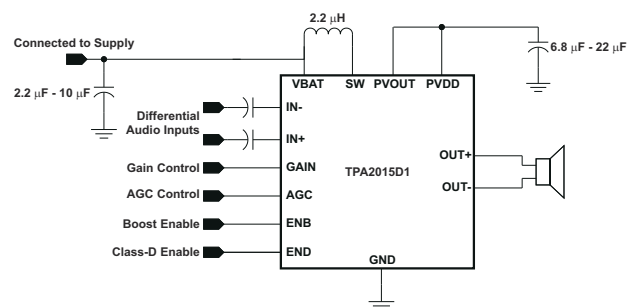
The TPA2015D1 has an integrated low-pass filter to improve the RF rejection and reduce DAC out-of-band noise, increasing the signal to noise ratio (SNR).

The TPA2015D1 is available in a space saving 1.954 mm  $\times$  1.954 mm, 0.5 mm pitch DSBGA package (YZH).

### Device Information<sup>(1)</sup>

| PART NUMBER | PACKAGE    | BODY SIZE (NOM)        |
|-------------|------------|------------------------|
| TPA2015D1   | DSBGA (16) | 2.0 mm $\times$ 2.0 mm |
| SN012020    | DSBGA (16) | 2.0 mm $\times$ 2.0 mm |

(1) For all available packages, see the orderable addendum at the end of the data sheet.



**Simplified Application Schematic**



## Table of Contents

|                                                  |           |                                                                  |           |
|--------------------------------------------------|-----------|------------------------------------------------------------------|-----------|
| <b>1 Features</b> .....                          | <b>1</b>  | 9.3 Feature Description.....                                     | <b>11</b> |
| <b>2 Applications</b> .....                      | <b>1</b>  | 9.4 Device Functional Modes.....                                 | <b>17</b> |
| <b>3 Description</b> .....                       | <b>1</b>  | <b>10 Application and Implementation</b> .....                   | <b>19</b> |
| <b>4 Revision History</b> .....                  | <b>2</b>  | 10.1 Application Information.....                                | <b>19</b> |
| <b>5 Device Comparison Table</b> .....           | <b>3</b>  | 10.2 Typical Applications.....                                   | <b>19</b> |
| <b>6 Pin Configuration and Functions</b> .....   | <b>3</b>  | <b>11 Power Supply Recommendations</b> .....                     | <b>23</b> |
| <b>7 Specifications</b> .....                    | <b>4</b>  | 11.1 Power Supply Decoupling Capacitors.....                     | <b>23</b> |
| 7.1 Absolute Maximum Ratings.....                | <b>4</b>  | <b>12 Layout</b> .....                                           | <b>24</b> |
| 7.2 ESD Ratings.....                             | <b>4</b>  | 12.1 Layout Guidelines.....                                      | <b>24</b> |
| 7.3 Recommended Operating Conditions.....        | <b>4</b>  | 12.2 Layout Example.....                                         | <b>25</b> |
| 7.4 Thermal Information.....                     | <b>4</b>  | <b>13 Device and Documentation Support</b> .....                 | <b>26</b> |
| 7.5 Electrical Characteristics.....              | <b>5</b>  | 13.1 Device Support.....                                         | <b>26</b> |
| 7.6 Operating Characteristics.....               | <b>5</b>  | 13.2 Community Resources.....                                    | <b>27</b> |
| 7.7 Typical Characteristics.....                 | <b>7</b>  | 13.3 Trademarks.....                                             | <b>27</b> |
| <b>8 Parameter Measurement Information</b> ..... | <b>10</b> | <b>14 Mechanical, Packaging, and Orderable Information</b> ..... | <b>28</b> |
| <b>9 Detailed Description</b> .....              | <b>11</b> | 14.1 Package Option Addendum.....                                | <b>29</b> |
| 9.1 Overview.....                                | <b>11</b> |                                                                  |           |
| 9.2 Functional Block Diagram.....                | <b>11</b> |                                                                  |           |

## 4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

|                                                                                                                                                                                                                                                                                                                                                                                                     |             |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| <b>Changes from Revision B (October 2015) to Revision C (June 2022)</b> .....                                                                                                                                                                                                                                                                                                                       | <b>Page</b> |
| • Added SN012020 device to data sheet.....                                                                                                                                                                                                                                                                                                                                                          | <b>1</b>    |
| <b>Changes from Revision A (November 2011) to Revision B (October 2015)</b> .....                                                                                                                                                                                                                                                                                                                   | <b>Page</b> |
| • Added <i>Pin Configuration and Functions</i> section, <i>ESD Ratings</i> table, <i>Feature Description</i> section, <i>Device Functional Modes</i> , <i>Application and Implementation</i> section, <i>Power Supply Recommendations</i> section, <i>Layout</i> section, <i>Device and Documentation Support</i> section, and <i>Mechanical, Packaging, and Orderable Information</i> section..... | <b>1</b>    |
| <b>Changes from Revision * (May 2010) to Revision A (November 2011)</b> .....                                                                                                                                                                                                                                                                                                                       | <b>Page</b> |
| • Changed the Boost Converter, PVOUT entry in the Operating Conditions Table.....                                                                                                                                                                                                                                                                                                                   | <b>5</b>    |

## 5 Device Comparison Table

| DEVICE NUMBER | SPEAKER CHANNELS | SPEAKER AMP TYPE | OUTPUT POWER (W) | PSRR (dB) |
|---------------|------------------|------------------|------------------|-----------|
| TPA2012D2     | Stereo           | Class D          | 2.1              | 71        |
| TPA2015D1     | Mono             | Class D          | 2                | 85        |
| TPA2026D2     | Stereo           | Class D          | 3.2              | 80        |
| TPA2028D1     | Mono             | Class D          | 3                | 80        |

## 6 Pin Configuration and Functions

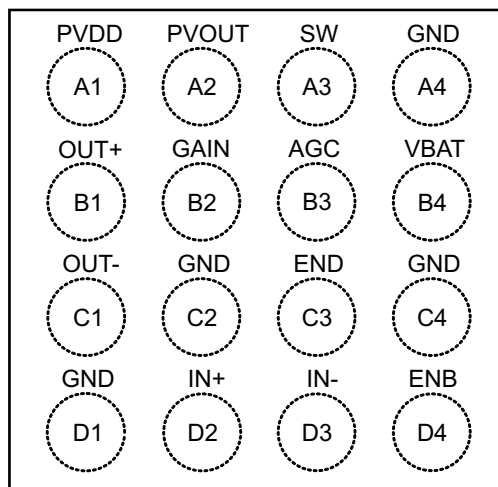


Figure 6-1. YZH Package 16-Pin DSBGA Top View

Table 6-1. Pin Functions

| PIN    |                | TYPE <sup>(1)</sup> | DESCRIPTION                                                          |
|--------|----------------|---------------------|----------------------------------------------------------------------|
| NAME   | NO.            |                     |                                                                      |
| AGC    | B3             | I                   | Enable and select AGC.                                               |
| ENB    | D4             | I                   | Enable for the boost converter; set to logic high to enable.         |
| END    | C3             | I                   | Enable for the Class-D amplifier; set to logic high to enable.       |
| GAIN   | B2             | I                   | Gain selection pin.                                                  |
| GND    | A4, C2, C4, D1 | P                   | Ground; all ground balls must be connected for proper functionality. |
| IN-    | D3             | I                   | Negative audio input.                                                |
| IN+    | D2             | I                   | Positive audio input.                                                |
| OUT-   | C1             | O                   | Negative audio output.                                               |
| OUT+   | B1             | O                   | Positive audio output.                                               |
| PVDD   | A1             | I                   | Class-D power stage supply voltage.                                  |
| PVOOUT | A2             | O                   | Boost converter output.                                              |
| SW     | A3             | I                   | Boost and rectifying switch input.                                   |
| VBAT   | B4             | P                   | Supply voltage.                                                      |

(1) I = Input, O = Output, P = Power

## 7 Specifications

### 7.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)<sup>(1)</sup>

|                                           |          | MIN                                 | MAX        | UNIT     |
|-------------------------------------------|----------|-------------------------------------|------------|----------|
| Supply voltage                            | VBAT     | −0.3                                | 6          | V        |
| Input Voltage, $V_I$                      | IN+, IN− | −0.3                                | VBAT + 0.3 | V        |
| Output continuous total power dissipation |          | See the <a href="#">Section 7.4</a> |            |          |
| Minimum load impedance                    |          | 6                                   |            | $\Omega$ |
| Operating free-air temperature, $T_A$     |          | −40                                 | 85         | °C       |
| Operating junction temperature, $T_J$     |          | −40                                 | 150        | °C       |
| Storage temperature, $T_{stg}$            |          | −65                                 | 150        | °C       |

- (1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

### 7.2 ESD Ratings

|                                     |                                                                                | VALUE | UNIT |
|-------------------------------------|--------------------------------------------------------------------------------|-------|------|
| $V_{(ESD)}$ Electrostatic discharge | Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 <sup>(1)</sup>              | ±2000 | V    |
|                                     | Charged-device model (CDM), per JEDEC specification JESD22-C101 <sup>(2)</sup> | ±500  |      |

- (1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

- (2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

### 7.3 Recommended Operating Conditions

|                                             | MIN | NOM | MAX | UNIT |
|---------------------------------------------|-----|-----|-----|------|
| Supply voltage, VBAT                        | 2.5 |     | 5.2 | V    |
| $V_{IH}$ High-level input voltage, END, ENB | 1.3 |     |     | V    |
| $V_{IL}$ Low-level input voltage, END, ENB  |     |     | 0.6 | V    |
| $T_A$ Operating free-air temperature        | −40 |     | 85  | °C   |
| $T_J$ Operating junction temperature        | −40 |     | 150 | °C   |

### 7.4 Thermal Information

| THERMAL METRIC <sup>(1)</sup> |                                              | TPA2015D1   | UNIT |
|-------------------------------|----------------------------------------------|-------------|------|
|                               |                                              | YZH (DSBGA) |      |
|                               |                                              | 16 PINS     |      |
| $R_{\theta JA}$               | Junction-to-ambient thermal resistance       | 75          | °C/W |
| $R_{\theta JC(top)}$          | Junction-to-case (top) thermal resistance    | 22          | °C/W |
| $R_{\theta JB}$               | Junction-to-board thermal resistance         | 26          | °C/W |
| $\psi_{JT}$                   | Junction-to-top characterization parameter   | 0.5         | °C/W |
| $\psi_{JB}$                   | Junction-to-board characterization parameter | 25          | °C/W |
| $R_{\theta JC(bot)}$          | Junction-to-case (bottom) thermal resistance | n/a         | °C/W |

- (1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report, [SPRA953](#).

## 7.5 Electrical Characteristics

V<sub>BAT</sub> = 3.6 V, Gain = 6 dB, R<sub>AGC</sub> = Float, T<sub>A</sub> = 25°C, R<sub>L</sub> = 8 Ω + 33 μH (unless otherwise noted)

| PARAMETER                             | TEST CONDITIONS                                                                           | MIN                     | TYP                     | MAX   | UNIT |
|---------------------------------------|-------------------------------------------------------------------------------------------|-------------------------|-------------------------|-------|------|
| V <sub>BAT</sub> supply voltage range | END = 0 V, ENB = V <sub>BAT</sub>                                                         | 2.5                     |                         | 5.2   | V    |
|                                       | END = V <sub>BAT</sub> , ENB = V <sub>BAT</sub> , AGC options 1, 2, and 3                 | 2.5                     |                         | 5.2   |      |
|                                       | END = V <sub>BAT</sub> , ENB = V <sub>BAT</sub> , AGC option 0                            | 2.8                     |                         | 5.2   |      |
| Class-D supply voltage range          | END = ENB = V <sub>BAT</sub> , boost converter active                                     | 5.2                     |                         | 5.8   | V    |
|                                       | END = V <sub>BAT</sub> , ENB = 0 V                                                        | 3.1                     |                         | 5.25  | V    |
| Power supply ripple rejection         | V <sub>BAT</sub> = 2.5 V to 5.2 V, END = ENB = V <sub>BAT</sub>                           |                         | 85                      |       | dB   |
|                                       | V <sub>BAT</sub> = 2.5 V to 5.2 V, END = V <sub>BAT</sub> , ENB = 0 V (pass through mode) |                         | 75                      |       |      |
| Operating quiescent current           | END = 0 V, ENB = V <sub>BAT</sub>                                                         |                         | 0.5                     |       | mA   |
|                                       | END = ENB = V <sub>BAT</sub>                                                              |                         | 1.7                     | 2.2   | mA   |
| Shutdown quiescent current            | V <sub>BAT</sub> = 2.5 V to 5.2 V, END = ENB = GND                                        |                         | 0.2                     | 3     | μA   |
| Gain control pin voltage              | Gain = 6 dB (connect to GND)                                                              | 0                       | 0.25 × V <sub>BAT</sub> |       | V    |
|                                       | Gain = 15.5 dB (float)                                                                    | 0.4 × V <sub>BAT</sub>  | 0.6 × V <sub>BAT</sub>  |       |      |
|                                       | Gain = 20 dB (connect to V <sub>BAT</sub> )                                               | 0.75 × V <sub>BAT</sub> |                         |       |      |
| AGC control pin voltage               | AGC with no inflection point, R <sub>(AGC)</sub> = Open                                   | 2                       |                         |       | V    |
|                                       | AGC option 1 (inflection = 3.55 V), R <sub>(AGC)</sub> = 39 kΩ (±5%)                      | 1.36                    |                         | 1.75  |      |
|                                       | AGC option 2 (inflection = 3.78 V), R <sub>(AGC)</sub> = 27 kΩ (±5%)                      | 0.94                    |                         | 1.2   |      |
|                                       | AGC option 3 (inflection = 3.96 V), R <sub>(AGC)</sub> = 18 kΩ (±5%)                      | 0                       |                         | 0.825 |      |
| AGC control pin output current        |                                                                                           | 37.6                    | 40                      | 42.4  | μA   |
| Input common-mode voltage range       | IN+, IN–                                                                                  | 0.6                     |                         | 1.3   | V    |
| Start-up time                         | Boost converter followed by Class-D amplifier                                             |                         | 6                       | 10    | ms   |
|                                       | Boost converter only                                                                      |                         | 1                       | 4     |      |
|                                       | Class-D amplifier only                                                                    |                         | 5                       | 6     |      |

