

TPA3245 115-W Stereo, 230-W Mono PurePath™ Ultra-HD Analog-Input Class-D Amplifier

1 Features

- Differential Analog Inputs
- Total Output Power at 10%THD+N
 - 115-W Stereo into 4 Ω in BTL Configuration
 - 145-W Stereo into 3 Ω in BTL Configuration
 - 230-W Mono into 2 Ω in PBTL Configuration
- Total Output Power at 1%THD+N
 - 95-W Stereo into 4 Ω in BTL Configuration
 - 115-W Stereo into 3 Ω in BTL Configuration
 - 185-W Mono into 2 Ω in PBTL Configuration
- Advanced Integrated Feedback Design with High-speed Gate Driver Error Correction (PurePath™ Ultra-HD)
 - Signal Bandwidth up to 100 kHz for High Frequency Content From HD Sources
 - Ultra Low 0.005% THD+N at 1 W into 4 Ω and <0.01% THD+N to Clipping
 - 65 dB PSRR (BTL, No Input Signal)
 - <50 μ V (A-Weighted) Output Noise
 - >112 dB (A Weighted) SNR
- Multiple Configurations Possible:
 - Stereo, Mono, 2.1 and 4xSE
- Click and Pop Free Startup and Stop
- 90% Efficient Class-D Operation (4 Ω)
- Wide 12-V to 30-V Supply Voltage Operation
- Self-Protection Design (Including Undervoltage, Overtemperature, Clipping, and Short Circuit Protection) With Error Reporting
- EMI Compliant When Used With Recommended System Design

2 Applications

- Blu-Ray Disc™ / DVD Receivers
- High End TV sets
- High End Soundbar
- Mini Combo Systems
- Active Speakers and Subwoofers

3 Description

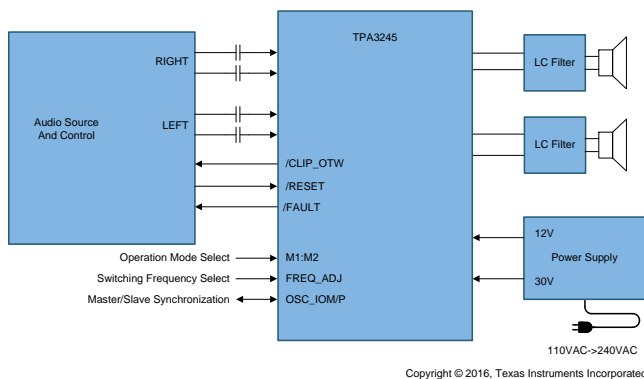
TPA3245 is a high performance class-D power amplifier that enables true premium sound quality with class-D efficiency. It features an advanced integrated feedback design and proprietary high-speed gate driver error correction (PurePath™ Ultra-HD). This technology allows ultra low distortion across the audio band and superior audio quality. The device is operated in AD-mode, and can drive up to 2 x 115 W into 4- Ω load and 2 x 145 W into 3- Ω load and features a 2 VRMS analog input interface that works seamlessly with high performance DACs such as TI's PCM5242. In addition to excellent audio performance, TPA3245 achieves both high power efficiency and very low power stage idle losses below 0.45 W. This is achieved through the use of 65 m Ω MOSFETs and an optimized gate driver scheme that achieves significantly lower idle losses than typical discrete implementations.

Device Information⁽¹⁾

PART NUMBER	PACKAGE	BODY SIZE (NOM)
TPA3245	HTSSOP (44)	6.10 mm x 14.00 mm

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

Simplified Schematic



Total Harmonic Distortion

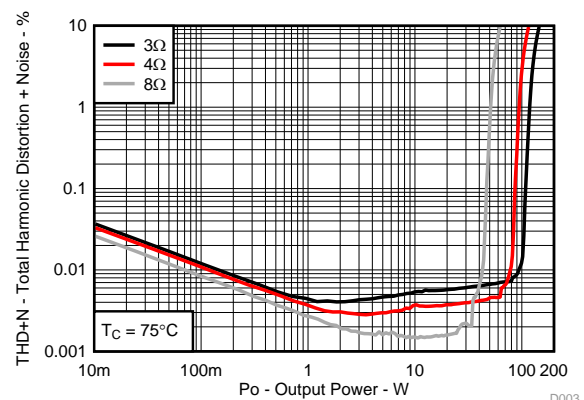


Table of Contents

1 Features	1	9.2 Functional Block Diagrams	15
2 Applications	1	9.3 Feature Description	17
3 Description	1	9.4 Device Protection System	17
4 Revision History	2	10 Application and Implementation	22
5 Device Comparison Table	3	10.1 Application Information	22
6 Pin Configuration and Functions	3	10.2 Typical Applications	22
7 Specifications	5	11 Power Supply Recommendations	31
7.1 Absolute Maximum Ratings	5	11.1 Power Supplies	31
7.2 ESD Ratings	5	11.2 Powering Up	31
7.3 Recommended Operating Conditions	6	11.3 Powering Down	32
7.4 Thermal Information	6	12 Layout	32
7.5 Electrical Characteristics	7	12.1 Layout Guidelines	32
7.6 Audio Characteristics (BTL)	8	12.2 Layout Examples	34
7.7 Audio Characteristics (SE)	9	13 Device and Documentation Support	38
7.8 Audio Characteristics (PBTL)	9	13.1 Documentation Support	38
7.9 Typical Characteristics, BTL Configuration	10	13.2 Receiving Notification of Documentation Updates	38
7.10 Typical Characteristics, SE Configuration	12	13.3 Community Resources	38
7.11 Typical Characteristics, PBTL Configuration	13	13.4 Trademarks	38
8 Parameter Measurement Information	14	13.5 Electrostatic Discharge Caution	38
9 Detailed Description	14	13.6 Glossary	38
9.1 Overview	14	14 Mechanical, Packaging, and Orderable Information	38

4 Revision History

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

Changes from Original (April 2016) to Revision A	Page
• Changed the device From: Preview To: Production	1

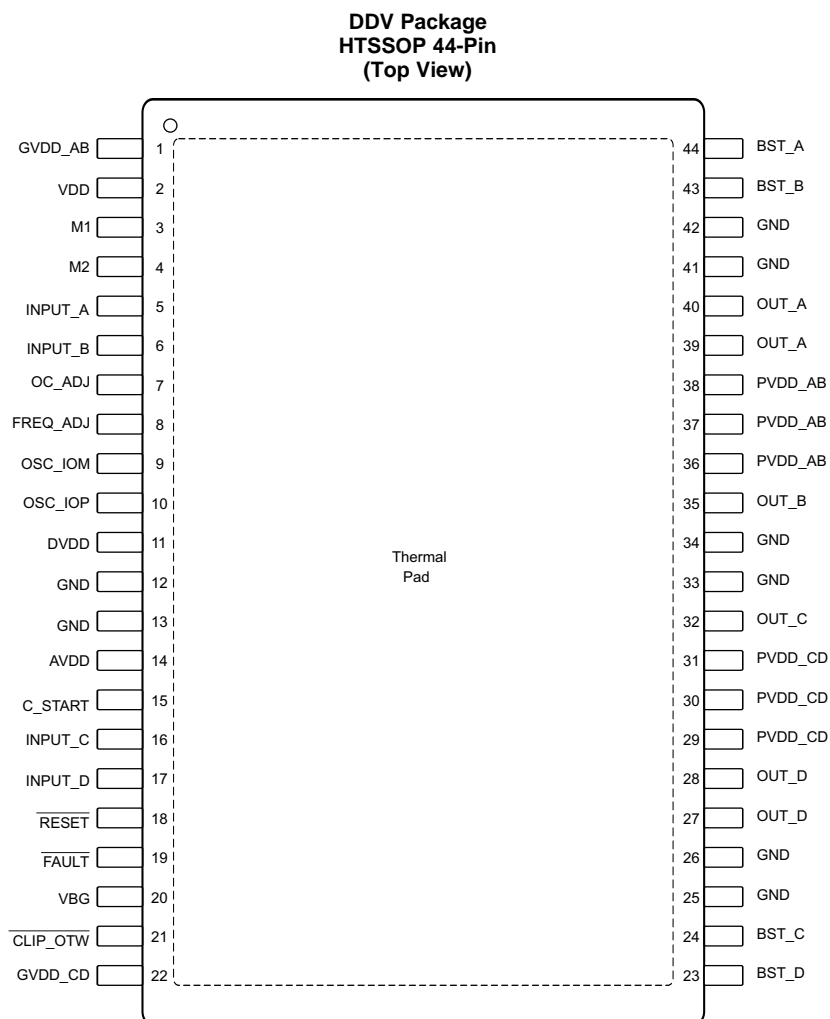
5 Device Comparison Table

DEVICE NAME	DESCRIPTION
TPA3244	40-W Stereo, 100-W peak PurePath™ Ultra-HD Pad Down Class-D Amplifier
TPA3250	70-W Stereo, 130-W peak PurePath™ Ultra-HD Pad Down Class-D Amplifier
TPA3251	175-W Stereo, 350-W Mono PurePath™ Ultra-HD Analog-Input Class-D Amplifier
TPA3255	315-W Stereo, 600-W Mono PurePath™ Ultra-HD Analog-Input Class-D Amplifier

6 Pin Configuration and Functions

The TPA3245 is available in a thermally enhanced TSSOP package.

The package type contains a PowerPAD™ that is located on the top side of the device for convenient thermal coupling to the heat sink.



Pin Functions

NAME	NO.	I/O	DESCRIPTION
AVDD	14	P	Internal voltage regulator, analog section
BST_A	44	P	HS bootstrap supply (BST), external 0.033 μ F capacitor to OUT_A required.
BST_B	43	P	HS bootstrap supply (BST), external 0.033 μ F capacitor to OUT_B required.
BST_C	24	P	HS bootstrap supply (BST), external 0.033 μ F capacitor to OUT_C required.
BST_D	23	P	HS bootstrap supply (BST), external 0.033 μ F capacitor to OUT_D required.
CLIP_OTW	21	O	Clipping warning and Over-temperature warning; open drain; active low. Do not connect if not used.
C_START	15	O	Startup ramp, requires a charging capacitor to GND
DVDD	11	P	Internal voltage regulator, digital section
FAULT	19	O	Shutdown signal, open drain; active low. Do not connect if not used.
FREQ_ADJ	8	O	Oscillator frequency programming pin
GND	12, 13, 25, 26, 33, 34, 41, 42	P	Ground
GVDD_AB	1	P	Gate-drive voltage supply; AB-side, requires 0.1 μ F capacitor to GND
GVDD_CD	22	P	Gate-drive voltage supply; CD-side, requires 0.1 μ F capacitor to GND
INPUT_A	5	I	Input signal for half bridge A
INPUT_B	6	I	Input signal for half bridge B
INPUT_C	16	I	Input signal for half bridge C
INPUT_D	17	I	Input signal for half bridge D
M1	3	I	Mode selection 1 (LSB)
M2	4	I	Mode selection 2 (MSB)
OC_ADJ	7	I/O	Over-Current threshold programming pin
OSC_IOM	9	I/O	Oscillator synchronization interface. Do not connect if not used.
OSC_IOP	10	O	Oscillator synchronization interface. Do not connect if not used.
OUT_A	39, 40	O	Output, half bridge A
OUT_B	35	O	Output, half bridge B
OUT_C	32	O	Output, half bridge C
OUT_D	27, 28	O	Output, half bridge D
PVDD_AB	36, 37, 38	P	PVDD supply for half-bridge A and B
PVDD_CD	29, 30, 31	P	PVDD supply for half-bridge C and D
RESET	18	I	Device reset Input; active low
VDD	2	P	Power supply for internal voltage regulator requires a 10- μ F capacitor with a 0.1- μ F capacitor to GND for decoupling.
VBG	20	P	Internal voltage reference requires a 0.1- μ F capacitor to GND for decoupling.
PowerPad™		P	Ground, connect to grounded heat sink

Table 1. Mode Selection Pins

MODE PINS		INPUT MODE	OUTPUT CONFIGURATION	DESCRIPTION
M2	M1			
0	0	2N + 1	2 x BTL	Stereo BTL output configuration
0	1	2N/1N + 1	1 x BTL + 2 x SE	2.1 BTL + SE mode. Channel AB: BTL, channel C + D: SE
1	0	2N + 1	1 x PBTL	Paralleled BTL configuration. Connect INPUT_C and INPUT_D to GND.
1	1	1N + 1	4 x SE	Single ended output configuration

7 Specifications

7.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted) ⁽¹⁾

		MIN	MAX	UNIT
Supply voltage	BST_X to GVDD_X ⁽²⁾	−0.3	43	V
	VDD to GND	−0.3	13.2	V
	GVDD_X to GND ⁽²⁾	−0.3	13.2	V
	PVDD_X to GND ⁽²⁾	−0.3	43	V
	DVDD to GND	−0.3	4.2	V
	AVDD to GND	−0.3	8.5	V
	VBG to GND	−0.3	4.2	V
Interface pins	OUT_X to GND ⁽²⁾	−0.3	43	V
	BST_X to GND ⁽²⁾	−0.3	55.5	V
	OC_ADJ, M1, M2, OSC_IOP, OSC_IOM, FREQ_ADJ, C_START, to GND	−0.3	4.2	V
	RESET, FAULT, CLIP_OTW to GND	−0.3	4.2	V
	INPUT_X to GND	−0.3	7	V
	Continuous sink current, RESET, FAULT, CLIP_OTW to GND		9	mA
T _J	Operating junction temperature range	0	150	°C
T _{stg}	Storage temperature range	−40	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.
- (2) These voltages represents the DC voltage + peak AC waveform measured at the terminal of the device in all conditions.

7.2 ESD Ratings

			VALUE	UNIT
V _{ESD}	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins ⁽¹⁾	±1000	V
		Charged device model (CDM), per JEDEC specification JESD22-C101, all pins ⁽²⁾	±250	V

- (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

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

			MIN	TYP	MAX	UNIT
PVDD_x	Half-bridge supply	DC supply voltage	12	30	31.5	V
GVDD_x	Supply for logic regulators and gate-drive circuitry	DC supply voltage	10.8	12	13.2	V
VDD	Digital regulator supply voltage	DC supply voltage	10.8	12	13.2	V
R _L (BTL)	Load impedance	Output filter inductance within recommended value range	2.7	4		Ω
R _L (SE)			1.5	3		
R _L (PBTL)			1.6	2		
L _{OUT} (BTL)	Output filter inductance	Minimum output inductance at I _{OC}	5			μH
L _{OUT} (SE)			5			
L _{OUT} (PBTL)			5			
F _{PWM}	PWM frame rate selectable for AM interference avoidance; 1% Resistor tolerance	Nominal	575	600	625	kHz
		AM1	475	500	525	
		AM2	430	450	470	
R _(FREQ_ADJ)	PWM frame rate programming resistor	Nominal; Master mode	9.9	10	10.1	kΩ
		AM1; Master mode	19.8	20	20.2	
		AM2; Master mode	29.7	30	30.3	
C _{PVDD}	PVDD close decoupling capacitors			1.0		μF
R _{OC}	Over-current programming resistor	Resistor tolerance = 5%	22		30	kΩ
R _{OC} (LATCHED)	Over-current programming resistor	Resistor tolerance = 5%	47		64	kΩ
V _(FREQ_ADJ)	Voltage on FREQ_ADJ pin for slave mode operation	Slave mode		3.3		V
T _J	Junction temperature		0		125	°C

7.4 Thermal Information

THERMAL METRIC ⁽¹⁾		TPA3251D2	UNIT
		DDV 44-PINS HTSSOP	
		FIXED 85°C HEATSINK TEMPERATURE ⁽²⁾	
R _{θJA}	Junction-to-ambient thermal resistance	2.8 ⁽²⁾	°C/W
R _{θJC(top)}	Junction-to-case (top) thermal resistance	0.5	
R _{θJB}	Junction-to-board thermal resistance	n/a	
ψ _{JT}	Junction-to-top characterization parameter	0.9	
ψ _{JB}	Junction-to-board characterization parameter	n/a	
R _{θJC(bot)}	Junction-to-case (bottom) thermal resistance	n/a	

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

(2) Thermal data are obtained with 85°C heat sink temperature using thermal compound with 0.7W/mK thermal conductivity and 2mil thickness. In this model heat sink temperature is considered to be the ambient temperature and only path for dissipation is to the heatsink.

7.5 Electrical Characteristics

PVDD_X = 30 V, GVDD_X = 12 V, VDD = 12 V, T_C (Case temperature) = 75°C, f_S = 600 kHz, unless otherwise specified.

