RICHTEK®

RTQ9154-QA

45W, Ultra-Low Noise, High-Efficiency, Digital-Input 4-Channel Automotive Audio Amplifier with I²C Diagnostics

1 General Description

The RTQ9154-QA is an ultra-low output noise, high-efficiency, four-channel class-D audio power amplifier. It delivers 4x27W into 4Ω at 10% THD+N from a 14.4V supply in automotive applications. It can achieve over 86% power efficiency with an output switching frequency of up to 2.1MHz for clarity, which enables a cost-optimized solution in a very small PCB size. Additionally, the RTQ9154-QA can be set either above the AM band, which eliminates the AM-band interference and reduces output filter size and cost, or below the AM band to optimize efficiency.

The RTQ9154-QA is fully configurable through the I²C bus interface and features comprehensive diagnostics array specially designed for automotive applications.

Its built-in protection circuits provide thermal fold-back, over-temperature, overcurrent, overvoltage, and undervoltage protections and report error status.

The RTQ9154-QA is a 3-wire device that receives all clocks from external sources with standard I²S and TDM (Time-Division Multiplexing) formats. It supports a wide range of input sampling rates from 32kHz to 192kHz. The device is offered in a 56-pin RTSSOP package with the exposed thermal pad facing up.

The recommended junction temperature range is –40°C to 150°C, and the ambient temperature range is –40°C to 125°C.

2 Features

- **AEC-Q100 Grade 1 Qualified**
- **I²S and TDM Input**
- **4x22W, THD + N = 1%, 4Ω, 14.4V BTL**
- **4x27W, THD + N = 10%, 4Ω, 14.4V BTL**
- **2x45W, THD + N = 10%, 2Ω, 14.4V PBTL**
- **THD + N is 0.03%**
- **SNR up to 115dB**
- **Ultra-Low Quiescent Current Mode**
- **Ultra-Low Noise = 18μV**
- **Switching Frequency up to 2.1MHz**
- **Sampling Frequency from 32kHz to 192kHz**
- **I²C Control with 16 Address Options**
- **Built-In Thermal Fold-Back and Clip Detection**
- **Load Diagnostics**
  - **Output Open Load and Short Load**
  - **Output Short to Ground or Power**
  - **DC and AC Coupled Load Detection**
- **Protection Features**
  - **Output Short-Circuit**
  - **Overvoltage and Undervoltage**
  - **Overcurrent Warning and Protection**
  - **Over-Temperature**
  - **DC Protection**
  - **40V Load Dump**
- **Ambient Temperature Range: –40°C to 125°C**
- **Junction Temperature Range: –40°C to 150°C**

3 Applications

- Automotive Head Units
- In-Vehicle Infotainment

4 Ordering Information

RTQ9154 □ - QA □

Packing
A: Standard

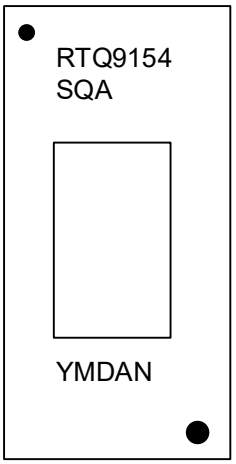
Grade
QA: AEC-Q100 Qualified
Screened by High Temperature

Package Type(1)
S: RTSSOP-56 (Exposed Pad)

Note 1.

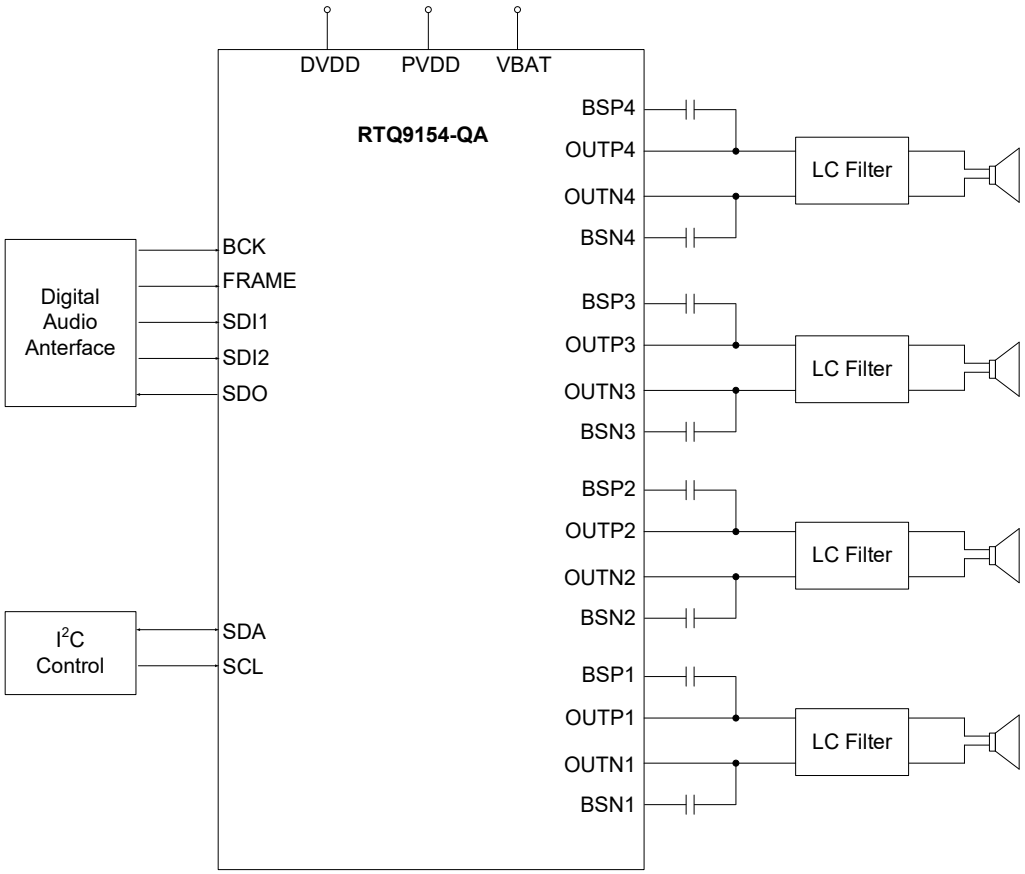
Richtek products are Richtek Green Policy compliant and marked with (1) indicates compatible with the current requirements of IPC/JEDEC J-STD-020.

5 Marking Information



RTQ9154S: Product Code
QA: Automotive Product Grade
YMDAN: Date Code

6 Simplified Application Circuit



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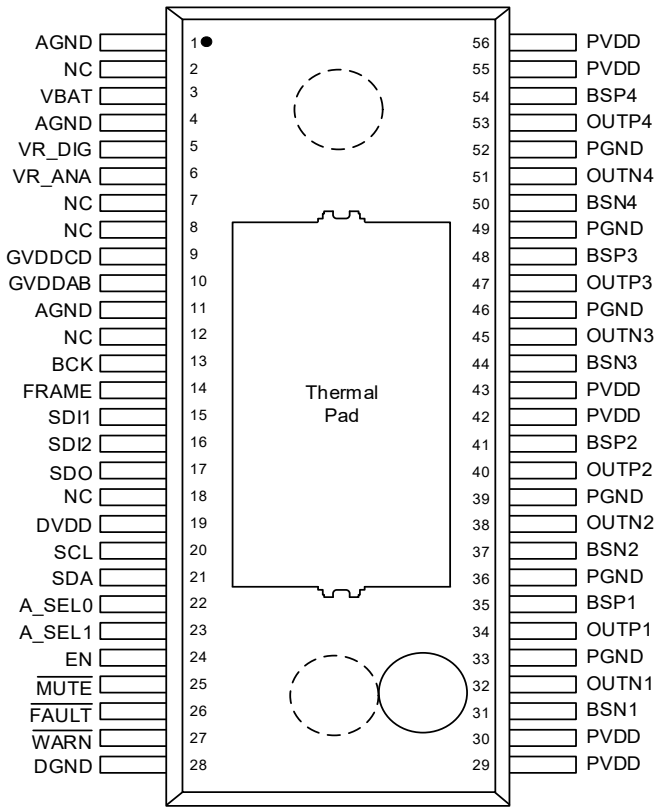
7 Pin Configuration

(TOP VIEW)



RTSSOP-56 (Exposed Pad)

8 Functional Pin Description

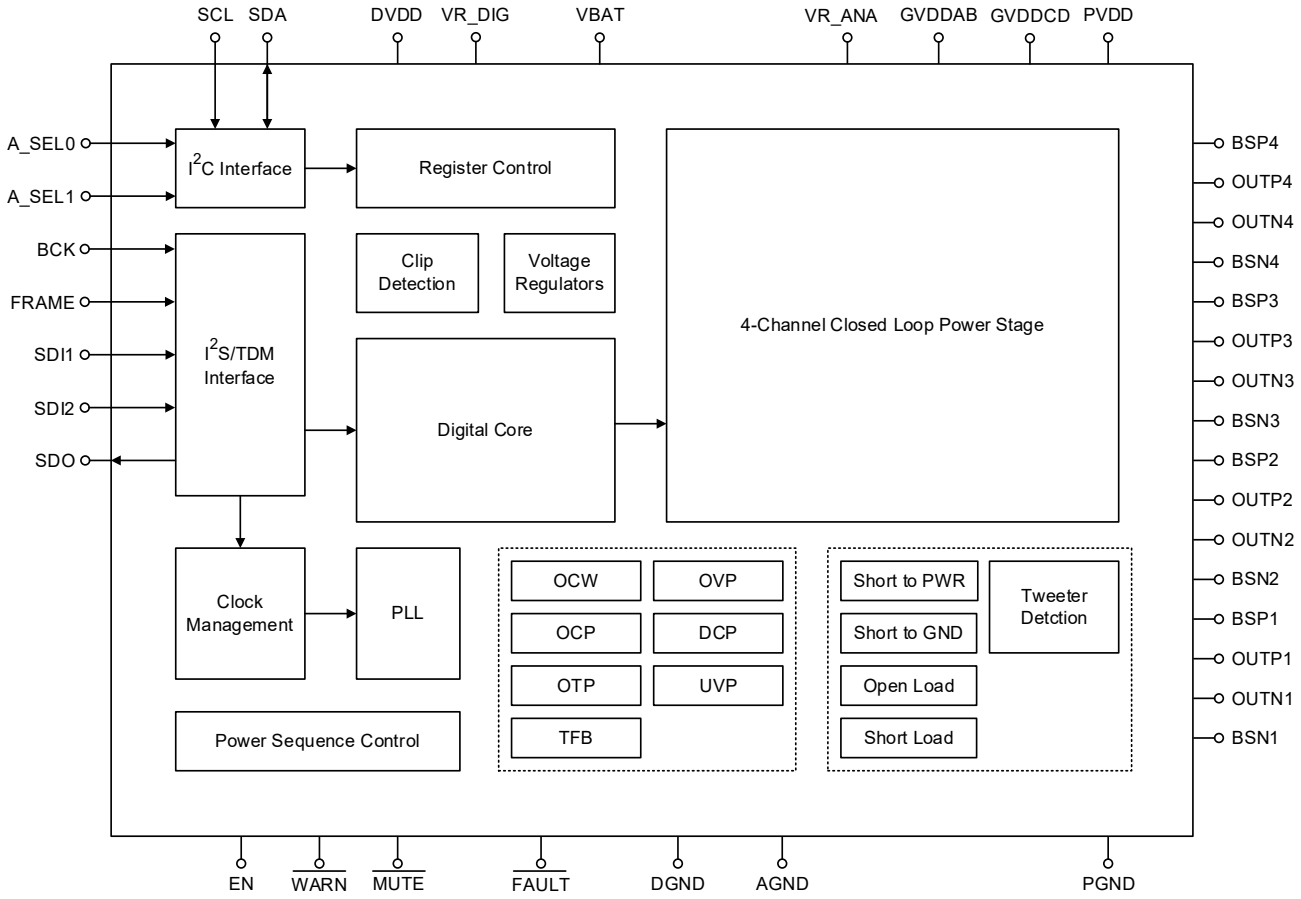
Pin No.	Pin Name	IO	Pin Function
1, 4, 11	AGND	GND	Ground for analog circuit.
2, 7, 8, 12,18	NC	NC	No internal connection.
3	VBAT	PWR	Battery voltage input.
5	VR_DIG	PWR	Voltage regulator output is 1.8V; tied to DVDD when DVDD = 1.8V
6	VR_ANA	PWR	Voltage regulator output, 5.1V.
9	GVDDCD	PWR	Gate drive voltage for CH1/CH2.
10	GVDDAB	PWR	Gate drive voltage for CH3/CH4.
13	BCK	DI	I^2S bit clock.
14	FRAME	DI	I^2S frame clock.
15	SDI1	DI	I^2S data in for CH1/CH2
16	SDI2	DI	I^2S data in for CH3/CH4.
17	SDO	DO	I^2S data out or tied to GND.
19	DVDD	PWR	Power supply for I/O, 3.3V/1.8V.
20	SCL	DI	I^2C reference clock.
21	SDA	DI/DO	I^2C data.

Pin No.	Pin Name	IO	Pin Function
22	A_SEL0	DI	I^2C address pins_0.
23	A_SEL1	DI	I^2C address pins_1.
24	EN	DI	Enable control. Pull low for shutdown; pull high to enable the chip.
25	$\overline{MUTE}$	DI	Mute control. Pull low for mute; pull high for unmute.
26	$\overline{FAULT}$	DO	Fault flag. When a fault occurs, the level goes low; normal operation is indicated by a high level.
27	$\overline{WARN}$	DO	Warning flag. When a warning occurs, the level goes low; normal operation is indicated by a high level.
28	DGND	GND	Ground for digital circuit.
29, 30, 42, 43, 55, 56	PVDD	PWR	Supply voltage for power stage.
31	BSN1	PWR	Bootstrap for CH1 negative output.
32	OUTN1	NO	Negative PWM output of CH1.
33, 36, 39, 46, 49, 52	PGND	GND	Ground for power stage.
34	OUTP1	PO	Positive PWM output of CH1.
35	BSP1	PWR	Bootstrap for CH1 positive output.
37	BSN2	PWR	Bootstrap for CH2 negative output.
38	OUTN2	NO	Negative PWM output of CH2.
40	OUTP2	PO	Positive PWM output of CH2.
41	BSP2	PWR	Bootstrap for CH2 positive output.
44	BSN3	PWR	Bootstrap for CH3 negative output.
45	OUTN3	NO	Negative PWM output of CH3.
47	OUTP3	PO	Positive PWM output of CH3.
48	BSP3	PWR	Bootstrap for CH3 positive output.
50	BSN4	PWR	Bootstrap for CH4 negative output.
51	OUTN4	NO	Negative PWM output of CH4.
53	OUTP4	PO	Positive PWM output of CH4.
54	BSP4	PWR	Bootstrap for CH4 positive output.

8.1 IO Type Definition

- GND: Ground
- PWR: Power
- PO: Positive Output
- NO: Negative Output
- DI: Digital Input
- DO: Digital Output
- DI/DO: Digital Input and Output
- AO: Analog Output

9 Functional Block Diagram



10 Absolute Maximum Ratings

(Note 2)

- Supply Voltage, PVDD, VBAT ---------- –0.3V to 32V
- Vpeak, Transient Supply Voltage, PVDD, VBAT
  (t ≤ 400ms Exposure) ---------- –1V to 40V
- Supply Voltage, DVDD ---------- –0.3V to 6V
- Speaker Amplifier Output Voltage, OUTPx, OUTNx ---------- –10V to 32V
- Vpeak, Speaker Amplifier Output Voltage, OUTPx, OUTNx (Note 3) ---------- –10V to 37V
- BSPx, BSNx to PGND DC ---------- –0.3V to 36V
- SCL, SDA, $\overline{\text{FAULT}}$, EN, $\overline{\text{WARN}}$, $\overline{\text{MUTE}}$, A_SEL0, A_SEL1 ---------- –0.3V to 6V
- FRAME, BCK, SDI1, SDI2, SDO ---------- –0.3V to DVDD + 0.5V
- GND to DGND, PGND, AGND ---------- –0.3V to 0.3V
- VR_ANA, GVDDAB, GVDDCD ---------- –0.3V to 6V
- VR_DIG ---------- –0.3V to 4V
- Power Dissipation, P_D @ T_A = 25°C
  RTSSOP-56 (Exposed Pad) ---------- 2.86 W
- Package Thermal Resistance (Note 4)
  RTSSOP-56 (Exposed Pad), θ_{JA} ---------- 43.74 °C/W
  RTSSOP-56 (Exposed Pad), θ_{JC} ---------- 0.64°C/W
- Junction Temperature ---------- 150°C
- Lead Temperature (Soldering, 10 sec.) ---------- 260°C
- Storage Temperature Range ---------- –65°C to 150°C
- ESD Susceptibility (Note 5)
  HBM (Human Body Model) ---------- ±2kV

Note 2. Stresses beyond those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions may affect device reliability.

Note 3. The switching terminal should be used within AC peak limits. Overshoot and undershoot must be less than 100ns.

Note 4. θ_{JA} is simulated under natural convection (still air) at T_A = 25°C with the component mounted on a high effective-thermal-conductivity four-layer test board on a JEDEC 51-7 thermal measurement standard. θ_{JC} is simulated at the bottom of the package. Refer to the EVB user guide for thermal information, which includes the heat sink.

Note 5. Devices are ESD sensitive. Handling precautions are recommended.

11 Recommended Operating Conditions

(Note 6)

- Supply Input Voltage Range, DVDD ---------- 1.62V to 3.63V
- Supply Input Voltage Range, PVDD, VBAT ---------- 4.5V to 18V
- Ambient Temperature Range ---------- –40°C to 125°C
- Junction Temperature Range ---------- –40°C to 150°C

Note 6. The device is not guaranteed to function outside its operating conditions.

12 Electrical Characteristics

(PVDD = VBAT = 14.4V, DVDD = 3.3V, RL = 4Ω, f_{SW} = 2.1MHz, T_A = 25°C, unless otherwise specified.)

Parameter		Symbol	Test Conditions	Min	Typ	Max	Unit
EN, A_SEL0, A_SEL1, $\overline{MUTE}$	Input Voltage Logic-High	V_{IH}		DVDD x 0.7	--	--	V
	Input Voltage Logic-Low	V_{IL}		--	--	DVDD x 0.3	
$\overline{FAULT}$, $\overline{WARN}$	Output Voltage Logic-Low	V_{OL}	I_{PULLUP} = 3mA	--	--	0.4	V
DVDD Quiescent Current		I_{Q_DVDD}	EN = 3.3V, 0dB FS input	--	15	18	mA
DVDD Shutdown Current		I_{SHDN_DVDD}	EN = 0V, for DVDD, no load	--	--	0.2	mA
PVDD Quiescent Current (BD Mode)		$I_{Q\_PVDD\_BD}$	EN = 3.3V, switch 50% duty for PVDD = 14.4V no load	--	40	--	mA
PVDD Quiescent Current (ULQM)		I_{ULQM_PVDD}	ULQM, no load	--	0.3	1	mA
VBAT Quiescent Current (BD Mode)		$I_{Q\_VBAT\_BD}$	EN = 3.3V, switch 50% duty for VBAT = 14.4V no load	--	65	--	mA
VBAT Quiescent Current (ULQM)		I_{ULQM_VBAT}	ULQM, no load	--	2	5	mA
PVDD Shutdown Current		I_{SHDN_PVDD}	EN = 0V, no load for PVDD	--	5	20	μA
VBAT Shutdown Current		I_{SHDN_VBAT}	EN = 0V, no load for VBAT	--	13	20	μA
GVDDAB, GVDDCD		V_{GVDDAB}, V_{GVDDCD}	All channels playing, 0dB input	4.8	5.1	5.5	V
VR_ANA		V_{VR_ANA}	All channels playing, 0dB input	4.8	5.1	5.5	V
VR_DIG		V_{VR_DIG}	All channels playing, 0dB input	--	1.8	--	V
Speaker Gain Variation		ΔA_{v_amp}	Channel-to-channel gain variation	–0.5	--	0.5	dB
PWM Switching Frequency		f_{SW}	384kHz mode	--	384	--	kHz
			2112kHz mode	--	2112	--	
RMS Output Power Per Channel, BTL		P_{O_BTL}	4Ω, PVDD = 14.4V, THD + N = 1%, T_A = 75°C	20	22	--	W
			4Ω, PVDD = 14.4V, THD + N = 10%, T_A = 75°C	25	27	--	
			4Ω, PVDD = 18V, THD + N = 1%, T_A = 75°C	34	36	--	
			4Ω, PVDD = 18V, THD + N = 10%, T_A = 75°C	43	48	--	
RMS Output Power Per Channel, PBTL		P_{O_PBTL}	2Ω, PVDD = 14.4V, THD + N = 1%, T_A = 75°C	35	40	--	W
			2Ω, PVDD = 14.4V, THD + N = 10%, T_A = 75°C	45	50	--	
Total Harmonic Distortion + Noise		THD+N	1kHz, P_O =1W (BTL)	--	0.03		%
Output Integrated Noise		Vn	20Hz to 20kHz, A-weighted	--	18	25	μV