## 7.6 Operating Characteristics

V<sub>BAT</sub> = 3.6 V, T<sub>A</sub> = 25°C, R<sub>L</sub> = 8 Ω + 33 μH (unless otherwise noted)

| PARAMETER                                                 | TEST CONDITIONS                                                                        | MIN | TYP  | MAX | UNIT |
|-----------------------------------------------------------|----------------------------------------------------------------------------------------|-----|------|-----|------|
| <b>BOOST CONVERTER</b>                                    |                                                                                        |     |      |     |      |
| V <sub>(PVOUT)</sub> Boost converter output voltage range | I <sub>(BOOST)</sub> = 0 mA                                                            | 5.4 |      | 6   | V    |
|                                                           | I <sub>(BOOST)</sub> = 700 mA                                                          |     | 5.4  |     |      |
| I <sub>L</sub>                                            | Boost converter input current limit                                                    |     | 1500 |     | mA   |
|                                                           | Boost converter start-up current limit                                                 |     | 450  |     | mA   |
| η Boost converter efficiency                              | END = 0 V, I <sub>(PVOUT)</sub> = 100 mA constant                                      |     | 88%  |     |      |
| f <sub>BOOST</sub> Boost converter frequency              |                                                                                        |     | 1.2  |     | MHz  |
| <b>CLASS-D AMPLIFIER</b>                                  |                                                                                        |     |      |     |      |
| P <sub>O</sub> Output power                               | THD = 1%, V <sub>BAT</sub> = 2.5 V, f = 1 kHz                                          |     | 1200 |     | mW   |
|                                                           | THD = 1%, V <sub>BAT</sub> = 3 V, f = 1 kHz                                            |     | 1500 |     |      |
|                                                           | THD = 1%, V <sub>BAT</sub> = 3.6 V, f = 1 kHz                                          |     | 1700 |     |      |
| V <sub>O</sub> Output peak voltage                        | THD = 1%, V <sub>BAT</sub> = 3 V, f = 1 kHz, 6 dB crest factor sine burst, no clipping |     | 5.2  |     | V    |

**TPA2015D1**

SLOS638C – NOVEMBER 2011 – REVISED JUNE 2022

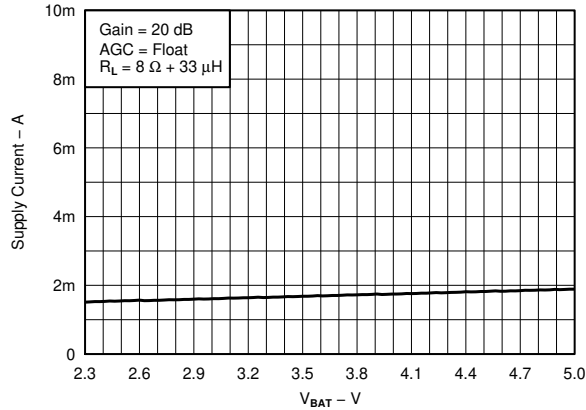
VBAT = 3.6 V, T<sub>A</sub> = 25°C, R<sub>L</sub> = 8 Ω + 33 μH (unless otherwise noted)

| PARAMETER              |                                                     | TEST CONDITIONS                                     | MIN   | TYP   | MAX | UNIT              |
|------------------------|-----------------------------------------------------|-----------------------------------------------------|-------|-------|-----|-------------------|
| A <sub>V</sub>         | Closed-loop voltage gain                            | GAIN < 0.25 × VBAT                                  | 6     |       |     | dB                |
|                        |                                                     | 0.4 × VBAT < GAIN < 0.6 × VBAT (or float)           | 15.5  |       |     |                   |
|                        |                                                     | GAIN > 0.75 × VBAT                                  | 20    |       |     |                   |
| ΔA <sub>V</sub>        | Gain accuracy                                       |                                                     | −0.5  |       | 0.5 | dB                |
| V <sub>OOS</sub>       | Output offset voltage                               |                                                     |       |       | 10  | mV                |
| R <sub>IN</sub>        | Input impedance (per input pin)                     | A <sub>V</sub> = 6 dB                               | 27.8  |       |     | kΩ                |
|                        |                                                     | A <sub>V</sub> = 15.5 dB                            | 14.9  |       |     |                   |
|                        |                                                     | A <sub>V</sub> = 20 dB                              | 10.1  |       |     |                   |
|                        | Input impedance in shutdown (per input pin)         | END = 0 V                                           | 88.4  |       |     | kΩ                |
| Z <sub>O</sub>         | Output impedance in shutdown                        | END = 0 V                                           | 2     |       |     | kΩ                |
| f <sub>CLASS-D</sub>   | Switching frequency                                 |                                                     | 560   | 600   | 640 | kHz               |
| E <sub>N</sub>         | Noise output voltage                                | A-weighted, GAIN = 6 dB                             | 24.8  |       |     | μV <sub>RMS</sub> |
|                        |                                                     | A-weighted, GAIN = 15.5 dB                          | 33.4  |       |     |                   |
|                        |                                                     | A-weighted, GAIN = 20 dB                            | 42.4  |       |     |                   |
| THD+N                  | Total harmonic distortion plus noise <sup>(1)</sup> | P <sub>O</sub> = 100 mW, f = 1 kHz                  | 0.06% |       |     |                   |
|                        |                                                     | P <sub>O</sub> = 500 mW, f = 1 kHz                  | 0.07% |       |     |                   |
| AC PSRR                | AC-Power supply ripple rejection (output referred)  | 200 mV <sub>PP</sub> ripple, f = 217 Hz             | 75    |       |     | dB                |
|                        |                                                     | 200 mV <sub>PP</sub> ripple, f = 4 kHz              | 70    |       |     |                   |
|                        | Audio frequency passband ripple                     | f <sub>AUDIO</sub> = 20 Hz, C <sub>IN</sub> = 1 μF  | −0.2  | −0.1  | 0   | dB                |
|                        |                                                     | f <sub>AUDIO</sub> = 16 kHz, C <sub>IN</sub> = 1 μF | −0.2  | −0.1  | 0   |                   |
| AUTOMATIC GAIN CONTROL |                                                     |                                                     |       |       |     |                   |
|                        | AGC gain range                                      |                                                     | 0     |       | 20  | dB                |
|                        | AGC gain step size                                  |                                                     |       | 0.5   |     | dB                |
|                        | AGC attack time (gain decrease)                     |                                                     |       | 0.026 |     | ms/dB             |
|                        | AGC release time (gain increase)                    |                                                     |       | 1600  |     | ms/dB             |
|                        | Limiter threshold voltage                           | VBAT > inflection point                             |       | 6.15  |     | V                 |
|                        | VBAT vs. Limiter slope                              | VBAT < inflection point                             |       | 3     |     | V/V               |
|                        | AGC inflection point                                | AGC option 1, R <sub>(AGC)</sub> = 39 kΩ (±5%)      | 3.55  |       |     | V                 |
|                        |                                                     | AGC option 2, R <sub>(AGC)</sub> = 27 kΩ (±5%)      | 3.78  |       |     |                   |
|                        |                                                     | AGC option 3, R <sub>(AGC)</sub> = 18 kΩ (±5%)      | 3.96  |       |     |                   |

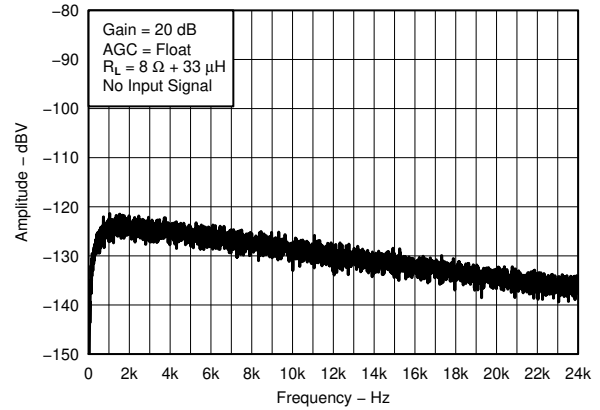
(1) A-weighted

## 7.7 Typical Characteristics

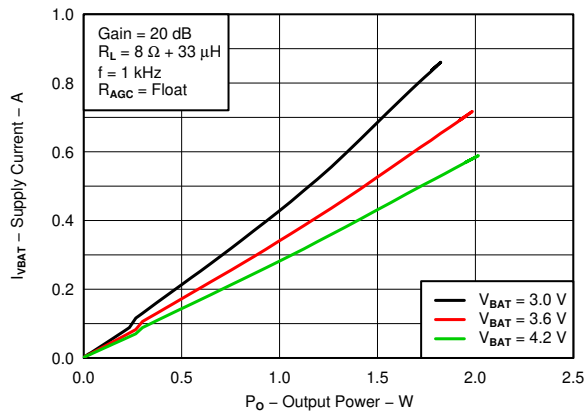
$V_{BAT} = 3.6\text{ V}$ , Gain = 6 dB,  $C_I = 1\text{ }\mu\text{F}$ ,  $C_{BOOST} = 22\text{ }\mu\text{F}$ ,  $L_{BOOST} = 2.2\text{ }\mu\text{H}$ , AGC = Float, ENB = END =  $V_{BAT}$ , and Load =  $8\text{ }\Omega + 33\text{ }\mu\text{H}$  unless otherwise specified.



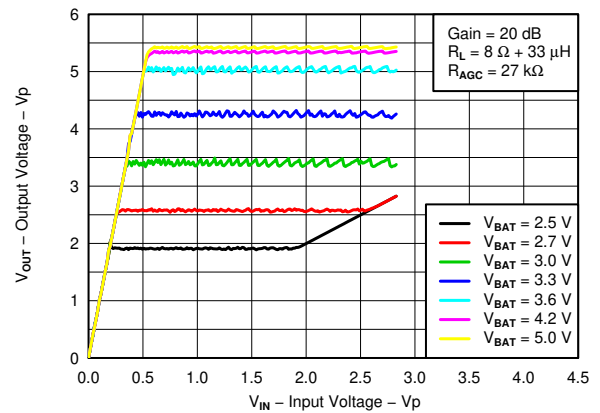
**Figure 7-1. Quiescent Supply Current vs Supply Voltage**



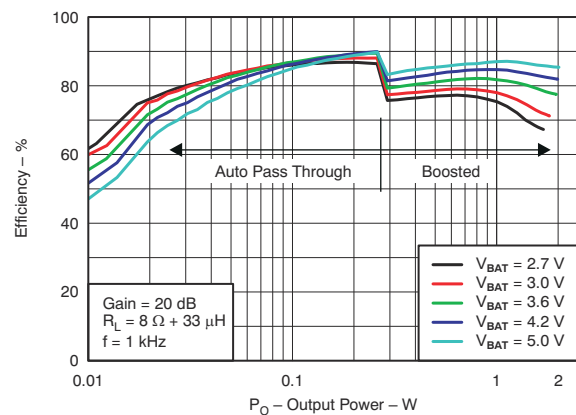
**Figure 7-2. A-Weighted Output Noise vs Frequency**



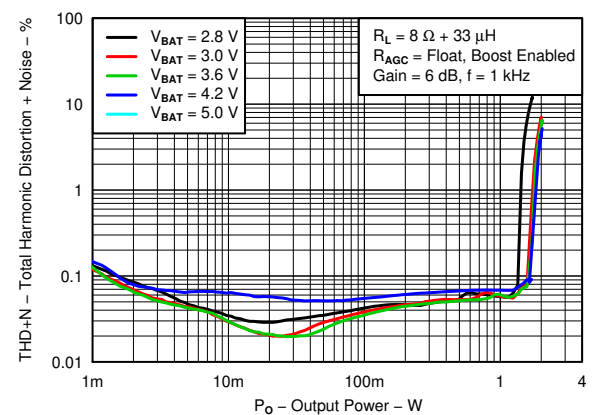
**Figure 7-3. Supply Current vs Output Power**



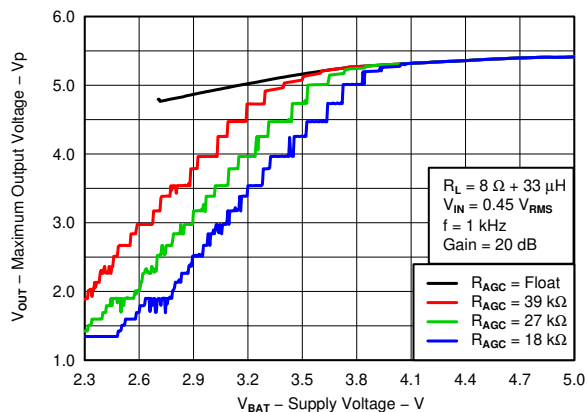
**Figure 7-4. Peak Output Voltage vs Peak Input Voltage**



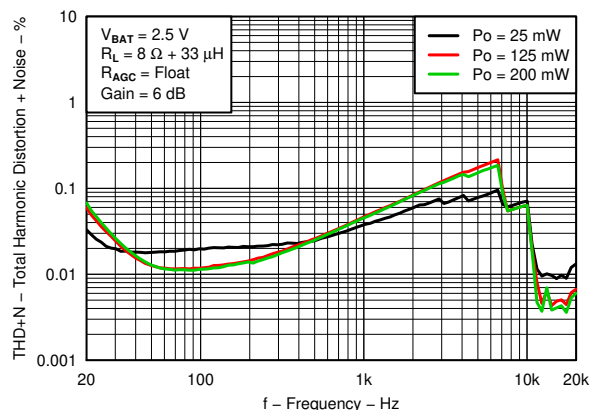
**Figure 7-5. Total Efficiency vs Output Power**



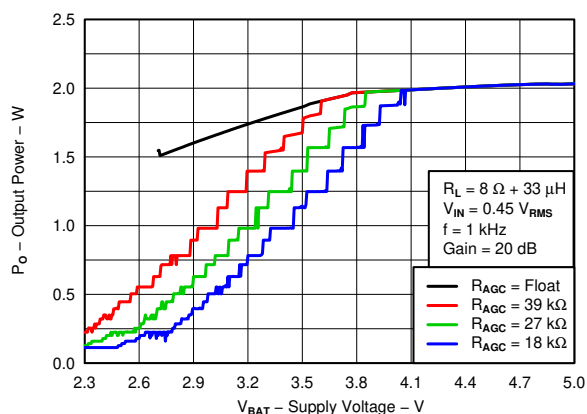
**Figure 7-6. Total Harmonic Distortion + Noise vs Output Power**



