2.5 V to 5.5 V

BaseBand

IN

CODEC

Analog

Digital

or

necessarily

Instruments

Products

PRODUCTION

APPLICATIONS

• Wireless or Cellular Handsets
• Portable DVD Player
• Personal Digital Assistants (PDAs)
• Electronic Dictionaries
• Digital Still Cameras

DESCRIPTION

The TPA2100P1 (sometimes referred to as TPA2100) is a mono, Class-D audio power amplifier with integrated DC-DC converter designed for piezo and ceramic speakers. The TPA2100P1 (TPA2100) is capable of driving a ceramic / piezo speaker with 19 V_pp (6.7 V_RMS) from a 2.5 V power supply at less than 1% THD+N.

The DC-DC converter operates at a fixed frequency of 1.2 MHz. The TPA2100P1 (TPA2100) DC-DC converter provides a 10 V supply with a minimum number of external components. The DC-DC converter can be used to drive other components that require a 10 V supply voltage (note: audio signal must be present for proper functionality of boost converter).

The TPA2100P1 (TPA2100) features an integrated audio low pass filter that rejects high frequency noise (CODEC out-of-band and RF noise) thus improving audio fidelity.

The TPA2100P1 (TPA2100) has three gain modes of 12 dB, 16 dB, and 24 dB. The TPA2100P1 (TPA2100) provides thermal and short circuit protection on the boost converter and the Class-D audio amplifier. The TPA2100P1 (TPA2100) is available in a 16-ball 2.1 mm × 2.1 mm WCSP package. The TPA2100P1 (TPA2100) requires only one small external inductor for operation.

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

NanoFree is a trademark of Texas Instruments.

PRODUCTION DATA information is current as of publication date. Products conform to specifications per the terms of Texas Instruments standard warranty. Production processing does not necessarily include testing of all parameters.
These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

**DEVICE PINOUT**

YZH wcsp) package
(TOP VIEW)

```
<table>
<thead>
<tr>
<th>PIN</th>
<th>I/O/P</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN+</td>
<td>D3</td>
<td>I Positive Differential Audio Input</td>
</tr>
<tr>
<td>IN–</td>
<td>D2</td>
<td>I Negative Differential Audio Input</td>
</tr>
<tr>
<td>SDa</td>
<td>C3</td>
<td>I Audio Amplifier Shutdown</td>
</tr>
<tr>
<td>GAIN</td>
<td>B2</td>
<td>I Gain Selection (tri-state input)</td>
</tr>
<tr>
<td>SD</td>
<td>D4</td>
<td>I Device Shutdown</td>
</tr>
<tr>
<td>Vref</td>
<td>C2</td>
<td>O Internal Analog Supply (Do not connect to external supply/circuit)</td>
</tr>
<tr>
<td>OUT+</td>
<td>B1</td>
<td>O Positive Differential Audio Output</td>
</tr>
<tr>
<td>OUT–</td>
<td>C1</td>
<td>O Negative Differential Audio Output</td>
</tr>
<tr>
<td>BST</td>
<td>B3</td>
<td>O Reference Voltage for Boost Converter</td>
</tr>
<tr>
<td>VDD</td>
<td>B4</td>
<td>P Power Supply</td>
</tr>
<tr>
<td>VCCOUT</td>
<td>A2</td>
<td>P DC-DC Converter Output Voltage</td>
</tr>
<tr>
<td>VCCIN</td>
<td>A1</td>
<td>P Audio Amplifier Power Supply</td>
</tr>
<tr>
<td>SW</td>
<td>A3</td>
<td>P Boost and Rectifying Switch Input</td>
</tr>
<tr>
<td>GND</td>
<td>A4, C4, D1</td>
<td>P Ground</td>
</tr>
</tbody>
</table>
```
ABSOLUTE MAXIMUM RATINGS\(^{(1)}\)

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

<table>
<thead>
<tr>
<th></th>
<th>VALUE</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage, (V_{DD})</td>
<td>–0.3 to 6.0 V</td>
<td></td>
</tr>
<tr>
<td>Amplifier supply voltage, (V_{ccOUT}, V_{ccIN})</td>
<td>–0.3 to 12.0 V</td>
<td></td>
</tr>
<tr>
<td>(V_I) Input voltage, (\text{IN}, \text{IN}^+, \text{SDa}, \text{SD}, \text{GAIN})</td>
<td>–0.3 to (V_{DD} + 0.3) V</td>
<td></td>
</tr>
<tr>
<td>Output continuous total power dissipation</td>
<td>See Dissipation Rating Table</td>
<td></td>
</tr>
<tr>
<td>(T_A) Operating free-air temperature range</td>
<td>–40 to 85 °C</td>
<td></td>
</tr>
<tr>
<td>(T_J) Operating junction temperature range</td>
<td>–40 to 150 °C</td>
<td></td>
</tr>
<tr>
<td>(T_{stg}) Storage temperature range</td>
<td>–65 to 150 °C</td>
<td></td>
</tr>
<tr>
<td>ESD Protection — HBM (All Pins)</td>
<td>2 kV</td>
<td></td>
</tr>
</tbody>
</table>

