

## Low Power F0 Detect and Tracking LRA Haptic Driver

### Features

- 1MHz I2C Bus
- Integrated 3K Memory
- 12k/24k/48k input wave sampling rate
- F0 detect and tracking
- Advance autobrake engine integrated
- Playback mode:
  - Real time playback
  - Memory playback
  - 3 Trigger playback
  - Cont playback
  - PWM playback
- Resistance-Based LRA Diagnostics
- Drive signal monitor for LRA protect
- Drive Compensation Over Battery Discharge
- Fast Start Up Time: 0.4ms
- Dedicated interrupt output pin
- Support automatically switch to standby mode
- Standby current: 3μA
- Shutdown current: <1μA
- Supply voltage range 3 to 5.5V
- Short-Circuit Protection, Over-Temperature Protection, Under-Voltage Protection
- QFN 2mmX2mmX0.5mm-12L Package

### Applications

- Mobile phones
- Tablets
- Wearable Devices

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### General Description

AW86223 is a low cost H-bridge, single chip LRA haptic driver, with F0 detecting and tracking based on BEMF, supporting real time playback, memory playback, CONT, PWM, and hardware pin triggered playback with fast start up time. All these make the AW86223 an ideal candidate for haptic driver.

AW86223 integrates a 3KByte SRAM for user-defined waveforms to achieve a variety of vibration experiences, supporting 3 sampling rate(12k/24k/48k) of waveforms loaded in SRAM, supporting output waveform sampling rate up-sampling to 48k.

AW86223 integrates an autobrake engine to suppress the aftershocks to zero for different drive waveforms (short or long) on different LRA motors.

AW86223 supports LRA fault diagnostic based on resistance measurement and protections of short-circuit, over-temperature and under-voltage.

AW86223 features configurable automatically switch to standby mode after haptic waveform playback finished. This can less quiescent power consumption. The RSTN pin provides further power saving by fully shut down the whole device. Dedicated interrupt output pin can detect real time FIFO status and the error status of the chip.

AW86223 features general settings are communicated via an I2C-bus interface.

AW86223 is available in a QFN 2mmX2mmX0.5mm-12L package.

## Pin Configuration And Top Mark

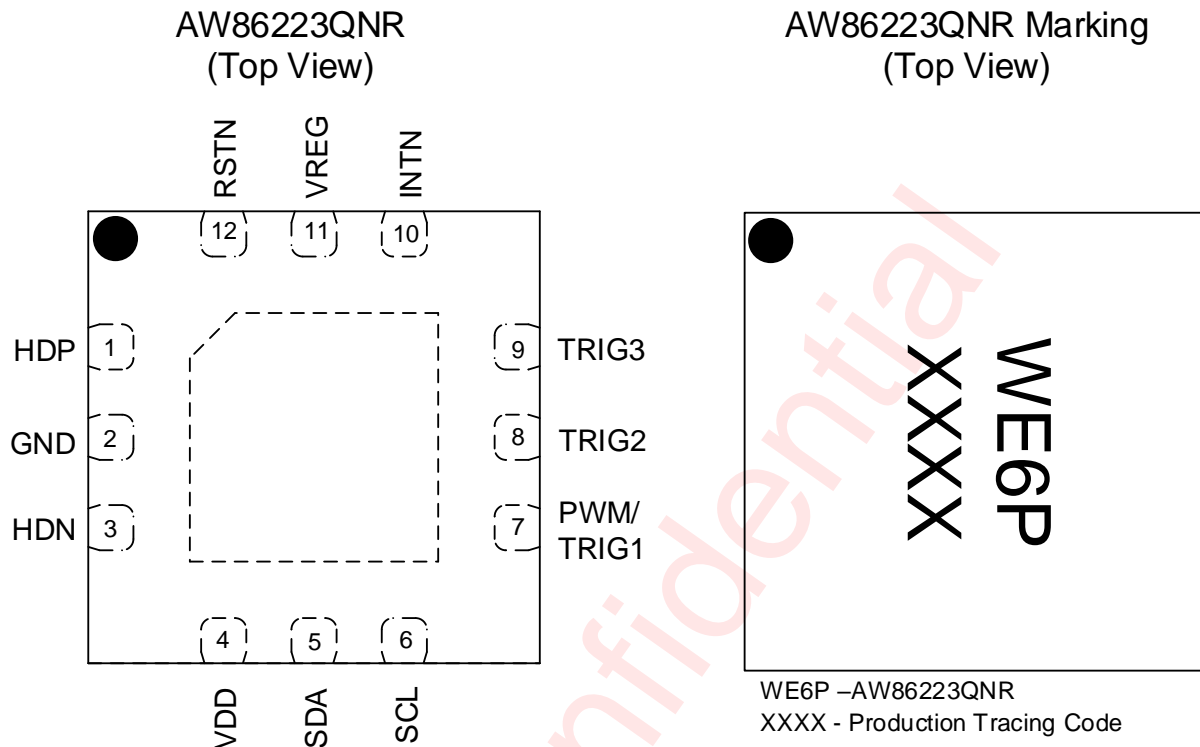


Figure 1 Pin Configuration and Top Mark

### Pin Definition

PIN NUMBER	NAME	TYPE	DESCRIPTION
1	HDP	O	Positive haptic driver differential output
2	GND	Ground	Supply ground
3	HDN	O	Negative haptic driver differential output
4	VDD	Power	Chip power supply
5	SDA	I/O	I2C bus data input/output(open drain)
6	SCL	I	I2C bus clock input
7	PWM/TRIG1	I	Multi-mode pin. Selectable as PWM input or trig input Default function is PWM. There is a pull-down resistance of 2M inside.
8	TRIG2	I	Hardware trigger2. There is a pull-down resistance of 2M inside.
9	TRIG3	I	Hardware trigger3. There is a pull-down resistance of 2M inside.
10	INTN	O	Interrupt open drain output, low active.
11	VREG	Power	Output of LDO
12	RSTN	I	Active low hardware reset High: standby/active mode Low: power-down mode There is no internal pull-down resistor. Recommend reserve an external 1M pull-down resistor.

### Functional Block Diagram

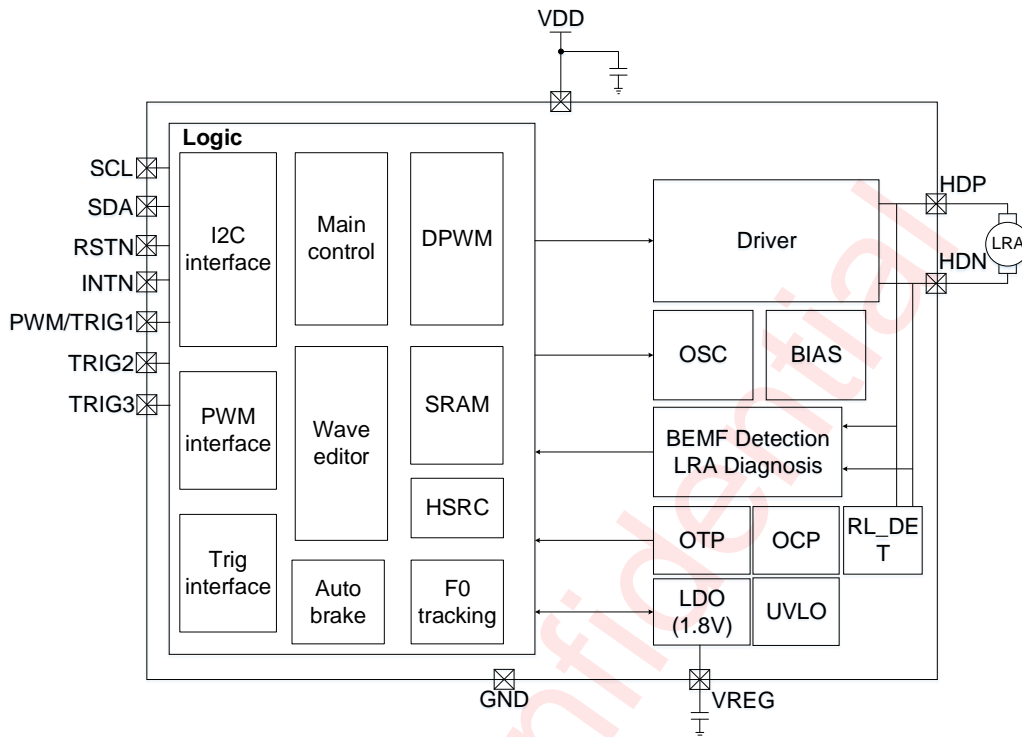


Figure 2 Functional Block Diagram

### Typical Application Circuits

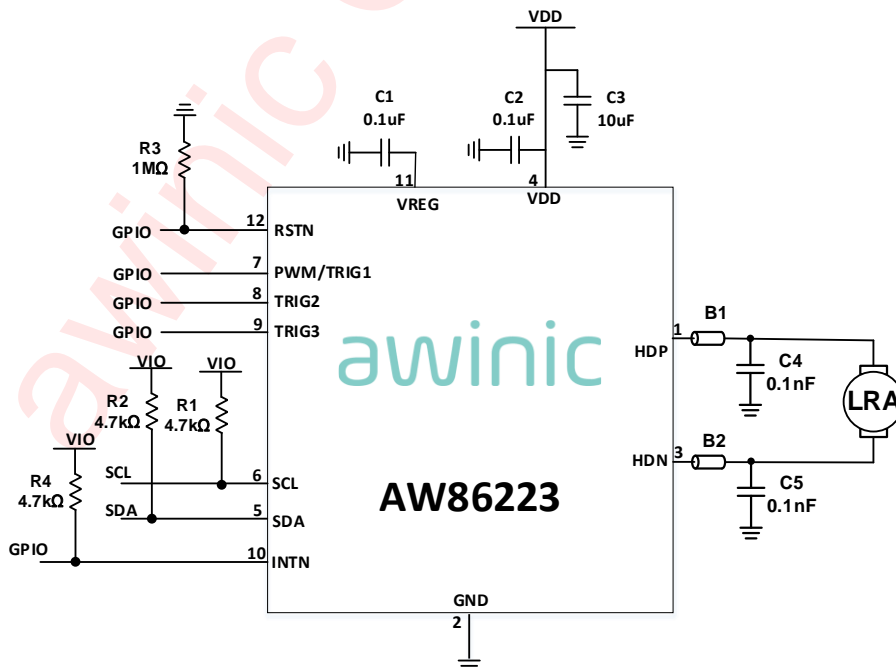


Figure 3 Typical Application Circuit of AW86223

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**Notice for Typical Application Circuits:**

1: Please place C1, C2, C3 as close to the chip as possible. The capacitors should be placed in the same layer with the AW86223 chip.

2: For the sake of driving capability, the power lines (especially the one to VDD) and output lines should be short and wide as possible.

**Ordering Information**

Part Number	Temperature	Package	Marking	Moisture Sensitivity Level	Environment Information	Delivery Form
AW86223QNR	-40°C ~ 85°C	QFN 2mmX2mmX0.5mm- 12L	WE6P	MSL1	ROHS+HF	4500 units/ Tape and Reel

Absolute Maximum Ratings<sup>(NOTE 1)</sup>

PARAMETERS	RANGE
Supply voltage range VDD	-0.3V to 6.0V
HDP, HDN, INTN ( $\leq VDD+0.3V$ )	-0.3V to 6.0V
SDA, SCL, RSTN, PWM/TRIG1, TRIG2, TRIG3	-0.3V to 6.0V
Junction-to-ambient thermal resistance $\theta_{JA}$	132°C/W
Operating free-air temperature range	-40°C to 85°C
Maximum Junction Temperature $T_{JMAX}$	150°C
Storage Temperature Range $T_{STG}$	-65°C to 150°C
Lead Temperature(Soldering 10 Seconds)	260°C
ESD(Including CDM HBM) <sup>(NOTE 2 3)</sup>	
HBM(Human Body Model)	±2KV
CDM(Charge Device Model)	±1.5KV
Latch-up	
Test Condition: JEDEC EIA/JESD78E	+IT: 200mA -IT: -200mA

NOTE 1: Conditions out of those ranges listed in "absolute maximum ratings" may cause permanent damages to the device. In spite of the limits above, functional operation conditions of the device should within the ranges listed in "recommended operating conditions". Exposure to absolute-maximum-rated conditions for prolonged periods may affect device reliability.

NOTE 2: The human body model is a 100pF capacitor discharged through a 1.5kΩ resistor into each pin. Test method: ANSI/ESDA/JEDEC JS-001-2017.

NOTE 3: Charge Device Model test method: ANSI/ESDA/JEDEC JS-002-2018.

