TFA9914_SDS

High Efficiency Class-D Amplifier for Haptic

Rev. 1 — 16 May 2019 Product data sheet

1 General description

The TFA9914 is a high efficiency 10 V boosted class-D haptic driver. It can deliver up to 5.6 W (AVG) output power into an 8 Ω load and up to 1.5 W (AVG) output power into 32 Ω load, at a battery supply voltage of 4.0 V. The internal adaptive DC-to-DC converter raises the power supply voltage up to 10 V, providing strong and sharp haptic feedbacks.

Internal adaptive DC-to-DC conversion boosts the supply rail to provide additional headroom and output power. The supply voltage is only raised when necessary. It maximizes the output power of the class-D amplifier while limiting quiescent power consumption.

The device can be configured to drive from 8 Ω up to 32 Ω load, allowing it to be embedded in a wide variety of haptic platforms.

The TFA9914 also incorporates battery protection. By limiting the supply current when the battery voltage is low, it prevents the haptic system from drawing excessive load currents from the battery, which could cause a system undervoltage. This circuitry minimizes the impact of a falling battery voltage by preventing unexpected device switch off / shutdowns due to excessive current drawn from the battery.

The device features a second order closed loop architecture, used in a class-D amplifier, providing an excellent signal performance and high supply voltage ripple rejection. The data input interface is TDM and the control settings are communicated via an I^2C-bus interface.

The TFA9914 is available in a 48-bump wafer level chip-size package (WLCSP) with a 400 µm pitch.

2 Features and benefits

- Fully integrated solution that includes class-D amplifier, DC-to-DC, voltage sensing and current sensing, and advanced haptic algorithms running on an on-chip 24-bit 100 MHz dual-MAC DSP.
- Very competitive PCB footprint (< 16 mm^2).
- 100 % compatible with Android haptic/vibration APIs
- Automatic transducer diagnosis and calibration at production line without human engagement.
- Run-time transducer model (f0) tracking after production.
- Run-time transducer distortion and temperature control.
- On-chip autonomous boot-up vibration playback.
- On-chip resonant drive signal (buzz/tone) generation with boosting and braking.
- On-chip click effect (for virtual buttons, etc.) via wave table playback.
- Real-time playback for haptic effect streams (I^2S/TDM).
- Audio display support (voice call without receiver speaker. Using LRA in place of the speaker) for intelligible speech playback.
- Embedded sequencer (NXP Semiconductors driver support), to enable complex haptic sequences.
- Audio-to-Haptics total solution for gaming experience enhancement with major SOC platforms.
- Supports size-limited low impedance transducers down to 8 Ω.
- Battery protection with minimal risk of black-out.
- Audio grade drive signal generation without hearable noise.
- Automatic power state management.
- High output power: 5.6 W (AVG) to 8 Ω at 4.0 V supply voltage (THD = 1 %; V_{BST} = 10 V).
- Supports 8 Ω to 32 Ω load configurations.
- High efficiency, low power dissipation, and low noise haptic driver (dynamic range > 110 dB).
- Adaptive DC-to-DC converter which, when switching between fixed boost and adaptive boost mode, increases the supply voltage smoothly, preventing large battery supply spikes and limiting quiescent power consumption.
- Wide supply voltage range (fully operational from 2.7 V to 5.5 V).
- Very low noise output (typ: 14 µV with null DATA input at f_s = 48 kHz).
- I^2C-bus control interface (400 kHz).
- Haptic current and voltage monitoring.
- 48 kHz dedicated sample frequency
- Configurable full duplex 4-wire TDM input interface.
- Programmable interrupt control via a dedicated interrupt pin.
- Thermal foldback and overtemperature protection.
- 15 kV system-level ESD protection without external components on amplifier output.

3 Applications

- Mobile phones and tablets
- Portable gaming devices
- Portable navigation devices (PND)

4 Quick reference data

Table 1. Quick reference data

All parameters are guaranteed for V_{BAT} = 4.0 V; V_{DDD} = V_{DDE} = 1.8 V; V_{DDP} = V_{BST} = 10 V, adaptive boost mode; L_{BST} = 1 µH[1]; R_L = 8 Ω[1]; L_L = 44 µH[1]; f_i = 1 kHz; f_s = 48 kHz; T_{amb} = 25 °C; default settings, unless otherwise specified.

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{BAT}	battery supply voltage	on pin V_{BAT}; In application, V_{BAT} must not be lower than V_{DDD} levels	2.7	-	5.5	V
V_{DDD}	digital supply voltage	on pin V_{DDD}	1.65	1.8	1.95	V
V_{DDE}	digital supply voltage	on pin V_{DDE}	1.65	1.8	1.95	V
V_{DDP}	power supply voltage	on pin V_{DDP}	2.7	-	10.2	V
R_L	load impedance		8	16	32	Ω
$f_{rsn(tr)}$	transducer resonance frequency		120	160	1000	Hz
I_{BAT}	battery supply current	active state; on pin VBAT; operating mode with load R_L = 8 Ω; DC-to-DC in adaptive boost mode; P_o = 600 mW; V_{BAT} = 4.0 V; V_{DDP} = 10 V; 100 Hz sine wave; running on MCLK (19.2 MHz)	-	165	-	mA
		idle state; on pin VBAT; operating mode with load R_L = 8 Ω and no output signal; no output capacitance; DC-to-DC converter in adaptive boost mode; V_{BAT} = 4.0 V; low power mode enabled; Running on MCLK (19.2 MHz)	-	2.7	-	mA
		power-down state; on pin VBAT; DC-to-DC in power-down mode; T_j = 25 °C; running on MCLK (19.2 MHz).	-	1	-	µA
I_{DDD}	digital supply current	active state (DSP Running); on pin VDDD; operating mode with load R_L = 8 Ω; DC-to-DC in adaptive boost mode; P_o = 600 mW; V_{BAT} = 4.0 V; V_{DDP} = 10 V; 100 Hz sine wave; running on MCLK (19.2 MHz)	-	11.2	-	mA
		idle state (DSP Disabled); on pin VDDD; operating mode with load R_L = 8 Ω and no output signal; no output capacitance; DC-to-DC converter in adaptive boost mode; V_{BAT} = 4.0 V; low power mode enabled; running on MCLK (19.2 MHz)	-	3.9	-	mA
		power-down state; on pin VDDD; DC-to-DC in power-down mode; T_j = 25 °C; running on MCLK (19.2 MHz).	-	124	-	µA
$P_{o(AVG)}$	average output power	THD+N = 1 %; (R_L = 8 Ω; L_L = 44µH); V_{BST} = 10 V; V_{BAT} = 4.0 V; V_{DDD} = 1.8 V	5.3	5.6	-	W
		THD+N = 1 %; (R_L = 32 Ω; L_L = 30µH); V_{BST} = 10 V; V_{BAT} = 4.0 V; V_{DDD} = 1.8 V	1.1	1.5	-	W
THD+N	total harmonic distortion-plus-noise	P_o = 2.0 W; R_L = 8 ΩI L_L = 44 µH	-	0.015	0.09	%
ΔG	gain variation over frequency	BW = 20 Hz to 15 kHz; V_{BAT} = 3.4 V to 5 V; P_o = 2.0 W	−0.1	-	+0.7	dB

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{POP}	pop noise	at mode transition and gain change; with C_L < 200 pF[2]	-	-	2	mV
$V_{n(o)}$	output noise voltage	a-weighted; no input signal; low noise mode[3]	-	14	18	µV
DR	dynamic range	a-weighted; V_{BAT} = 3.4 V to 5 V; S/N = maximum signal (at THD = 1 %) − output noise voltage ($V_{n(o)}$); no signal applied	110	114	-	dB
S/N	signal-to-noise ratio	a-weighted; V_{BAT} = 3.4 V to 5 V; S/N = maximum signal (at THD = 1 %) − output noise voltage ($V_{n(o)}$); signal applied	100	-	-	dB
η_{po}	output power efficiency	on pin V_{BAT}; input: 100 Hz sine wave; DC-to-DC in adaptive boost mode; V_{BAT} = 4.0 V; V_{DDP} = 10 V; P_o = 4 W	-	82	-	%

[1] L_{BST} = boost converter inductance; R_L = load resistance; L_L = load inductance.
[2] When C_L exceeds 200 pF, low power mode must be disabled.
[3] This parameter is not tested during production; the value is guaranteed by design and checked during product validation.