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

DISSIPATION RATINGS\(^{(1)}\)

<table>
<thead>
<tr>
<th>PACKAGE</th>
<th>(T_A \leq 25^\circ)C</th>
<th>DERATING FACTOR</th>
<th>(T_A = 70^\circ)C</th>
<th>(T_A = 85^\circ)C</th>
</tr>
</thead>
<tbody>
<tr>
<td>16-ball WCSP (YZH)</td>
<td>1.66 W</td>
<td>13.3 mW/°C</td>
<td>1.06 W</td>
<td>0.86 W</td>
</tr>
</tbody>
</table>

(1) Dissipation ratings are for a 2-side, 2-plane board JEDEC high K board.

AVAILABLE OPTIONS

<table>
<thead>
<tr>
<th>(T_A)</th>
<th>PACKAGED DEVICES(^{(1)})</th>
<th>PART NUMBER(^{(2)})</th>
<th>SYMBOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>–40°C to 85°C</td>
<td>16-ball WCSP, 2.1 mm × 2.1 mm (+0.01/–0.09 mm)</td>
<td>TPA2100P1YZHR</td>
<td>CEH</td>
</tr>
<tr>
<td></td>
<td>TPA2100P1YZHT</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

(2) The YZH package is only available taped and reeled. The suffix "R" indicates a reel of 3000; the suffix "T" indicates a reel of 250.
RECOMMENDED OPERATING CONDITIONS

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage VDD</td>
<td></td>
<td>2.5</td>
<td>3.6</td>
<td>5.5</td>
<td>V</td>
</tr>
<tr>
<td>Output voltage range VccIN, VccOUT</td>
<td></td>
<td>9.5</td>
<td>10.5</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>VIH High-level input voltage SD, SDa</td>
<td></td>
<td>1.3</td>
<td></td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>VIL Low-level input voltage SD, SDa</td>
<td></td>
<td>0.6</td>
<td></td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>IHI High-level input current SD, SDa, VDD = 2.5 V to 5.5 V</td>
<td></td>
<td>1</td>
<td></td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>ILI Low-level input current SD, SDa, VDD = 2.5 V to 5.5 V</td>
<td></td>
<td>1</td>
<td></td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>fOSC Oscillator frequency</td>
<td></td>
<td>1.1</td>
<td>1.2</td>
<td>1.3</td>
<td>MHz</td>
</tr>
<tr>
<td>TA Operating free-air temperature</td>
<td></td>
<td>–40</td>
<td>85</td>
<td></td>
<td>°C</td>
</tr>
</tbody>
</table>

ELECTRICAL CHARACTERISTICS

TA = 25°C, SD ≥ 1.3 V, GAIN = 12 dB, LOAD = 10 Ω +1 µF + 33 µH (unless otherwise noted)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDD Supply voltage range</td>
<td></td>
<td>2.5</td>
<td>3.6</td>
<td>5.5</td>
<td>V</td>
</tr>
<tr>
<td>ISD Shutdown quiescent current</td>
<td></td>
<td>0.5</td>
<td>1</td>
<td></td>
<td>µA</td>
</tr>
<tr>
<td>IDD Supply current</td>
<td>VDD = 3.0 V</td>
<td>6</td>
<td>9</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td>VDD = 3.6 V</td>
<td>5.5</td>
<td>8</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td>VDD = 5.5 V</td>
<td>4</td>
<td>5</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>ISW Class-D switching frequency</td>
<td></td>
<td>250</td>
<td>300</td>
<td>350</td>
<td>kHz</td>
</tr>
<tr>
<td>fBOOST Boost converter switching frequency</td>
<td></td>
<td>1.1</td>
<td>1.2</td>
<td>1.3</td>
<td>MHz</td>
</tr>
<tr>
<td>POR Power on reset on threshold</td>
<td></td>
<td>2.2</td>
<td></td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>POR Power on reset hysteresis</td>
<td></td>
<td>0.2</td>
<td></td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>CMR Input common mode range</td>
<td>VDD = ±0.001 V, VDD = 2.5 V</td>
<td>0.5</td>
<td>2</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>VDD = 100 mV, VDD = 3.6 V</td>
<td>0.5</td>
<td>2.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>VDD = 100 mV, VDD = 5.5 V</td>
<td>0.5</td>
<td>2.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VDOS Output offset voltage</td>
<td>VDD = 3.6 V, Av = 12 dB, inputs ac grounded</td>
<td>1.4</td>
<td>5</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>ZOUT Output Impedance in shutdown mode</td>
<td>SD = 0.35 V</td>
<td>2</td>
<td></td>
<td>kΩ</td>
<td></td>
</tr>
<tr>
<td>AV Gain</td>
<td>GAIN ≤ 0.35 V</td>
<td>11.3</td>
<td>11.8</td>
<td>12.3</td>
<td>dB</td>
</tr>
<tr>
<td></td>
<td>0.7 V ≤ GAIN ≤ 1 V</td>
<td>15.5</td>
<td>16</td>
<td>16.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GAIN ≥ 1.35 V</td>
<td>23.5</td>
<td>24</td>
<td>24.5</td>
<td></td>
</tr>
</tbody>
</table>
OPERATING CHARACTERISTICS