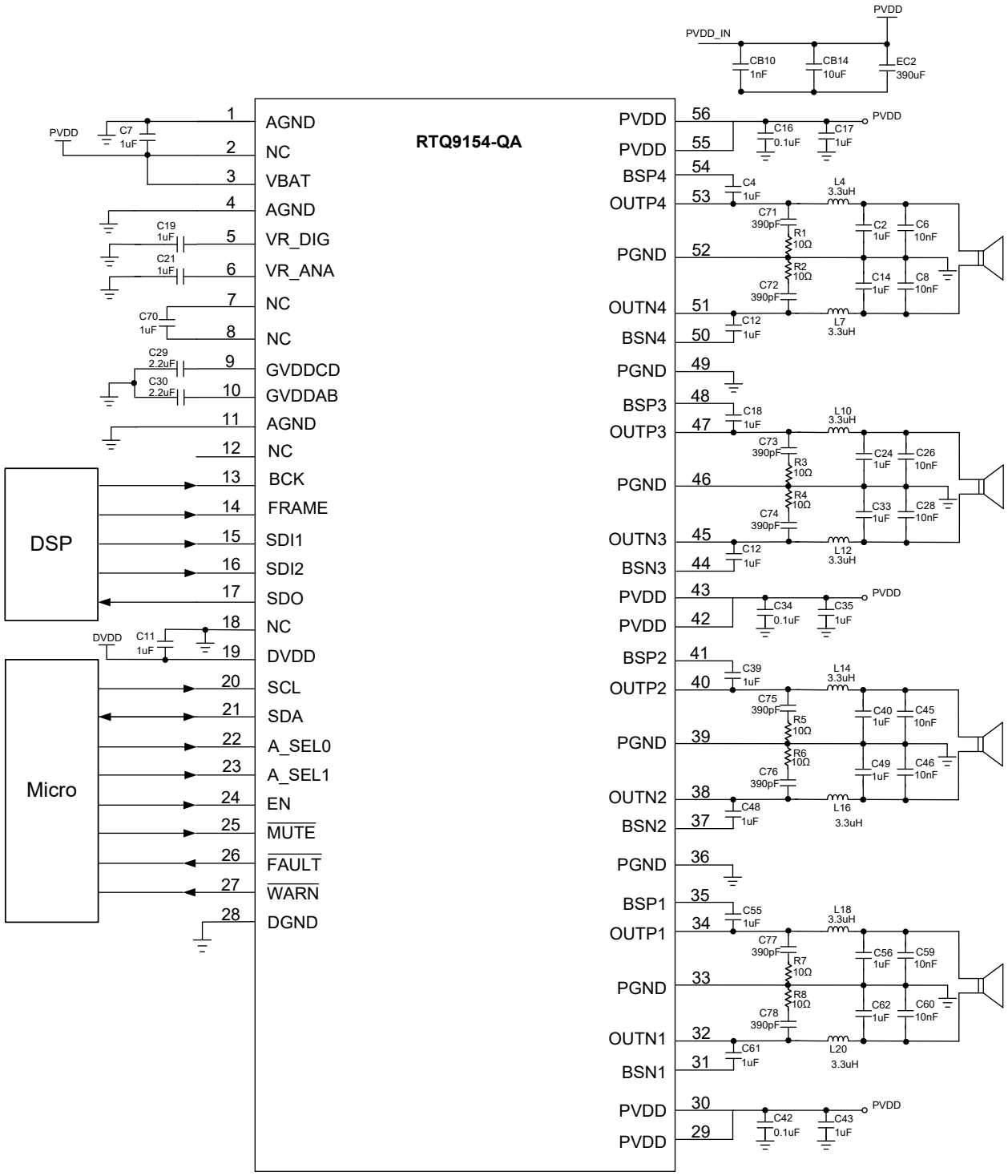
Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Output Offset Voltage	V_{OS}		–6.5	--	6.5	mV
Crosstalk	X-talk	1kHz, P_O = 1W	--	–90	--	dB
Signal-to-Noise Ratio	SNR	PVDD = 14.4V, THD + N = 10%	--	115	--	dB
Power Supply Rejection Ratio	PSRR	Frequency @1kHz	–70	–80	--	dB
Dynamic Range	DR	Input level –60dBFS	--	115	--	dB
Output Attenuation		$\overline{MUTE}$= 0V	--	100	--	dB
Efficiency	η	4-channel operating, 25W output/CH 4Ω load, PVDD = 14.4V, including inductor loss (L = 3.3μH, C = 1μF)	--	86	--	%
Global Junction Over-Temperature Warning	T_{OTWG}		--	130	--	°C
Global Junction Over-Temperature Protection	T_{OTPG}		--	160	--	°C
Over-Temperature Hysteresis	T_{OTP_HYS}		--	30	--	°C
Channel Junction Over-Temperature Warning	T_{OTWC}		--	130	--	°C
Channel Junction Over-Temperature Protection	T_{OTPC}		--	170	--	°C
Overcurrent Warning	I_{OCW}	OCW_SEL_x	--	5.8	--	A
		OCW_SEL_x	--	7.3	--	
Overcurrent Protection	I_{OCP}	Any short to supply, ground or channels	--	8	10	A
PVDD Overvoltage Protection	V_{PVDD_OVP}		--	21.5	--	V
PVDD Overvoltage Hysteresis	$V_{PVDD\_OVP\_HYS}$		--	0.6	--	V
VBAT Overvoltage Protection	V_{BAT_OVP}		--	21.5	--	V
VBAT Overvoltage Hysteresis	$V_{BAT\_OVP\_HYS}$		--	0.6	--	V
PVDD Undervoltage	V_{PVDD_UVP}		--	4	4.5	V
PVDD Undervoltage Hysteresis	$V_{PVDD\_UVP\_HYS}$		--	0.3	--	V
VBAT Undervoltage	V_{BAT_UVP}		--	4	4.5	V
VBAT Undervoltage Hysteresis	$V_{BAT\_UVP\_HYS}$		--	0.3	--	V
DC Protection	V_{DCP}	Output DC fault protection	--	0.9	--	V
Maximum Resistance to Detect a Short from the OUT Pins to PVDD	R_{S2P}		--	--	1200	Ω

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Maximum Resistance to Detect a Short from the OUT Pins to Ground	R_{S2G}		--	--	400	Ω
Short Load Detection Tolerance	R_{SL}	Other channels in Hi-Z	--	--	±0.5	Ω
Open Load	R_{OL}	Other channels in Hi-Z	40	70	--	Ω
DC Diagnostic Time	t_{DC_DIAG}	All 4 channels	--	--	100	ms
AC Impedance Accuracy	$R_{AC\_IMP\_ACC}$	Gain linearity, f = 19kHz, R_L = 2Ω to 16Ω	--	--	0.25	Ω
		Offset	--	--	±0.5	
AC Diagnostic Time	t_{AC_DIAG}	All 4 channels	--	100	--	ms
I²C Interface Electrical Characteristics						
SCL, SDA High-Level Input Threshold Voltage	V_{IH_I2C}		DVDD x 0.7	--	--	V
SCL, SDA Low-Level Input Threshold Voltage	V_{IL_I2C}		--	--	DVDD x 0.3	V
Output Low Level for SDA	V_{OL_SDA}	I_{PULLUP} = 3mA	--	--	0.4	V
SCL Clock Frequency	f_{SCL}		--	--	400	kHz
Bus Free Time Between Stop and Start Condition	t_{BUF}		1.3	--	--	µs
(Repeated) Start Hold Time	$t_{HD;STA}$		0.6	--	--	µs
(Repeated) Start Setup Time	$t_{SU;STA}$		0.6	--	--	µs
Stop Condition Setup Time	$t_{SU;STO}$		0.6	--	--	µs
Output Data Hold Time	$t_{HD;DAT\ (OUT)}$		225	--	--	ns
Input Data Hold Time	$t_{HD;DAT\ (IN)}$		0	--	900	ns
Data Setup Time	$t_{SU;DAT}$		100	--	--	ns
SCL Clock Low Period	t_{LOW}		1.3	--	--	µs
SCL Clock High Period	t_{HIGH}		0.6	--	--	µs
Fall Time of SDA and SCL Signals	t_F		20	--	300	ns
Rise Time of SDA and SCL Signals	t_R		20	--	300	ns
Pulse Width of Suppressed Spike	t_{SP}		--	--	20	ns
Slave Mode I²S Interface Electrical Characteristics						
High-Level Input Threshold Voltage	V_{IH_I2S}		DVDD x 0.7	--	--	V
Low-Level Input Threshold Voltage	V_{IL_I2S}		--	--	DVDD x 0.3	V

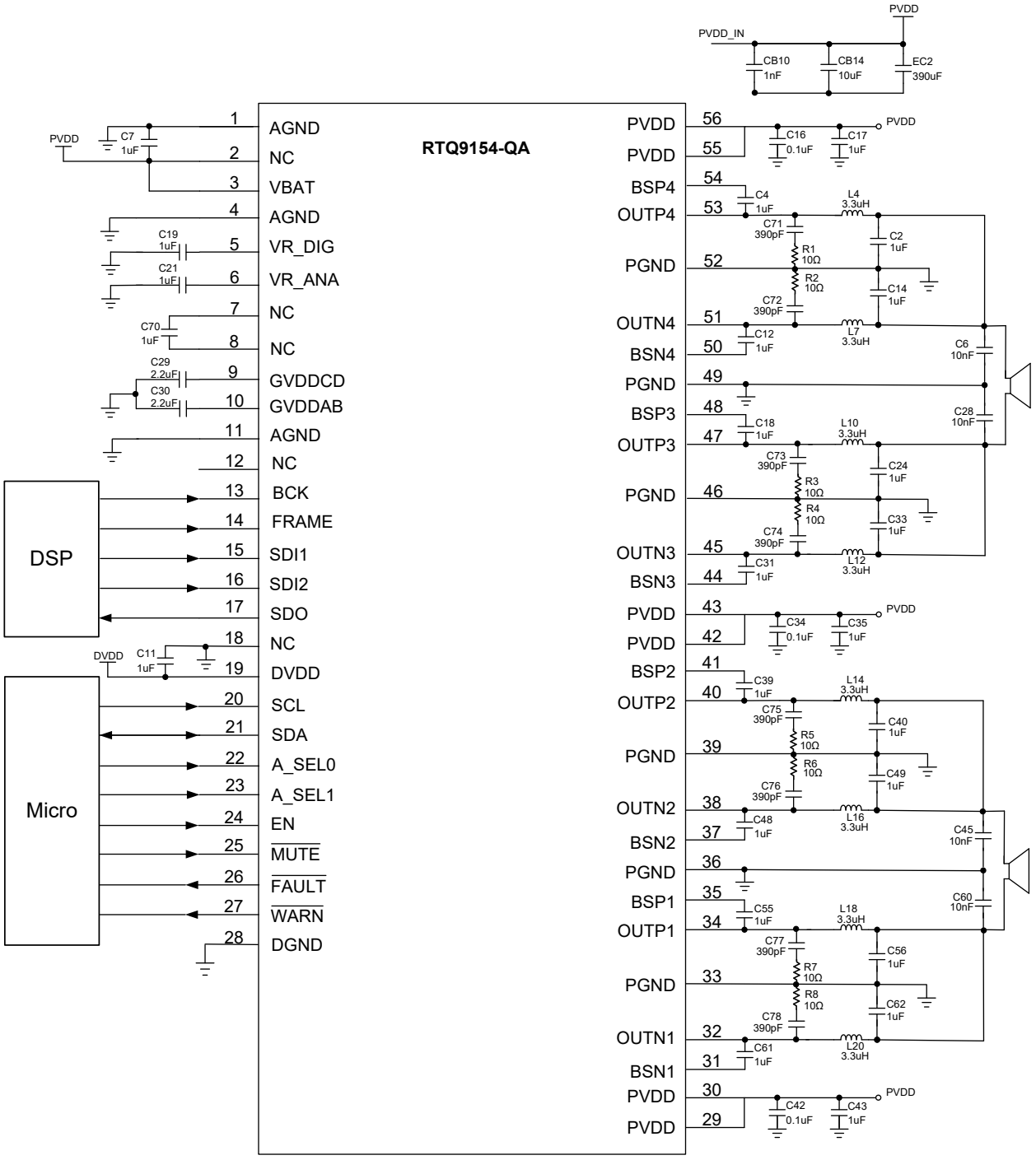
Parameter		Symbol	Test Conditions	Min	Typ	Max	Unit
SDO	SDO High-Level Output Threshold Voltage	V_{OH_SDO}		--	--	3.3	V
	SDO Low-Level Output Threshold Voltage	V_{OL_SDO}		--	--	0.4	
Frequency		f_{BCKIN}		1.024	--	24.576	MHz
Setup Time, FRAME to BCK Rising Edge		t_{SU1}		10	--	--	ns
Hold Time, FRAME from BCK Rising Edge		t_{H1}		10	--	--	ns
Setup Time, SDI to BCK Rising Edge		t_{SU2}		10	--	--	ns
Hold Time, SDI from BCK Rising Edge		t_{H2}		10	--	--	ns
Rise/Fall Time for BCK/FRAME		t_R/t_F		--	--	8	ns
I^2S Duty Cycle for Rising		%		40	--	60	%

13 Typical Application Circuit

13.1 4-Channel Bridge-Tied Load (BTL) Configuration



13.2 2-Channel Parallel Bridge-Tied Load (PBTL) Configuration



14 Timing Diagram

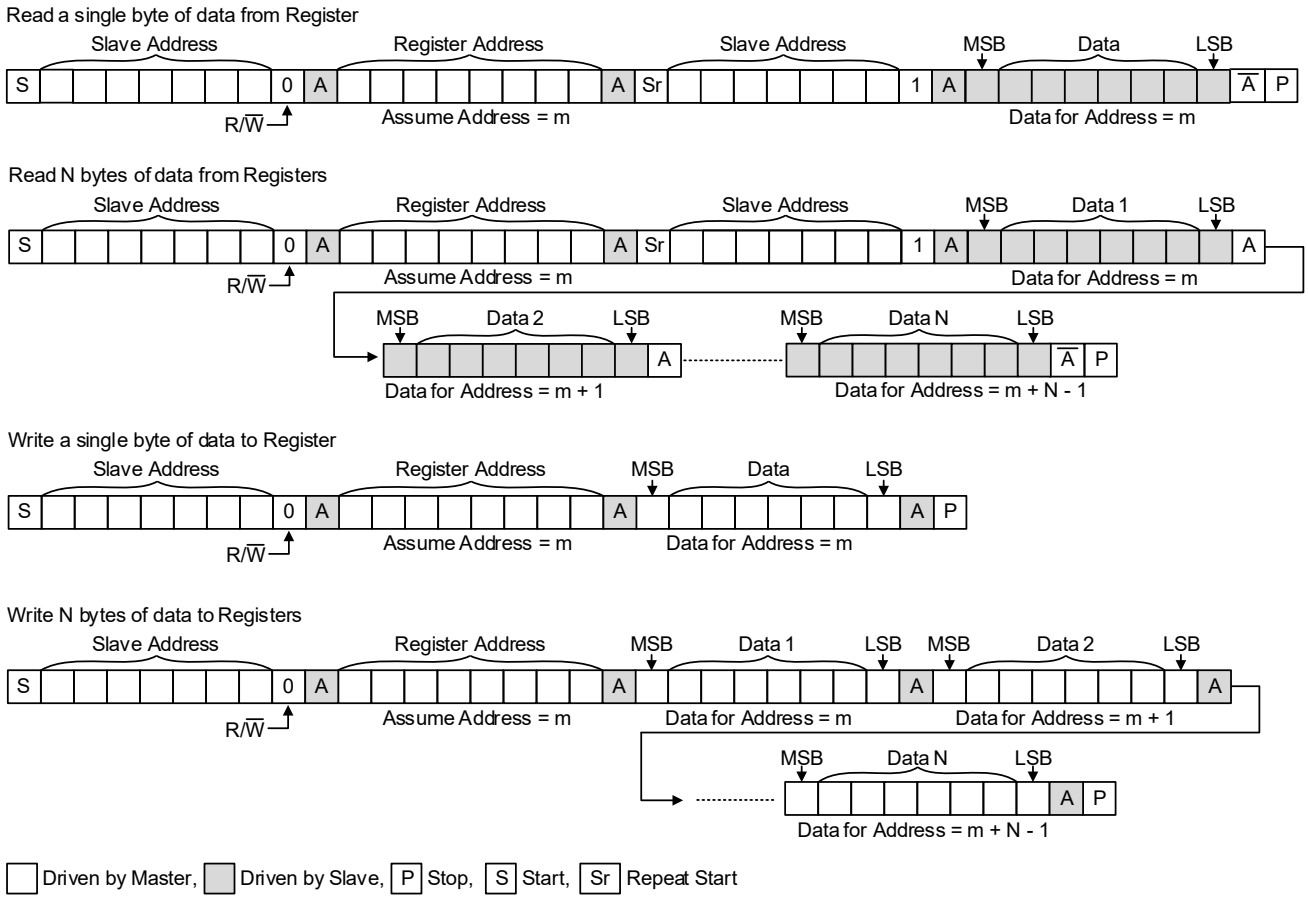


Figure 1. Read and Write Function

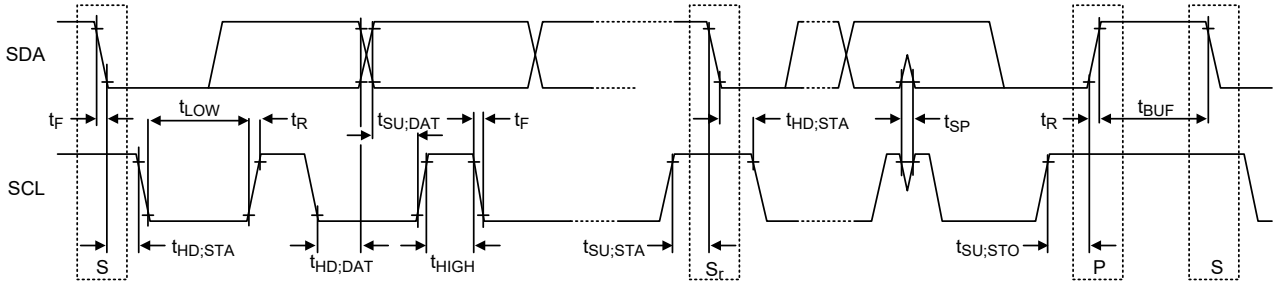


Figure 2. I²C Waveform Information

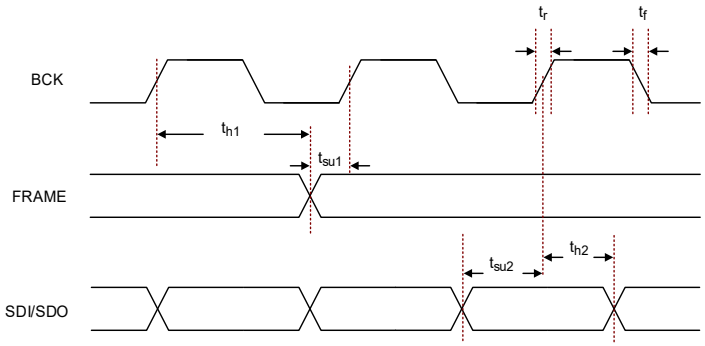


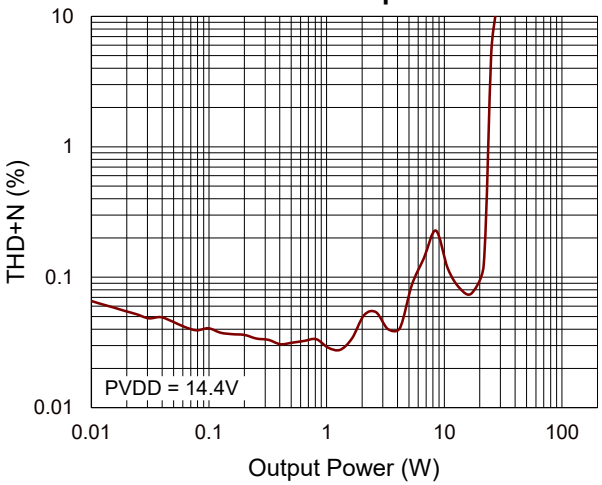
Figure 3. Timing Diagram of Slave Mode I²S Interface

15 Typical Operating Characteristics

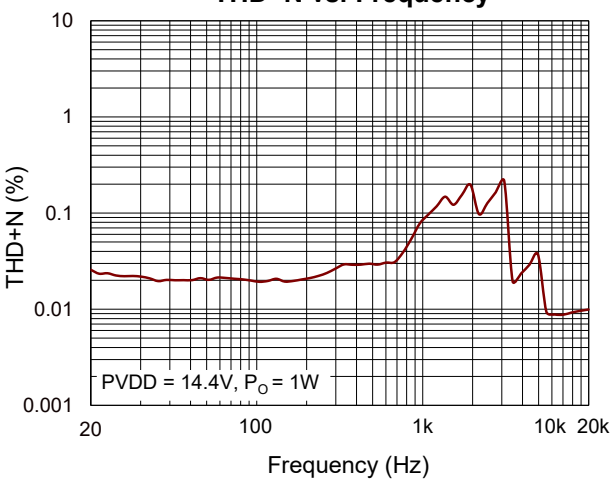
15.1 Bridge-Tied Load (BTL)

T_A = 25°C, DVDD = 3.3V, VBAT = PVDD = 14.4V, R_L = 4Ω, fin = 1kHz, f_S = 48kHz, f_{SW} = 2.1MHz, AES17 filter, LC filter: L=3.3μH – HCM1A0703V2-3R3-R, C=1μF