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INTERNAL VOLTAGE REGULATOR AND CURRENT CONSUMPTION						
DVDD	Voltage regulator, only used as reference node	VDD = 12 V	3.3			V
AVDD	Voltage regulator, only used as reference node	VDD = 12 V	7.8			V
I _{VDD}	VDD supply current	Operating, 50% duty cycle	40			mA
		Idle, reset mode	10			
I _{GVDD_X}	Gate-supply current per full-bridge	50% duty cycle	19			mA
		Reset mode	2.5			
I _{PVDD_X}	PVDD idle current per full bridge	50% duty cycle with recommended output filter	15			mA
		Reset mode, No switching	1.1			mA
ANALOG INPUTS						
R _{IN}	Input resistance		24			kΩ
V _{IN}	Maximum input voltage swing		7			V
I _{IN}	Maximum input current		1			mA
G	Inverting voltage Gain	V _{OUT} /V _{IN}	18			dB
OSCILLATOR						
f _{OSC(I/O+)} ⁽¹⁾	Nominal, Master Mode	F _{PWM} × 6	3.45	3.6	3.75	MHz
	AM1, Master Mode		2.85	3	3.15	
	AM2, Master Mode		2.58	2.7	2.82	
V _{IH}	High level input voltage		1.86			V
V _{IL}	Low level input voltage		1.45			V
OUTPUT-STAGE MOSFETs						
R _{DS(on)}	Drain-to-source resistance, low side (LS)	T _J = 25°C, Includes metallization resistance, GVDD = 12 V	65			mΩ
	Drain-to-source resistance, high side (HS)		65			mΩ
I/O PROTECTION						
V _{uvp,VDD,GVDD}	Undervoltage protection limit, GVDD_x and VDD		8.6			V
V _{uvp,VDD, GVDD,hyst} ⁽²⁾			0.85			V
V _{uvp,PVDD}	Undervoltage protection limit, PVDD_x		9.7			V
V _{uvp,PVDD,hyst} ⁽²⁾			1.25			V
OTW	Overtemperature warning, $\overline{\text{CLIP_OTW}}$ ⁽²⁾		115	125	135	°C
OTW _{hyst} ⁽²⁾	Temperature drop needed below OTW temperature for $\overline{\text{CLIP_OTW}}$ to be inactive after OTW event.		20			°C
OTE ⁽²⁾	Overtemperature error		145	155	165	°C
OTE _{hyst} ⁽²⁾	A reset needs to occur for $\overline{\text{FAULT}}$ to be released following an OTE event		20			°C
OTE-OTW _(differential) ⁽²⁾	OTE-OTW differential		30			°C
OLPC	Overload protection counter	f _{PWM} = 600 kHz (1024 PWM cycles)	1.7			ms
I _{OC}	Overcurrent limit protection	Resistor – programmable, nominal peak current in 1Ω load, R _{OCp} = 22 kΩ	13.5			A
I _{OC(LATCHED)}	Overcurrent limit protection	Resistor – programmable, peak current in 1Ω load, R _{OCp} = 47kΩ	13.5			A
I _{DCspkr}	DC Speaker Protection Current Threshold	BTL current imbalance threshold	2			A
I _{OCT}	Overcurrent response time	Time from switching transition to flip-state induced by overcurrent.	150			ns
I _{PD}	Output pulldown current of each half	Connected when $\overline{\text{RESET}}$ is active to provide bootstrap charge. Not used in SE mode.	3			mA

(1) Nominal, AM1 and AM2 use same internal oscillator with fixed ratio 6 : 5 : 4.5

(2) Specified by design.

Electrical Characteristics (continued)

PVDD_X = 30 V, GVDD_X = 12 V, VDD = 12 V, T_C (Case temperature) = 75°C, f_S = 600 kHz, unless otherwise specified.

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
STATIC DIGITAL SPECIFICATIONS						
V _{IH}	High level input voltage	M1, M2, OSC_IOP, OSC_IOM, RESET	1.9		0.8	V
V _{IL}	Low level input voltage					V
I _{ikg}	Input leakage current				100	μA
OTW/SHUTDOWN (FAULT)						
R _{INT_PU}	Internal pullup resistance, $\overline{\text{CLIP_OTW}}$ to DVDD, $\overline{\text{FAULT}}$ to DVDD		20	26	32	kΩ
V _{OH}	High level output voltage	Internal pullup resistor	3	3.3	3.6	V
V _{OL}	Low level output voltage	I _O = 4 mA		200	500	mV
Device fanout	$\overline{\text{CLIP_OTW}}$, $\overline{\text{FAULT}}$	No external pullup		30		devices

7.6 Audio Characteristics (BTL)

PCB and system configuration are in accordance with recommended guidelines. Audio frequency = 1 kHz, PVDD_X = 30 V, GVDD_X = 12 V, R_L = 4 Ω, f_S = 600 kHz, R_{OC} = 22 kΩ, T_C = 75°C, Output Filter: L_{DEM} = 10 μH, C_{DEM} = 1 μF, mode = 00, AES17 + AUX-0025 measurement filters, unless otherwise noted.

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
P _O	Power output per channel	R _L = 3 Ω, 10% THD+N		145		W
		R _L = 4 Ω, 10% THD+N		115		
		R _L = 3 Ω, 1% THD+N		115		
		R _L = 4 Ω, 1% THD+N		95		
THD+N	Total harmonic distortion + noise	1 W		0.005%		
V _n	Output integrated noise	A-weighted, AES17 filter, Input Capacitor Grounded		50		μV
V _{OS}	Output offset voltage	Inputs AC coupled to GND		20	60	mV
SNR	Signal-to-noise ratio ⁽¹⁾			112		dB
DNR	Dynamic range			113		dB
P _{idle}	Power dissipation due to Idle losses (I _{PVDD_X})	P _O = 0, 4 channels switching ⁽²⁾		0.45		W

(1) SNR is calculated relative to 1% THD+N output level.

(2) Actual system idle losses also are affected by core losses of output inductors.

7.7 Audio Characteristics (SE)

PCB and system configuration are in accordance with recommended guidelines. Audio frequency = 1 kHz, PVDD_X = 30 V, GVDD_X = 12 V, $R_L = 2\ \Omega$, $f_s = 600\ \text{kHz}$, $R_{OC} = 22\ \text{k}\Omega$, $T_C = 75^\circ\text{C}$, Output Filter: $L_{DEM} = 15\ \mu\text{H}$, $C_{DEM} = 680\ \text{nF}$, MODE = 11, AES17 + AUX-0025 measurement filters, unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
P_O Power output per channel	$R_L = 2\ \Omega$, 10% THD+N		55		W
	$R_L = 3\ \Omega$, 10% THD+N		39		
	$R_L = 4\ \Omega$, 10% THD+N		30		
	$R_L = 2\ \Omega$, 1% THD+N		44		
	$R_L = 3\ \Omega$, 1% THD+N		32		
	$R_L = 4\ \Omega$, 1% THD+N		25		
THD+N Total harmonic distortion + noise	1 W		0.01%		
V_n Output integrated noise	A-weighted, AES17 filter, Input Capacitor Grounded		100		μV
SNR Signal to noise ratio ⁽¹⁾	A-weighted		106		dB
DNR Dynamic range	A-weighted		101		dB
P_{idle} Power dissipation due to idle losses (IPVDD_X)	$P_O = 0$, 4 channels switching ⁽²⁾		0.45		W

(1) SNR is calculated relative to 1% THD+N output level.

(2) Actual system idle losses are affected by core losses of output inductors.

7.8 Audio Characteristics (PBTl)

PCB and system configuration are in accordance with recommended guidelines. Audio frequency = 1 kHz, PVDD_X = 30 V, GVDD_X = 12 V, $R_L = 2\ \Omega$, $f_s = 600\ \text{kHz}$, $R_{OC} = 22\ \text{k}\Omega$, $T_C = 75^\circ\text{C}$, Output Filter: $L_{DEM} = 10\ \mu\text{H}$, $C_{DEM} = 1\ \mu\text{F}$, MODE = 10, outputs paralleled before LC filter, AES17 + AUX-0025 measurement filters, unless otherwise noted.

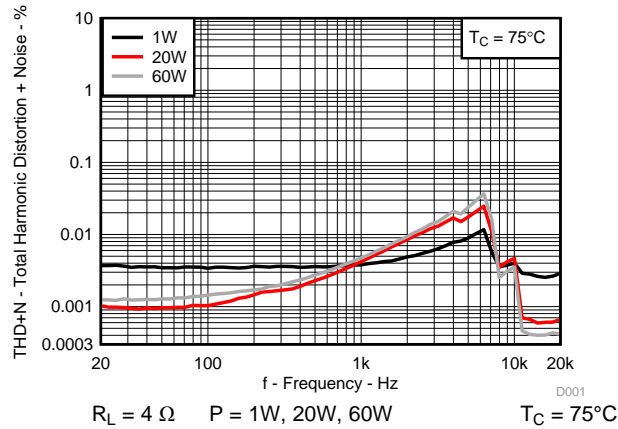
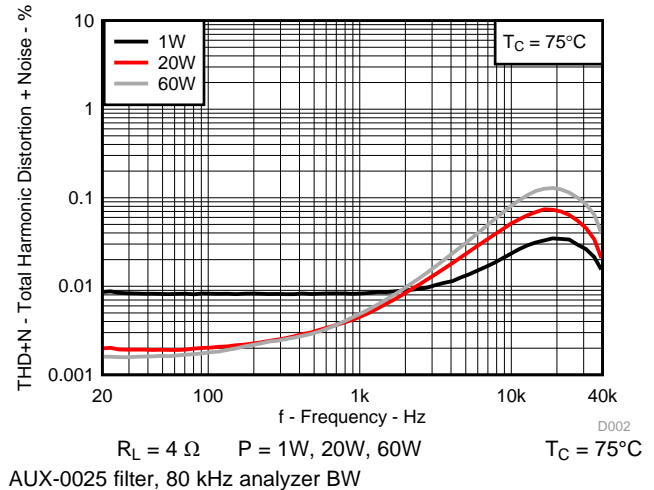
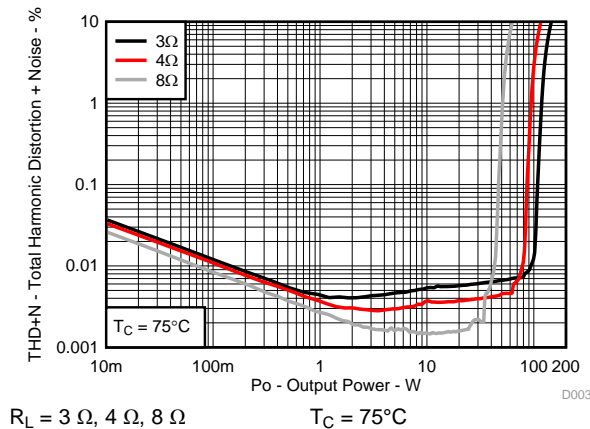
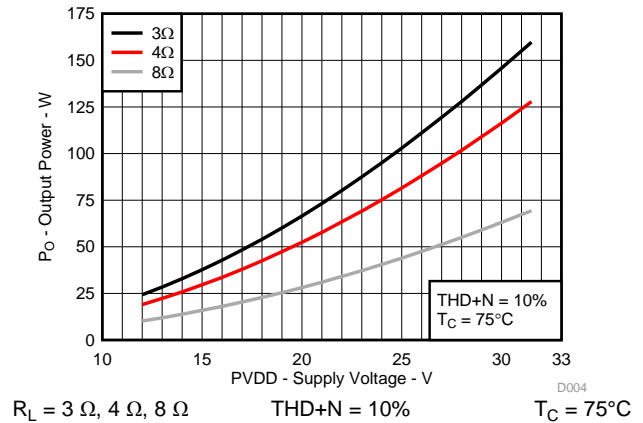
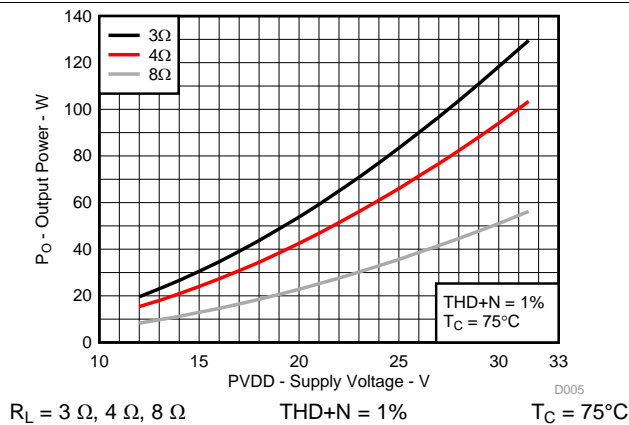
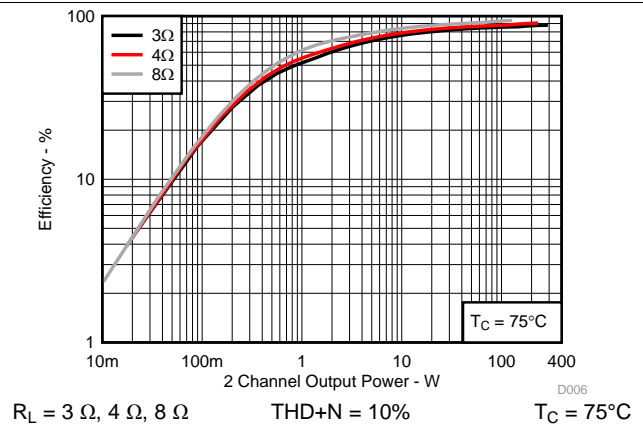
PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
P_O Power output per channel	$R_L = 2\ \Omega$, 10% THD+N		230		W
	$R_L = 3\ \Omega$, 10% THD+N		160		
	$R_L = 4\ \Omega$, 10% THD+N		125		
	$R_L = 2\ \Omega$, 1% THD+N		185		
	$R_L = 3\ \Omega$, 1% THD+N		130		
	$R_L = 4\ \Omega$, 1% THD+N		100		
THD+N Total harmonic distortion + noise	1 W		0.005%		
V_n Output integrated noise	A-weighted, AES17 filter, Input Capacitor Grounded		45		μV
SNR Signal to noise ratio ⁽¹⁾	A-weighted		113		dB
DNR Dynamic range	A-weighted		113		dB
P_{idle} Power dissipation due to idle losses (IPVDD_X)	$P_O = 0$, 4 channels switching ⁽²⁾		0.45		W

(1) SNR is calculated relative to 1% THD+N output level.

(2) Actual system idle losses are affected by core losses of output inductors.

7.9 Typical Characteristics, BTL Configuration

All Measurements taken at audio frequency = 1 kHz, PVDD_X = 30 V, GVDD_X = 12 V, $R_L = 4\ \Omega$, $f_s = 600\text{ kHz}$, $R_{OC} = 22\text{ k}\Omega$, $T_C = 75^\circ\text{C}$, Output Filter: $L_{DEM} = 10\ \mu\text{H}$, $C_{DEM} = 1\ \mu\text{F}$, mode = 00, AES17 + AUX-0025 measurement filters, unless otherwise noted.


Figure 1. Total Harmonic Distortion+Noise vs Frequency

Figure 2. Total Harmonic Distortion+Noise vs Frequency

Figure 3. Total Harmonic Distortion + Noise vs Output Power

Figure 4. Output Power vs Supply Voltage

Figure 5. Output Power vs Supply Voltage

Figure 6. System Efficiency vs Output Power

Typical Characteristics, BTL Configuration (continued)

All Measurements taken at audio frequency = 1 kHz, PVDD_X = 30 V, GVDD_X = 12 V, $R_L = 4\ \Omega$, $f_s = 600\ \text{kHz}$, $R_{OC} = 22\ \text{k}\Omega$, $T_C = 75^\circ\text{C}$, Output Filter: $L_{DEM} = 10\ \mu\text{H}$, $C_{DEM} = 1\ \mu\text{F}$, mode = 00, AES17 + AUX-0025 measurement filters, unless otherwise noted.