$T_A = 25^\circ C, \ V_{DD} = 3.6 \ V, \ SD = SDa = 1.3 \ V, \ Gain = 12 \ dB, \ Load = 10 \ \Omega + 1 \ \mu F + 22 \ \mu H$ (unless otherwise noted)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{OUT\text{MAX}}$</td>
<td>Maximum output voltage swing</td>
<td>0.00</td>
<td>0.05</td>
<td>0.10</td>
<td>V_{PP}</td>
</tr>
<tr>
<td>THD+N</td>
<td>Total harmonic distortion plus noise</td>
<td>0.00</td>
<td>0.05</td>
<td>0.10</td>
<td>V_{PP}</td>
</tr>
<tr>
<td>$k_{SVR}$</td>
<td>Supply ripple rejection ratio</td>
<td>0.07%</td>
<td></td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>CMRR</td>
<td>Input common mode rejection</td>
<td>−60</td>
<td>0.07</td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>$Z_{IN}$</td>
<td>Input impedance</td>
<td>10</td>
<td>18.5</td>
<td>23.2</td>
<td>kΩ</td>
</tr>
<tr>
<td>SNR</td>
<td>Signal to noise ratio</td>
<td>94</td>
<td>8</td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>$t_{ON}$</td>
<td>Start up time (Class-D and Boost converter)</td>
<td>8</td>
<td></td>
<td></td>
<td>ms</td>
</tr>
</tbody>
</table>

TYPICAL CHARACTERISTICS

$T_A = 25^\circ C, \ V_{DD} = 3.6 \ V, \ Gain = 12 \ dB, \ C_N = 1 \ \mu F, \ L_{\text{BOOST}} = 4.7 \ \mu H, \ C_{\text{BOOST}} = 10 \ \mu F, \ SD = SDa = 3.6 \ V, \ Load = 10 \ \Omega + 1 \ \mu F + 22 \ \mu H$ (unless otherwise noted)

**QUIESCENT SUPPLY CURRENT**

**AVG. POWER CONSUMPTION**

**SUPPLY VOLTAGE**

**AVG. POWER CONSUMPTION**

*Figure 1.*

*Figure 2.*
TYPICAL CHARACTERISTICS (continued)

$T_A = 25^\circ C$, $V_{DD} = 3.6\, \text{V}$, Gain = 12 dB, $C_{IN} = 1\, \mu\text{F}$, $L_{BOOST} = 4.7\, \mu\text{H}$, $C_{BOOST} = 10\, \mu\text{F}$, $\overline{SD} = \overline{SDa} = 3.6\, \text{V}$,
Load = 10 $\Omega + 1\, \mu\text{F} + 22\, \mu\text{H}$ (unless otherwise noted)

![Graphs showing total supply input power vs output voltage and total supply current vs output voltage](images/graphs.png)

**Figure 3.**

**Figure 4.**

![Graphs showing output voltage drive vs frequency](images/graphs.png)

**Figure 5.**

**Figure 6.**
TYPICAL CHARACTERISTICS (continued)

\[ T_A = 25^\circ C, \quad V_{DD} = 3.6 \text{ V}, \quad \text{Gain} = 12 \text{ dB}, \quad C_{IN} = 1 \mu \text{F}, \quad L_{BOOST} = 4.7 \mu \text{H}, \quad C_{BOOST} = 10 \mu \text{F}, \quad SD = SDA = 3.6 \text{ V}, \]

Load = 10 Ω + 1 μF + 22 μH (unless otherwise noted)

**Figure 7.**

Total Harmonic Distortion + Noise vs Output Voltage

**Figure 8.**

Total Harmonic Distortion + Noise vs Frequency

**Figure 9.**

Total Harmonic Distortion + Noise vs Frequency

**Figure 10.**

Total Harmonic Distortion + Noise vs Frequency

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Product Folder Link(s): TPA2100P1
TYPICAL CHARACTERISTICS (continued)

T_A = 25°C, V_DD = 3.6 V, Gain = 12 dB, C_IN = 1 µF, L_BOOST = 4.7 µH, C_BOOST = 10 µF, SD = SDa = 3.6 V, Load = 10 Ω + 1 µF + 22 µH (unless otherwise noted)

**SUPPLY RIPPLE REJECTION RATIO vs FREQUENCY**

*V_RIPPLE* = 200 mVpp

*V_DD* = 5.5 V

*V_DD* = 3.6 V

**GAIN AND PHASE vs FREQUENCY**

Gain = 24 dB

Gain = 16 dB

Gain = 12 dB

C_I = 1 µF

V_I = 100 mVrms

**STARTUP WAVEFORMS vs TIME**

*V_DD* = 3.6 V

**TOTAL SUPPLY INPUT POWER AND OUTPUT VOLTAGE vs INPUT VOLTAGE**

*V_DD* = 3.6 V

Supply Input Power

Output Voltage

V_D and V_CC

V_O and SD and SDa

Figure 11.

