

NAU8325

Datasheet

This page is intentionally left blank

1 Contents

1	CONTENTS	3
1.1	List of Figures	6
1.2	List of Tables	6
2	GENERAL DESCRIPTION	8
3	PIN CONFIGURATION.....	9
4	PIN DESCRIPTIONS.....	10
5	SYSTEM DIAGRAM	11
5.1	Reference System Diagram	11
6	BLOCK DIAGRAM.....	12
7	FUNCTIONAL DESCRIPTION	13
7.1	Inputs.....	13
7.2	Outputs.....	13
7.3	Digital Interfaces.....	13
7.4	Power Supply	13
7.5	Power-On-and-Off Reset.....	14
7.6	Voltage Reference (VREF).....	14
7.7	DAC Soft Mute	15
7.8	Companing.....	15
7.9	Hardware and Software Reset	16
7.10	Clocking and Sample Rates	16
7.10.1	Clock Control and Detection.....	16
7.10.2	Automatic Power Control and Mute.....	17
7.10.3	Disabling Clock Detection	19
7.10.4	Sample and Over Sampling Rates	19
7.11	Automatic Level Control	22
7.11.1	ALC Operation.....	22
7.11.2	ALC Parameter Definitions.....	23
7.12	Device Protection	25
7.13	Power-up and Power-Down Control.....	25
7.14	Bypass Capacitors.....	25
7.15	Printed Circuit Board Layout Considerations.....	25
7.15.1	PCB Layout Notes.....	26
7.16	Filters.....	26
7.16.1	Class D without Filters.....	26
7.16.2	Class D with Filters.....	26
8	CONTROL AND STATUS REGISTERS	29
8.1	Digital Control Interface.....	29

8.1.1	2-Wire Protocol Convention	29
8.1.2	2-Wire Write Operation.....	29
8.1.3	2-Wire Read Operation	30
8.2	Digital Audio Interface	31
8.2.1	Right-Justified Audio Data.....	32
8.2.2	Left-Justified Audio Data	32
8.2.3	I2S Audio Data	32
8.2.4	TDM Left-Justified Audio Data.....	33
8.2.5	TDM I2S Audio Data	33
8.2.6	PCM A Audio Data	34
8.2.7	PCM B Audio Data	34
8.2.8	PCM Time Slot Audio Data	35
8.2.9	PCM Time Offset Audio Data	35
8.3	Control Registers.....	37
	HARDWARE_RST.....	37
	SOFTWARE_RST	37
	DEVICE_ID.....	37
	CLK_CTRL	37
	ENA_CTRL.....	38
	INT_CLR_STATUS.....	39
	IRQOUT	39
	IO_CTRL	39
	PDM_CTRL	40
	PDM_LCH_EDGE	40
	PDM_MODE	40
	TDM_CTRL.....	40
	I2S_PCM_CTRL1	40
	I2S_PCM_CTRL2	41
	LEFT_TIME_SLOT	41
	RIGHT_TIME_SLOT.....	41
	HPF_CTRL	41
	MUTE_CTRL	41
	DAC_VOLUME	42
	Debug Read 1.....	42
	Debug Read 2.....	43
	Debug Read 3.....	43
	DAC_CTRL1	43
	DAC_CTRL2.....	43
	ALC_CTRL1	44

ALC_CTRL2	44
ALC_CTRL3	45
ALC_CTRL4	45
CLK_DET_CTRL	45
TEST STATUS	46
ANALOG_READ	46
MIXER_CTRL	46
MISC_CTRL	46
BIAS_ADJ.....	47
ANALOG_CONTROL_1	47
ANALOG_CONTROL_2	48
ANALOG_CONTROL_3	48
ANALOG_CONTROL_4	49
ANALOG_CONTROL_5	49
ANALOG_CONTROL_6	50
CLIP_CTRL	50
RDAC	50
9 ELECTRICAL CHARACTERISTICS	51
9.1 Absolute Maximum Ratings.....	51
9.2 Operating Conditions.....	51
9.3 Electrical Parameters	51
9.4 Digital I/O Parameters	53
10 PACKAGE SPECIFICATION.....	54
11 ORDERING INFORMATION	55
12 REVISION HISTORY.....	56
IMPORTANT NOTICE.....	57

1.1 List of Figures

Figure 1	Pin Configuration of NAU8325 (TOP VIEW)	9
Figure 2	NAU8325 Simplified System Diagram.....	11
Figure 3	NAU8325 Block Diagram	12
Figure 4	VREF Circuitry	14
Figure 5	NAU8325 Clock Detection Circuit	17
Figure 6	PWRUPEN startup sequence.	18
Figure 7	Automatic Level Control	22
Figure 8	ALC Operation	23
Figure 9	ALC using Hold time	24
Figure 10	NAU8325 Speaker Connections without Filter.....	26
Figure 11	NAU8325 Speaker Connections with Ferrite Bead Filters	27
Figure 12	NAU8325 Speaker Connections with LC Filters	27
Figure 13	NAU8325 Speaker Connections with Low-Pass Filters	27
Figure 14	Valid START Condition	29
Figure 15	Valid Acknowledge.....	29
Figure 16	Valid STOP Condition	29
Figure 17	Slave Address Byte, Control Address Byte, and Data Byte	30
Figure 18	2-Wire Write Sequence.....	30
Figure 19	2-Wire Read Sequence.....	31
Figure 20	Right-Justified Audio Data	32
Figure 21	Left-Justified Audio Data.....	32
Figure 22	I2S Audio Data.....	33
Figure 23	TDM Left-Justified Audio Data	33
Figure 24	TDM I2S Audio Data	34
Figure 25	PCM A Audio Data.....	34
Figure 26	PCM B Audio Data.....	35
Figure 27	PCM Time Slot Audio Data	35
Figure 28	PCM Time Offset Audio Data.....	36
Figure 29	NAU8325 Package Specification	54

1.2 List of Tables

Table 1	Pin Descriptions for the NAU8325.....	10
Table 2	VREF Output Impedance Selection.....	14
Table 3	Range of Input Clocks	19
Table 4	Sampling and Over Sampling Rates (Ranges 1-3)	19
Table 5	Sampling and Over Sampling Rates (Range 4)	19
Table 6	Effective MCLK/FS Ratios.....	20

Table 7	High-Pass Filter Cut-Off Frequencies.....	28
Table 8	Digital Audio Interface Mode Settings	31

2 GENERAL DESCRIPTION

The NAU8325 is a stereo high efficiency filter-free Class-D audio amplifier, which is capable of driving a 4Ω load with up to 3.0W output power. This device provides I2C control and I2S audio input with low standby current and fast start-up time.

The NAU8325 is ideal for the portable applications of battery drive, as it has advanced features like 80dB PSRR, 90% efficiency, ultra-low quiescent current (i.e. 2.1mA at 3.7V for 2 channels) and superior EMI performance. NAU8325 is available in Miniature QFN-20 package.

Key Features

- Low SPK_VDD Quiescent Current:
 - 2.1mA at 3.7V for 2 channels
 - 3.2mA at 5V for 2 channels
- Gain Setting with 2 wire interface
 - 22dB to -62dB (plus mute)
- Powerful Stereo Class-D Amplifier:
 - 2ch x 3.0W (4Ω @ 5V, 10% THD+N)
 - 2ch x 1.32W (4Ω @ 3.7V, 1% THD+N)
 - 2ch x 1.72W (8Ω @ 5V, 10% THD+N)
 - 2ch x 0.75W (8Ω @ 3.7V, 1% THD+N)
- Low Output Noise: 18 μV_{RMS} @0dB gain
- 80dB PSRR @217Hz
- Low Current Shutdown Mode
- Click-and Pop Suppression

Applications

- Notebooks / Tablet PCs
- Personal Media Players / Portable TVs
- MP3 Players
- Portable Game Players
- Digital Camcorders

3 PIN CONFIGURATION

The NAU8325 package is shown in **Figure 1**.

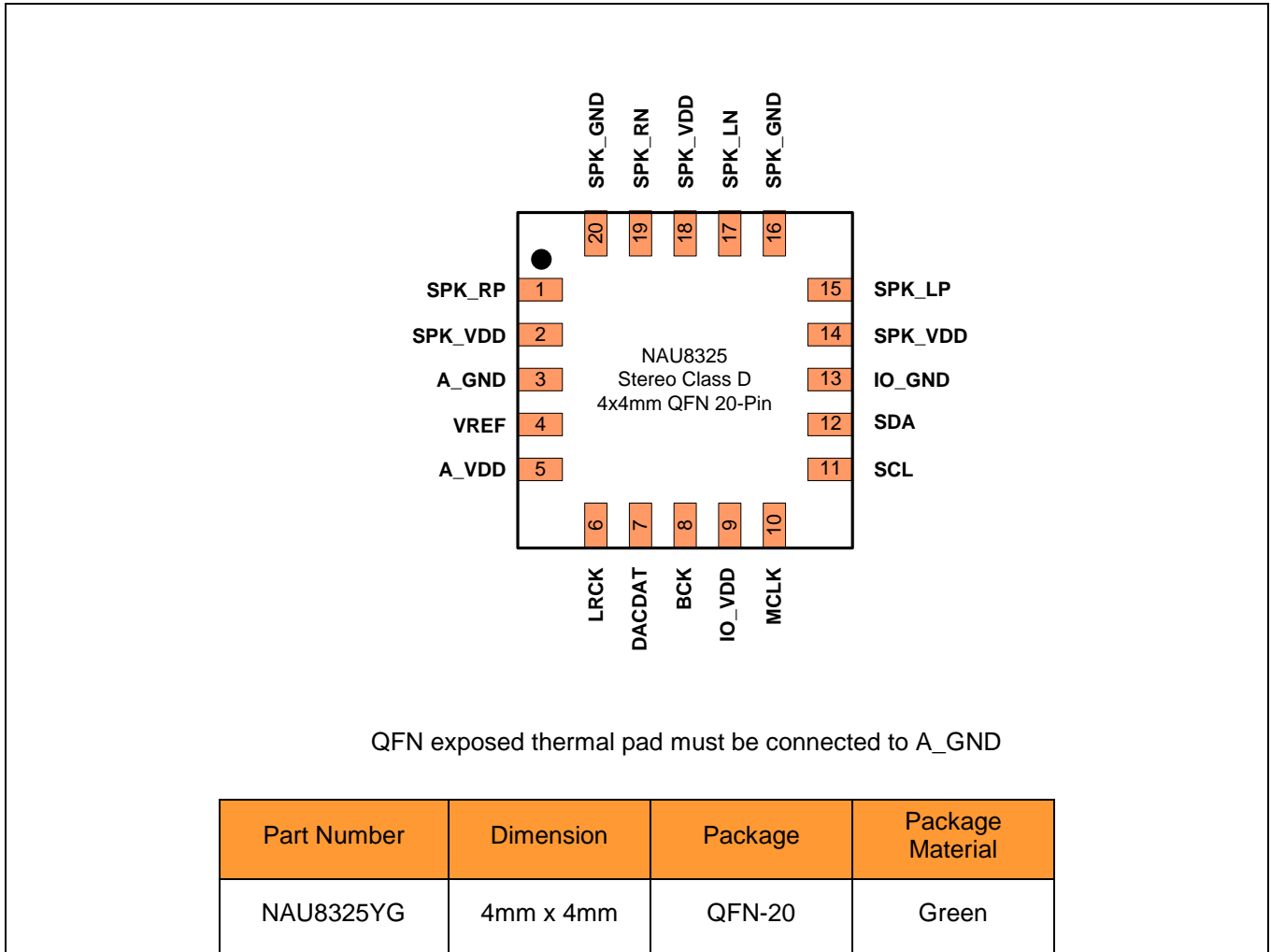


Figure 1 Pin Configuration of NAU8325 (TOP VIEW)

4 PIN DESCRIPTIONS

Pin descriptions for the NAU8325 are provided in **Table 1**.