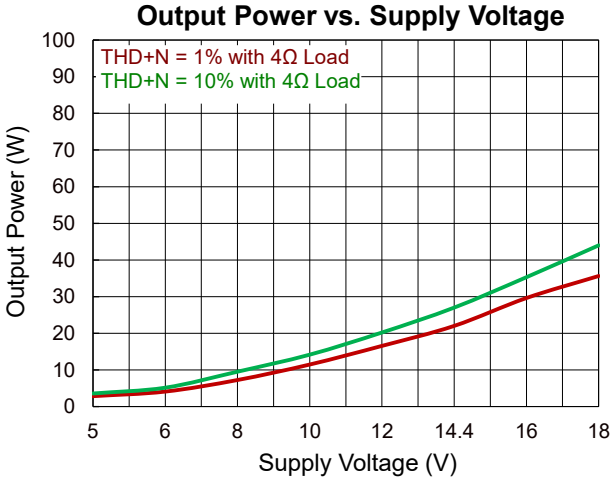
THD+N vs. Output Power



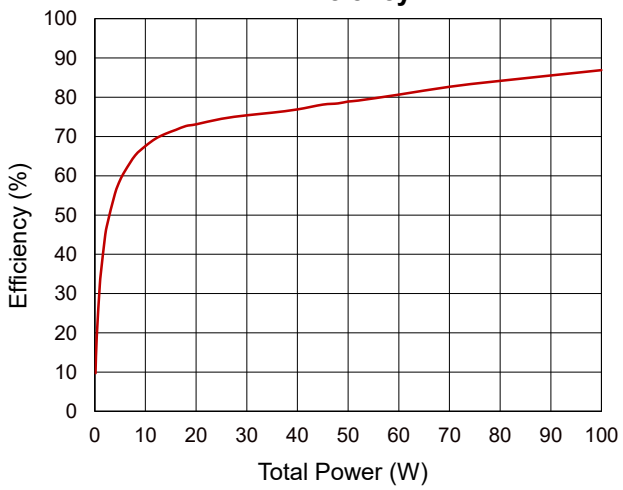
THD+N vs. Frequency



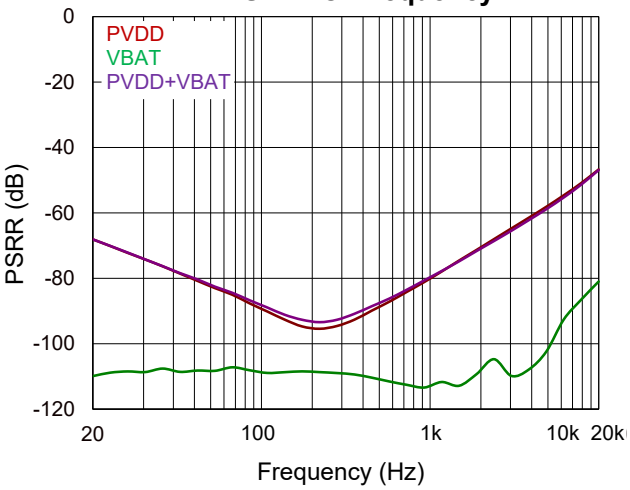
Output Power vs. Supply Voltage



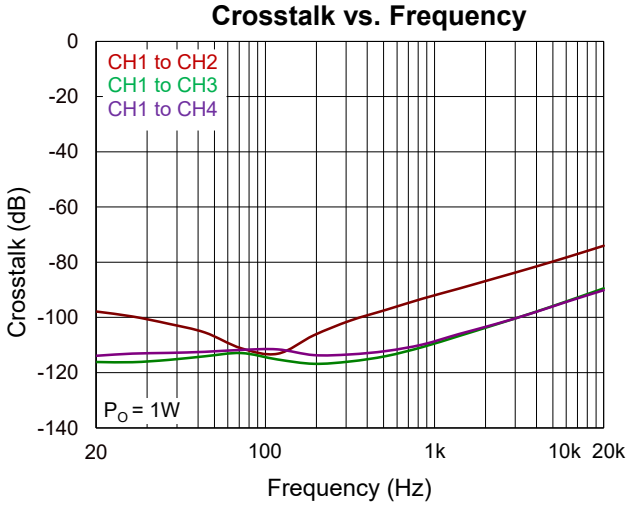
Efficiency



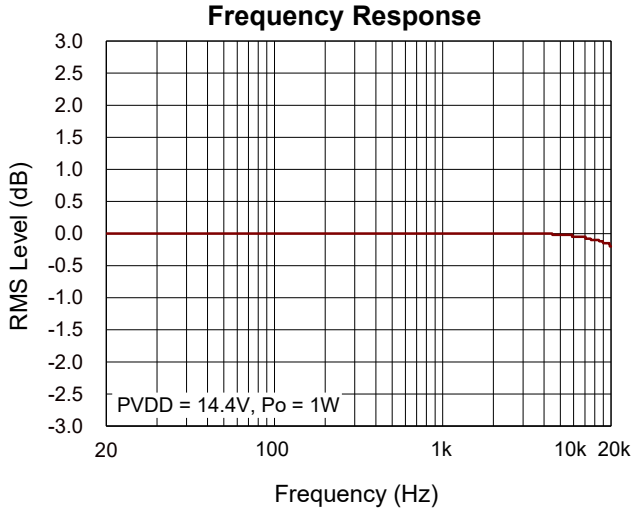
PSRR vs. Frequency



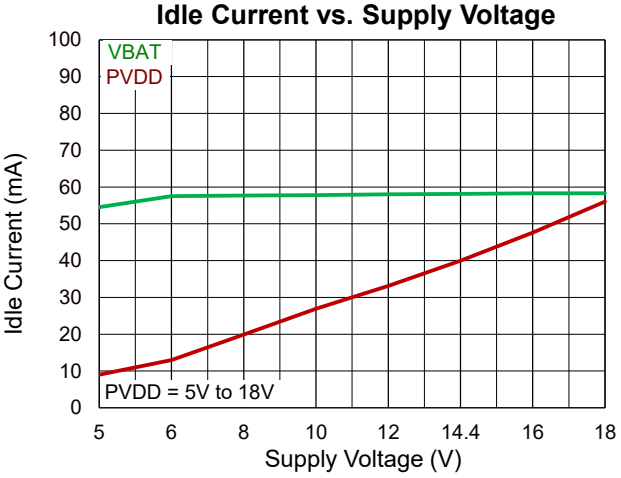
Crosstalk vs. Frequency



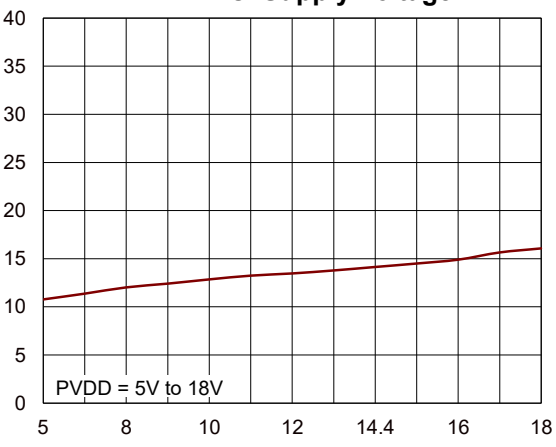
Frequency Response



Idle Current vs. Supply Voltage



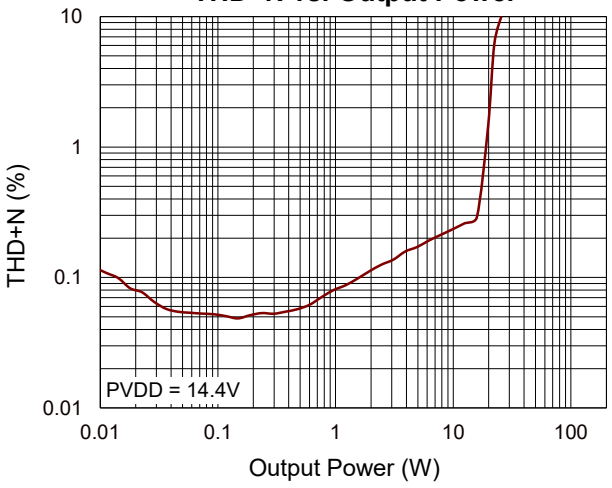
Vn vs. Supply Voltage



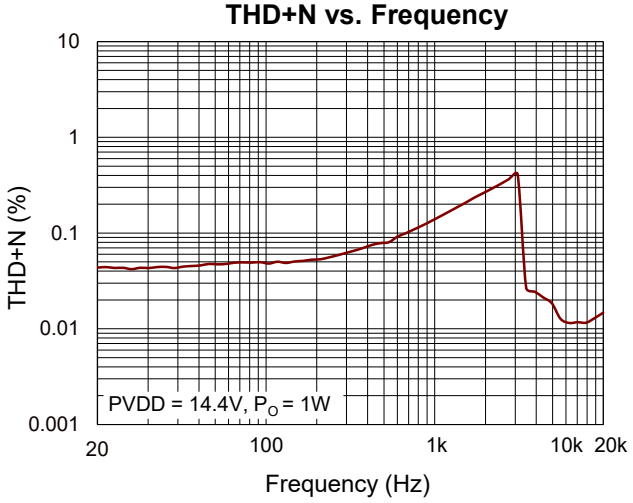
15.2 Bridge-Tied Load (BTL)

T_A = 25°C, DVDD = 3.3V, VBAT = PVDD = 14.4V, R_L = 4Ω, fin = 1kHz, f_S = 48kHz, f_{SW} = 384kHz, AES17 filter, LC filter: L=10μH – HCM1A1307V2-100-R, C=1μF

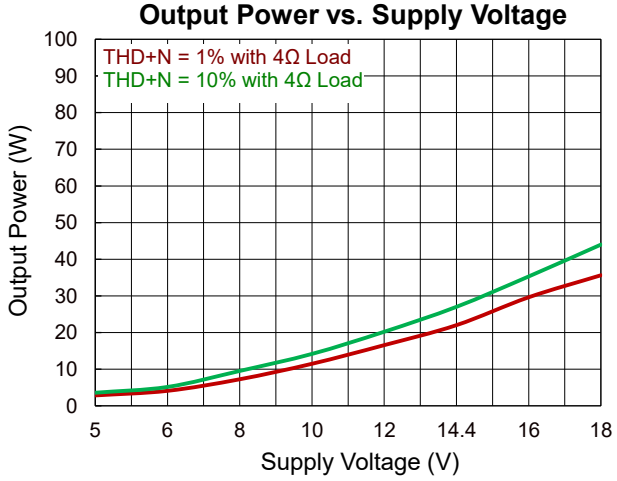
THD+N vs. Output Power



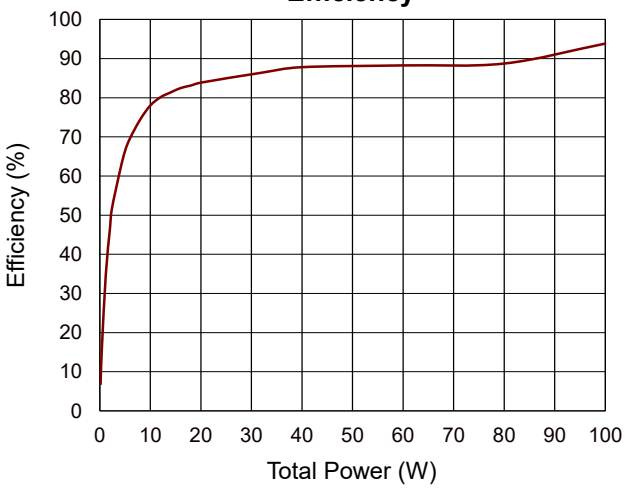
THD+N vs. Frequency



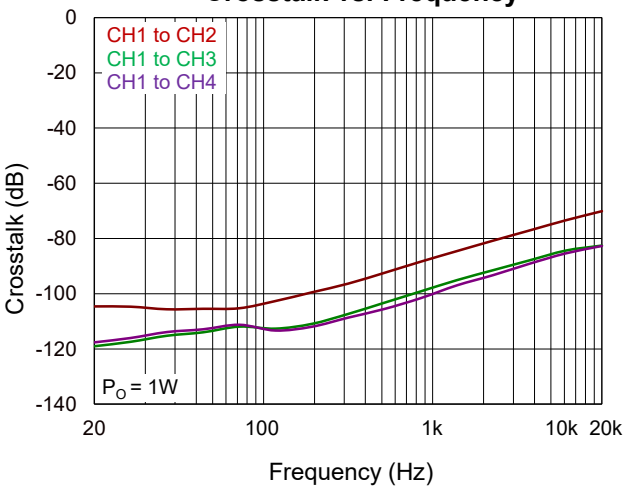
Output Power vs. Supply Voltage



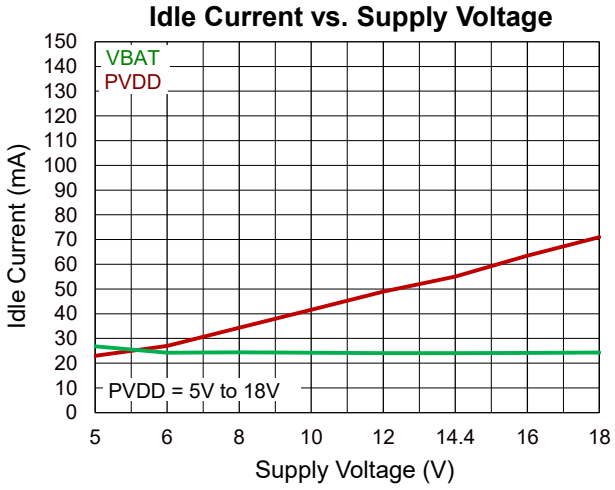
Efficiency

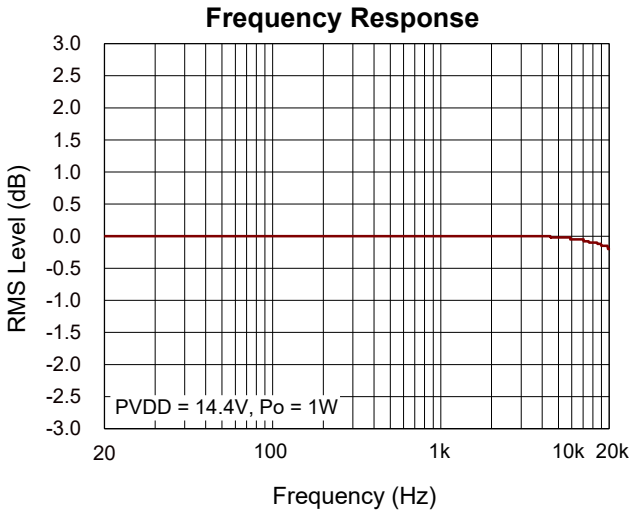


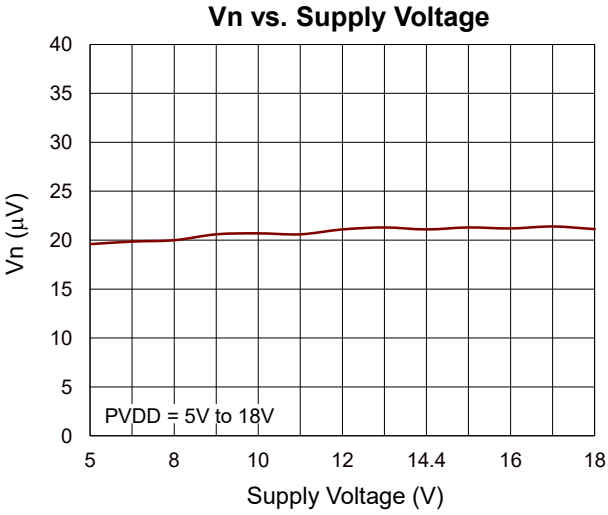
Crosstalk vs. Frequency



Idle Current vs. Supply Voltage



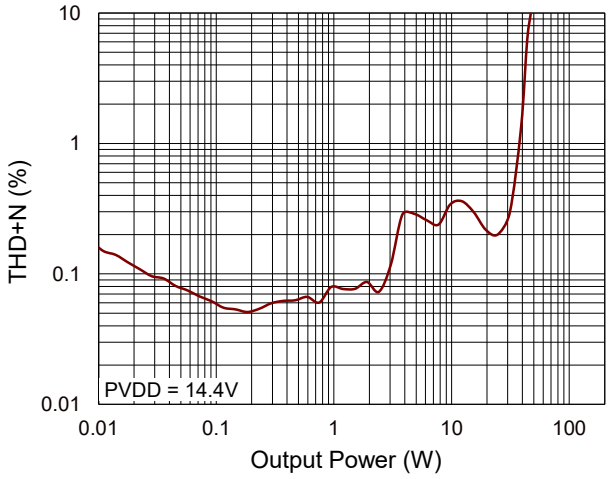




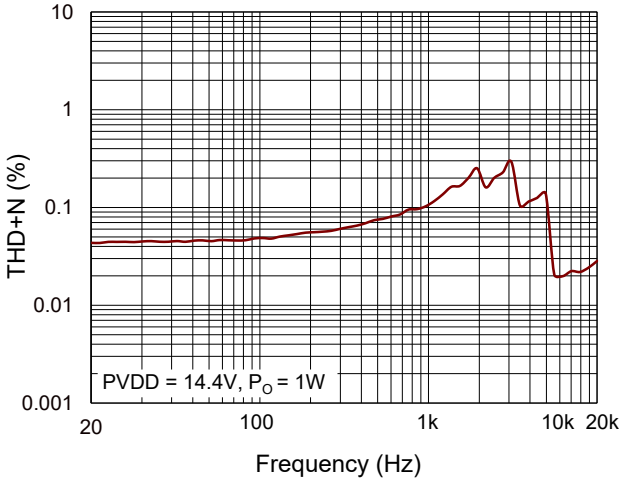
15.3 Parallel Bridge-Tied Load (PBTL)

T_A = 25°C, DVDD = 3.3V, VBAT = PVDD = 14.4V, R_L = 2Ω, fin = 1kHz, f_S = 48kHz, f_{SW} = 2.1MHz, AES17 filter, LC filter: L=3.3μF – HCM1A1104V2-3R3-R, C=1μF

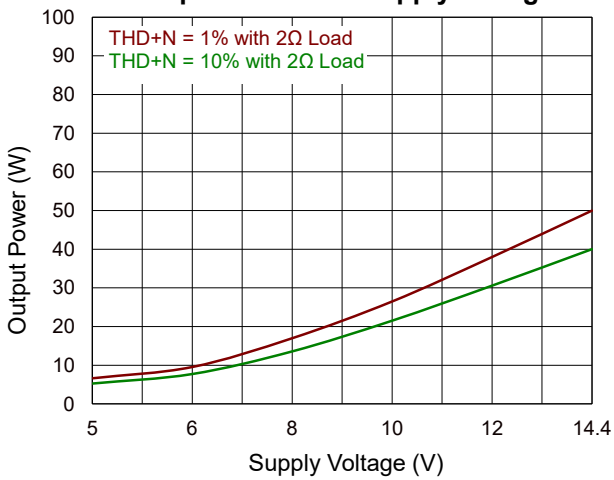
THD+N vs. Output Power



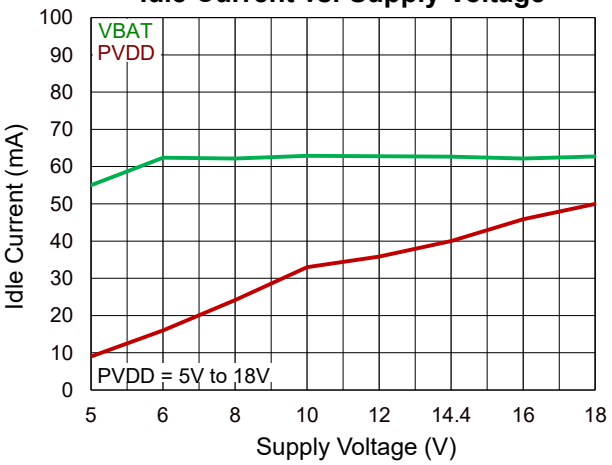
THD+N vs. Frequency



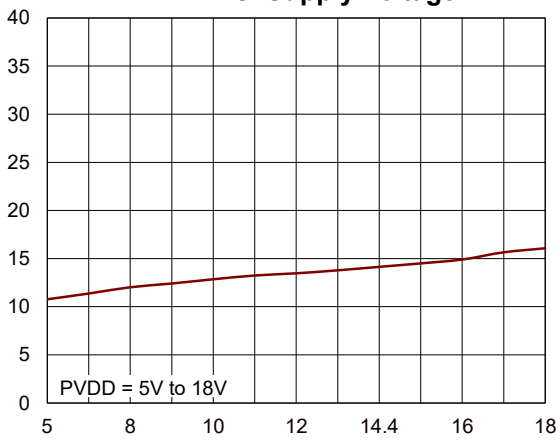
Output Power vs. Supply Voltage



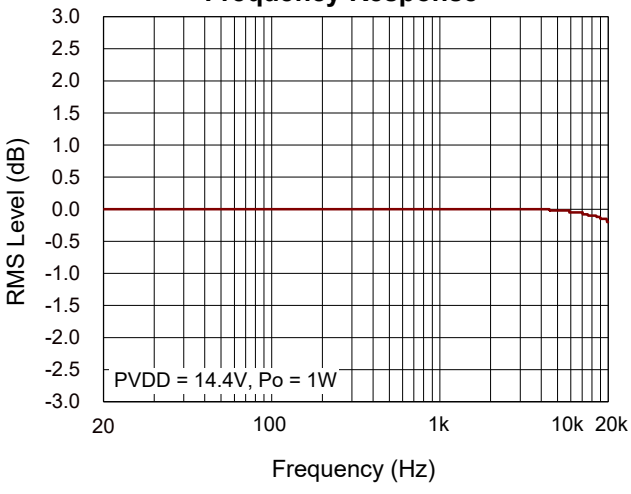
Idle Current vs. Supply Voltage



Vn vs. Supply Voltage

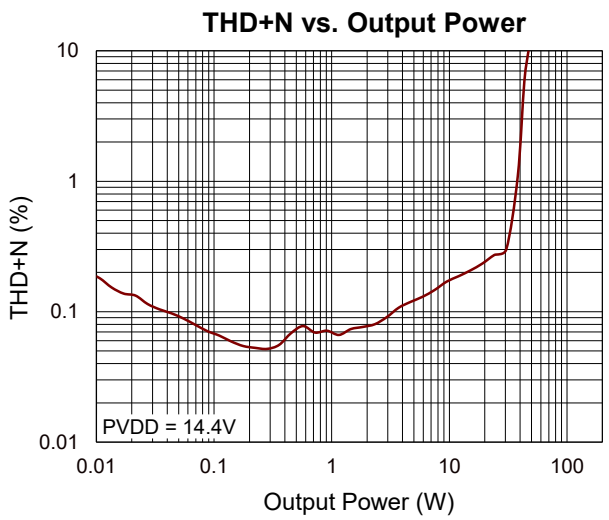


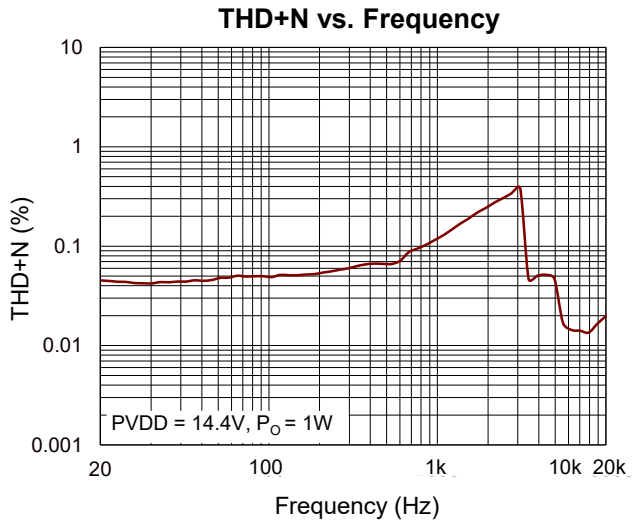
Frequency Response

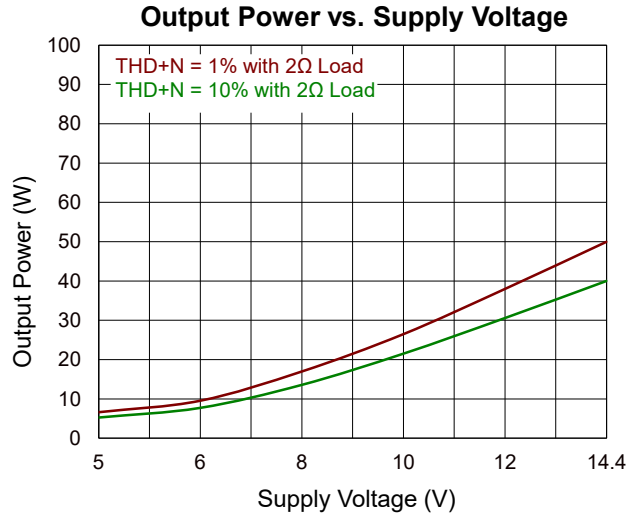


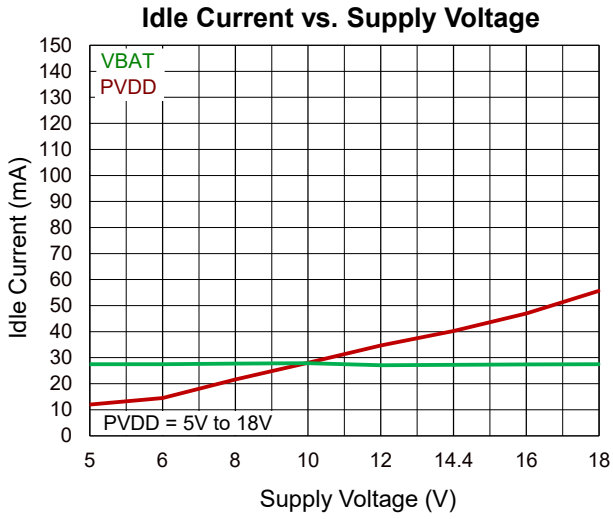
15.4 Parallel Bridge-Tied Load (PBTL)

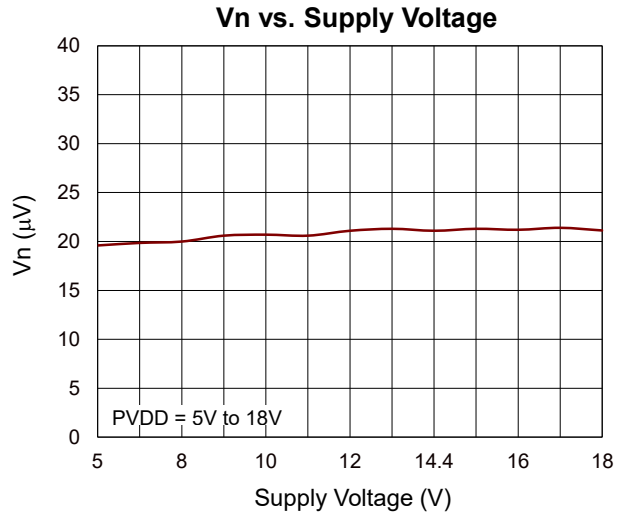
T_A = 25°C, DVDD = 3.3V, VBAT = PVDD = 14.4V, R_L = 2Ω, fin = 1kHz, f_S = 48kHz, f_{SW} = 384kHz, AES17 filter, LC filter: L=10μH – HCM1A1307V2-100-R, C=1μF

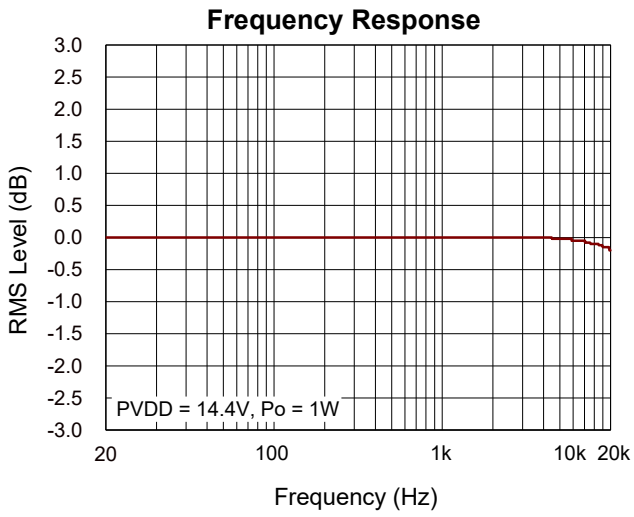








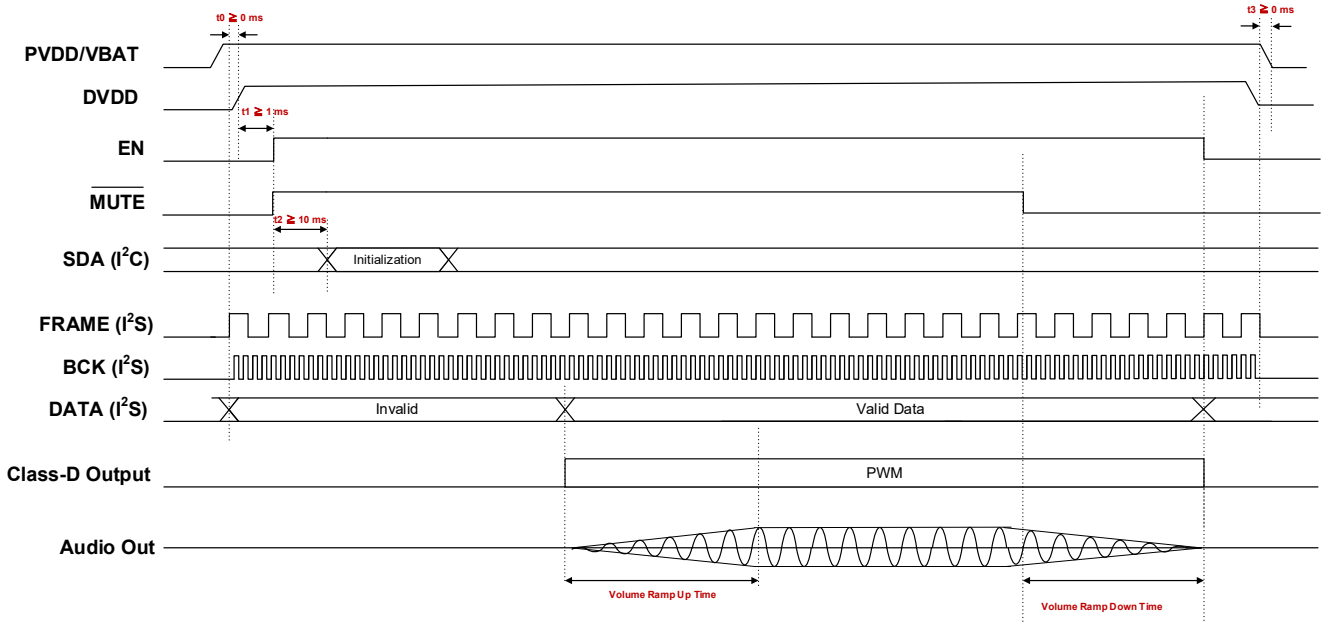




Note 7. Measurements were made using the RTQ9154-QA_EVM board and Audio Precision with AUX-0025 low-pass filter. All measurements taken with 1kHz.