Figure 12.

Figure 13.

Figure 14.
APPLICATION INFORMATION

The TPA2100P1 consists of a boost converter and a Class-D amplifier. The boost converter takes a low supply voltage, VDD, and increases it to a higher output voltage, \( V_{\text{CCOUT}} \). \( V_{\text{CCIN}} \) is the power supply for the Class-D amplifier. Connect \( V_{\text{CCOUT}} \) to \( V_{\text{CCIN}} \).

FULLY DIFFERENTIAL CLASS-D AUDIO POWER AMPLIFIER

The TPA2100P1 is a fully differential amplifier. The fully differential amplifier includes a differential amplifier with common-mode feedback. The differential output is equal to the differential input times the gain. The common-mode feedback ensures that the common-mode voltage at the output is biased around \( V_{\text{CCOUT}}/2 \) (Class-D supply voltage, \( V_{\text{CCOUT}} \), divided by 2) regardless of the common-mode voltage at the input. The fully differential TPA2100P1 can still be used with a single-ended input; however, the TPA2100P1 should be used with differential inputs when in a noisy environment, like a wireless handset, to ensure maximum noise rejection.

- Input-coupling capacitors are not required:
  - The TPA2100P1 inputs can be biased anywhere within the common mode input voltage range listed in the Recommended Operating Conditions table. If the inputs are biased outside of that range, then input-coupling capacitors are required.
- Mid-supply bypass capacitor, \( C_{\text{BYPASS}} \), is not required:
  - The fully differential amplifier does not require a bypass capacitor. Any shift in the midsupply affects both positive and negative channels equally and cancels at the differential output.
- Excellent RF-immunity and supply noise rejection:
  - GSM handsets save power by turning on and off the RF transmitter at 217 Hz. The transmitted signal is picked-up on input, output, and power supply traces. The fully differential amplifier cancels the signal better than a typical audio amplifier.

DRIVING A CERAMIC/PIEZO SPEAKER

Applications that require thin cases, such as mobile phones, demand that external components have a small form factor. Dynamic loudspeakers that use a cone and voice coil typically cannot conform to the height requirements. The option for these applications is to use a ceramic/piezoelectric loudspeaker.

Ceramic speakers have a capacitive behavior unlike a conventional loudspeaker, which has an inductive behavior. Typical capacitance values for ceramic/piezo speakers are as high as 2 \( \mu \)F. High peak-to-peak voltage drive is required to achieve acceptable sound pressure levels. Ceramic/piezo speakers have low current consumption at frequencies up to 8 kHz. The impedance of the ceramic/piezo speaker decreases with increasing audio frequency, thus requiring higher current as the frequency increases. However, audio signals in this range are higher harmonics of lower fundamentals, so the current demand is still small when compared to dynamic speaker current consumption.

Due to these characteristics, ceramic/piezo speakers are efficient in converting electrical audio signals into sound pressure in the mid and high audio bands (starting at 900 Hz).

The TPA2100P1 overcomes the challenges of driving a ceramic/piezo speaker. The TPA2100P1 drives the ceramic/piezo speaker with a constant output voltage over the battery life and across the audio frequency range.

LOAD CONFIGURATION

The TPA2100P1 can be configured in several different ways to drive a ceramic/piezo speaker. The most obvious configuration is to place a resistor on each output of the Class-D amplifier. A more efficient configuration is to replace one resistor with an inductor at one of the outputs. A third way to configure is to place just one resistor between the output and the speaker and connect the other output directly to the speaker.

For proper configuration of the load, it is important to observe the following variables:

- Speaker capacitance – \( C_{\text{SPK}} \)
- Maximum available current from the Boost converter – \( I_{\text{BOOSTMAX}} \)
- Highest desired audio frequency – \( f_{\text{AUDMAX}} \)
- Maximum voltage allowed across the speaker – \( V_{\text{OUTPEAK}} \)
- Peak Output Current from the Class-D Amplifier – \( I_{\text{CLASSDPEAK}} \)
RESISTOR – SPEAKER – RESISTOR LOAD CONFIGURATION

This is the simplest configuration. However, this type of load configuration does not achieve the best efficiency possible. Thus, it is recommended to use the resistor – speaker – inductor load configuration. The following figure shows an example of the resistor – speaker – resistor configuration.

Figure 15. Application Schematic with Resistor – Speaker – Resistor Load Configuration

For the RC load configuration, only two calculations are required. Note that R in Equation 1 is the sum of the two output resistors in Figure 15.

The highest desired audio frequency will be limited by the RC low-pass filter configuration of the load:

$$f_{\text{AUDMAX}} = \frac{1}{2 \times \pi \times R \times C_{\text{SPK}}}$$  \hspace{1cm} (1)

Peak Output Current from the Class-D Amplifier should therefore be limited to the maximum audio frequency:

$$I_{\text{CLASSDPEAK}} = \frac{V_{\text{OUTPEAK}}}{\sqrt{R^2 + X_C^2}}$$  \hspace{1cm} (2)

Where $$X_C$$ is:

$$X_C = \frac{1}{2 \times \pi \times f_{\text{AUDMAX}} \times C_{\text{SPK}}}$$  \hspace{1cm} (3)

To calculate the proper boost converter inductor required for this application, see the Inductor Selection section.