## Electrical Characteristics

### Characteristics

Test condition: TA=25°C, VDD=3.6V, RL=8Ω+100μH, f=160Hz (unless otherwise noted)

Symbol	Description	Test Conditions	Min	Typ.	Max	Units
V <sub>VDD</sub>	Battery supply voltage	On pin VDD	3		5.5	V
V <sub>VREG</sub>	Voltage at VREG pin			1.8		V
V <sub>IL</sub>	Logic input low level	RSTN/PWM/TRIG1/TRIG2/ TRIG3/SCL/SDA			0.5	V
V <sub>IH</sub>	Logic input high level	RSTN/PWM/TRIG1/TRIG2/ TRIG3/SCL/SDA	1.3			V
V <sub>OL</sub>	Logic output low level	INTN/SDA I <sub>OUT</sub> =4mA			0.4	V
V <sub>OS</sub>	Output offset voltage	I2C signal input 0	-30	0	30	mV
I <sub>SD</sub>	Shutdown current	RSTN =0V	0	0.1	1	μA
I <sub>STBY</sub>	Standby current	TRIG1=TRIG2=TRIG3=0V RSTN=1.8V	0	3	8	μA
I <sub>Q</sub>	Quiescent current		0.8	1.3	1.8	mA
UVP	Under-voltage protection voltage		2.6	2.7	2.8	V
	Under-voltage protection hysteresis voltage		50	100	150	mV
T <sub>SD</sub>	Over temperature protection threshold			160		°C
T <sub>SDR</sub>	Over temperature protection recovery threshold			130		°C
T <sub>ON1</sub>	Time from shutdown to standby				3	ms
T <sub>ON2</sub>	Waveform startup time	From trigger to output signal	0.2	0.4	0.8	ms
<b>HDRIVER</b>						
R <sub>ds(on)</sub>	Drain-Source on-state resistance	Include NMOS and PMOS, VDD=4.2V	400	750	1100	mΩ
R <sub>ocp</sub>	Load impedance threshold for over current protection			2		Ω
F <sub>PWM</sub>	PWM output frequency	VDD=4.2V, PD_HWM=0	95.04	96	96.96	kHz
		VDD=4.2V, PD_HWM=1	47.52	48	48.48	kHz
F <sub>CALI_ACC_LRA</sub>	LRA Consistency Calibration accuracy		F0-2	F0	F0+2	Hz

Symbol	Description	Test Conditions	Min	Typ.	Max	Units
$V_{peak}$	Output voltage	RL=8Ω+100μH, VDD=4.2V		3.6		V
	Output voltage	RL=16Ω+100μH, VDD=4.2V		3.8		V

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## I2C Interface Timing

Parameter			fast mode			fast mode plus			UNIT
No.	Symbol	Name	MIN	TYP	MAX	MIN	TYP	MAX	
1	$f_{SCL}$	SCL Clock frequency			400			1000	kHz
2	$t_{LOW}$	SCL Low level Duration	1.3			0.5			$\mu s$
3	$t_{HIGH}$	SCL High level Duration	0.6			0.26			$\mu s$
4	$t_{RISE}$	SCL, SDA rise time			0.3			0.12	$\mu s$
5	$t_{FALL}$	SCL, SDA fall time			0.3			0.12	$\mu s$
6	$t_{SU:STA}$	Setup time SCL to START state	0.6			0.26			$\mu s$
7	$t_{HD:STA}$	(Repeat-start) Start condition hold time	0.6			0.26			$\mu s$
8	$t_{SU:STO}$	Stop condition setup time	0.6			0.26			$\mu s$
9	$t_{BUF}$	the Bus idle time START state to STOP state	1.3			0.5			$\mu s$
10	$t_{SU:DAT}$	SDA setup time	0.1			0.1			$\mu s$
11	$t_{HD:DAT}$	SDA hold time	10			10			ns

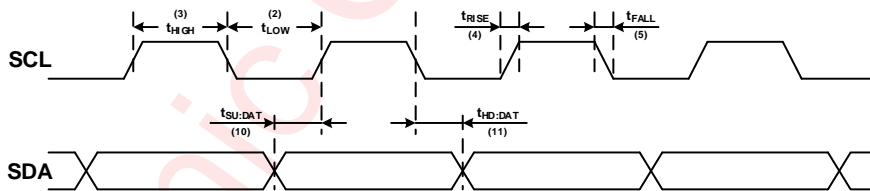


Figure 4 SCL and SDA timing relationships in the data transmission process

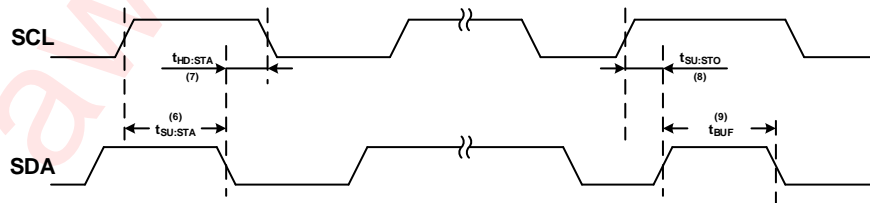


Figure 5 The timing relationship between START and STOP state

## Measurement Setup

AW86223 features switching digital output, as shown in Figure 6. Need to connect a low pass filter to HDP/HDN output respectively to filter out switch modulation frequency, then measure the differential output of filter to obtain analog output signal.

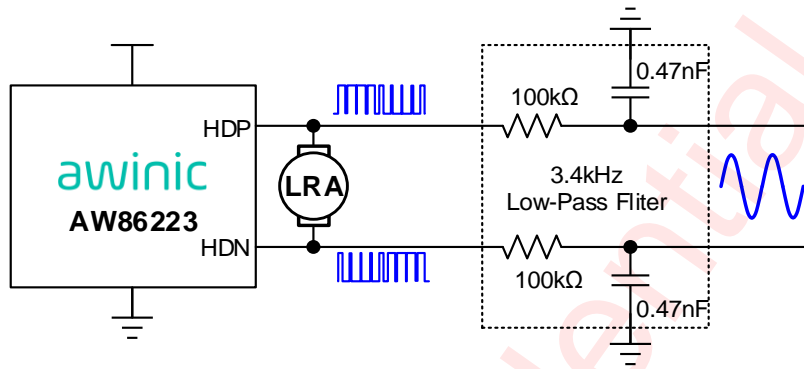


Figure 6 AW86223 test setup

### Typical Characteristics

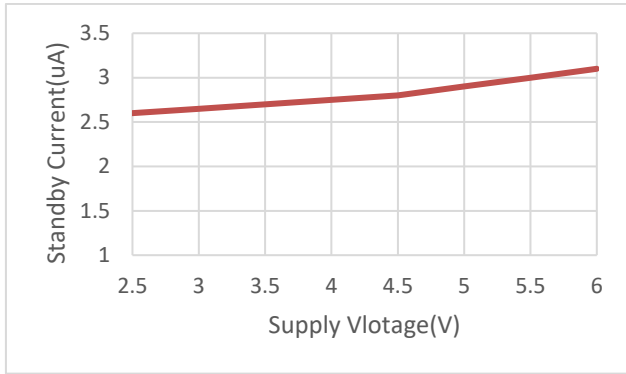


Figure 7 Standby Current Vs Supply Voltage

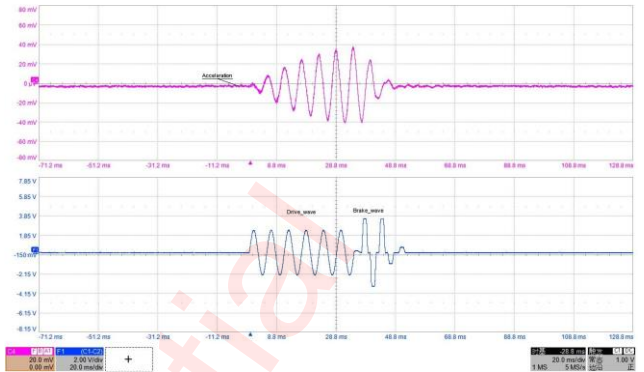


Figure 8 LRA with Automatic Braking

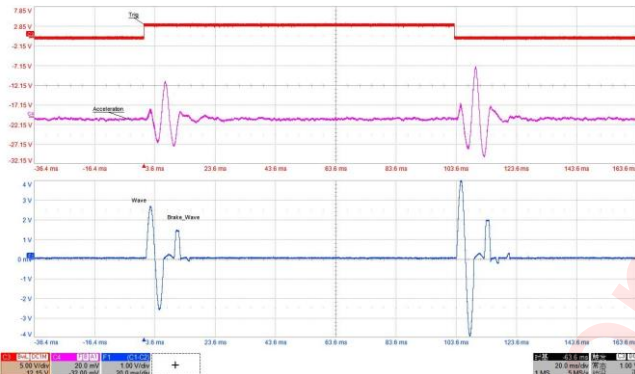


Figure 9 Trig Application

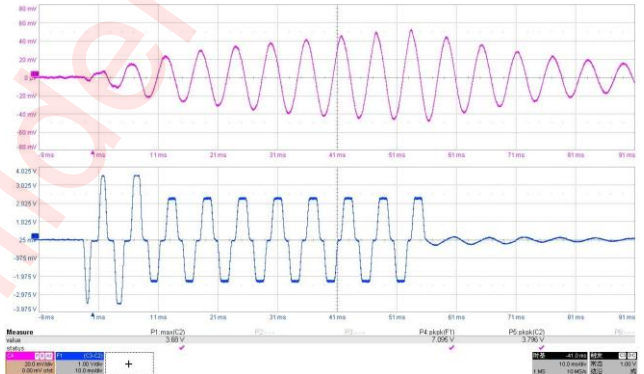


Figure 10 Automatic Resonance Tracking

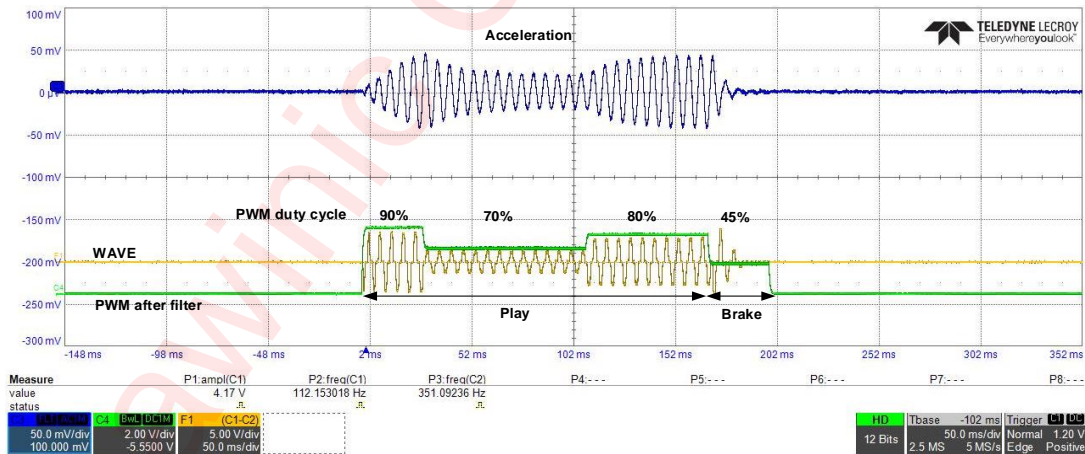


Figure 11 Automatic Resonance Tracking

## Detailed Functional Description

### Power On Reset

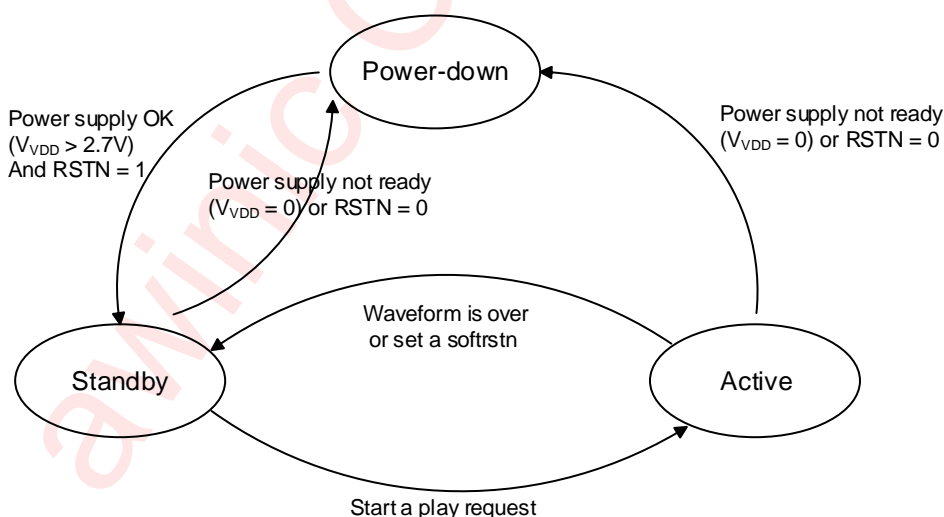
The device provides a power-on reset feature that is controlled by LDO\_OK. The reset signal will be generated to perform a power-on reset operation, which will reset all circuits and configuration registers. When the VDD power on, the VREG voltage raises and produce the LDO\_OK indication, the reset is over.

### Operation Mode

The device supports 3 operation modes.

**Table 1 Operating Mode**

Mode	Condition	Description
Power-Down	VDD = 0V or RSTN = 0V	Power supply is not ready or RSTN is tie to low. Whole chip shutdown including I2C interface.
Standby	VDD > 2.7V and RSTN = HIGH and no wave is going	Power supply is ready and RSTN is tie to high. Most parts of the device are power down for low power consumption except I2C interface and LDO.
Active	Playing a waveform	Most parts of the device are working



**Figure 12 Device operating modes transition**

### POWER-DOWN MODE

The device switches to power-down mode when the supply voltage is not ready or RSTN pin is set to low. In this mode, all circuits inside this device will be shut down. I2C interface isn't accessible in this mode, and all of the internal configurable registers and Memory are cleared.

The device will jump out of the power-down mode automatically when the supply voltages are OK and RSTN pin is set to high.

### Standby Mode

The device switches standby mode when the power supply voltages are OK and RSTN pin set to high. In this mode I2C interface is accessible, other modules except LDO module are still powered down. Customer can force device to this mode by setting STANDBY to high. Also in this mode, customer can initialize waveform library in SRAM. Device will be switched to this mode after haptic waveform playback finished.

### Active Mode

The device is fully operational in this mode. H-bridge driver circuits will start to work. Users can send a playback request to make device in this mode.