16 Application Information

16.1 Power-On Sequence



16.2 Initial Sequence (BTL Mode, PWM = 2.1MHz)

Sequence	reg_addr	reg_size	reg_value	Description	
1	0x00	1	0xE4	SDIO_SEL	Initial setting
2	0x03	1	0x4D	Internal setting (SPK gain selection)	
3	0x0F	1	0x00	Clear error flag	
4	0xAD	1	0xB2	Auto ULQM	
5	0x30	2	0x01, 0x80	Set the volume 0dB	
6	0x04	1	0x00	Amp turn on	Amp turn on

16.3 Initial Sequence (BTL Mode, PWM = 384kHz)

Sequence	reg_addr	reg_size	reg_value	Description	
1	0x00	1	0xE4	SDIO_SEL	Initial setting
2	0x03	1	0x4D	Internal setting (SPK gain selection)	
3	0x05	1	0x01	PWM is 384kHz	
4	0x0F	1	0x00	Clear error flag	
5	0xAD	1	0xB2	Auto ULQM	
6	0x30	2	0x01, 0x80	Set the volume 0dB	
7	0x04	1	0x00	Amp turn on	Amp turn on

16.4 Initial Sequence (PBTL Mode, PWM = 2.1MHz)

Sequence	reg_addr	reg_size	reg_value	Description	
1	0x00	1	0xE4	SDIO_SEL	Initial setting
2	0x03	1	0x7D	Internal setting (SPK gain selection)	
3	0x0F	1	0x00	Clear error flag	
4	0xAD	1	0xB2	Auto ULQM	
5	0x30	2	0x01, 0x80	Set the volume 0dB	
6	0x04	1	0x00	Amp turn on	Amp turn on

16.5 Initial Sequence (PBTL Mode, PWM = 384kHz)

Sequence	reg_addr	reg_size	reg_value	Description	
1	0x00	1	0xE4	SDIO_SEL	Initial setting
2	0x03	1	0x7D	Internal setting (SPK gain selection)	
3	0x05	1	0x01	PWM is 384kHz	
4	0x0F	1	0x00	Clear error flag	
5	0xAD	1	0xB2	Auto ULQM	
6	0x30	2	0x01, 0x80	Set the volume 0dB	
7	0x04	1	0x00	Amp turn on	Amp turn on

16.6 I²C Serial Communication Bus

The RTQ9154-QA supports 16 sets of slave addresses, configurable through combinations of the A_SEL0 and A_SEL1 pins. These pins can be set using different resistors, each with a tolerance of 20%. Refer to the Table 1 below for specific address configurations.

Table 1. Slave Address Selection

A_SEL1 Pin	A_SEL0 Pin	Slave Address	Write	Read
Pull low	Pull low	0x10 (0010000x)	0x20	0x21
Pull low	Pull high	0x11 (0010001x)	0x22	0x23
Pull low	Pull low with 600kΩ	0x12 (0010010x)	0x24	0x25
Pull low	Pull high with 600kΩ	0x13 (0010011x)	0x26	0x27
Pull high	Pull low	0x14 (0010100x)	0x28	0x29
Pull high	Pull high	0x15 (0010101x)	0x2A	0x2B
Pull high	Pull low with 600kΩ	0x16 (0010110x)	0x2C	0x2D
Pull high	Pull high with 600kΩ	0x17 (0010111x)	0x2E	0x2F
Pull low with 600kΩ	Pull low	0x18 (0011000x)	0x30	0x31
Pull low with 600kΩ	Pull high	0x19 (0011001x)	0x32	0x33
Pull low with 600kΩ	Pull low with 600kΩ	0x1A (0011010x)	0x34	0x35
Pull low with 600kΩ	Pull high with 600kΩ	0x1B (0011011x)	0x36	0x37
Pull high with 600kΩ	Pull low	0x1C (0011100x)	0x38	0x39
Pull high with 600kΩ	Pull high	0x1D (0011101x)	0x3A	0x3B
Pull high with 600kΩ	Pull low with 600kΩ	0x1E (0011110x)	0x3C	0x3D
Pull high with 600kΩ	Pull high with 600kΩ	0x1F (0011111x)	0x3E	0x3F

The RTQ9154-QA is equipped with I²C communication capabilities, utilizing the SCL and SDA input ports. In the I²C protocol, devices transmitting data are designated as transmitters, while those reading the data are receivers. The master device initiates and controls the data transfer, supplying the serial clock to ensure synchronization. The RTQ9154-QA functions exclusively as a slave device in all communications and is capable of operating at speeds of up to 400 kB/s. Its I²C interface is designed to be slave-only.

16.7 I²C Bus Protocol

Data transitions on the SDA line are only permitted when the SCL clock signal is low. Transitions on the SDA line while the SCL signal is high indicate a START or STOP condition. A START condition is signaled by a high-to-low transition on the SDA line while the SCL line remains high and stable. This condition must be established before any data transfer command is issued. Conversely, a STOP condition is signaled by a low-to-high transition on the SDA line while the SCL line remains high and stable, marking the end of communication between the RTQ9154-QA and the bus master. During data reception, the RTQ9154-QA samples the SDA line at the rising edge of the SCL signal. To ensure proper operation of the device, the SDA signal must remain stable during the rising edge of the SCL signal, and data changes on the SDA line should only occur when the SCL signal is low.

16.8 Audio Interface

The RTQ9154-QA supports four types of audio interfaces: I^{2}S, Left-Justified, Right-Justified, and TDM. Each interface is capable of handling audio data formats of 32-bit, 24-bit, 20-bit, and 16-bit. The corresponding timing diagrams are provided below.

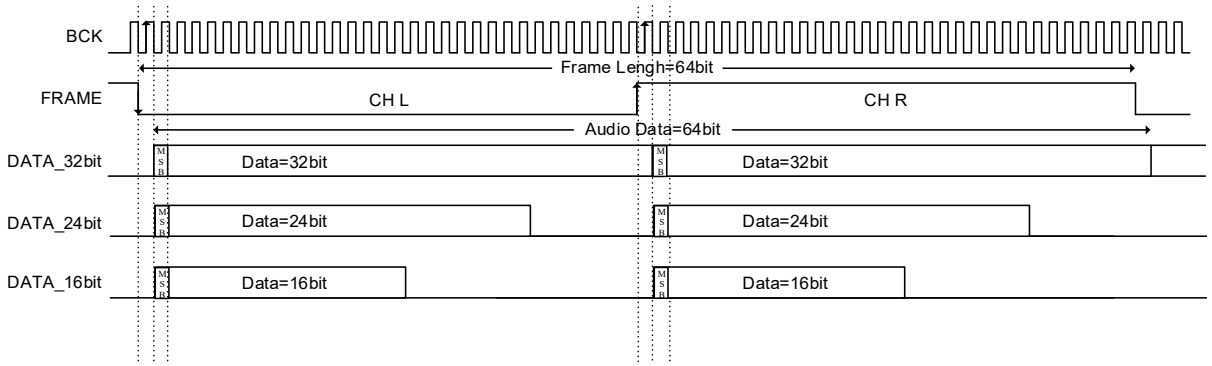


Figure 4. I^{2}S Format

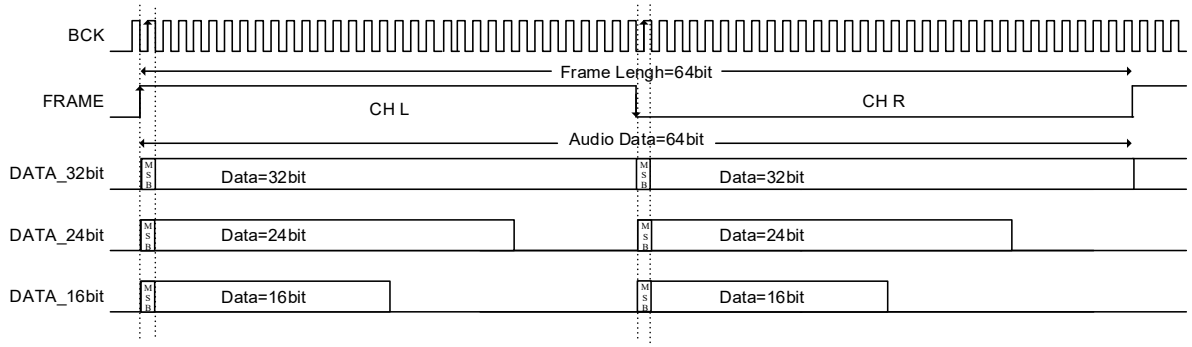


Figure 5. Left-Justified

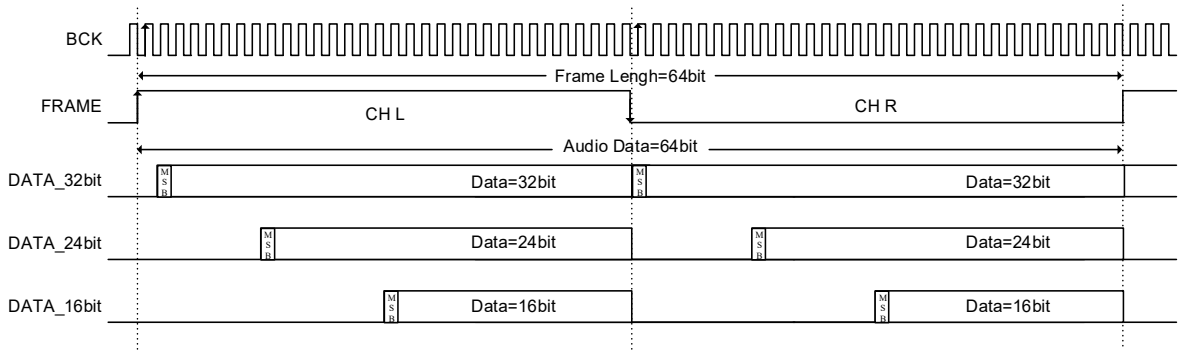


Figure 6. Right-Justified

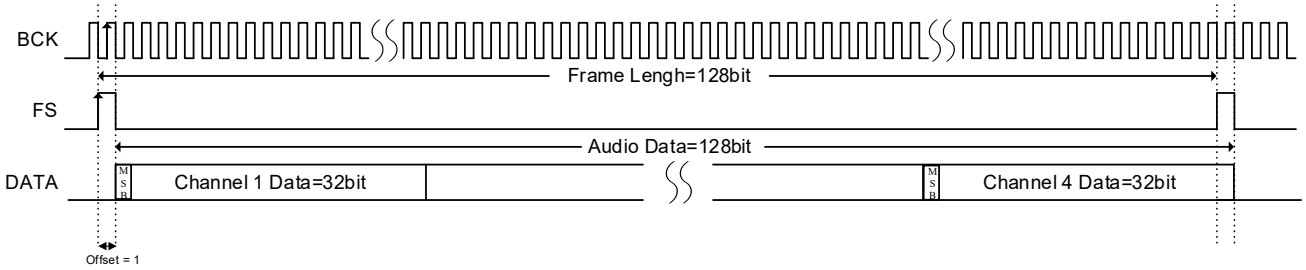


Figure 7. TDM (Offset = 1)

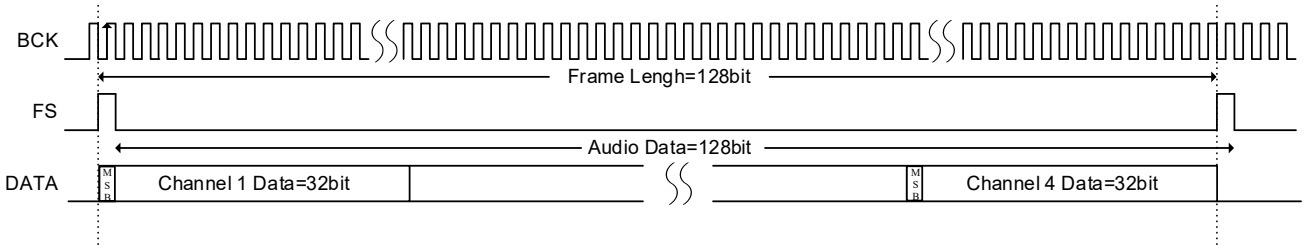


Figure 8. TDM (Offset = 0)

16.9 Time-Division Multiplexing (TDM) Mode

The TDM mode supports a maximum of 16 audio channels. The device can be configured via I^{2}C to select different stereo pairs within the TDM data stream.

16.10 Digital Signal Processor

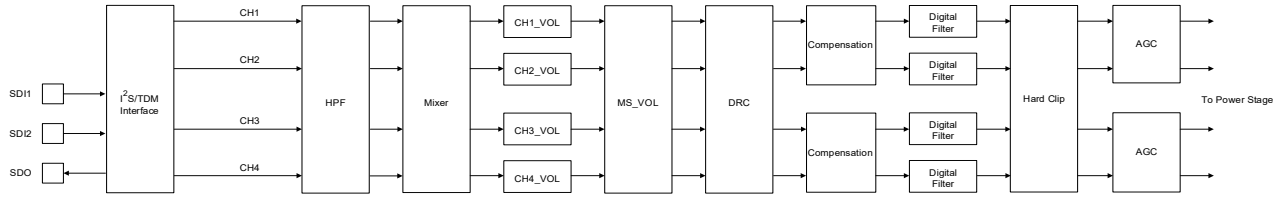


Figure 9. Digital Signal Processor

16.11 High-Pass Filter (HPF)

The RTQ9154-QA supports an input high-pass filter (HPF) for each channel, designed to act as a DC-cut filter with a cutoff frequency of 1.5Hz.

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x08	1	7	RW	HPF_EN	High-Pass filter enable 0: Disable 1: Enable (default)	1

16.12 Mixer

The RTQ9154-QA supports an input channel mixer that can route to any output channel.

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x00	1	7:6	RW	Ch4_SI	00: CH1 to CH4 (default) 01: CH2 to CH4 10: CH3 to CH4 11: CH4 to CH4	00
		5:4	RW	Ch3_SI	00: CH1 to CH3 01: CH2 to CH3 (default) 10: CH3 to CH3 11: CH4 to CH3	01
		3:2	RW	Ch2_SI	00: CH1 to CH2 01: CH2 to CH2 10: CH3 to CH2 (default) 11: CH4 to CH2	10
		1:0	RW	Ch1_SI	00: CH1 to CH1 01: CH2 to CH1 10: CH3 to CH1 11: CH4 to CH1 (default)	11

16.13 Volume

The RTQ9154-QA features a master volume control (MS_VOL) and individual channel volume controls (CH1_VOL, CH2_VOL, CH3_VOL, and CH4_VOL). The volume adjustment step size is 0.0625dB, ranging from 24dB to mute. Each channel also includes a mute control (CH1_MUTE, CH2_MUTE, CH3_MUTE, and CH4_MUTE).

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x30	2	10:0	RW	MS_VOL	Master volume control 11'h000: 24dB 11'h180: 0dB 11'h7FF: Mute (default) 0.0625dB per step	11'h7FF

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x31	2	10:0	RW	CH4_VOL	CH4 volume control 11'h000: 24dB 11'h180: 0dB (default) 11'h7FF: Mute 0.0625dB per step	11'h180

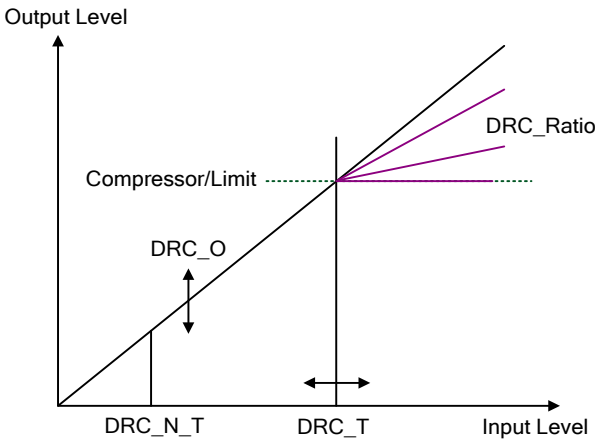
ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x32	2	10:0	RW	CH3_VOL	CH3 volume control 11'h000: 24dB 11'h180: 0dB (default) 11'h7FF: Mute 0.0625dB per step	11'h180

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x33	2	10:0	RW	CH2_VOL	CH2 volume control 11'h000: 24dB 11'h180: 0dB (default) 11'h7FF: Mute 0.0625dB per step	11'h180

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x34	2	10:0	RW	CH1_VOL	CH1 volume control 11'h000: 24dB 11'h180: 0dB (default) 11'h7FF: Mute 0.0625dB per step	11'h180

16.14 Dynamic Range Control (DRC)

The RTQ9154-QA features Dynamic Range Control (DRC), which provides compression capabilities to adjust audio signals, making them sound softer or louder based on the input level.

DRC Description	Address	Description
DRC_T: Threshold	0x40	
DRC_O: Make up gain	0x41	
DRC_Ratio: Compress ratio	0x42	
DRC_N_T: Noise gate threshold	0x43	
Noise gate enable	0x2A	

16.14.1 DRC Threshold

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x40	3	10:0	RW	DRC_TH	DRC threshold 11'h000: 0dB (default) 11'h180: −24dB 11'h67E: −103.875dB 11'h67F ~ 11'h7FF: Not available 0.0625dB per step	11'h000

16.14.2 DRC Offset

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x41	3	10:0	RW	DRC_ OFFSET	DRC make up gain (Offset) 11'h000: 24dB 11'h180: 0dB (default) 11'h7FF: −103.9375dB 0.0625dB per step	11'h180

16.14.3 DRC_RATIO

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x42	3	7:0	RW	DRC_ RATIO	DRC compress ratio 8'h00: No compression 8'h80 (default) ~ 8'hFF: Full compression 1/128 per step	8'h80

16.14.4 Noise Gate Threshold

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x43	3	10:0	RW	DRC_NG_ TH	Noise gate threshold 11'h000: 0dB 11'h180: −24dB 11'h640: −100dB (default) 11'h67E: −103.875dB 11'h67F ~ 11'h7FF: Not available 0.0625dB per step	11'h640

16.14.5 DRC_EN

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x2A	1	7:4	RW	DRC_EN_ CH	Dynamic range control (DRC) enabled {CH1, CH2, CH3, CH4} 0: Disable (default) 1: Enable	0000
		3:0	RW	DRC_N_E N_CH	DRC Noise gate enabled {CH1, CH2, CH3, CH4} 0: Disable (default) 1: Enable	0000

16.15 Compensation Filter

The compensation filter is used to adjust the internal gain from the DAC. This filter can also correct the frequency response affected by the LC filter. The recommended settings will vary based on different application circuits to achieve the desired response curve.

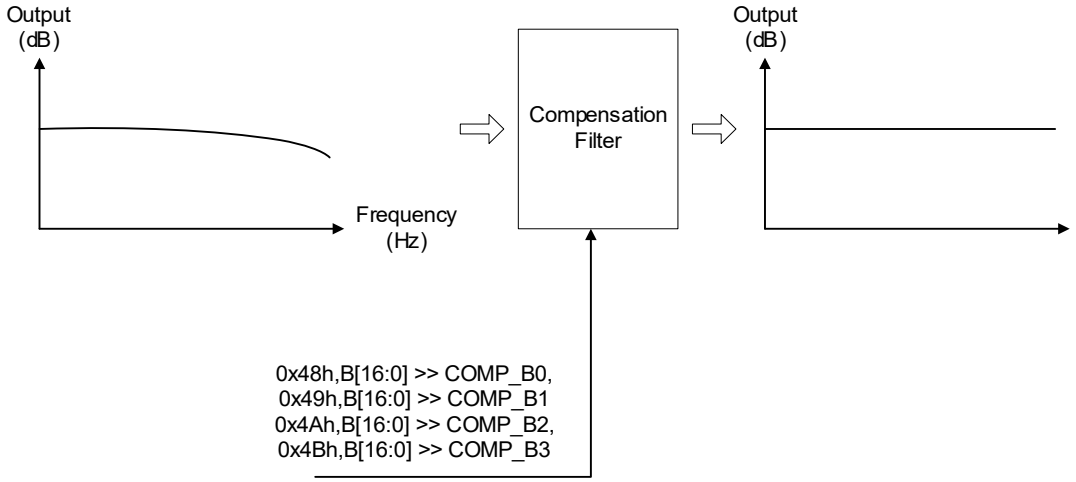


Figure 10. Compensation Filter

Table 2. Compensation Table

	−1	−0.9	−0.8	−0.7	−0.6	−0.5	−0.4	−0.3	−0.2	−0.1	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
B3 0x4B	1FFE6	1FFE8	1FFEA	1FFED	1FFF0	1FFF2	1FFF5	1FFF8	1FFFA	1FFFE	0	2	6	9	C	F	12	16	19	1D	21
B2 0x4A	1FFBD	1FFC3	1FFCA	1FFD2	1FFD7	1FFDE	1FFE5	1FFEC	1FFF2	1FFF9	0	7	E	14	1B	22	29	30	37	3B	43
B1 0x49	3D7	37A	31B	2B6	255	1F4	193	130	CC	62	0	1FF9D	1FF2F	1FEC5	1FE5A	1FDED	1FD7F	1FD10	1FC9F	1FC2C	1FBB0
B0 0x48	790E	79B6	7A60	7B17	7BC9	7C77	7D27	7DDA	7E8F	7F50	8000	80B3	817A	823B	82FE	83C3	848B	8555	8622	86F6	87D9

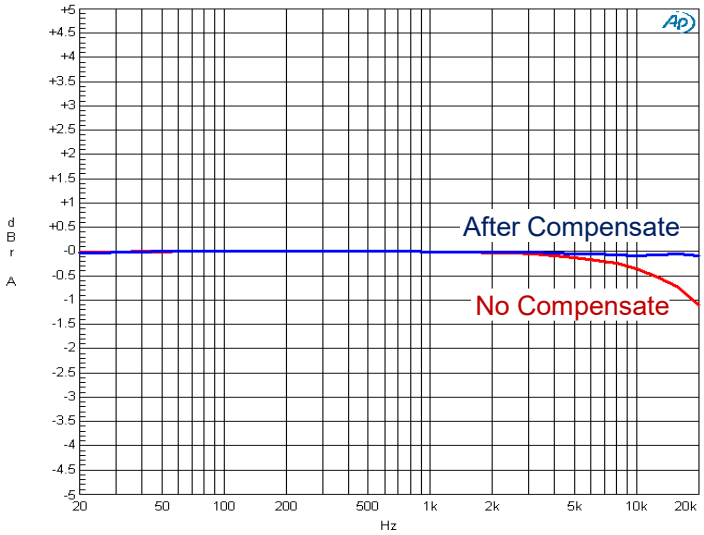


Figure 11. Compensation Filter Measured Result

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x48	3	16:0	RW	COMP_B0	Compensation filter coefficient B0, COEF_PAGE_SEL (0x09) select CH34 or CH12	17'h0_8000
0x49	3	16:0	RW	COMP_B1	Compensation filter coefficient B1, COEF_PAGE_SEL (0x09) select CH34 or CH12	17'h0_0000
0x4A	3	16:0	RW	COMP_B2	Compensation filter coefficient B2, COEF_PAGE_SEL (0x09) select CH34 or CH12	17'h0_0000
0x4B	3	16:0	RW	COMP_B3	Compensation filter coefficient B3, COEF_PAGE_SEL (0x09) select CH34 or CH12	17'h0_0000

16.16 Hard Clip Function

A hard clip can be employed to digitally maintain specified THD levels without resorting to voltage clipping. This feature enables users to consistently achieve the same THD (for example, 10% THD) across various power levels (15W, 10W, and 5W) while using the same PVDD level.