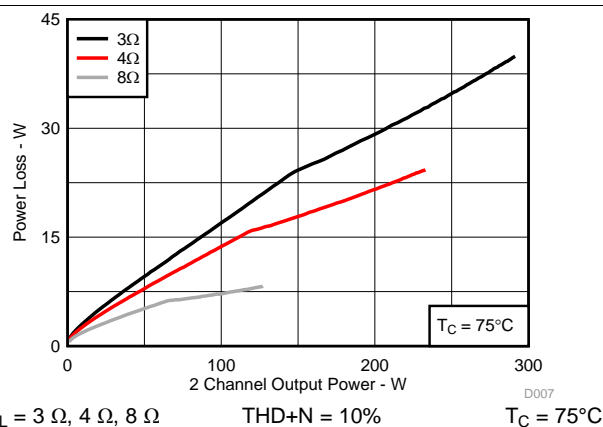


Figure 7. System Power Loss vs Output Power

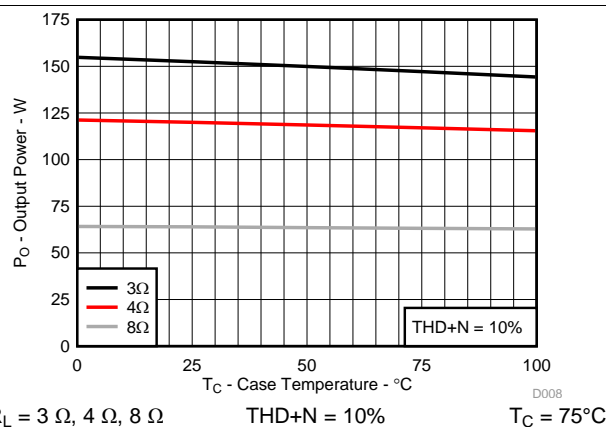


Figure 8. Output Power vs Case Temperature

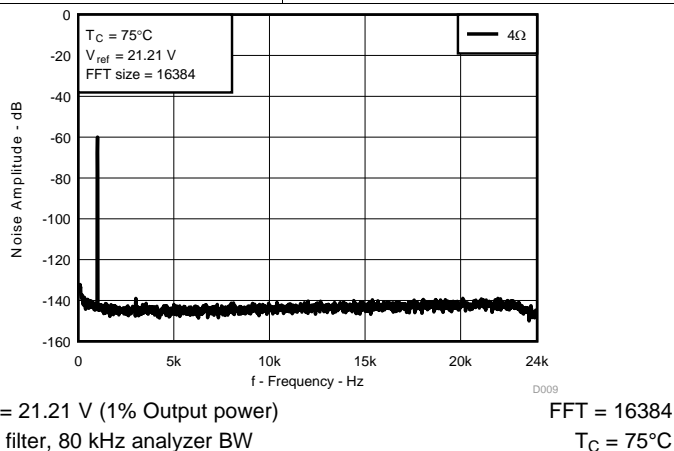
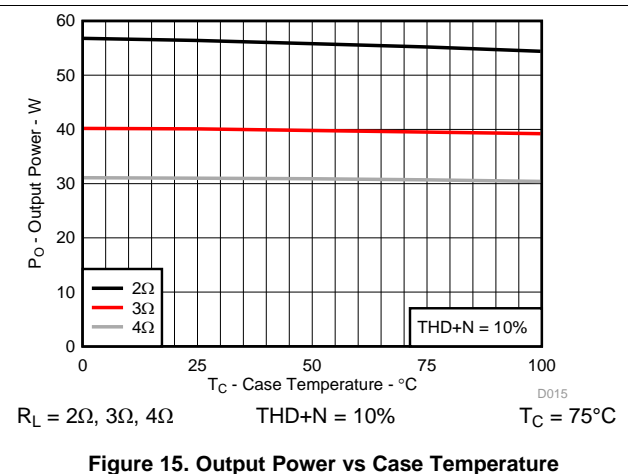
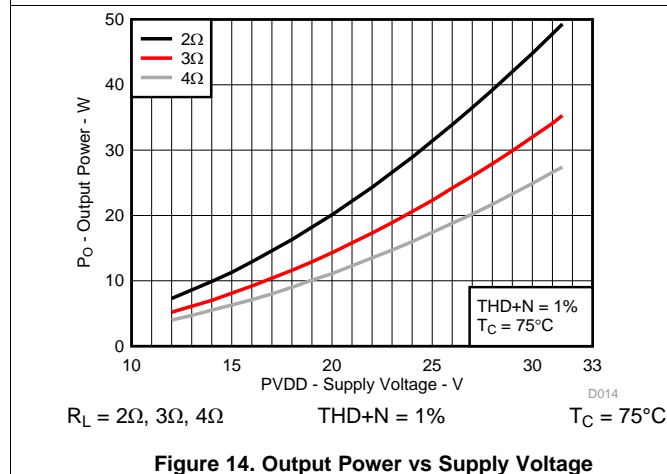
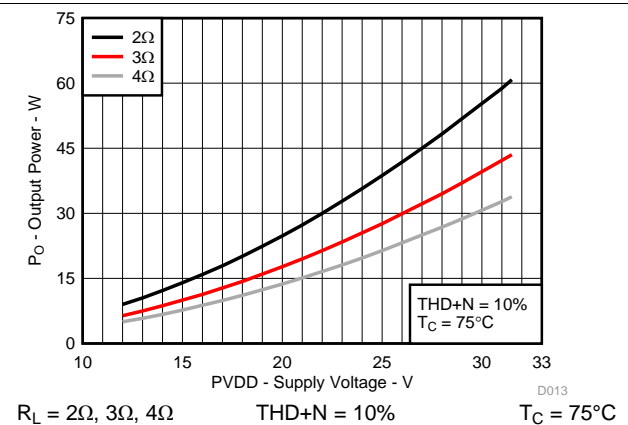
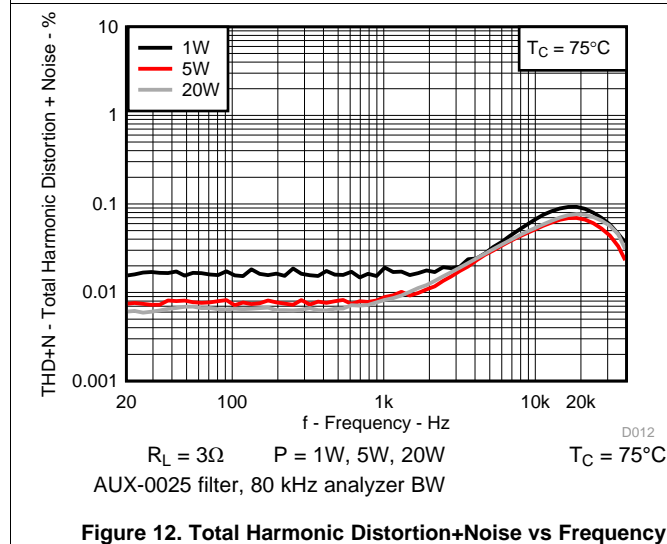
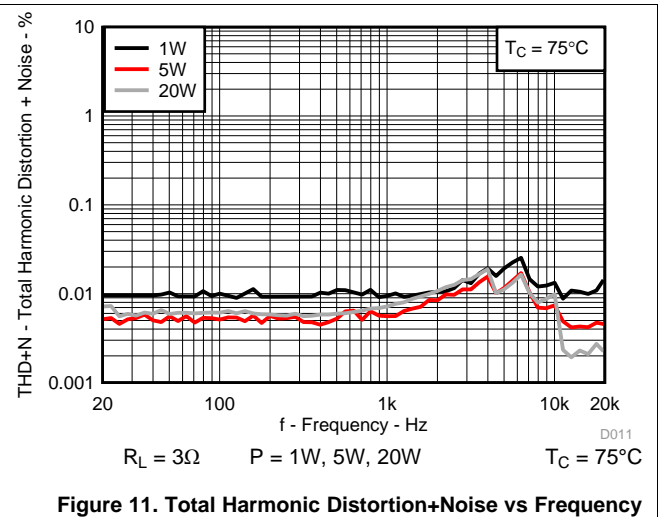
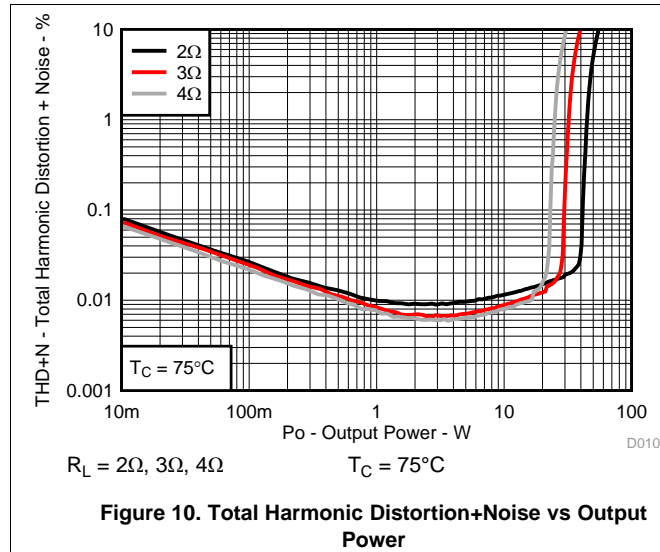


Figure 9. Noise Amplitude vs Frequency

7.10 Typical Characteristics, SE Configuration

All Measurements taken at audio frequency = 1 kHz, PVDD_X = 30 V, GVDD_X = 12 V, $R_L = 3\ \Omega$, $f_s = 600\ \text{kHz}$, $R_{OC} = 22\ \text{k}\Omega$, $T_C = 75^\circ\text{C}$, Output Filter: $L_{DEM} = 15\ \mu\text{H}$, $C_{DEM} = 680\ \text{nF}$, MODE = 11, AES17 + AUX-0025 measurement filters, unless otherwise noted.



7.11 Typical Characteristics, PBTL Configuration

All Measurements taken at audio frequency = 1kHz, PVDD_X = 30

V, GVDD_X = 12V, $R_L = 2\Omega$, $f_s = 600$ kHz, $R_{OC} = 22k\Omega$, $T_C = 75^\circ\text{C}$, Output Filter: $L_{DEM} = 10\mu\text{H}$, $C_{DEM} = 1\mu\text{F}$, MODE = 10, outputs paralleled before LC filter, AES17 + AUX-0025 measurement filters, unless otherwise noted.

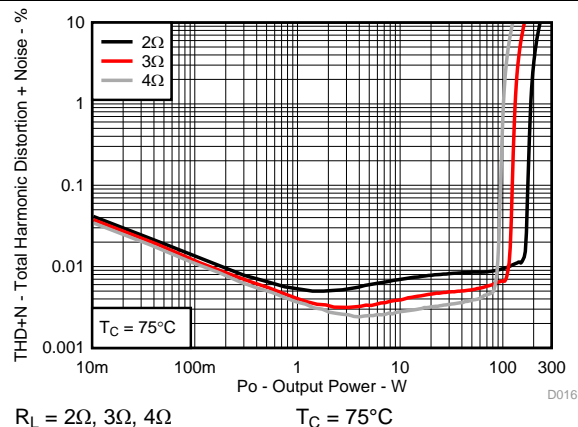


Figure 16. Total Harmonic Distortion+Noise vs Output Power

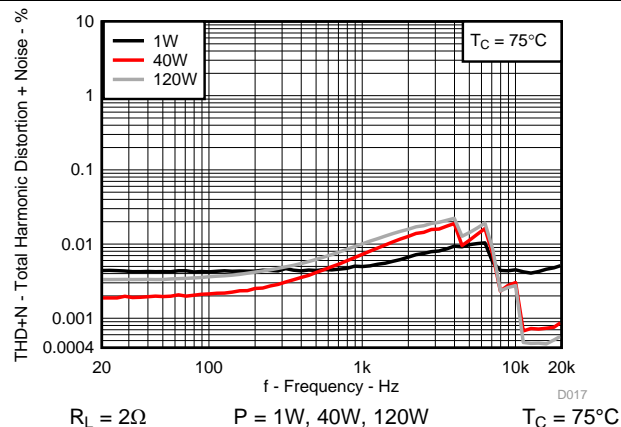


Figure 17. Total Harmonic Distortion+Noise vs Frequency

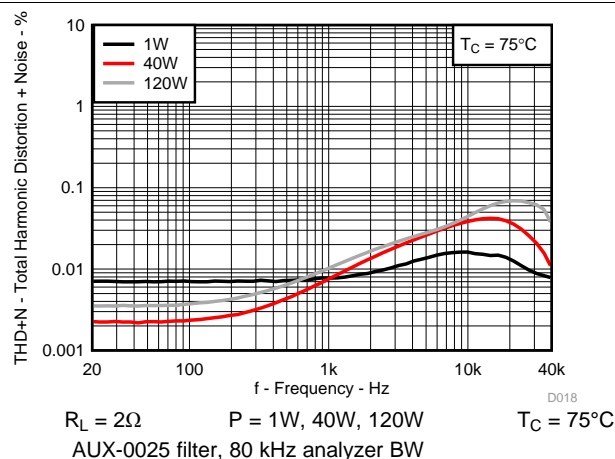


Figure 18. Total Harmonic Distortion+Noise vs Frequency

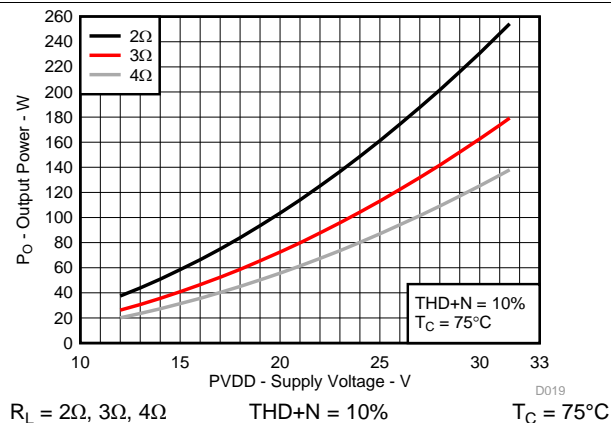


Figure 19. Output Power vs Supply Voltage

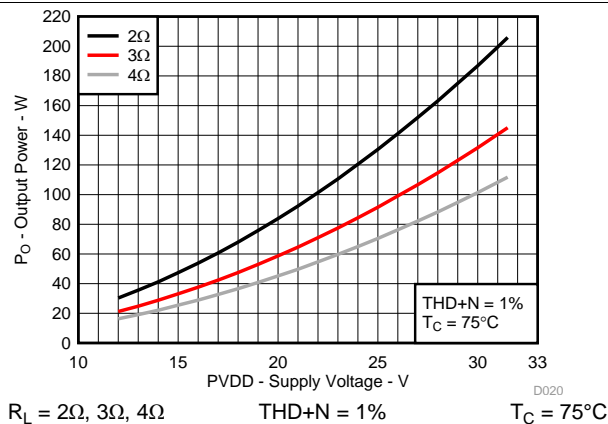


Figure 20. Output Power vs Supply Voltage

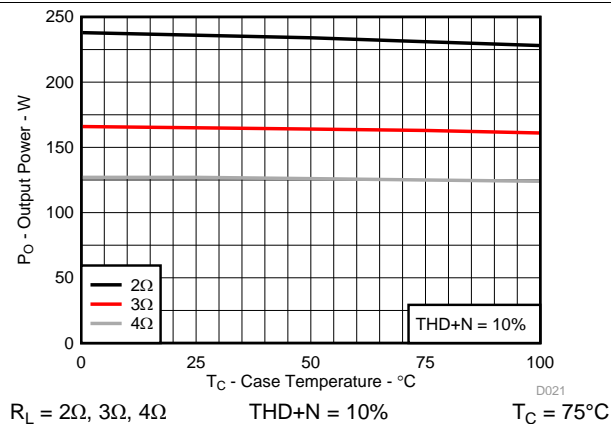


Figure 21. Output Power vs Case Temperature

8 Parameter Measurement Information

All parameters are measured according to the conditions described in the [Recommended Operating Conditions](#) and [Typical Characteristics, BTL Configuration](#) sections.

Most audio analyzers will not give correct readings of Class-D amplifiers' performance due to their sensitivity to out of band noise present at the amplifier output. AES-17 + AUX-0025 pre-analyzer filters are recommended to use for Class-D amplifier measurements. In absence of such filters, a 30-kHz low-pass filter ($10\ \Omega + 47\ \text{nF}$) can be used to reduce the out of band noise remaining on the amplifier outputs.

9 Detailed Description

9.1 Overview

To facilitate system design, the TPA3245 needs only a 12-V supply in addition to the (typical) 30-V power-stage supply. An internal voltage regulator provides suitable voltage levels for the digital and low-voltage analog circuitry, AVDD and DVDD. Additionally, all circuitry requiring a floating voltage supply, that is, the high-side gate drive, is accommodated by built-in bootstrap circuitry requiring only an external capacitor for each half-bridge.

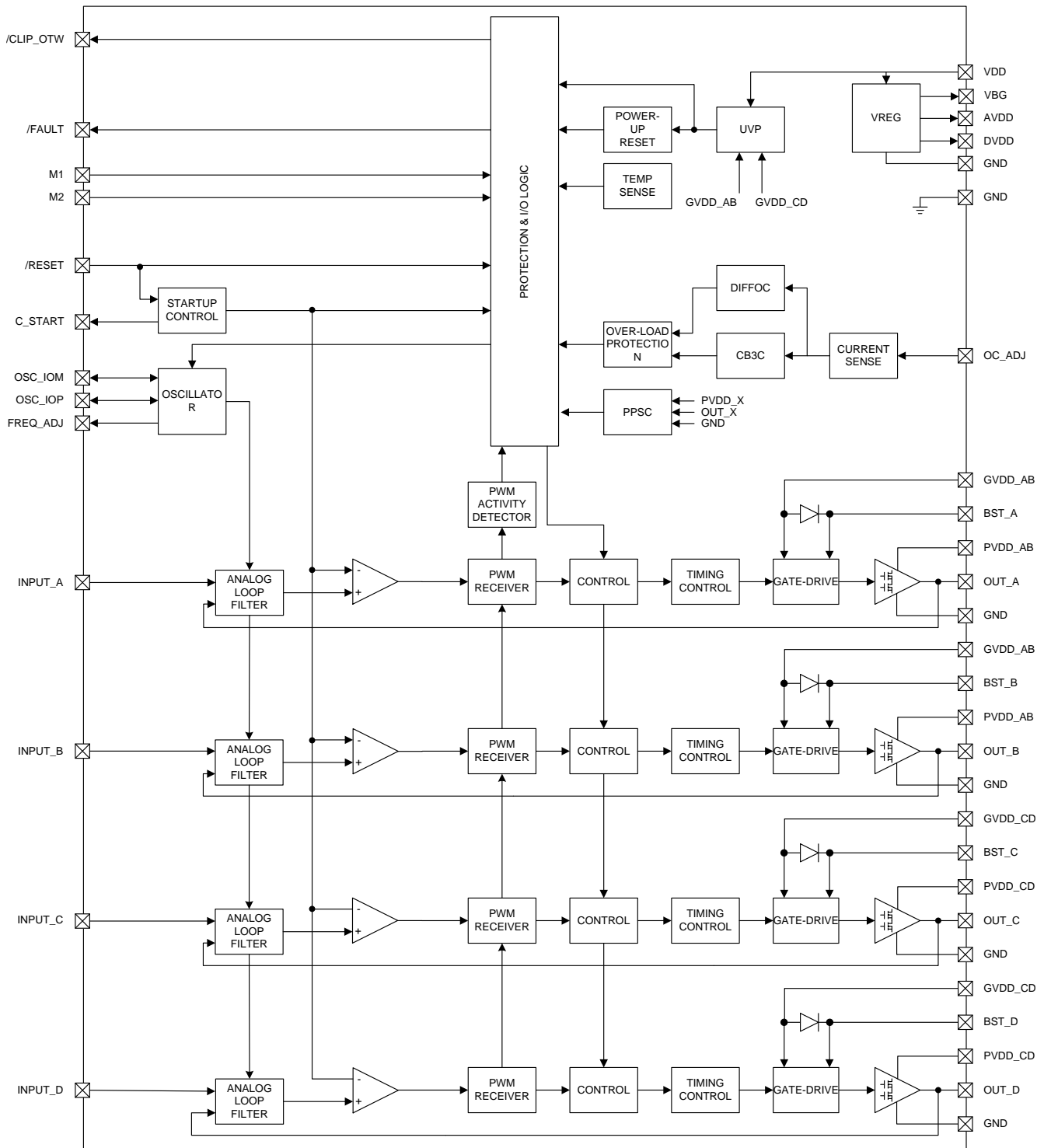
The audio signal path including gate drive and output stage is designed as identical, independent half-bridges. For this reason, each half-bridge has separate bootstrap pins (BST_X). Power-stage supply pins (PVDD_X) and gate drive supply pins (GVDD_X) are separate for each full bridge. Although supplied from the same 12-V source, separating to GVDD_AB, GVDD_CD, and VDD on the printed-circuit board (PCB) by RC filters (see application diagram for details) is recommended. These RC filters provide the recommended high-frequency isolation. Special attention should be paid to placing all decoupling capacitors as close to their associated pins as possible. In general, the physical loop with the power supply pins, decoupling capacitors and GND return path to the device pins must be kept as short as possible and with as little area as possible to minimize induction (see reference board documentation for additional information).