5 Ordering information

Table 2. Ordering information

Type number	Package		
	Name	Description	Version
TFA9914UK/N1	WLCSP48	wafer-level chip-scale package; 48 bumps; 0.4 mm pitch; 2.51 mm × 3.55 mm × 0.50 mm body; no backside coating	SOT1887-2
TFA9914BUK/N1	WLCSP48	wafer-level chip-scale package; 48 bumps; 0.4 mm pitch; 2.51 mm × 3.55 mm × 0.50 mm body; backside coating	SOT1887-3

6 Block diagram

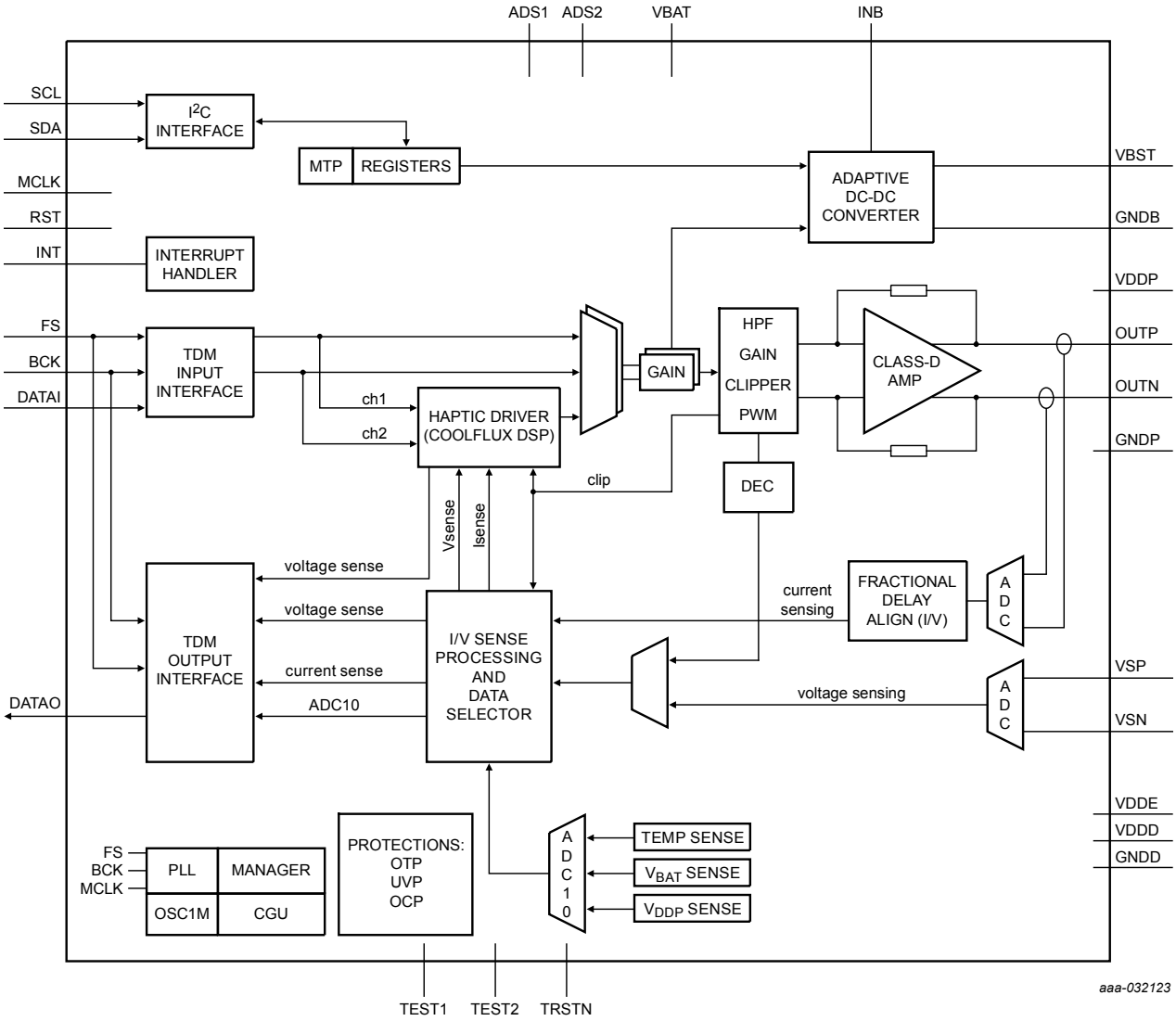
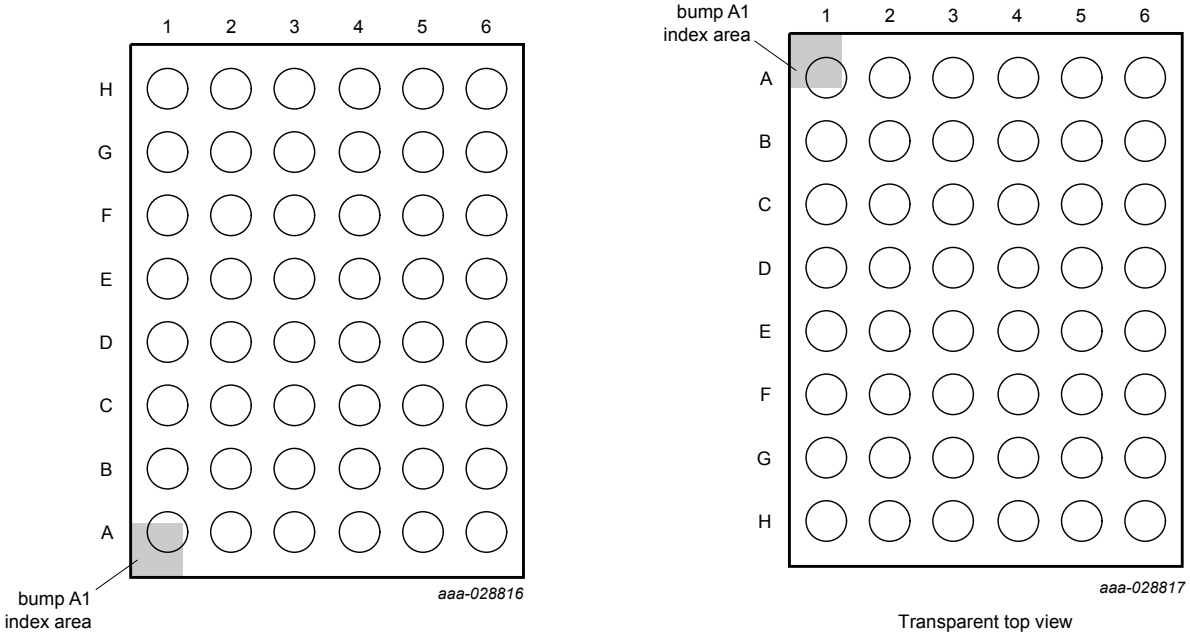


Figure 1. Block diagram

7 Pinning information

7.1 Pinning



a. Bottom view

b. Transparent top view

Figure 2. Bump configuration

	1	2	3	4	5	6
A	MCLK	VDDE	VDDD	GNDD	GNDD	GNDD
B	GNDD	FS	VDDD	SCL	GNDD	GNDD
C	BCK	FS	VDDD	SCL	SDA	TRSTN
D	DATAO	DATAI	ADS2	ADS1	INT	VBAT
E	RST	GNDD	VSN	TEST2	TEST1	VSP
F	GNDB	GNDB	GNDB	GNDD	GNDP	GNDD
G	INB	INB	INB	OUTP	GNDP	OUTN
H	VBST	VBST	VBST	VDDP	VDDP	VDDP

aaa-028818

Transparent top view

Figure 3. Bump mapping

Table 3. Pinning

Symbol	Pin	Type	Description
MCLK	A1	I	master clock input
VDDE	A2	P	pad digital supply voltage (to be connected to VDDD)
VDDD	A3	P	digital supply voltage
GNDD	A4	P	digital ground
GNDD	A5	P	digital ground
GNDD	A6	P	digital ground
GNDD	B1	P	digital ground
FS	B2	I	digital data frame sync for TDM interface
VDDD	B3	P	digital supply voltage
SCL	B4	I	digital I^2C-bus clock input
GNDD	B5	P	digital ground
GNDD	B6	P	digital ground
BCK	C1	I	digital data bit clock input for TDM interface
FS	C2	I	digital data frame sync for TDM interface
VDDD	C3	P	digital supply voltage
SCL	C4	I	digital I^2C-bus clock input
SDA	C5	I/O	digital I^2C-bus data input/output
TRSTN	C6	I	test signal input TRSTN, connect to PCB ground
DATAO	D1	O	digital data data output for TDM interface
DATAI	D2	I	digital data data input for TDM interface
ADS2	D3	I	digital address select input 2
ADS1	D4	I	digital address select input 1
INT	D5	O	digital interrupt output
VBAT	D6	P	battery supply voltage
RST	E1	I	digital reset input
GNDD	E2	P	digital ground
VSN	E3	I/O	voltage sensing inverting
TEST2	E4	I/O	test signal IO 2; for test purposes only, connect to PCB ground
TEST1	E5	I/O	test signal IO 1; for test purposes only, connect to PCB ground
VSP	E6	I/O	voltage sensing non-inverting
GNDB	F1	P	booster ground
GNDB	F2	P	booster ground
GNDB	F3	P	booster ground
GNDD	F4	P	digital ground
GNDP	F5	P	power ground
GNDD	F6	P	digital ground

Symbol	Pin	Type	Description
INB	G1	P	DC-to-DC boost converter input
INB	G2	P	DC-to-DC boost converter input
INB	G3	P	DC-to-DC boost converter input
OUTP	G4	P	non-inverting output
GNDP	G5	P	power ground
OUTN	G6	P	inverting output
VBST	H1	O	boosted supply voltage output
VBST	H2	O	boosted supply voltage output
VBST	H3	O	boosted supply voltage output
VDDP	H4	P	power supply voltage
VDDP	H5	P	power supply voltage
VDDP	H6	P	power supply voltage

8 Functional description

The TFA9914 is a highly efficient bridge-tied load (BTL) class-D amplifier for Haptic, depicted in block diagram of Figure 1.