### Power On And Power Down Sequence

This device power on sequence is illustrated in the following figure:

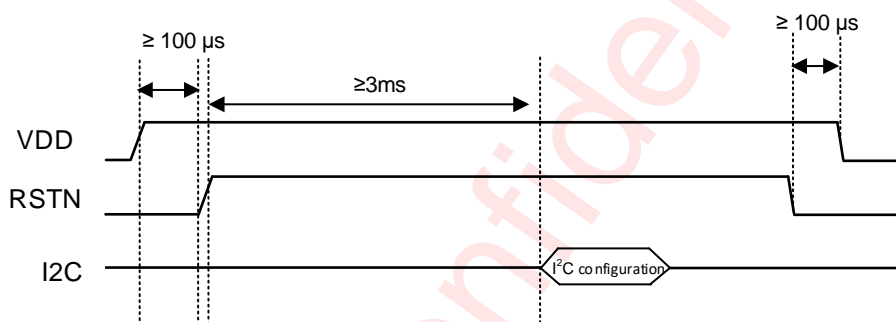


Figure 13 Power On Sequence

### Playback Sequence

Make sure the device is not in POWER-DOWN MODE before sending a playback request, then the playback sequence is illustrated in the following figure:

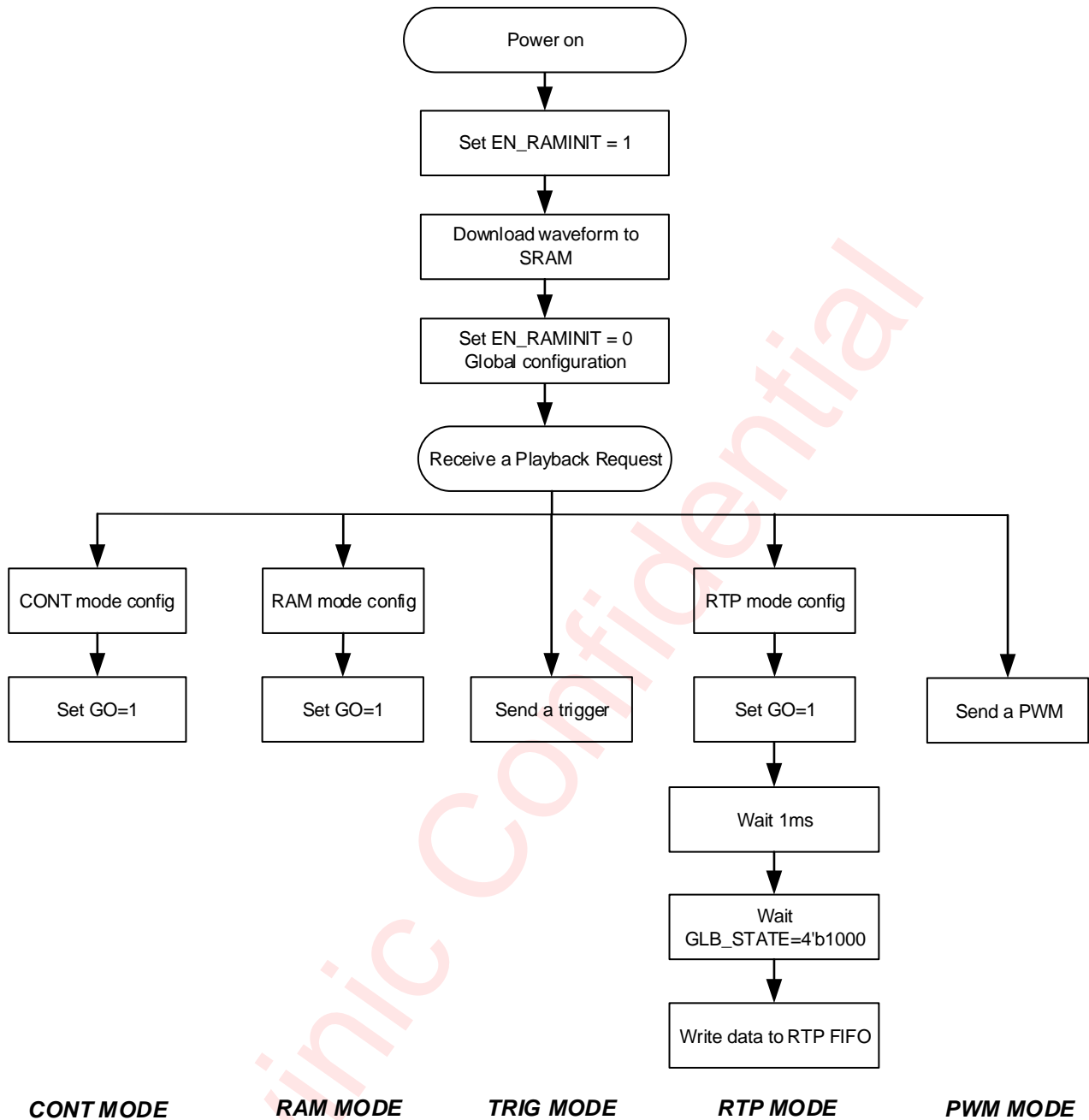


Figure 14 Power up and playback sequence

## Software Reset

Writing 0xAA to register SRST(0x00) via I2C interface will reset the device internal circuits except SRAM, including configuration registers.

## Battery Voltage Detect

Software can send command to detect the battery voltage.

### Detect steps:

- Set EN\_RAMINIT to 1 in register 0x43;
- Set VBAT\_GO to 1 in register 0x52;

- Wait 3ms;
- Set EN\_RAMINIT to 0 in register 0x43;
- Read VBAT in register 0x55 and VBAT\_LO in register 0x57.

The code is a 10bit unsigned number.

$$VDD = \frac{6.1 \times (VBAT \times 4 + VBAT\_LO)}{1024} (V)$$

## Constant Vibration Strength

The device features power-supply feedback. If the supply voltage discharge over time, the vibration strength remains the same as long as enough supply voltage is available to sustain the required output voltage. It is especially useful for ring application. Power-supply feedback only works in CONT playback mode.

### Use steps:

- Set VBAT\_MODE to 1 in register 0x43;
- Initiates a CONT playback request.

## LRA Consistency Calibration

Different motor batches, assembly conditions and other factors can result in f0 deviation of LRA. When the drive waveform does not match the LRA monomer, the vibration may be inconsistent and the braking effect becomes worse, especially for short vibration waveforms. So it's necessary to perform consistency calibration of LRA. Firstly, the power-on f0 detection can be launched to get the f0 of LRA. Secondly the waveform frequency stored in SRAM and the f0 of LRA are used to calculate the code for calibration. The f0 accuracy after LRA consistency calibration is  $\pm 2$ Hz.

## LRA Resistance Detect

Software can send command to detect the LRA's resistance.

### Detect steps:

- Set EN\_RAMINIT to 1 in register 0x43;
- Read D2S\_GAIN register and save the result as d2s\_gain\_pre;
- Set D2S\_GAIN with an appropriate with in register 0x49;
- Set RL\_OS to 1 in register 0x51;
- Set DIAG\_GO to 1 in register 0x52;
- Wait 3ms;
- Set EN\_RAMINIT to 0 in register 0x43;
- Restore the value of D2S\_GAIN register to d2s\_gain\_pre;
- Read RL\_H in register 0x53 and RL\_LO in register 0x57.

Based on this information host can diagnosis used LRA's status. The code is a 10bit unsigned number.

$$RL = \frac{678 \times (RL\_H \times 4 + RL\_LO)}{1024 \times D2S\_GAIN} (\Omega)$$

The values of the D2S\_GAIN that can be configured for different sizes of RL are listed below. The higher the RL, the smaller the configurable D2S\_GAIN.

Table 2 D2S\_GAIN Selection

RL( $\Omega$ )	D2S_GAIN
2~25	20
20~60	10

## Flexible Haptic Data Playback

The device offers multiple ways to playback haptic effects data. The PLAY\_MODE bits select RAM mode, RTP mode, CONT mode. Additional flexibility is provided by the three hardware TRIG pins, which can override PLAY\_MODE bit to playback haptic effects data as configuration.

The device contains 3 kB of integrated SRAM to store customer haptic waveforms' data. The whole SRAM is separated to RAM waveform library and RTP FIFO region by base address. And RAM waveform library is including waveform library version, waveform header and waveform data.

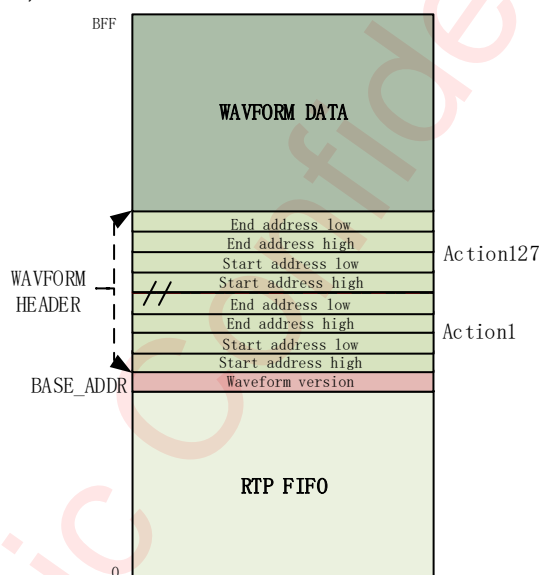


Figure 15 Data structure in SRAM

SRAM mode and TRIG mode playback the waveforms in RAM waveform library and RTP mode playback the waveform data written in RTP FIFO, CONT mode playback non-filtered or filtered square wave with rated drive voltage.

### Sram Structure

A RAM waveform library consists of a waveform version byte, a waveform header section, and the waveform data content. The waveform header defines the data boundaries for each waveform ID in the data field, and the waveform data contains a signed data format (2's complement) to specify the magnitude of the drive.

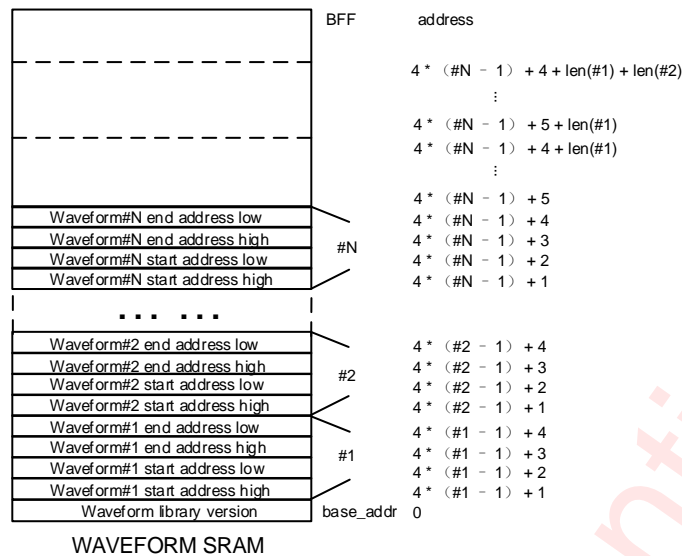


Figure 16 Waveform library data structure

#### Waveform version:

One byte located on SRAM base address, setting to different value to identify different version of RAM waveform library.

#### Waveform header:

The waveform header block consist of N-boundary definition blocks of 4 bytes each. N is the number of waveforms stored in the SRAM (N cannot exceed 127). Each of the boundary definition blocks contain the start address (2 bytes) and end address (2 bytes). So the total length of waveform header block are  $N*4$  bytes.

The start address contains the location in the memory where the waveform data associated with this waveform begins.

The end address contains the location in the memory where the waveform data associated with this waveform ends.

The waveform ID is determined after base address is defined. Four bytes begins with the address next to base address are the first waveform ID's header, and next four bytes are the second waveform ID's header, and so on.

#### Waveform data:

The waveform data contains a signed data format (2's complement) to specify the magnitude of the drive. The begin address and end address is specified in waveform ID's header.

#### Waveform library initialization steps:

- Prepare waveform library data including: waveform library version, waveform header fields for waveform in library and waveform data of each waveform;
- Set register EN\_RAMINIT=1 in register 0x43, to enable SRAM initial;
- Set base address (register 0x2D, 0x2E);
- Write waveform library data into register 0x42 continually until all the waveform library data written;
- Set register EN\_RAMINIT=0, to disable SRAM initial.

## Ram Mode

To playback haptic data with RAM mode, the waveform ID must first be configured into the waveform playback queue and then the waveform can be played by writing GO bit register.

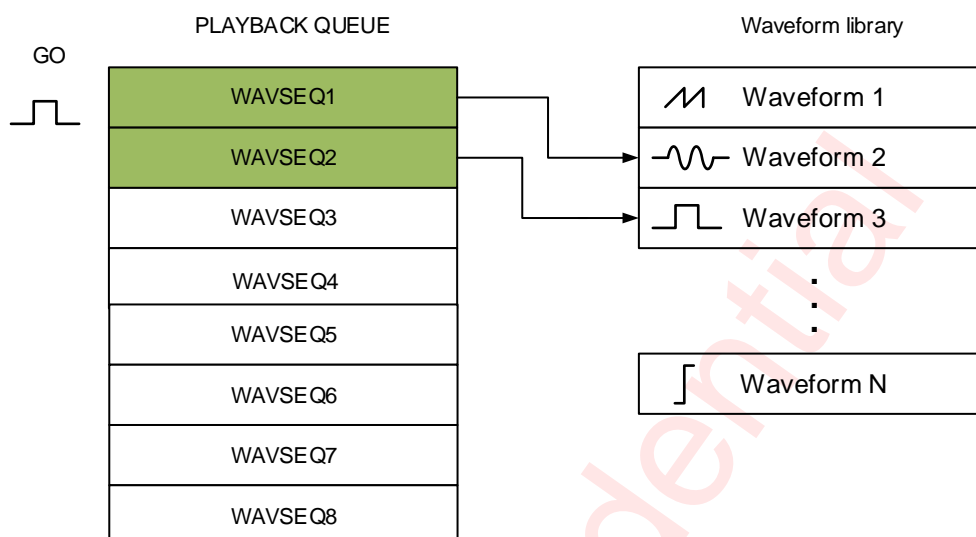


Figure 17 RAM mode playback

The waveform playback queue defines waveform IDs in waveform library for playback. Eight WAVSEQx registers queue up to eight library waveforms for sequential playback. A waveform ID is an integer value referring to the index of a waveform in the waveform library. Playback begins at WAVSEQ1 when the user triggers the waveform playback queue. When playback of that waveform ends, the waveform queue plays the next waveform ID held in WAVSEQ2 (if non-zero). The waveform queue continues in this way until the queue reaches an ID value of zero or until all eight IDs are played whichever comes first.

The waveform ID is a 7-bit number. The MSB of each ID register can be used to implement a delay between queue waveforms. When the MSB is high, bits 6-0 indicate the length of the wait time. The wait time for that step then becomes  $\text{WAVSEQ}[6:0] \times \text{wait\_time unit}$ . Wait\_time unit can be configuration of WAITSLOT register.

The device allows for looping of individual waveforms by using the SEQxLOOP registers. When used, the state machine will loop the particular waveform the number of times specified in the associated SEQxLOOP register before moving to the next waveform. The device allows for looping of the entire playback sequence by using the MAIN\_LOOP register. The waveform-looping feature is useful for long, custom haptic playbacks, such as a haptic ringtone.