Note that an input low-pass filter should be added before the audio amplifier in order to limit the audio frequency, $$f_{\text{AUDMAX}}$$.

RESISTOR – SPEAKER – INDUCTOR LOAD CONFIGURATION

The second configuration with a resistor – speaker – inductor load is the most efficient configuration and is the preferred solution. Figure 16 shows an example of this configuration.
For the resistor – speaker – inductor load configuration, it is desired to make the output load configuration overdamped (Zeta ($\zeta$) > 0.707). Use Equation 4 to calculate $\zeta$:

$$\zeta = \frac{R \times \sqrt{C_{SPK}}}{2 \times \sqrt{L}}$$

(4)

If $\zeta$ is greater than one, then the maximum audio frequency will be limited by the resistor – speaker capacitance low pass filter as shown in Equation 5.

$$f_{AUDMAX} = \frac{1}{2 \times \pi \times R \times C_{SPK}}$$

(5)

Calculate equivalent load impedance with Equation 6, through Equation 9.

$$XC = \frac{1}{2 \times \pi \times f_{AUDMAX} \times C_{SPK}}$$

(6)

$$XL = 2 \times \pi \times f_{AUDMAX} \times L$$

(7)

$$Z = \sqrt{R^2 + (XL - XC)^2}$$

(8)

$$I_{CLASSDPEAK} = \frac{V_{OUTPEAK}}{Z}$$

(9)

To calculate the proper boost converter inductor required for this application, see the Inductor Selection section. Note that an input low pass filter should be added before the audio amplifier in order to limit the audio frequency, $f_{AUDMAX}$.

**RESISTOR – SPEAKER LOAD CONFIGURATION**

This load configuration is similar to the resistor – speaker – resistor load configuration. Apply the same equations here to calculate the maximum audio frequency and maximum required current from the class-D audio amplifier.
BOOST CONVERTER

There are two main passive components necessary for the functioning of a boost converter. The boost inductor stores current, and the boost capacitor stores charge. When the Class-D amplifier depletes the charge in the boost capacitor, the boost inductor charges it back up with the stored current. The cycle of charge/discharge occurs at a frequency of $f_{\text{boost}}$.

The following is a list of terms and definitions used in the boost equations found in this document.

- **C**: Minimum boost capacitance required for a given ripple voltage on $V_{\text{CC}}$
- **L**: Boost inductor
- **$f_{\text{BOOST}}$**: Switching frequency of the boost converter.
- **$I_{\text{CC}}$**: Current pulled by the Class-D amplifier from the boost converter.
- **$I_L$**: Average current through the boost inductor.
- **$V_{\text{CC}}$**: Boost voltage. Generated by the boost converter ($V_{\text{CCOUT}}$). Voltage supply for the Class-D amplifier ($V_{\text{CCIN}}$).
- **$V_{\text{DD}}$**: Supply voltage to the IC.
- **$\Delta I_L$**: Ripple current through the inductor.
- **$\Delta V$**: Ripple voltage of $V_{\text{CC}}$ due to capacitance. $V_{\text{CC}}$ is the voltage on the VccOUT and VclIN pins.

INDUCTOR SELECTION

SURFACE MOUNT INDUCTORS

Working inductance decreases as inductor current increases. If the drop in working inductance is severe enough, it may cause the boost converter to become unstable, or cause the TPA2100P1 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.

TPA2100P1 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 10 to determine the required current rating. Equation 10 shows the approximate relationship between the average inductor current, $I_L$, to the load current, load voltage, and input voltage ($I_{CC}$, $V_{CC}$, and $V_{DD}$, respectively). Insert $I_{CC}$, $V_{CC}$, and $V_{DD}$ into Equation 10 to solve for $I_L$. The inductor must maintain at least 90% of its initial inductance value at this current.

$$I_L = I_{CC} \left( \frac{V_{CC}}{V_{DD} \times 0.8} \right)$$  \hspace{1cm} (10)

The minimum working inductance is 3.3 μH. A lower value may cause instability.

Ripple current, $\Delta I_L$, is peak-to-peak variation in inductor current. Smaller ripple current reduces core losses in the inductor as well as the potential for EMI. Use Equation 11 to determine the value of the inductor, L. Equation 11 shows the relationship between inductance $L$, $V_{DD}$, $V_{CC}$, the switching frequency, $f_{BOOST}$, and $\Delta I_L$. Insert the maximum acceptable ripple current into Equation 11 to solve for $L$.

$$L = \frac{V_{DD} \times (V_{CC} - V_{DD})}{\Delta I_L \times f_{\text{BOOST}} \times V_{CC}}$$  \hspace{1cm} (11)

$\Delta I_L$ 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. Note that making the inductance value of $L$ greater than 10 μH will prevent the boost converter from responding to fast load changes properly. A typical inductor value for the TPA2100P1 is 4.7 μH.