TFA9914 contains a TDM input/output interface for communicating with the host. The interface is compliant with standard TDM interfaces and supports a wide range of configurations. It can be configured to output current sense and voltage sense information, which can be further used by the host.

The Haptic pattern generation is automatically handled by the embedded Coolflux digital signal processor (DSP) together with dedicated libraries running on host. It supports the following haptic features:

- Wave table playback: prestored pattern playback from embedded wave pattern table
- Tone generator: resonant tone playback with resonant frequency (f0) tracking at ±2 Hz accuracy
- Automatic boost/brake effect for fast ramp-up/ramp-down and ringing compensation
- TDM real-time streaming support (for external pattern playback)
- Concurrent playback of tone generator, wavetable, and streaming inputs
- Dedicated sequencer for complex haptic feedback
- Preprocessing libraries (available from NXP for host execution) supporting Audio-to-Haptics (gaming and multimedia experience enhancement) and Audio-Display (voice call handset mode with LRA in place for a regular RCV speaker).

At low battery voltage levels, the output level is automatically clipped to limit battery current (when battery safeguard is enabled).

The digital data stream is converted into two pulse width modulated (PWM) signals which are then injected into the class-D amplifier. The 3-level PWM scheme supports filterless haptic drive.

When the data stream crosses a programmable voltage threshold, an adaptive DC-to-DC converter boosts the battery supply voltage. When boosting, the DC-to-DC provides a boosted supply in line with the data signal. In this mode, 2 configurations are available (Two-levels mode or Tracking mode (default)).

9 I²C-bus interface and register settings

The TFA9914 supports the 400 kHz I²C-bus microcontroller interface mode standard. The I²C-bus is used to control the TFA9914 and to transmit and receive data. The TFA9914 can only operate in I²C slave mode, as a slave receiver or as a slave transmitter.

9.1 TFA9914 addressing

The TFA9914 is accessed via an 8-bit code (see Table 4). Bits 1 to 7 contain the device address. Bit 0 (R/$\overline{W}$) indicates whether a read (1) or a write (0) operation has been requested. Four separate addresses are supported for stereo applications. Address selection is via pins ADS1 and ADS2. The levels on pins ADS1 and ADS2 determine the values of bits 1 and 2, respectively, of the device address, as detailed in Table 4. The generic address is independent of pins ADS1 and ADS2.

Table 4. Address selection via pins ADS1 and ADS2

ADS2 pin voltage (V)	ADS1 pin voltage (V)	Address	Function
0	0	01101000	for write mode
		01101001	for read mode
0	V_{DDD}	01101010	for write mode
		01101011	for read mode
V_{DDD}	0	01101100	for write mode
		01101101	for read mode
V_{DDD}	V_{DDD}	01101110	for write mode
		01101111	for read mode
do not care	do not care	00011100 (generic address)	for write mode
do not care	do not care	00011101 (generic address)	for read mode

9.2 I²C-bus write cycle

The sequence of events that must be followed when writing data to the I²C-bus registers of the TFA9914 is detailed in Table 5. One byte is transmitted at a time. Each register stores two bytes of data. Data is always written in byte pairs. Data transfer is always MSB first.

The write cycle sequence using SDA is as follows:

1. The microcontroller asserts a start condition (S).
2. The microcontroller transmits the 7-bit device address of the TFA9914, followed by the R/$\overline{W}$ bit set to 0.
3. The TFA9914 asserts an acknowledge (A).
4. The microcontroller transmits the 8-bit TFA9914 register address to which the first data byte is written.
5. The TFA9914 asserts an acknowledge.
6. The microcontroller transmits the first byte (the most significant byte).
7. The TFA9914 asserts an acknowledge.
8. The microcontroller transmits the second byte (the least significant byte).

9. The TFA9914 asserts an acknowledge.
10. The microcontroller can either assert the stop condition (P) or continue transmitting data by sending another pair of data bytes, repeating the sequence from step 6. In the latter case, the targeted register address has been auto-incremented by the TFA9914.

Table 5. I^2C-bus write cycle

Start	TFA9914 address	R/$\overline{W}$		TFA9914 first register address		MSB		LSB		More data...	Stop
S	01101A_2A_1	0	A	ADDR	A	MS1	A	LS1	A	<....>	P

9.3 I^2C-bus read cycle

The sequence of events that must be followed when reading data from the I^2C-bus registers of the TFA9914 is detailed in Table 6. One byte is transmitted at a time. Each of the registers stores two bytes of data. Data is always written in byte pairs. Data transfer is always MSB first.

The read cycle sequence using SDA is as follows:

1. The microcontroller asserts a start condition (S).
2. The microcontroller transmits the 7-bit device address of the TFA9914, followed by the R/$\overline{W}$ bit set to 0.
3. The TFA9914 asserts an acknowledge (A).
4. The microcontroller transmits the 8-bit TFA9914 register address from which the first data byte is read.
5. The TFA9914 asserts an acknowledge.
6. The microcontroller asserts a repeated start (Sr).
7. The microcontroller retransmits the device address followed by the R/$\overline{W}$ bit set to 1.
8. The TFA9914 asserts an acknowledge.
9. The TFA9914 transmits the first byte (the MSB).
10. The microcontroller asserts an acknowledge.
11. The TFA9914 transmits the second byte (the LSB).
12. The microcontroller asserts either an acknowledge or a negative acknowledge (NA).
    - If the microcontroller asserts an acknowledge, the target register address is auto-increased by the TFA9914 and steps 9 to 12 are repeated.
    - If the microcontroller asserts a negative acknowledge, the TFA9914 frees the I^2C-bus and the microcontroller generates a stop condition (P).

Table 6. I^2C-bus read cycle

Start	TFA9914 address	R/$\overline{W}$		First register address			TFA9914 address	R/$\overline{W}$		MSB		LSB		More data...		Stop
S	01101A_2A_1	0	A	ADDR	A	Sr	01101A_2A_1	1	A	MS1	A	LS1	A	<....>	NA	P

10 Limiting values

Table 7. Limiting values

In accordance with the Absolute Maximum Rating System (IEC 60134).

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{BAT}	battery supply voltage	on pin V_{BAT}	−0.3	-	+6	V
V_{BST}	booster output voltage	on pin V_{BST}	−0.3	-	+12	V
V_{INB}	booster input voltage	on pin INB	−0.3	-	+12 [1]	V
V_{DDP}	power supply voltage	on pin V_{DDP}	−0.3	-	+12	V
V_{OUTx}	voltage on amplifier connections	on pin OUTN, OUTP	−0.3	-	+12[1]	V
V_{DDD}	digital supply voltage	on pin V_{DDD}	−0.3	-	+2.5	V
V_{DDE}	digital supply voltage	on pin V_{DDE}	−0.3	-	+2.5	V
V_{LTESTx}	low-voltage test pins	on pin TEST1/TEST2	−0.3	-	+6	V
V_{HVSx}	high-voltage pins	on pin VSP, VSN	−0.3	-	+12[1]	V
T_j	junction temperature		-	-	+125	°C
T_{stg}	storage temperature		−55	-	+150	°C
T_{amb}	ambient temperature		−40	-	+85	°C
V_{ESD}	electrostatic discharge voltage	according to human body model (HBM)	−2	-	+2	kV
		according to charge device model (CDM)	−500	-	+500	V

[1] Using NXP demo board, with a 1 mm wire/PCB track lengths, AC pulse from −6 V to +15 V can be observed on INB, OUTP, OUTN, VSP, VSN without damaging the device as these spikes do not end up inside the actual device.