For a properly functioning bootstrap circuit, a small ceramic capacitor must be connected from each bootstrap pin (BST_X) to the power-stage output pin (OUT_X). When the power-stage output is low, the bootstrap capacitor is charged through an internal diode connected between the gate-drive power-supply pin (GVDD_X) and the bootstrap pins. When the power-stage output is high, the bootstrap capacitor potential is shifted above the output potential and thus provides a suitable voltage supply for the high-side gate driver. It is recommended to use 33-nF ceramic capacitors, size 0603 or 0805, for the bootstrap supply. These 33nF capacitors ensure sufficient energy storage, even during minimal PWM duty cycles, to keep the high-side power stage FET (LDMOS) fully turned on during the remaining part of the PWM cycle.

Special attention should be paid to the power-stage power supply; this includes component selection, PCB placement, and routing. As indicated, each full-bridge has independent power-stage supply pins (PVDD_X). For optimal electrical performance, EMI compliance, and system reliability, it is important that each PVDD_X node is decoupled with 1- μF ceramic capacitor placed as close as possible to the supply pins. It is recommended to follow the PCB layout of the TPA3245 reference design. For additional information on recommended power supply and required components, see the application diagrams in this data sheet.

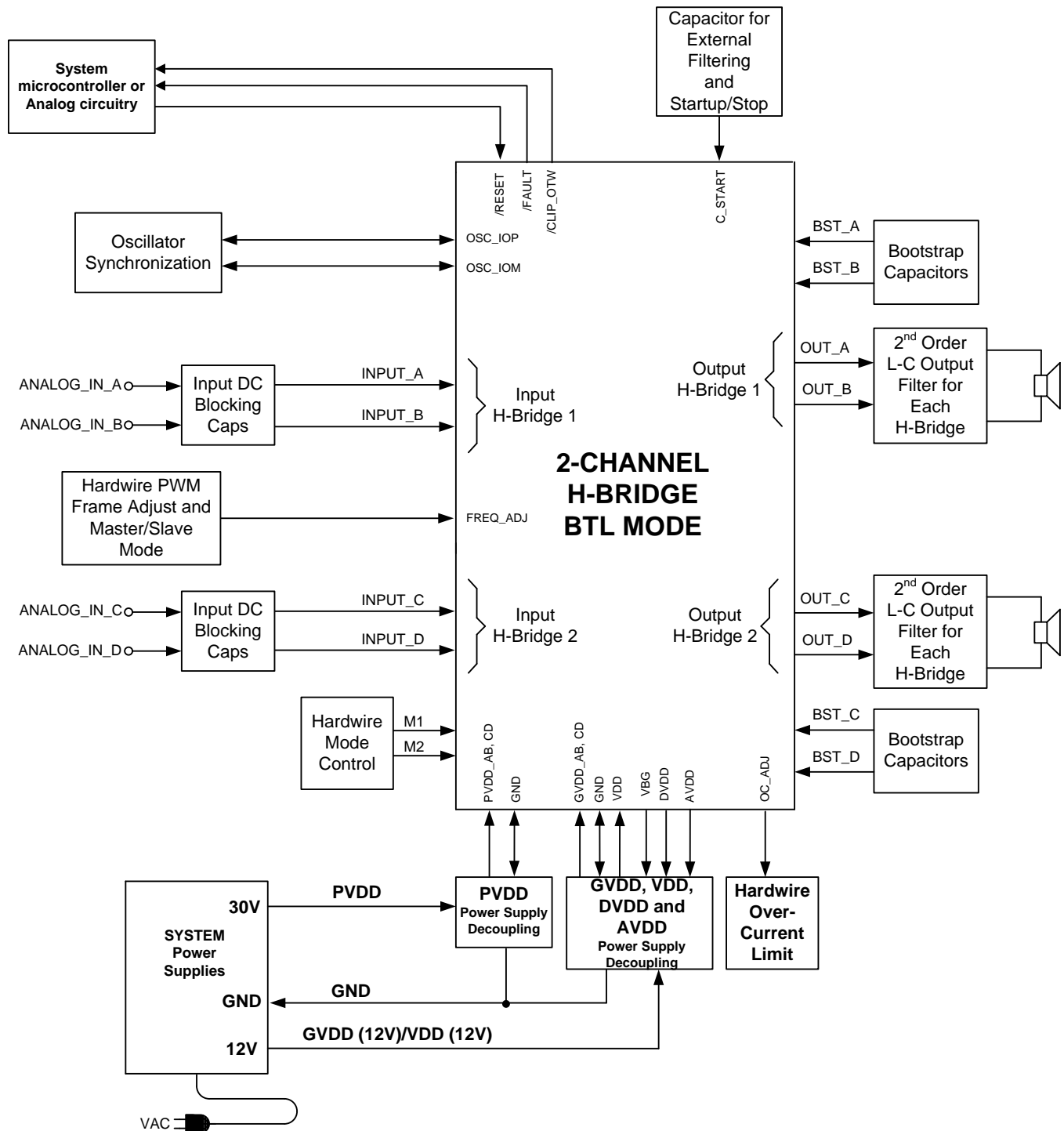
The 12-V supply should be from a low-noise, low-output-impedance voltage regulator. Likewise, the 30-V power-stage supply is assumed to have low output impedance and low noise. The power-supply sequence is not critical as facilitated by the internal power-on-reset circuit, but it is recommended to release RESET after the power supply is settled for minimum turn on audible artefacts. Moreover, the TPA3245 is fully protected against erroneous power-stage turn on due to parasitic gate charging. Thus, voltage-supply ramp rates (dV/dt) are non-critical within the specified range (see the [Recommended Operating Conditions](#) table of this data sheet).

9.2 Functional Block Diagrams



Copyright © 2016, Texas Instruments Incorporated

Functional Block Diagrams (continued)



*NOTE1: Logic AND in or outside microcontroller

Copyright © 2016, Texas Instruments Incorporated

Figure 22. System Block Diagram

9.3 Feature Description

9.3.1 Error Reporting

The $\overline{\text{FAULT}}$, and $\overline{\text{CLIP_OTW}}$, pins are active-low, open-drain outputs. The function is for protection-mode signaling to a system-control device.

Any fault resulting in device shutdown is signaled by the $\overline{\text{FAULT}}$ pin going low. Also, $\overline{\text{CLIP_OTW}}$ goes low when the device junction temperature exceeds 125°C (see [Table 2](#)).

Table 2. Error Reporting

$\overline{\text{FAULT}}$	$\overline{\text{CLIP_OTW}}$	DESCRIPTION
0	0	Overtemperature (OTE) or overload (OLP) or undervoltage (UVP) Junction temperature higher than 125°C (overtemperature warning)
0	0	Overload (OLP) or undervoltage (UVP). Junction temperature higher than 125°C (overtemperature warning)
0	1	Overload (OLP) or undervoltage (UVP). Junction temperature lower than 125°C
1	0	Junction temperature higher than 125°C (overtemperature warning)
1	1	Junction temperature lower than 125°C and no OLP or UVP faults (normal operation)

Note that asserting $\overline{\text{RESET}}$ low forces the $\overline{\text{FAULT}}$ signal high, independent of faults being present. TI recommends monitoring the $\overline{\text{CLIP_OTW}}$ signal using the system microcontroller and responding to an overtemperature warning signal by turning down the volume to prevent further heating of the device resulting in device shutdown (OTE).

To reduce external component count, an internal pullup resistor to 3.3 V is provided on both $\overline{\text{FAULT}}$ and $\overline{\text{CLIP_OTW}}$ outputs.

9.4 Device Protection System

The TPA3245 contains advanced protection circuitry carefully designed to facilitate system integration and ease of use, as well as to safeguard the device from permanent failure due to a wide range of fault conditions such as short circuits, overload, overtemperature, and undervoltage. The TPA3245 responds to a fault by immediately setting the power stage in a high-impedance (Hi-Z) state and asserting the $\overline{\text{FAULT}}$ pin low. In situations other than overload and overtemperature error (OTE), the device automatically recovers when the fault condition has been removed, that is, the supply voltage has increased.

The device will handle errors, as shown in [Table 3](#).

Table 3. Device Protection

BTL MODE		PBTL MODE		SE MODE	
LOCAL ERROR IN	TURNS OFF	LOCAL ERROR IN	TURNS OFF	LOCAL ERROR IN	TURNS OFF
A	A+B	A	A+B+C+D	A	A+B
B		B		B	
C	C+D	C		C	C+D
D		D		D	

Bootstrap UVP does not shutdown according to the table, it shuts down the respective halfbridge (non-latching, does not assert $\overline{\text{FAULT}}$).

9.4.1 Overload and Short Circuit Current Protection

TPA3245 has fast reacting current sensors with a programmable trip threshold (OC threshold) on all high-side and low-side FETs. To prevent output current from increasing beyond the programmed threshold, TPA3245 has the option of either limiting the output current for each switching cycle (Cycle By Cycle Current Control, CB3C) or to perform an immediate shutdown of the output in case of excess output current (Latching Shutdown). CB3C prevents premature shutdown due to high output current transients caused by high level music transients and a drop of real speaker's load impedance, and allows the output current to be limited to a maximum programmed

level. If the maximum output current persists, i.e. the power stage being overloaded with too low load impedance, the device will shut down the affected output channel and the affected output is put in a high-impedance (Hi- Z) state until a RESET cycle is initiated. CB3C works individually for each half bridge output. If an over current event is triggered, CB3C performs a state flip of the half bridge output that is cleared upon beginning of next PWM frame.

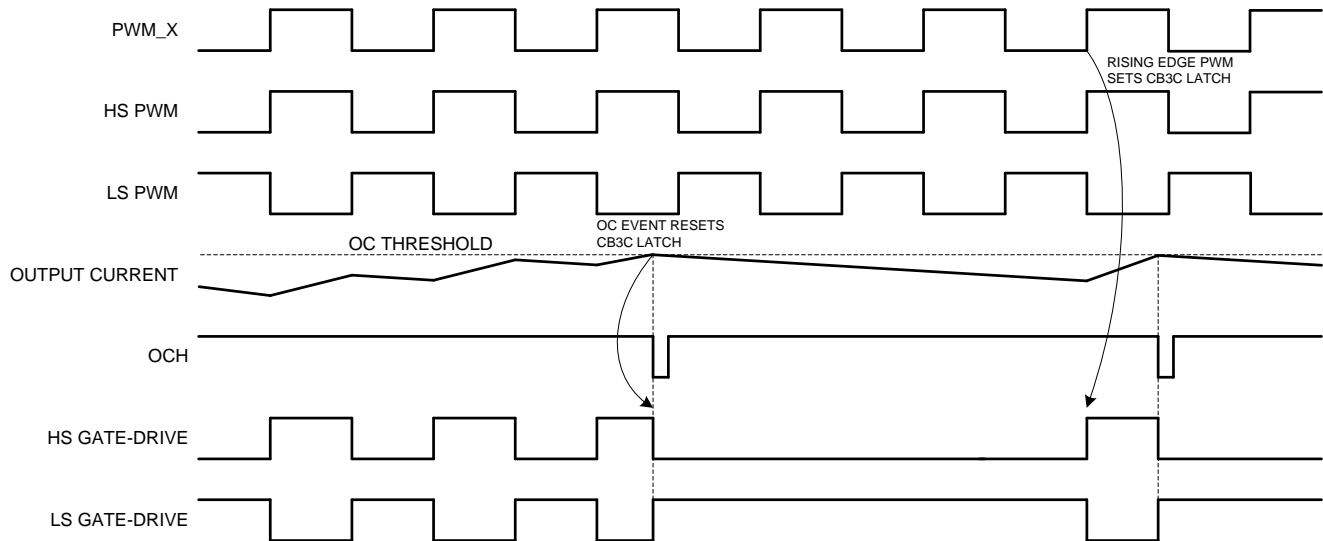


Figure 23. CB3C Timing Example

During CB3C an over load counter increments for each over current event and decrease for each non-over current PWM cycle. This allows full amplitude transients into a low speaker impedance without a shutdown protection action. In the event of a short circuit condition, the over current protection limits the output current by the CB3C operation and eventually shut down the affected output if the overload counter reaches its maximum value. If a latched OC operation is required such that the device shuts down the affected output immediately upon first detected over current event, this protection mode should be selected. The over current threshold and mode (CB3C or Latched OC) is programmed by the OC_ADJ resistor value. The OC_ADJ resistor needs to be within its intentional value range for either CB3C operation or Latched OC operation.

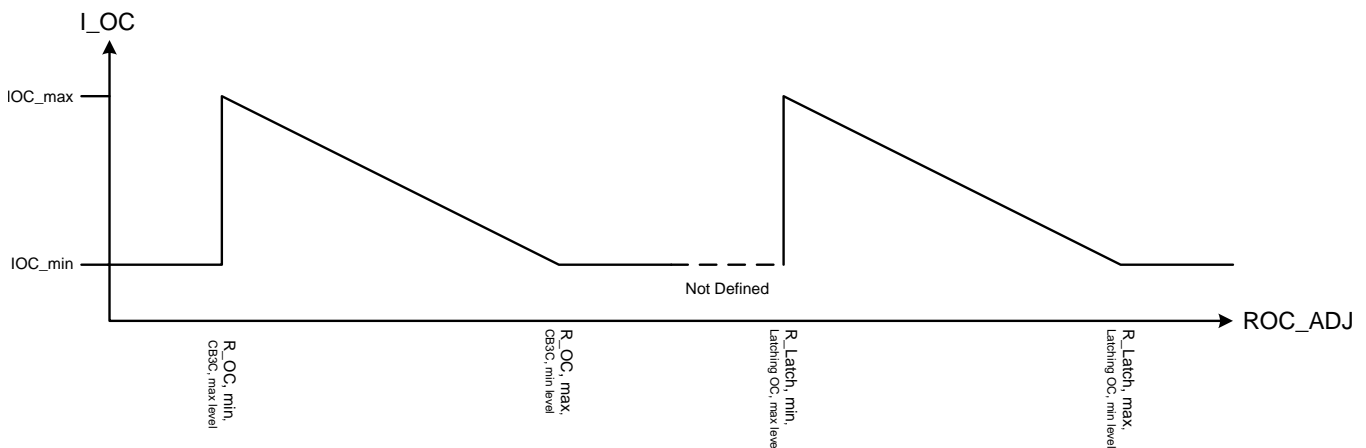


Figure 24. OC Threshold versus OC ADJ Resistor Value Example

OC_ADJ values outside specified value range for either CB3C or latched OC operation will result in minimum OC threshold.

Table 4. Device Protection

OC_ADJ Resistor Value	Protection Mode	OC Threshold
22k Ω	CB3C	13.5A
24k Ω	CB3C	12.5A
27k Ω	CB3C	11.3A
30k Ω	CB3C	10.3A
47k Ω	Latched OC	13.5A
51k Ω	Latched OC	12.5A
56k Ω	Latched OC	11.3A
64k Ω	Latched OC	10.3A

9.4.2 Signal Clipping and Pulse Injector

A built in activity detector monitors the PWM activity of the OUT_X pins. TPA3245 is designed to drive unclipped output signals all the way to PVDD and GND rails. In case of audio signal clipping when applying excessive input signal voltage, or in case of CB3C current protection being active, the amplifier feedback loop of the audio channel will respond to this condition with a saturated state, and the output PWM signals will stop unless special circuitry is implemented to handle this situation. To prevent the output PWM signals from stopping in a clipping or CB3C situation, narrow pulses are injected to the gate drive to maintain output activity. The injected narrow pulses are injected at every 4th PWM frame, and thus the effective switching frequency during this state is reduced to 1/4 of the normal switching frequency.

Signal clipping is signalled on the CLIP_OTW pin and is self clearing when signal level reduces and the device reverts to normal operation. The CLIP_OTW pulses starts at the onset to output clipping, typically at a THD level around 0.01%, resulting in narrow CLIP_OTW pulses starting with a pulse width of ~500ns.

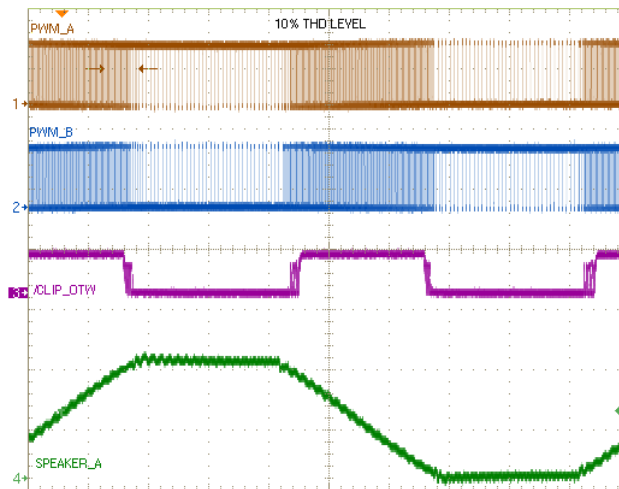


Figure 25. Signal Clipping PWM and Speaker Output Signals

9.4.3 DC Speaker Protection

The output DC protection scheme protects a speaker from excess DC current in case one terminal of the speaker is connected to the amplifier while the other is accidentally shorted to the chassis ground. Such a short circuit results in a DC voltage of PVDD/2 across the speaker, which potentially can result in destructive current levels. The output DC protection detects any unbalance of the output and input current of a BTL output, and in the event of the unbalance exceeding a programmed threshold, the overload counter increments until its maximum value and the affected output channel is shut down. DC Speaker Protection is disabled in PBTL and SE mode operation.