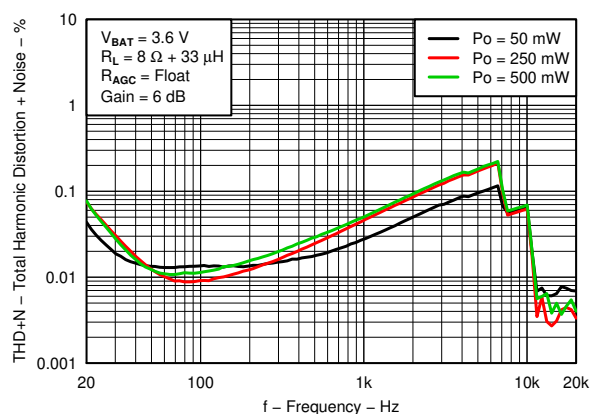
**Figure 7-7. Maximum Output Voltage vs Supply Voltage**



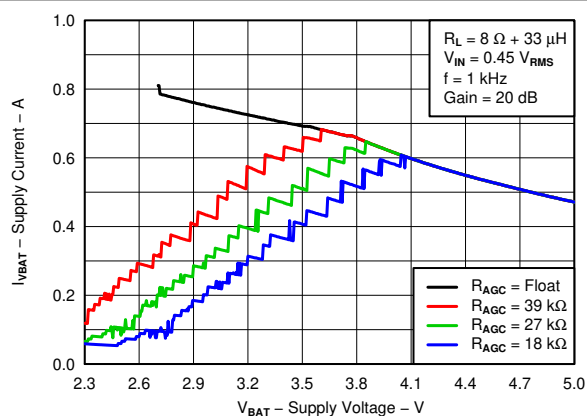
**Figure 7-8. Total Harmonic Distortion + Noise vs Frequency**



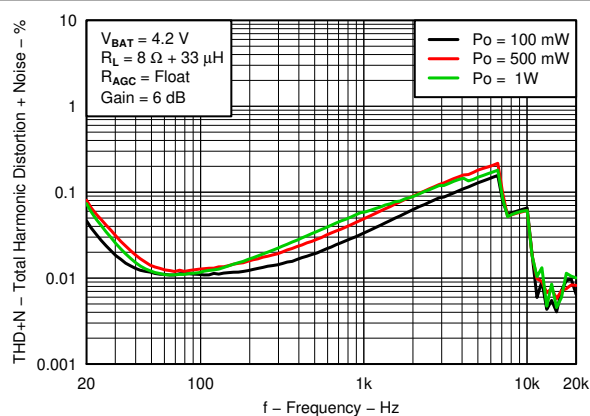
**Figure 7-9. Output Power vs Supply Voltage**



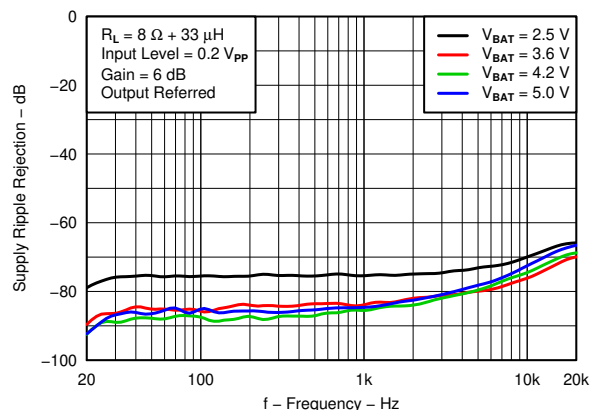
**Figure 7-10. Total Harmonic Distortion + Noise vs Frequency**



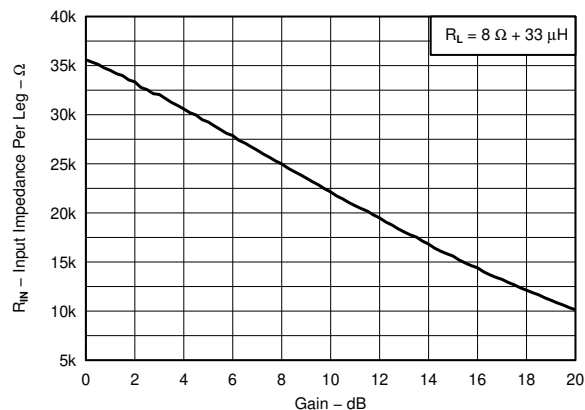
**Figure 7-11. Supply Current vs Supply Voltage**



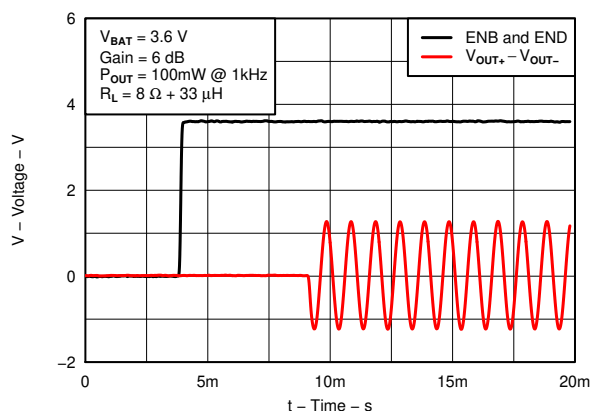
**Figure 7-12. Total Harmonic Distortion + Noise vs Frequency**



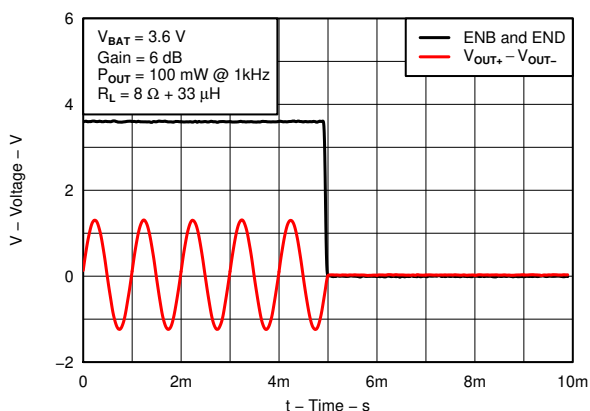
**Figure 7-13. Supply Ripple Rejection vs Frequency**



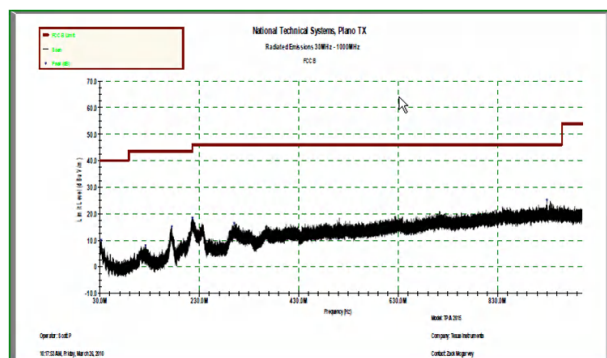
**Figure 7-14. Input Impedance (Per Input) vs Gain**



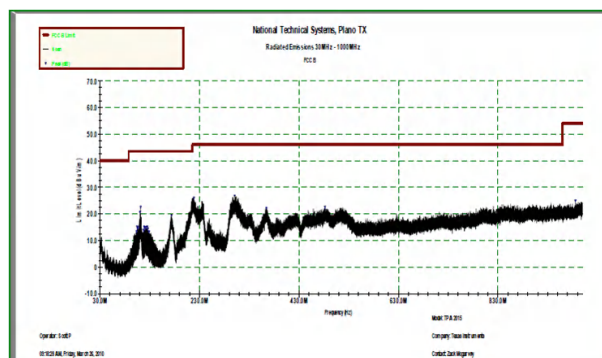
**Figure 7-15. Startup Timing**



**Figure 7-16. Shutdown Timing**



**Figure 7-17. EMI Performance  $P_O = 50$  mW With 2 Inch Speaker Cable**

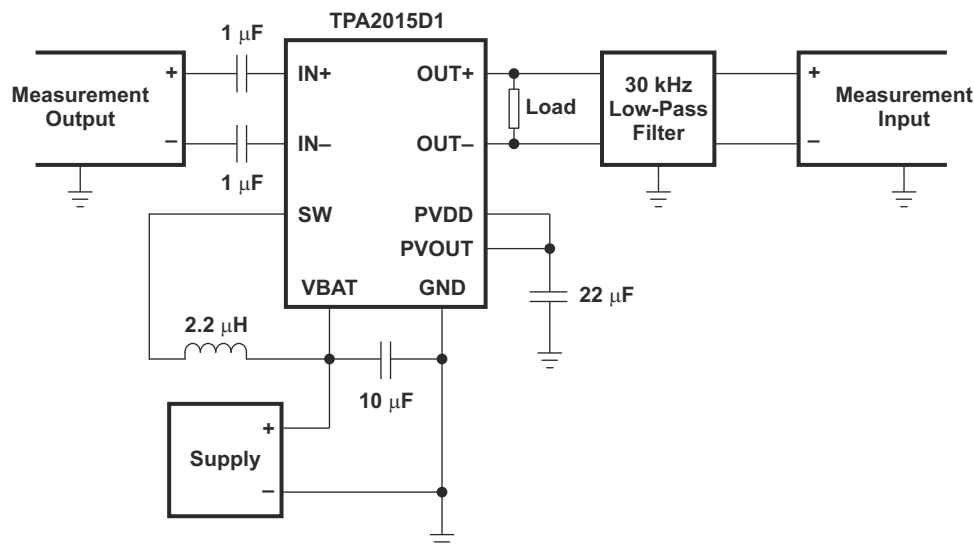


**Figure 7-18. EMI Performance  $P_O = 750$  mW With 2 Inch Speaker Cable**

## 8 Parameter Measurement Information

All parameters are measured according to the conditions described in the [Section 7](#) section.

[Figure 8-1](#) shows the setup used to test the device's typical characteristics.



- A. The 1  $\mu\text{F}$  input capacitors ( $C_i$ ) were shorted for input common-mode voltage measurements.
- B. A 33  $\mu\text{H}$  inductor was placed in series with the load resistor to emulate a small speaker for efficiency measurements.
- C. The 30 kHz low-pass filter is required even if the analyzer has an internal low-pass filter. An R-C low pass filter (100  $\Omega$ , 47 nF) is used on each output for the data sheet graphs.

**Figure 8-1. Test Setup for Typical Characteristics Graphs**

## 9 Detailed Description

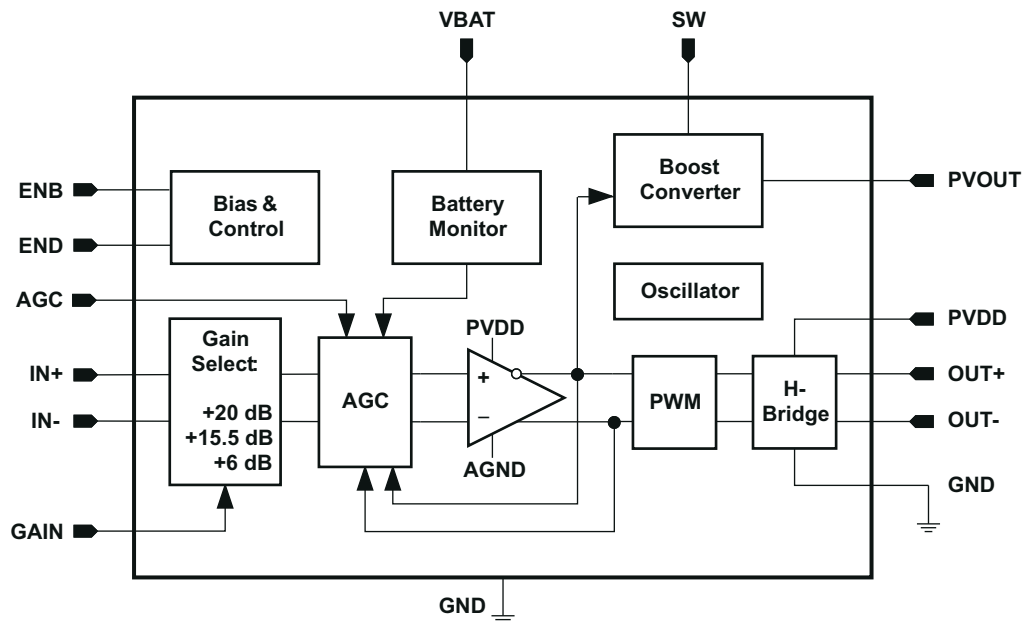
### 9.1 Overview

The TPA2015D1 is a high efficiency Class-D audio power amplifier with battery-tracking SpeakerGuard™ AGC technology. It drives up to 2 W into an 8  $\Omega$  speaker.

The built-in boost converter generates a 5.5 V supply voltage for the Class-D amplifier. The SpeakerGuard™ AGC adjusts the Class-D gain to limit battery current and prevent heavy clipping. The TPA2015D1 has an integrated low-pass filter to improve the RF rejection and reduce DAC out-of-band noise, increasing the signal to noise ratio (SNR).

See [Section 13.1.1.1](#) for a list of terms and definitions used throughout the following sections.