Select an inductor with a dc resistance, DCR, no greater than 0.5 Ω. DCR reduces the amount of power the device receives from the supply due to the voltage drop across the inductor.

**CAPACITOR SELECTION**

**SURFACE MOUNT CAPACITORS**

Temperature and applied dc voltage influence the actual capacitance of high-K materials.

Table 1 shows the relationship between the different types of high-K materials and their associated tolerances, temperature coefficients, and temperature ranges. Notice that a capacitor made with X5R material can lose up to 15% of its capacitance within its working temperature range.

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>COG/NPO</th>
<th>X7R</th>
<th>X5R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical tolerance</td>
<td>±5%</td>
<td>±10%</td>
<td>±20%</td>
</tr>
<tr>
<td>Temperature Coefficient</td>
<td>±30 ppm</td>
<td>±15%</td>
<td>±15%</td>
</tr>
<tr>
<td>Temperature range, °C</td>
<td>−55/125°C</td>
<td>−55/125°C</td>
<td>−55/85°C</td>
</tr>
</tbody>
</table>

High-K material is very sensitive to applied dc voltage. X5R capacitors have can have losses ranging from 15% to 45% of their initial capacitance with only half of their dc rated voltage applied. For example, if 5 Vdc is applied to a 10 V, 1 μF X5R capacitor, the measured capacitance at that point may show between 0.55 μF and 0.85 μF. Y5V capacitors have losses that can reach or exceed 50% to 75% of their rated value.

The working capacitance of components made with high-K materials is generally much lower than nominal capacitance. A worst case result with a typical X5R material might be −10% tolerance, −15% temperature effect, and −45% dc voltage effect at 50% of the rated voltage. This particular case would result in a working capacitance of 42% (0.9 × 0.85 × 0.55) of the nominal value.

Select high-K ceramic capacitors according to the following rules:
1. Use capacitors made of materials with temperature coefficients of X5R, X7R, or better.
2. Use capacitors with dc voltage ratings of at least twice the application voltage, because high-K capacitor values generally are reduced by dc voltage. 25V capacitors are recommended when boost converter output is 10V. The minimum rating that should be used in this case is 16V, but correct operation should be verified carefully.
3. Choose a capacitance value at least twice the nominal value calculated for the application. Multiply the nominal value by a factor of 2 for safety. If a 10 μF capacitor is required, use 22 μF.
The preceding rules and recommendations apply to capacitors used in connection with the TPA2100P1. The TPA2100P1 cannot meet its performance specifications if the rules and recommendations are not followed.

**TPA2100P1 CAPACITOR EQUATIONS**

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 $V_{CC}$ in the application. The minimum value of working capacitance is 10 µF. Do not use any component with a working capacitance less than 10 µF.

For X5R or X7R ceramic capacitors, Equation 12 shows the relationship between the boost capacitance, $C$, to load current, load voltage, ripple voltage, input voltage, and switching frequency ($I_{CC}$, $V_{CC}$, $\Delta V$, $V_{DD}$, $I_{BOOST}$ respectively).

Insert the maximum allowed ripple voltage into Equation 12 to solve for $C$. A factor of 2 is included to implement the rules and specifications listed earlier.

$$C = 2 \times \frac{I_{CC} \times (V_{CC} - V_{DD})}{\Delta V \times f_{boost} \times V_{CC}}$$

(12)

For aluminum or tantalum capacitors, Equation 13 shows the relationship between he boost capacitance, $C$, to load current, load voltage, ripple voltage, input voltage, and switching frequency ($I_{CC}$, $V_{CC}$, $\Delta V$, $V_{DD}$, $I_{BOOST}$ respectively). Insert the maximum allowed ripple voltage into Equation 12 to solve for $C$. Solve this equation assuming ESR is zero.

$$C = \frac{I_{CC} \times (V_{CC} - V_{DD})}{\Delta V \times f_{boost} \times V_{CC}}$$

(13)

Capacitance of aluminum and tantalum capacitors is normally not sensitive to applied voltage so there is no factor of 2 included in Equation 4. However, the ESR in aluminum and tantalum capacitors can be significant. Choosing an aluminum or tantalum capacitor with ESR around 30 mΩ is acceptable.

**Decoupling Capacitors**

The TPA2100P1 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. In addition to the 10 µF capacitor at $V_{DD}$, place a 1 µF low ESR capacitor within 1 mm of the $V_{DD}$ pin to reduce higher frequency transients, spikes, or digital hash on the line. For the same reasons place a 1 µF low ESR capacitor within 1 mm of the $V_{CCOUT}$ pin in addition to the boost output capacitor.

**Input Capacitors, $C_I$**

The TPA2100P1 does not require input coupling capacitors if the design uses a low offset differential source that is biased within the common mode input voltage range. Note that source offset is amplified if no DC blocking capacitors are used. If the input signal is not biased within the recommended common-mode input range, if high pass filtering is needed, or if using a single-ended source, input coupling capacitors are required.