### Playback steps:

- Waveform library must be initialized before playback;
- Set PLAY\_MODE bit to 0 in register 0x08;
- Set playback queue registers (0x0A ~ 0x11) as desired;
- Set playback loop registers (0x12~ 0x16) as desired;
- Set GO bit to 1 in register 0x09 to trigger waveform playback.
- Device will be switched to STANDBY mode after haptic waveform playback finished.

## Rtp Mode

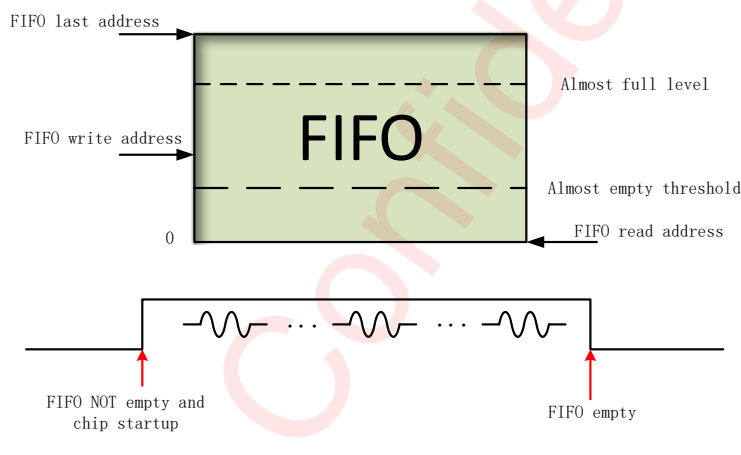
The real-time playback mode is a simple, single 8-bit register interface that holds an amplitude value. When real-time playback is enabled, begin to enters a register value to RTP\_DATA over the I2C will trigger the

playback, the value is played until the data sending finished or removes the device from RTP mode. During writing data to the RTP\_DATA register, the I2C speed cannot be too low, see the table below for details.

**Table 3 Minimum I2C speed**

WAVDAT_MODE(0x44)	Sample rate of waveform	I2C speed
2'b10/2'b11	12K	$\geq 250\text{kHz}$
2'b00	24K	$\geq 400\text{kHz}$
2'b01	48K	1MHz

After FF\_AEM or FF\_AFM register is configured as 0, HOST can obtain the RTP FIFO almost empty or almost full status through interrupt signal (pin INTN) or read FF\_AES or FF\_AFS register. RTP FIFO almost empty and almost full threshold can be configured through FIFO\_AE and FIFO\_AF registers.



**Figure 18 RTP mode playback**

#### Playback steps:

- Prepare RTP data before playback;
- Set PLAY\_MODE bit to 1 in register 0x08;
- Set GO bit to 1 in register 0x09 to trigger waveform playback;
- Delay 1ms;
- Check GLB\_STATE=4'b1000, if HOST don't send data to FIFO, chip will wait for RTP data coming in this state forever;
- Write RTP data continually to register 0x32 to playback RTP waveform;
- HOST need monitor the full and empty status for RTP FIFO.
- Device will be switched to STANDBY mode after wave data in RTP FIFO is played empty.

#### Trig Mode

The device has three hardware pins for quickly trigger haptic data playback. Each pin can be configured posedge/negedge/both-edge/level trigger.

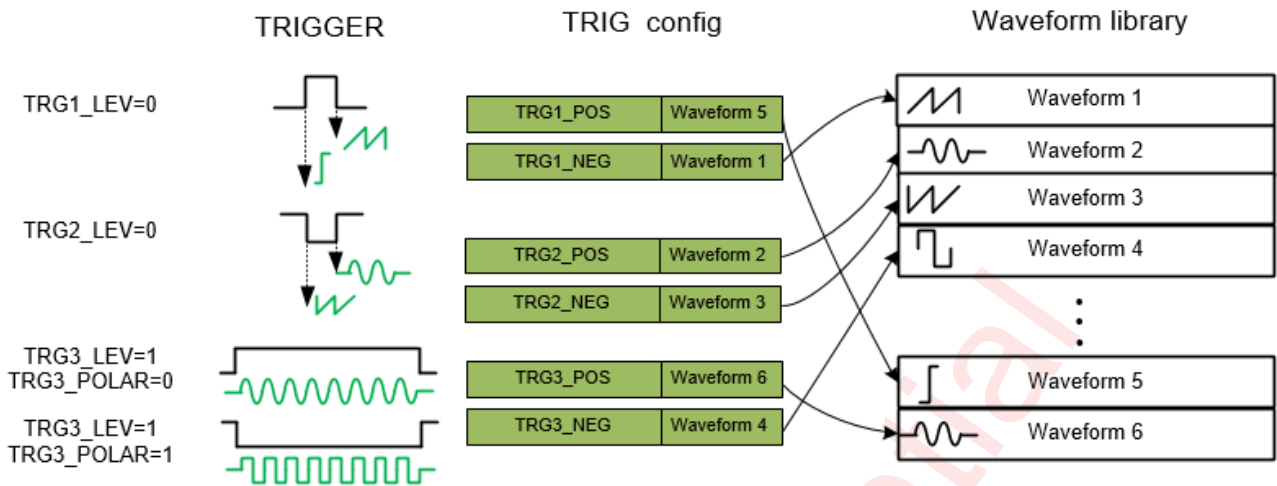


Figure 19 TRIG mode playback

Edge mode or level mode is accessible through configuration register TRGx\_LEV. When an edge mode is needed, user should set TRGx\_LEV =0. In edge mode, register TRGxSEQ\_P and TRGx\_POS respectively represent the waveform and enable signal of positive edge, where register TRGxSEQ\_N and TRGx\_NEG respectively represent the waveform and enable signal of negative edge.

When a level mode is needed, user should set TRGx\_LEV =1, and positive level and negative level can be supported by setting register TRGX\_POLAR=0 and setting TRGX\_POLAR=1.

Table 4 TRIG MODE CONFIG

I2C reg				Trigger	Waveform
TRGx_LVL	TRGx_POLAR	TRGx_POS	TRGx_NEG		
0	X	0	0	-	none
	X	1	0	↑	TRGxSEQ_P
	X	0	1	↓	TRGxSEQ_N
	X	1	1	↑ / ↓	TRGxSEQ_P / TRGxSEQ_N
1	0	X	X	High level	TRGxSEQ_P
	1	X	X	Low level	TRGxSEQ_N

**Playback steps:**

- Waveform library must be initialized before playback;
- Set trigger playback registers (0x33 ~ 0x3A) as desired;
- Send trigger pulse(≥1μs) on TRIG pins to playback waveform.
- Device will be switched to STANDBY mode after haptic waveform playback finished.

**Cont Mode**

The CONT mode mainly performs two functions: F0 detection and real-time resonance-frequency tracking. F0 detection can be launched by setting EN\_F0\_DET=1 and BRK\_EN =1. When set TRACK\_EN=1, real-time resonance-frequency tracking will be launched by tracking the BEMF of actuator constantly. It provides stronger and more consistent vibrations and lower power consumption. If the resonant frequency shifts for any reason, the function tracks the frequency from cycle to cycle. When TRACK\_EN is set to 0, the width of waveform of cont mode is determined by DRV\_WIDTH in register 0x1A.

When the EDGE\_FRE register is set to 4'b1xxx, the CONT mode outputs a filtered square wave. The edge of filtered square wave is composed of SIN or COS wave whose frequency can be configured by EDGE\_FRE register. When SIN\_MODE register is set to 1, filtered square wave is composed of COS wave.

#### Playback steps:

- Set PLAY\_MODE = 2 in register 0x08 to enable CONT mode;
- (optional)Set EN\_F0\_DET = 1 and BRK\_EN =1 to enable F0 detection;
- Set cont mode by configuring registers(0x18~0x20 and 0x22);
- Set GO bit to 1 in register 0x09 to trigger waveform playback;
- Delay 1ms;
- If enable F0 detection, get F0 information from registers(0x25~0x28) after GLB\_STATE=0;
- Device will be switched to STANDBY mode after haptic waveform playback finished.

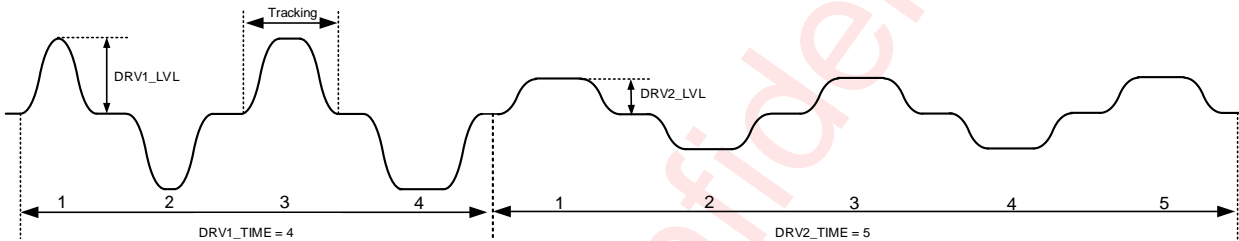


Figure 20 Cont mode playback

#### Auto Brake Engine

An auto-brake engine is integrated into this device. Users can adjust the brake strength by setting D2S\_GAIN in register 0x49. The greater D2S\_GAIN, the greater brake strength and the worse loop stability. Auto-brake engine is disabled when setting BRK\_EN=0 or BRK\_TIME=0.

#### To enable Auto-brake engine, there are some points to note:

- TRGx\_BRK in register 0x39,0x3A should be set to 1 when in TRIG mode;
- Auto-brake engine will not work when EN\_F0\_DET in register 0x18 is set to 1.
- Auto-brake engine will not work when BRK\_TIME in register 0x21 is set to 0.
- Device will be switched to STANDBY mode after haptic waveform playback finished.

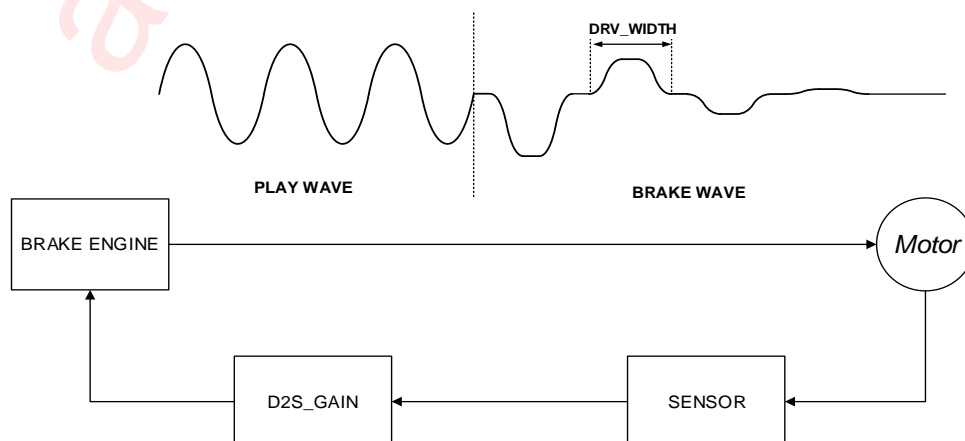


Figure 21 Brake loop

**PWM Mode**

The device has a configuration, multi-mode pin PWM/TRG1. It can serve as a dedicated hardware pin for PWM mode. User can configure LRA mode or ERM mode by configuring TRG1\_MODE in 0x3A. The minimum interval between two PWM playback times is 10ms.

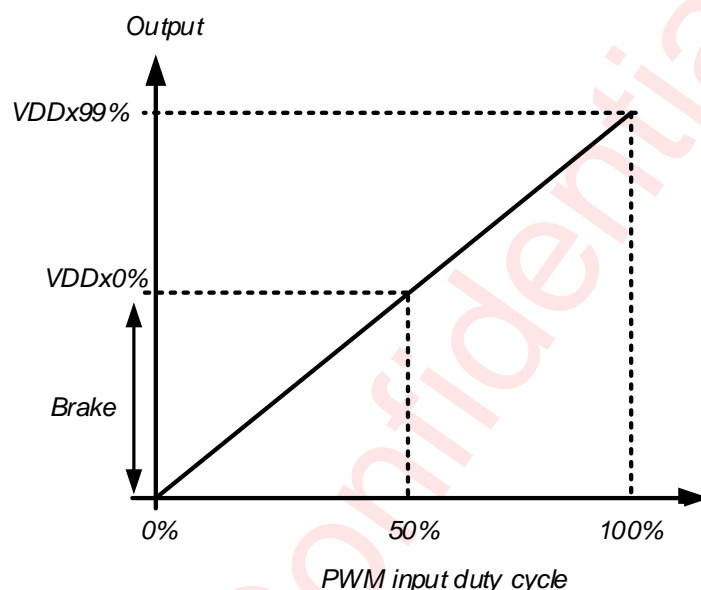


Figure 22 PWM mode(LRA) playback

**Playback steps:**

- Set TRG1\_MODE=2'b00 or 2'b01 in register 0x3A;
- Send a PWM signal(24kHz~250kHz) to pin PWM/TRG1;
- **When the driver is playing PWM MODE, master should not configure I2C;**

After the pin PWM/TRIG1 changes to level 0, the chip will go to STANDBY within a half period of motor F0.

**Protection Mechanisms****Over Temperature Protection (OTP)**

The device has automatic temperature protection mechanism which prevents heat damage to the chip. It is triggered when the junction temperature is larger than the preset temperature high threshold (default = 160°C). When it happens, the output stages will be disabled. When the junction temperature drops below the preset temperature low threshold (less than 130°C), the output stages will start to operate normally again.

### Over Current (Short) Protection (OCP)

The short circuit protection function is triggered when HDP/HDN is short too VDD/GND or HDP is short to HDN, the output stages will be shut down to prevent damage to itself. When the fault condition is disappeared, the output stages of device will restart.

### VDD Under Voltage Lock Out Protection (UVLO)

The device has a battery monitor that monitors the VDD level to ensure that is above threshold 2.7V, In the event of a VDD drop, the device immediately power down the H-bridge driver and latches the UVLO flag.

### Drive Data Error Protection (DDEP)

When haptic data sent to drive LRA is error such as: a DC data or almost DC data, it will cause the LRA heat to stop. The device configurable immediately power down the H-bridge driver and latched the DDEP flag.