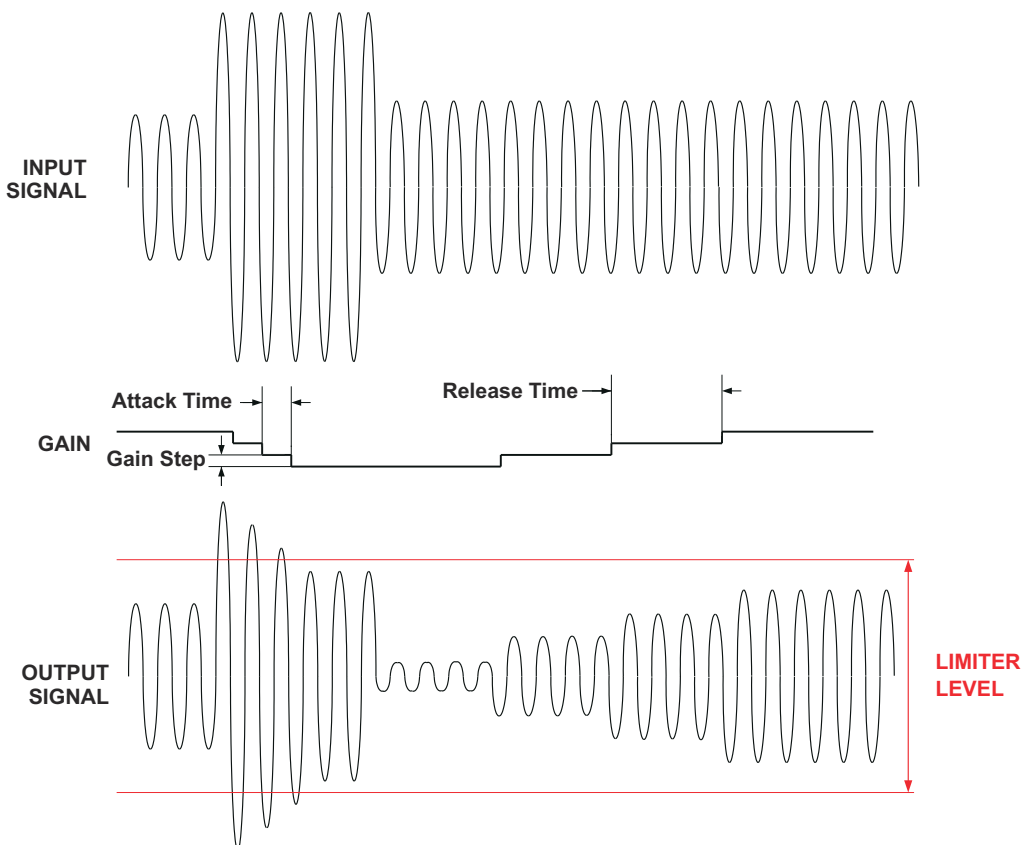
### 9.2 Functional Block Diagram



### 9.3 Feature Description

#### 9.3.1 SpeakerGuard™ Theory of Operation

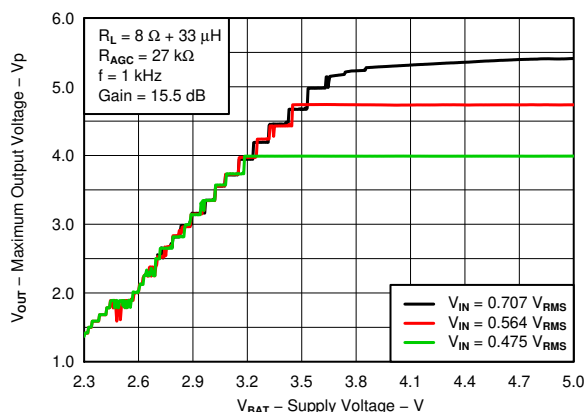
SpeakerGuard™ protects speakers, improves loudness, and limits peak supply current. If the output audio signal exceeds the limiter level, then SpeakerGuard™ decreases amplifier gain. The rate of gain decrease, the attack time, is fixed at 0.026 ms/dB. SpeakerGuard™ increases the gain once the output audio signal is below the limiter level. The rate of gain increase, the release time, is fixed at 1600 ms/dB. [Figure 9-1](#) shows this relationship.



**Figure 9-1. SpeakerGuard™ Attack and Release Times**

### 9.3.1.1 SpeakerGuard™ With Varying Input Levels

SpeakerGuard™ protects speakers by decreasing gain during large output transients. Figure 9-2 shows the maximum output voltage at different input voltage levels. The load is  $8\ \Omega$  and the gain is 15.5 dB (6 V/V).



**Figure 9-2. Maximum Output Voltage vs Supply Voltage**

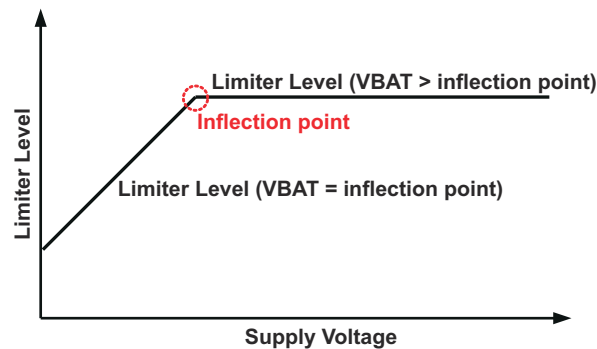
A  $0.707\ V_{RMS}$  sine-wave input signal forces the output voltage to  $4.242\ V_{RMS}$ , or  $6.0\ V_{PEAK}$ . Above 3.9 V supply, the boost converter voltage sags due to high output current, resulting in a peak Class-D output voltage of about 5.4 V. As the supply voltage decreases below 3.9 V, the limiter level decreases. This causes the gain to decrease, and the peak Class-D output voltage lowers.

With a 0.564 V<sub>RMS</sub> input signal, the peak Class-D output voltage is 4.78 V. When the supply voltage is above 3.45 V, the output voltage remains below the limiter level, and the gain stays at 15.5 dB. Once the supply drops below 3.45 V, the limiter level decreases below 4.78 V, and SpeakerGuard™ decreases the gain.

The same rationale applies to the 0.475 V<sub>RMS</sub> input signal. Although the supply voltage may be below the inflection point, audio gain does not decrease until the Class-D output voltage is above the limiter level.

### 9.3.1.2 Battery Tracking SpeakerGuard™

The TPA2015D1 monitors the battery voltage and the audio signal, automatically decreasing gain when battery voltage is low and audio output power is high. It finds the optimal gain to maximize loudness and minimize battery current, providing louder audio and preventing early shutdown at end-of-charge battery voltages. SpeakerGuard™ decreases amplifier gain when the audio signal exceeds the limiter level. The limiter level automatically decreases when the supply voltage (VBAT) is below the inflection point. Figure 9-3 shows a plot of the limiter level as a function of the supply voltage.



**Figure 9-3. Limiter Level vs Supply Voltage**

The limiter level decreases within 60 μs of the supply voltage dropping below the inflection point. Although this is slightly slower than the 26 μs/dB SpeakerGuard™ attack time, the difference is audibly imperceptible.

Connect a resistor between the AGC pin and ground to set the inflection point, as shown in Table 9-1. Leave the AGC pin floating to disable the inflection point, keeping the limiter level constant over all supply voltages.

The maximum limiter level is fixed, as is the slope of the limiter level versus supply voltage. If different values for maximum limiter level and slope are required, contact your local Texas Instruments representative.

**Table 9-1. AGC Function Table**

| FUNCTION                                  | RESISTOR ON AGC PIN           | INFLECTION POINT |
|-------------------------------------------|-------------------------------|------------------|
| Constant limiter level; battery track OFF | Floating or connected to VBAT | disabled         |
| AGC battery track option 1                | 39 kΩ                         | 3.55 V           |
| AGC battery track option 2                | 27 kΩ                         | 3.78 V           |
| AGC battery track option 3                | 18 kΩ                         | 3.96 V           |

The audio signal is not affected by the SpeakerGuard™ function unless the peak audio output voltage exceeds the limiter level. Figure 9-7 shows the relationship between the audio signal, the limiter level, the supply voltage, and the supply current.

When VBAT is greater than the inflection point, the limiter level allows the output signal to slightly clip to roughly 6% THD at 2 W into 8 Ω. This is an acceptable peak distortion level for most small-sized portable speakers, while ensuring maximum loudness from the speaker.

### 9.3.2 Fully Differential Class-D Amplifier

The TPA2015D1 uses a fully differential amplifier with differential inputs and outputs. The differential output voltage equals the differential input multiplied by the amplifier gain. The TPA2015D1 can also be used with a single-ended input. However, using differential input signals when in a noisy environment, like a wireless handset, ensures maximum system noise rejection.

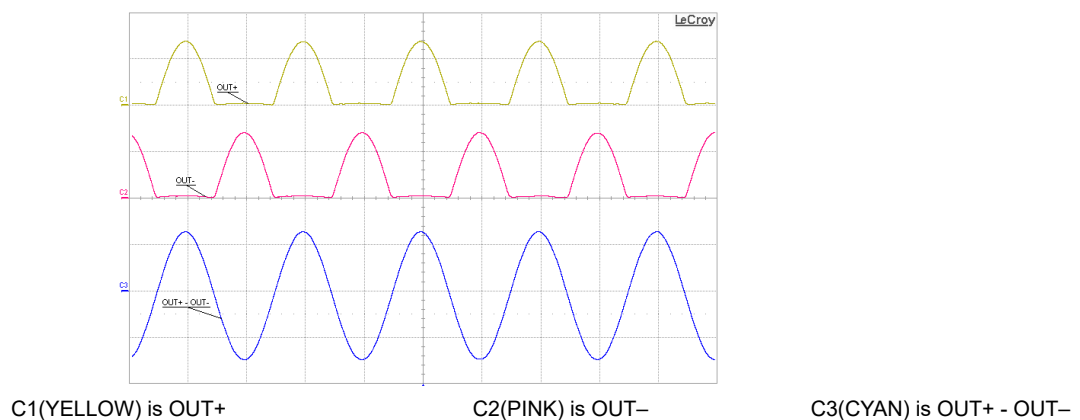
### 9.3.2.1 Advantages of Fully Differential Amplifiers

- Mid-supply bypass capacitor,  $C_{BYPASS}$ , not required:
  - The fully differential amplifier does not require a mid-supply bypass capacitor. Any shift in the mid-supply affects both positive and negative channels equally and cancels at the differential output.
- Improved RF-immunity:
  - GSM handsets save power by turning on and shutting off the RF transmitter at a rate of 217 Hz. This 217 Hz burst often couples to audio amplifier input and output traces causing frame-rate noise. Fully differential amplifiers cancel frame-rate noise better than non-differential amplifiers.
- Input-coupling capacitors not required, but recommended:
  - The fully differential amplifier allows the inputs to be biased at voltages other than mid-supply ( $PVDD/2$ ). The TPA2015D1 inputs can be biased anywhere within the common mode input voltage range, as listed in the [Section 7.6](#) table. If the inputs are biased outside of that range, then input-coupling capacitors are required.
  - Note that without input coupling capacitors, any dc offset from the audio source will be modulated by the AGC. This could cause artifacts in the audio output signal. Perform listening tests to determine if direct input coupling is acceptable.

### 9.3.2.2 Improved Class-D Efficiency

The TPA2015D1 output stage uses a modulation technique that modulates the PWM output only on one side of the differential output, leaving the other side held at ground. Although the differential output voltage is undistorted, each output appears as a half-wave rectified signal.

This technique reduces output switching losses and improves overall amplifier efficiency. [Figure 9-4](#) shows how  $OUT+$ ,  $OUT-$ , and the differential output voltages appear on an oscilloscope.



**Figure 9-4. Filtered Output Waveforms**

### 9.3.3 Adaptive Boost Converter

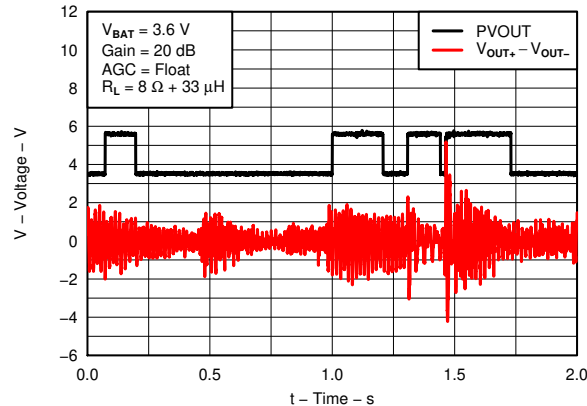
The TPA2015D1 consists of an adaptive boost converter and a Class-D amplifier. The boost converter takes the supply voltage,  $V_{BAT}$ , and increases it to a higher output voltage,  $PVOUT$ .  $PVOUT$  drives the supply voltage of the Class-D amplifier,  $PVDD$ . This improves loudness over non-boosted solutions.

The boost converter is adaptive and activates automatically depending on the output audio signal amplitude. When the peak output audio signal exceeds a preset voltage threshold, the boost converter is enabled, and the voltage at  $PVOUT$  is 5.5 V. When the audio output voltage is lower than the threshold voltage, the boost deactivates automatically. The boost activation threshold voltage is not user programmable. It is optimized to prevent clipping while maximizing system efficiency.

The boost converter can be forcibly deactivated by setting the  $ENB$  pin to logic-low. When the boost is deactivated,  $PVOUT$  is equal to the supply voltage ( $V_{BAT}$ ) minus the  $I \times R$  drop across the inductor and boost converter pass transistor.

A timer prevents the input signal from modulating the PVOUT voltage within the audio frequency range, eliminating the potential for audible artifacts on the Class-D output.

Figure 9-5 shows how the adaptive boost modulates with a typical audio signal. By automatically deactivating the boost converter and passing VBAT to PVOUT, the TPA2015D1 efficiency is improved at low output power.



**Figure 9-5. Adaptive Boost Converter With Typical Music Playback**

The primary external components for the boost converter are the inductor and the boost capacitor. The inductor stores current, and the boost capacitor stores charge. As the Class-D amplifier depletes the charge in the boost capacitor, the boost inductor replenishes charge with its stored current. The cycle of charge and discharge occurs frequently enough to keep PVOUT within its minimum and maximum voltage specification.

The boost converter design is optimized for driving the integrated Class-D amplifier only. It lacks protection circuitry recommended for driving loads other than the integrated Class-D amplifier.

#### 9.3.3.1 Boost Converter Overvoltage Protection

The TPA2015D1 internal boost converter operates in a discontinuous mode to improve the efficiency at light loads. The boost converter has overvoltage protection that disables the boost converter if the output voltage exceeds 5.8 V. If current is forced into the PVOUT terminal, the voltage clamp will sink up to 10 mA. If more than 10 mA is forced into PVOUT, then the PVOUT voltage will increase. Refer to the [Section 9.3.6](#) section for details.

See [Section 13.1.1.2](#) for a list of terms and definitions used in the boost equations.

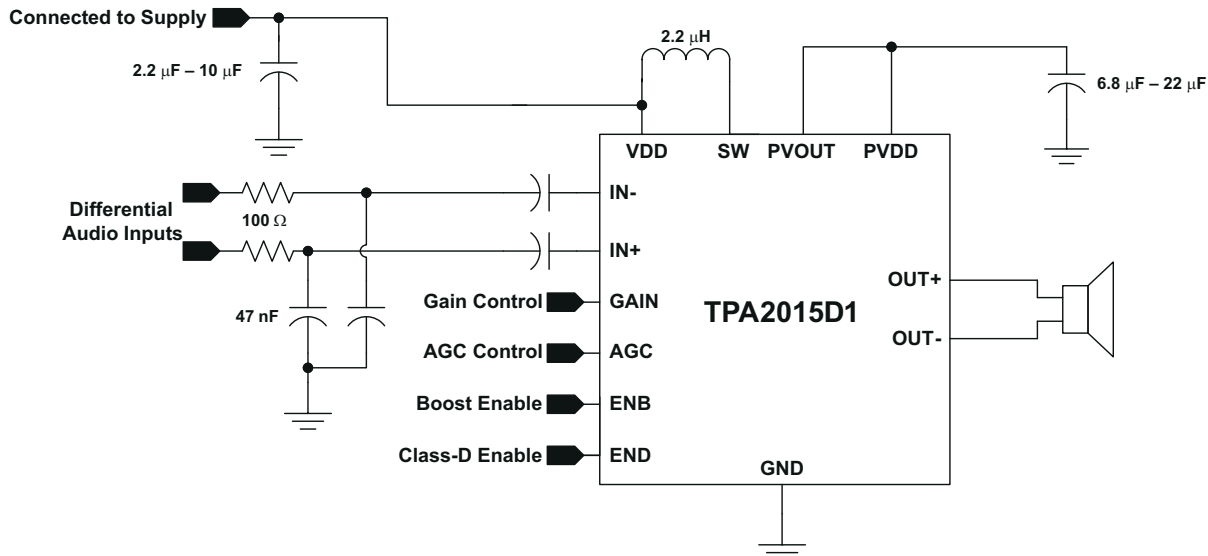
#### 9.3.4 Operation With DACs and CODECs

Large ripple voltages can be present at the output of  $\Delta\Sigma$  DACs and CODECs, just above the audio frequency (for example: 80 kHz with a 300 mV<sub>PP</sub>). This out-of-band noise is due to the noise shaping of the delta-sigma modulator in the DAC.