11 Thermal characteristics

Table 8. Thermal characteristics

Symbol	Parameter	Conditions	Typ	Unit
$R_{th(j-a)}$	thermal resistance from junction to ambient	4-layer application board	37	K/W

12 Characteristics

12.1 DC Characteristics

Table 9. DC characteristics

All parameters are guaranteed for V_{BAT} = 4.0 V; V_{DDD} = V_{DDE} = 1.8 V; V_{DDP} = V_{BST} = 10 V, adaptive boost mode; L_{BST} = 1 µH[1]; R_L = 8 Ω[1]; L_L = 44 µH[1]; f_i = 1 kHz; f_s = 48 kHz; T_{amb} = 25 °C; default settings, unless otherwise specified.

Symbol	Parameter	Conditions		Min	Typ	Max	Unit
V_{BAT}	battery supply voltage	on pin V_{BAT}; in application, V_{BAT} must not be lower than V_{DDD}		2.7	-	5.5	V
I_{BAT}	battery supply current	active state; on pin VBAT; operating mode with load R_L = 8 Ω; DC-to-DC in adaptive boost mode; P_o = 600 mW; V_{BAT} = 4.0 V; V_{DDP} = 10 V; 100 Hz sine wave; running on MCLK (19.2 MHz)		-	165	-	mA
		idle state; on pin VBAT; operating mode with load R_L = 8 Ω; no output signal; no output capacitance; DC-to-DC converter in adaptive boost mode; V_{BAT} = 4.0 V; low-power mode enabled; running on MCLK (19.2 MHz)		-	2.7	-	mA
		Idle state on pin VBAT; operating mode with load R_L = 8 Ω; no output signal; no output capacitance; DC-to-DC converter in adaptive boost mode; V_{BAT} = 4.0 V; low-power mode disabled; running on MCLK (19.2 MHz)		-	5.7	-	mA
		power-down state; on pin VBAT; DC-to-DC in power-down mode. T_j = 25 °C; running on MCLK (19.2 MHz).		-	1	-	µA
V_{DDP}	power supply voltage	on pin V_{DDP}		2.7	-	10.2	V
V_{DDD}	digital supply voltage	on pin V_{DDD}		1.65	1.8	1.95	V
V_{DDE}	digital supply voltage	on pin V_{DDE}		1.65	1.8	1.95	V

Symbol	Parameter	Conditions		Min	Typ	Max	Unit
I_{DDD}	digital supply current	active state (DSP running); on pin VDDD; operating mode with load R_L = 8 Ω; DC-to-DC in adaptive boost mode, P_o = 600 mW; V_{BAT} = 4.0 V; V_{DDP} = 10 V; 100 Hz sine wave; running on MCLK (19.2 MHz)		-	11.2	-	mA
		idle state (DSP disabled); on pin VDDD; operating mode with load R_L = 8 Ω; no output signal; no output capacitance; DC-to-DC converter in adaptive boost mode; V_{BAT} = 4.0 V; low-power mode enabled; running on MCLK (19.2 MHz)		-	3.9	-	mA
		idle state (DSP disabled); on pin VDDD; operating mode with load R_L = 8 Ω; no output signal; no output capacitance; DC-to-DC converter in adaptive boost mode; V_{BAT} = 4.0 V; low-power mode disabled; running on MCLK (19.2 MHz)		-	5.2	-	mA
		power-down state; on pin VDDD; DC-to-DC in power-down mode; T_j = 25 °C; running on MCLK (19.2 MHz).		-	124	-	µA
Pins FS, BCK, DATAI, ADS1, ADS2, SCL, SDA, RST, TRST, MCLK (input)							
V_{IH}	HIGH-level input voltage			0.7V_{DDD}	-	V_{DDD}	V
V_{IL}	LOW-level input voltage			-	-	0.3V_{DDD}	V
C_{in}	input capacitance		[2]	-	-	3	pF
I_{LI}	input leakage current	1.8 V on input pin		-	-	0.1	µA
		1.8 V on input pin RST; (90 kΩ pull-down)		-	90	120	µA
		1.8 V on input pin TRST; (20 kΩ pull-down)		-	20	30	µA
Pins DATAO, INT push-pull output stages (output)							
V_{OH}	HIGH-level output voltage	I_{OH} = 4 mA		V_{DDD} − 0.4	-	-	V
V_{OL}	LOW-level output voltage	I_{OL} = 4 mA		-	-	400	mV
Pins SDA, open-drain outputs, external 10 kΩ resistor to V_{DDD}							
V_{OH}	HIGH-level output voltage	I_{OH} = 4 mA		V_{DDD} − 0.4	-	-	V
V_{OL}	LOW-level output voltage	I_{OL} = 4 mA		-	-	400	mV
Pins OUTP, OUTN							
R_{DSon}	total drain-source on-state resistance	(PMOS+NMOS transistors)		-	430	520	mΩ

Symbol	Parameter	Conditions		Min	Typ	Max	Unit
Protection							
$T_{act(th\_prot)}$	thermal protection activation temperature			130	-	-	°C
$V_{uvp(VBAT)}$	undervoltage protection on pin VBAT			2.3	-	2.7	V
$I_{O(ocp)}$	overcurrent protection output current			2.5	-	-	A
DC-to-DC converter							
V_{BST}	voltage on pin V_{BST}	DCVOS = "111111"; fixed boost mode and switching amplifier		9.8	10	10.2	V

[1] L_{BST} = boost converter inductance; R_L = load resistance; L_L = load inductance.
[2] This parameter is not tested during production; the value is guaranteed by design and checked during product validation.

12.2 AC characteristics

Table 10. AC characteristics

All parameters are guaranteed for V_{BAT} = 4.0 V; V_{DDD} = V_{DDE} = 1.8 V; V_{DDP} = V_{BST} = 10 V, adaptive boost mode; L_{BST} = 1 µH[1]; R_L = 8 Ω[1]; L_L = 44 µH[1]; f_i = 1 kHz; f_s = 48 kHz; T_{amb} = 25 °C; default settings, unless otherwise specified.

Symbol	Parameter	Conditions		Min	Typ	Max	Unit
Amplifier output power							
$P_{o(AVG)}$	average output power	THD+N = 1 %					
		R_L = 8 Ω; L_L = 44 µH; V_{BAT} = 4.0 V		5.30	5.60	-	W
		R_L = 32 Ω; L_L = 30 µH; V_{BAT} = 4.0 V		1.10	1.50	-	W
Amplifier output pins (OUTP and OUTN)							
$\|V_O(offset)\|$	output offset voltage after trimming	absolute value, after trimming; V_{DDP} = 3.4 V to 10 V; V_{BAT} = 3.4 V to 5 V		-	-	1.0	mV
Amplifier performances							
η_{po}	output power efficiency	on pin V_{BAT}; input: 100 Hz sine wave; DC-to-DC in adaptive boost mode, V_{BAT} = 4.0 V; P_o = 600 mW	[2]	-	91	-	%
		on pin V_{BAT}; input: 100 Hz sine wave; DC-to-DC in adaptive boost mode; V_{BAT} = 4.0 V; P_o = 4 W	[2]	-	82	-	%
THD+N	total harmonic distortion-plus-noise	P_o = 2.0 W; R_L = 8 Ω; L_L = 44 µH	[3]	-	0.015	0.09	%
		P_o = 0.1 W; R_L = 32 Ω; L_L = 44 µH	[3]	-	0.04	0.09	%
$V_{n(o)}$	output noise voltage	a-weighted; no input signal; low noise mode;	[2] [4]	-	14	18	µV
DR	dynamic range	a-weighted; V_{BAT} = 3.4 V to 5 V; S/N = maximum signal (at THD = 1 %) − output noise voltage ($V_{n(o)}$); no signal applied	[2]	110	114	-	dB
S/N	signal-to-noise ratio	a-weighted; V_{BAT} = 3.4 V to 5 V; S/N = maximum signal (at THD = 1 %) − output noise voltage ($V_{n(o)}$); signal applied	[2]	100	-	-	dB
PSRR	power supply rejection ratio (from V_{BAT})	booster in follower mode (V_{DDP} = V_{BAT}); f_{ripple} = 217 Hz square wave; V_{ripple} = 50 mV_{pp}; V_{BAT} = 4.0 V		70	80	-	dB
		booster in follower mode (V_{DDP} = V_{BAT}); f_{ripple} = 20 Hz to 1 kHz sine wave; V_{ripple} = 200 mV_{RMS}; V_{BAT} = 3.4 V to 5.0 V		70	80	-	dB
		booster in follower mode (V_{DDP}=V_{BAT}); f_{ripple} = 1 kHz to 20 kHz sine wave; V_{ripple} = 200 mV_{RMS}; V_{BAT} = 3.4 V to 5.0 V		55	64	-	dB
ΔG	gain variation over frequency	BW = 20 Hz to 15 kHz; V_{BAT} = 3.4 V to 5 V; P_o = 2.0 W		−0.1	-	+0.7	dB
V_{POP}	pop noise	at mode transition and gain change; with C_L < 200 pF[5]		-	-	2	mV
R_L	load resistance			8	16	32	Ω
$f_{rsn(tr)}$	transducer resonance frequency			120	160	1000	Hz
C_L	load capacitance	[6]		-	200	1000	pF