## I2C Interface

This device supports the I2C serial bus and data transmission protocol in fast mode at 400kHz and fast mode plus at 1000kHz. This device operates as a slave on the I2C bus. Connections to the bus are made via the open-drain I/O pin SDA and I pin SCL. The pull-up resistor can be selected in the range of 1k~10kΩ and the typical value is 4.7kΩ. This device can support different high level (1.8V~3.3V) of this I2C interface.

### Device Address

The I2C device address is 0x58 and cannot be set.

### Data Validation

When SCL is high level, SDA level must be constant. SDA can be changed only when SCL is low level.

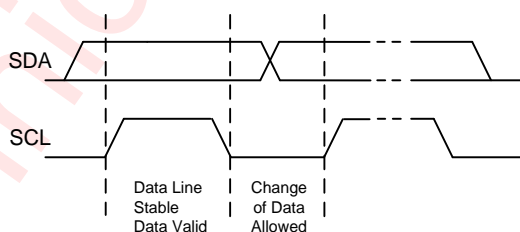


Figure 23 Data Validation Diagram

### General I2C Operation

The I2C bus employs two signals, SDA (data) and SCL (clock), to communicate between integrated circuits in a system. The device is addressed by a unique 7-bit address; the same device can send and receive data. In addition, Communications equipment has distinguished master from slave device: In the communication process, only the master device can initiate a transfer and terminate data and generate a corresponding clock signal. The devices using the address access during transmission can be seen as a slave device.

SDA and SCL connect to the power supply through the current source or pull-up resistor. SDA and SCL default is a high level. There is no limit on the number of bytes that can be transmitted between start and stop conditions. When the last word transfers, the master generates a stop condition to release the bus.

START state: The SCL maintain a high level, SDA from high to low level.

STOP state: The SCL maintain a high level, SDA pulled low to high level.

Start and Stop states can be only generated by the master device. In addition, if the device does not produce STOP state after the data transmission is completed, instead re-generate a START state (Repeated START, Sr), and it is believed that this bus is still in the process of data transmission. Functionally, Sr state and START state is the same. As shown in Figure 24.

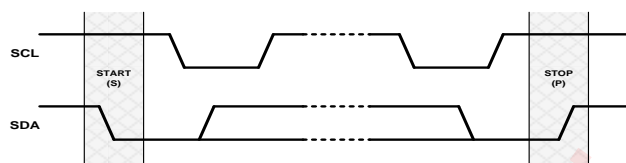


Figure 24 START and STOP state generation process

In the data transmission process, when the clock line SCL maintains a high level, the data line SDA must remain the same. Only when the SCL maintain a low level, the data line SDA can be changed, as shown in Figure 25. Each transmission of information on the SDA is 9 bits as a unit. The first eight bits are the data to be transmitted, and the first one is the most significant bit (Most Significant Bit, MSB), the ninth bit is an confirmation bit (Acknowledge, ACK or A), as shown in Figure 26. When the SDA transmits a low level in ninth clock pulse, it means the acknowledgment bit is 1, namely the current transmission of 8 bits data are confirmed, otherwise it means that the data transmission has not been confirmed. Any amount of data can be transferred between START and STOP state.

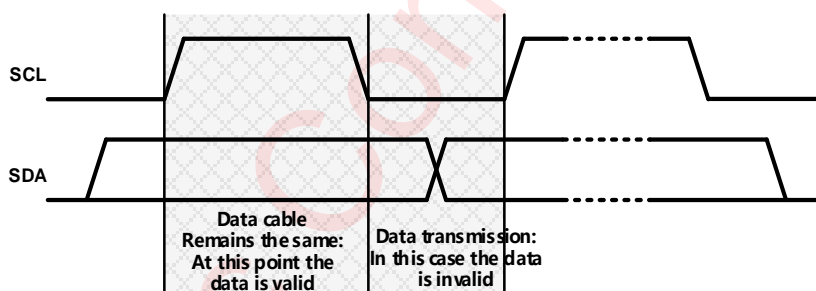


Figure 25 The data transfer rules on the I2C bus

The whole process of actual data transmission is shown in Figure 26. When generating a START condition, the master device sends an 8-bit data, including a 7-bit slave addresses (Slave Address), and followed by a "read / write" flag ( $\overline{R/W}$ ). The flag is used to specify the direction of transmission of subsequent data. The master device will produce the STOP state to end the process after the data transmission is completed. However, if the master device intends to continue data transmission, you can directly send a Repeated START state, without the need to use the STOP state to end transmission.

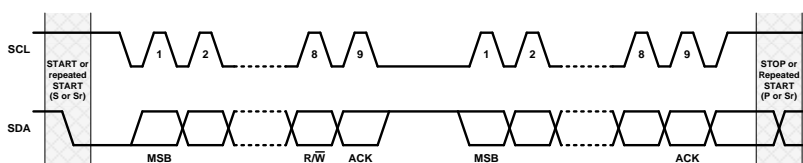


Figure 26 Data transmission on the I2C bus

## Write Process

Writing process refers to the master device write data into the slave device. In this process, the transfer direction of the data is always unchanged from the master device to the slave device. All acknowledge bits are transferred by the slave device, in particular, the device as the slave device, the transmission process in accordance with the following steps, as shown in Figure 27:

Master device generates START state. The START state is produced by pulling the data line SDA to a low level when the clock SCL signal is a high level.

Master device transmits the 7-bits device address of the slave device, followed by the "read / write" flag (flag  $R/\overline{W} = 0$ );

The slave device asserts an acknowledgment bit (ACK) to confirm whether the device address is correct;

The master device transmits the 8-bit register address to which the first data byte will written;

The slave device asserts an acknowledgment (ACK) bit to confirm the register address is correct;

Master sends 8 bits of data to register which needs to be written;

The slave device asserts an acknowledgment bit (ACK) to confirm whether the data is sent successfully;

If the master device needs to continue transmitting data by sending another pair of data bytes, just need to repeat the sequence from step 6. In the latter case, the targeted register address will have been auto-incremented by the device.

The master device generates the STOP state to end the data transmission.



Figure 27 Writing process (data transmission direction remains the same)

## Read Process

Reading process refers to the slave device reading data back to the master device. In this process, the direction of data transmission will change. Before and after the change, the master device sends START state and slave address twice, and sends the opposite "read/write" flag. In particular, AW86223 as the slave device, the transmission process carried out by following steps listed in Figure 28:

Master device asserts a start condition;

Master device transmits the 7 bits address of the device, and followed by a "read / write" flag ( $R/\overline{W} = 1$ );

The slave device asserts an acknowledgment bit (ACK) to confirm whether the device address is correct;

The master device transmits the register address to make sure where the first data byte will read;

The slave device asserts an acknowledgment (ACK) bit to confirm whether the register address is correct or not;

The master device restarts the data transfer process by continuously generating STOP state and START state or a separate Repeated START;

Master sends 7-bits address of the slave device and followed by a read / write flag (flag  $R/\overline{W} = 1$ ) again;

The slave device asserts an acknowledgment (ACK) bit to confirm whether the register address is correct or not;

Master transmits 8 bits of data to register which needs to be read;

The slave device sends an acknowledgment bit (ACK) to confirm whether the data is sent successfully;

The device automatically increments register address once after sent each acknowledge bit (ACK),

The master device generates the STOP state to end the data transmission.

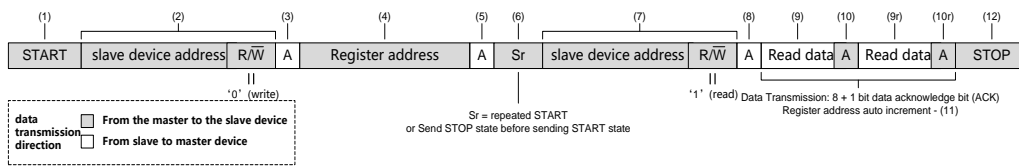


Figure 28 Reading process (data transmission direction remains the same)

## CHIP ID

CHIPID(2-bit) consists of CHIPID\_H and CHIPID\_L. The features of CHIPID are shown in the following table.

Table 5 CHIPID feature

BIT	Feature
CHIPID_H	0: AW86223/AW86224/AW86225 1: AW86214
CHIPID_L	0: AW86224/AW86225 1: AW86223/AW86214

## Register Configuration

## Register List

ADDR	NAME	R/W	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0	Default		
0x00	SRST	WO	RESET									0x00	
0x01	SYSST	RO			UVLS	FF_AES	FF_AFS	OCDS	OTS	DONES	0x10		
0x02	SYSINT	RC			UVLI	FF_AEI	FF_AFI	OCDI	OTI	DONEI	0x10		
0x03	SYSINTM	RW			UVLM	FF_AEM	FF_AFM	OCDM	OTM	DONEM	0x3F		
0x04	SYSST2	RO					LDO_OK					0x2D	
0x07	PLAYCFG2	RW	GAIN									0x80	
0x08	PLAYCFG3	RW				STOP_MODE			BRK_EN	PLAY_MODE		0x04	
0x09	PLAYCFG4	RW							STOP	GO			0x00
0x0A	WAVCFG1	RW	SEQ1WAIT	WAVSEQ1								0x01	
0x0B	WAVCFG2	RW	SEQ2WAIT	WAVSEQ2								0x00	
0x0C	WAVCFG3	RW	SEQ3WAIT	WAVSEQ3								0x00	
0x0D	WAVCFG4	RW	SEQ4WAIT	WAVSEQ4								0x00	
0x0E	WAVCFG5	RW	SEQ5WAIT	WAVSEQ5								0x00	
0x0F	WAVCFG6	RW	SEQ6WAIT	WAVSEQ6								0x00	
0x10	WAVCFG7	RW	SEQ7WAIT	WAVSEQ7								0x00	
0x11	WAVCFG8	RW	SEQ8WAIT	WAVSEQ8								0x00	
0x12	WAVCFG9	RW	SEQ1LOOP				SEQ2LOOP				0x00		
0x13	WAVCFG10	RW	SEQ3LOOP				SEQ4LOOP				0x00		
0x14	WAVCFG11	RW	SEQ5LOOP				SEQ6LOOP				0x00		
0x15	WAVCFG12	RW	SEQ7LOOP				SEQ8LOOP				0x00		
0x16	WAVCFG13	RW			WAITSLLOT			MAINLOOP			0x00		
0x18	CONTCFG1	RW	EDGE_FRE				EN_F0_DET			SIN_MODE	0xE1		
0x19	CONTCFG2	RW	F_PRE									0x8D	
0x1A	CONTCFG3	RW	DRV_WIDTH									0x6A	
0x1C	CONTCFG5	RW							BRK_GAIN			0x08	
0x1D	CONTCFG6	RW	TRACK_EN	DRV1_LVL								0xFF	
0x1E	CONTCFG7	RW	DRV2_LVL									0x50	
0x1F	CONTCFG8	RW	DRV1_TIME									0x04	
0x20	CONTCFG9	RW	DRV2_TIME									0x06	
0x21	CONTCFG10	RW	BRK_TIME									0x08	
0x22	CONTCFG11	RW	TRACK_MARGIN									0x0F	
0x25	CONTRD14	RO	F_LRA_F0_H									0x00	
0x26	CONTRD15	RO	F_LRA_F0_L									0x00	
0x27	CONTRD16	RO	CONT_F0_H									0x00	
0x28	CONTRD17	RO	CONT_F0_L									0x00	
0x2D	RTPCFG1	RW							BASE_ADDR_H			0x38	
0x2E	RTPCFG2	RW	BASE_ADDR_L									0x00	
0x2F	RTPCFG3	RW	FIFO_AEH				FIFO_AFH				0x26		
0x30	RTPCFG4	RW	FIFO_AEL									0x00	
0x31	RTPCFG5	RW	FIFO_AFL									0x00	
0x32	RTPDATA	RW	RTP_DATA									0x00	
0x33	TRGCFG1	RW	TRG1_POS	TRG1SEQ_P								0x01	
0x34	TRGCFG2	RW	TRG2_POS	TRG2SEQ_P								0x01	
0x35	TRGCFG3	RW	TRG3_POS	TRG3SEQ_P								0x01	
0x36	TRGCFG4	RW	TRG1_NEG	TRG1SEQ_N								0x01	
0x37	TRGCFG5	RW	TRG2_NEG	TRG2SEQ_N								0x01	
0x38	TRGCFG6	RW	TRG3_NEG	TRG3SEQ_N								0x01	
0x39	TRGCFG7	RW	TRG1_POLAR	TRG1_LEV	TRG1_BRK			TRG2_POLAR	TRG2_LEV	TRG2_BRK	0x22		
0x3A	TRGCFG8	RW	TRG3_POLAR	TRG3_LEV	TRG3_BRK	TRG1_MODE		TRG1_STOP	TRG2_STOP	TRG3_STOP	0x20		
0x3C	GLBCFG2	RW	START_DLY									0x04	
0x3E	GLBCFG4	RW	GO_PRIO			TRG3_PRIO		TRG2_PRIO		TRG1_PRIO		0x1B	
0x3F	GLBRD5	RO	GLB_STATE									0x00	

0x40	RAMADDRH	RW					RAMADDRH	0x00	
0x41	RAMADDRL	RW	RAMADDRL					0x00	
0x42	RAMDATA	RW	RAMDATA					0x00	
0x43	SYSCTRL1	RW	VBAT_MODE			EN_RAMINIT	EN_FIR	0x04	
0x44	SYSCTRL2	RW	WAKE	STANDBY			WAVDAT_MODE	0x28	
0x49	SYSCTRL7	RW					D2S_GAIN	0x14	
0x4C	PWMCFG1	RW	PRC_EN	PRCTIME				0xA0	
0x4D	PWMCFG2	RW			PD_HWM			0x28	
0x4E	PWMCFG3	RW	PR_EN	PRLVL				0xBF	
0x4F	PWMCFG4	RW	PRTIME					0x32	
0x51	DETCFG1	RW					CLK_ADC	0x02	
0x52	DETCFG2	RW					VDD_GO	DIAG_GO	0x00
0x53	DET_RL	RO	RL_H					0x00	
0x55	DET_VDD	RO	VDD					0x00	
0x57	DET_LO	RO			VDD_LO		RL_LO	0x00	
0x5A	TRIMCFG3	RW	TRIM_LRA					0x00	
0x64	CHIPID	RO	CHIPID_H				CHIPID_L		
0x77	ANACFG8	RW	TRTF_CTRL_HDRV					0x00	