Some Class-D amplifiers have higher output noise when used in combination with these DACs and CODECs. This is because out-of-band noise from the CODEC/DAC mixes with the Class-D switching frequencies in the audio amplifier input stage.

The TPA2015D1 has a built-in low-pass filter that reduces the out-of-band noise and RF noise, filtering out-of-band frequencies that could degrade in-band noise performance. The TPA2015D1 AGC calculates gain based on input signal amplitude only.

If driving the TPA2015D1 input with 4th-order or higher  $\Delta\Sigma$  DACs or CODECs, add an R-C low pass filter at each of the audio inputs (IN+ and IN-) of the TPA2015D1 to ensure best performance. The recommended resistor value is 100  $\Omega$  and the capacitor value of 47 nF.



**Figure 9-6. Reducing Out-of-Band DAC Noise With External Input Filter**

### 9.3.5 Filter Free Operation and Ferrite Bead Filters

The TPA2015D1 is designed to minimize RF emissions. For more information about RF emissions and filtering requirements, see [SLOA145](#).

### 9.3.6 Speaker Load Limitation

Speakers are non-linear loads with varying impedance (magnitude and phase) over the audio frequency. A portion of speaker load current can flow back into the boost converter output via the Class-D output H-bridge high-side device. This is dependent on the speaker's phase change over frequency, and the audio signal amplitude and frequency content.

Most portable speakers have limited phase change at the resonant frequency, typically no more than 40 or 50 degrees. To avoid excess flow-back current, use speakers with limited phase change. Otherwise, flow-back current could exceed the 10 mA rating of the boost converter voltage clamp and drive the PVOUT voltage above the absolute maximum recommended operational voltage.

Confirm proper operation by connecting the speaker to the TPA2015D1 and driving it at maximum output swing. Observe the PVOUT voltage with an oscilloscope. In the unlikely event the PVOUT voltage exceeds 6.5 V, add a 6.8 V Zener diode between PVOUT and ground to ensure the TPA2015D1 operates properly.

The amplifier has thermal overload protection and deactivates if the die temperature exceeds 150°C. It automatically reactivates once die temperature returns below 150°C. Built-in output over-current protection deactivates the amplifier if the speaker load becomes short-circuited. The amplifier automatically restarts within 200 ms after the over-current event. Although the TPA2015D1 Class-D output can withstand a short between OUT+ and OUT-, do not connect either output directly to GND, PVDD, or VBAT as this could damage the device.

#### CAUTION

Do not connect OUT+ or OUT- directly to GND, PVDD, or VBAT as this could damage the Class-D output stage.

### 9.3.7 Fixed Gain Setting

The TPA2015D1 has 3 selectable fixed-gains: 6 dB, 15.5 dB, and 20 dB. Connect the GAIN pin as shown in [Table 9-2](#).

**Table 9-2. Amplifier Fixed-Gain**

| CONNECT GAIN PIN TO      | AMPLIFIER GAIN |
|--------------------------|----------------|
| GND                      | 6 dB           |
| No Connection (Floating) | 15.5 dB        |
| VBAT                     | 20 dB          |

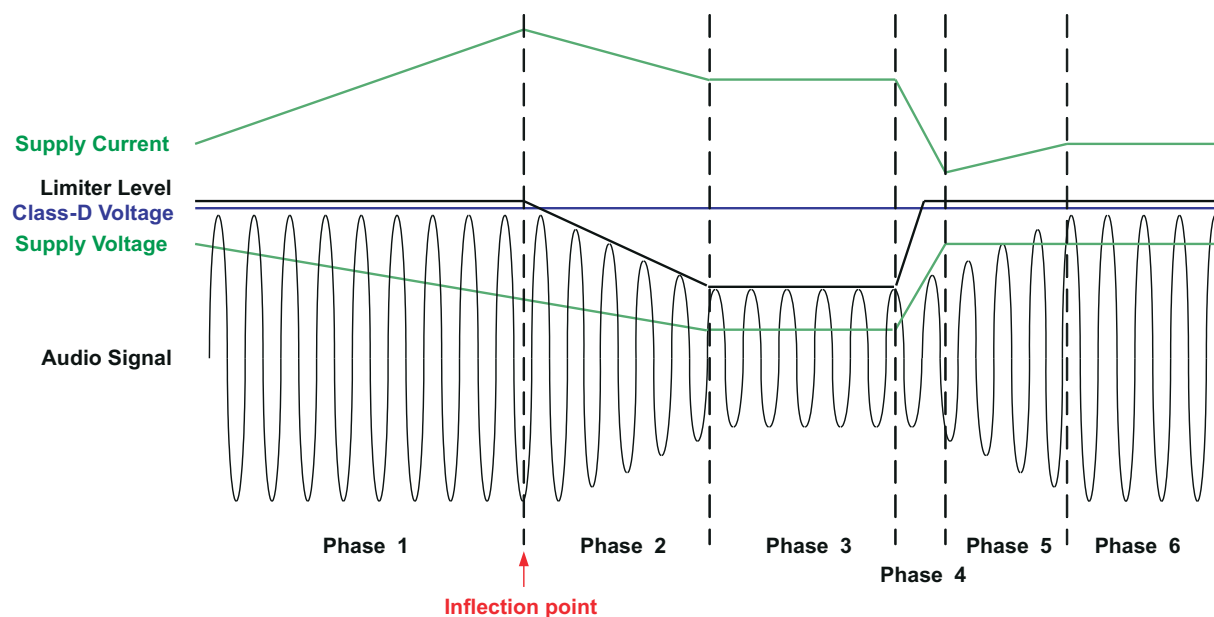
## 9.4 Device Functional Modes

### 9.4.1 Shutdown Mode

The TPA2025D1 can be put in shutdown mode when asserting ENB and END pins to a logic LOW. While in shutdown mode, the device output stage is turned off and the current consumption is very low. The device exits shutdown mode when a HIGH logic level is applied to ENB and END pins.

### 9.4.2 Battery Tracking SpeakerGuard™ Operation

- Phase 1      Battery discharging normally; supply voltage is above inflection point; audio output remains below limiter level.**  
The limiter level remains constant because the supply voltage is greater than the inflection point. Amplifier gain is constant at fixed-gain as set by the GAIN pin. The audio output remains at a constant loudness. The boost converter allows the audio output to swing above the battery supply voltage. Battery supply current increases as supply voltage decreases.
- Phase 2      Battery continues to discharge normally; supply voltage decreases below inflection point; limiter level decreases below audio output.**  
The limiter level decreases as the battery supply voltage continues to decrease. SpeakerGuard™ lowers amplifier gain, reducing the audio output below the new limiter level. The supply current decreases due to reduced output power.
- Phase 3      Battery supply voltage is constant; audio output remains below limiter level.**  
The audio output, limiter level, and supply current remain constant as well.
- Phase 4      Phone plugged in and battery re-charges; supply voltage increases.**  
The limiter level increases as the supply voltage increases. SpeakerGuard™ increases amplifier gain slowly, increasing audio output. Because the TPA2015D1 supply current is proportional to the PVOUT-to-VBAT ratio, the supply current decreases as battery supply voltage increases.
- Phase 5      Battery supply voltage is constant; audio output is below limiter level.**  
SpeakerGuard™ continues to increase amplifier gain to the fixed-gain as set by the GAIN pin. The audio output signal increases (slowly due to release time) to original value.
- Phase 6      Battery supply voltage is constant; audio output remains below limiter level.**  
Amplifier gain equal to fixed-gain as set by the GAIN pin. Audio output signal does not change. Supply current remains constant.



**Figure 9-7. Relationship Between Supply Voltage, Current, Limiter Level, and Output Audio Signal**

## 10 Application and Implementation

### Note

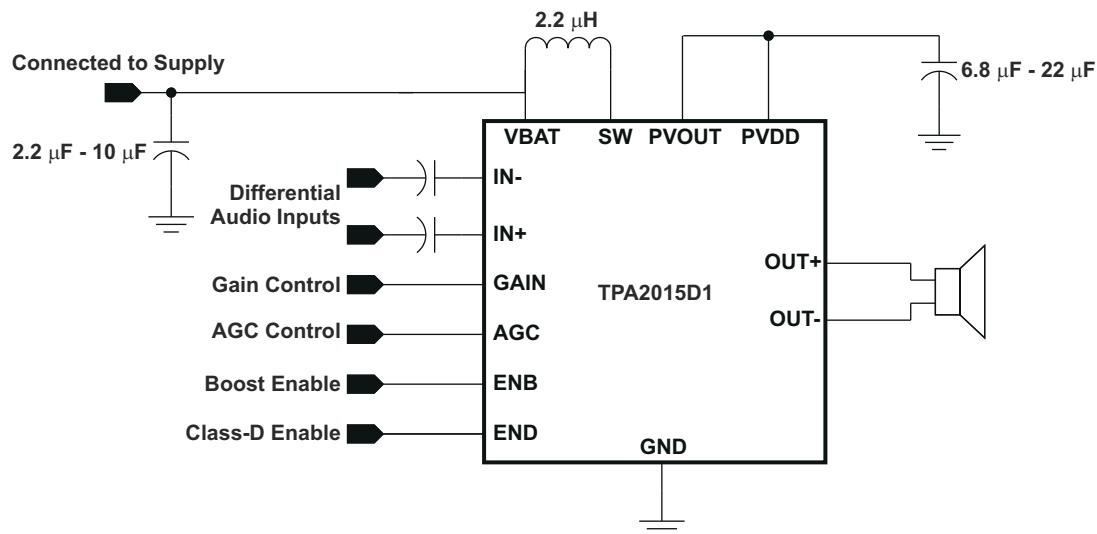
Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

### 10.1 Application Information

These typical connection diagrams highlight the required external components and system level connections for proper operation of the device. Each of these configurations can be realized using the Evaluation Modules (EVMs) for the device. These flexible modules allow full evaluation of the device in the most common modes of operation. Any design variation can be supported by TI through schematic and layout reviews. Visit [e2e.ti.com](http://e2e.ti.com) for design assistance and join the audio amplifier discussion forum for additional information.

### 10.2 Typical Applications

#### 10.2.1 TPA2015D1 With Differential Input Signals



**Figure 10-1. Schematic with Differential Input Signals**

#### 10.2.1.1 Design Requirements

For this design example, use the parameters listed in [Table 10-1](#).

**Table 10-1. Design Parameters**

| DESIGN PARAMETER | EXAMPLE VALUE |
|------------------|---------------|
| Power Supply     | 5 V           |
| Enable Inputs    | High > 1.3 V  |
|                  | Low < 0.6 V   |
| Speaker          | 8 Ω           |

#### 10.2.1.2 Detailed Design Procedure

##### 10.2.1.2.1 Boost Converter Inductor Selection

Working inductance decreases as inductor current and temperature increases. If the drop in working inductance is severe enough, it may cause the boost converter to become unstable, or cause the TPA2015D1 to reach its current limit at a lower output voltage than expected. Inductor vendors specify currents at which inductor values

decrease by a specific percentage. This can vary by 10% to 35%. Inductance is also affected by dc current and temperature.

#### 10.2.1.2.1.1 Inductor Equations

Inductor current rating is determined by the requirements of the load. The inductance is determined by two factors: the minimum value required for stability and the maximum ripple current permitted in the application.

Use Equation 1 to determine the required current rating. Equation 1 shows the approximate relationship between the average inductor current,  $I_L$ , to the load current, load voltage, and input voltage ( $I_{PVDD}$ ,  $PVDD$ , and  $VBAT$ , respectively). Insert  $I_{PVDD}$ ,  $PVDD$ , and  $VBAT$  into Equation 1 and solve for  $I_L$ . The inductor must maintain at least 90% of its initial inductance value at this current.

$$I_L = I_{PVDD} \times \left( \frac{PVDD}{VBAT \times 0.8} \right) \quad (1)$$

#### CAUTION

Use a minimum working inductance of 1.3  $\mu\text{H}$ . Lower values may damage the inductor.

Use a minimum working inductance of 1.3  $\mu\text{H}$ . Lower values may damage the inductor.

Ripple current,  $\Delta I_L$ , is peak-to-peak variation in inductor current. Smaller ripple current reduces core losses in the inductor and reduces the potential for EMI. Use Equation 2 to determine the value of the inductor,  $L$ . Equation 2 shows the relationship between inductance  $L$ ,  $VBAT$ ,  $PVDD$ , the switching frequency,  $f_{BOOST}$ , and  $\Delta I_L$ . Insert the maximum acceptable ripple current into Equation 2 and solve for  $L$ .

$$L = \frac{VBAT \times (PVDD - VBAT)}{\Delta I_L \times f_{BOOST} \times PVDD} \quad (2)$$

$\Delta I_L$  is inversely proportional to  $L$ . Minimize  $\Delta I_L$  as much as is necessary for a specific application. Increase the inductance to reduce the ripple current. Do not use greater than 4.7  $\mu\text{H}$ , as this prevents the boost converter from responding to fast output current changes properly. If using above 3.3  $\mu\text{H}$ , then use at least 10  $\mu\text{F}$  capacitance on  $PVOUT$  to ensure boost converter stability.

The typical inductor value range for the TPA2015D1 is 2.2  $\mu\text{H}$  to 3.3  $\mu\text{H}$ . Select an inductor with less than 0.5  $\Omega$  dc resistance, DCR. Higher DCR reduces total efficiency due to an increase in voltage drop across the inductor.