Table 1 Pin Descriptions for the NAU8325

Pin #	Name	Type, (Supply Domain)	Description
1	SPK_RP	Analog Output	Right Speaker positive output
2	SPK_VDD	Supply	Supply speaker Driver
3	A_GND	Supply	Ground for Analog
4	VREF	Analog Output	Analog Voltage Reference
5	A_VDD	Supply	Analog supply
6	LRCK	Digital Input	I2S I/F Frame clock
7	DACDAT	Digital Input	I2S I/F DAC digital audio data
8	BCK	Digital Input	I2S I/F bit clock
9	IO_VDD	Supply	Digital I/F Power supply
10	MCLK	Digital Input	Master clock
11	SCL	Digital I/O	I2C clock
12	SDA	Digital I/O	I2C data
13	IO_GND	Supply	Digital Ground
14	SPK_VDD	Supply	Supply speaker Driver
15	SPK_LP	Analog Output	Left Speaker positive output
16	SPK_GND	Supply	Ground for speaker driver
17	SPK_LN	Analog Output	Left Speaker negative output
18	SPK_VDD	Supply	Supply speaker Driver
19	SPK_RN	Analog Output	Right Speaker negative output
20	SPK_GND	Supply	Ground for speaker driver
21	Ex-Pad	Analog Input	Thermal Tab (must be connected to A_GND)

5 SYSTEM DIAGRAM

5.1 Reference System Diagram

A basic system reference diagram is provided in **Figure 2**.

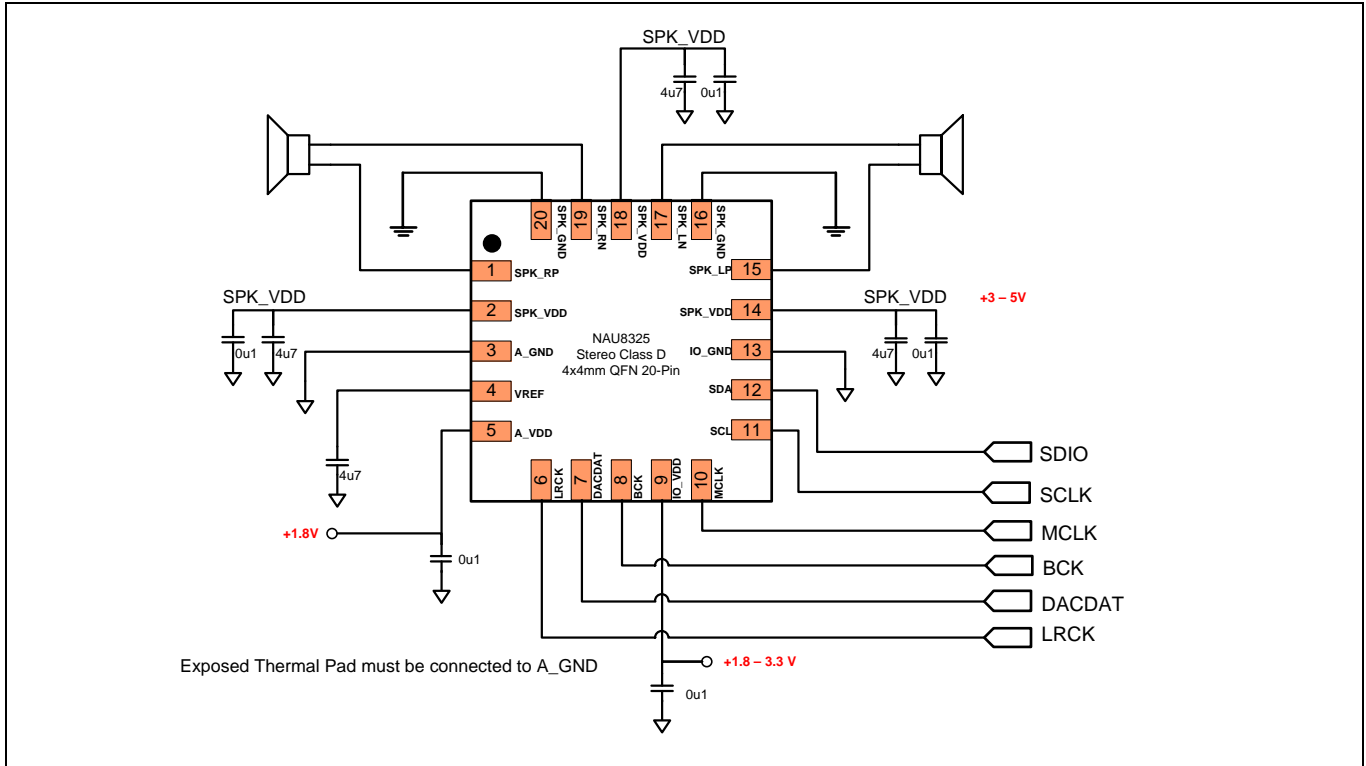


Figure 2 NAU8325 Simplified System Diagram

6 BLOCK DIAGRAM

A Block Diagram for the NAU8325 is provided in **Figure 3**.

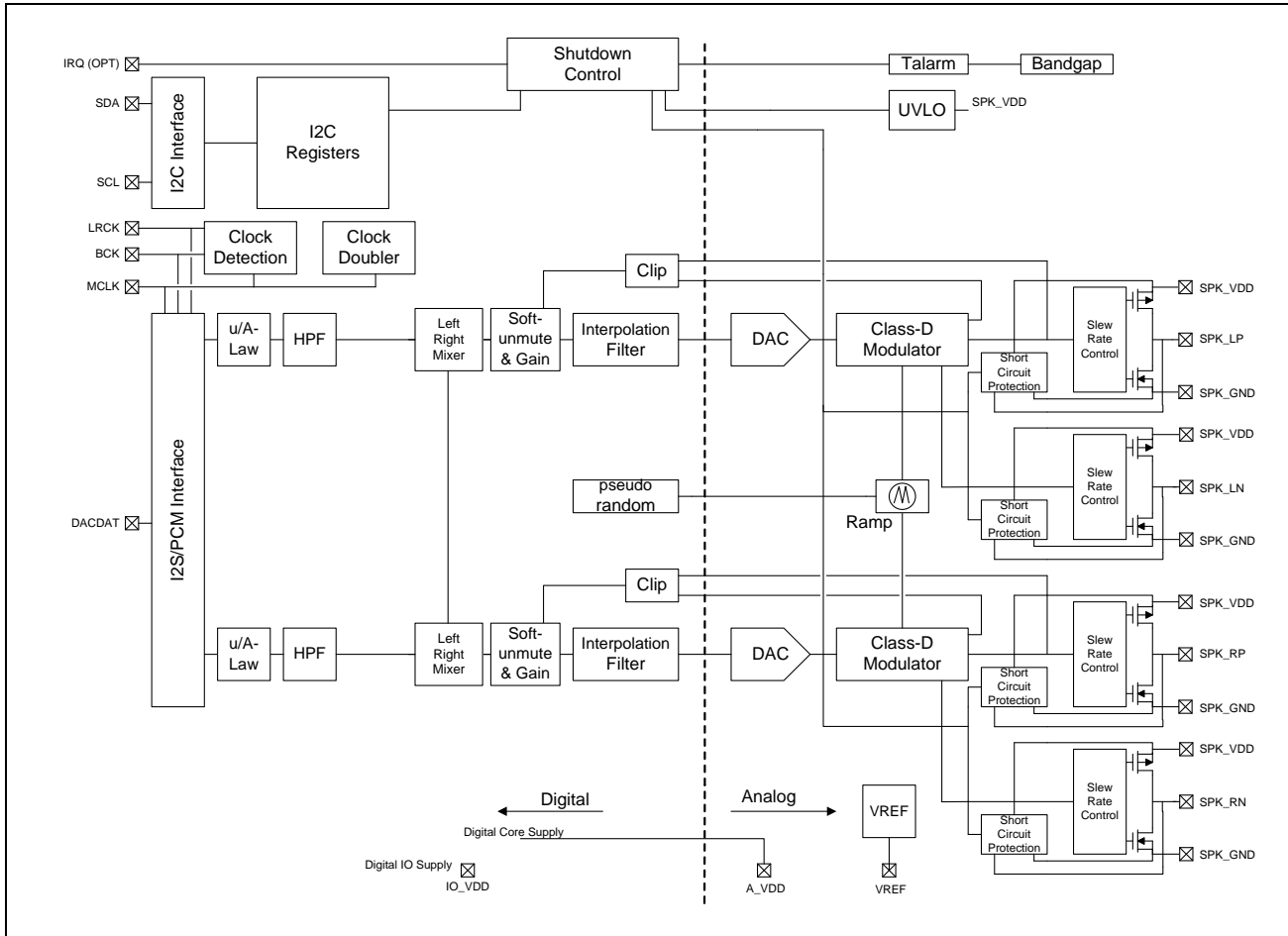


Figure 3 NAU8325 Block Diagram

7 FUNCTIONAL DESCRIPTION

This chapter provides detailed descriptions of the major functions of the NAU8325 Amplifier.

7.1 Inputs

The NAU8325 provides digital inputs to acquire and process audio signals with high fidelity and flexibility. The audio input path is from an I2S/PCM Interface. Additionally, the NAU8325 has a two wire serial interface for control input.

7.2 Outputs

The NAU8325 Stereo Class-D PWM Amplifier has a gain range from 0dB to 22dB, and is powered by a separate power supply SPK_VDD, which can go up to 5V. This amplifier is capable of delivering up to 3.0W into a 4Ω load with a 5V supply.

7.3 Digital Interfaces

Command and control of the device is accomplished by using a Serial Control Interface. The simple, but highly flexible, 2-wire Serial Control Interface is compatible with I2C protocol. Audio data is passed to the device through a serial data interface compatible with industry standard I2S and PCM devices.

7.4 Power Supply

This NAU8325 has been designed to operate reliably under a wide range of power supply conditions and Power-On/Power-Off sequences. SPK_VDD, A_VDD and IO_VDD can all operate independently of one another. However, the Electro Static Detection (ESD) protection diodes between the supplies impact the application of the supplies. Because of these diodes, the following conditions need to be met:

$$\text{IO_VDD} > \text{A_VDD} - 0.6 \text{ V}$$

7.5 Power-On-and-Off Reset

The NAU8325 includes a Power-On-and-Off Reset circuit on-chip. The circuit resets the internal logic control at A_VDD supply power-up and this reset function is automatically generated internally when power supplies are too low for reliable operation. Reset threshold is 1.3 V for A_VDD during a power-on ramp and 0.8 V for A_VDD during a power-down ramp. It should be noted that these values are much lower than the required voltage for normal operation of the chip.

The reset is held ON while the power levels A_VDD is below the threshold. Once the power level rises above the threshold, the reset is released. Once the reset is released, the registers are ready to be written to.

The preferred power-up sequence is for SPK_VDD and IO_VDD to come up first followed by A_VDD. The preferred power-down sequence is for A_VDD to power down first.

NOTE: It is also important that all the registers should be kept in their reset state for at least 6 μ sec.

An additional internal RC filter-based circuit is added which helps the circuit to respond for fast ramp rates ($\sim 3 \mu$ sec) and to generate the desired reset period width ($\sim 3 \mu$ sec at typical corner). This filter is also used to eliminate supply glitches which can generate a false reset condition, typically 50 nsec.

For reliable operation, it is recommended to write to register **REG0X00** upon power-up. This will reset all registers to the known default state.

NOTE: When A_VDD is below the power-on reset threshold, the digital IO pins will go to a tri-state condition. IO_VDD is not involved in power-on reset function. It is preferred IO_VDD is available before A_VDD to ensure no glitches occur on SCL/SDA but it is not essential.

7.6 Voltage Reference (VREF)

The NAU8325 includes a mid-supply, reference circuit that produces voltage close to A_VDD/2 that is decoupled to A_GND through the VREF pin by means of an external bypass capacitor. Because VREF is used as a reference voltage for the NAU8325, a large capacitance is required to achieve good power supply rejection at low frequency, typically 4.7 μ F is used. The Reference Voltage circuitry is shown in **Figure 4**.