## Register Detailed Description

Note: Reserved register should not be write

SRST: (Address 00h)				
Bit	Symbol	R/W	Description	Default
7:0	RESET	WO	All configuration registers will be reset to default value after 0xaa is written	0x00

SYSST: (Address 01h)				
Bit	Symbol	R/W	Description	Default
7:6	Reserved	RO	Not used	0
5	UVLS	RO	1: VBAT voltage is under UV voltage (2.7V)	0
4	FF_AES	RO	1: RTP FIFO almost empty	1
3	FF_AFS	RO	1: RTP FIFO almost full	0
2	OCDS	RO	1: Over Current status	0
1	OTS	RO	1: Over Temperature status	0
0	DONES	RO	1: The indication of playback	0

SYSINT: (Address 02h)				
Bit	Symbol	R/W	Description	Default
7:6	Reserved	RC	Not used	0
5	UVLI	RC	When UVLI=1, it means UVLS has been 1 at least once since the last read	0
4	FF_AEI	RC	When FF_AEI=1, it means FF_AES has been 1 at least once since the last read	1
3	FF_AFI	RC	When FF_AFI=1, it means FF_AFS has been 1 at least once since the last read	0
2	OCDI	RC	When OCDI=1, it means OCDS has been 1 at least once since the last read	0
1	OTI	RC	When OTI=1, it means OTS has been 1 at least once since the last read	0
0	DONEI	RC	When DONEI=1, it means DONES has been 1 at least once since the last read	0

SYSINTM: (Address 03h)				
Bit	Symbol	R/W	Description	Default
7:6	Reserved	RW	Not used	0
5	UVLM	RW	Interrupt mask for UVLI: 0: INTN pin will be pulled down when UVLI=1 1: INTN pin will not be pulled down when UVLI=1	1

4	FF_AEM	RW	Interrupt mask for FF_AEI: 0: INTN pin will be pulled down when FF_AEI=1 1: INTN pin will not be pulled down when FF_AEI=1	1
3	FF_AFM	RW	Interrupt mask for FF_AFI: 0: INTN pin will be pulled down when FF_AFI=1 1: INTN pin will not be pulled down when FF_AFI=1	1
2	OCDM	RW	Interrupt mask for OCDI: 0: INTN pin will be pulled down when OCDI=1 1: INTN pin will not be pulled down when OCDI=1	1
1	OTM	RW	Interrupt mask for OTI: 0: INTN pin will be pulled down when OTI=1 1: INTN pin will not be pulled down when OTI=1	1
0	DONEM	RW	Interrupt mask for DONEI: 0: INTN pin will be pulled down when DONEI=1 1: INTN pin will not be pulled down when DONEI=1	1

SYSST2: (Address 04h)				
Bit	Symbol	R/W	Description	Default
7:4	Reserved	RO	Not used	2
3	LDO_OK	RO	LDO OK indication	1
2:0	Reserved	RO	Not used	5

PLAYCFG2: (Address 07h)				
Bit	Symbol	R/W	Description	Default
7:0	GAIN	RW	gain setting for waveform data of RAM/RTP/TRIG/PWM mode, GAIN=code/128	0x80

PLAYCFG3: (Address 08h)				
Bit	Symbol	R/W	Description	Default
7:6	Reserved	RW	Not used	0
5	STOP_MODE	RW	0: stop when current wave is over 1: stop right now	0
4:3	Reserved	RW	Not used	0
2	BRK_EN	RW	When set 1, enable auto brake after RTP/RAM/CONT playback mode is stopped	1
1:0	PLAY_MODE	RW	Waveform play mode for GO TRIG: b00: RAM mode b01: RTP mode b10: CONT mode b11: no play	0

PLAYCFG4: (Address 09h)				
Bit	Symbol	R/W	Description	Default
7:2	Reserved	RW	Not used	0
1	STOP	RW	when set 1, stop the current playback mode	0
0	GO	RW	RAM/RTP/CONT mode playback trig bit when set to 1, chip will playback one of the play mode.	0

WAVCFG1: (Address 0Ah)				
Bit	Symbol	R/W	Description	Default
7	SEQ1WAIT	RW	When set to 1, WAVSEQ1 means wait time, else means wave sequence number	0
6:0	WAVSEQ1	RW	Wait time (code*WAIT SLOT) or wave sequence number	1

WAVCFG2: (Address 0Bh)				
Bit	Symbol	R/W	Description	Default
7	SEQ2WAIT	RW	When set to 1, WAVSEQ2 means wait time, else means wave sequence number	0
6:0	WAVSEQ2	RW	Wait time (code*WAIT SLOT) or wave sequence number	0

WAVCFG3: (Address 0Ch)				
Bit	Symbol	R/W	Description	Default
7	SEQ3WAIT	RW	When set to 1, WAVSEQ3 means wait time, else means wave sequence number	0
6:0	WAVSEQ3	RW	Wait time (code*WAITSLOT) or wave sequence number	0

WAVCFG4: (Address 0Dh)				
Bit	Symbol	R/W	Description	Default
7	SEQ4WAIT	RW	When set to 1, WAVSEQ4 means wait time, else means wave sequence number	0
6:0	WAVSEQ4	RW	Wait time (code*WAITSLOT) or wave sequence number	0

WAVCFG5: (Address 0Eh)				
Bit	Symbol	R/W	Description	Default
7	SEQ5WAIT	RW	When set to 1, WAVSEQ5 means wait time, else means wave sequence number	0
6:0	WAVSEQ5	RW	Wait time (code*WAITSLOT) or wave sequence number	0

WAVCFG6: (Address 0Fh)				
Bit	Symbol	R/W	Description	Default
7	SEQ6WAIT	RW	When set to 1, WAVSEQ6 means wait time, else means wave sequence number	0
6:0	WAVSEQ6	RW	Wait time (code*WAITSLOT) or wave sequence number	0

WAVCFG7: (Address 10h)				
Bit	Symbol	R/W	Description	Default
7	SEQ7WAIT	RW	When set to 1, WAVSEQ7 means wait time, else means wave sequence number	0
6:0	WAVSEQ7	RW	Wait time (code*WAITSLOT) or wave sequence number	0

WAVCFG8: (Address 11h)				
Bit	Symbol	R/W	Description	Default
7	SEQ8WAIT	RW	When set to 1, WAVSEQ8 means wait time, else means wave sequence number	0
6:0	WAVSEQ8	RW	Wait time (code*WAITSLOT) or wave sequence number	0

WAVCFG9: (Address 12h)				
Bit	Symbol	R/W	Description	Default
7:4	SEQ1LOOP	RW	Control the loop number of the first sequence: b0000~b1110: play code+1 time b1111: playback infinitely until STOP set to 1 or SEQ1LOOP $\neq$ 0xF	0
3:0	SEQ2LOOP	RW	Control the loop number of the second sequence: b0000~b1110: play code+1 time b1111: playback infinitely until STOP set to 1 or SEQ2LOOP $\neq$ 0xF	0

WAVCFG10: (Address 13h)				
Bit	Symbol	R/W	Description	Default
7:4	SEQ3LOOP	RW	control the loop number of the third sequence b0000~b1110: play code+1 time b1111: playback infinitely until STOP set to 1 or SEQ3LOOP $\neq$ 0xF	0
3:0	SEQ4LOOP	RW	control the loop number of the fourth sequence b0000~b1110: play code+1 time b1111: playback infinitely until STOP set to 1 or SEQ4LOOP $\neq$ 0xF	0

WAVCFG11: (Address 14h)				
Bit	Symbol	R/W	Description	Default
7:4	SEQ5LOOP	RW	control the loop number of the fifth sequence b0000~b1110: play code+1 time b1111: playback infinitely until STOP set to 1 or SEQ5LOOP $\neq$ 0xF	0

3:0	SEQ6LOOP	RW	control the loop number of the sixth sequence b0000~b1110: play code+1 time b1111: playback infinitely until STOP set to 1 or SEQ6LOOP $\neq$ 0xF	0
-----	----------	----	---	---

WAVCFG12: (Address 15h)				
Bit	Symbol	R/W	Description	Default
7:4	SEQ7LOOP	RW	control the loop number of the seventh sequence b0000~b1110: play code+1 time b1111: playback infinitely until STOP set to 1 or SEQ7LOOP $\neq$ 0xF	0
3:0	SEQ8LOOP	RW	control the loop number of the eighth sequence b0000~b1110: play code+1 time b1111: playback infinitely until STOP set to 1 or SEQ8LOOP $\neq$ 0xF	0

WAVCFG13: (Address 16h)				
Bit	Symbol	R/W	Description	Default
7	Reserved	RW	Not used	0
6:5	WAIT SLOT	RW	Unit of wait time b00: (1/WAVDAT_MODE)s b01: (8/WAVDAT_MODE)s b10: (64/WAVDAT_MODE)s b11: (512/WAVDAT_MODE)s	0
4	Reserved	RW	Not used	0
3:0	MAINLOOP	RW	control the main loop number b0000~b1110: play code+1 time b1111: playback infinitely until STOP set to 1 or MAINLOOP $\neq$ 0xF	0

CONTCFG1: (Address 18h)				
Bit	Symbol	R/W	Description	Default
7:4	EDGE_FRE	RW	Define the edge frequency b1000: 200Hz b1001: 210Hz b1010: 260Hz b1011: 280Hz b1100: 300Hz b1101: 600Hz b1110: 700Hz b1111: 800Hz b0000-b0111: play non-filtered square wave in CONT mode	14
3	EN_F0_DET	RW	F0 detection mode enable 0: disable 1: enable	0
2:1	Reserved	RW	Not used	0
0	SIN_MODE	RW	Edge mode for filtered square wave of CONT mode: 0: sine 1: cos	1

CONTCFG2: (Address 19h)				
Bit	Symbol	R/W	Description	Default
7:0	F_PRE	RW	Set the value of F0, $F0=(24K/code)Hz$	0x8D

CONTCFG3: (Address 1Ah)				
Bit	Symbol	R/W	Description	Default
7:0	DRV_WIDTH	RW	half cycle drive time(code/48K s) of brake, this value must be smaller than half cycle time of F0. DRV_WIDTH is recommended to be configured as $(24k/F0)-8-TRACK\_MARGIN-BRK\_GAIN$	0x6A

CONTCFG5: (Address 1Ch)				
Bit	Symbol	R/W	Description	Default
7:4	Reserved	RW	Not used	0
3:0	BRK_GAIN	RW	Gain factor of brake	8

CONTCFG6: (Address 1Dh)				
Bit	Symbol	R/W	Description	Default
7	TRACK_EN	RW	Track switch: 0: disable 1: enable	1
6:0	DRV1_LVL	RW	Level for the first cont drive. When VBAT_MODE=1: no load output voltage=6.1*DRV1_LVL/128(V); if (6.1*DRV1_LVL)/VBAT > 128, no load output voltage=VDD; When VBAT_MODE=0: no load output voltage=VDD*DRV1_LVL/128(V)	0x7F

CONTCFG7: (Address 1Eh)				
Bit	Symbol	R/W	Description	Default
7	Reserved	RW	Not used	0
6:0	DRV2_LVL	RW	Level for the second cont drive. When VBAT_MODE=1: no load output voltage=6.1*DRV2_LVL/128(V); if (6.1*DRV2_LVL)/VBAT > 128, no load output voltage=VDD; When VBAT_MODE=0: no load output voltage=VDD*DRV2_LVL/128(V)	0x50

CONTCFG8: (Address 1Fh)				
Bit	Symbol	R/W	Description	Default
7:0	DRV1_TIME	RW	Number of half cycle for the first cont drive	4

CONTCFG9: (Address 20h)				
Bit	Symbol	R/W	Description	Default
7:0	DRV2_TIME	RW	Number of half cycle for the second cont drive.	6

CONTCFG10: (Address 21h)				
Bit	Symbol	R/W	Description	Default
7:0	BRK_TIME	RW	The number of half cycle of brake mode	8

CONTCFG11: (Address 22h)				
Bit	Symbol	R/W	Description	Default
7:0	TRACK_MARGIN	RW	Margin value of tracking, the smaller margin, the higher tracking accuracy and the lower loop stability(unit: 1/48K s)	15

CONTRD14: (Address 25h)				
Bit	Symbol	R/W	Description	Default
7:0	F_LRA_F0_H	RO	High 8 bit of the measure value for the f0 of LRA in the f0 detection mode $F0=(384000/(F\_LRA\_F0\_H*256+F\_LRA\_F0\_L))Hz$	0

CONTRD15: (Address 26h)				
Bit	Symbol	R/W	Description	Default
7:0	F_LRA_F0_L	RO	Low 8 bit of the measure value for the f0 of LRA in the f0 detection mode $F0=(384000/(F\_LRA\_F0\_H*256+F\_LRA\_F0\_L))Hz$	0

CONTRD16: (Address 27h)				
Bit	Symbol	R/W	Description	Default
7:0	CONT_F0_H	RO	The measure value for the f0 of LRA in the continuous detection mode(high eight bits) $F0=(384000)/(CONT\_F0\_H*256+CONT\_F0\_L)$ Hz	0

CONTRD17: (Address 28h)				
Bit	Symbol	R/W	Description	Default
7:0	CONT_F0_L	RO	The measure value for the f0 of LRA in the continuous detection mode(low eight bits) $F0=(384000)/(CONT\_F0\_H*256+CONT\_F0\_L)$ Hz	0

RTPCFG1: (Address 2Dh)				
Bit	Symbol	R/W	Description	Default
7:4	Reserved	RW	Not used	3
3:0	BASE_ADDR_H	RW	High four bits of start address of wave SRAM $BASE\_ADDR = BASE\_ADDR\_H * 256 + BASE\_ADDR\_L$	0x08

RTPCFG2: (Address 2Eh)				
Bit	Symbol	R/W	Description	Default
7:0	BASE_ADDR_L	RW	Low eight bits of start address of wave SRAM $BASE\_ADDR = BASE\_ADDR\_H * 256 + BASE\_ADDR\_L$	0