**Table 10-2. Sample Inductors**

| L<br>( $\mu\text{H}$ ) | SUPPLIER                      | COMPONENT CODE     | SIZE<br>(L×W×H mm) | DCR TYP<br>(m $\Omega$ ) | $I_{SAT}$ MAX<br>(A) | C RANGE                                                        |
|------------------------|-------------------------------|--------------------|--------------------|--------------------------|----------------------|----------------------------------------------------------------|
| 2.2                    | Chilisin<br>Electronics Corp. | CLCN252012T-2R2M-N | 2.5 × 2.0 × 1.2    | 105                      | 1.2                  | 4.7 – 22 $\mu\text{F}$ / 16 V<br>6.8 – 22 $\mu\text{F}$ / 10 V |
| 2.2                    | Toko                          | 1239AS-H-2R2N=P2   | 2.5 × 2.0 × 1.2    | 96                       | 2.3                  |                                                                |
| 2.2                    | Coilcraft                     | XFL4020-222MEC     | 4.0 × 4.0 × 2.15   | 22                       | 3.5                  |                                                                |
| 3.3                    | Toko                          | 1239AS-H-3R3N=P2   | 2.5 × 2.0 × 1.2    | 160                      | 2.0                  | 10 – 22 $\mu\text{F}$ / 10 V                                   |
| 3.3                    | Coilcraft                     | XFL4020-332MEC     | 4.0 × 4.0 × 2.15   | 35                       | 2.8                  |                                                                |

#### 10.2.1.2.2 Boost Converter Capacitor Selection

The value of the boost capacitor is determined by the minimum value of working capacitance required for stability and the maximum voltage ripple allowed on  $PVDD$  in the application. Working capacitance refers to the available capacitance after derating the capacitor value for DC bias, temperature, and aging.

Do not use any component with a working capacitance less than 4.7  $\mu\text{F}$ . This corresponds to a 4.7  $\mu\text{F}$  / 16 V capacitor, or a 6.8  $\mu\text{F}$  / 10 V capacitor. Do not use above 22  $\mu\text{F}$  capacitance as it will reduce the boost converter response time to large output current transients.

[Equation 3](#) shows the relationship between the boost capacitance, C, to load current, load voltage, ripple voltage, input voltage, and switching frequency ( $I_{PVDD}$ , PVDD,  $\Delta V$ , VBAT, and  $f_{BOOST}$  respectively).

Insert the maximum allowed ripple voltage into [Equation 3](#) and solve for C. The 1.5 multiplier accounts for capacitance loss due to applied dc voltage and temperature for X5R and X7R ceramic capacitors.

$$C = 1.5 \times \frac{I_{PVDD} \times (PVDD - VBAT)}{\Delta V \times f_{BOOST} \times PVDD} \quad (3)$$

#### 10.2.1.2.3 Components Location and Selection

##### 10.2.1.2.3.1 Decoupling Capacitors

The TPA2015D1 is a high-performance Class-D audio amplifier that requires adequate power supply decoupling. Adequate power supply decoupling ensures that the efficiency is high and total harmonic distortion (THD) is low.

Place a low equivalent-series-resistance (ESR) ceramic capacitor, typically 0.1  $\mu F$ , within 2 mm of the VBAT ball. This choice of capacitor and placement helps with higher frequency transients, spikes, or digital hash on the line. Additionally, placing this decoupling capacitor close to the TPA2015D1 is important, as any parasitic resistance or inductance between the device and the capacitor causes efficiency loss. In addition to the 0.1  $\mu F$  ceramic capacitor, place a 2.2  $\mu F$  to 10  $\mu F$  capacitor on the VBAT supply trace. This larger capacitor acts as a charge reservoir, providing energy faster than the board supply, thus helping to prevent any droop in the supply voltage.

##### 10.2.1.2.3.2 Input Capacitors

Input audio DC decoupling capacitors are recommended. The input audio DC decoupling capacitors prevents the AGC from changing the gain due to audio DAC output offset. The input capacitors and TPA2015D1 input impedance form a high-pass filter with the corner frequency,  $f_c$ , determined in [Equation 4](#).

Any mismatch in capacitance between the two inputs will cause a mismatch in the corner frequencies. Severe mismatch may also cause turn-on pop noise. Choose capacitors with a tolerance of  $\pm 10\%$  or better.

$$f_c = \frac{1}{(2 \times \pi \times R_i C_i)} \quad (4)$$

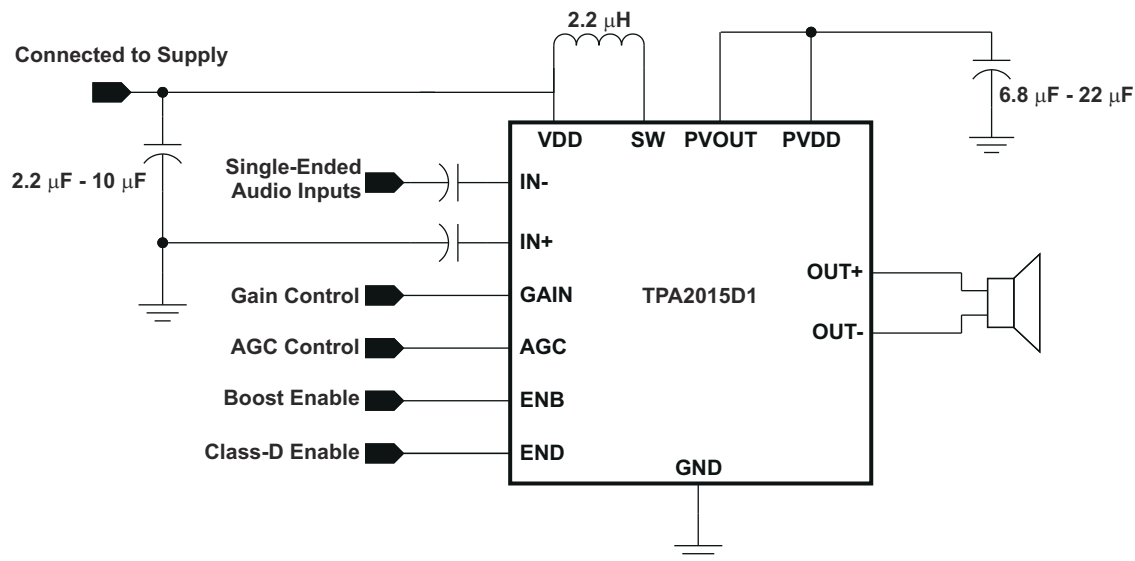
#### 10.2.1.3 Application Curves

For application curves, see the figures listed in [Table 10-3](#).

**Table 10-3. Table of Graphs**

| DESCRIPTION                               | FIGURE NUMBER              |
|-------------------------------------------|----------------------------|
| Supply Current vs Output Power            | <a href="#">Figure 7-3</a> |
| Peak Output Voltage vs Peak Input Voltage | <a href="#">Figure 7-4</a> |
| Total Efficiency vs Output Power          | <a href="#">Figure 7-5</a> |
| Output Power vs Supply Voltage            | <a href="#">Figure 7-9</a> |

## 10.2.2 TPA2015D1 with Single-Ended Input Signals



**Figure 10-2. Typical Application Schematic with Single-Ended Input Signals**

### 10.2.2.1 Design Requirements

For this design example, use the parameters listed in [Table 10-1](#).

### 10.2.2.2 Detailed Design Procedure

For the design procedure see [Section 10.2.1.2](#) from the previous section.

### 10.2.2.3 Application Curves

For application curves, see the figures listed in [Table 10-3](#).

## 11 Power Supply Recommendations

The TPA2015D1 is designed to operate from an input voltage supply range between 2.5-V and 5.2-V. Therefore the output voltage range of the power supply should be within this range. The current capability of upper power should not exceed the maximum current limit of the power switch.

### 11.1 Power Supply Decoupling Capacitors

The TPA2015D1 requires adequate power supply decoupling to ensure a high efficiency operation with low total harmonic distortion (THD). Place a low equivalent-series-resistance (ESR) ceramic capacitor, typically 0.1  $\mu\text{F}$ , within 2 mm of the PVDD/PVOUT pin. This choice of capacitor and placement helps with higher frequency transients, spikes, or digital hash on the line. In addition to the 0.1  $\mu\text{F}$  ceramic capacitor, is recommended to place a 2.2  $\mu\text{F}$  to 10  $\mu\text{F}$  capacitor on the VDD supply trace. This larger capacitor acts as a charge reservoir, providing energy faster than the board supply, thus helping to prevent any droop in the supply voltage.

## 12 Layout

### 12.1 Layout Guidelines

#### 12.1.1 Component Placement

Place all the external components close to the TPA2015D1 device. Placing the decoupling capacitors as close as possible to the device is important for the efficiency of the class-D amplifier. Any resistance or inductance in the trace between the device and the capacitor can cause a loss in efficiency.

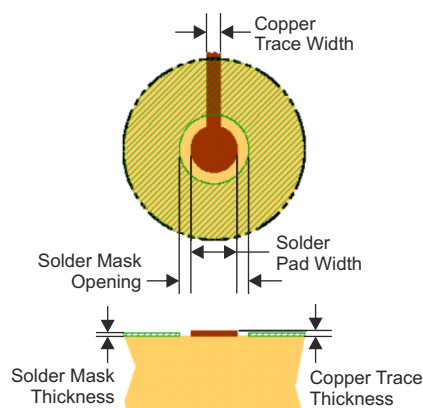
#### 12.1.2 Trace Width

Recommended trace width at the solder balls is 75  $\mu\text{m}$  to 100  $\mu\text{m}$  to prevent solder wicking onto wider PCB traces. For high current pins (SW, GND, OUT+, OUT-, PVOU, and PVDD) of the TPA2015D1, use 100  $\mu\text{m}$  trace widths at the solder balls and at least 500  $\mu\text{m}$  PCB traces to ensure proper performance and output power for the device. For low current pins (IN-, IN+, END, ENB, GAIN, AGC, VBAT) of the TPA2015D1, use 75  $\mu\text{m}$  to 100  $\mu\text{m}$  trace widths at the solder balls. Run IN- and IN+ traces side-by-side (and if possible, same length) to maximize common-mode noise cancellation.

#### 12.1.3 Pad Size

In making the pad size for the DSBGA balls, TI recommends 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 12-1 and Table 12-1 show the appropriate diameters for a DSBGA layout.



**Figure 12-1. Land Pattern Dimensions**

**Table 12-1. Land Pattern Dimensions<sup>(1) (3) (2) (4)</sup>**

| SOLDER PAD DEFINITIONS        | COPPER PAD                                      | SOLDER MASK <sup>(5)</sup> OPENING           | COPPER THICKNESS             | STENCIL <sup>(6) (7)</sup> OPENING                             | STENCIL THICKNESS       |
|-------------------------------|-------------------------------------------------|----------------------------------------------|------------------------------|----------------------------------------------------------------|-------------------------|
| Nonsolder mask defined (NSMD) | 275 $\mu\text{m}$<br>(+0.0, -25 $\mu\text{m}$ ) | 375 $\mu\text{m}$ (+0.0, -25 $\mu\text{m}$ ) | 1 oz max (32 $\mu\text{m}$ ) | 275 $\mu\text{m}$ x 275 $\mu\text{m}$ Sq.<br>(rounded corners) | 125 $\mu\text{m}$ thick |

- (1) Circuit traces from NSMD defined PWB lands should be 75  $\mu\text{m}$  to 100  $\mu\text{m}$  wide in the exposed area inside the solder mask opening. Wider trace widths reduce device stand off and impact reliability.
- (2) Recommend solder paste is Type 3 or Type 4.
- (3) Best reliability results are achieved when the PWB laminate glass transition temperature is above the operating range of the intended application.
- (4) For a PWB using a Ni/Au surface finish, the gold thickness should be less 0.5  $\mu\text{m}$  to avoid a reduction in thermal fatigue performance.
- (5) Solder mask thickness should be less than 20  $\mu\text{m}$  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 results in inferior solder paste volume control.
- (7) Trace routing away from DSBGA device should be balanced in X and Y directions to avoid unintentional component movement due to solder wetting forces.

## 12.2 Layout Example

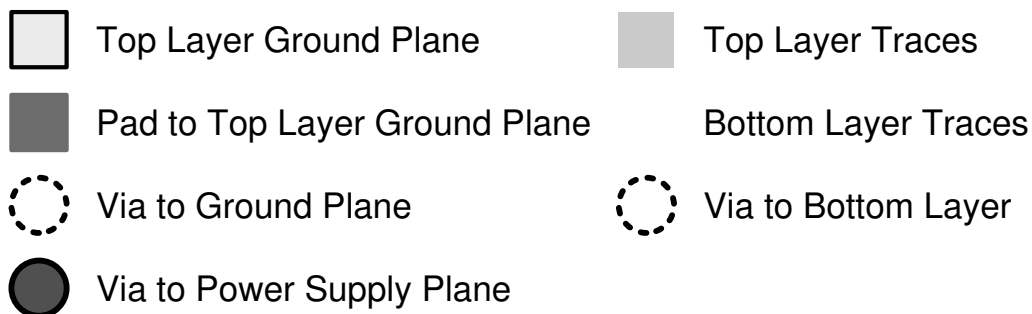
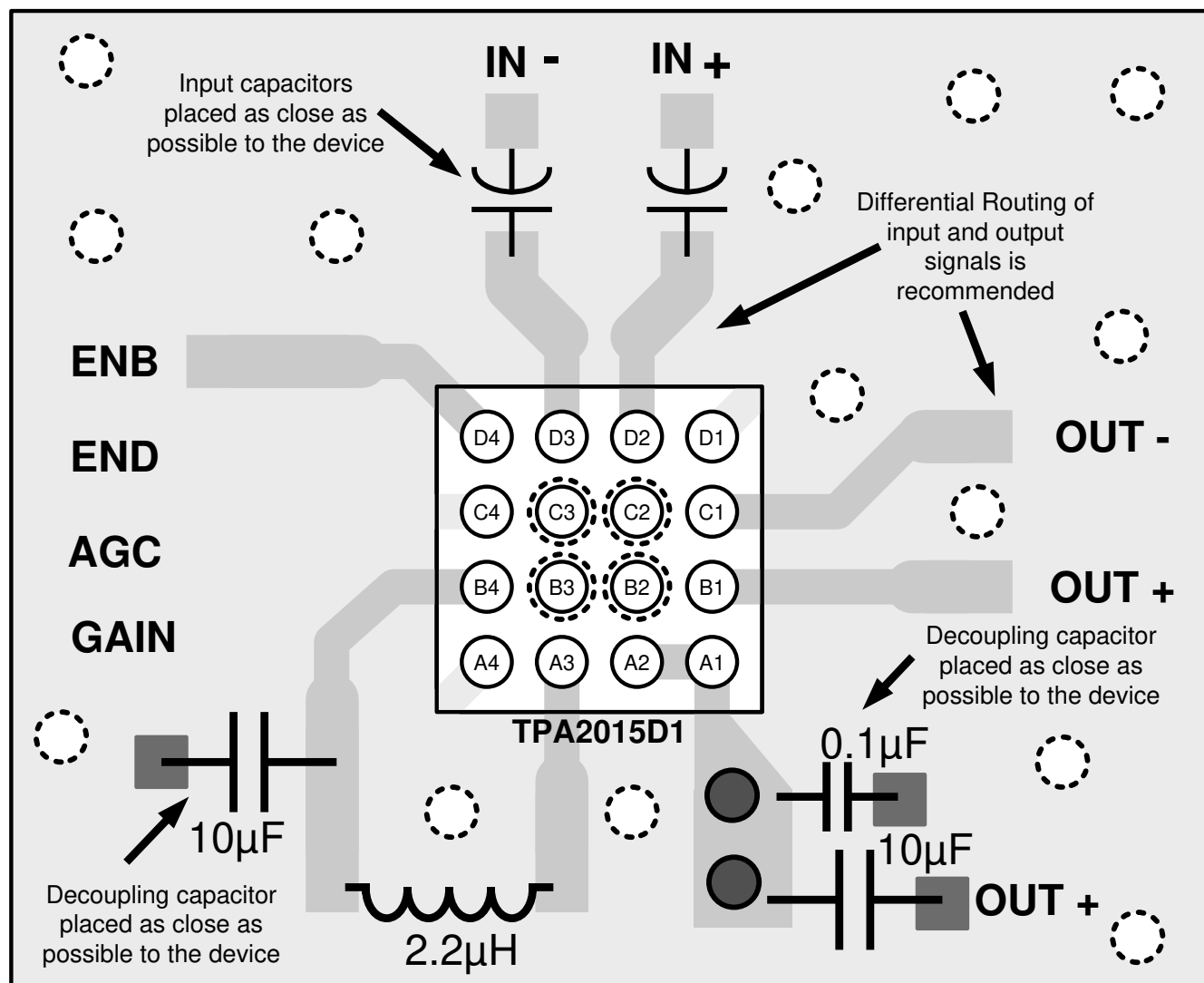