9.4.4 Pin-to-Pin Short Circuit Protection (PPSC)

The PPSC detection system protects the device from permanent damage in the case that a power output pin (OUT_X) is shorted to GND_X or PVDD_X. For comparison, the OC protection system detects an overcurrent after the demodulation filter where PPSC detects shorts directly at the pin before the filter. PPSC detection is performed at startup i.e. when VDD is supplied, consequently a short to either GND_X or PVDD_X after system startup does not activate the PPSC detection system. When PPSC detection is activated by a short on the output, all half bridges are kept in a Hi-Z state until the short is removed; the device then continues the startup sequence and starts switching. The detection is controlled globally by a two step sequence. The first step ensures that there are no shorts from OUT_X to GND_X, the second step tests that there are no shorts from OUT_X to PVDD_X. The total duration of this process is roughly proportional to the capacitance of the output LC filter. The typical duration is $< 15 \text{ ms}/\mu\text{F}$. While the PPSC detection is in progress, $\overline{\text{FAULT}}$ is kept low, and the device will not react to changes applied to the $\overline{\text{RESET}}$ pin. If no shorts are present the PPSC detection passes, and $\overline{\text{FAULT}}$ is released. A device reset will not start a new PPSC detection. PPSC detection is enabled in BTL and PBTl output configurations, the detection is not performed in SE mode. To make sure not to trip the PPSC detection system it is recommended not to insert a resistive load to GND_X or PVDD_X.

9.4.5 Overtemperature Protection OTW and OTE

TPA3245 has a two-level temperature-protection system that asserts an active-low warning signal ($\overline{\text{CLIP_OTW}}$) when the device junction temperature exceeds 125°C (typical) and, if the device junction temperature exceeds 155°C (typical), the device is put into thermal shutdown, resulting in all half-bridge outputs being set in the high-impedance (Hi-Z) state and $\overline{\text{FAULT}}$ being asserted low. OTE is latched in this case. To clear the OTE latch, $\overline{\text{RESET}}$ must be asserted. Thereafter, the device resumes normal operation.

9.4.6 Undervoltage Protection (UVP) and Power-on Reset (POR)

The UVP and POR circuits of the TPA3255 fully protect the device in any power-up/down and brownout situation. While powering up, the POR circuit ensures that all circuits are fully operational when the GVDD_X and VDD supply voltages reach values stated in the [Electrical Characteristics](#) table. Although GVDD_X and VDD are independently monitored, a supply voltage drop below the UVP threshold on any VDD or GVDD_X pin results in all half-bridge outputs immediately being set in the high-impedance (Hi-Z) state and $\overline{\text{FAULT}}$ being asserted low. The device automatically resumes operation when all supply voltages have increased above the UVP threshold.

9.4.7 Fault Handling

If a fault situation occurs while in operation, the device acts accordingly to the fault being a global or a channel fault. A global fault is a chip-wide fault situation and causes all PWM activity of the device to be shut down, and will assert $\overline{\text{FAULT}}$ low. A global fault is a latching fault and clearing $\overline{\text{FAULT}}$ and restarting operation requires resetting the device by toggling $\overline{\text{RESET}}$. Deasserting $\overline{\text{RESET}}$ should never be allowed with excessive system temperature, so it is advised to monitor $\overline{\text{RESET}}$ by a system microcontroller and only allow releasing $\overline{\text{RESET}}$ ($\overline{\text{RESET}}$ high) if the $\overline{\text{CLIP_OTW}}$ signal is cleared (high). A channel fault results in shutdown of the PWM activity of the affected channel(s). Note that asserting $\overline{\text{RESET}}$ low forces the $\overline{\text{FAULT}}$ signal high, independent of faults being present.

Table 5. Error Reporting

Fault/Event	Fault/Event Description	Global or Channel	Reporting Method	Latched/Self Clearing	Action needed to Clear	Output FETs
PVDD_X UVP	Voltage Fault	Global	$\overline{\text{FAULT}}$ pin	Self Clearing	Increase affected supply voltage	HI-Z
VDD UVP						
AVDD UVP						
POR (DVDD UVP)	Power On Reset	Global	$\overline{\text{FAULT}}$ pin	Self Clearing	Allow DVDD to rise	HI-Z
BST_X UVP	Voltage Fault	Channel (Half Bridge)	None	Self Clearing	Allow BST cap to recharge (lowside ON, VDD 12V)	HighSide off
OTW	Thermal Warning	Global	$\overline{\text{OTW}}$ pin	Self Clearing	Cool below OTW threshold	Normal operation
OTE	Thermal Shutdown	Global	$\overline{\text{FAULT}}$ pin	Latched	Toggle $\overline{\text{RESET}}$	HI-Z
OLP (CB3C>1.7ms)	OC Shutdown	Channel	$\overline{\text{FAULT}}$ pin	Latched	Toggle $\overline{\text{RESET}}$	HI-Z
Latched OC (47k Ω <ROC_ADJ<68 k Ω)	OC Shutdown	Channel	$\overline{\text{FAULT}}$ pin	Latched	Toggle $\overline{\text{RESET}}$	HI-Z
CB3C (22k Ω <ROC_ADJ<30 k Ω)	OC Limiting	Channel	None	Self Clearing	Reduce signal level or remove short	Flip state, cycle by cycle at fs/3
Stuck at Fault ⁽¹⁾	No OSC_IO activity in Slave Mode	Global	None	Self Clearing	Resume OSC_IO activity	HI-Z

(1) Stuck at Fault occurs when input OSC_IO input signal frequency drops below minimum frequency given in the [Electrical Characteristics](#) table of this data sheet.

9.4.8 Device Reset

Asserting $\overline{\text{RESET}}$ low initiates the device ramp down. The output FETs go into a Hi-Z state after the ramp down is complete. Output pull downs are active both in SE mode and BTL mode with $\overline{\text{RESET}}$ low.

In BTL modes, to accommodate bootstrap charging prior to switching start, asserting the reset input low enables weak pulldown of the half-bridge outputs.

Asserting reset input low removes any fault information to be signaled on the $\overline{\text{FAULT}}$ output, that is, $\overline{\text{FAULT}}$ is forced high. A rising-edge transition on reset input allows the device to resume operation after a fault. To ensure thermal reliability, the rising edge of reset must occur no sooner than 4 ms after the falling edge of $\overline{\text{FAULT}}$.

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.

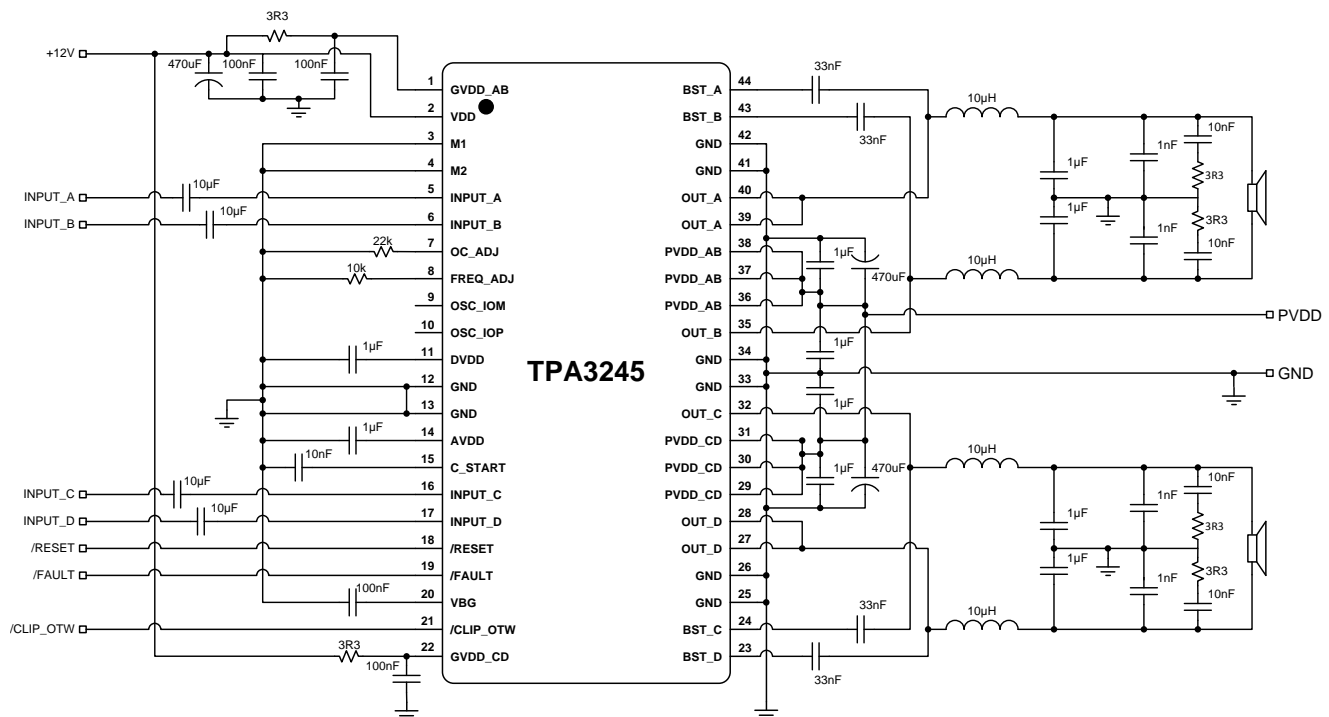
10.1 Application Information

TPA3245 can be configured either in stereo BTL mode, 4 channel SE mode, mono PBTL mode, or in 2.1 mixed 1x BTL + 2x SE mode depending on output power conditions and system design.

10.2 Typical Applications

10.2.1 Stereo BTL Application

This section provides an example for configuring the TPA3245 in bridge-tied load (BTL) mode.



Copyright © 2016, Texas Instruments Incorporated

Figure 26. Typical Differential (2N) BTL Application

Typical Applications (continued)

10.2.1.1 Design Requirements

For this design example, use the parameters in [Table 6](#).

Table 6. Design Requirements, BTL Application

DESIGN PARAMETER	EXAMPLE
Low Power (Pull-up) Supply	3.3 V
Mid Power Supply 12 V	12 V
High Power Supply	12 - 30 V
Mode Selection	M2 = L
	M1 = L
Analog Inputs	INPUT_A = ± 3.9 V (peak, max)
	INPUT_B = ± 3.9 V (peak, max)
	INPUT_C = ± 3.9 V (peak, max)
	INPUT_D = ± 3.9 V (peak, max)
Output Filters	Inductor-Capacitor Low Pass Filter (10 μ H + 1 μ F)
Speaker Impedance	3-8 Ω

10.2.1.2 Detailed Design Procedures

A rising-edge transition on reset input allows the device to execute the startup sequence and starts switching.

The CLIP signal is indicating that the output is approaching clipping. The signal can be used either to decrease audio volume or to control an intelligent power supply nominally operating at a low rail adjusting to a higher supply rail.

The device is inverting the audio signal from input to output.

The DVDD and AVDD pins are not recommended to be used as a voltage sources for external circuitry.

10.2.1.2.1 Decoupling Capacitor Recommendations

In order to design an amplifier that has robust performance, passes regulatory requirements, and exhibits good audio performance, good quality decoupling capacitors should be used. In practice, X7R should be used in this application.

10.2.1.2.2 PVDD Capacitor Recommendation

The PVDD decoupling capacitors must be placed as close to the device pins as possible to insure short trace length and low inductance path. Likewise the ground path for these capacitors must provide a good reference and should be substantial. This will keep voltage ringing on PVDD to a minimum.

The voltage of the decoupling capacitors should be selected in accordance with good design practices. Temperature, ripple current, and voltage overshoot must be considered. This fact is particularly true in the selection of the 1 μ F that is placed on the power supply to each full-bridge. It must withstand the voltage overshoot of the PWM switching, the heat generated by the amplifier during high power output, and the ripple current created by high power output. A minimum voltage rating of 50 V is required for use with a 30V power supply.

The large capacitors used in conjunction with each full-bridge, are referred to as the PVDD Capacitors. These capacitors should be selected for proper voltage margin and adequate capacitance to support the power requirements. In practice, with a well designed system power supply, 1000 μ F, 50 V supports most applications. The PVDD capacitors should be low ESR type because they are used in a circuit associated with high-speed switching.

10.2.1.2.3 PCB Material Recommendation

FR-4 Glass Epoxy material with 2 oz. (70 μ m) copper is recommended for use with the TPA3245. The use of this material can provide for higher power output, improved thermal performance, and better EMI margin (due to lower PCB trace inductance).

10.2.1.2.4 Oscillator

The built in oscillator frequency can be trimmed by an external resistor from the `FREQ_ADJ` pin to GND. Changes in the oscillator frequency should be made with resistor values specified in [Recommended Operating Conditions](#) while `RESET` is low.

To reduce interference problems while using a radio receiver tuned within the AM band, the switching frequency can be changed from nominal to lower or higher values. These values should be chosen such that the nominal and the alternate switching frequencies together result in the fewest cases of interference throughout the AM band. The oscillator frequency can be selected by the value of the `FREQ_ADJ` resistor connected to GND in master mode.

For slave mode operation, turn off the oscillator by pulling the `FREQ_ADJ` pin to DVDD. This configures the `OSC_I/O` pins as inputs to be slaved from an external differential clock. In a master/slave system inter-channel delay is automatically set up between the switching of the audio channels, which can be illustrated by no idle channels switching at the same time. This will not influence the audio output, but only the switch timing to minimize noise coupling between audio channels through the power supply. Inter-channel delay is needed to optimize audio performance and to get better operating conditions for the power supply. The inter-channel delay will be set up for a slave device depending on the polarity of the `OSC_I/O` connection as follows:

- Slave 1 mode has normal polarity (master + to slave + and master - to slave -)
- Slave 2 mode has reverse polarity (master + to slave - and master - to slave +)

The interchannel delay for interleaved channel idle switching is given in the table below for the master/slave and output configuration modes in degrees relative to the PWM frame.

Table 7. Master/Slave Inter Channel Delay Settings

Master	M1 = 0, M2 = 0, 2 x BTL mode	M1 = 1, M2 = 0, 1 x BTL + 2 x SE mode	M1 = 0, M2 = 1, 1 x PBTTL mode	M1 = 1, M2 = 1, 4 x SE mode
OUT_A	0°	0°	0°	0°
OUT_B	180°	180°	180°	60°
OUT_C	60°	60°	0°	0°
OUT_D	240°	120°	180°	60°
Slave 1				
OUT_A	60°	60°	60°	60°
OUT_B	240°	240°	240°	120°
OUT_C	120°	120°	60°	60°
OUT_D	300°	180°	240°	120°
Slave 2				
OUT_A	30°	30°	30°	30°
OUT_B	210°	210°	210°	90°
OUT_C	90°	90°	30°	30°
OUT_D	270°	150°	210°	90°

10.2.2 Application Curves

Relevant performance plots for TPA3245 in BTL configuration are shown in [Typical Characteristics](#), [BTL Configuration](#)

Table 8. Relevant Performance Plots, BTL Configuration

PLOT TITLE	FIGURE NUMBER
Total Harmonic Distortion+Noise vs Frequency	Figure 1
Total Harmonic Distortion+Noise vs Frequency, 80kHz analyzer BW	Figure 2
Total Harmonic Distortion + Noise vs Output Power	Figure 3
Output Power vs Supply Voltage, 10% THD+N	Figure 4
Output Power vs Supply Voltage, 10% THD+N	Figure 6
System Efficiency vs Output Power	Figure 6
System Power Loss vs Output Power	Figure 7
Output Power vs Case Temperature	Figure 8
Noise Amplitude vs Frequency	Figure 9

TPA3245

SLASEC7A – SEPTEMBER 2016 – REVISED OCTOBER 2016

www.ti.com

10.2.3 Typical Application, Single Ended (1N) SE

This section provides an example for configuring the TPA3245 in single-ended output (SE) mode.