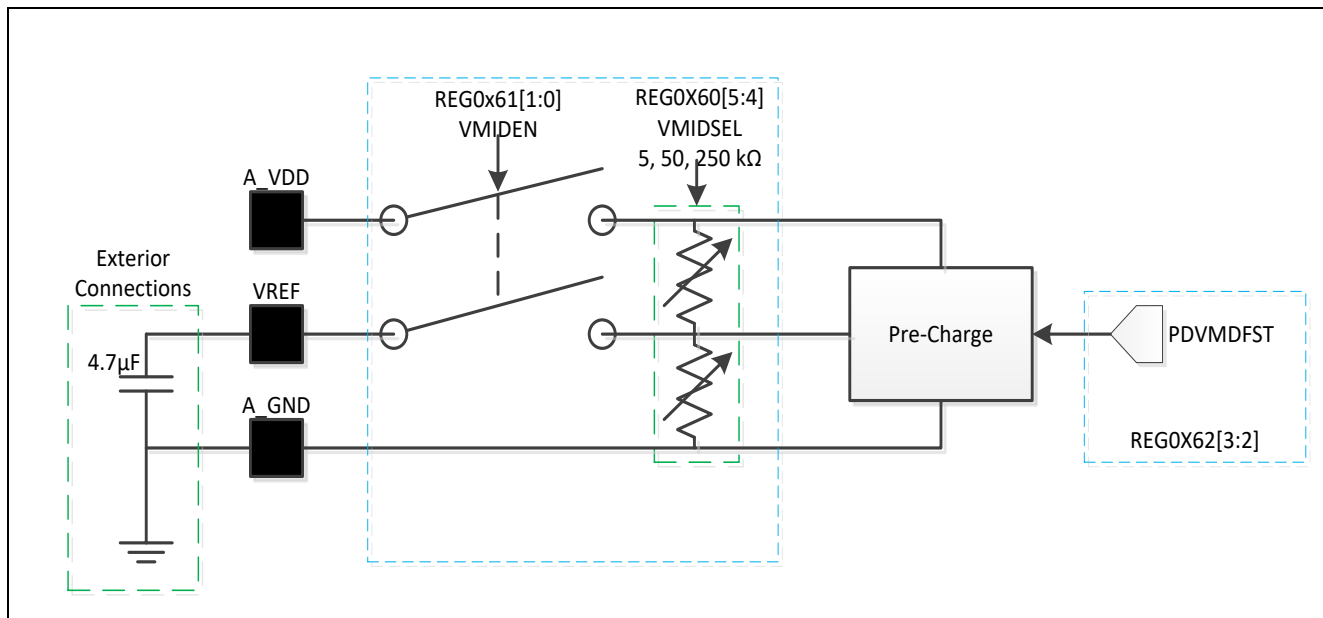


Figure 4 VREF Circuitry

The output impedance can be set using **VMID_SEL REG0X60[5:4]**. Refer to **Table 2**.

Table 2 VREF Output Impedance Selection

VMID_SEL REG0X60[5:4]	VREF Resistor Selection	VREF Impedance
00	Open, no resistor selected	Open, no impedance installed
01	50 kOhm	2.5 kOhm
10	250 kOhm	125 kOhm
11	5 kOhm	2.5 kOhm

APPLICATION NOTES:

- Larger capacitances can be used but increase the rise time of VREF and delay the line output signal.
- Due to the high impedance of the VREF pin, it is important to use a low-leakage capacitor.

7.7 DAC Soft Mute

The Soft Mute function ramps down the DAC digital volume to zero when it is enabled by **SMUTE_EN REG0X12[15]**. When disabled, the volume increases to the register-specified volume level for each channel. This function is beneficial for using the DAC without introducing pop-and-click sounds. When **DACEN_SM REG0X12[13]** is set to '1', the volume will ramp up to the register-specified volume level if the DAC path has been enabled by setting **DACEN REG0X4[3:2]**. The volume goes down to zero directly if the DAC path is disabled.

7.8 Companding

Companding is used in digital communication systems to optimize Signal-to-Noise Ratios (SNR) with reduced data bit rates using non-linear algorithms. The NAU8325 supports the two main telecommunications companding standards -- A-Law and μ -Law -- in both transmit and receive directions. The A-Law algorithm is primarily used in European communication systems; the μ -Law algorithm is primarily used in North American, Japanese, and Australian communications systems.

Companding converts 14 bits (μ -Law) or 13 bits (A-Law) to 8 bits using non-linear quantization resulting in 1 sign bit, 3 exponent bits and 4 mantissa bits. This option can be enabled for the DAC using the **DACCM0 REG0X0D[15:14]** registers. When the Companding Mode is enabled, **CMB8_0 REG0X0D[10]** must be enabled for 8-bit operation. This will disable the word length selection in **WLEN0 REG0X0D[3:2]** for this port and allow the companding functions to use an 8-bit word length.

The compression equations set by the ITU-T G.711 Standard and implemented in the NAU8325 Amplifier are provided here for reference:

μ -Law

$$F(x) = \frac{\ln(1 + \mu \times |x|)}{\ln(1 + \mu)}, \quad -1 < x < 1$$

$$\mu = 255$$

A-Law

$$F(x) = \frac{A \times |x|}{(1 + \ln(A))}, \quad 0 < x < \frac{1}{A}$$

$$F(x) = \frac{(1 + \ln(A \times |x|))}{(1 + \ln(A))}, \quad \frac{1}{A} \leq x \leq 1$$

$$A = 87.6$$

7.9 Hardware and Software Reset

The NAU8325 and all of its control registers can be reset to initial default power-up conditions by writing any value to **REG0X00** *once* using the control interface. Writing to any other valid register address terminates the reset condition, but all registers will be set to their power-on default values. This is typically done during hardware reset.

The NAU8325 can be reset to initialized power-up conditions by writing any value to **REG0X01** *twice* using the control interface. Writing to **REG0X01** will reset the NAU8325, but all registers values will be unaffected. This is typically done during operation to quickly force NAU8325 in the known initialized startup state.

7.10 Clocking and Sample Rates

The internal clocks for the NAU8325 are derived from a common internal clock source. This master system clock can set directly by the MCLK input or it can be generated from a clock multiplier using the MCLK as a reference.

The following sections illustrate how the various register settings can be used to adjust/select the MCLK_SRC and DAC_CLK clock frequencies.

7.10.1 Clock Control and Detection

The NAU8325 includes a Clock Detection circuit that can be used to enable and disable the audio paths, based on an initialized audio path setting. Enable the audio path through the I2C Interface; but, the actual power up/down can be gated by the clock detection circuit. The block diagram of the clock detection circuit is shown in **Figure 5**.

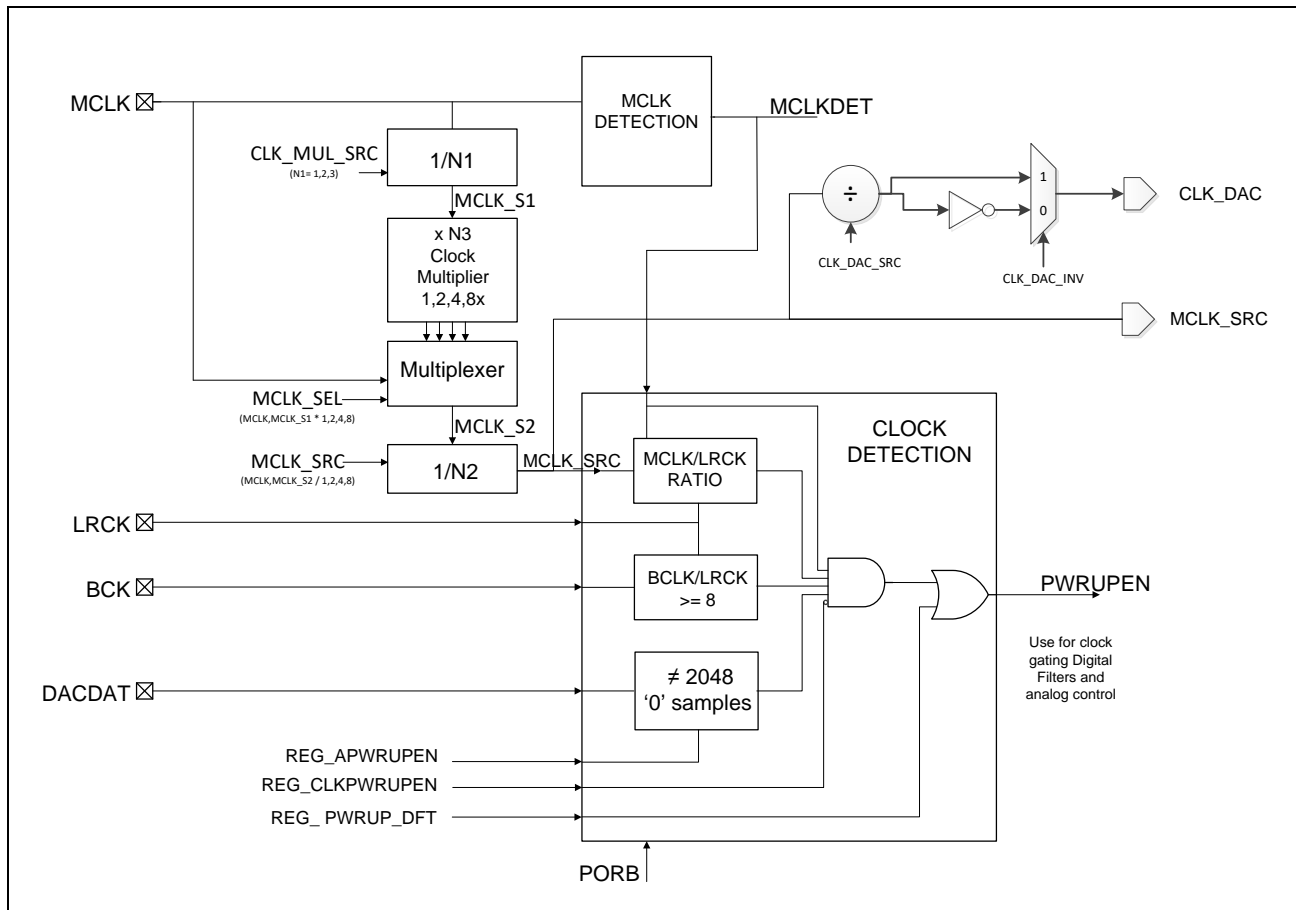


Figure 5 NAU8325 Clock Detection Circuit

Clock Detection by the NAU8325 uses the MCLK, BCK, LRCK and DACDAT to control the PWRUPEN signal and set the clock divider ratios.

7.10.2 Automatic Power Control and Mute.

Clock detection and automatic power control in the NAU8325 is enabled by setting **REG_CLKPWRUPEN** = 0 (default) and meeting three or four conditions, depending on the configuration. If all conditions are met, the PWRUPEN signal will be asserted to 1. If any of the conditions are not met, the PWRUPEN signal is set to 0.

The conditions for generating the PWRUPEN signal are:

- 1) The NAU8325 has custom logic clock detection circuits that detect if MCLK is present. Upon MCLK detection, the detector output MCLKDET goes to 1. When the MCLK disappears, MCLKDET goes back to 0. Up to 1 μ sec is required to detect MCLK and the MCLK release time is about 50 μ sec.
- 2) The clock detection logic also needs to detect the ratio MCLK_SRC/LRCK of 256, 400 or 500.
- 3) The clock detection logic also needs to detect the BCLK to make sure data is present. There needs to be at least 8 BCLK cycles per Frame Sync.
- 4) If REG_APWRUPEN is set to '1', the clock detection will require non-zero samples on any channel in order to enable the output power up signal. Any non-zero sample will be sufficient. After power up if 2048 zero samples are detected on both channels the PWRUPEN signal is asserted to '0'. If REG_APWRUPEN is set to '0', this function does not control the PWRUPEN signal.

The PWRUPEN signal is capable of controlling all the analog power consuming blocks such as the Class D driver, the VMID block, the DAC and bias generation. The register **ANALOG_CONTROL_1** determines which blocks are controlled by PWRUPEN.