Symbol	Parameter	Conditions		Min	Typ	Max	Unit
L_L	load inductance			30	-	-	µH
f_{sw}	switching frequency	directly coupled to the TDM input frequency		-	384	-	kHz
$G_{(TDM-VO)}$	TDM to V_O gain	INPLEV = 0 dB		6	-	21	dBV
		INPLEV = −6 dB		0	-	15	dBV
Amplifier power-up, power-down, and propagation delays							
$t_{d(on)PLL}$	PLL turn-on delay time	PLL locked on BCK		-	1.3	-	ms
		PLL locked on FS		-	0.3	-	ms
		PLL locked on MCLK		-	1.3	-	ms
$t_{d(on)amp}$	amplifier turn-on delay time	[7]		-	55	-	µs
$t_{d(pd)}$	turn-off delay time			-	115	-	µs
$t_{d(alarm)}$	alarm delay time			-	300	-	ms
t_{PD}	propagation delay		[4]	-	650	700	µs
Booster inductance							
L	inductance			0.33	1.0	2.2	µH
$f_{s(bst)}$	boost switching frequency	fixed boost; V_{DDP} = 10 V; I_{load} = 1 A; f_s = 48 kHz		-	2.05		MHz
Current-sensing performance							
$\Delta V_{sense}/I_{sense}$	V_{sense}/I_{sense} ratio mismatch	pilot tone = 100 mVpk[8]		-	2	-	%
THD+N	total harmonic distortion-plus-noise	on current sensing; V_{in} = −12 dBFS		-	-	0.75	%
S/N	signal-to-noise ratio	on current sensing; I_o = 1 A (peak); a-weighted		62	65	-	dB
Brownout detection (BOD)							
$V_{th(BOD)}$	BOD threshold voltage	BODTHLVL = "10"[9]		1.55	1.575	1.6	V
$V_{hys(BOD)}$	BOD hysteresis voltage	BODHYS = 1		-	20	-	mV
$t_{t(BOD)}$	BOD delay time	BODFILT = "10"		-	10	-	µs
Clocks							
$t_{jit(p-p)}$	input clock jitter	MCLK		-	0.5	1.0	ns
		BCK (3.072 MHz)		-	1.0	2.0	ns
		FS[10]		-	-	20	ns
$\delta_{i(clk)}$	clock input duty cycle	MCLK		40	-	60	%

[1] L_{BST} = boost converter inductance; R_L = load resistance; L_L = load inductance.
[2] This parameter is not tested during production; the value is guaranteed by design and checked during product validation.
[3] L_{BST} = boost converter inductor; R_L = load resistance; L_L = load inductance.
[4] Only supports f_s = 48 kHz.
[5] When C_L exceeds 200 pF, low-power mode must be disabled.
[6] When C_L exceeds 200 pF, low-power mode must be disabled.
[7] At power-up, data is output on OUTP/OUTN after $t_{d(on)amp} + t_{d(on)PLL}$.
[8] Intended for temperature protection. In combination with NXP Semiconductors temperature protection, a temperature accuracy of ±10 °C can be realized.
[9] Recommended setting.
[10] When the PLL is locked on FS, the system is less sensitive to jitter.

12.3 TDM timing characteristics

Table 11. TDM bus interface characteristics

All parameters are guaranteed for V_{BAT} = 4.0 V; V_{DDD} = V_{DDE} = 1.8 V; V_{DDP} = V_{BST} = 10 V, adaptive boost mode; L_{BST} = 1 µH[1]; R_L = 8 Ω[1]; L_L = 44 µH[1]; f_i = 1 kHz; f_s = 48 kHz; T_{amb} = 25 °C; default settings, unless otherwise specified.

Symbol	Parameter	Conditions		Min	Typ	Max	Unit
f_s	sampling frequency	on pin FS	[2]		48	-	kHz
f_{clk}	clock frequency	on pin BCK	[2]	$32f_s$	-	$384f_s$	kHz
t_{su}	set-up time	FS edge to BCK HIGH	[3]	10	-	-	ns
		DATA edge to BCK HIGH		10	-	-	ns
t_h	hold time	BCK HIGH to FS edge	[3]	10	-	-	ns
		BCK HIGH to DATA edge		10	-	-	ns

[1] L_{BST} = boost converter inductance; R_L = load resistance; L_L = load inductance.
[2] The TDM bit clock input (BCK) is used as a clock input for the amplifier and the DC-to-DC converter. The BCK and FS signals must be present for the clock to operate correctly.
[3] This parameter is not tested during production; the value is guaranteed by design and checked during product validation

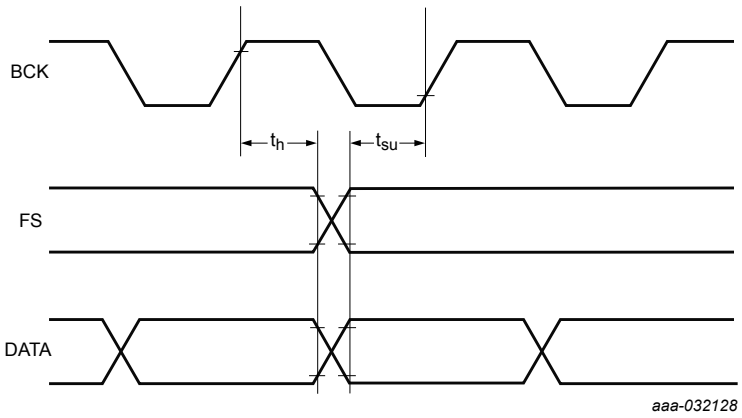


Figure 4. TDM timing

12.4 I²C timing characteristics

Table 12. I²C-bus interface characteristics

All parameters are guaranteed for V_{BAT} = 4.0 V; V_{DDD} = V_{DDE} = 1.8 V; V_{DDP} = V_{BST} = 10 V, adaptive boost mode; L_{BST} = 1 µH[1]; R_L = 8 Ω[1]; L_L = 44 µH[1]; f_i = 1 kHz; f_s = 48 kHz; T_{amb} = 25 °C; default settings, unless otherwise specified.

Symbol	Parameter	Conditions		Min	Typ	Max	Unit
f_{SCL}	SCL clock frequency			-	-	400	kHz
t_{LOW}	LOW period of the SCL clock			1.3	-	-	µs
t_{HIGH}	HIGH period of the SCL clock			0.6	-	-	µs
t_r	rise time	SDA and SCL signals	[2]	20 + 0.1C_b	-	-	ns
t_f	fall time	SDA and SCL signals	[2]	20 + 0.1C_b	-	-	ns
$t_{HD;STA}$	hold time (repeated) START condition		[3]	0.6	-	-	µs
$t_{SU;STA}$	set-up time for a repeated START condition			0.6	-	-	µs
$t_{SU;STO}$	set-up time for STOP condition			0.6	-	-	µs
t_{BUF}	bus free time between a STOP and START condition			1.3	-	-	µs
$t_{SU;DAT}$	data set-up time			100	-	-	ns
$t_{HD;DAT}$	data hold time			0	-	-	µs
t_{SP}	pulse width of spikes that must be suppressed by the input filter		[4]	0	-	50	ns
C_b	capacitive load for each bus line			-	-	400	pF

[1] L_{BST} = boost converter inductance; R_L = load resistance; L_L = load inductance.
[2] C_b is the total capacitance of one bus line in pF. The maximum capacitive load for each bus line is 400 pF.
[3] After this period, the first clock pulse is generated.
[4] To be suppressed by the input filter.

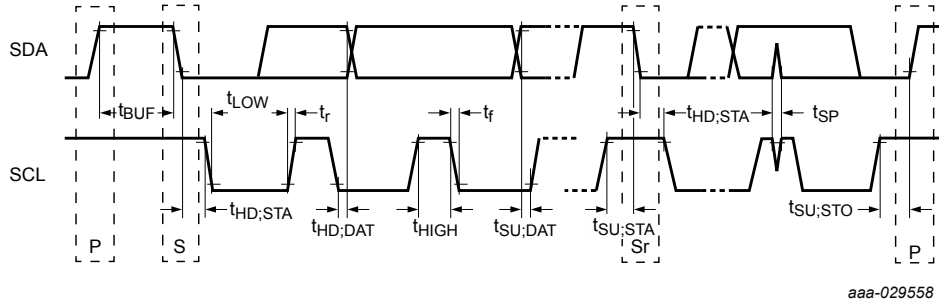


Figure 5. I2C timing

13 Application information

13.1 External components

The DC-to-DC converter requires a battery supply voltage capacitor (C_{VBAT}), an output capacitor (C_{VDDP}), and an inductor (L_{BST}) to work properly. The nominal values of these components are 22 µF, 33 µF, and 1 µH, respectively. If a larger coil is used, the capacitance must also be increased. A 1 µF decoupling capacitor (C_{VDDD}) must be connected close to the V_{DDD} pin. The V_{DDE} pin must be connected externally to the V_{DDD} pin. One 4.7 kΩ resistor, R_{VS}, must be connected between each voltage sensing input and its corresponding amplifier output (VSP/OUTP and VSN/OUTN).