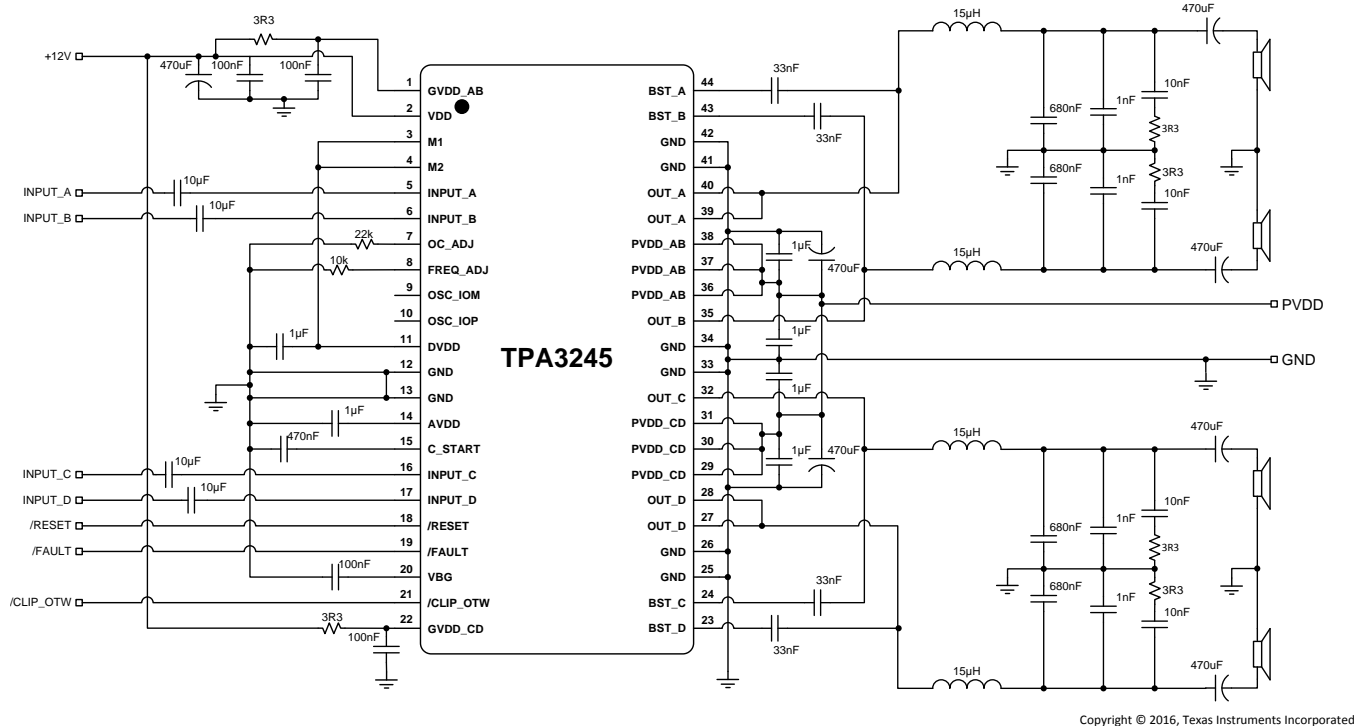


Figure 27. Typical Single Ended (1N) SE Application

10.2.3.1 Design Requirements

Refer to [Stereo BTL Application](#) for the Design Requirements.

Table 9. Design Requirements, SE Application

DESIGN PARAMETER	EXAMPLE
Low Power (Pull-up) Supply	3.3 V
Mid Power Supply 1 2V	12 V
High Power Supply	12 - 30 V
Mode Selection	M2 = H
	M1 = H
Analog Inputs	INPUT_A = ± 3.9 V (peak, max)
	INPUT_B = ± 3.9 V (peak, max)
	INPUT_C = ± 3.9 V (peak, max)
	INPUT_D = ± 3.9 V (peak, max)
Output Filters	Inductor-Capacitor Low Pass Filter (15 μ H + 680 nF)
Speaker Impedance	2 - 8 Ω

10.2.3.2 Detailed Design Procedures

Refer to [Stereo BTL Application](#) for the Detailed Design Procedures.

10.2.3.3 Application Curves

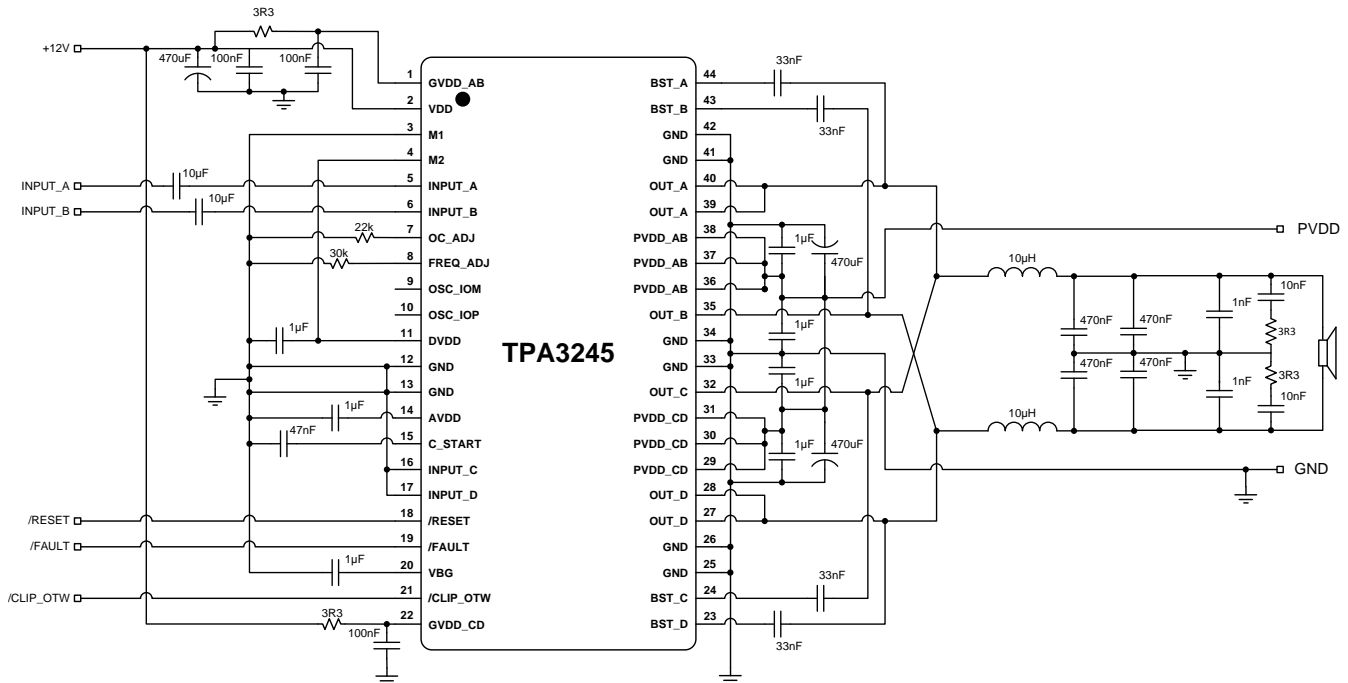
Relevant performance plots for TPA3245 in SE configuration are shown in [Typical Characteristics, SE Configuration](#)

Table 10. Relevant Performance Plots, SE Configuration

PLOT TITLE	FIGURE NUMBER
Total Harmonic Distortion+Noise vs Output Power	Figure 10
Total Harmonic Distortion+Noise vs Frequency	Figure 11
Total Harmonic Distortion+Noise vs Frequency, 80kHz analyzer BW	Figure 12
Output Power vs Supply Voltage, 10% THD+N	Figure 13
Output Power vs Supply Voltage, 1% THD+N	Figure 14
Output Power vs Case Temperature	Figure 15

10.2.4 Typical Application, Differential (2N), PBTL (Outputs Paralleled before LC filter)

TPA3245 can be configured in mono PBTL mode by paralleling the outputs before the LC filter or after the LC filter (see [Typical Application, Differential \(2N\), PBTL \(Outputs Paralleled after LC filter\)](#)). Paralleled outputs before the LC filter is recommended for better performance and limiting the number of output LC filter inductors, only two inductors required. This sections shows an example of paralleled outputs before the LC filter.



Copyright © 2016, Texas Instruments Incorporated

Figure 28. Typical Differential (2N) PBTL (Outputs Paralleled before LC filter) Application

10.2.4.1 Design Requirements

Refer to [Stereo BTL Application](#) for the Design Requirements.

Table 11. Design Requirements, PBTL (Outputs Paralleled before LC filter) Application

DESIGN PARAMETER	EXAMPLE
Low Power (Pull-up) Supply	3.3 V
Mid Power Supply 12 V	12 V
High Power Supply	12 - 30 V
Mode Selection	M2 = H
	M1 = L
Analog Inputs	INPUT_A = ± 3.9 V (peak, max)
	INPUT_B = ± 3.9 V (peak, max)
	INPUT_C = Grounded
	INPUT_D = Grounded
Output Filters	Inductor-Capacitor Low Pass Filter (10 μ H + 1 μ F)
Speaker Impedance	2 - 4 Ω

10.2.4.2 Detailed Design Procedures

Refer to [Stereo BTL Application](#) for the Detailed Design Procedures.

10.2.4.3 Application Curves

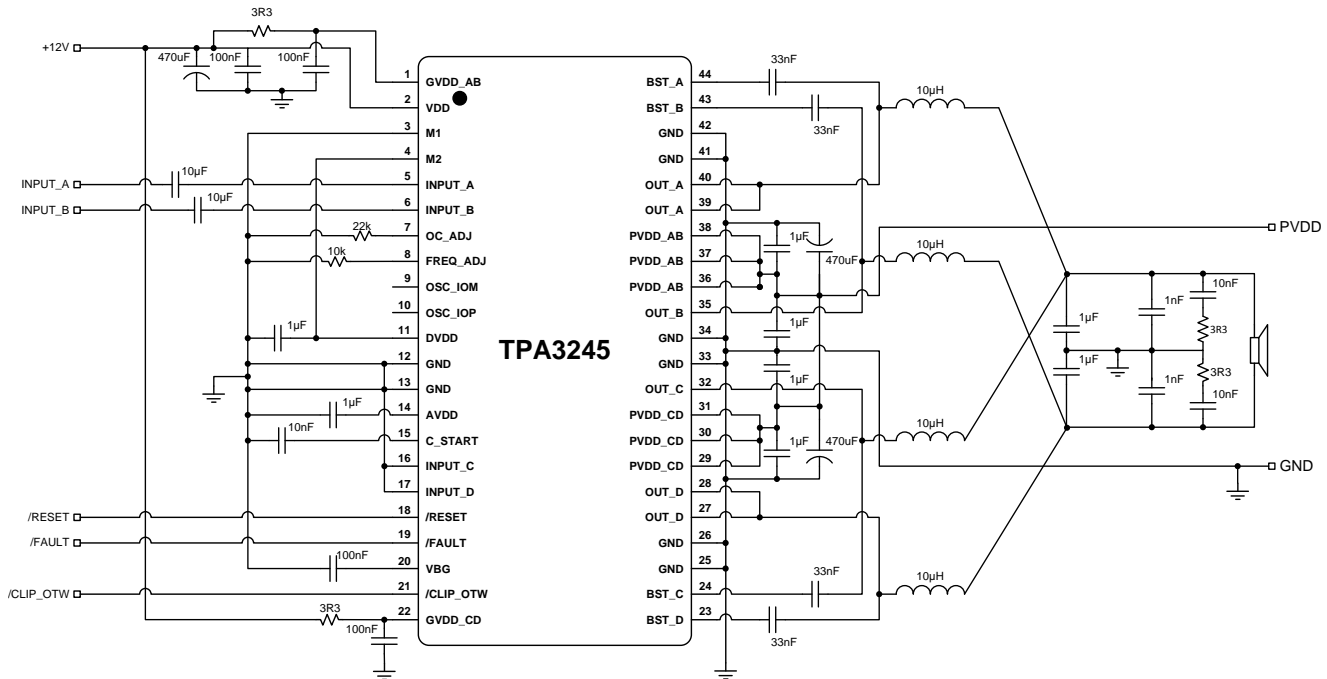
Relevant performance plots for TPA3245 in PBTL configuration are shown in [Typical Characteristics](#), [PBTL Configuration](#)

Table 12. Relevant Performance Plots, PBTL (Outputs Paralleled before LC filter) Configuration

PLOT TITLE	FIGURE NUMBER
Total Harmonic Distortion+Noise vs Output Power	Figure 16
Total Harmonic Distortion+Noise vs Frequency	Figure 17
Total Harmonic Distortion+Noise vs Frequency, 80kHz analyzer BW	Figure 18
Output Power vs Supply Voltage, 10% THD+N	Figure 19
Output Power vs Supply Voltage, 1% THD+N	Figure 20
Output Power vs Case Temperature	Figure 21

10.2.5 Typical Application, Differential (2N), PBTL (Outputs Paralleled after LC filter)

TPA3245 can be configured in mono PBTL mode by paralleling the outputs before the LC filter (see [Typical Application, Differential \(2N\), PBTL \(Outputs Paralleled before LC filter\)](#)) or after the LC filter. Paralleled outputs after the LC filter may be preferred if: a single board design must support both PBTL and BTL, or in the case multiple, smaller paralleled inductors are preferred due to size or cost. Paralleling after the LC filter requires four inductors, one for each OUT_x. This section shows an example of paralleled outputs after the LC filter.



Copyright © 2016, Texas Instruments Incorporated

Figure 29. Typical Differential (2N) PBTL (Outputs Paralleled after LC filter) Application

10.2.5.1 Design Requirements

Refer to [Stereo BTL Application](#) for the Design Requirements.

Table 13. Design Requirements, PBTL (Outputs Paralleled after LC filter) Application

DESIGN PARAMETER	EXAMPLE
Low Power (Pull-up) Supply	3.3 V
Mid Power Supply 12 V	12 V
High Power Supply	12 - 30 V
Mode Selection	M2 = H
	M1 = L
Analogue Inputs	INPUT_A = ± 3.9 V (peak, max)
	INPUT_B = ± 3.9 V (peak, max)
	INPUT_C = Grounded
	INPUT_D = Grounded
Output Filters	Inductor-Capacitor Low Pass Filter (10 μ H + 1 μ F)
Speaker Impedance	2 - 4 Ω

10.2.5.2 Detailed Design Procedures

Refer to [Stereo BTL Application](#) for the Detailed Design Procedures.

11 Power Supply Recommendations

11.1 Power Supplies

The TPA3245 device requires two external power supplies for proper operation. A high-voltage supply called PVDD is required to power the output stage of the speaker amplifier and its associated circuitry. Additionally, one mid-voltage power supply for GVDD_X and VDD is required to power the gate-drive and other internal digital and analog portions of the device. The allowable voltage range for both the PVDD and the GVDD_X/VDD supplies are listed in the [Recommended Operating Conditions](#) table. Ensure both the PVDD and the GVDD_X/VDD supplies can deliver more current than listed in the [Electrical Characteristics](#) table.

11.1.1 VDD Supply

The VDD supply required from the system is used to power several portions of the device. It provides power to internal regulators DVDD and AVDD that are used to power digital and analog sections of the device, respectively. Proper connection, routing, and decoupling techniques are highlighted in the TPA3245 device EVM User's Guide [SLVUAG8](#) (as well as the [Application Information](#) section and [Layout Examples](#) section) and must be followed as closely as possible for proper operation and performance. Deviation from the guidance offered in the TPA3245 device EVM User's Guide, which followed the same techniques as those shown in the [Application Information](#) section, may result in reduced performance, errant functionality, or even damage to the TPA3245 device. Some portions of the device also require a separate power supply which is a lower voltage than the VDD supply. To simplify the power supply requirements for the system, the TPA3245 device includes integrated low-dropout (LDO) linear regulators to create these supplies. These linear regulators are internally connected to the VDD supply and their outputs are presented on AVDD and DVDD pins, providing a connection point for an external bypass capacitors. It is important to note that the linear regulators integrated in the device have only been designed to support the current requirements of the internal circuitry, and should not be used to power any additional external circuitry. Additional loading on these pins could cause the voltage to sag and increase noise injection, which negatively affects the performance and operation of the device.

11.1.2 GVDD_X Supply

The GVDD_X supply required from the system is used to power the gate-drives for the output H-bridges. Proper connection, routing, and decoupling techniques are highlighted in the TPA3245 device EVM User's Guide [SLVUAG8](#) (as well as the [Application Information](#) section and [Layout Examples](#) section) and must be followed as closely as possible for proper operation and performance. Deviation from the guidance offered in the TPA3245 device EVM User's Guide, which followed the same techniques as those shown in the [Application Information](#) section, may result in reduced performance, errant functionality, or even damage to the TPA3245 device.

11.1.3 PVDD Supply

The output stage of the amplifier drives the load using the PVDD supply. This is the power supply which provides the drive current to the load during playback. Proper connection, routing, and decoupling techniques are highlighted in the TPA3245 device EVM User's Guide [SLVUAG8](#) (as well as the [Application Information](#) section and [Layout Examples](#) section) and must be followed as closely as possible for proper operation and performance. Due the high-voltage switching of the output stage, it is particularly important to properly decouple the output power stages in the manner described in the TPA3245 device EVM User's Guide [SLVUAG8](#). The lack of proper decoupling, like that shown in the EVM User's Guide, can results in voltage spikes which can damage the device, or cause poor audio performance and device shutdown faults.

11.2 Powering Up

The TPA3245 does not require a power-up sequence, but it is recommended to hold $\overline{\text{RESET}}$ low for at least 250 ms after PVDD supply voltage is turned ON. The outputs of the H-bridges remain in a high-impedance state until the gate-drive supply voltage (GVDD_X) and VDD voltages are above the undervoltage protection (UVP) voltage threshold (see the [Electrical Characteristics](#) table of this data sheet). This allows an internal circuit to charge the external bootstrap capacitors by enabling a weak pulldown of the half-bridge output as well as initiating a controlled ramp up sequence of the output voltage.