When PWRUPEN goes high an internal sequence is triggered to bring up analog functions. This includes an analog MUTE to allow stabilization of internal analog blocks, followed by a soft unmute of the DAC. The analog MUTE time is determined by **REG_MUTE_CTRL.ANA_MUTE** and is between 430us and 4ms. The soft mute ramps the gain on the DAC input from MUTE to DAC_VOLUME at a rate determined by **REG_MUTE_CTRL.UNMUTE_CTL**. This register can disable the soft unmute, or ramp the gain at 32 or 512 MCLK_SRC periods per gain step. For the 512 setting, the soft unmute takes $256 * 512 * T_{mclk}$ seconds to reach 0dB (10ms for 12.288MHz MCLK_SRC). This ensures pop free startup of the amplifier. An example of this startup is shown in figure below.

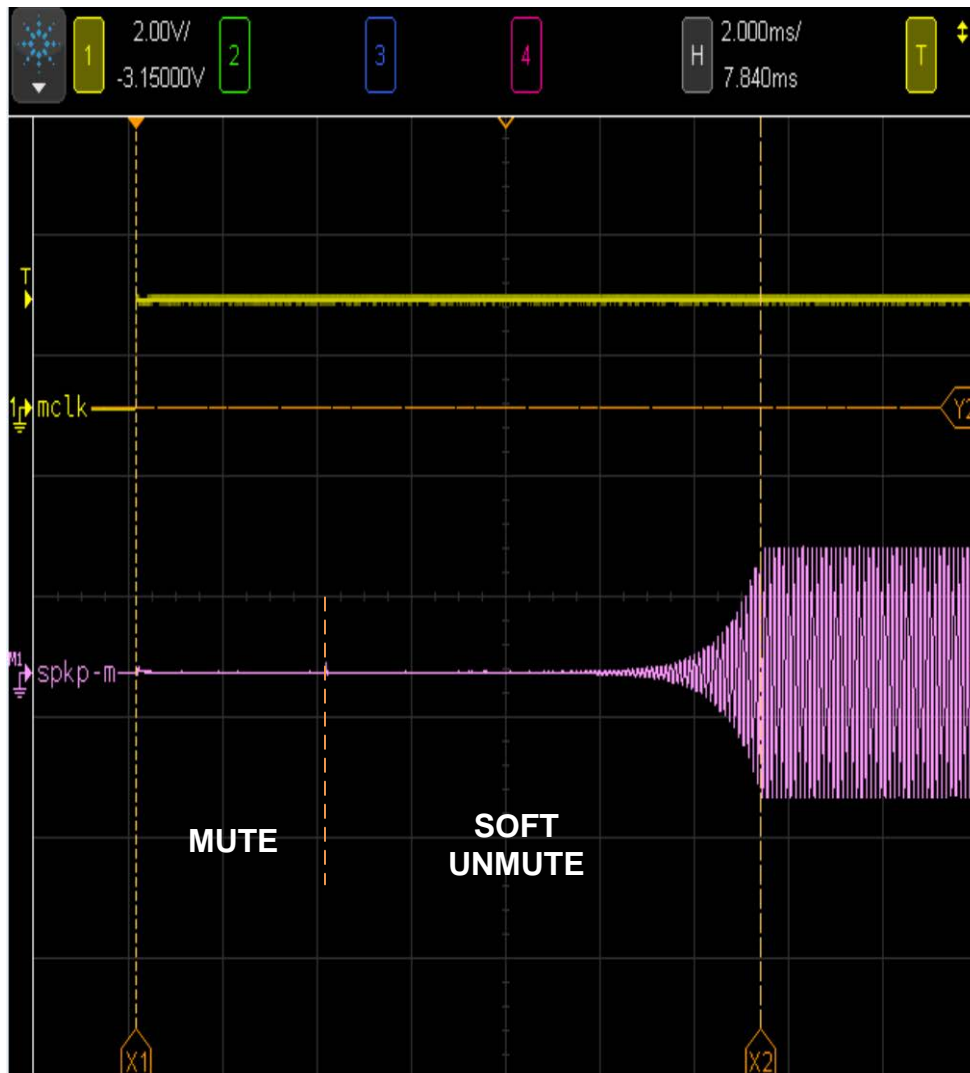


Figure 6 PWRUPEN startup sequence.

Before reaching the DAC the incoming PCM signal is processed by a digital signal path. To ensure complete flushing and transient free audio of this path it is recommended that 2048 zero samples are sent to the device before stopping clocks. The DAC soft mute function is also beneficial for eliminating any audio transients from audio path.

The preferred operating scenario is as follows:

- 1) Initialize I2C registers at power up;
- 2) Start clocks.
- 3) Send 1-14ms of zero samples (optional)
- 4) Play sound.
- 5) Send 2048 zero samples at the end of a sound file to prevent transients.
- 6) Stop the clocks.
- 7) Repeat 2) onwards when required.

In addition to power up control there is an AUTO_MUTE feature. If **REG_MUTE_CTRL.AUTO_MUTE** is set then when 2048 zero samples are detected the PWM driver is MUTED. Upon reception of further data the driver is UNMUTED immediately. This mode has no delay apart from the group delay of audio signal path, but also does not have the same power saving benefits as the automatic power control feature described above.

7.10.3 Disabling Clock Detection

Clock detection in the NAU8325 is disabled by setting **REG_CLKPWRUPEN** to 1. In this state, PWRUPEN is no longer controlled by the enabling conditions listed above, but is set to 1. However, the MCLKDET and clock dividers are still active.

The range of the input clocks is shown in **Table 3**.

Table 3 Range of Input Clocks

Signal	Min	Max
Frame Synch (FS) (kHz)	8	96
Master Clock MCLK (MHz)	2.048	24.576

7.10.4 Sample and Over Sampling Rates

Possible Sample Rate and MCLK_SRC selections are shown in **Table 4** and **Table 5**. Note that **REG_SRATE REG 0X40** must be programmed to identify the target sample rate.

Table 4 Sampling and Over Sampling Rates (Ranges 1-3)

REG_SRATE												
MCLK_SRC/FS Ratio	Range 1 000				Range 2 001				Range 3 010			
	FS (kHz)		MCLK_SRC (MHz)		FS (kHz)		MCLK_SRC (MHz)		FS (kHz)		MCLK_SRC (MHz)	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
256	8	12	2.048	3.072	16	24	4.096	6.144	32	48	8.192	12.288
400	8	12	3.2	4.8	16	24	6.4	9.6	32	48	12.8	19.2
500	8	12	4	6	16	24	8	12	32	48	16	24

Table 5 Sampling and Over Sampling Rates (Range 4)

REG_SRATE	
MCLK_SRC/FS	Range 4 011

Ratio	FS (kHz)		MCLK_SRC (MHz)	
	Min	Max	Min	Max
256	64	96	16,384	24,576
400	64	96	25.6	38.4
500	64	96	32	48

The MCLK_SRC frequency is defined as:

$$F_MCLK_SRC = F_MCLK / N2 \text{ when } MCLK_SEL = 0$$

$$F_MCLK_SRC = N3 \times F_MCLK / (N1 \times N2) \text{ when } MCLK_SEL \neq 0$$

Where N1 & N2 are selectable to 1, 2, 3, 4, 5, 6 or 7 and N3 is selectable to 1, 2, 4 & 8.

The only internal MCLK_SRC/FS ratios allowed are: 256, 400 & 500. The clock divider or multiplier in register 0x03 needs to be setup to achieve one these three possible ratios.

Given N1=N2=1, effective MCLK/FS ratios can be achieved with the clock multiplier, as shown in **Table 6**.

Table 6 Effective MCLK/FS Ratios

MCLK_SRC/FS ratio	Clock Multiplier (MCLK_SEL REG0x03)	Effective ratio MCLK/FS
256	8	32
400	8	50
500	8	62.5
256	4	64
400	4	100
500	4	125
256	2	128
400	2	200
500	2	250
256	1	256
400	1	400
500	1	500

For MCLK_SRC/FS ratios of 256 the Over Sampling Ratio (OSR) can be set in register 0x29 to: 32, 64, 128 & 256. Note that the DAC clock needs to be set to the matching values in register 0x03 CLK_DAC_SRC.

For MCLK_SRC/FS ratios of 400 & 500 the Over Sampling Ratio (OSR) is fixed to 100. For MCLK_SRC/FS ratios of 400 the DAC clock divider needs to be set to ¼ in register 0x03. For MCLK_SRC/FS ratios of 500 the DAC clock divider is automatically set to 1/5.

For example if MCLK is provided as 256* Fs, then N2=1 and MCLK_SEL = 0 will set MCLK_SRC as the correct 256*Fs. If MCLK proved is 512*Fs, then N2=2 and MCLK_SEL = 0 will set MCLK_SRC as the correct 256*Fs.

In addition to MCLK_SRC, the clock to the DAC must be configured correctly. For MCLK_SRC/FS ratios of 256 the Over Sampling Ratio (OSR) can be set via DAC_RATE in register REG29 to: 32, 64, 128 & 256. The DAC clocks need to be set to its corresponding value in register 0x03 given by:

$$F_DAC_CLK = F_MCLK_SRC * CLK_DAC_SRC$$

And

$$F_DAC_CLK = DAC_RATE * Fs$$

CLK_DAC_SRC is 1, ½, ¼, ⅛ and is set to match the desired sample rate Fs and the DAC oversampling setting DAC_RATE in REG29.

.

For MCLK_SRC/FS ratios of 400 & 500 the Over Sampling Ratio (OSR) is fixed to 100. For MCLK_SRC/FS ratios of 400 the DAC clock divider needs to be set to ¼ in register 0x03. For MCLK_SRC/FS ratios of 500 the ADC & DAC clock dividers are automatically set to 1/5.

the hold time. The ALC gain is then ramped up to the target following the pre-programmed ALC Release Time rate

7.11.2 ALC Parameter Definitions

ALC Minimum Gain (ALCMIN): This sets the minimum allowed gain during all modes of ALC operation. This is useful to keep the ALC operating range close to the desired range for a given application scenario.

ALC Attack Time (ALCATK): Attack time refers to how quickly a system responds to a clipping event. Typically, attack time is much faster than decay time.

ALC Decay Time (ALCDCY): Decay time refers to how quickly a system responds after the hold time. Typically, decay time is much slower than attack time. When no more clipping events occur, the gain will increase at a rate determined by this parameter.

ALC Hold Time (ALCHLD): Hold time refers to the duration of time when no action is taken. This is typically to avoid undesirable sounds that can happen when an ALC responds too quickly to a changing input signal. In the NAU8325, the hold time value is the duration from the last clipping event before there is an actual gain increase during the decay time.

CLIP_GAINADJUST sets the maximum gain decrease per clipping event. During a clipping event the gain decreases by 0.250dB (1-1/64) per attack time step until the clipping event no longer occurs or the maximum gain reduction limit set in CLIP_GAINADJUST has been reached or the ALC Minimum Gain is reached.

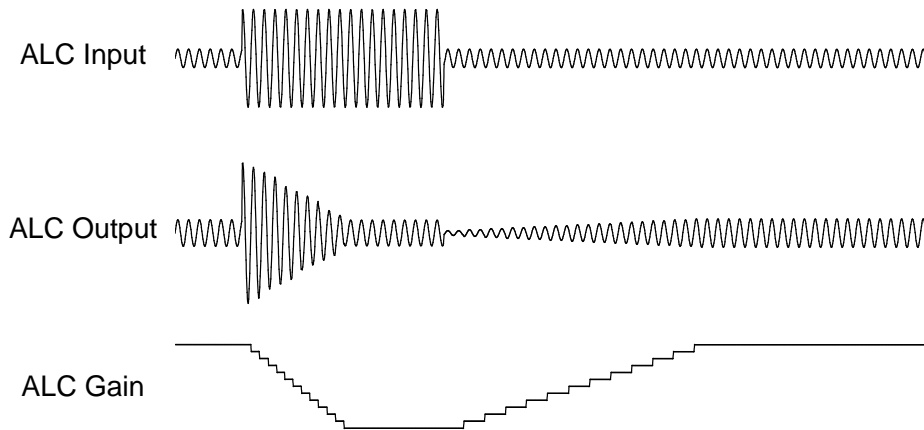


Figure 8 ALC Operation

The waveform below shows the operation of the ALC hold delay time.