RTPCFG3: (Address 2Fh)				
Bit	Symbol	R/W	Description	Default
7:4	FIFO_AEH	RW	High four bits of RTP FIFO almost empty threshold $FIFO\_AE = FIFO\_AEH * 256 + FIFO\_AEL$	0x02
3:0	FIFO_AFH	RW	High four bits of RTP FIFO almost full threshold $FIFO\_AF = FIFO\_AFH * 256 + FIFO\_AFL$	0x06

RTPCFG4: (Address 30h)				
Bit	Symbol	R/W	Description	Default
7:0	FIFO_AEL	RW	Low eight bits of RTP FIFO almost empty threshold $FIFO\_AE = FIFO\_AEH * 256 + FIFO\_AEL$	0x00

RTPCFG5: (Address 31h)				
Bit	Symbol	R/W	Description	Default
7:0	FIFO_AFL	RW	Low eight bits of RTP FIFO almost full threshold $FIFO\_AF = FIFO\_AFH * 256 + FIFO\_AFL$	0x00

RTPDATA: (Address 32h)				
Bit	Symbol	R/W	Description	Default
7:0	RTP_DATA	RW	RTP mode , data write entry, when data written into this register, the data will be written into RTP FIFO	0

TRGCFG1: (Address 33h)				
Bit	Symbol	R/W	Description	Default
7	TRG1_POS	RW	TRG1 rising edge enable/disable control 0: disable 1: enable	0
6:0	TRG1SEQ_P	RW	TRIG1 posedge triggered wave sequence number	1

TRGCFG2: (Address 34h)				
Bit	Symbol	R/W	Description	Default

7	TRG2_POS	RW	TRG2 rising edge enable/disable control 0: disable 1: enable	0
6:0	TRG2SEQ_P	RW	Trig2 posedge triggered wave sequence number	1

TRGCFG3: (Address 35h)				
Bit	Symbol	R/W	Description	Default
7	TRG3_POS	RW	TRG3 rising edge enable/disable control 0: disable 1: enable	0
6:0	TRG3SEQ_P	RW	Trig3 posedge triggered wave sequence number	1

TRGCFG4: (Address 36h)				
Bit	Symbol	R/W	Description	Default
7	TRG1_NEG	RW	TRG1 falling edge enable/disable control 0: disable 1: enable	0
6:0	TRG1SEQ_N	RW	Trig1 negedge triggered wave sequence number	1

TRGCFG5: (Address 37h)				
Bit	Symbol	R/W	Description	Default
7	TRG2_NEG	RW	TRG2 falling edge enable/disable control 0: disable 1: enable	0
6:0	TRG2SEQ_N	RW	Trig2 negedge triggered wave sequence number	1

TRGCFG6: (Address 38h)				
Bit	Symbol	R/W	Description	Default
7	TRG3_NEG	RW	TRG3 falling edge enable/disable control 0: disable 1: enable	0
6:0	TRG3SEQ_N	RW	Trig3 negedge triggered wave sequence number	1

TRGCFG7: (Address 39h)				
Bit	Symbol	R/W	Description	Default
7	TRG1_POLAR	RW	TRG1 pin active polarity, when host supply positive level, this bit set to 0, else set to 1	0
6	TRG1_LEV	RW	TRG1 mode control 0: edge 1: level	0
5	TRG1_BRK	RW	When set 1, enable auto brake after TRG1 playback mode is stopped	1
4	Reserved	RW	Not used	0
3	TRG2_POLAR	RW	TRG2 pin active polarity, when host supply positive level, this bit set to 0, else set to 1	0
2	TRG2_LEV	RW	TRG2 mode control 0: edge 1: level	0
1	TRG2_BRK	RW	When set 1, enable auto brake after TRG2 playback mode is stopped	1
0	Reserved	RW	Not used	0

TRGCFG8: (Address 3Ah)				
Bit	Symbol	R/W	Description	Default
7	TRG3_POLAR	RW	TRG3 pin active polarity, when host supply positive level, this bit set to 0, else set to 1	0

6	TRG3_LEV	RW	TRG3 mode control: 0: edge 1: level	0
5	TRG3_BRK	RW	When set 1, enable auto brake after TRG3 playback mode is stopped	1
4:3	TRG1_MODE	RW	Pin TRIG1 playback mode control b00: PWM_LRA b01: PWM_ERM b10: TRIG1 b11: disable	0
2	TRG1_STOP	RW	When set 1, TRG1 playback mode can be stopped immediately	0
1	TRG2_STOP	RW	When set 1, TRG2 playback mode can be stopped immediately	0
0	TRG3_STOP	RW	When set 1, TRG3 playback mode can be stopped immediately	0

GLBCFG2: (Address 3Ch)				
Bit	Symbol	R/W	Description	Default
7:0	START_DLY	RW	Startup delay time, unit time is (1/48k)s	4

GLBCFG4: (Address 3Eh)				
Bit	Symbol	R/W	Description	Default
7:6	GO_PRIO	RW	Priority value of GO TRIG High priority can interrupt the playback of low priority, and low priority cannot interrupt the playback of high priority. When the priority settings are consistent, the default priority will be implemented	0
5:4	TRG3_PRIO	RW	Priority value of TRIG 3 pin High priority can interrupt the playback of low priority, and low priority cannot interrupt the playback of high priority. When the priority settings are consistent, the default priority will be implemented	1
3:2	TRG2_PRIO	RW	Priority value of TRIG 2 pin High priority can interrupt the playback of low priority, and low priority cannot interrupt the playback of high priority. When the priority settings are consistent, the default priority will be implemented	2
1:0	TRG1_PRIO	RW	Priority value of TRIG1 pin High priority can interrupt the playback of low priority, and low priority cannot interrupt the playback of high priority. When the priority settings are consistent, the default priority will be implemented	3

GLBRD5: (Address 3Fh)				
Bit	Symbol	R/W	Description	Default
7:4	Reserved	RO	Not used	0
3:0	GLB_STATE	RO	The state of glb state b0000: STANDBY b0110: CONT b0111: RAM b1000: RTP b1001: TRIG b1010: PWM b1011: BRAKE	0

RAMADDRH: (Address 40h)				
Bit	Symbol	R/W	Description	Default
7:4	Reserved	RW	Not used	0
3:0	RAMADDRH	RW	SRAM address high 4 bits	0

RAMADDRL: (Address 41h)				
Bit	Symbol	R/W	Description	Default
7:0	RAMADDRL	RW	SRAM address low eight bits	0

RAMDATA: (Address 42h)				
Bit	Symbol	R/W	Description	Default
7:0	RAMDATA	RW	SRAM data entry	0

SYSCTRL1: (Address 43h)				
Bit	Symbol	R/W	Description	Default
7	VBAT_MODE	RW	VDD adjust mode: 0: software adjust mode 1: hardware adjust mode	0
6:4	Reserved	RW	Not used	0
3	EN_RAMINIT	RW	Enable clock: 1: open the digital module clock 0: close the digital module clock	0
2	EN_FIR	RW	Set enable of FIR filter	1
1:0	Reserved	RW	Not used	0

SYSCTRL2: (Address 44h)				
Bit	Symbol	R/W	Description	Default
7	WAKE	RW	Chip enable control 1: force the chip to enter active mode	0
6	STANDBY	RW	Chip disable control: 1: force the chip to enter standby mode	0
5:2	Reserved	RW	Not used	0x0A
1:0	WAVDAT_MODE	RW	Waveform data sample rate selection: b00: 24kHz b01: 48kHz others: 12kHz rate	0

SYSCTRL7: (Address 49h)				
Bit	Symbol	R/W	Description	Default
7:3	Reserved	RW	Not used	2
2:0	D2S_GAIN	RW	Set D2S gain: b000: 1 b001: 2 b010: 4 b011: 5 b100: 8 b101: 10 b110: 20 b111: 40	4

PWMCFG1: (Address 4Ch)				
Bit	Symbol	R/W	Description	Default
7	PRC_EN	RW	Set enable of output signal protection mode of pwm: 0: disable 1: HDP/HDN output voltage $\geq 124/128 * VDD$ maintains (PRCTIME/3k)s, HDP/HDN is pulled down protectively	1
6:0	PRCTIME	RW	Set protection time of output signal protection mode of pwm, unit time is (1/3k)s.	0x20

PWMCFG2: (Address 4Dh)				
Bit	Symbol	R/W	Description	Default
7:5	Reserved	RW	Not used	1
4	PD_HWM	RW	shutdown half wave modulate 0: half wave mode 1: full wave mode	0

3:0	Reserved	RW	Not used	8
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PWMCFG3: (Address 4Eh)				
Bit	Symbol	R/W	Description	Default
7	PR_EN	RW	Set enable of input signal protection mode of pwm: 0: disable 1: HDP/HDN output voltage $\geq$ PRLVL/128*VDD maintains (PRTIME/3k)s, HDP/HDN is pulled down protectively	1
6:0	PRLVL	RW	Set protection voltage of output signal protection mode of pwm	0x3F

PWMCFG4: (Address 4Fh)				
Bit	Symbol	R/W	Description	Default
7:0	PRTIME	RW	Set protection time of input signal protection mode of pwm, unit time is (1/3k)s.	0x32

DETCFG1: (Address 51h)				
Bit	Symbol	R/W	Description	Default
7:5	Reserved	RW	Not used	0
4	RL_OS	RW	Set diagnostic mode 0:disable 1:RL	0
3	Reserved	RW	Not used	0
2:0	CLK_ADC	RW	Set frequency of ADC clock b000: 12MHz b001: 6MHz b010: 3MHz b011: 1.5MHz b100: 0.75MHz b101: 0.375MHz b110: 0.1875MHz b111: 0.09375MHz	2

DETCFG2: (Address 52h)				
Bit	Symbol	R/W	Description	Default
7:2	Reserved	RW	Not used	0
1	VDD_GO	RW	Set the enabled of VBAT mode	0
0	DIAG_GO	RW	Set the enabled of DIAG mode	0

DET_RL: (Address 53h)				
Bit	Symbol	R/W	Description	Default
7:0	RL_H	RO	The measured value of resistance of LRA in DIAG mode(high eight bits) $RL = ((RL\_H * 4 + RL\_LO) * 678) / (1024 * d2s\_gain) \Omega$	0

DET_VDD: (Address 55h)				
Bit	Symbol	R/W	Description	Default
7:0	VBAT	RO	The measured value of VDD in VBAT mode(high eight bits) $VDD = ((VBAT * 4 + VBAT\_LO) * 6.1 / 1024) V$	0

DET_LO: (Address 57h)				
Bit	Symbol	R/W	Description	Default
7:6	Reserved	RO	Not used	0
5:4	VBAT_LO	RO	The measured value of VDD in VBAT mode(low two bits) $VDD = ((VBAT * 4 + VBAT\_LO) * 6.1 / 1024) V$	0
3:2	Reserved	RO	Not used	0

1:0	RL_LO	RO	the Measured value of resistance of LRA in DIAG mode(low two bits) $RL = ((RL\_H * 4 + RL\_LO) * 678) / (1024 * d2s\_gain) \Omega$	0
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TRIMCFG3: (Address 5Ah)				
Bit	Symbol	R/W	Description	Default
7:6	Reserved	RW	Not used	0
5:0	TRIM_LRA	RW	Change the frequency of output waveform, and one LSB is 0.24% 011111: 31xLSB 011110: 30xLSB ..... 000001: 1xLSB 000000: 0xLSB 111111: -1xLSB ..... 100001: -31xLSB 100000: -32xLSB	0

CHIPID: (Address 64h)				
Bit	Symbol	R/W	Description	Default
7	Reserved	RO	Not used	1
6	CHIPID_H	RO	Enable I2C address selection pin 0: disable(AW86223/AW86224/AW86225) 1: enable(AW86214)	0
5:1	Reserved	RO	TRIM data	
0	CHIPID_L	RO	Distinguish between 9pin chip and 12pin chip 0: 9pin chip(AW86224/AW86225) 1: 12pin chip(AW86223/AW86214)	1

ANACFG8: (Address 77h)				
Bit	Symbol	R/W	Description	Default
7:6	TRTF_CTRL_HDRV	RW	HDP and HDN rising time control b00: Trise = 60ns b01: Trise = 20ns b10: Trise = 10ns b11: Trise = 4ns	0
5:0	Reserved	RW	Not used	0

## Application Information

### Capacitors Selection

#### SUPPLY DECOUPLING CAPACITOR (CS)

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

#### OUTPUT BEADS, CAPACITORS

The device output is a square wave signal, which causing switch current at the output capacitor, increasing static power consumption, and therefore output capacitor should not be too large,  $0.1\text{nF}$  ceramic capacitors is recommended.

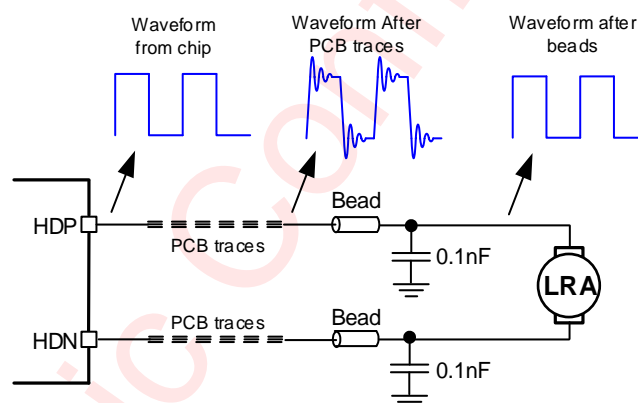


Figure 29 Ferrite Chip Bead and capacitor

The device output is a square wave signal. The voltage across the capacitor will be much larger than the VDD voltage after increasing the bead capacitor. It suggested the use of rated voltage above 10V capacitor. At the same time a square wave signal at the output capacitor switching current form, the static power consumption increases, so the output capacitance should not be too much which is recommended  $0.1\text{nF}$  ceramic capacitor rated voltage of 10V. If you want to get better EMI suppression performance, can use  $1\text{nF}$ , rated voltage 10V capacitor, but quiescent current will increase.