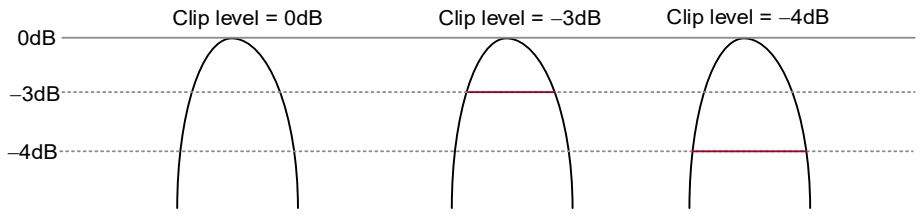


Figure 12. Hard Clip

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x35	2	10:0	RW	HC_TH	Hard clip threshold when HARD_CLIP_EN = 1 > 0dB is not allowable for hard clip threshold setting 11'h180: 0dB (default) 0.0625db per step	11'h180

16.17 SDO Output Configure

The I²S/TDM digital input signal path from the input pin to the power stage is illustrated in Figure 13. There are several nodes along the digital signal transmission path where the signal can be measured to verify proper functionality. The settings in register 0x01 Bit[3:0] can be output through the SDO pin.

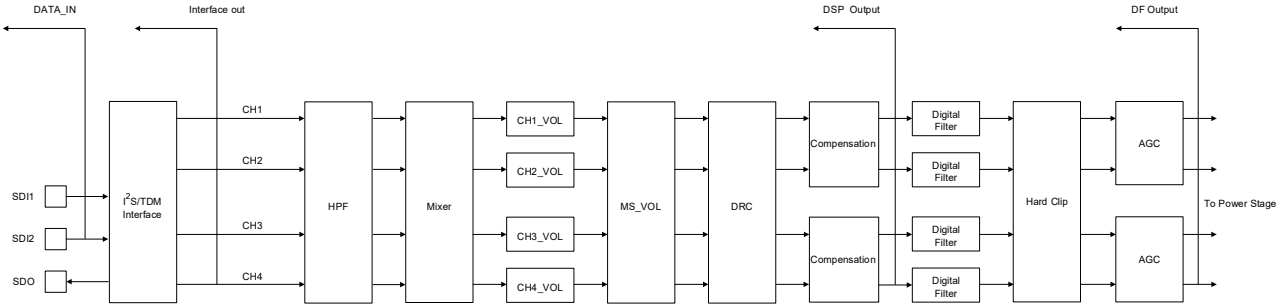


Figure 13. SDO Output Configure

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x01	1	3:0	RW	SDO_SEL	I²S/LJ/RJ/DSPM 0000: No output (default) 0001: I2S_DATAI_1 0010: I2S_DATAI_2 0100: Interface output CH4, CH3 0101: Interface output CH2, CH1 0110: DSP output CH4, CH3 0111: DSP output CH2, CH1 1000: DF output CH4, CH3 1001: DF output CH2, CH1 Others: No output TDM 0000: No output (default) 0001: I2S_DATAI_1 0010: I2S_DATAI_2 010X: Interface output CH4, CH3, CH2, CH1 011X: DSP output CH4, CH3, CH2, CH1 100X: DF output CH4, CH3, CH2, CH1 Others: No output	0000

Under specific conditions, the Serial Data Output (SDO) supports a maximum frequency of 18.8MHz. Considering the variable stray capacitance of external wiring, the internal drive current of the SDO can be adjusted as needed through register settings. For scenarios where the stray capacitance is 30pF, increasing the drive current to 16mA ensures reliable operation of the application at 18.8MHz.

0xF3, D_DRV bit[7:6]	Io at DVDD = 3.3V
D_DRV bit[7:6] = 00	4mA
D_DRV bit[7:6] = 01	8mA
D_DRV bit[7:6] = 10	12mA
D_DRV bit[7:6] = 11	16mA

16.18 Hardware Control Pins

The device features four pins for control and status indication: $\overline{\text{FAULT}}$, $\overline{\text{MUTE}}$, $\overline{\text{WARN}}$, and EN. The $\overline{\text{FAULT}}$ pin reports faults and is active low under any of the following conditions:

- Any channel faults (overcurrent or DC Protection)
- Over-temperature protection
- Overvoltage or undervoltage conditions on the VBAT or PVDD pins
- Clock errors

For all listed faults, the $\overline{\text{FAULT}}$ pin remains asserted even after the fault condition is rectified. The register reports for all faults remain asserted until the CLEAR FAULT method is executed by writing to address 0x0F=00. At that point, all faults register reports in ERR_INT_INDEX will be cleared to their default values, and the $\overline{\text{FAULT}}$ pin will no longer remain asserted.

Register bits are available to mask fault categories from being reported to the $\overline{\text{FAULT}}$ pin. These bits only mask the pin's status and do not affect the register reporting or the device's protection mechanisms. By default, all faults are reported to the pin. Refer to the Register Maps section for a description of the mask settings.

The active-low output $\overline{\text{WARN}}$ pin reports audio clipping, over-temperature warning, and overcurrent warning. Clipping is reported when any channel reaches maximum modulation for 20 consecutive PWM clocks (default value), resulting in a 10μs delay in reporting the onset of clipping. The Clip Detect Warning bit, which is sticky in latching mode, can be cleared by accessing the ERR_INT_INDEX in the register at address 0x0F and writing to address 0x0F = 00. An over-temperature warning (OTW) is triggered if the general temperature or any channel-specific temperature warnings are activated. Register bits are available to selectively mask the reporting of clipping, OTW, or OCW to the pin. These bits solely affect the pin's setting and do not influence the register reporting. By default, clipping, OCW, and OTW are reported at addresses 0x14 and 0x15.

The active-low input $\overline{\text{MUTE}}$ pin controls the mute and unmute functions for all channels.

When the EN pin is at a low level, the device enters shutdown mode, the I^2C function is disabled, and the current consumption is minimized. This pin allows for rapid shutdown of the device and resets the registers to their default values. When the EN pin is at a high level, the device enters standby mode and the I^2C function is enabled. In this mode, the RTQ9154-QA can be commanded via I^2C to enter other modes.

16.19 Operating Modes and Faults

STATE_CTRL	Power MOSFETS	OSCILLATOR	I²C
Normal	Switching with input signal	Active	Active
Shutdown	Hi-Z	Stopped	Inactive
Standby (I²S – Clock Off)	Hi-Z	Stopped	Active
Hi-Z	Hi-Z	Active	Active
MUTE	50% (BD) switching	Active	Active
ULQM (I²S – No Data)	Hi-Z	Stopped	Active

Fault Event	Reporting	Result	Monitor State	Protection Active	Behavior
CLK Error	I²C+$\overline{\text{FAULT}}$ pin	Hi-Z	All	4 Channel	Auto-recovery (default)
DVDD UV	I²C+$\overline{\text{FAULT}}$ pin	Hi-Z	All	4 Channel	Auto-recovery (default)
VR_ANA/GVDD UV	I²C+$\overline{\text{FAULT}}$ pin	Hi-Z	All	4 Channel	Auto-recovery (default)
VBAT/PVDD UV	I²C+$\overline{\text{FAULT}}$ pin	Hi-Z	All	4 Channel	Auto-recovery (default)
VBAT/PVDD OV	I²C+$\overline{\text{FAULT}}$ pin	Hi-Z	All	4 Channel	Auto-recovery (default)
OTPG	I²C+$\overline{\text{FAULT}}$ pin	Hi-Z	All	4 Channel	Auto-recovery (default)
OTPC	I²C+$\overline{\text{FAULT}}$ pin	Hi-Z	All	1 Channel (individual)	Auto-recovery (default)
S2P/S2G/OL/SL	I²C+$\overline{\text{FAULT}}$ pin	Hi-Z	Load detection	1 Channel (individual)	Latch (default)
Overcurrent	I²C+$\overline{\text{FAULT}}$ pin	Hi-Z	Normal, Mute	1 Channel (individual)	Latch (default)
DC	I²C+$\overline{\text{FAULT}}$ pin	Hi-Z	Normal, Mute	1 Channel (individual)	Latch (default)
POR	I²C+$\overline{\text{WARN}}$ pin	N/A	All	N/A	N/A
OTWG	I²C+$\overline{\text{WARN}}$ pin	TFB (optional)	All	N/A	N/A
OTWC	I²C+$\overline{\text{WARN}}$ pin	TFB (optional)	All	1 Channel (individual TFB)	N/A
OCW	I²C+$\overline{\text{WARN}}$ pin	N/A	All	1 Channel (individual)	N/A
Clip	I²C+$\overline{\text{WARN}}$ pin	N/A	All	1 Channel (individual)	N/A

16.20 Ultra-Low Quiescent Mode (ULQM)

In ULQM, the RTQ9154-QA powers the FETs in Hi-Z status with low standby current, and the transition time from ULQM to normal mode is approximately 5ms. After the initial power-on, it is recommended to use ULQM to save energy.

16.21 Pulse-Width-Modulator (PWM) Frequency

The output switching rate is synchronous to the serial audio clock input and is programmed through I^2C to match the input sample rate in the register (address 0x05[6:4]). The option to switch at a high frequency allows the use of smaller and lower-cost external filtering components.

Sample Rate	Reg 0x05h, Bits 6:4 Setting				
	000	001	010	011	100
32kHz	Not support	Not support	1.28MHz	1.41MHz	1.53MHz
44.1kHz	352kHz	441kHz	1.76MHz	1.94MHz	2.1MHz
48kHz	384kHz	480kHz	1.92MHz	2.1MHz	2.3MHz
88.2kHz	352kHz	441kHz	1.76MHz	1.94MHz	Not support
96kHz	384kHz	480kHz	1.92MHz	2.1MHz	Not support
192kHz	384kHz	480kHz	1.92MHz	2.1MHz	Not support

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x05	1	6:4	RW	PWM_ FREQ	PWM frequency selection 000: 8*fs 001: 10*fs 010: 40*fs 011: 44*fs (default) 100: 48*fs Others: Reserved	011

16.22 AM-Radio Band Avoidance

By setting the switching frequency of the device above the AM frequency band, interference with AM radio frequencies can be avoided. The available switching frequency options include 38fs, 44fs, and 48fs. If the switching frequency cannot be set above the AM frequency band, the alternatives of 8fs and 10fs should be used. These settings should be adjusted to avoid active AM channels.

16.23 EMI Management Feature

The RTQ9154-QA features a spread-spectrum function and output phase control to address EMI issues.

16.23.1 Spread-Spectrum Function

There are two methods: varying the spread-spectrum frequency and adding noise to the triangular modulation.

The spread-spectrum frequency variation amplitude is controlled via the register at address 0x07[1:0], and noise can be added to the triangular modulation through the register at address 0x07[6:2].

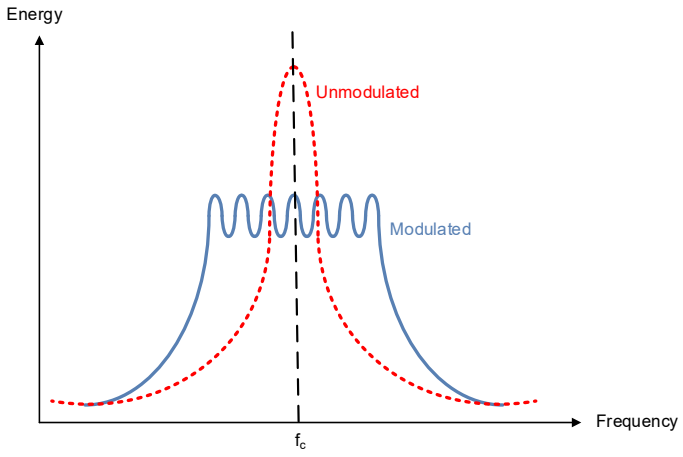


Figure 14. Spread-Spectrum Algorithm

16.24 Channel-to-Channel Output Phase Control

The RTQ9154-QA features a channel-to-channel phase control function. Channel 4 is used as a reference for other channels, and the PWM phase of channels 1, 2, and 3 can be shifted from 0 to 315 degrees in 45-degree increments.

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x05	1	2:0	RW	OUT_ PHASE_3	CH3 output phase offset 000: 0 degree 001: 45 degree (default) 010: 90 degree 011: 135 degree 100: 180 degree 101: 225 degree 110: 270 degree 111: 315 degree	001

0x06	1	6:4	RW	OUT_ PHASE_2	CH2 output phase offset 000: 0 degree 001: 45 degree 010: 90 degree (default) 011: 135 degree 100: 180 degree 101: 225 degree 110: 270 degree 111: 315 degree	010
		2:0	RW	OUT_ PHASE_1	CH1 output phase offset 000: 0 degree 001: 45 degree 010: 90 degree 011: 135 degree (default) 100: 180 degree 101: 225 degree 110: 270 degree 111: 315 degree	011

16.25 Load Diagnostics

The device features both DC and AC load diagnostics to assess the status of the load. DC diagnostics are enabled by default via the register at address 0x03[6]. However, for a fast start-up that bypasses diagnostics, DC diagnostics can be disabled through I^2C. DC diagnostics activate when any channel transitions from the Hi-Z state to either the MUTE or PLAY state. Additionally, DC diagnostics can be manually activated for any or all channels. They can commence under any operating condition; however, if a channel is in the PLAY state, the diagnostic process takes longer. This delay occurs because the device must decrease the audio signal of that channel before it can switch to the Hi-Z state. DC diagnostics become available as soon as the device's power supply is within the recommended operating range. These diagnostics do not depend on the availability of audio input clocks. Results from the DC diagnostics are reported individually for each channel via the I^2C registers.

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x03	1	6	RW	EN_DC_LOAD_DET	Execute DC load diagnostics before amp on sequence 0: Disable 1: Enable (default)	1

16.26 DC Load Detection

DC load detection assesses the status of the speaker side to prevent speaker damage. During this process, the device remains in a high-impedance state while playing a detection pattern. There are five types of DC load detection results: S2G (short to ground), SL (short load), normal, OL (open load), and S2P (short to power). The DC load detection method involves playing a pattern between the output channels OUTP and OUTN to diagnose the load (RL) status. The diagnostic results are obtained through an internal ADC and stored in registers 0x8C to 0x8F after offset subtraction. Converting these register values to decimal and dividing by 740 provides the diagnostic results. For load resistances below 5Ω, the tolerance is within ±0.5Ω. DC load detection can be automatically initiated when the amplifier is powered on, as configured by bit 6 of register 0x03. It can also be manually triggered by setting bits [7:4] of register 0x53. The thresholds for short load detection are controlled by registers at addresses 0x51 and 0x52, while the typical threshold for an open load is 70Ω. Thus, a normal status falls between the short and open load thresholds.

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x51	1	7:4	RW	SL_TH_CH4	CH4 SL threshold selection (0.5Ω each step) 0000: 0.5Ω 0001: 1Ω (default) 0010: 1.5Ω ... 1001: 5Ω Others: Reserved	0001
		3:0	RW	SL_TH_CH3	CH3 SL threshold selection (0.5Ω each step) 0000: 0.5Ω 0001: 1Ω (default) 0010: 1.5Ω ... 1001: 5Ω Others: Reserved	0001

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x52	1	7:4	RW	SL_TH_CH2	CH2 SL threshold selection (0.5Ω each step) 0000: 0.5Ω 0001: 1Ω (default) 0010: 1.5Ω ... 1001: 5Ω Others: Reserved	0001
		3:0	RW	SL_TH_CH1	CH1 SL threshold selection (0.5Ω each step) 0000: 0.5Ω 0001: 1Ω (default) 0010: 1.5Ω ... 1001: 5Ω Others: Reserved	0001

When the DC load detection result indicates an abnormal output channel, the device will pull the $\overline{\text{FAULT}}$ voltage low. Registers 0x16 and 0x17 can be read to confirm the diagnostic result and identify the abnormal output channel.

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x16	1	7:4	W0C	S2P	Output short to power {CH1, CH2, CH3, CH4} 0: Normal (default) 1: Fault (write 0 to clear)	0000
		3:0	W0C	S2G	Output short to ground {CH1, CH2, CH3, CH4} 0: Normal (default) 1: Fault (write 0 to clear)	0000
0x17	1	7:4	W0C	OL	Output open load {CH1, CH2, CH3, CH4} 0: Normal (default) 1: Fault (write 0 to clear)	0000
		3:0	W0C	SL	Positive output shorting to negative output {CH1, CH2, CH3, CH4} 0: Normal (default) 1: Fault (write 0 to clear)	0000

16.27 AC Load Detection

AC load detection can help distinguish speaker types such as woofers and tweeters. For AC load detection, the device must be in the Hi-Z state. When detection finishes, users can obtain the magnitude and phase. The method of AC diagnosis involves playing a signal frequency pattern between the output channels OUTP and OUTN to diagnose the speaker status. The diagnostic result is obtained through an internal ADC, and the parameter values can be compensated and converted internally to obtain the magnitude and phase. AC load detection can be manually executed by setting bits [7:4] of register 0x55. The RTQ9154-QA GUI provides a load diagnostics function, which allows the load detection results to be displayed through the GUI without the need for manual calculation.

16.28 Output Voltage

There are three types of gain in the RTQ9154-QA: digital volume gain, analog DAC gain, and speaker gain. The output voltage calculation formula is: Output Voltage (Vp) = 10^ ((D + Volume Gain)/20) x 3.74 x Output Gain.

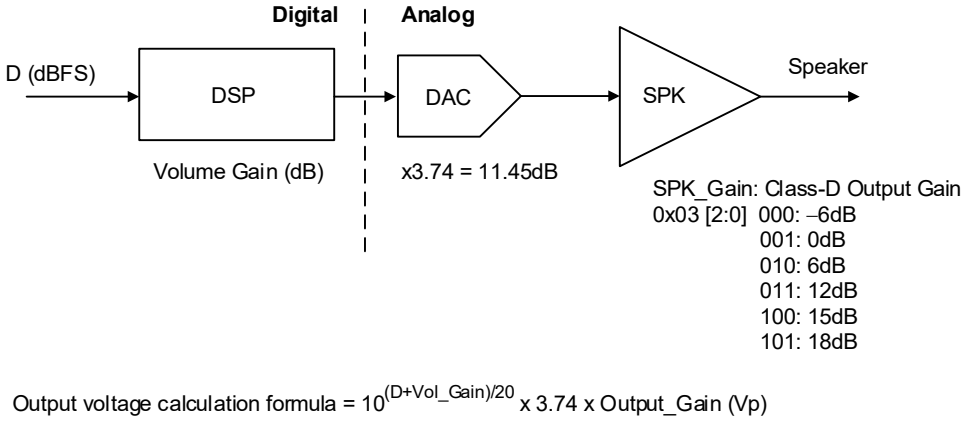


Figure 15. Output Voltage Calculation

16.29 Overcurrent Warning (OCW)

When the overcurrent warning (OCW) is triggered, a warning flag is raised to alert the system of the overcurrent condition. This warning indicates that the current level has reached the preset threshold. OCW is not reported as a fault condition to registers or the $\overline{\text{FAULT}}$ pin; instead, it is indicated as a warning condition on the $\overline{\text{WARN}}$ pin and in the OCW status register (address 0x15). Each channel is monitored independently. Four programmable levels can be configured using two bits in the register at address 0xB4.

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x15	1	3	W0C	OCW_Flag_1	Overcurrent warning CH1 0: Normal (default) 1: Warning (write 0 to clear)	0
		2	W0C	OCW_Flag_2	Overcurrent warning CH2 0: Normal (default) 1: Warning (write 0 to clear)	0
		1	W0C	OCW_Flag_3	Overcurrent warning CH3 0: Normal (default) 1: Warning (write 0 to clear)	0
		0	W0C	OCW_Flag_4	Overcurrent warning CH4 0: Normal (default) 1: Warning (write 0 to clear)	0

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0xB4	1	7:6	RW	OCW_SEL_4	CH4 overcurrent warning threshold selection 00: 4.8A 01: 5.8A (default) 10: 7.3A 11: 8.5A	01
		5:4	RW	OCW_SEL_1	CH1 overcurrent warning threshold selection 00: 4.8A 01: 5.8A (default) 10: 7.3A 11: 8.5A	01
		3:2	RW	OCW_SEL_2	CH2 overcurrent warning threshold selection 00: 4.8A 01: 5.8A (default) 10: 7.3A 11: 8.5A	01
		1:0	RW	OCW_SEL_3	CH3 overcurrent warning threshold selection 00: 4.8A 01: 5.8A (default) 10: 7.3A 11: 8.5A	01

16.30 Overcurrent Protection (OCP)

The RTQ9154-QA features an Overcurrent Protection (OCP) function to prevent damage to the device under overload or short-circuit conditions. This function is monitored by an internal sensing circuit. If the output current reaches the OC threshold, such as in case of an output short to GND, a peak current is triggered, which by default shuts down the channel in latch mode. Users can also select an auto-recovery mode for different applications. The RTQ9154-QA supports four programmable levels, which can be configured using two bits in the registers at addresses 0xB3.

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0xB3	1	7:6	RW	LS_OC_SEL_4	CH4 OC protection threshold selection 00: 6.5A 01: 8A (default) 10: Reserved 11: Reserved	01
		5:4	RW	LS_OC_SEL_1	CH1 OC protection threshold selection 00: 6.5A 01: 8A (default) 10: Reserved 11: Reserved	01
		3:2	RW	LS_OC_SEL_2	CH2 OC protection threshold selection 00: 6.5A 01: 8A (default) 10: Reserved 11: Reserved	01
		1:0	RW	LS_OC_SEL_3	CH3 OC protection threshold selection 00: 6.5A 01: 8A (default) 10: Reserved 11: Reserved	01

16.31 DC Protection (DCP)

During normal operation, the amplifier circuit continuously monitors the DC offset. If the DC offset exceeds a specified threshold, the channel is placed in the Hi-Z state, a fault is reported to the I^2C register, and the $\overline{\text{FAULT}}$ pin is activated. Optionally, register bits can be configured to mask this fault report to the $\overline{\text{FAULT}}$ pin. This monitoring is crucial for protecting the loudspeaker from DC at the output. The detection method involves analyzing the DC at the final PWM stage, calculating the difference between the PWM output and a sinc filter to determine the DC level. The IC will automatically shut down upon detecting excessive DC.