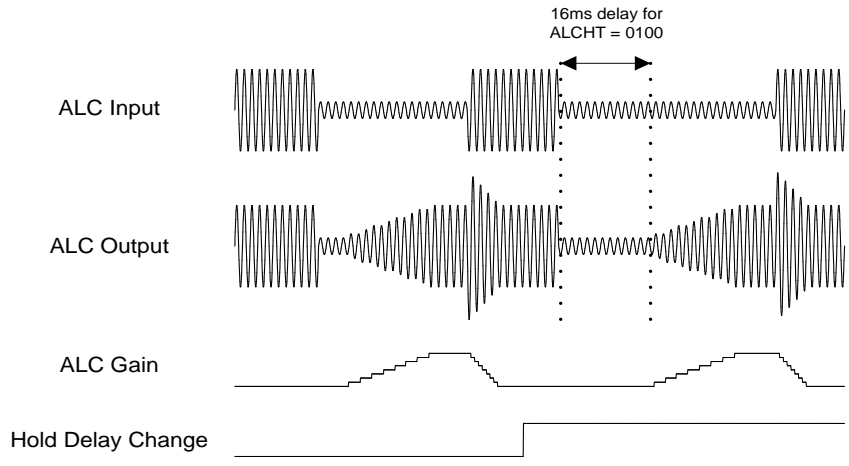


Figure 9 ALC using Hold time

7.12 Device Protection

The NAU8325 includes the following types of device protection:

- Over Current Protection (OCP)
- Under Voltage Lock Out (UVLO)
- Over Temperature Protection (OTP)
- Clock Termination Protection (CTP)

Over Current Protection is provided in the NAU8325. If a short circuit is detected on any of the pull-up or pull-down devices on the output drivers for at least 14 μ s, the output drivers will be disabled for 100ms. The output drivers will then be re-enabled and checked for a short circuit again. If the short circuit is still present for another 14 μ s, the cycle will repeat until the short circuit has been fixed. The short circuit threshold is set at 2.1A.

Under Voltage Lock Out (UVLO) provides Supply Under Voltage Protection in the NAU8325. If the SPK_VDD drops under 2.1V, the output drivers are disabled, however, the NAU8325 control circuitry will still operate. This is useful to help avoid the battery supply voltage dropping before the host processor can safely shutdown the devices on the system. If the SPK_VDD drops below 1.4V, the internal power-on-reset will activate and put the class-D driver in power down state.

Over Temperature Protection (OTP) is provided in the event of thermal overload. When the device internal junction temperature reaches 130°C, the NAU8325 will disable the output drivers. Once the device cools down to a safe operating temperature (115°C) for at least 100 μ s, the output drivers will be re-enabled.

Clock Termination Protection (CTP) is provided in the NAU8325. If the clock stops running, the NAU8325 automatically shuts down the Class-D driver if Clock Detection is enabled.

7.13 Power-up and Power-Down Control

When the supply voltage ramps up, the internal power on reset circuit is triggered. At this time, all internal circuits will be set to the power-down state. The device can be enabled by initializing the registers and starting the clocks. Upon starting the clocks, the device will go through an internal power-up sequence in order to minimize 'pops' on the speaker output. The complete power-up sequence requires about 14 msec. The device will power down in about 30 μ sec, when the clocks are stopped.

NOTE: It is important to keep the input signal at zero amplitude or enable the mute condition in order to minimize 'pops' when the clocks are stopped.

7.14 Bypass Capacitors

Bypass capacitors are required to remove the AC ripple on the VDD pins. The value of these capacitors depends on the length of the VDD trace. In most cases, 10 μ F and 0.1 μ F are sufficient to achieve good performance.

7.15 Printed Circuit Board Layout Considerations

Good Printed Circuit Board (PCB) layout and grounding techniques are essential to achieve good audio performance. It is better to use low-resistance traces as these devices are driving low impedance loads. The resistance of the traces has a significant effect on the output power delivered to the load. In order to dissipate more heat, use wide traces for the power and ground lines.

7.15.1 PCB Layout Notes

The Class-D Amplifier is a high power switching circuits that can cause Electro Magnetic Interference (EMI) when poorly connected. Therefore, care must be taken to design the PCB eliminate Electro Magnetic Interference (EMI), reduce IR drops, and maximize heat dissipation.

The following notes are provided to assist product design and enhance product performance:

- Use a GND plane, preferably on both sides, to shield clocks and reduce EMI
- Maximize the copper to the GND pins and have solid connections to the plane
- Planes on A_VDD, IO_VDD & SPK_VDD are optional
- The SPK_VDD connection needs to be a solid piece of copper
- Use thick copper options on the supply layers if cost permits
- Keep the speaker connections short and thick. Do not use VIAs
- Use a small speaker connector like a wire terminal block (Phoenix Contact)
- Keep the VREF capacitor close to the pin
- For better heat dissipation, use VIAs to conduct heat to the other side of the PCB
- Do not use VIA's to connect SPK_LP, SPK_LN, SPK_RP & SPK_RN to U1. Use a direct top layer copper connection to the pins. Thick copper is preferred.
- Use large or multiple parallel VIAs to decoupling capacitors when connecting to a ground plane
- The digital IO lines can be shielded between power planes

7.16 Filters

The NAU8325 is designed for use without any filter on the output line. However, the NAU8325 may be used with or without various types of filters, depending on the needs of the application.

7.16.1 Class D without Filters

The NAU8325 is designed for use without any filter on the output line. That means the outputs can be directly connected to the speaker in the simplest configuration. This type of filter-less design is suitable for portable applications where the speaker is very close to the amplifier. In other words, this is preferable in applications where the length of the traces between the speaker and amplifier is short. **Figure 10** illustrates this simple configuration.

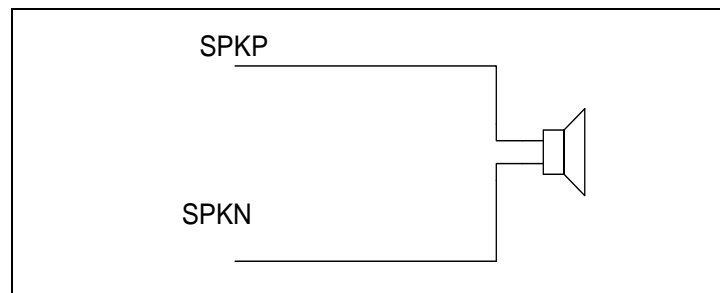


Figure 10 NAU8325 Speaker Connections without Filter

7.16.2 Class D with Filters

In some applications, shorter trace lengths are not possible because of speaker size limitations and other layout reasons. In these applications, long traces will cause EMI issues. Several types of filter circuits are available to reduce the EMI effects. These are Ferrite Bead Filters, LC filters, Low-Pass LCR Filters, and High-Pass Filters.

Ferrite Bead Filters are used to reduce high-frequency emissions. The characteristic of a Ferrite Bead Filter is such that it offers higher impedance at high frequencies. For better EMI performance, select a Ferrite Bead Filter which offers the highest impedance at high frequencies, so that it will attenuate the signals at higher frequencies. The typical circuit diagram using a Ferrite Bead Filter for each output to the speaker is shown **Figure 11**.

NOTE: Usually, the ferrite beads have low impedance in the audio range, so they will act as pass-through filters in the audio frequency range.

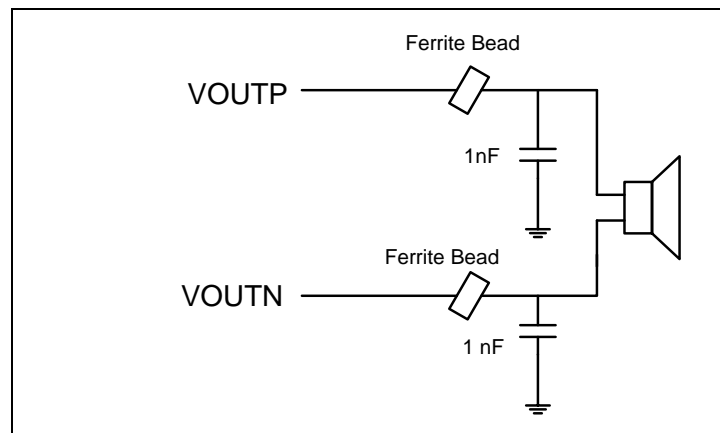


Figure 11 NAU8325 Speaker Connections with Ferrite Bead Filters

LC Filters are used to suppress low-frequency emissions. The diagram in **Figure 12** shows the NAU8325 outputs connected to the speaker with an LC Filter circuit. R_L is the resistance of the speaker coil.

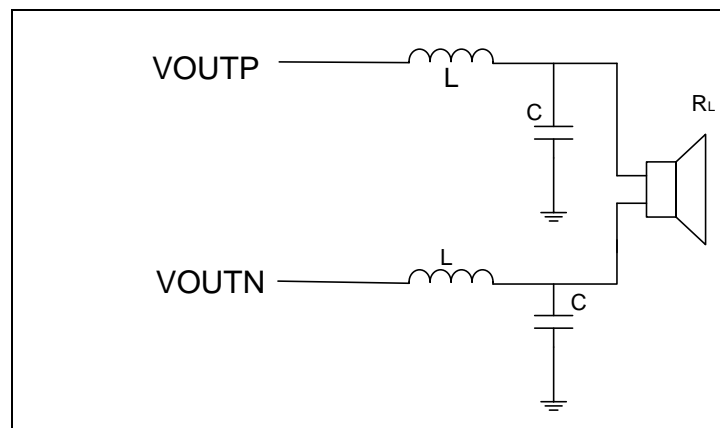


Figure 12 NAU8325 Speaker Connections with LC Filters

Low-Pass LCR Filters may also be useful in some applications where long traces or wires to the speakers are used. **Figure 13** shows the speaker connections using standard Low-Pass LCR Filters.

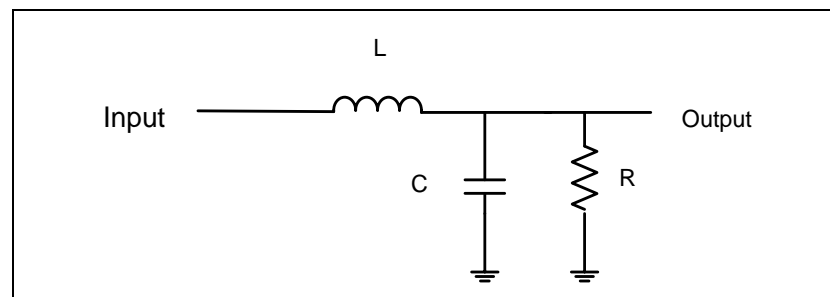


Figure 13 NAU8325 Speaker Connections with Low-Pass Filters

The following equations apply for critically damped ($\zeta = 0.707$) standard Low-Pass LCR Filters:

$$2\pi fc = \frac{1}{\sqrt{LC}} \quad fc \text{ is the cut-off frequency}$$

$$\zeta = 0.707 = \frac{1}{2R} * \sqrt{\frac{L}{C}}$$

NOTE: The L and C values for differential configuration can be calculated by duplicating the single-ended configuration values and substituting $RL = 2R$.

High-Pass Filters may also be useful in some applications. There is a High-Pass Filter for each DAC Channel. The High-Pass Filters may be enabled by setting **DAC_HPF_EN REG0X11[15]**. The High-Pass Filter has two operation modes that apply to both channels simultaneously. In the Audio Mode, the filter is a simple first-order DC blocking filter, with a cut-off frequency of 3.7 Hz. In the Application-Specific Mode, the filter is a second-order audio frequency filter, with a programmable cut-off frequency. The programmable filter mode may be enabled by setting **DAC_HPF_APP REG0X11[14]**.

Table 7 identifies the cut-off frequencies with different sample rates.