The input capacitors and input resistors form a high-pass filter with the corner frequency, $f_C$, determined in Equation 14.

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

(14)

The value of the input capacitor directly affects the bass (low frequency) performance of the circuit. Piezo speakers cannot usually respond well to low frequencies, so the corner frequency can be set to block low frequencies and reduce speaker distortion in this application. Not using input capacitors can increase output offset.

Use Equation 15 to solve for the input coupling capacitance. If the corner frequency is within the audio band, the input capacitors should have a tolerance of ±10% or better, because any mismatch in capacitance causes an impedance mismatch at the corner frequency and below.


\[ C_l = \frac{1}{2\pi R \times f_C} \]  

(15)

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 18 and Table 2 shows the appropriate diameters for a WCSP layout.

![Figure 18. Land Pattern Dimensions](image)

Table 2. Land Pattern Dimensions

<table>
<thead>
<tr>
<th>SOLDER PAD DEFINITIONS</th>
<th>COPPER PAD</th>
<th>SOLDER MASK OPENING</th>
<th>COPPER THICKNESS</th>
<th>STENCIL OPENING</th>
<th>STENCIL THICKNESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonsolder mask defined (NSMD)</td>
<td>275 µm (+0.0, –25 µm)</td>
<td>375 µm (+0.0, –25 µm)</td>
<td>1 oz max (32 µm)</td>
<td>275 µm x 275 µm Sq. (rounded corners)</td>
<td>125 µm thick</td>
</tr>
</tbody>
</table>

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 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 results in 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.
Component Location

Place all the external components as close as possible to the TPA2100P1. Placing the decoupling capacitor as close as possible to the TPA2100P1 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.

Trace Width

Recommended trace width at the solder balls is 75 µm to 100 µm to prevent solder wicking onto wider PCB traces.

For high current pins (SW, VccOUT, VccIN, GND, and audio output pins) of the TPA2100P1, use 100 µm trace widths at the solder balls and at least 500 µm PCB traces to ensure proper performance and output power for the device.

For the remaining signals of the TPA2100P1, use 75 µm to 100 µm trace widths at the solder balls. The audio input pins (IN- and IN+) must run side-by-side to maximize common-mode noise cancellation.

EFFICIENCY AND THERMAL INFORMATION

The maximum ambient temperature depends on the heat-sinking ability of the PCB system. The derating factor for the packages are shown in the dissipation rating table. Converting this to θJA for the WCSP package:

\[
θ_{JA} = \frac{1}{\text{Derating Factor}} = \frac{1}{0.0133} = 75°C/W
\]

Given θJA of 75°C/W, the maximum allowable junction temperature of 150°C, and the maximum estimated internal dissipation of 1 W (driving 1 µF speaker with 6 Vrms 15 kHz sine wave, the maximum ambient temperature is calculated with Equation 17.

\[
T_{A\text{Max}} = T_{J\text{Max}} - θ_{JA}P_{\text{Dmax}} = 150 - 75(1) = 75°C
\]

Equation 17 shows that the calculated maximum ambient temperature is 75°C at maximum power dissipation. The TPA2100P1 is designed with thermal protection that turns the device off when the junction temperature surpasses 150°C to prevent damage to the IC. Using the resistor- speaker - resistor or the resistor - speaker load configurations dramatically increases the temperature of the TPA2100P1 since those configurations require a much higher output current.

OPERATION WITH DACs AND CODECs

When using Class-D amplifiers with CODECs and DACs, sometimes there is an increase in the output noise floor from the audio amplifier. This occurs when the output frequencies of the CODEC/DAC mix with the switching frequencies of the audio amplifier input stage.

The TPA2100P1 has a built-in low-pass filter to reduce CODEC/DAC out-of-band noise that could mix with the switching frequency of the Class-D amplifier.

FILTER FREE OPERATION

A ferrite bead filter is not required for operation with the resistor – speaker – resistor load configuration or with the resistor – speaker – inductor load configuration. In order to achieve low radiated emissions, the resistor and/or inductor should be placed within 1 cm of the output of the amplifier and followed with a 100 pF to 1000 pF capacitor to GND. Figure 19 and Figure 20 show typical load configurations to reduce radiated emissions.
Figure 19. Typical Radiated Emissions Suppression Circuit (Resistor-Speaker-Inductor Load)

Figure 20. Typical Radiated Emissions Suppression Circuit (Resistor-Speaker-Resistor Load)

Figure 21 shows the EMC performance of Figure 19 using a 1 µF load to simulate the speaker. Table 3 list the measurement conditions. The worst-case quasi-peak margin is 14.4 dB at 55.9 MHz.