16.32 Global Over-Temperature Warning (OTWG) and Over-Temperature Protection (OTPG)

The device offers four over-temperature warning levels (see the Register Map section for threshold values). When the junction temperature surpasses a warning level, the $\overline{\text{WARN}}$ pin is activated unless the mask bit in the pin control register (address 0x19) is configured to disable this alert. The device operates normally until it reaches the OTSD threshold, at which point it places all channels in Hi-Z state and activates the $\overline{\text{FAULT}}$ pin. By default, the device remains deactivated until the temperature normalizes. However, this behavior can be modified to automatic recovery by setting bits 2 and 0 in the miscellaneous control register (address 0x0D). Upon normalization of the junction temperature, the device automatically resumes operation and restores the channels to the configurations specified in the state control register. It is important to note that, even with automatic recovery enabled, the $\overline{\text{FAULT}}$ pin stays active until the CLEAR FAULT bit (bit 1) in the register (address 0x11) is activated.

16.33 Channel Over-Temperature Warning (OTWC) and Over-Temperature Protection (OTPC)

In addition to the Global Over-Temperature Warning (OTWG) and Over-Temperature Protection (OTPG), each output channel has individual over-temperature warning and protection functions. If any channel exceeds the OTW threshold, the corresponding bit in the warning register (address 0x14) will be set, and the $\overline{\text{WARN}}$ pin will be activated unless the mask bit is configured to disable reporting. If the channel temperature exceeds the OTSD threshold, the channel enters Hi-Z state and remains in that state. Alternatively, it can automatically return to the state indicated by the status control register when the temperature drops below the OTW threshold, depending on

the setting of bit 0 in the miscellaneous control register (address 0x0D).

16.34 Undervoltage Protection (UVP) and Power-On-Reset (POR)

The RTQ9154-QA monitors the PVDD voltage threshold. When the voltage at the PVDD pin drops below the programmable undervoltage threshold of 4V, the Undervoltage Protection (UVP) circuit immediately shuts down the output. This device can also be configured to operate in latch mode instead.

When the DVDD voltage is set to 3.3V, the DVDD UVP is configured to 2.3V. If the DVDD operating voltage is 1.8V, then the VR_DIG pin must also be supplied with 1.8V, and the register must be configured to lower the DVDD UVP to 1.4V.

16.35 Overvoltage Protection (OVP) and Load Dump

The RTQ9154-QA monitors the voltage thresholds of the PVDD and VBAT pins. When the voltage on the PVDD pin or the VBAT pin rises above the overvoltage threshold of 21.5V, the OVP circuit immediately shuts down the output. The device can then operate in auto-recovery mode or be configured to use latch mode.

16.36 Clip Detection

Clip detection is reported on the $\overline{\text{WARN}}$ pin if a 100% duty-cycle PWM is sustained for a minimum number of PWM cycles as set by the Clip Window Register (address 0x73). The default setting is 20 PWM cycles.

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x73	1	3:0	RW	CLIP_DET_SEL	Clipping detect threshold, release threshold (unit: PWM cycle) 4'b0000: 1, 0 4'b0001: 5, 3 4'b0010: 10, 5 4'b0011: 20, 5 (default) 4'b0100: 50, 30 4'b0101: 100, 80 4'b0110: 150, 130 Others: 250, 230	0011

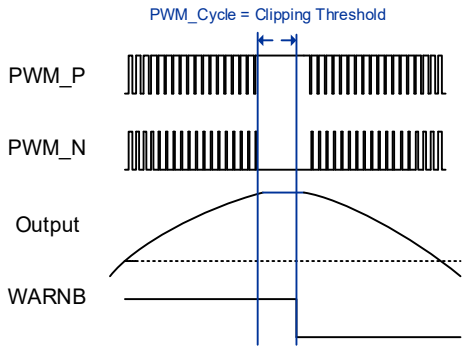


Figure 16. Clip Detection

16.37 Thermal Fold-Back (TFB)

The RTQ9154-QA features built-in Thermal Fold-Back Protection (TFP), which is activated when the average junction temperature exceeds a specified threshold. TFP decreases the amplifier gain to reduce power dissipation, maintaining the junction temperature around the threshold level. The device will not completely switch off but will remain operational at lower output power levels. If the average junction temperature continues to rise, a second built-in temperature protection threshold will shut down the amplifier completely.

16.38 Parallel BTL Operation (PBTL)

The RTQ9154-QA can drive more current to the load side of the LC output filter by paralleling the BTL channels. For parallel operation, the Parallel BTL (PBTL) mode must be used, and both parallel channels must have the same status in the status control register. If the statuses are inconsistent, the device will report a fault condition. To set a channel to PBTL mode, the device must be in standby mode for the command to take effect. PBTL channels support load diagnosis but cannot be paralleled on the load side of the LC output filter.

16.39 Recommended Operating Conditions

The RTQ9154-QA is designed for specific application conditions. It supports speakers with a typical impedance of 4Ω and a minimum impedance of 3.2Ω.

Minimum Speaker Load Impedance		
Min	**Typ**	**Max**
3.2Ω	4Ω	--

Based on the internal settings of the RTQ9154-QA and the LDMOS parameters, recommended application ranges are provided for the corresponding loaded speaker impedance and PVDD voltage.

Speaker Load	PVDD Range		
R_L (Ω)	**Min**	**Typ**	**Max**
≥3.2	4.5V	--	18V

It is recommended that the inductance value of the loaded speaker not exceed 10mH.

Minimum Speaker Load Impedance		
Min	**Typ**	**Max**
--	--	10mH

16.40 Thermal Considerations

The junction temperature should never exceed the absolute maximum junction temperature $T_{J(MAX)}$, listed under Absolute Maximum Ratings, to avoid permanent damage to the device. The maximum allowable power dissipation depends on the thermal resistance of the IC package, the PCB layout, the rate of surrounding airflow, and the difference between the junction and ambient temperatures. The maximum power dissipation can be calculated using the following formula:

$P_{D(MAX)} = (T_{J(MAX)} - T_A) / \theta_{JA}$

where $T_{J(MAX)}$ is the maximum junction temperature, T_A is the ambient temperature, and θ_{JA} is the junction-to-ambient thermal resistance.

For continuous operation, the maximum operating junction temperature indicated under Recommended Operating Conditions is 150°C. The junction-to-ambient thermal resistance, θ_{JA}, is highly package dependent. For a RTSSOP-56 package, the thermal resistance, θ_{JA}, is 43.74°C/W on a standard JEDEC 51-7 high effective-thermal-conductivity four-layer test board. The maximum power dissipation at T_A = 25°C can be calculated as follows:

$P_{D(MAX)}$ = (150°C - 25°C) / (43.74°C/W) = 2.86W for a RTSSOP-56 package.

The maximum power dissipation depends on the operating ambient temperature for the fixed $T_{J(MAX)}$ and the thermal resistance, θ_{JA}. The derating curve in Figure 17 allows the user to see the effect of rising ambient temperature on the maximum power dissipation.

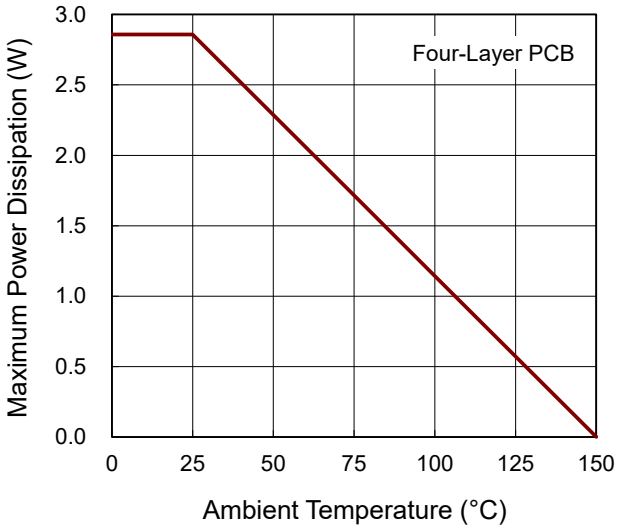
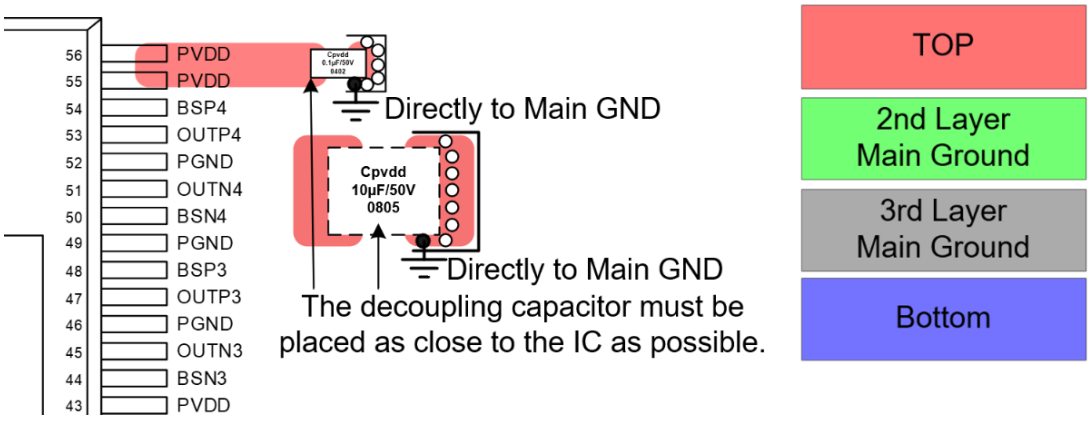


Figure 17. Derating Curve of Maximum Power Dissipation

16.41 Layout Considerations

For the best performance of the RTQ9154-QA, the following PCB layout guidelines must be strictly followed.

1. In the RTQ9154-QA pin configuration, the digital signal pin and the power pin have been separated. Digital signal traces and power traces must be separated, and layout traces should not cross. The trace from VSYS or battery to the PVDD pin must be wide enough to meet the current demand.
2. Pins 29, 30, 42, 43, 55, and 56 are PVDD power pins for the 4-CH Class-D structure application. Place the filter capacitors as close as possible to the PVDD pins and use the shortest possible traces to connect these capacitors. Capacitors with smaller capacitance should be placed near the PVDD pins. To reduce parasitic inductance and resistance, use multiple vias to connect to the main ground. The optimal approach is to use vias that are directly connected to the Main GND. Before making this connection, ensure that the vias are isolated to prevent unintended connections with other grounds.



3. In RTQ9154-QA, bulk capacitors(390uF) need to be placed near the power input, they’re mainly used for power storage and voltage stabilization, suppressing low-frequency noise. And decoupling capacitors(0.1uF) are used to remove high-frequency noise and improve IC operating stability and should be placed as close as possible to the PVDD and GND. Using both types together effectively enhances power quality and ensures stable circuit operation.
4. To ensure the upper MOSFET turns on normally, place a bootstrap capacitor between the OUT and BSP pins. Position this capacitor as close as possible to the pins for optimal performance. The application circuit requires a total of eight capacitors. Refer to the placement diagram below for details.
5. The ground defined by the VR_ANA pin is AGND. The AGND pin trace should first connect to the ground terminal of the capacitor, and then use a via (a conductive hole that connects different layers of the PCB) to connect to the Main GND. To achieve good audio quality, the ground connection of decoupling capacitors (DVDD caps) should be linked to DGND first before connecting to the main ground. Similarly, the VR_DIG decoupling capacitor ground connection should be linked to DGND, and then use a via to connect to the Main GND.
6. In RTQ9154-QA, it is recommended to connect vias (12/20mil for every 0.5A) directly to the main ground (GND), ensure isolation from other ground networks before connection. Depending on requirements, choose single-point or multi-point grounding to enhance interference immunity and grounding effectiveness.
7. The ground defined by the VBAT and VR_ANA pins is AGND. The AGND pin trace should first connect to the

ground terminal of the capacitor, and then use a via to connect to the Main GND. The VBAT pin must be separated from PVDD using a star connection and routed separately from the electrolytic capacitor on the battery path to Cvbat.

(The ground defined by the GVDDAB/GVDDCD pins is Main GND)

8. The traces for OUTP and OUTN should have equal widths and lengths to ensure signal balanced and integrity. Ferrite bead filter, LC filter or snubber (CR) should be placed to the chip for optimal EMI suppression.. It is recommended to position ground vias around the output traces to enhance grounding effectiveness and noise immunity. Additionally, a solid ground plane should be placed beneath the differential pair, avoiding any gaps, and vias should be placed together when changing layers to ensure optimal signal quality.
9. Due to the many external traces, the ground of the RTQ9154-QA is connected to the Main GND using vias. Copper can be placed under the IC, and additional GND vias can be used to better connect the PGND pin on the top layer to the Main GND. This approach can also increase the heat dissipation area.

Note 8. The information provided in this section is for reference only. The customer is solely responsible for designing, validating, and testing any applications incorporating Richtek's product(s). The customer is also responsible for applicable standards and any safety, security, or other requirements.

17 Functional Register Description

17.1 Register Map

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x00	1	7:6	RW	CH4_SI	00: CH1 to CH4 (default) 01: CH2 to CH4 10: CH3 to CH4 11: CH4 to CH4	00
		5:4	RW	CH3_SI	00: CH1 to CH3 01: CH2 to CH3 (default) 10: CH3 to CH3 11: CH4 to CH3	01
		3:2	RW	CH2_SI	00: CH1 to CH2 01: CH2 to CH2 10: CH3 to CH2 (default) 11: CH4 to CH2	10
		1:0	RW	CH1_SI	00: CH1 to CH1 01: CH2 to CH1 10: CH3 to CH1 11: CH4 to CH1 (default)	11
0x01	1	7:6	RW	I2S_DO_LEN	I^2S data out length 00: 16bits 01: 24bits 10: 32bits (default) 11: Reserved	10
		5	RW	TDM_CH43_SEL	TDM CH43 receive data select 0: Receive from I^2S data 1 (default) 1: Receive from I^2S data 2	0
		4	RW	TDM_CH21_SEL	TDM CH21 receive data select 0: Receive from I^2S data 1 1: Receive from I^2S data 2 (default)	1
		3:0	RW	SDO_SEL	I^2S/LJ/RJ/DSPM 0000: No output (default) 0001: I2S_DATAI_1 0010: I2S_DATAI_2 0100: Interface output CH4, CH3 0101: Interface output CH2, CH1 0110: DSP output CH4, CH3 0111: DSP output CH2, CH1 1000: DF output CH4, CH3 1001: DF output CH2, CH1 Others: No output TDM 0000: No output (default) 0001: I2S_DATAI_1 0010: I2S_DATAI_2 010X: Interface output CH4, CH3, CH2, CH1 011X: DSP output CH4, CH3, CH2 CH1 100X: DF output CH4, CH3, CH2, CH1 Others: No output	0000

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x02	1	7	RW	BCK_EDGE_SEL	0: FRAME transition align with BCK falling (default) 1: FRAME transition align with BCK rising	0
		6	RW	SDO_EDGE_SEL	I^2S data out launch edge selection 0: BCK_EDGE_SEL = 0, launch with falling edge (default) 1: BCK EDGE_SEL = 0, launch with rising edge	0
		5:4	RW	AUD_BITS	00: 16 bits 01: 18 bits 10: 20 bits 11: 24 bits (default)	11
		3	RW	TDM_DSP_OFFSET	TDM or DSPM offset selection 0: Without offset (DSPMB) 1: 1 bit clock offset (DSPMA) (default)	1
		2:0	RW	AUD_FMT	000: I^2S (default) 001: Left-Justified 010: Right-Justified 011: DSP mode 1xx: TDM mode	000
0x03	1	7	RV	Reserved	Reserved	0
		6	RW	EN_DC_LOAD_DET	Execute DC load diagnostics before amp on sequence 0: Disable 1: Enable (default)	1
		5	RW	PBTL43	CH4, CH3 operation mode 0: BTL (default) 1: PBTL	0
		4	RW	PBTL21	CH2, CH1 operation mode 0: BTL (default) 1: PBTL	0
		3	RW	I2S_DEG_EN	I^2S data deglitch time selection 0: No deglitch 1: 2T deglitch (default)	1
		2:0	RW	SPK_GAIN_SEL	Speaker gain selection 000: –6dB (0.5x) 001: 0dB (1x) 010: 6dB (2x) 011: 12dB (4x) (default) 100: 15dB (5.5x) 101: 18dB (8x) Others: Reserved	011

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x04	1	7:6	RW	CH4_STATE	CH4 mode 00: Normal 01: Hi-Z (default) 10: MUTE 11: ULQM mode	01
		5:4	RW	CH3_STATE	CH3 mode 00: Normal 01: Hi-Z (default) 10: MUTE 11: ULQM mode	01
		3:2	RW	CH2_STATE	CH2 mode 00: Normal 01: Hi-Z (default) 10: MUTE 11: ULQM mode	01
		1:0	RW	CH1_STATE	CH1 mode 00: Normal 01: Hi-Z (default) 10: MUTE 11: ULQM mode	01
0x05	1	7	RV	Reserved	Reserved	0
		6:4	RW	PWM_FREQ	PWM frequency selection 000: 8*fs 001: 10*fs 010: 40*fs 011: 44*fs (default) 100: 48*fs Others: Reserved	011
		3	RV	Reserved	Reserved	0
		2:0	RW	OUT_PHASE_3	CH3 output phase offset 000: 0 degree 001: 45 degree (default) 010: 90 degree 011: 135 degree 100: 180 degree 101: 225 degree 110: 270 degree 111: 315 degree	001

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x06	1	7	RV	Reserved	Reserved	0
		6:4	RW	OUT_PHASE_2	CH2 output phase offset 000: 0 degree 001: 45 degree 010: 90 degree (default) 011: 135 degree 100: 180 degree 101: 225 degree 110: 270 degree 111: 315 degree	010
		3	RV	Reserved	Reserved	0
		2:0	RW	OUT_PHASE_1	CH1 output phase offset 000: 0 degree 001: 45 degree 010: 90 degree 011: 135 degree (default) 100: 180 degree 101: 225 degree 110: 270 degree 111: 315 degree	011
0x07	1	7	RW	FSS_EN	Spread spectrum enable 0: Disable (default) 1: Enable	0
		6	RW	PWM_MODEWHITE	Noise select 0: Pink noise (default) 1: White noise	0
		5	RW	PWM_SELCOEF	Pink noise coefficient This will affect the noise amplitude for spread spectrum signal. It is not recommended to modify it. 0: 1/2 (default) 1: 1/4	0
		4	RW	PWM_NOISE_EN	Add noise to TRI_GEN 0: Disable (default) 1: Enable	0
		3:2	RW	NOISE_AMP	Nosie amplitude for SSC 00: 6.3% (default) 01: 11.7% 10: 17.1% 11: 35.1%	00
		1:0	RW	FSS_AMP	Spread spectrum frequency variation amplitude 00: 14.73% 01: 22.5% (default) 10: 22.5% 11: 30.35%	01

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x08	1	7	RW	HPF_EN	High-Pass filter enabled 0: Disable 1: Enable (default)	1
		6	RW	COMP_EN	Compensation filter enable 0: Disable (default) 1: Enable (not available at 192kHz sampling rate)	0
		5	RW	DRC_EN	DRC enabled 0: Disable (default) 1: Enable	0
		4	RW	DRC_N_EN	DRC Noise Gate enabled 0: Disable (default) 1: Enable	0
		3	RW	HARD_CLIP_EN	Hard clip enabled 0: Disable (default) 1: Enable	0
		2	RW	DRE_EN	DRE enabled 0: Disable 1: Enable (default)	1
		1	RW	DRC_PEAK	DRC mode selection 0: RMS mode 1: Peak mode (default)	1
		0	RW	MS_MUTE	1: Master soft mute	0
0x09	1	7:3	RV	Reserved	Reserved	0000
		2	RW	DRC_GAIN_HYS_EN	0: DRC gain hysteresis disable 1: DRC gain hysteresis enable (default) Gain release condition is gain difference ≥ 0.125dB	1
		1	RW	COMP_SHARE	Compensation filter common coefficients selection 0: CH4/CH3 share CH4 coefficients, CH2/CH1 share CH2 coefficients 1: All channel share CH4 coefficients (default)	1
		0	RW	COEF_PAGE_SEL	DSP Coefficient page selection for mixer (0x4C to 0x4F)/compensation (0x48 to 0x4B) 0: Setting for CH4/CH3 (default) 1: Setting for CH2/CH1	0

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x0A	1	7	RW	SKIP_RAMP	Skip volume ramp 0: Disable (default) 1: Enable	0
		6	RW	FAST_RAMP_MUTE	Mute pin fast mute, mute time < 1ms 0: Normal ramp time (default) 1: Fast mute time	0
		5	RW	MUTE_MODE	Mute pin behavior 0: Mute only (default) 1: Enter ULQM	0
		4:2	RV	Reserved	Reserved	000
		1:0	RW	VOL_RAMP_MODE	Volume Slew step control 00: 1 step in every sample 01: mute → –40dB, every sample with1 step. –40dB → 24dB, 2 samples with 1 step. (default) 10: mute → –40dB, 2 samples with 1 step. –40dB → 24dB, 4 samples with 1 step. Others: Mute → –40dB, 4 samples with 1 step. –40dB → 24dB, 8 samples with 1 step.	01
0x0B	1	7:5	RV	Reserved	Reserved	000
		4	RW	FAULT_B_TYPE	0: Recovery type 1: Latch type (default)	1
		3:0	RW	RCVRY_TIME	Power stage auto-recovery time 0000: 100ms 0001: 150ms 0010: 300ms (default) 0011: 450ms 0100: 600ms 0101: 750ms 0110: 900ms 0111: 1050ms 1000: 1200ms 1001: 1350ms Others: 1500ms	0010
0x0C	1	7:3	RV	Reserved	Reserved	00000
		2	RW	I2S_FAULT_TYPE	Fault behavior type select. 0: Auto-recovery (default) 1: Latch	0
		1	RW	UVP_DVDD_TYPE	Fault behavior type select. 0: Auto-recovery (default) 1: Latch	0
		0	RW	UVP_VBAT_TYPE	Fault behavior type select. 0: Auto-recovery (default) 1: Latch	0

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x0D	1	7	RW	OVP_VBAT_TYPE	Fault behavior type select. 0: Auto-recovery (default) 1: Latch	0
		6	RW	UVP_VR_ANA _TYPE	Fault behavior type select. 0: Auto-recovery (default) 1: Latch	0
		5	RW	UVP_PVDD_TYPE	Fault behavior type select. 0: Auto-recovery (default) 1: Latch	0
		4	RW	OVP_PVDD_TYPE	Fault behavior type select. 0: Auto-recovery (default) 1: Latch	0
		3	RW	UVP_GVDD_TYPE	Fault behavior type select. 0: Auto-recovery (default) 1: Latch	0
		2	RW	OTPG_TYPE	Fault behavior type select. 0: Auto-recovery (default) 1: Latch	0
		1	RW	OCPC_TYPE	Fault behavior type select. 0: Auto-recovery 1: Latch (default)	1
		0	RW	OTPC_TYPE	Fault behavior type select. 0: Auto-recovery (default) 1: Latch	0
0x0E	1	7:4	RV	Reserved	Reserved	0000
		3	RW	I2C_TIMEOUT_TIME_SEL	I^2C timeout timing selection 0: 100ms (default) 1: 150ms	0
		2	RW	I2C_TIMEOUT_TYPE_SEL	I^2C timeout check pin type 0: SCL & SDA both keep low start timeout counting 1: SDA keep low start timeout counting (default)	1
		1	RW	I2C_TIME_OUT_SEL	I^2C timeout reset selection 0: Reset I^2C IP only (default) 1: Reset whole chip	0
		0	RW	I2C_TIME_OUT_EN	I^2C timeout function: If SDA & SCL remain low for 100ms, an I^2C timeout reset will occur. Bit 0 of register 0x05 is a reset option to select the reset block. Bit 1 of register 0x05 is used to enable the I^2C timeout function. 0: Disable 1: Enable (default)	1
0x0F	1	7:0	R	ERR_INT_INDEX	Report ERR_INT summary from ERR_INT0 (0x10) to ERR_INT7 (0x17)	00000001