Figure 12-2. TPA2015D1 Layout Example

## 13 Device and Documentation Support

### 13.1 Device Support

#### 13.1.1 Device Nomenclature

##### 13.1.1.1 TPA2015D1 Glossary

|                  |                                                                                                                                                                                                                                                                                       |
|------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Limiter level    | The maximum output voltage allowed before amplifier gain is automatically reduced.                                                                                                                                                                                                    |
| SpeakerGuard™    | TI's trademark name for the automatic gain control technology. It protects speakers by limiting maximum output power.                                                                                                                                                                 |
| Inflection point | The battery voltage threshold for reducing the limiter level. If the battery voltage drops below the inflection point, the limiter level automatically reduces. Although it lowers the maximum output power, it prevents high battery currents at end-of-charge low battery voltages. |
| Battery track    | The name for the continuous limiter level reduction at battery voltages below the inflection point.                                                                                                                                                                                   |
| AGC              | Automatic gain control.                                                                                                                                                                                                                                                               |
| VBAT             | The battery supply voltage to the TPA2015D1. The VBAT pin is the input to the boost converter.                                                                                                                                                                                        |
| Fixed-gain       | The nominal audio gain as set by the GAIN pin. If the audio output voltage remains below the limiter level, the amplifier gain will return to the fixed-gain.                                                                                                                         |
| Attack time      | The rate of AGC gain decrease. The attack time is constant at 0.026 ms/dB.                                                                                                                                                                                                            |
| Release time     | The rate of AGC gain increase. The release time is constant at 1600 ms/dB.                                                                                                                                                                                                            |

##### 13.1.1.2 Boost Terms

|                    |                                                                                              |
|--------------------|----------------------------------------------------------------------------------------------|
| C                  | Minimum boost capacitance required for a given ripple voltage on PVOUT.                      |
| L                  | Boost inductor.                                                                              |
| $f_{\text{BOOST}}$ | Switching frequency of the boost converter.                                                  |
| $I_{\text{PVDD}}$  | Current pulled by the Class-D amplifier from the boost converter.                            |
| $I_L$              | Average current through the boost inductor.                                                  |
| PVDD (PVOUT)       | Supply voltage for the Class-D amplifier. (Voltage generated by the boost converter output.) |
| VBAT               | Supply voltage to the IC.                                                                    |
| $\Delta I_L$       | Ripple current through the inductor.                                                         |
| $\Delta V$         | Ripple voltage on PVOUT.                                                                     |

## 13.2 Community Resources

### 13.3 Trademarks

SpeakerGuard™ is a trademark of Texas Instruments.  
All trademarks are the property of their respective owners.

## 14 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

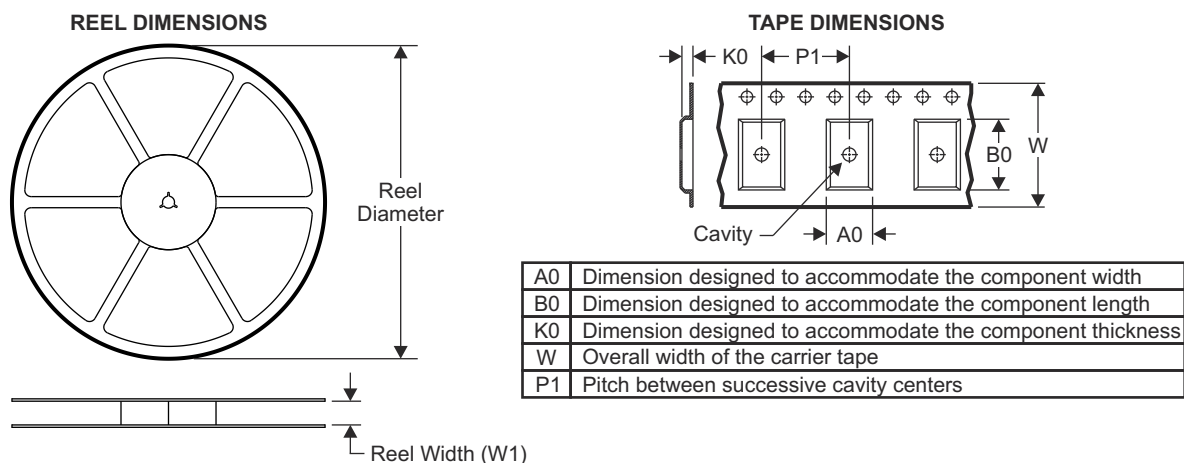
## 14.1 Package Option Addendum

### 14.1.1 Packaging Information

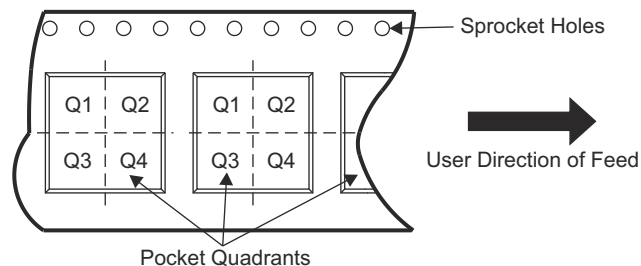
| Orderable Device | Status <sup>(1)</sup> | Package Type | Package Drawing | Pins | Package Qty | Eco Plan <sup>(2)</sup> | Lead/Ball Finish <sup>(4)</sup> | MSL Peak Temp <sup>(3)</sup> | Op Temp (°C) | Device Marking <sup>(5) (6)</sup> |
|------------------|-----------------------|--------------|-----------------|------|-------------|-------------------------|---------------------------------|------------------------------|--------------|-----------------------------------|
| SN012020YZHR     | ACTIVE                | DSBGA        | YZH             | 16   | 3000        | Green (RoHS & no Sb/Br) | SNAGCU                          | Level-1-260C-UNLIM           | –40 to 85    | 1D8                               |
| SN012020YZHT     | ACTIVE                | DSBGA        | YZH             | 16   | 250         | Green (RoHS & no Sb/Br) | SNAGCU                          | Level-1-260C-UNLIM           | –40 to 85    | 1D8                               |

- (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.  
**PRE\_PROD** Unannounced device, not in production, not available for mass market, nor on the web, samples not available.  
**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.
- (4) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.
- (5) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device
- (6) Multiple Device markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.  
**Important Information and Disclaimer:** The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.  
 In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

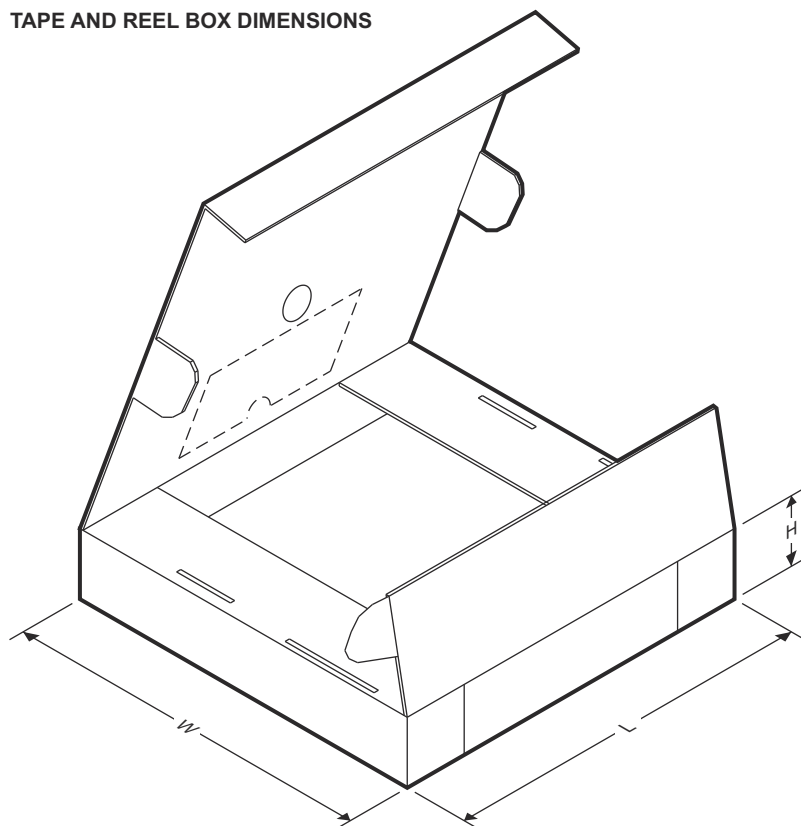
## 14.1.2 Tape and Reel Information



### QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



| 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 |
|--------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| SN012020YZHR | DSBGA        | YZH             | 16   | 3000 | 180.0              | 8.4                | 2.07    | 2.07    | 0.81    | 4.0     | 8.0    | Q1            |
| SN012020YZHT | DSBGA        | YZH             | 16   | 250  | 180.0              | 8.4                | 2.07    | 2.07    | 0.81    | 4.0     | 8.0    | Q1            |

**TAPE AND REEL BOX DIMENSIONS**

| Device       | Package Type | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|--------------|--------------|-----------------|------|------|-------------|------------|-------------|
| SN012020YZHR | DSBGA        | YZH             | 16   | 3000 | 182.0       | 182.0      | 20.0        |
| SN012020YZHT | DSBGA        | YZH             | 16   | 250  | 182.0       | 182.0      | 20.0        |

## PACKAGING INFORMATION

| Orderable part number         | Status<br>(1) | Material type<br>(2) | Package   Pins   | Package qty   Carrier | RoHS<br>(3) | Lead finish/<br>Ball material<br>(4) | MSL rating/<br>Peak reflow<br>(5) | Op temp (°C) | Part marking<br>(6) |
|-------------------------------|---------------|----------------------|------------------|-----------------------|-------------|--------------------------------------|-----------------------------------|--------------|---------------------|
| <a href="#">SN012020YZHR</a>  | Active        | Production           | DSBGA (YZH)   16 | 3000   LARGE T&R      | Yes         | SNAGCU                               | Level-1-260C-UNLIM                | -40 to 85    | 1D8                 |
| SN012020YZHR.A                | Active        | Production           | DSBGA (YZH)   16 | 3000   LARGE T&R      | Yes         | SNAGCU                               | Level-1-260C-UNLIM                | -40 to 85    | 1D8                 |
| <a href="#">TPA2015D1YZHR</a> | Active        | Production           | DSBGA (YZH)   16 | 3000   LARGE T&R      | Yes         | SNAGCU                               | Level-1-260C-UNLIM                | -40 to 85    | OEN                 |
| TPA2015D1YZHR.A               | Active        | Production           | DSBGA (YZH)   16 | 3000   LARGE T&R      | Yes         | SNAGCU                               | Level-1-260C-UNLIM                | -40 to 85    | OEN                 |
| TPA2015D1YZHR.B               | Active        | Production           | DSBGA (YZH)   16 | 3000   LARGE T&R      | Yes         | SNAGCU                               | Level-1-260C-UNLIM                | -40 to 85    | OEN                 |
| <a href="#">TPA2015D1YZHT</a> | Active        | Production           | DSBGA (YZH)   16 | 250   SMALL T&R       | Yes         | SNAGCU                               | Level-1-260C-UNLIM                | -40 to 85    | OEN                 |
| TPA2015D1YZHT.A               | Active        | Production           | DSBGA (YZH)   16 | 250   SMALL T&R       | Yes         | SNAGCU                               | Level-1-260C-UNLIM                | -40 to 85    | OEN                 |
| TPA2015D1YZHT.B               | Active        | Production           | DSBGA (YZH)   16 | 250   SMALL T&R       | Yes         | SNAGCU                               | Level-1-260C-UNLIM                | -40 to 85    | OEN                 |

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

<sup>(2)</sup> **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.

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

<sup>(4)</sup> **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.

<sup>(5)</sup> **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.