Table 7 High-Pass Filter Cut-Off Frequencies

HPFCUT	Sample Rate in KHz (FS)							
	REG_SRATE= 3'b000		REG_SRATE= 3'b001		REG_SRATE= 3'b010		REG_SRATE= 3'b011	
	8	12	16	24	32	48	64	96
000	87	130	87	130	87	130	87	130
001	103	155	103	155	103	155	103	155
010	132	198	132	198	132	198	132	198
011	165	248	165	248	165	248	165	248
100	207	311	207	311	207	311	207	311
101	265	398	265	398	265	398	265	398
110	335	503	335	503	335	503	335	503
111	409	614	409	614	409	614	409	614

8 Control and Status Registers

The NAU8325 includes an I2C Control Interface as well as an I2S/PCM Audio Interface. The following sections describe the Control and Audio Interfaces and registers.

8.1 Digital Control Interface

The NAU8325 uses a 2-wire I2C Interface for command and control. The I2C Slave address is 0x21.

The 2-wire bus is a bidirectional serial bus protocol. This protocol defines any device that sends data onto the bus as a transmitter (or master), and the receiving device as the receiver (or slave). The NAU8325 can function only as a slave device on the 2-wire interface.

8.1.1 2-Wire Protocol Convention

To initiate communication, all 2-Wire interface operations must begin with a START condition, which is a HIGH-to-LOW transition of SDA while SCL is HIGH.

Following a START condition, the master must output a device address byte consisting of a 7-bit device address, and a Read/Write control bit in the LSB of the address byte. To read from the slave device, the R/W bit must be set to 1. To initiate a write to the slave device, the R/W bit must be 0. If the device address matches the address of a slave device, the slave will output an acknowledgement bit.

An acknowledge (ACK), is a software convention used to indicate a successful data transfer. To allow for the ACK response, the transmitting device releases the SDA bus after transmitting eight bits and during the ninth clock cycle, the receiver (slave) pulls the SDA line LOW to acknowledge the reception of the eight bits of data.

To terminate a read/write session, all 2-Wire interface operations must end with a STOP condition, which is a LOW to HIGH transition of SDA while SCL is HIGH. A STOP condition at the end of a read or write operation places the device in a standby mode.

Application Notes:

- The NAU8325 is permanently programmed with 0x21 “0100001” as the Device Address.

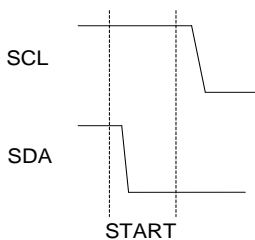


Figure 14 Valid START Condition

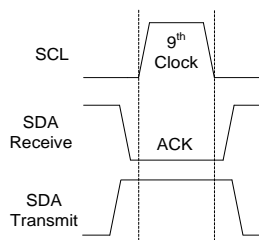


Figure 15 Valid Acknowledge

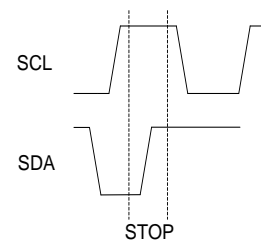


Figure 16 Valid STOP Condition

8.1.2 2-Wire Write Operation

A Write operation consists of a three-byte instruction followed by one or more data bytes as seen in Figure 17. These instructions consist of the Address byte and two Control Address bytes that precede the START condition and are followed by the STOP condition. Figure 18 shows the data bus and the corresponding clock cycles.

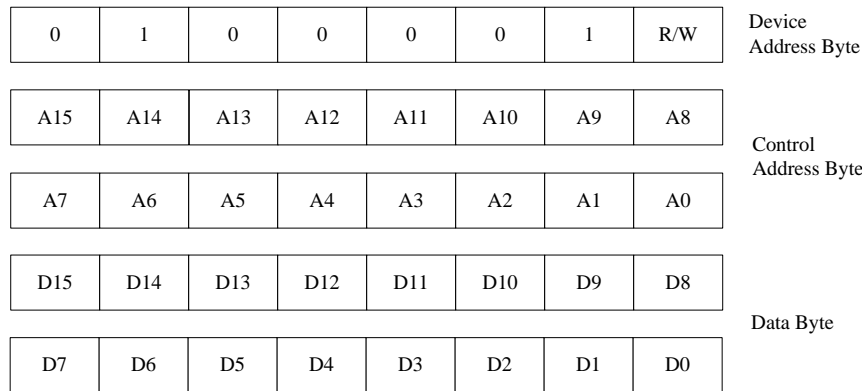


Figure 17 Slave Address Byte, Control Address Byte, and Data Byte

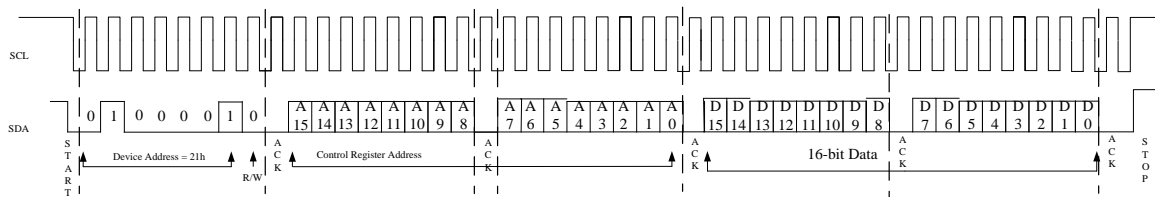


Figure 18 2-Wire Write Sequence

8.1.3 2-Wire Read Operation

A Read operation consists of the three-byte Write instruction followed by a Read instruction of one or more data bytes. The bus master initiates the operation issuing the following sequence: a START condition, Device Address byte with the R/W bit set to “0”, and a Control Register Address byte. This indicates to the NAU8325 which of its control registers is going to be accessed.

After this, the NAU8325 will respond with an ACK as it accepts the Control Register Address that the master is transmitting to it. After the Control Register Address has been sent, the master will send a second START condition and Device address but with R/W = 1.

After the NAU8325 recognizes its Device Address the second time, it will transmit an ACK followed by a two byte value containing the 16 bits of data in the NAU8325 control registers requested by the master. During this phase, the master generates an ACK with each byte of data transferred.

After the two bytes have been transmitted, the master will send a STOP condition ending the read phase. If no STOP condition is received, the NAU8325 will automatically increment the target Control Register Address and then start sending the two bytes of data for the next register in the sequence. This will continue as long as the master continues to send ACK signals. Once the target register reaches 0xFFFF, it will send the associated data then roll over to 0x0000 and continue as before.

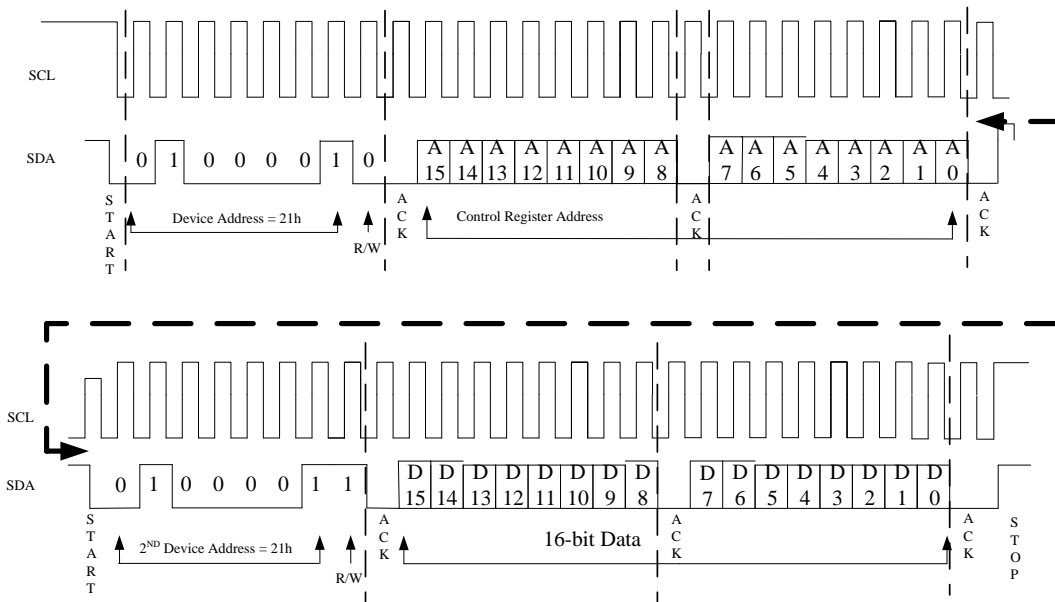


Figure 19 2-Wire Read Sequence

8.2 Digital Audio Interface

The NAU8325 is an I2S slave device. In Slave Mode, an external controller supplies BCK (bit clock) and LRCK (the frame synchronization or FS signal). Data is latched on the rising edge of BCK.

The NAU8325 has two DAC channels.

The NAU8325 supports five port data lengths: 8, 16, 20, 24, and 32 bits by setting **I2S_PCM_CTRL1 WLEN0 REG0XD[4:2]** The chip also supports 8-bit word length for Companding Mode operation by setting **I2S_PCM_CTRL1 CMB8_0 REG0XD** to 1.

The NAU8325 supports audio formats: I2S, Right Justified, Left Justified, TDM I2S, TDM Left Justified, PCM A, PCM B, PCM Offset, and PCM Time Slot.

When operated in the TDM I2S or TDM Left Justified mode and in all PCM modes, the NAU8325 supports 8-channel data transmission on DAC path simultaneously. **TDM_CTRL TDM REG0XC[15]** should be set = 1 if using TDM I2S or TDM Left Justified modes.

Table 8 Digital Audio Interface Mode Settings

PCM Mode	I2S_PCM_CTRL1 AIFMT0 REG0XD[1:0]	I2S_PCM_CTRL1 LRP0 REG0XD[6]	I2S_PCM_CTRL2 PCM_TS_EN0 REG0XE[10]	TDM_CTRL PCM_OFFSET MODE_CTRL REG0XC[14]
Right Justified	00	0	0	0
Left Justified	01	0	0	0
I2S	10	0	0	0
PCM A	11	0	0	0
PCM B	11	1	0	0
PCM Offset	11	Don't care	0	1

PCM Mode	I2S_PCM_CTRL1 AIFMT0 REG0XD[1:0]	I2S_PCM_CTRL1 LRP0 REG0XD[6]	I2S_PCM_CTRL2 PCM_TS_EN0 REG0XE[10]	TDM_CTRL PCM_OFFSET MODE_CTRL REG0XC[14]
PCM Time Slot	11	Don't care	1	0

8.2.1 Right-Justified Audio Data

In Right-Justified Mode, the LSB is clocked on the last BCLK rising edge before the FS transitions. When FS is HIGH, Channel 0 data is transmitted; when FS is LOW, Channel 1 data is transmitted. This can be seen in **Figure 20**.

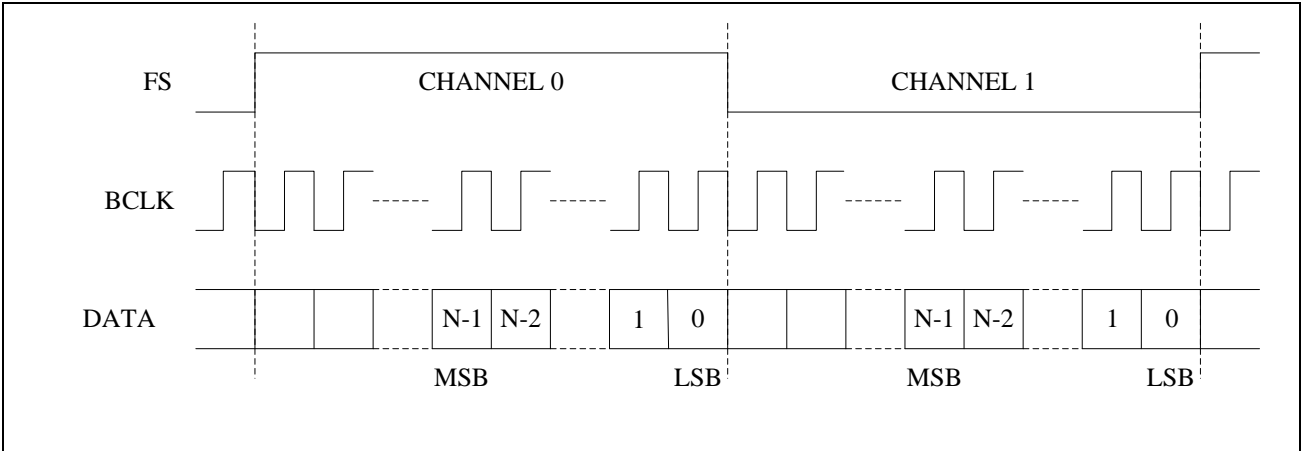


Figure 20 Right-Justified Audio Data

8.2.2 Left-Justified Audio Data

In Left-Justified Mode, the MSB is clocked on the first BCLK rising edge after the FS transitions. When FS is HIGH, Channel 0 data is transmitted; when FS is LOW, Channel 1 data is transmitted. This can be seen in **Figure 21**.