## PCB Layout Consideration

To obtain the optimal performance, PCB layout should be considered carefully. The suggested Layout is illustrated in the following diagram:

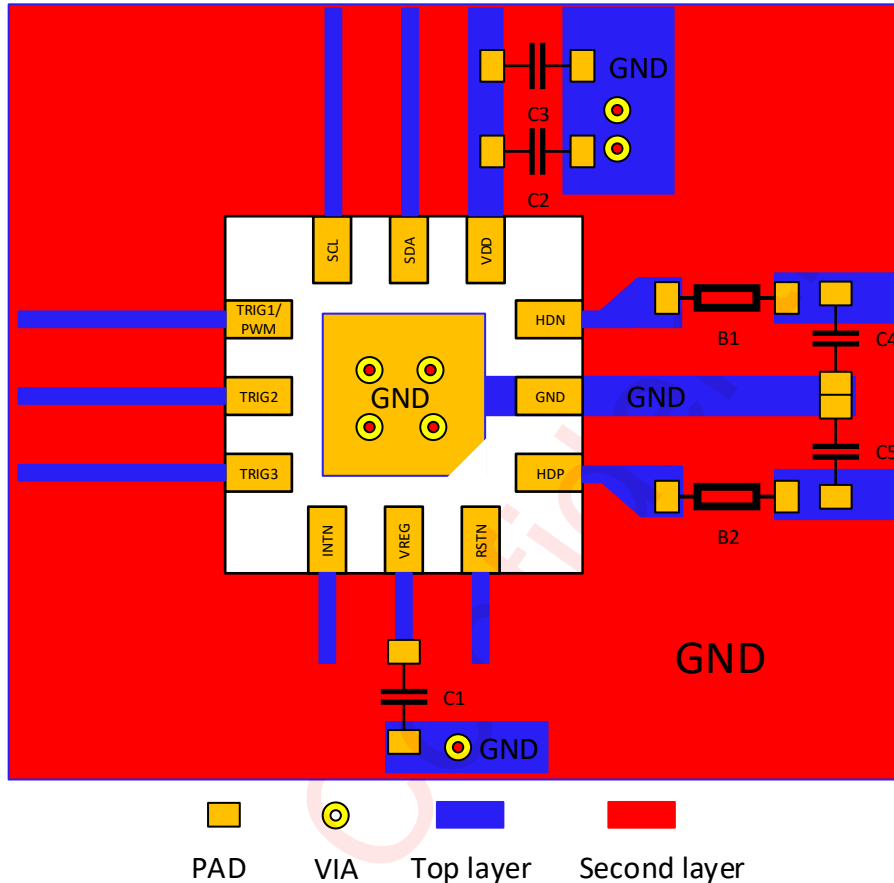
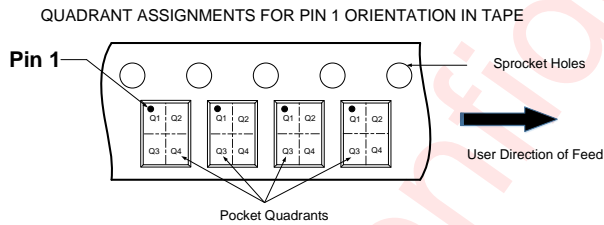
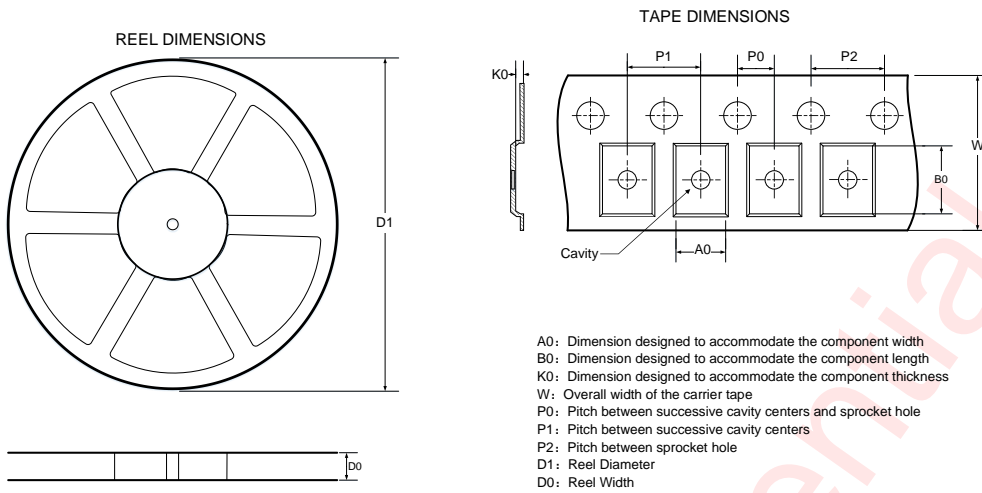


Figure 30 AW86223 Board Layout

PCB Layout Guidelines:

1. Devices around the chip should be placed as close as possible to the chip pins.
2. I2C are recommended to be shield by gnd.
3. VDD/VREG power supply lines are as short and thick as possible. The current flow capacity of the traces not be less than  $\frac{VDD}{(RL+R_{dson})*\eta}$ . (RL is motor DC impedance, R<sub>dson</sub> takes 0.75Ω, η is chip overall efficiency takes 80%)
4. HDP/HDN lines are as short and thick as possible. and the current flow capacity of the traces not be less than  $\frac{VDD}{(RL+R_{dson})}$
5. HDP, HDN are recommended to be shield by gnd, away from interfering sources (especially FLY capacitors of high power charge IC), otherwise F0 detection may be inaccurate.

## Tape And Reel Information



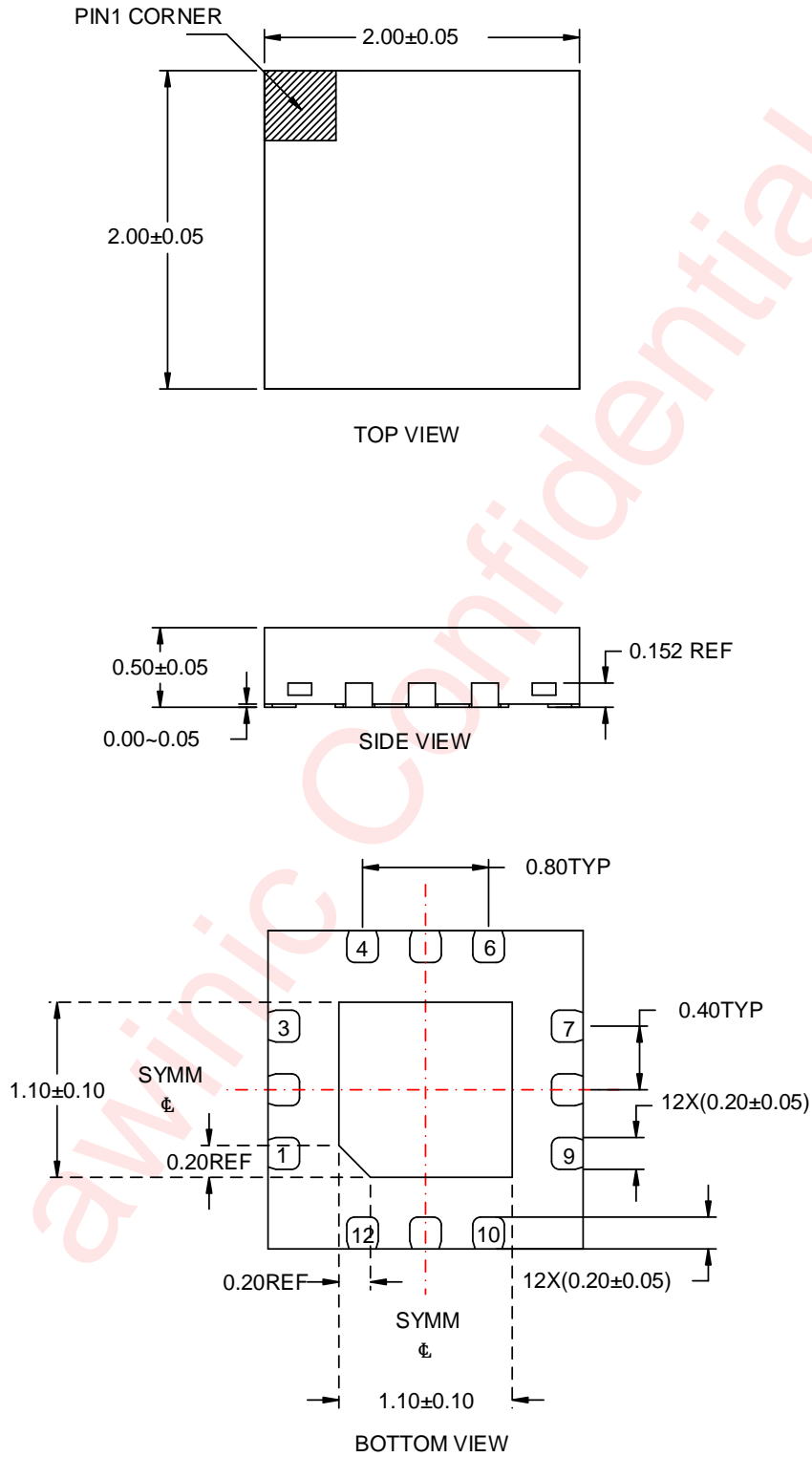
NOTE: The above picture is for reference only. Please refer to the value in the table below for the actual size

**DIMENSIONS AND PIN1 ORIENTATION**

D1 (mm)	D0 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P0 (mm)	P1 (mm)	P2 (mm)	W (mm)	Pin1 Quadrant
178.0±1.0	8.4+2.0/-0.0	2.25±0.10	2.25±0.10	0.75±0.10	2.00±0.05	4.00±0.10	4.00±0.10	8.00+0.30/-0.10	Q1

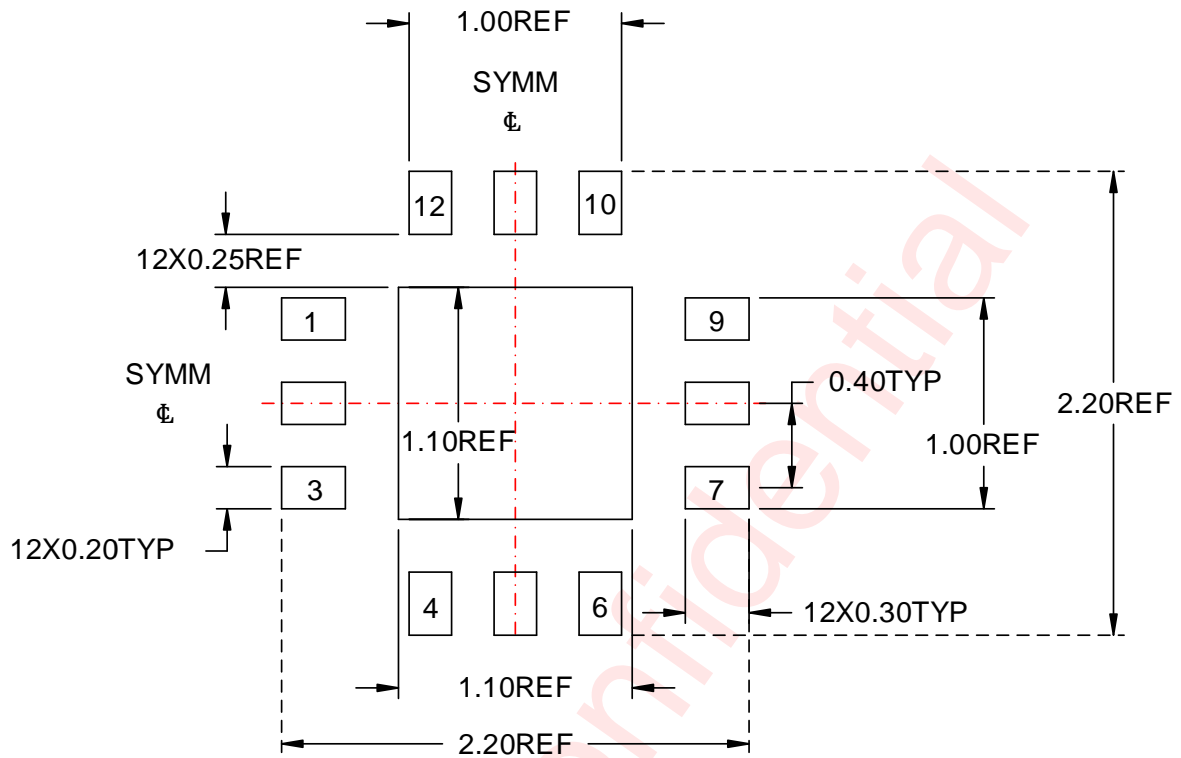
All dimensions are nominal

### Package Description

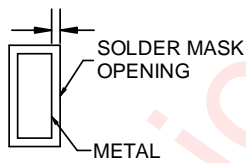


Unit: mm

Land Pattern Data

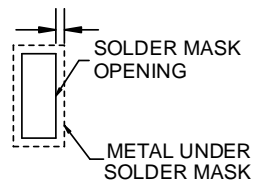


0.05 MAX  
All AROUND



NON SOLDER MASK DEFINED

0.05 MIN  
All AROUND



SOLDER MASK DEFINED

Unit: mm

## Revision History

Version	Date	Change Record
V1.0	November 2020	Official Version
V1.1	January 2021	Modify manual format and PCB Layout
V1.2	January 2021	I2C address is configurable
V1.3	February 2021	Modify SRST(0x00) Register Detailed Description
V1.4	March 2021	Modify LRA Resistance Detect and Typical Application Circuits
V1.5	March 2021	Modify I2C Interface and Top Mark
V1.6	April 2021	Modify Pin definition
V1.7	June 2021	Modify Register Configuration and Waveform library initialization steps and Pin Definition
V1.8	August 2021	Modify Register Detailed Description and Detailed Functional Description
V1.9	September 2021	Modify Detailed Functional Description
V2.0	October 2021	Modify Tape And Reel Information
V2.1	February 2022	Modify Electrical Characteristics
V2.2	September 2022	Modify LRA Resistance Detect and Register Description Modify TRIM_LRA/DRV2_LVL Register Description Modify misspelling
V2.3	September 2023	Modify Pin Definition and Typical Application Circuits

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