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x10	1	7:6	RV	Reserved	Reserved	00
		5	W0C	PWM_ERR	PWM frequency setting error under sampling rate (0x06, 0x20) 0: PWM is supported (default) 1: PWM is not supported (write 0 to clear)	0
		4:3	W0C	ADS_ERR	Address R detection error {A_SEL1, A_SEL0} 0: R detect correct (default) 1: R detect error (write 0 to clear flag)	00
		2	W0C	POR	Power-on reset 0: Normal 1: Warning (write 0 to clear) (default)	1
		1	W0C	BCK_ERR	0: No BCK error (default) 1: BCK error, write 0 to clear flag	0
		0	W0C	FRAME_ERR	0: No FRAME clock error (default) 1: FRAME clock error, write0 to clear flag	0
0x11	1	7	W0C	VR_ANA _UV	VR_ANA UVP 0: Normal (default) 1: Fault (write 0 to clear)	0
		6	W0C	GVDDAB_UV	GVDDAB UVP 0: Normal (default) 1: Fault (write 0 to clear)	0
		5	W0C	GVDDCD_UV	GVDDCD UVP 0: Normal (default) 1: Fault (write 0 to clear)	0
		4	W0C	DVDD_UV	DVDD UVP 0: Normal (default) 1: Fault (write 0 to clear)	0
		3	W0C	VBAT_UV	VBAT UVP 0: Normal (default) 1: Fault (write 0 to clear)	0
		2	W0C	VBAT_OV	VBAT OVP 0: Normal (default) 1: Fault (write 0 to clear)	0
		1	W0C	OTPG	Global OTP 0: Normal (default) 1: Fault (write 0 to clear)	0
		0	W0C	OTWG	Global OT warning 0: Normal (default) 1: Warning (write 0 to clear)	0

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x12	1	7:6	W0C	PVDD_UV	PVDD UVP {AB, CD} 0: Normal (default) 1: Fault (write 0 to clear)	00
		5:4	W0C	PVDD_OV	PVDD OVP {AB, CD} 0: Normal (default) 1: Fault (write 0 to clear)	00
		3:0	W0C	DCP	Output DC detected flag {CH1, CH2, CH3, CH4} 0: Normal (default) 1: Fault (write 0 to clear)	0000
0x13	1	7:4	W0C	OTPC	Channel OTP {CH1, CH2, CH3, CH4} 0: Normal (default) 1: Fault (write 0 to clear)	0000
		3:0	W0C	OCPC	Channel OCP {CH1, CH2, CH3, CH4} 0: Normal (default) 1: Fault (write 0 to clear)	0000
0x14	1	7:4	W0C	OTWC	Channel OT Warning {CH1, CH2, CH3, CH4} 0: Normal (default) 1: Warning (write 0 to clear)	0000
		3:0	W0C	BS_LOW	Channel boost low {CH1, CH2, CH3, CH4} 0: Normal (default) 1: Warning (write 0 to clear)	0000
0x15	1	7:4	W0C	CLIP	Clip detection {CH1, CH2, CH3, CH4} 0: Normal (default) 1: Warning (write 0 to clear)	0000
		3	W0C	OCW_Flag_1	Overcurrent warning CH1 0: Normal (default) 1: Warning (write 0 to clear)	0
		2	W0C	OCW_Flag_2	Overcurrent warning CH2 0: Normal (default) 1: Warning (write 0 to clear)	0
		1	W0C	OCW_Flag_3	Overcurrent warning CH3 0: Normal (default) 1: Warning (write 0 to clear)	0
		0	W0C	OCW_Flag_4	Overcurrent warning CH4 0: Normal (default) 1: Warning (write 0 to clear)	0
0x16	1	7:4	W0C	S2P	Output short to power {CH1, CH2, CH3, CH4} 0: Normal (default) 1: Fault (write 0 to clear)	0000
		3:0	W0C	S2G	Output short to ground {CH1, CH2, CH3, CH4} 0: Normal (default) 1: Fault (write 0 to clear)	0000

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x17	1	7:4	W0C	OL	Output open load {CH1, CH2, CH3, CH4} 0: Normal (default) 1: Fault (write 0 to clear)	0000
		3:0	W0C	SL	Positive output shorting to negative output {CH1, CH2, CH3, CH4} 0: Normal (default) 1: Fault (write 0 to clear)	0000
0x18	1	7:6	RV	Reserved	Reserved	00
		5	RW	MASK_PWM_ERR	Fault mask for PWM setting error 0: Not mask (default) 1: Mask	0
		4:1	RV	Reserved	Reserved	0000
		0	RW	MASK_I2S_FAULT	Fault mask for BCK and FRAME error 0: Not mask (default) 1: Mask	0
0x19	1	7	RW	MASK_UV_VR_ANA	Fault mask for VR_ANA UV 0: Not mask (default) 1: Mask	0
		6	RW	MASK_UV_GVAB	Fault mask for GVAB UV 0: Not mask (default) 1: Mask	0
		5	RW	MASK_UV_GVCD	Fault mask for GVCD UV 0: Not mask (default) 1: Mask	0
		4	RW	MASK_UV_DVDD	Fault mask for DVDD UV 0: Not mask (default) 1: Mask	0
		3	RW	MASK_UV_VBAT	Fault mask for VBAT UV 0: Not mask (default) 1: Mask	0
		2	RW	MASK_OV_VBAT	Fault mask for VBAT OV 0: Not mask (default) 1: Mask	0
		1	RW	MASK_OTPG	Fault mask for OTPG 0: Not mask (default) 1: Mask	0
		0	RW	MASK_OTWG	Fault mask for OTWG 0: Not mask (default) 1: Mask	0
0x1A	1	7:6	RW	MASK_UV_PVDD	Fault mask for PVDD UV {AB, CD} 0: Not mask (default) 1: Mask	00
		5:4	RW	MASK_OV_PVDD	Fault mask for PVDD OV {AB, CD} 0: Not mask (default) 1: Mask	00
		3:0	RW	MASK_DCP	Fault mask for DCP {CH1, CH2, CH3, CH4} 0: Not mask (default) 1: Mask	0000

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x1B	1	7:4	RW	MASK_OTPC	Fault mask for OTPC {CH1, CH2, CH3, CH4} 0: Not mask (default) 1: Mask	0000
		3:0	RW	MASK_OCPC	Fault mask for OCPC {CH1, CH2, CH3, CH4} 0: Not mask (default) 1: Mask	0000
0x1C	1	7:4	RW	MASK_OTWC	Fault mask for OTWC {CH1, CH2, CH3, CH4} 0: Not mask (default) 1: Mask	0000
		3:0	RW	MASK_BS_LOW	Fault mask for BST_LOW {CH1, CH2, CH3, CH4} 0: Not mask (default) 1: Mask	0000
0x1D	1	7:4	RW	MASK_CLIP	Fault mask for chip detection {CH1, CH2, CH3, CH4} 0: Not mask (default) 1: Mask	0000
		3:0	RW	MASK_OCW	Fault mask for overcurrent warning {CH1, CH2, CH3, CH4} 0: Not mask (default) 1: Mask	0000
0x1E	1	7:4	RW	MASK_S2P	Fault mask for S2P {CH1, CH2, CH3, CH4} 0: Not mask (default) 1: Mask	0000
		3:0	RW	MASK_S2G	Fault mask for S2G {CH1, CH2, CH3, CH4} 0: Not mask (default) 1: Mask	0000
0x1F	1	7:4	RW	MASK_OL	Fault mask for OL {CH1, CH2, CH3, CH4} 0: Not mask (default) 1: Mask	0000
		3:0	RW	MASK_SL	Fault mask for SL {CH1, CH2, CH3, CH4} 0: Not mask (default) 1: Mask	0000

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x20	1	7	R	PWM_ STATUS	PWM status 0: Sampling rate vs. PWM frequency is supported (default) 1: Sampling rate vs. PWM frequency is not supported	0
		6:4	RW	SR_MODE	Sampling rate: manual or auto-detected. SR_AUTO_DET enabled: SR_MODE reports result. SR_AUTO_DET disabled: Set SR_MODE manually. 100: 32kHz 101: 44.1/48kHz (default) 110: 88.2/96kHz 111: 192kHz Others: Reserved	101
		3:0	RW	BCK_MODE	BCK mode: manual or auto-detected. SR_AUTO_DET enabled: BCK_MODE reports result. SR_AUTO_DET disabled: Set BCK_MODE manually. 0000: BCK = 32fs 0001: BCK = 48fs 0010: BCK = 64fs (default) 0011: BCK = 96fs 0100: BCK = 128fs 0101: BCK = 192fs (not support 192K-SR) 0110: BCK = 256fs (not support 192K-SR) 0111: BCK = 384fs (not support 96K-SR, 192K-SR) 1000: BCK =512fs (not support 96K-SR, 192K-SR) Others: Reserved	0010
0x21	1	7:6	RV	Reserved	Reserved	00
		5:0	RW	TDM_TX_ LOC_CH4	TDM start transmitting location select for CH4 000000: Start from 0+offset (default) 000001: Start from 8+offset … 111100: Start from 480+offest 111101: Start from 488+offset 111110: Not available 111111: Not available	000000

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x22	1	7:6	RV	Reserved	Reserved	00
		5:0	RW	TDM_TX_LOC_CH3	TDM start transmitting location select for CH3 000000: Start from 0+offset 000001: Start from 8+offset … 000011: Start from 24+offset (default) … 111100: Start from 480+offest 111101: Start from 488+offset 111110: Not available 111111: Not available	000011
0x23	1	7:6	RV	Reserved	Reserved	00
		5:0	RW	TDM_TX_LOC_CH2	TDM start transmitting location select for CH2 000000: Start from 0+offset 000001: Start from 8+offset … 000110: Start from 48+offset (default) … 111100: Start from 480+offest 111101: Start from 488+offset 111110: Not available 111111: Not available	000110
0x24	1	7:6	RV	Reserved	Reserved	00
		5:0	RW	TDM_TX_LOC_CH1	TDM start transmitting location select for CH1 000000: Start from 0+offset 000001: Start from 8+offset … 001001: Start from 72+offset (default) … 111100: Start from 480+offest 111101: Start from 488+offset 111110: Not available 111111: Not available	001001
0x25	1	7:6	RV	Reserved	Reserved	00
		5:0	RW	TDM_RX_LOC_CH1	TDM start receiving location select for CH1 000000: Start from 0+offset (default) 000001: Start from 8+offset … 111100: Start from 480+offest 111101: Start from 488+offset 111110: Not available 111111: Not available	000000

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x26	1	7:6	RV	Reserved	Reserved	00
		5:0	RW	TDM_RX_LOC_CH2	TDM start receiving location select for CH2 000000: Start from 0+offset 000001: Start from 8+offset … 000011: Start from 24+offset (default) … 111100: Start from 480+offest 111101: Start from 488+offset 111110: Not available 111111: Not available	000011
0x27	1	7:6	RV	Reserved	Reserved	00
		5:0	RW	TDM_RX_LOC_CH3	TDM start receiving location select for CH3 000000: Start from 0+offset 000001: Start from 8+offset … 000110: Start from 48+offset (default) … 111100: Start from 480+offest 111101: Start from 488+offset 111110: Not available 111111: Not available	000110
0x28	1	7:6	RV	Reserved	Reserved	00
		5:0	RW	TDM_RX_LOC_CH4	TDM start receiving location select for CH4 000000: Start from 0+offset 000001: Start from 8+offset … 001001: Start from 72+offset (default) … 111100: Start from 480+offest 111101: Start from 488+offset 111110: Not available 111111: Not available	001001
0x29	1	7:4	RW	HPF_EN_CH	High-pass filter enabled {CH1, CH2, CH3, CH4} 0: Disable (default) 1: Enable	0000
		3:0	RW	COMP_EN_CH	Compensation filter enabled {CH1, CH2, CH3, CH4} 0: Disable (default) 1: Enable (not available at 192kHz sampling rate)	0000
0x2A	1	7:4	RW	DRC_EN_CH	Dynamic range control (DRC) enabled {CH1, CH2, CH3, CH4} 0: Disable (default) 1: Enable	0000
		3:0	RW	DRC_N_EN_CH	DRC Noise Gate enabled {CH1, CH2, CH3, CH4} 0: Disable (default) 1: Enable	0000

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x2B	1	7:4	RW	HARD_CLIP_EN_CH	Hard clip enabled {CH1, CH2, CH3, CH4} 0: Disable (default) 1: Enable	0000
		3:0	RW	DRE_EN_CH	DRE enabled {CH1, CH2, CH3, CH4} 0: Disable (default) 1: Enable	0000
0x30	2	15:11	RV	Reserved	Reserved	00000
		10:0	RW	MS_VOL	Master Volume control 11'h000: 24dB 11'h180: 0dB 11'h7FF: Mute (default) 0.0625dB per step	11'h7FF
0x31	2	15:11	RV	Reserved	Reserved	00000
		10:0	RW	CH4_VOL	CH4 Volume control 11'h000: 24dB 11'h180: 0dB (default) 11'h7FF: Mute 0.0625dB per step	11'h180
0x32	2	15:11	RV	Reserved	Reserved	00000
		10:0	RW	CH3_VOL	CH3 Volume control 11'h000: 24dB 11'h180: 0dB (default) 11'h7FF: Mute 0.0625dB per step	11'h180
0x33	2	15:11	RV	Reserved	Reserved	00000
		10:0	RW	CH2_VOL	CH2 Volume control 11'h000: 24dB 11'h180: 0dB (default) 11'h7FF: Mute 0.0625dB per step	11'h180
0x34	2	15:11	RV	Reserved	Reserved	00000
		10:0	RW	CH1_VOL	CH1 Volume control 11'h000: 24dB 11'h180: 0dB (default) 11'h7FF: Mute 0.0625dB per step	11'h180
0x35	2	15:11	RV	Reserved	Reserved	00000
		10:0	RW	HC_TH	Hard clip threshold when HARD_CLIP_EN = 1 > 0dB is not allowable for hard clip threshold setting 11'h180: 0dB (default) 0.0625db per step	11'h180

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x40	3	23:11	RV	Reserved	Reserved	13'h0000
		10:0	RW	DRC_TH	DRC threshold 11'h000: 0dB (default) 11'h180: −24dB 11'h67E: −103.875dB 11'h67F to 11'h7FF: not available 0.0625dB per step	11'h000
0x41	3	23:11	RV	Reserved	Reserved	13'h0000
		10:0	RW	DRC_ OFFSET	DRC make up gain (Offset) 11'h000: 24dB 11'h180: 0dB (default) 11'h7FF: −103.9375dB 0.0625dB per step	11'h180
0x42	3	23:8	RV	Reserved	Reserved	16'h0000
		7:0	RW	DRC_RATIO	DRC compress ratio 8'h00: No compression 8'h80 (default) ~ 8'hFF: Full compression 1/128 per step	8'h80
0x43	3	23:11	RV	Reserved	Reserved	13'h0000
		10:0	RW	DRC_NG_TH	Noise gate threshold 11'h000: 0dB 11'h180: -24dB 11'h640: −100dB (default) 11'h67E: −103.875dB 11'h67F to 11'h7FF: Not available 0.0625dB per step	11'h640
0x44	3	23:17	RV	Reserved	Reserved	0000000
		16:0	RW	DRC_AE	DRC_AE	17'h0_8000
0x45	3	23:17	RV	Reserved	Reserved	0000000
		16:0	RW	DRC_1_AE	DRC_1_AE	17'h0_0000
0x46	3	23:17	RV	Reserved	Reserved	0000000
		16:0	RW	DRC_AD	DRC_AD	17'h0_8000
0x47	3	23:17	RV	Reserved	Reserved	0000000
		16:0	RW	DRC_AA	DRC_AA	17'h0_8000
0x48	3	23:17	RV	Reserved	Reserved	0000000
		16:0	RW	COMP_B0	Compensation filter coefficient B0, COEF_PAGE_SEL (0x09) select CH12 or CH34	17'h0_8000
0x49	3	23:17	RV	Reserved	Reserved	0000000
		16:0	RW	COMP_B1	Compensation filter coefficient B1, COEF_PAGE_SEL (0x09) select CH43 or CH21	17'h0_0000

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x4A	3	23:17	RV	Reserved	Reserved	0000000
		16:0	RW	COMP_B2	Compensation filter coefficient B2, COEF_PAGE_SEL (0x09) select CH43 or CH21	17'h0_0000
0x4B	3	23:17	RV	Reserved	Reserved	0000000
		16:0	RW	COMP_B3	Compensation filter coefficient B3, COEF_PAGE_SEL (0x09) select CH43 or CH21	17'h0_0000
0x4C	3	23:17	RV	Reserved	Reserved	0000000
		16:0	RW	CH42_MIX_0	Channel input mixer coefficient 0, COEF_PAGE_SEL (0x09) select CH4 or CH2	17'h0_8000
0x4D	3	23:17	RV	Reserved	Reserved	0000000
		16:0	RW	CH42_MIX_1	Channel input mixer coefficient 1, COEF_PAGE_SEL (0x09) select CH4 or CH2	17'h0_0000
0x4E	3	23:17	RV	Reserved	Reserved	0000000
		16:0	RW	CH31_MIX_0	Channel input mixer coefficient 0, COEF_PAGE_SEL (0x09) select CH3 or CH1	17'h0_0000
0x4F	3	23:17	RV	Reserved	Reserved	0000000
		16:0	RW	CH31_MIX_1	Channel input mixer coefficient 1, COEF_PAGE_SEL (0x09) select CH3 or CH1	17'h0_8000
0x51	1	7:4	RW	SL_TH_CH4	CH4 SL threshold selection (0.5Ω each step) 0000: 0.5Ω 0001: 1Ω (default) 0010: 1.5Ω ... 1001: 5Ω Others: Reserved	0001
		3:0	RW	SL_TH_CH3	CH3 SL threshold selection (0.5Ω each step) 0000: 0.5Ω 0001: 1Ω (default) 0010: 1.5Ω ... 1001: 5Ω Others: Reserved	0001

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x52	1	7:4	RW	SL_TH_CH2	CH2 SL threshold selection (0.5Ω each step) 0000: 0.5Ω 0001: 1Ω (default) 0010: 1.5Ω ... 1001: 5Ω Others: Reserved	0001
		3:0	RW	SL_TH_CH1	CH1 SL threshold selection (0.5Ω each step) 0000: 0.5Ω 0001: 1Ω (default) 0010: 1.5Ω ... 1001: 5Ω Others: Reserved	0001
0x53	1	7:4	RW	EN_DC_DET	DC load detection enable {CH1, CH2, CH3, CH4} 0: Disable (default) 1: Enable After the command is executed, the value is returned to 0, and the command is set to 1 to enable DC load detection.	0000
		3:0	R	DC_DET_DONE	DC load detection done flag after enabling DC load detection {CH1, CH2, CH3, CH4} 0: DC load detection do not executed or do not finished 1: DC load detection finishes (default)	1111
0x54	1	7:5	RV	Reserved	Reserved	000
		4:0	RW	AC_PHI	Generated signal frequency: 00: No signal 01: Set 1 = 1kHz, 02: set 2 = 2kHz, …, set 17 = 23kHz 13: Set 19kHz (default) 18~1F: Reserved	5'h13
0x55	1	7:4	RW	EN_AC_DET	AC load detection enable {CH1, CH2, CH3, CH4} 0: Disable (default) 1: Enable	0000
		3:0	R	AC_DET_DONE	AC detection done flag after enabling AC load detection {CH1, CH2, CH3, CH4} 0: AC_PHASE_R and AC_PHASE_I keep the last result if ever enabling detection 1: AC_PHASE_R and AC_PHASE_I is valid (default)	1111
0x5C	4	31:16	R	AC_MAG_4	Report CH4 magnitude	16'd0
		15:0	R	AC_PHA_4	Report CH4 phase	16'd0
0x5D	4	31:16	R	AC_MAG_3	Report CH3 magnitude	16'd0
		15:0	R	AC_PHA_3	Report CH3 phase	16'd0
0x5E	4	31:16	R	AC_MAG_2	Report CH2 magnitude	16'd0
		15:0	R	AC_PHA_2	Report CH2 phase	16'd0

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x5F	4	31:16	R	AC_MAG_1	Report CH1 magnitude	16'd0
		15:0	R	AC_PHA_1	Report CH1 phase	16'd0
0x60	4	31:0	R	AC_INT_R_4	Report the real part of CH4 internal phase	32'd0
0x61	4	31:0	R	AC_INT_I_4	Report the imaginary part of CH4 internal phase	32'd0
0x62	4	31:0	R	AC_SPK_R_4	Report the real part of CH4 speaker phase	32'd0
0x63	4	31:0	R	AC_SPK_I_4	Report the imaginary part of CH4 speaker phase	32'd0
0x64	4	31:0	R	AC_INT_R_3	Report the real part of CH3 internal phase	32'd0
0x65	4	31:0	R	AC_INT_I_3	Report the imaginary part of CH3 internal phase	32'd0
0x66	4	31:0	R	AC_SPK_R_3	Report the real part of CH3 speaker phase	32'd0
0x67	4	31:0	R	AC_SPK_I_3	Report the imaginary part of CH3 speaker phase	32'd0
0x68	4	31:0	R	AC_INT_R_2	Report the real part of CH2 internal phase	32'd0
0x69	4	31:0	R	AC_INT_I_2	Report the imaginary part of CH2 internal phase	32'd0
0x6A	4	31:0	R	AC_SPK_R_2	Report the real part of CH2 speaker phase	32'd0
0x6B	4	31:0	R	AC_SPK_I_2	Report the imaginary part of CH2 speaker phase	32'd0
0x6C	4	31:0	R	AC_INT_R_1	Report the real part of CH1 internal phase	32'd0
0x6D	4	31:0	R	AC_INT_I_1	Report the imaginary part of CH1 internal phase	32'd0
0x6E	4	31:0	R	AC_SPK_R_1	Report the real part of CH1 speaker phase	32'd0
0x6F	4	31:0	R	AC_SPK_I_1	Report the imaginary part of CH1 speaker phase	32'd0

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x70	1	7	RV	Reserved	Reserved	0
		6	RW	EN_OTPC	Channel OT protection enabled 0: Disable 1: Enable (default)	1
		5	RW	EN_OTWC	Channel OT warning enabled 0: Disable 1: Enable (default)	1
		4	RW	EN_UVOVOT	Enable UV/OV/OT 0: Disable 1: Enable (default)	1
		3	RW	EN_OCW	Enable overcurrent warning function 0: Disable 1: Enable (default)	1
		2	RW	EN_DC_PROT	DC protection enabled 0: Disable 1: Enable (default)	1
		1	RW	EN_CLIP_DET	Clip detection enabled 0: Disable 1: Enable (default)	1
		0	RW	EN_BS_PROT	Boot low protection enabled 0: Disable 1: Enable (default)	1
0x71	1	7:6	RW	UV_DV_SEL	DVDD UV threshold selection 00: 1.4V 01: 1.5V 10: 2.1V 11: 2.3V (default)	11
		5	RW	DC_UVP_CAL_EN	PVDD UVP re-calibration dc offset enabled 0: Disable (default) 1: Enable	0
		4	RW	UV_RAMP_DOWN	PVDD UV protection behavior 0: HZ_PROT directly (default) 1: Power-off sequence	0
		3	RV	Reserved	Reserved	1
		2	RW	EN_OTW_TFC	Enable thermal fold-back 0: Disable (default) 1: Enable	0
		1	RV	Reserved	Reserved	1
		0	RV	Reserved	Reserved	0