13.1.1 DC-to-DC converter output capacitor

A ceramic capacitor is required at the output of the DC-to-DC converter (C_{VDDP}).

Capacitors constructed using X5R (−55 °C to +85 °C) or X7R (−55 °C to +125 °C) dielectric materials are preferred because they are compact, feature low ESR and are sufficiently stable over a wide temperature range. The capacitance value decreases over the DC biasing voltage range (50 % to 85 % decrease). Consequently, the selected capacitor must have a nominal value three to four times higher than the required minimum effective capacitance.

Note: *The DC-to-DC converter capacitor connected to pin VBST (C_{VDDP}) is critical for stability. The recommended effective value (the capacitance value at the maximum boost voltage) of C_{VDDP} depends on the coil inductance, and is given in Table 13. The position of the capacitor and the layout of the board are also critical. Connect C_{VDDP} as close as possible to the BST and GNDB pins without vias in the PCB tracks.*

In many applications, it is desirable to limit the height of components as much as possible. Limiting the height of the componetns can be achieved for C_{VDDP} by placing two smaller capacitors in parallel. The rated voltage must be 10 V or higher.

Table 13. DC-to-DC minimum output capacitor

Effective coil value (at maximum current)	Minimum effective capacitance (at the boost voltage)
0.47 µH	3.4 µF
1 µH[1]	4 µF
1.5 µH	12 µF
2.2 µH	20 µF

[1] Recommended value. Higher values are not preferred because of the cost and space required for the coil (L_{BST}) and the capacitor (C_{VDDP}).

The values in the Table 14 and Table 15 are guaranteed for capacitors rated X5R or higher.

Table 14. DC-to-DC recommended output capacitor

Specification	Conditions	Min	Typ	Max	Unit
nominal capacitance; 20 % tolerance	6 Ω or 8 Ω load; 1 µH inductor (L_{BST})	-	33	-	µF
minimum effective capacitance		4	-	-	µF

Specification	Conditions	Min	Typ	Max	Unit
rated voltage		10	-	-	V

13.1.2 Battery capacitor

C_{VBAT} must be at least half the value of C_{VDDP}.

Table 15. Battery recommended capacitor

Specification	Min	Typ	Max	Unit
nominal capacitance; 20 % tolerance	-	22	-	µF
rated voltage	10	-	-	V

13.1.3 DC-to-DC converter inductor

An inductor is required at the output of the DC-to-DC converter (L_{BST}). For stability, the inductance of the coil should remain above 0.33 µH and below 2.2 µH under all conditions. The most commonly available values are 1 µH and 1.5 µH. A nominal value 1 µH provides the optimum balance between current capability, component size and efficiency.

The choice of inductor is configured using DCCV bit. It is strongly influenced by the impedance of the haptic device used in the application. The haptic impedance determines the output current of the DC-to-DC converter. The coil current contains a ripple around the average current resulting in a peak inductor current, $I_{L(peak)}$. The value of the peak inductor current is determined by the minimum required battery voltage, the boost voltage and the inductor value.

Recommend specifications for the DC-to-DC convertor inductor are given in Table 16.

Table 16. DC-to_DC recommended inductor

Specification	Min	Typ	Max	Unit
nominal inductance; 20 % tolerance	0.47[1]	-	2.2	µH
DC resistance	-	-	100	mΩ
saturation current	-	4.2	-	A

[1] 0.33 µH (min) at $I_{L(peak)}$.

13.2 PCB layout considerations

When designing the PCB layout for a class-D amplifier and booster, great care must be taken circuit. The layout can affect the haptic performance, the booster performance, the electromagnetic compatibility (EMC) performance, and/or the thermal performance.

13.2.1 DC-to-DC converter stability

To avoid stability problems, the DC-to-DC converter output capacitor must be connected as close as possible to GNDB/GNDP via thick tracks. ly must also be connected to V_{BST}/ V_{DDP} in the top layer.

13.2.2 EMC considerations

EMC standards define to what degree a (sub)system is susceptible to externally imposed electromagnetic influences and to what degree a (sub)system is responsible for emitting electromagnetic signals in standby and in normal operating modes.

EMC immunity and emission values are normally measured over a frequency range from 180 kHz up to 3 GHz.

The coupling capacitors on pins V_{DDD}, V_{DDP} and V_{BAT} and the booster inductor L_{BST} must be placed close to the TFA9914, referenced to a solid ground plane. The design must include a solid ground plane below the IC.

When designing a filterless class-D amplifier, long haptic cables (or traces) must be avoided. Long haptic cables have a negative effect on electromagnetic emissions. Use haptic traces/cables of less than 10 cm.