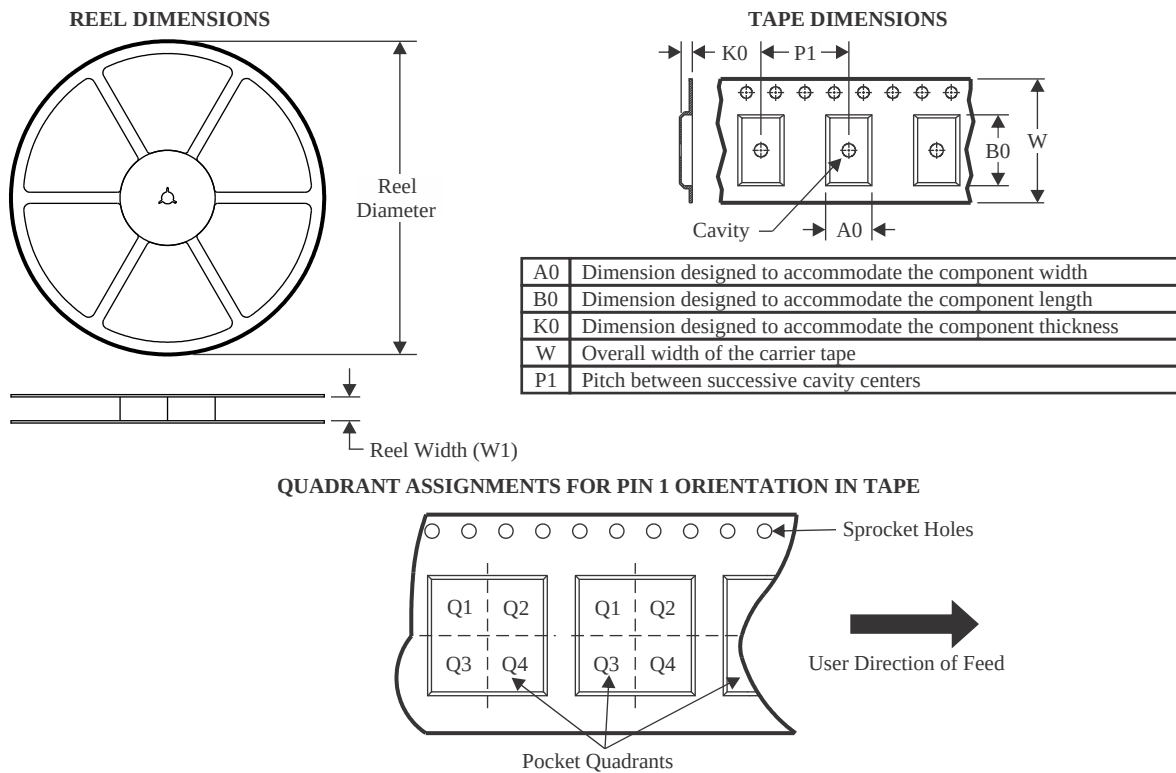
<sup>(6)</sup> **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

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.

**Important Information and Disclaimer:** The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

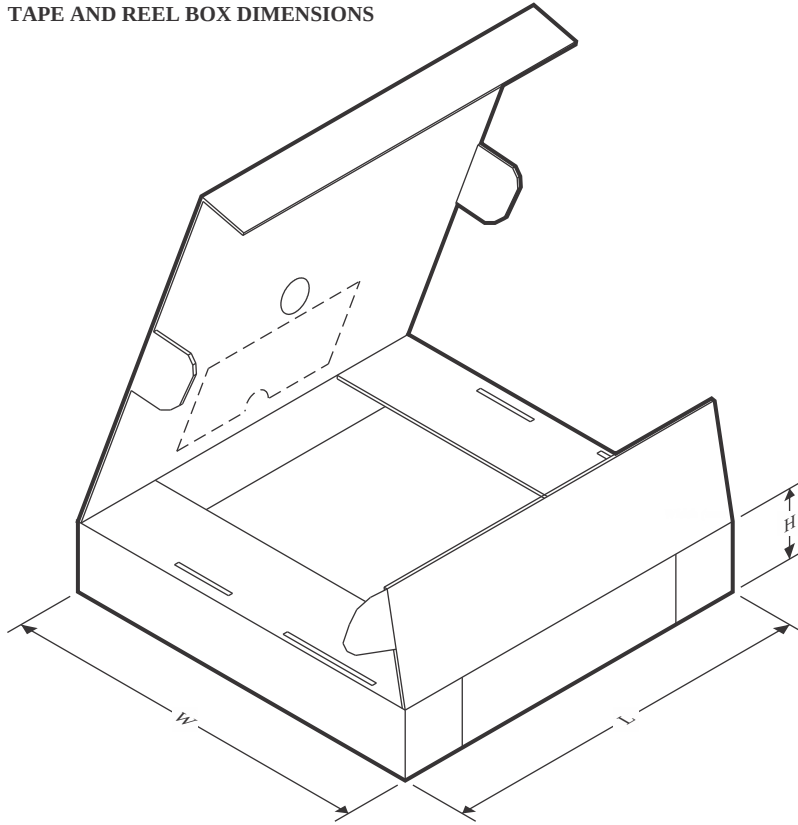
## TAPE AND REEL INFORMATION



\*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 |
|---------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| SN012020YZHR  | DSBGA        | YZH             | 16   | 3000 | 180.0              | 8.4                | 2.07    | 2.07    | 0.81    | 4.0     | 8.0    | Q1            |
| TPA2015D1YZHR | DSBGA        | YZH             | 16   | 3000 | 180.0              | 8.4                | 2.07    | 2.07    | 0.81    | 4.0     | 8.0    | Q1            |
| TPA2015D1YZHT | DSBGA        | YZH             | 16   | 250  | 180.0              | 8.4                | 2.07    | 2.07    | 0.81    | 4.0     | 8.0    | Q1            |

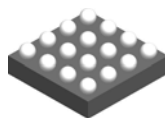
## TAPE AND REEL BOX DIMENSIONS



\*All dimensions are nominal

| Device        | Package Type | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|---------------|--------------|-----------------|------|------|-------------|------------|-------------|
| SN012020YZHR  | DSBGA        | YZH             | 16   | 3000 | 182.0       | 182.0      | 20.0        |
| TPA2015D1YZHR | DSBGA        | YZH             | 16   | 3000 | 182.0       | 182.0      | 20.0        |
| TPA2015D1YZHT | DSBGA        | YZH             | 16   | 250  | 182.0       | 182.0      | 20.0        |

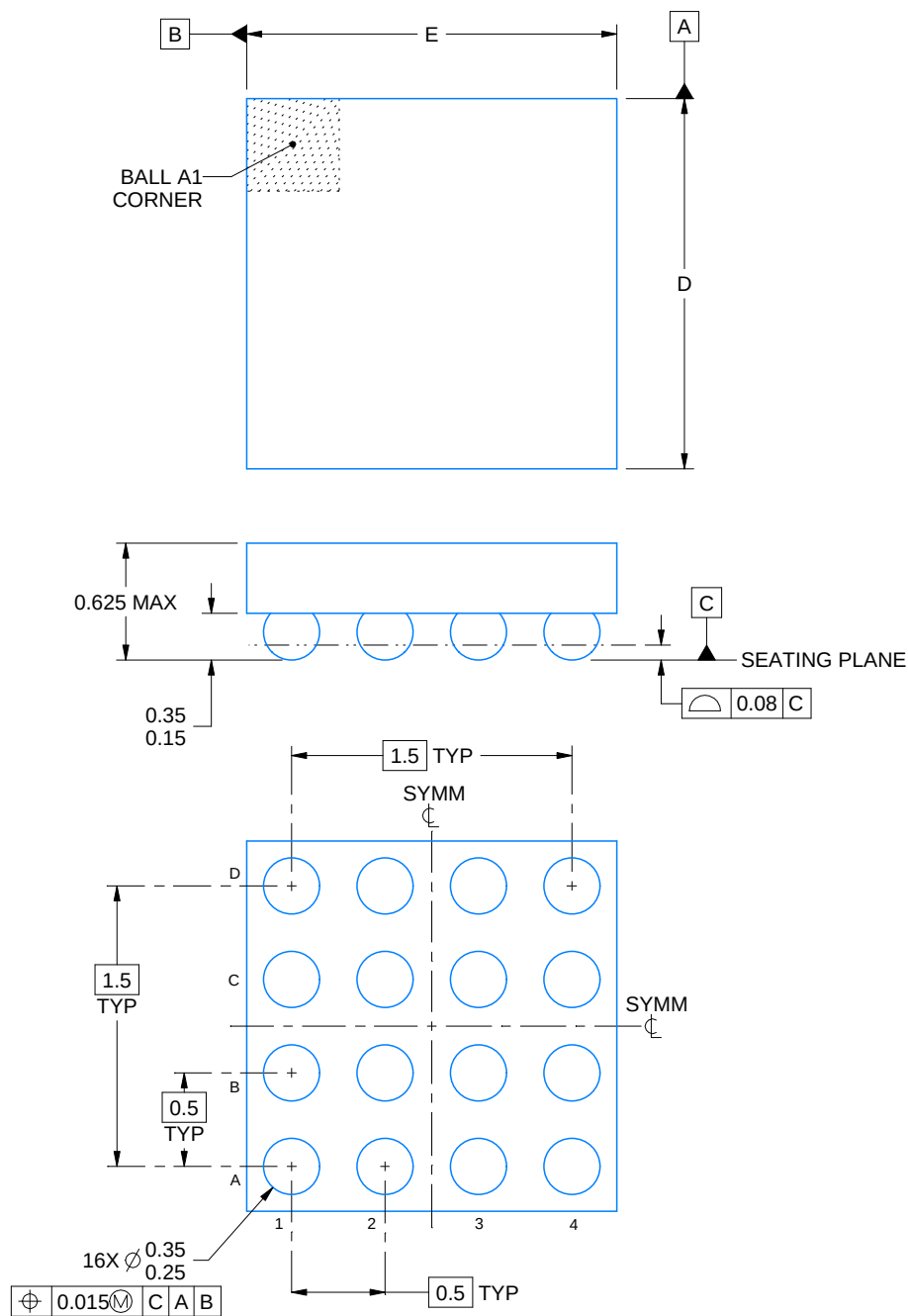
YZH0016



# PACKAGE OUTLINE

DSBGA - 0.625 mm max height

DIE SIZE BALL GRID ARRAY



4226617/A 03/2021

## NOTES:

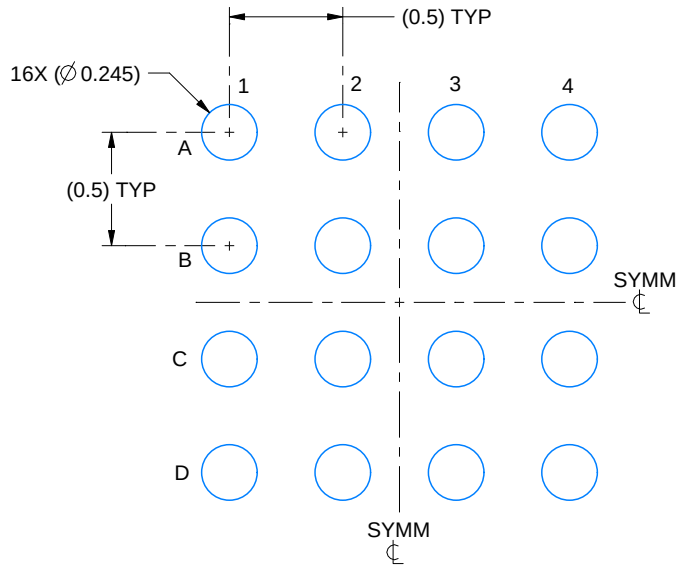
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.

# EXAMPLE BOARD LAYOUT

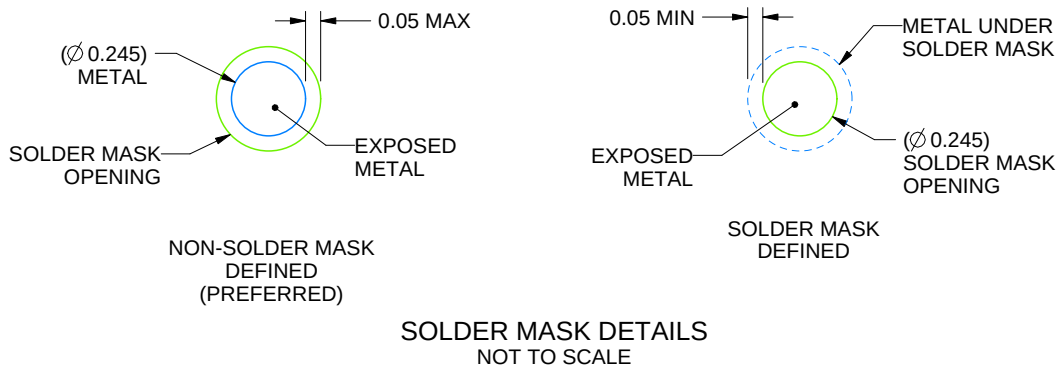
YZH0016

DSBGA - 0.625 mm max height

DIE SIZE BALL GRID ARRAY



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE: 30X



4226617/A 03/2021

NOTES: (continued)

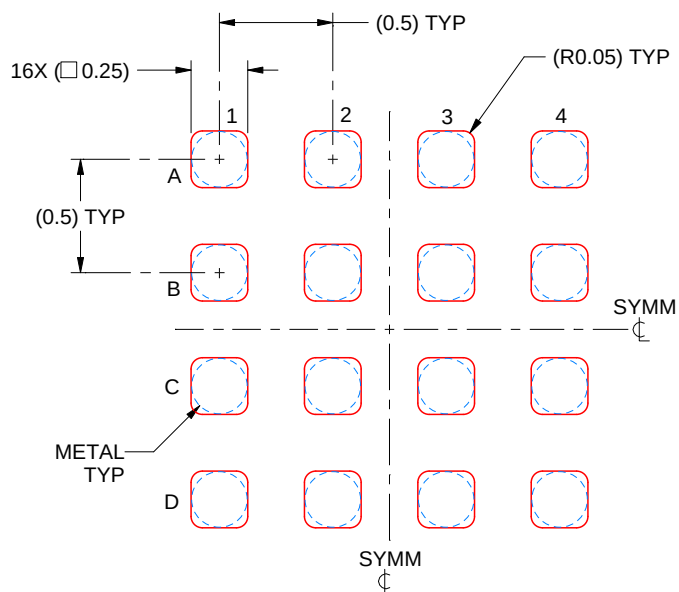
- Final dimensions may vary due to manufacturing tolerance considerations and also routing constraints. See Texas Instruments Literature No. SNVA009 ([www.ti.com/lit/snva009](http://www.ti.com/lit/snva009)).

## EXAMPLE STENCIL DESIGN

YZH0016

DSBGA - 0.625 mm max height

DIE SIZE BALL GRID ARRAY



SOLDER PASTE EXAMPLE  
BASED ON 0.075 mm THICK STENCIL  
SCALE: 30X

4226617/A 03/2021

NOTES: (continued)

4. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release.

## IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#) or other applicable terms available either on [ti.com](#) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265  
Copyright © 2025, Texas Instruments Incorporated