Figure 21. Measured Radiated Emissions – Vertical Front
Table 3. Measurement Conditions for Radiated Emissions of Figure 21

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUE</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V_{DD})</td>
<td>3.6</td>
<td>V</td>
</tr>
<tr>
<td>(A_V)</td>
<td>12</td>
<td>dB</td>
</tr>
<tr>
<td>(f_{AUD})</td>
<td>1</td>
<td>kHz</td>
</tr>
<tr>
<td>(V_I)</td>
<td>1.3</td>
<td>(V_{RMS})</td>
</tr>
<tr>
<td>(V_O)</td>
<td>5.3</td>
<td>(V_{RMS})</td>
</tr>
<tr>
<td>(C_L)</td>
<td>1</td>
<td>(\mu F)</td>
</tr>
<tr>
<td>Cable length</td>
<td>25.4</td>
<td>mm</td>
</tr>
<tr>
<td>Antenna position</td>
<td>Vertical Front</td>
<td>–</td>
</tr>
</tbody>
</table>

For a full Radiated Emissions report, please contact your local TI representative.

For operation with a resistor – speaker load configuration the ferrite bead filter can often be used if the design is failing radiated emissions without an LC filter and the frequency sensitive circuit is greater than 1 MHz. This filter functions well for circuits that just have to pass FCC and CE because FCC and CE only test radiated emissions greater than 30 MHz. When choosing a ferrite bead, choose one with high impedance at high frequencies, and very low impedance at low frequencies. In addition, select a ferrite bead with adequate current rating to prevent distortion of the output signal.

Figure 22 shows a typical ferrite bead output filter.

**Figure 22. Typical Ferrite Bead Filter (Chip bead example: TDK: MPZ1608Y101B)**
## PACKAGING INFORMATION

<table>
<thead>
<tr>
<th>Orderable Device</th>
<th>Status (1)</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>Pins</th>
<th>Package Qty</th>
<th>Eco Plan</th>
<th>Lead/Ball Finish</th>
<th>MSL Peak Temp</th>
<th>Op Temp (°C)</th>
<th>Top-Side Markings</th>
<th>Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPA2100P1YZHR</td>
<td>ACTIVE</td>
<td>DSBGA</td>
<td>YZH</td>
<td>16</td>
<td>3000</td>
<td>Green (RoHS &amp; no Sb/Br)</td>
<td>SNAGCU</td>
<td>Level-1-260C-UNLIM</td>
<td>CEH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TPA2100P1YZHT</td>
<td>ACTIVE</td>
<td>DSBGA</td>
<td>YZH</td>
<td>16</td>
<td>250</td>
<td>Green (RoHS &amp; no Sb/Br)</td>
<td>SNAGCU</td>
<td>Level-1-260C-UNLIM</td>
<td>CEH</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) The marketing status values are defined as follows:
- **ACTIVE**: Product device recommended for new designs.
- **LIFEBUY**: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
- **NRND**: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
- **PREVIEW**: Device has been announced but is not in production. Samples may or may not be available.
- **OBSOLETE**: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check [http://www.ti.com/productcontent](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) Only one of markings shown within the brackets will appear on the physical device.

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## TAPE AND REEL INFORMATION

### TAPE DIMENSIONS

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

### REEL DIMENSIONS

- **Reel Diameter**
- **Reel Width (W1)**

### QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE

- **Q1**: Quadrant 1
- **Q2**: Quadrant 2
- **Q3**: Quadrant 3
- **Q4**: Quadrant 4

*All dimensions are nominal.*

<table>
<thead>
<tr>
<th>Device</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>Pins</th>
<th>SPQ</th>
<th>Reel Diameter (mm)</th>
<th>Reel Width W1 (mm)</th>
<th>A0 (mm)</th>
<th>B0 (mm)</th>
<th>K0 (mm)</th>
<th>P1 (mm)</th>
<th>W (mm)</th>
<th>Pin 1 Quadrant</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPA2100P1YZHR</td>
<td>DSBGA</td>
<td>YZH</td>
<td>16</td>
<td>3000</td>
<td>180.0</td>
<td>8.4</td>
<td>2.35</td>
<td>2.35</td>
<td>0.81</td>
<td>4.0</td>
<td>8.0</td>
<td>Q1</td>
</tr>
<tr>
<td>TPA2100P1YZHT</td>
<td>DSBGA</td>
<td>YZH</td>
<td>16</td>
<td>250</td>
<td>180.0</td>
<td>8.4</td>
<td>2.35</td>
<td>2.35</td>
<td>0.81</td>
<td>4.0</td>
<td>8.0</td>
<td>Q1</td>
</tr>
</tbody>
</table>
### TAPE AND REEL BOX DIMENSIONS

*All dimensions are nominal*

<table>
<thead>
<tr>
<th>Device</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>Pins</th>
<th>SPQ</th>
<th>Length (mm)</th>
<th>Width (mm)</th>
<th>Height (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPA2100P1YZHR</td>
<td>DSBGA</td>
<td>YZH</td>
<td>16</td>
<td>3000</td>
<td>182.0</td>
<td>182.0</td>
<td>20.0</td>
</tr>
<tr>
<td>TPA2100P1YZHT</td>
<td>DSBGA</td>
<td>YZH</td>
<td>16</td>
<td>250</td>
<td>182.0</td>
<td>182.0</td>
<td>20.0</td>
</tr>
</tbody>
</table>
NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. NanoFree™ package configuration.

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