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x72	1	7	RW	BS_LOW_SEL	Boot low protection threshold selection 0: 3V (default) 1: 3.5V	0
		6:4	RW	UV_VBAT_SEL	Battery UV threshold selection 000: 4V (default) 001: 6.12V 010: 8.88V 011: 11.1V 100: 12.67V 101: 15.26V 110: Reserved 111: Reserved	000
		3	RV	Reserved	Reserved	0
		2:0	RW	UV_PVDD_SEL	PVDD UV threshold selection 000: 4V (default) 001: 6.12V 010: 8.88V 011: 11.1V 100: 12.67V 101: 15.26V 110: Reserved 111: Reserved	000
0x73	1	7:6	RW	OTPG_SEL	Global OTP threshold selection 00: 160°C (default) 01: 170°C 10: Reserved 11: Reserved	00
		5:4	RW	OTPC_SEL	Channel OTP threshold selection 00: 160°C 01: 170°C (default) 10: Reserved 11: Reserved	01
		3:0	RW	CLIP_DET_SEL	Clip detect threshold, release threshold (unit: PWM cycle) 0000: 1, 0 0001: 5, 3 0010: 10, 5 0011: 20, 5 (default) 0100: 50, 30 0101: 100, 80 0110: 150, 130 Others: 250, 230	0011

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x74	1	7:6	RW	TFC_ATTACK_RATE	Thermal Fold-Back attack rate 00: 0.0625dB/25ms (default) 01: 0.0625dB/50ms 10: 0.0625dB/100ms 11: 0.0625dB/200ms	00
		5:4	RW	TFC_RELEASE_RATE	Thermal Fold-Back release rate 00: 0.0625dB/50ms (default) 01: 0.0625dB/100ms 10: 0.0625dB/200ms 11: 0.0625dB/400ms	00
		3:2	RV	Reserved	Reserved	01
		1:0	RV	Reserved	Reserved	01
0x75	1	7:6	RV	Reserved	Reserved	00
		5:4	RW	OC_HZ_DELAY_SEL	HZ delay time after OCP is triggered. 00: 1.5ms 01: 3.4ms (default) 10: 8.8ms 11: 21.5ms	01
		3:0	RV	Reserved	Reserved	1111
0x76	1	7:5	RV	Reserved	Reserved	000
		4	RW	DC_DET_REF_TIME	DC offset detection reference time strobe 0: Follow sampling rate (default) 1: PLL divide down to 16kHz	0
		3	RW	DC_DET_MODE	DC offset detection mode 0: Detect DC every (detection time) 1: Consecutively 8 times of (detection time/8) (default)	1
		2	RW	DC_TIME_SEL	DC offset detection time 0: 342ms (default) 1: 684ms	0
		1:0	RW	DC_TH	DC offset detection threshold at PWM frequency = 384kHz 00: No available 01: 12.5% (default) 10: 18.75% 11: 25% For example, DC offset = PVDD x DC offset detection threshold → DC offset = 14.4V x 12.5% = 1.8V	01

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x80	1	7:6	RV	Reserved	Reserved	00
		5	RW	ADC_CKSEL	ADC clock selection when VT sense & DC load detection 0: 192kHz 1: 384kHz (default)	1
		4	RW	ADC_AVG_SEL	VT sense & DC load detection average method, only support ADC_CKSEL = 1 0: Average 2 samples 1: Average 8 samples (default)	1
		3:2	RW	ADC_CHP_FREQ	ADC chopper frequency selection 00: div 64 01: div 32 10: div 16 11: div 8 (default)	11
		1	RW	ADC_DITH_EN	ADC dither enabled 0: Disable (default) 1: Enable	0
		0	RW	ADC_CHP_EN	ADC chopper enable 0: Disable (default) 1: Enable	0
0x81	1	7:4	RW	ADC_G_PVDD	The median value offset of ADC gain at PVDD sense	1101
		3:0	RW	ADC_G_TEMP	The median value offset of ADC gain at temperature sense	0000
0x82	1	7	RV	Reserved	Reserved	0
		6:0	RW	ADC_G_DC	The median value offset of ADC gain at DC load detection	0000000
0x83	1	7:5	RV	Reserved	Reserved	000
		4:0	RW	ADC_G_AC	The median value offset of ADC gain at AC load detection	00000

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x84	1	7:6	RV	Reserved	Reserved	00
		5:4	RW	R_SPSG_GAIN_ADC_SEL	ADC PGA gain for DC load short to power/ground 00: 1x (default) 01: 4x 1x: 8x	00
		3:2	RW	R_OLSLAC_GAIN_ADC_SEL	ADC PGA gain for DC load open/short load and AC load 00: 1x (default) 01: 4x 1x: 8x	00
		1	RW	IDAC_IMAX_SEL	0: 1.5mA (−6dB) (default) 1: 3mA (0dB)	0
		0	RW	LDET_GAIN_MANUAL	Load detection manual mode 0: Gain select from IDAC_IMAX_SEL (default) 1: AC gain select from MS_VOL; DC gain select from IDAC_VEC_MSB/IDAC_VEC_SSB	0
0x85	1	7:1	RV	Reserved	Reserved	0000000
		0	RW	DC_RAMP_TIME	DC load detection ramp time 0: 1.28ms (default) 1: 2.56ms (ramp from 0.9V to 1.2V)	0
0x86	1	7	RW	AC_BIT	Phase resolution within computation stage 0: 16-bit 1: 32-bit (default)	1
		6	RW	AC_SETTLE_TIME	AC load detection settle time 0: 1ms (default) 1: 2ms	0
		5:4	RW	AC_DFT_DELAY	Delay to start computing AC phase 00: Delay 1ms (48*1 samples) (default) 01: Delay 2ms (48*2 samples) 10: Delay 5ms (48*5 samples) 11: Delay 10ms (48*10 samples)	00
		3:2	RW	AC_LOOP_MODE	AC load detection loop-back mode 00: ADC output: analog loop-back and then speaker detection (default) 01: ADC output: analog loop-back and then still analog loop-back 10: Generated sine (0x51), ignore analog path 11: Down-sampled digital filter output, ignore analog path	00
		1	RW	AC_INT_PHASE	Digital internal built-in phase enabled 0: Disable, phase 90 (generated sine) (default) 1: Enable, phase 0 (generated cosine)	0
		0	RW	AC_OFS_GAIN_EN	AC load detection ADC offset-gain function 0: Disable 1: Enable (default)	1

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x87	1	7	RW	EN_ VR_ANA	Enable VR_ANA 0: Disable 1: Enable (default)	1
		6	RW	EN_GVAB	Enable GVDDAB 0: Disable 1: Enable (default)	1
		5	RW	EN_GVCD	Enable GVDDCD 0: Disable 1: Enable (default)	1
		4	RW	EN_UV_DV	Enable DVDD UV detection 0: Disable 1: Enable (default)	1
		3:0	RW	EN_PWR	Enable power stage {CH1, CH2, CH3, CH4} 0: Disable 1: Enable (default)	1111
0x88	1	7:4	RW	EN_SCDAC	Enable DAC for Channel {CH1, CH2, CH3, CH4} 0: Disable 1: Enable (default)	1111
		3:0	RW	EN_TRI	Enable triangle generator {CH1, CH2, CH3, CH4} 0: Disable 1: Enable (default)	1111
0x89	1	7:4	RW	EN_SPK	Enable SPK for Channel {CH1, CH2, CH3, CH4} 0: Disable 1: Enable (default)	1111
		3	RV	Reserved	Reserved	0
		2	RW	VR_ANA_SEL	VR_ANA voltage selection 0: 5V (default) 1: 5.5V	0
		1	RW	GVDD_SEL	GVDD_AB/CD voltage selection 0: 5V (default) 1: 5.5V	0
		0	RW	SEQ_TIME_SEL	Power down to Disable LDO time select 0: 10ms (default) 1: 20ms	0

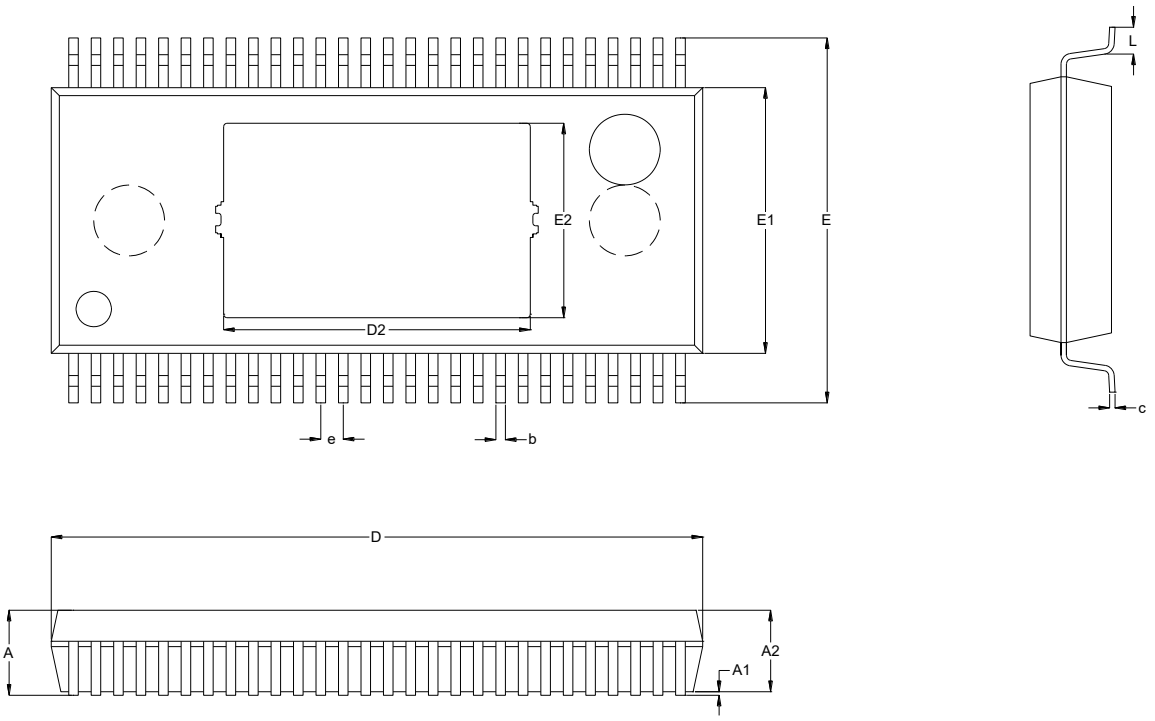
ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x8A	1	7:6	RW	D_KDC_QC_TIME	KDC unity-gain time option 00: 25μs 01: 50μs (default) 10: 200μs 11: 1ms	01
		5	RV	Reserved	Reserved	0
		4	RW	PVDD_SET_TIME	0: 2ms 1: 16ms (default)	1
		3:2	RW	SPK_SST	SPK start-up time 00: 2.5ms 01: 5ms (default) 10: 10ms 11: 20ms	01
		1:0	RW	D_KDC_CMP_TIME	KDC compare time option 00: 25μs 01: 50μs (default) 10: 200μs 11: 1ms	01
0x8B	1	7:3	RV	Reserved	Reserved	00000
		2:0	RW	R_DC_LOAD_ADC_SEL	DC load ADC report selection 000: 0 (default) 001: S2PG channel P 010: S2PG channel N 011: OLSL channel offset 100: OLSL channel data 101: OLSL channel data - offset	000
0x8C	2	15:00	R	RDC_LOAD_ADC_RPT_CH1	DC load ADC report data	16'd0
0x8D	2	15:00	R	RDC_LOAD_ADC_RPT_CH2	DC load ADC report data	16'd0
0x8E	2	15:00	R	RDC_LOAD_ADC_RPT_CH3	DC load ADC report data	16'd0
0x8F	2	15:00	R	RDC_LOAD_ADC_RPT_CH4	DC load ADC report data	16'd0
0x90	2	16	R	SENSE_PVDDAB	PVDDAB sense code	16'd0
0x91	2	15:0	R	SENSE_PVDDCD	PVDDCD sense code	16'd0
0x92	2	15:0	R	SENSE_VBAT	VBAT sense code	16'd0
0x93	2	15:0	R	SENSE_TEMP_G	Global temperature sense code	16'd0
0x94	2	15:0	R	SENSE_TEMP_4	CH4 Temperature sense code	16'd0

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0x95	2	15:0	R	SENSE_TEMP_3	CH3 Temperature sense code	16'd0
0x96	2	15:0	R	SENSE_TEMP_2	CH2 Temperature sense code	16'd0
0x97	2	15:0	R	SENSE_TEMP_1	CH1 Temperature sense code	16'd0
0x98	4	31:16	R	AC_INT_MAG_4	Report CH4 internal magnitude	16'd0
		15:0	R	AC_INT_PHA_4	Report CH4 internal phase	16'd0
0x99	4	31:16	R	AC_SPK_MAG_4	Report CH4 speaker magnitude	16'd0
		15:0	R	AC_SPK_PHA_4	Report CH4 speaker phase	16'd0
0x9A	4	31:16	R	AC_INT_MAG_3	Report CH3 internal magnitude	16'd0
		15:0	R	AC_INT_PHA_3	Report CH3 internal phase	16'd0
0x9B	4	31:16	R	AC_SPK_MAG_3	Report CH3 speaker magnitude	16'd0
		15:0	R	AC_SPK_PHA_3	Report CH3 speaker phase	16'd0
0x9C	4	31:16	R	AC_INT_MAG_2	Report CH2 internal magnitude	16'd0
		15:0	R	AC_INT_PHA_2	Report CH2 internal phase	16'd0
0x9D	4	31:16	R	AC_SPK_MAG_2	Report CH2 speaker magnitude	16'd0
		15:0	R	AC_SPK_PHA_2	Report CH2 speaker phase	16'd0
0x9E	4	31:16	R	AC_INT_MAG_1	Report CH1 internal magnitude	16'd0
		15:0	R	AC_INT_PHA_1	Report CH1 internal phase	16'd0
0x9F	4	31:16	R	AC_SPK_MAG_1	Report CH1 speaker magnitude	16'd0
		15:0	R	AC_SPK_PHA_1	Report CH1 speaker phase	16'd0
0xAD	1	7	RW	Auto_ULQM	Auto ULQM 0: Disable (default) 1: Enable	0
		6:0	RW	Reserved	Reserved	0110010

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0xB3	1	7:6	RW	LS_OC_SEL_4	CH4 OC protection threshold selection 00: 6.5A 01: 8A (default) 10: Reserved 11: Reserved	01
		5:4	RW	LS_OC_SEL_1	CH1 OC protection threshold selection 00: 6.5A 01: 8A (default) 10: Reserved 11: Reserved	01
		3:2	RW	LS_OC_SEL_2	CH2 OC protection threshold selection 00: 6.5A 01: 8A (default) 10: Reserved 11: Reserved	01
		1:0	RW	LS_OC_SEL_3	CH3 OC protection threshold selection 00: 6.5A 01: 8A (default) 10: Reserved 11: Reserved	01

ADDR	Byte Number	Bits	Type	Reg Name	Description	Default
0xB4	1	7:6	RW	OCW_SEL_4	CH4 overcurrent warning threshold selection 00: 4.8A 01: 5.8A (default) 10: 7.3A 11: 8.5A	01
		5:4	RW	OCW_SEL_1	CH1 overcurrent warning threshold selection 00: 4.8A 01: 5.8A (default) 10: 7.3A 11: 8.5A	01
		3:2	RW	OCW_SEL_2	CH2 overcurrent warning threshold selection 00: 4.8A 01: 5.8A (default) 10: 7.3A 11: 8.5A	01
		1:0	RW	OCW_SEL_3	CH3 overcurrent warning threshold selection 00: 4.8A 01: 5.8A (default) 10: 7.3A 11: 8.5A	01
0xF7	1	7	RW	SR_AUTO_DET	Sampling rate detection enable bit detect sampling rate and BCK mode 0: Disable, manual set 0x01 SR mode and BCK mode 1: Enable (default)	1

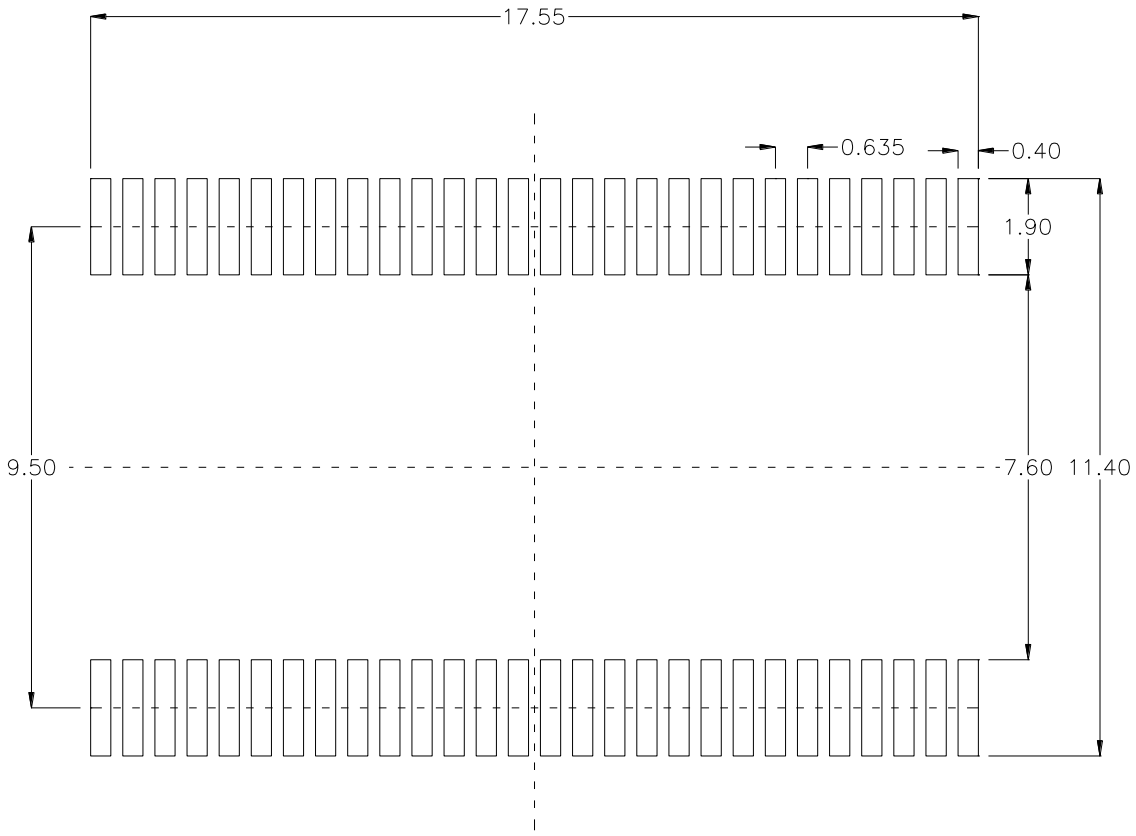
18 Outline Dimension



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	--	2.475	--	0.097
A1	0.000	0.150	0.000	0.006
A2	2.220	2.320	0.087	0.091
b	0.230	0.310	0.009	0.012
D	18.300	18.500	0.720	0.728
D1	8.561	8.761	0.337	0.345
e	0.635		0.025	
E	10.100	10.500	0.398	0.413
E1	7.400	7.600	0.291	0.299
E2	5.390	5.590	0.212	0.220
L	0.500	1.000	0.020	0.039
c	0.150	0.190	0.006	0.007

56-Lead RTSSOP (Exposed Pad) Package

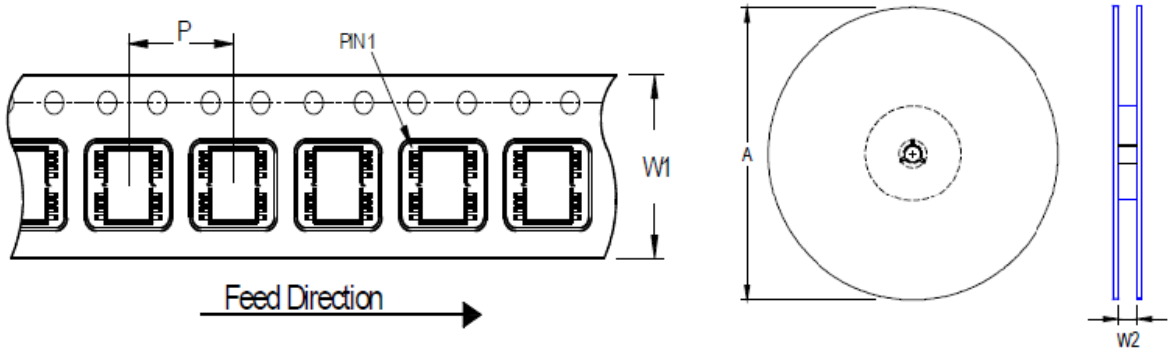
19 Footprint Information

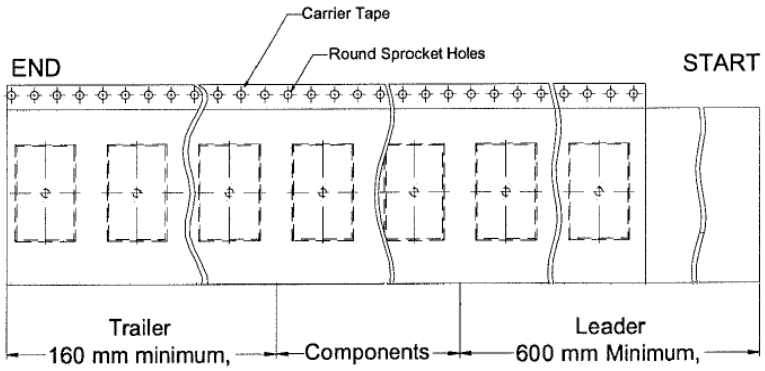


Package	Number of Pins	Tolerance
RTSSOP-56(PP)	56	±0.10

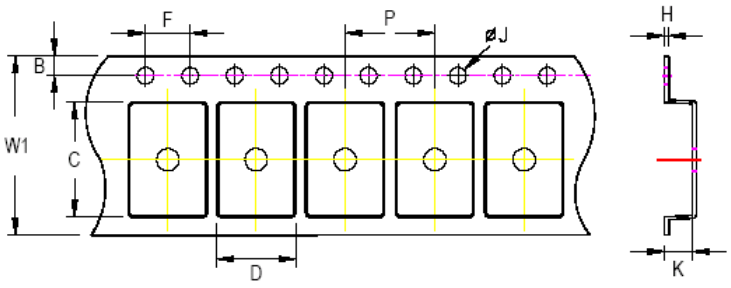
20 Packing Information

20.1 Tape and Reel Data





Package Type	Tape Size (W1) (mm)	Pocket Pitch (P) (mm)	Reel Size (A)		Units per Reel	Trailer (mm)	Leader (mm)	Reel Width (W2) Min./Max. (mm)
			(mm)	(in)				
TSSOP-56L	32	16	330	13	1,000	160	600	32.4/34.4



C, D, and K are determined by component size.

The clearance between the components and the cavity is as follows:

- For 32mm carrier tape: 1.0mm max.

Tape Size	W1	P		B		F		ØJ		K		H
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Max.
32mm	32.3mm	15.9mm	16.1mm	1.65mm	1.85mm	3.9mm	4.1mm	1.5mm	1.6mm	2.9mm	3.1mm	0.6mm

20.2 Tape and Reel Packing

Step	Photo/Description	Step	Photo/Description
1	 Reel 13”	4	 1 reel per inner box **Box B**
2	 HIC & Desiccant (2 Unit) inside	5	 5 inner boxes per outer box
3	 Caution label is on backside of Al bag	6	 Outer box **Carton A**

Container / Package	Reel		Box			Carton		
	Size	Units	Item	Reels	Units	Item	Boxes	Units
TSSOP-56L	13”	1,000	Box G	1	1,000	Carton A	6	6,000

20.3 Packing Material Anti-ESD Property

Surface Resistance	Aluminum Bag	Reel	Cover tape	Carrier tape	Tube	Protection Band
Ω/cm^2	**10^4 to 10^{11}**	**10^4 to 10^{11}**	**10^4 to 10^{11}**	**10^4 to 10^{11}**	**10^4 to 10^{11}**	**10^4 to 10^{11}**

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21 Datasheet Revision History

Version	Date	Description
00	2026/4/20	First Edition