13.3 Application diagrams

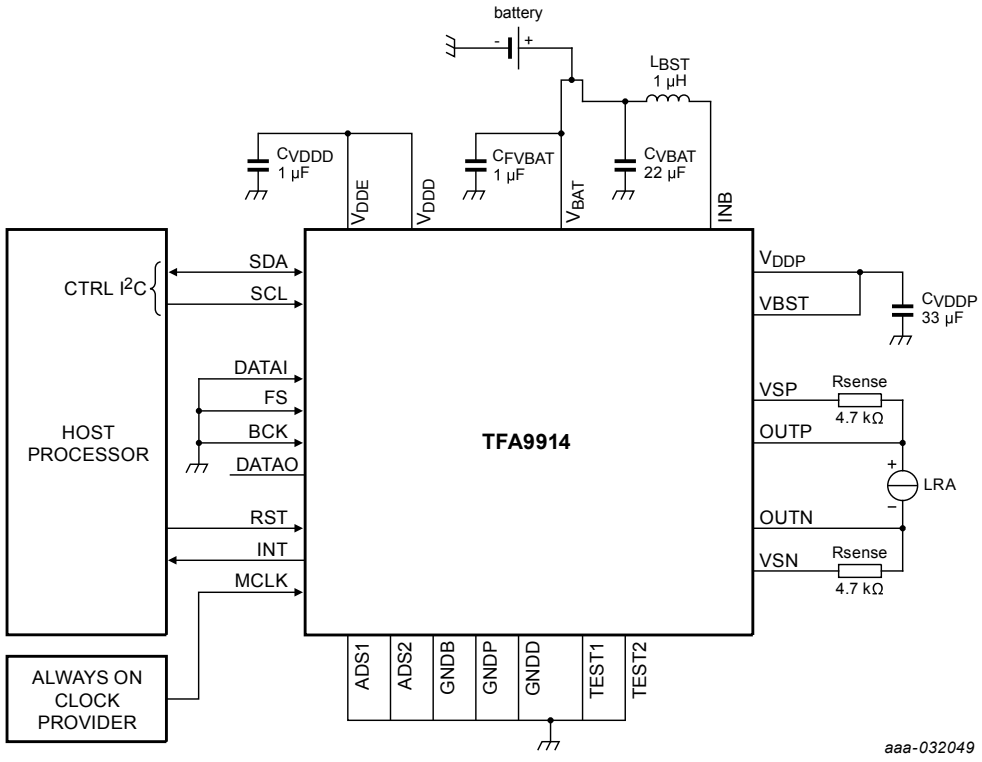


Figure 6. Haptic application with always-on MCLK

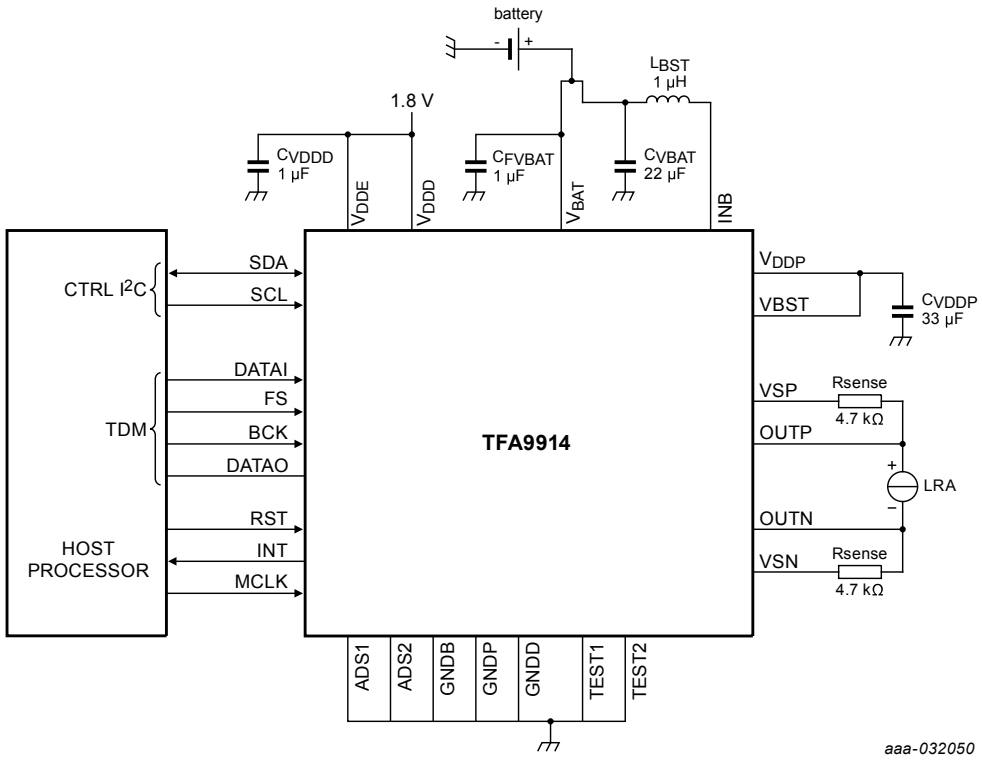


Figure 7. Haptic application with TDM stream

14 Package outline

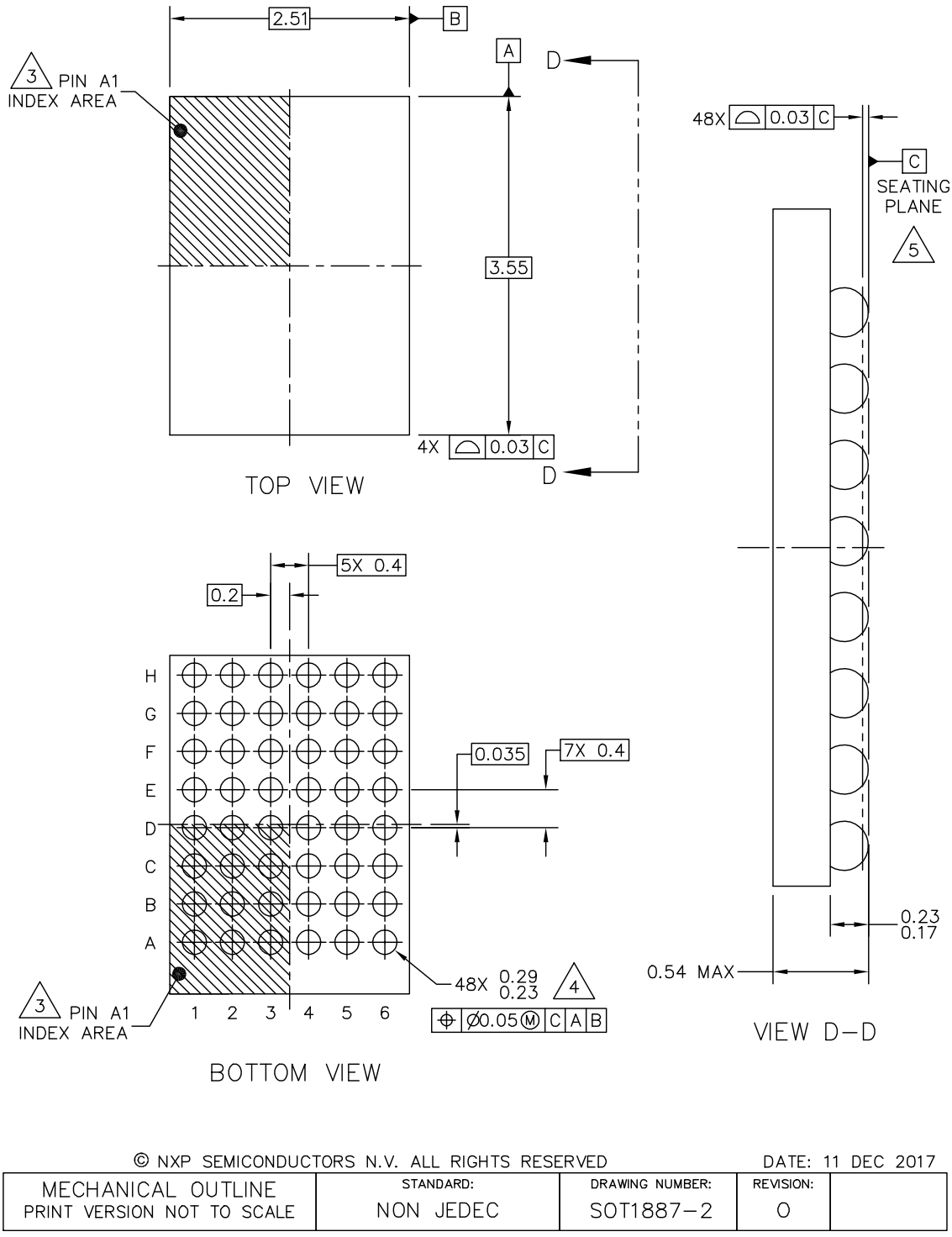


Figure 8. TFA9914UK package outline SOT1887-2 (WLCSP48)

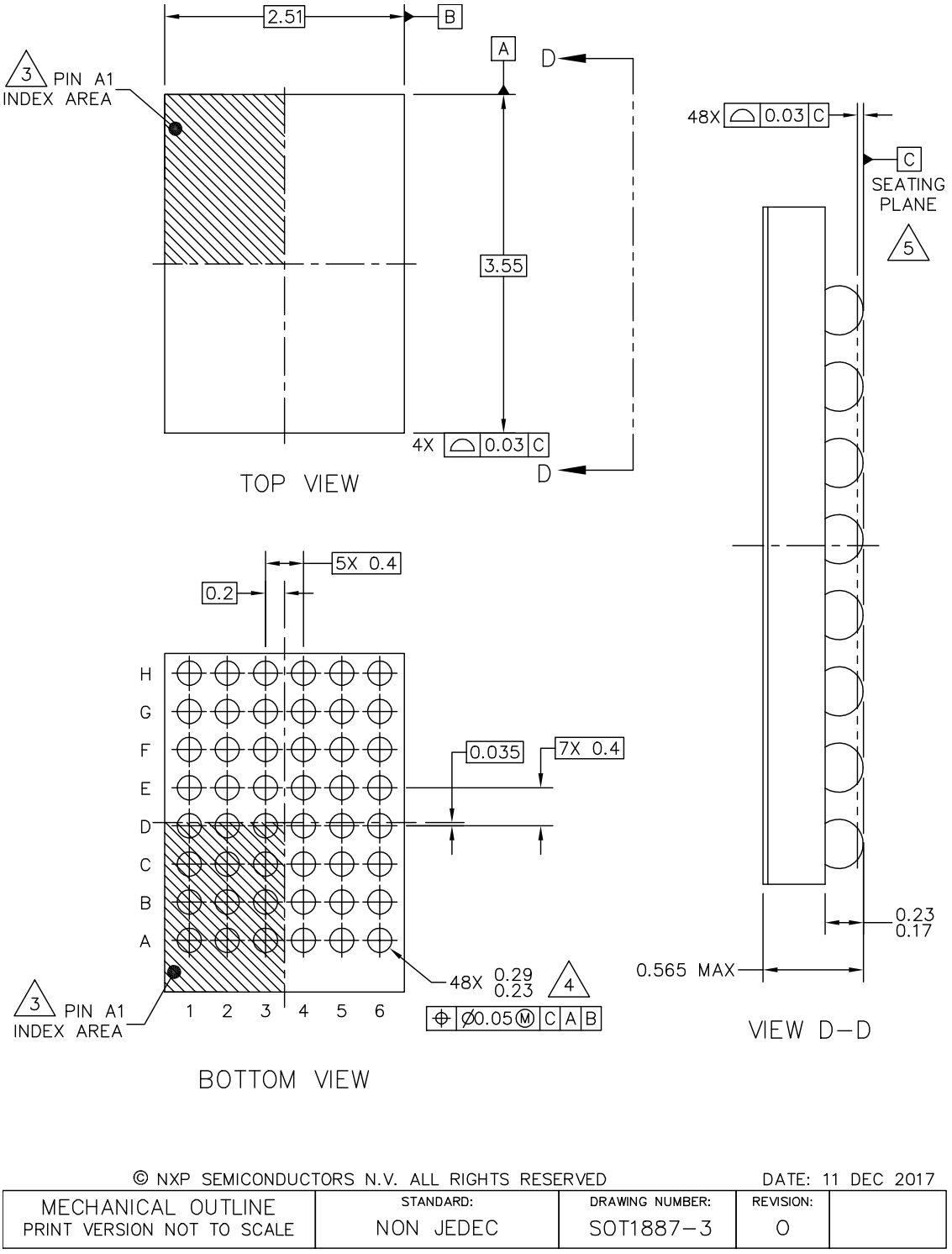


Figure 9. TFA9914BUK package outline SOT1887-3 (WLCSP48)

15 Soldering of WLCSP packages

15.1 Introduction to soldering WLCSP packages

This section provides a very brief insight into a complex technology. A more in-depth account of soldering wafer level chip-scale packages (WLCSP) can be found in the "Wafer Level Chip Scale Package" application note (AN10439) and in the "Surface mount reflow soldering description" application note (AN10365).