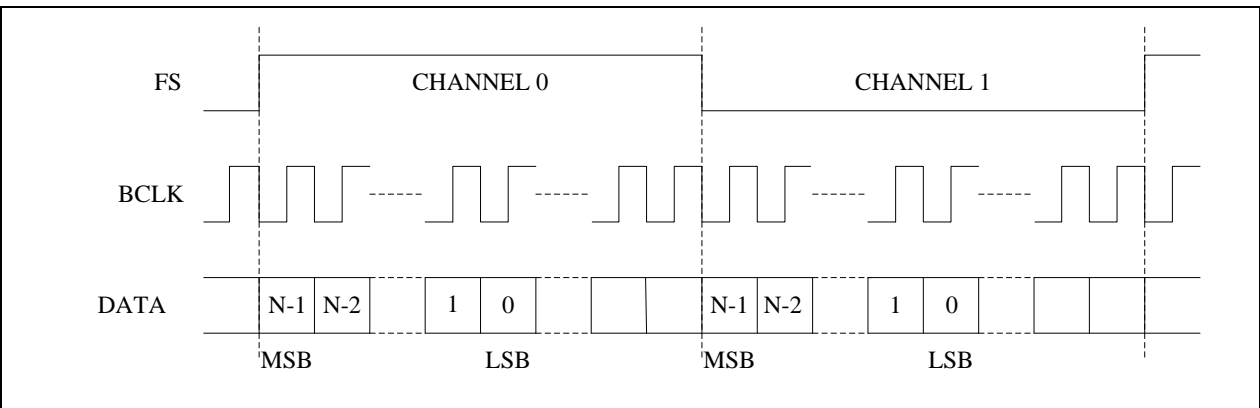


Figure 21 Left-Justified Audio Data

8.2.3 I2S Audio Data

In I2S Mode, the MSB is clocked on the second BCLK rising edge after the FS transitions. When FS is LOW, Left Channel data is transmitted; when FS is HIGH, Right Channel data is transmitted. This can be seen in **Figure 22**.

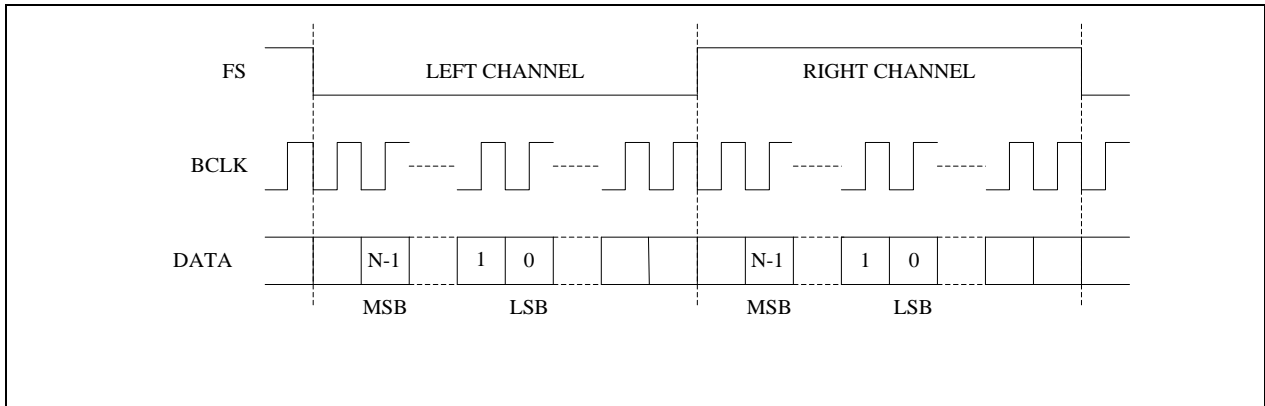


Figure 22 I2S Audio Data

8.2.4 TDM Left-Justified Audio Data

In TDM Left-Justified Mode, the MSB is clocked on the first BCLK rising edge after the FS transitions. When FS is LOW, Channel 1 data is transmitted, then Channel 3, 5, and 7 data are transmitted; when FS is HIGH, Channel 0 data is transmitted, then Channel 2, 4, and 6 data are transmitted. This is shown in **Figure 23**.

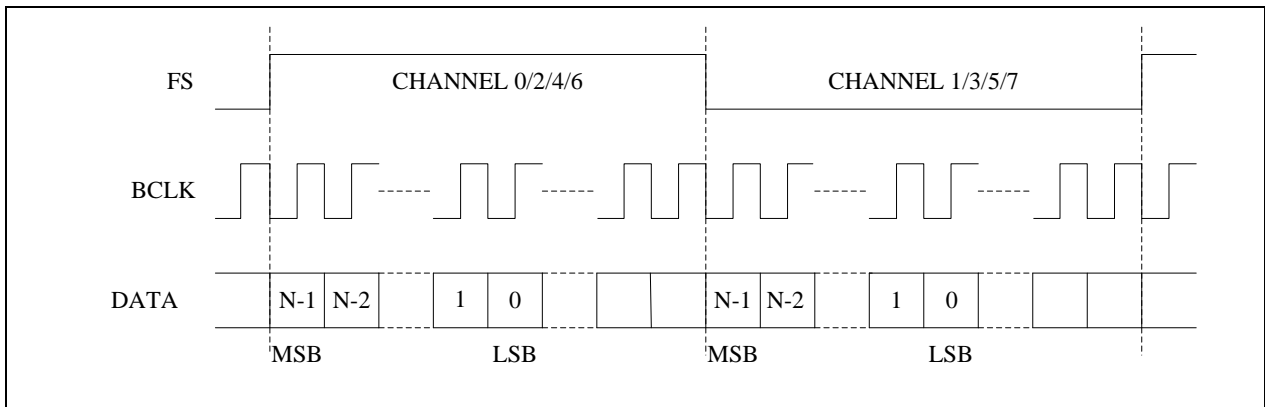


Figure 23 TDM Left-Justified Audio Data

8.2.5 TDM I2S Audio Data

In I2S Mode, the MSB is clocked on the second BCLK rising edge after the FS transitions. When FS is LOW, Channel 0 data is transmitted, then Channel 2, 4, and 6 data are transmitted; when FS is HIGH, Channel 1 data is transmitted, then Channel 3, 5, and 7 data are transmitted. This is shown in **Figure 24**.

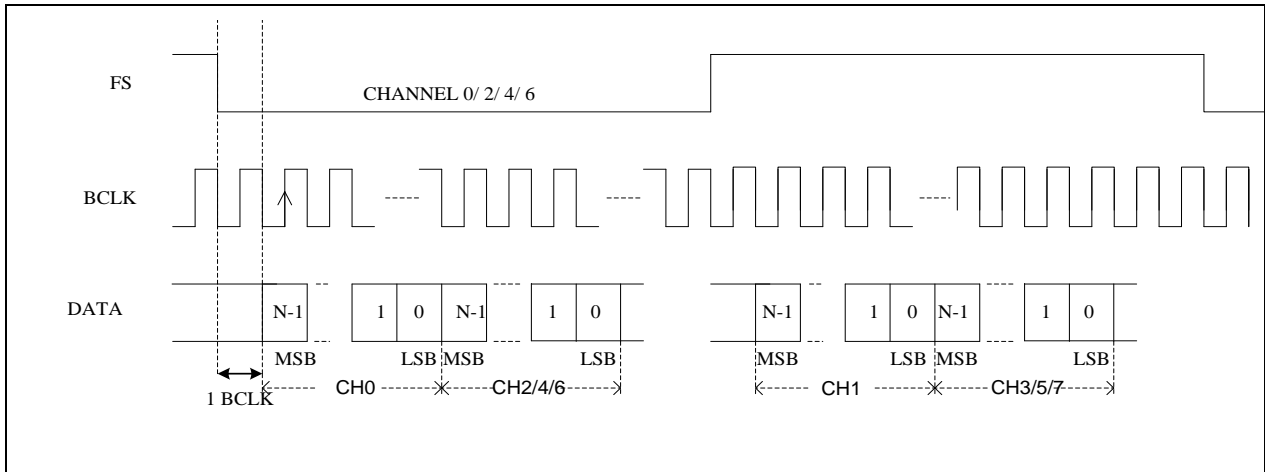


Figure 24 TDM I2S Audio Data

8.2.6 PCM A Audio Data

In PCM A Mode, Channel 0 data is transmitted first, followed sequentially by Channel 1, 2, and 3, 4, 5, 6, and 7 data immediately after. The Channel 0 MSB is clocked on the second BCLK rising edge after the FS pulse rising edge, and the subsequent channel's MSB is clocked on the next BCLK after the previous channel's LSB. This is shown in Figure 25.

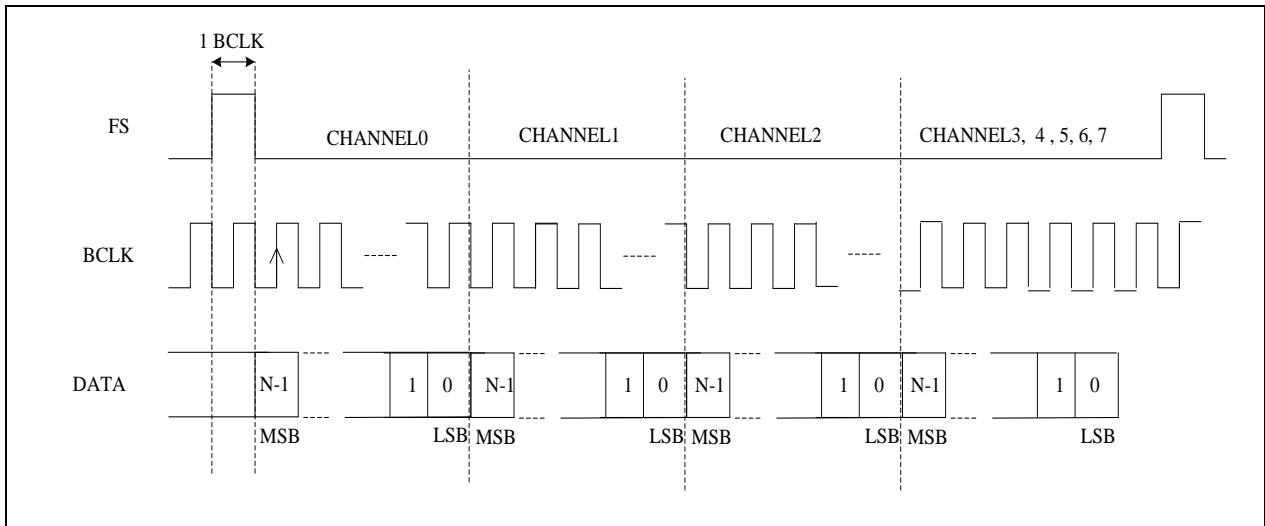


Figure 25 PCM A Audio Data

8.2.7 PCM B Audio Data

In PCM B Mode, Channel 0 data is transmitted first, followed immediately by Channel 1, 2, and 3, 4, 5, 6, and 7 data immediately after. The Channel 0 MSB is clocked on the first BCLK rising edge after the FS pulse rising edge, and the Channel 1 MSB is clocked on the next BCLK after the Channel 0 LSB. This is shown in Figure 26.