Powering Up (continued)

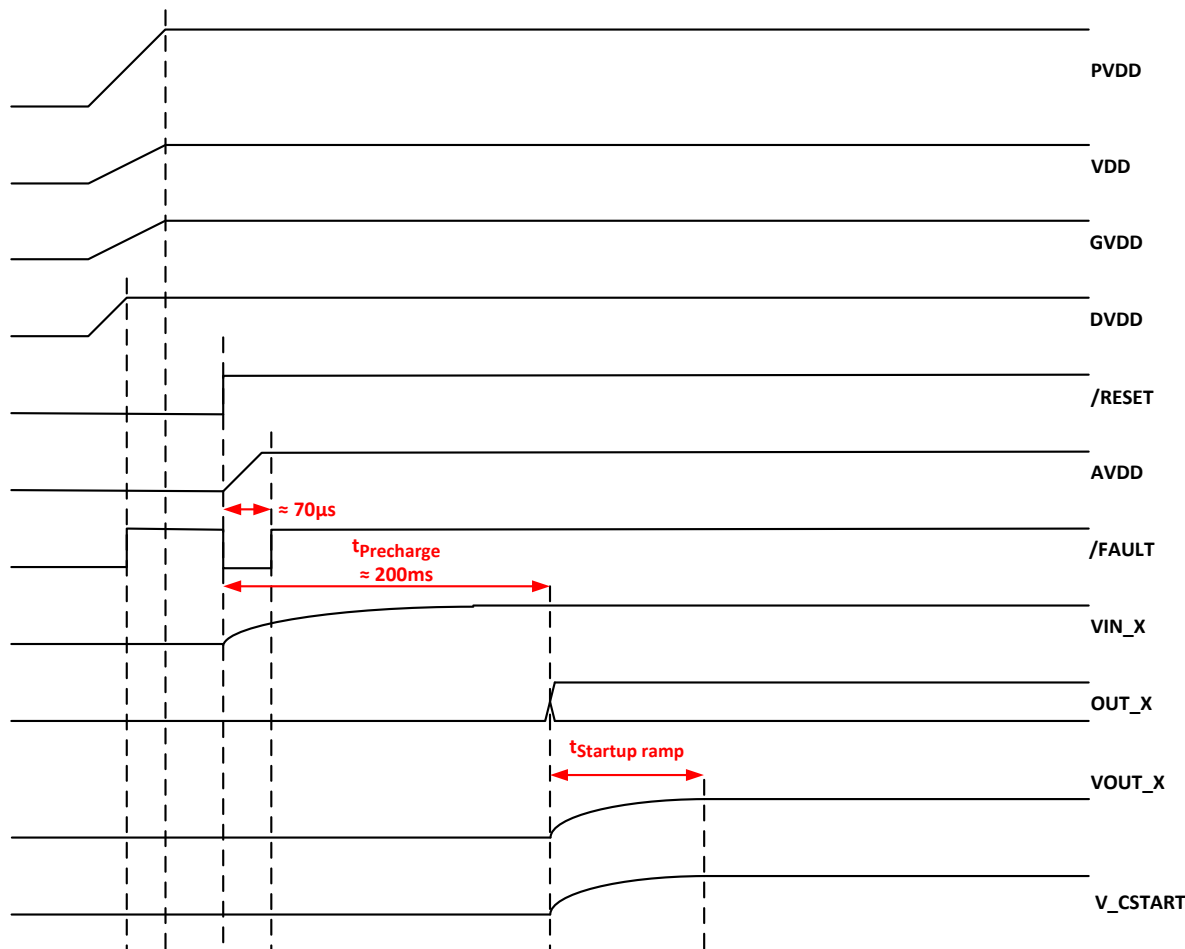


Figure 30. Startup Timing

When $\overline{\text{RESET}}$ is released to turn on TPA3245, $\overline{\text{FAULT}}$ signal will turn low and AVDD voltage regulator will be enabled. $\overline{\text{FAULT}}$ will stay low until AVDD reaches the undervoltage protection (UVP) voltage threshold (see the Electrical Characteristics table of this data sheet). After a precharge time to stabilize the DC voltage across the input AC coupling capacitors, the ramp up sequence starts.

11.3 Powering Down

The TPA3245 does not require a power-down sequence. The device remains fully operational as long as the gate-drive supply (GVDD_X) voltage and VDD voltage are above the undervoltage protection (UVP) voltage threshold (see the [Electrical Characteristics](#) table of this data sheet). Although not specifically required, it is a good practice to hold $\overline{\text{RESET}}$ low during power down, thus preventing audible artifacts including pops or clicks by initiating a controlled ramp down sequence of the output voltage.

12 Layout

12.1 Layout Guidelines

- Use an unbroken ground plane to have good low impedance and inductance return path to the power supply for power and audio signals.
- Maintain a contiguous ground plane from the ground pins to the PCB area surrounding the device for as many of the ground pins as possible, since the ground pins are the best conductors of heat in the package.

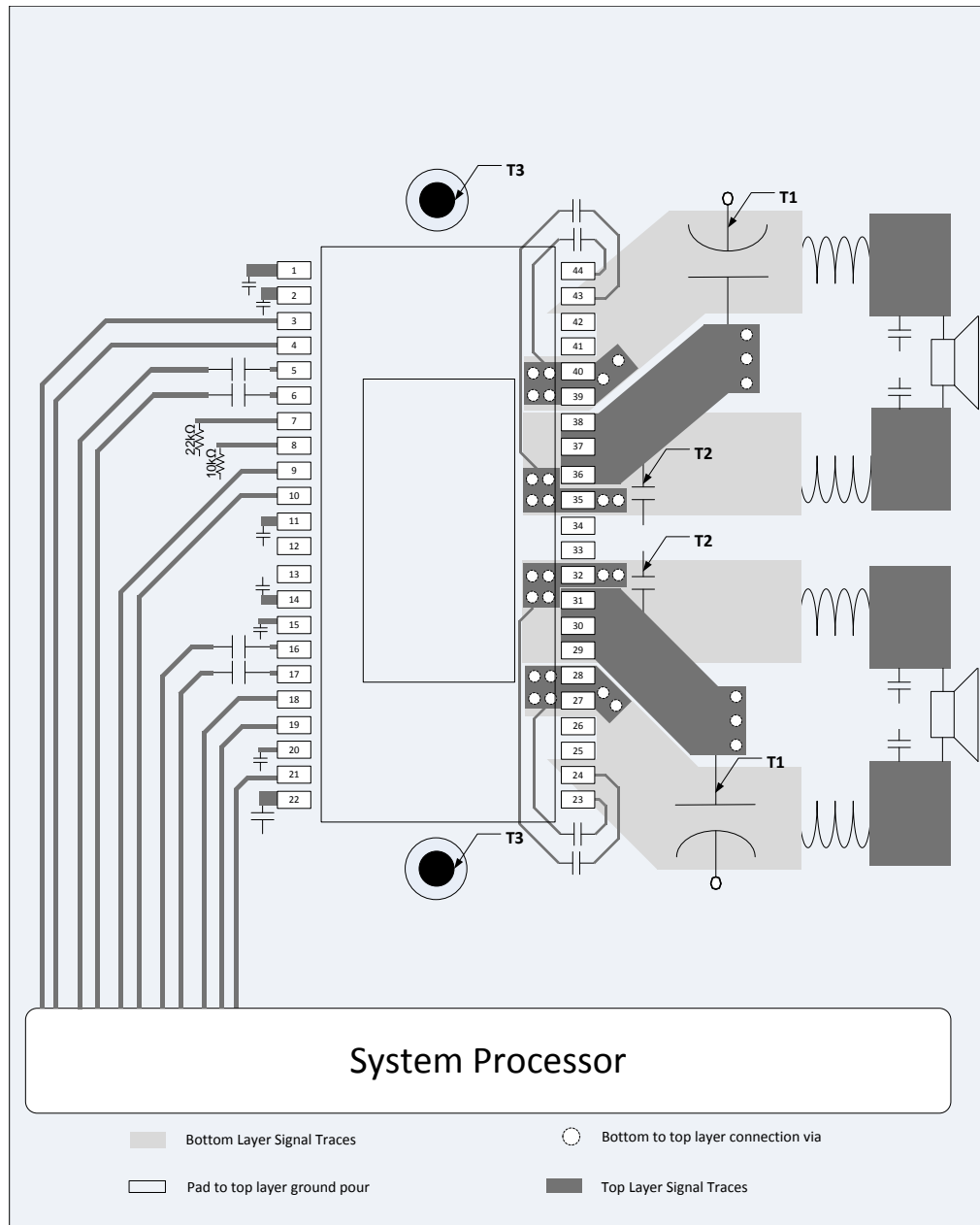
Layout Guidelines (continued)

- PCB layout, audio performance and EMI are linked closely together.
- Routing the audio input should be kept short and together with the accompanied audio source ground.
- The small bypass capacitors on the PVDD lines of the DUT be placed as close the PVDD pins as possible.
- A local ground area underneath the device is important to keep solid to minimize ground bounce.
- Orient the passive component so that the narrow end of the passive component is facing the TPA3245 device, unless the area between two pads of a passive component is large enough to allow copper to flow in between the two pads.
- Avoid placing other heat producing components or structures near the TPA3245 device.
- Avoid cutting off the flow of heat from the TPA3245 device to the surrounding ground areas with traces or via strings, especially on output side of device.

Netlist for this printed circuit board is generated from the schematic in [Figure 31](#).

12.2 Layout Examples

12.2.1 BTL Application Printed Circuit Board Layout Example

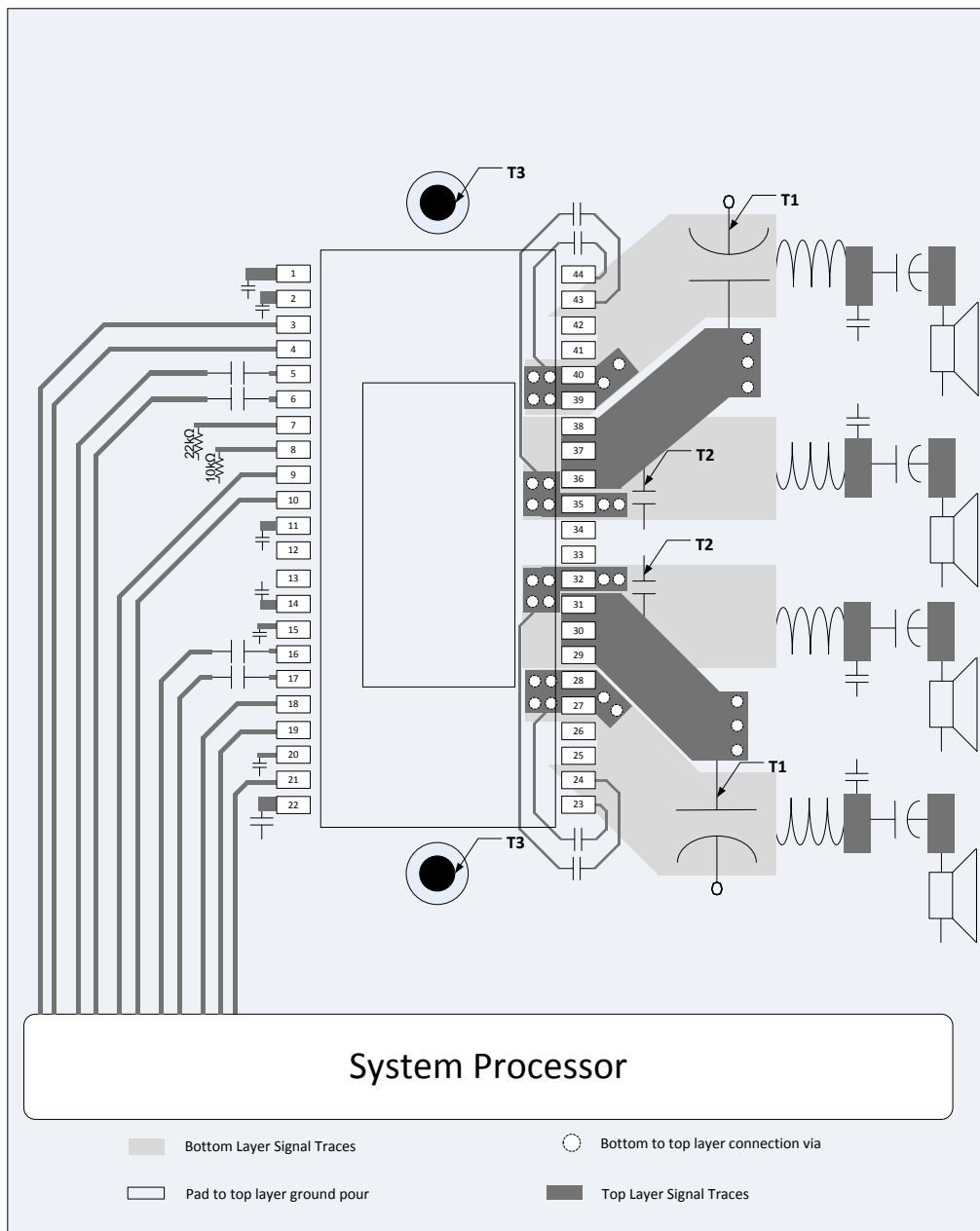


- Note: PCB layout example shows composite layout. Dark grey: Top layer copper traces, light gray: Bottom layer copper traces. All PCB area not used for traces should be GND copper pour (transparent on example image)
- Note T1:** PVDD decoupling bulk capacitors should be as close as possible to the PVDD and GND_X pins, the heat sink sets the distance. Wide traces should be routed on the top layer with direct connection to the pins and without going through vias. No vias or traces should be blocking the current path.
- Note T2:** Close decoupling of PVDD with low impedance X7R ceramic capacitors is placed under the heat sink and close to the pins.
- Note T3:** Heat sink needs to have a good connection to PCB ground.

Figure 31. BTL Application Printed Circuit Board - Composite

Layout Examples (continued)

12.2.2 SE Application Printed Circuit Board Layout Example

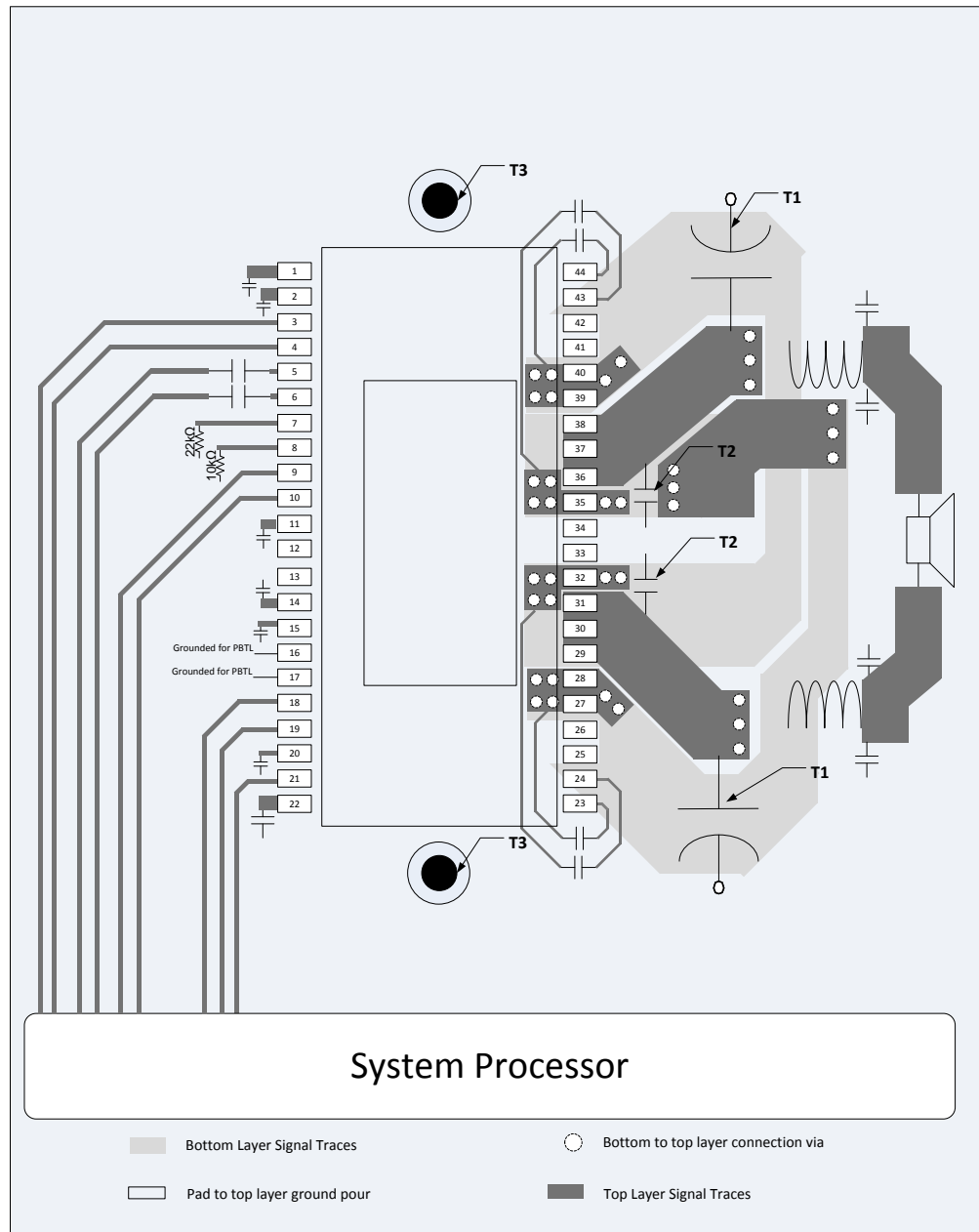


- A. Note: PCB layout example shows composite layout. Dark grey: Top layer copper traces, light gray: Bottom layer copper traces. All PCB area not used for traces should be GND copper pour (transparent on example image)
- B. **Note T1:** PVDD decoupling bulk capacitors should be as close as possible to the PVDD and GND_X pins, the heat sink sets the distance. Wide traces should be routed on the top layer with direct connection to the pins and without going through vias. No vias or traces should be blocking the current path.
- C. **Note T2:** Close decoupling of PVDD with low impedance X7R ceramic capacitors is placed under the heat sink and close to the pins.
- D. **Note T3:** Heat sink needs to have a good connection to PCB ground.