Wave soldering is not suitable for this package.

All NXP Semiconductors WLCSP packages are lead-free.

15.2 Board mounting

Board mounting of a WLCSP requires several steps:

1. Solder paste printing on the PCB
2. Component placement with a pick and place machine
3. The reflow soldering itself

15.3 Reflow soldering

Key characteristics in reflow soldering are:

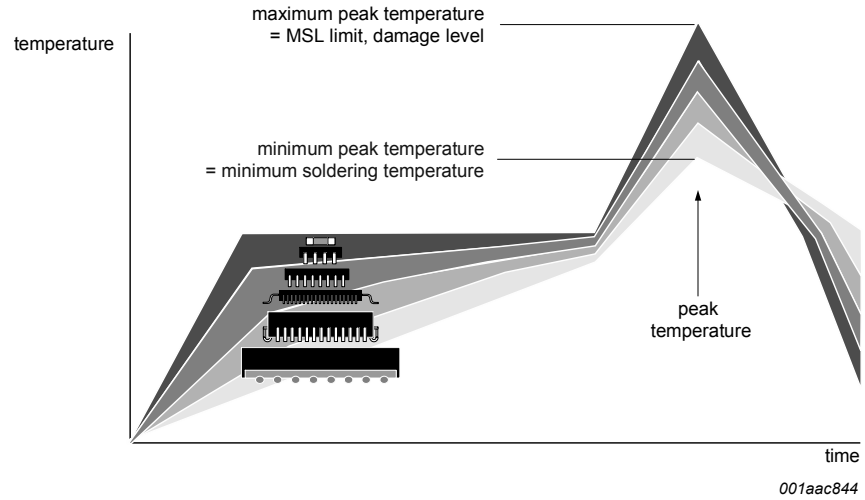
- Lead-free versus SnPb soldering
  A lead-free reflow process usually leads to higher minimum peak temperatures (see Figure 10) than a SnPb process, thus reducing the process window.
- Solder paste printing issues, such as smearing, release, and adjusting the process window for a mix of large and small components on one board.
- Reflow temperature profile
  This profile includes preheat, reflow (in which the board is heated to the peak temperature), and cooling down. The peak temperature must be high enough for the solder to make reliable solder joints (a solder paste characteristic) while it is low enough to not damage the packages and/or boards. The peak temperature of the package depends on package thickness and volume and is classified in accordance with Table 17.

Table 17. Lead-free process (from J-STD-020D)

Package thickness (mm)	Package reflow temperature (°C)		
	Volume (mm^3)		
	< 350	350 to 2 000	> 2 000
< 1.6	260	260	260
1.6 to 2.5	260	250	245
> 2.5	250	245	245

Moisture sensitivity precautions, as indicated on the packing, must be respected at all times.

Studies have shown that small packages reach higher temperatures during reflow soldering (see Figure 10).



MSL: Moisture sensitivity level

Figure 10. Temperature profiles

For further information on temperature profiles, see the "Surface mount reflow soldering description" application note (AN10365).

15.3.1 Stand-off

The stand-off between the substrate and the chip is determined by:

- The amount of printed solder on the substrate
- The size of the solder land on the substrate
- The bump height on the chip

The higher the stand-off, the better the stresses are released due to thermal expansion coefficient (TEC) differences between substrate and chip.

15.3.2 Quality of solder joint

When the entire solder land has been wetted by the solder from the bump, a flip-chip joint is considered to be a good joint. The surface of the joint must be smooth and the shape symmetrical. The soldered joints on a chip must be uniform. Voids in the bumps after reflow can occur during the reflow process in bumps with a high ratio of the bump diameter to bump height, i.e. low bumps with a large diameter. No failures have been found to be related to these voids. To monitor defects such as bridging, open circuits, and voids, solder joint inspection after reflow can be done using X-ray.

15.3.3 Rework

In general, rework is not recommended. Rework is the process of removing the chip from the substrate and replacing it with a new chip. If a chip is removed from the substrate, most solder balls of the chip are damaged. In that case,do not reuse the chip.

When the substrate is heated until it is certain that all solder joints are molten, the device can be removed. The chip can then be carefully removed from the substrate without damaging the tracks and solder lands on the substrate. Use plastic tweezers to remove the device, because metal tweezers can damage the silicon. The surface of the substrate must be carefully cleaned and all solder and flux residues and/or underfill must be removed. When a new chip is placed on the substrate, use the flux process instead of solder on the solder lands. Apply flux on the bumps at the chip side as well as on the solder pads on the substrate. Place and align the new chip while viewing with a microscope. To reflow the solder, use the solder profile shown in the "Surface mount reflow soldering description" application note (AN10365).

15.3.4 Cleaning

Cleaning can be done after reflow soldering.

16 Revision history

Table 18. Revision history

Document ID	Release date	Data sheet status	Change notice	Supersedes
TFA9914_SDS v.1	20190516	Product data sheet	-	-

17 Legal information

17.1 Data sheet status

Document status[1][2]	Product status[3]	Definition
Objective [short] data sheet	Development	This document contains data from the objective specification for product development.
Preliminary [short] data sheet	Qualification	This document contains data from the preliminary specification.
Product [short] data sheet	Production	This document contains the product specification.

[1] Please consult the most recently issued document before initiating or completing a design.
[2] The term 'short data sheet' is explained in section "Definitions".
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Tables

Tab. 1. Quick reference data 4
Tab. 2. Ordering information 6
Tab. 3. Pinning 9
Tab. 4. Address selection via pins ADS1 and ADS2 12
Tab. 5. I2C-bus write cycle 13
Tab. 6. I2C-bus read cycle 13
Tab. 7. Limiting values 14
Tab. 8. Thermal characteristics 15
Tab. 9. DC characteristics 16
Tab. 10. AC characteristics 19
Tab. 11. TDM bus interface characteristics 21
Tab. 12. I2C-bus interface characteristics 22
Tab. 13. DC-to-DC minimum output capacitor 23
Tab. 14. DC-to-DC recommended output capacitor 23
Tab. 15. Battery recommended capacitor 24
Tab. 16. DC-to_DC recommended inductor 24
Tab. 17. Lead-free process (from J-STD-020D) 29
Tab. 18. Revision history 32

Figures

Fig. 1. Block diagram 7
Fig. 2. Bump configuration 8
Fig. 3. Bump mapping 8
Fig. 4. TDM timing 21
Fig. 5. I2C timing 22
Fig. 6. Haptic application with always-on MCLK 25
Fig. 7. Haptic application with TDM stream 26
Fig. 8. TFA9914UK package outline SOT1887-2 (WLCSP48) 27
Fig. 9. TFA9914BUK package outline SOT1887-3 (WLCSP48) 28
Fig. 10. Temperature profiles 30

Contents

1 General description 1
2 Features and benefits 2
3 Applications 3
4 Quick reference data 4
5 Ordering information 6
6 Block diagram 7
7 Pinning information 8
7.1 Pinning 8
8 Functional description 11
9 I2C-bus interface and register settings 12
9.1 TFA9914 addressing 12
9.2 I2C-bus write cycle 12
9.3 I2C-bus read cycle 13
10 Limiting values 14
11 Thermal characteristics 15
12 Characteristics 16
12.1 DC Characteristics 16
12.2 AC characteristics 19
12.3 TDM timing characteristics 21
12.4 I2C timing characteristics 22
13 Application information 23
13.1 External components 23
13.1.1 DC-to-DC converter output capacitor 23
13.1.2 Battery capacitor 24
13.1.3 DC-to-DC converter inductor 24
13.2 PCB layout considerations 24
13.2.1 DC-to-DC converter stability 24
13.2.2 EMC considerations 25
13.3 Application diagrams 25
14 Package outline 27
15 Soldering of WLCSP packages 29
15.1 Introduction to soldering WLCSP packages 29
15.2 Board mounting 29
15.3 Reflow soldering 29
15.3.1 Stand-off 30
15.3.2 Quality of solder joint 30
15.3.3 Rework 31
15.3.4 Cleaning 31
16 Revision history 32
17 Legal information 33

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