Figure 32. SE Application Printed Circuit Board - Composite

Layout Examples (continued)

12.2.3 PBTL (Outputs Paralleled before LC filter) Application Printed Circuit Board Layout Example

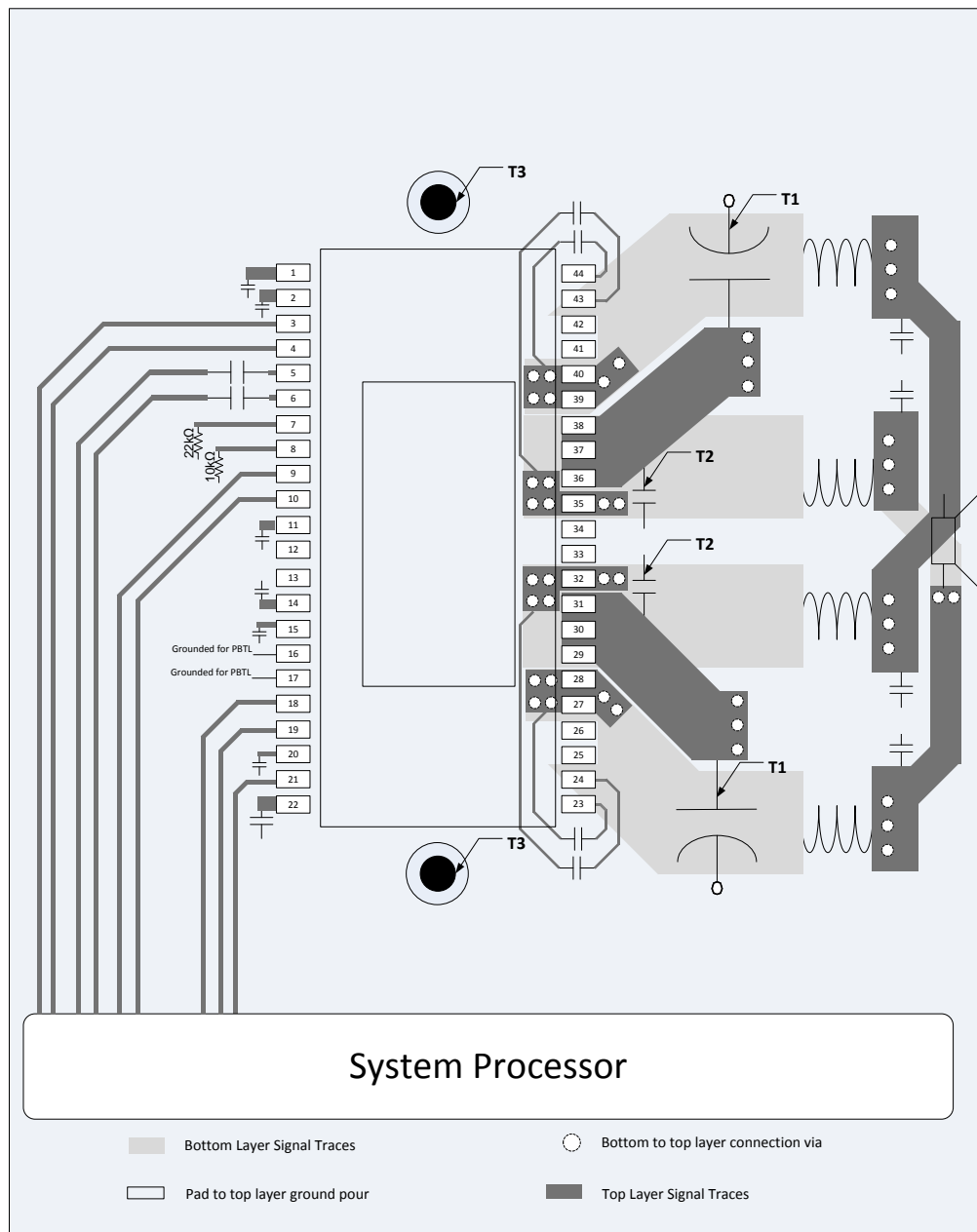


- Note: PCB layout example shows composite layout. Dark grey: Top layer copper traces, light gray: Bottom layer copper traces. All PCB area not used for traces should be GND copper pour (transparent on example image)
- Note T1:** PVDD decoupling bulk capacitors should be as close as possible to the PVDD and GND_X pins, the heat sink sets the distance. Wide traces should be routed on the top layer with direct connection to the pins and without going through vias. No vias or traces should be blocking the current path.
- Note T2:** Close decoupling of PVDD with low impedance X7R ceramic capacitors is placed under the heat sink and close to the pins.
- Note T3:** Heat sink needs to have a good connection to PCB ground.

Figure 33. PBTL (Outputs Paralleled before LC filter) Application Printed Circuit Board - Composite

Layout Examples (continued)

12.2.4 PBTL (Outputs Paralleled after LC filter) Application Printed Circuit Board Layout Example



- Note: PCB layout example shows composite layout. Dark grey: Top layer copper traces, light gray: Bottom layer copper traces. All PCB area not used for traces should be GND copper pour (transparent on example image)
- Note T1:** PVDD decoupling bulk capacitors should be as close as possible to the PVDD and GND_X pins, the heat sink sets the distance. Wide traces should be routed on the top layer with direct connection to the pins and without going through vias. No vias or traces should be blocking the current path.
- Note T2:** Close decoupling of PVDD with low impedance X7R ceramic capacitors is placed under the heat sink and close to the pins.
- Note T3:** Heat sink needs to have a good connection to PCB ground.

Figure 34. PBTL (Outputs Paralleled after LC filter) Application Printed Circuit Board - Composite

13 Device and Documentation Support

13.1 Documentation Support

TPA3245EVM User's Guide, [SLVUAG8](#)

13.2 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. In the upper right corner, click on *Alert me* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document

13.3 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's [Terms of Use](#).

TI E2E™ Online Community *TI's Engineer-to-Engineer (E2E) Community*. Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

Design Support *TI's Design Support* Quickly find helpful E2E forums along with design support tools and contact information for technical support.

13.4 Trademarks

PurePath, E2E are trademarks of Texas Instruments.
Blu-Ray Disc is a trademark of Blu-ray Disc Association.
All other trademarks are the property of their respective owners.

13.5 Electrostatic Discharge Caution



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.

13.6 Glossary

[SLYZ022](#) — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

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.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
TPA3245DDV	ACTIVE	HTSSOP	DDV	44	35	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR	0 to 70	3245	Samples
TPA3245DDVR	ACTIVE	HTSSOP	DDV	44	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR	0 to 70	3245	Samples

(1) The marketing status values are defined as follows:

ACTIVE: Product device recommended for new designs.

LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

PREVIEW: Device has been announced but is not in production. Samples may or may not be available.

OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

TBD: The Pb-Free/Green conversion plan has not been defined.

Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) 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.

(6) 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.

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

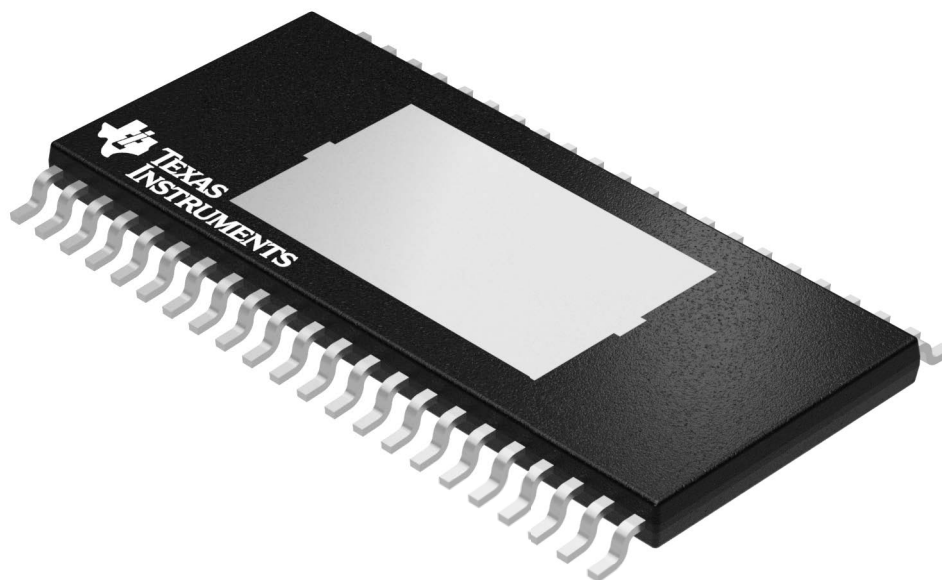
Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TPA3245DDVR	HTSSOP	DDV	44	2000	330.0	24.4	8.6	15.6	1.8	12.0	24.0	Q1

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPA3245DDVR	HTSSOP	DDV	44	2000	367.0	367.0	45.0



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



PowerPAD™ TSSOP - 1.2 mm max height

Technical drawing of a multi-pin connector assembly, showing a top view and a side view (DETAIL A).

Top View Dimensions and Callouts:

- Overall width: 14.1 (13.9 NOTE 3)
- Overall height: 6.2 (6.0)
- Pin 1 ID AREA: 8.3 TYP (7.9)
- Pin 1 ID AREA: 42X 0.635
- Pin 1 ID AREA: 2X (0.3) NOTE 6
- EXPOSED THERMAL PAD: 2X 13.335
- Pin 1 ID AREA: 44X 0.27 (0.17)
- Pin 1 ID AREA: 44X 0.08 (0.05) C A B
- Pin 1 ID AREA: 2X (0.6) NOTE 6
- Pin 1 ID AREA: (0.15) TYP NOTE 6
- Pin 1 ID AREA: 7.30 (6.72)
- Pin 1 ID AREA: 4.43 (3.85)
- Pin 1 ID AREA: 6.2 (6.0)
- Pin 1 ID AREA: 22
- Pin 1 ID AREA: 23

Side View (DETAIL A) Dimensions and Callouts:

- Overall height: 1.2 (1.0)
- Overall width: 0.75 (0.50)
- Pin 1 ID AREA: 0.25
- Pin 1 ID AREA: 0.15 (0.05)
- Pin 1 ID AREA: 0° - 8°
- Pin 1 ID AREA: GAGE PLANE
- Pin 1 ID AREA: (0.15) TYP

Other Callouts:

- SEATING PLANE
- 0.1 C
- SEE DETAIL A

PowerPAD is a trademark of Texas Instruments.

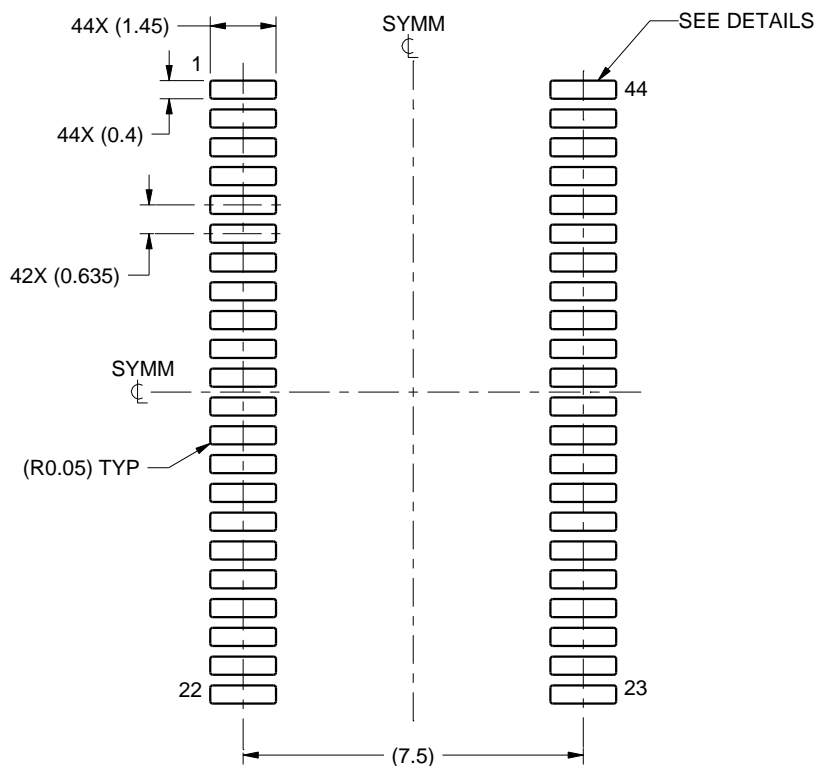
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm per side.
4. Reference JEDEC registration MO-153.
5. The exposed thermal pad is designed to be attached to an external heatsink.
6. Features may differ or may not be present.

EXAMPLE BOARD LAYOUT

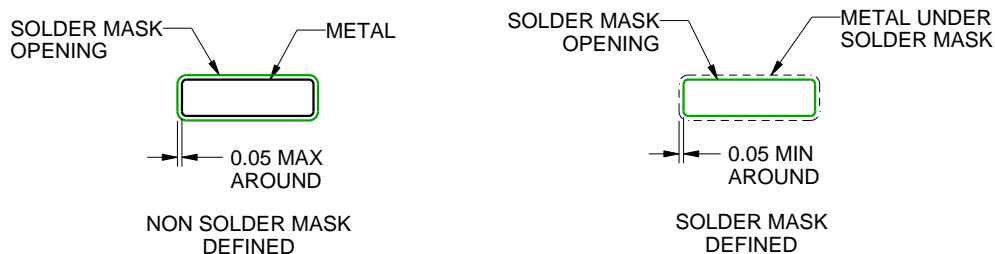
DDV0044D

PowerPAD™ TSSOP - 1.2 mm max height

PLASTIC SMALL OUTLINE



LAND PATTERN EXAMPLE
SCALE:6X



SOLDER MASK DETAILS
NOT TO SCALE

4218830/A 08/2016

NOTES: (continued)

7. Publication IPC-7351 may have alternate designs.

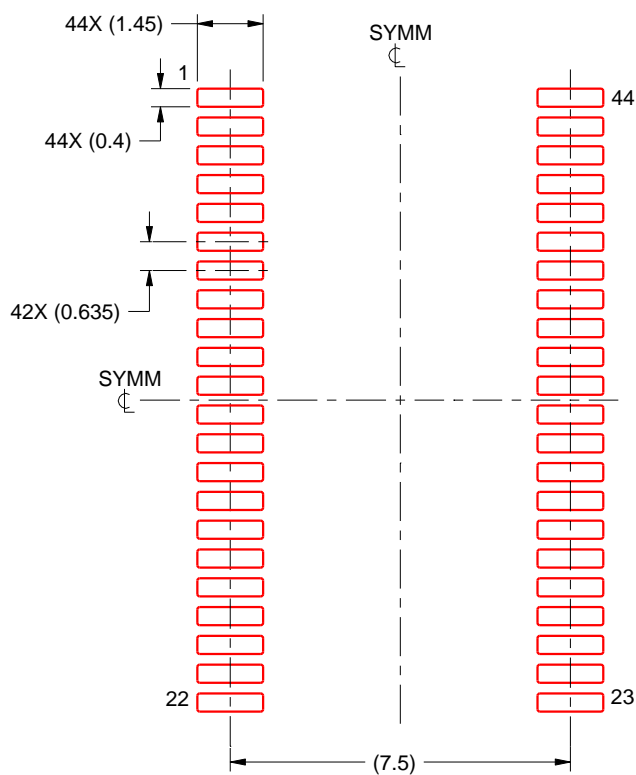
8. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

EXAMPLE STENCIL DESIGN

DDV0044D

PowerPAD™ TSSOP - 1.2 mm max height

PLASTIC SMALL OUTLINE



SOLDER PASTE EXAMPLE
BASED ON 0.125 MM THICK STENCIL
SCALE :6X

4218830/A 08/2016

NOTES: (continued)

9. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
10. Board assembly site may have different recommendations for stencil design.

IMPORTANT NOTICE

Texas Instruments Incorporated (TI) reserves the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete.

TI's published terms of sale for semiconductor products (<http://www.ti.com/sc/docs/stdterms.htm>) apply to the sale of packaged integrated circuit products that TI has qualified and released to market. Additional terms may apply to the use or sale of other types of TI products and services.

Reproduction of significant portions of TI information in TI data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such reproduced documentation. Information of third parties may be subject to additional restrictions. Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyers and others who are developing systems that incorporate TI products (collectively, "Designers") understand and agree that Designers remain responsible for using their independent analysis, evaluation and judgment in designing their applications and that Designers have full and exclusive responsibility to assure the safety of Designers' applications and compliance of their applications (and of all TI products used in or for Designers' applications) with all applicable regulations, laws and other applicable requirements. Designer represents that, with respect to their applications, Designer has all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. Designer agrees that prior to using or distributing any applications that include TI products, Designer will thoroughly test such applications and the functionality of such TI products as used in such applications.

TI's provision of technical, application or other design advice, quality characterization, reliability data or other services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, "TI Resources") are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using TI Resources in any way, Designer (individually or, if Designer is acting on behalf of a company, Designer's company) agrees to use any particular TI Resource solely for this purpose and subject to the terms of this Notice.

TI's provision of TI Resources does not expand or otherwise alter TI's applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

Designer is authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED "AS IS" AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS. TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY DESIGNER AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

Unless TI has explicitly designated an individual product as meeting the requirements of a particular industry standard (e.g., ISO/TS 16949 and ISO 26262), TI is not responsible for any failure to meet such industry standard requirements.

Where TI specifically promotes products as facilitating functional safety or as compliant with industry functional safety standards, such products are intended to help enable customers to design and create their own applications that meet applicable functional safety standards and requirements. Using products in an application does not by itself establish any safety features in the application. Designers must ensure compliance with safety-related requirements and standards applicable to their applications. Designer may not use any TI products in life-critical medical equipment unless authorized officers of the parties have executed a special contract specifically governing such use. Life-critical medical equipment is medical equipment where failure of such equipment would cause serious bodily injury or death (e.g., life support, pacemakers, defibrillators, heart pumps, neurostimulators, and implantables). Such equipment includes, without limitation, all medical devices identified by the U.S. Food and Drug Administration as Class III devices and equivalent classifications outside the U.S.

TI may expressly designate certain products as completing a particular qualification (e.g., Q100, Military Grade, or Enhanced Product). Designers agree that it has the necessary expertise to select the product with the appropriate qualification designation for their applications and that proper product selection is at Designers' own risk. Designers are solely responsible for compliance with all legal and regulatory requirements in connection with such selection.

Designer will fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of Designer's non-compliance with the terms and provisions of this Notice.