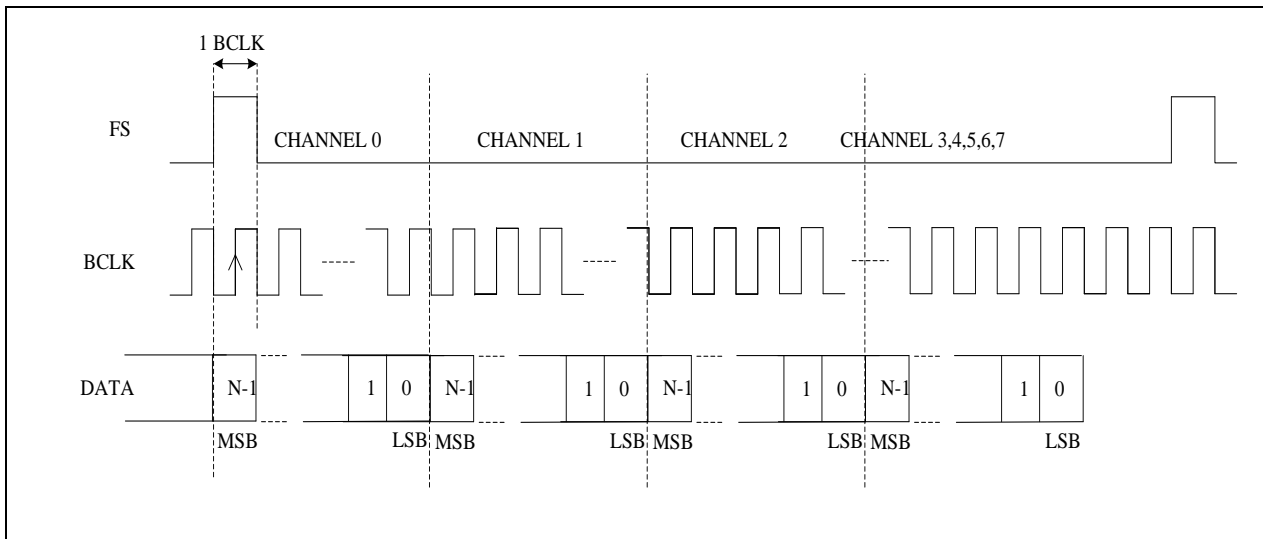


Figure 26 PCM B Audio Data

8.2.8 PCM Time Slot Audio Data

PCM Time Slot Mode is used to delay the time at which the DAC data is clocked into the device. This can be useful when multiple NAU8325 chips or other devices share the same audio bus. This will allow the audio from the chips to be delayed around each other without interference.

Normally, the DAC data is clocked immediately after the Frame Sync (FS); however, in PCM Time Slot Mode, the audio data can be delayed by setting **LEFT_TIME_SLOT TSLOT_L0 REG0XF[9:0]** and **RIGHT_TIME_SLOT TSLOT_R0 REG0X10[9:0]** for the left and right channels, respectively. **I2S_PCM_CTRL2 PCM_TS_EN0 REG0XE[10]** needs to be set to 1. These delays can be seen before the MSB in **Figure 27**.

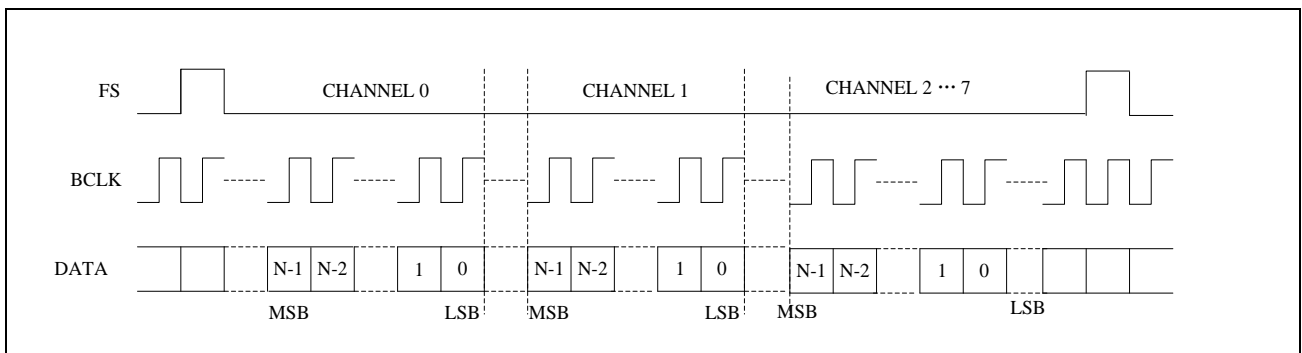


Figure 27 PCM Time Slot Audio Data

8.2.9 PCM Time Offset Audio Data

PCM Time Offset Mode is used to delay the time at which the DAC data are clocked. This increases the flexibility of the NAU8325 for use in a wide range of system designs. One key application of this feature is to enable multiple NAU8325 chips or other devices to share the audio data bus, thus enabling more than four channels of audio. This feature may also be used to swap channel data, or to cause multiple channels to use the same data. **TDM_CTRL PCM_OFFSET_MODE_CTRL REG0XC[14]** must be set to 1 for this application.

Normally, the DAC data is clocked immediately after the Frame Sync (FS). In this mode, audio data is delayed by a delay count specified in the device control registers. The Channel 0 MSB is clocked on the BCLK rising edge defined by the delay count set in **LEFT_TIME_SLOT TSLOT_L0 REG0XF[9:0]**. The

subsequent channel's MSB is clocked on the next BCLK after the LSB of the previous channel. This can be seen in **Figure 28**.

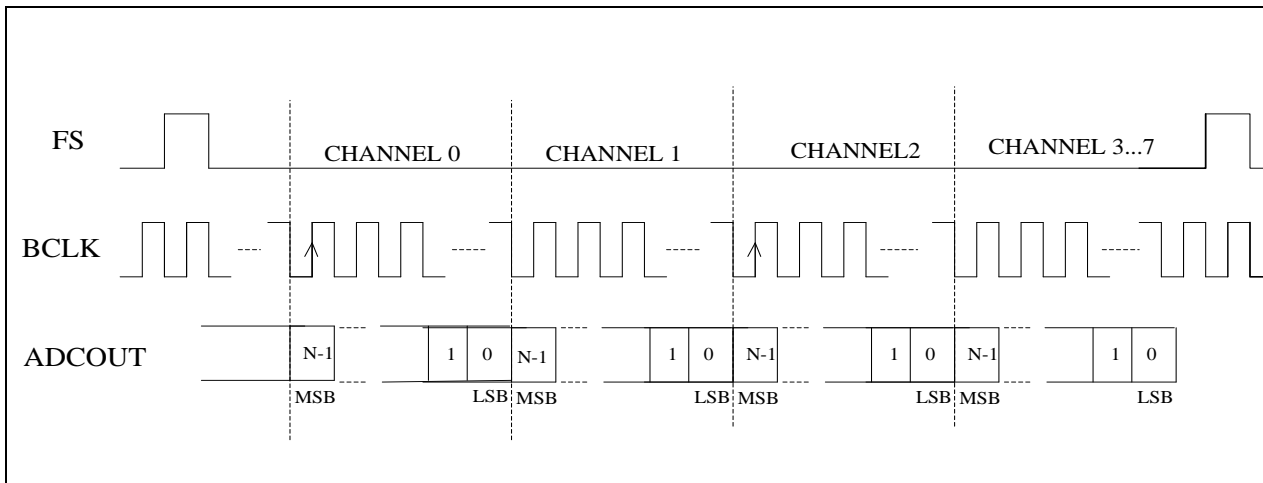


Figure 28 PCM Time Offset Audio Data

Table 9 Digital Audio Interface Timing Parameter
BCLK=3.072MHz, Fs=48KHz, 64Bit, VDD 2.5 -5.25V, Room Temperature

Description	Symbol	Min	Typ	Max	Unit
BCLK Cycle Time (Slave Mode)	T _{BCK}	35	---	---	ns
BCLK High Pulse Width (Slave Mode)	T _{BCKH}	20	---	---	ns
BCLK Low Pulse Width (Slave Mode)	T _{BCKL}	50	---	---	ns
Fs to CLK Rising Edge Setup Time (Slave Mode)	T _{FSS}	20	---	---	ns
BCLK Rising Edge to Fs Hold Time (Slave Mode)	T _{FSH}	40	---	---	ns
Rise Time for All Audio Interface Signals	T _{RISE}	---	---	TBD	ns
Fall Time for All Audio Interface Signals	T _{FALL}	---	---	TBD	ns
ADCIN to BCLK Rising Edge Setup Time	T _{DIS}	15	---	---	ns
BCLK Rising Edge to DACIN Hold Time	T _{DIH}	15	---	---	ns
Delay Time from SCLK Falling Edge to ADCOUT	T _{DOD}	---	---	TBD	ns

8.3 Control Registers

provides detailed information for the NAU8325 Control Registers. Note that all registers marked as 'Reserved' should not be overwritten, unless it is requested to do so by Nuvoton Technology Corporation.

Table 10 Control Registers

#	Function	Name	Bit																Description
			5	4	3	2	1	0	9	8	7	6	5	4	3	2	1	0	
0	HARDWARE_RST	RESET_N1																Hardware Reset Write once to reset all the registers.	
1	SOFTWARE_RST	RESET_N_SOFT_PRE																Software Reset Write twice to reset all internal states without resetting the config registers.	
2	DEVICE_ID	I2C_DEVICE_ID																I2C Slave Address	
		REG_SI_REV																Silicon revision	
		Default	0	0	1	0	0	0	0	1	1	1	1	1	0	0	1	0	0x21F2 Read Only
3	CLK_CTRL	CLK_DAC_INV																DAC Clock Inversion in Analog Domain 1 = Enable 0 = Disable	

#	Function	Name	Bit																Description
			15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
		CLK_DAC_SRC																Scaling for DAC Clock from MCLK 00 = 1 01 = 1/2 10 = 1/4 11 = 1/8	
		CLK_MUL_SRC (N1)																Select the reference clock for internal clock multiplier Input: MCLK input pin; Output: MCLK_S1 00 = MCLK input pin 01 = MCLK input pin/2 10 = MCLK input pin/3 11 = off	
		MCLK_SEL (N3)																Select a clock from outputs of clock multiplier Output: MCLK_S2 000 = MCLK input PIN 001 = MCLK_S1 010 = 2*MCLK_S1 011 = 4*MCLK_S1** 100 = 8*MCLK_S1** 11x = MCLK off ** Requires Reg 0x65 to be set to enable 4x & 8x multipliers When the clock multiplier is used, it is recommended to set N1 to '10' or '01' to reduce jitter and duty cycle sensitivity. It is also recommended to use a DAC_RATE of 64 or 100 when the clock multiplier is used	
		MCLK_SRC (N2)																Scaling MCLK_S2 for system MCLK Input: MCLK_S2; Output: MCLK_SRC 000: MCLK_S2 001: MCLK_S2/2 010: MCLK_S2/4 011: MCLK_S2/8 100: MCLK input pin	
		Default	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0x0000
4	ENA_CTRL	DACEN_L															DAC Left Channel Enable 1 = ON 0 = OFF		
		DACEN_R															DAC Right Channel Enable 1 = ON 0 = OFF		
		Default	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0x0000	
5	INTERRUPT MASK	OCP_OR_OTP_SHTDWN1_INTP_MASK															OCP/OTP Shutdown Interrupt Mask (Over Current/Over Temperature Shutdown) 1 = Mask the Interrupt 0 = Unmask		
		CLIP_INTP_MASK															Clip Interrupt Mask 1 = Mask the Interrupt 0 = Unmask		
		LOVDDDET_INTP_MASK															Low Voltage Detection Interrupt Mask 1 = Mask the Interrupt 0 = Unmask		
		PWRUPEN_INTP_MASK															Power Up Interrupt mask 1 = Mask the Interrupt 0 = Unmask		
		OCP_OR_OTP_SHTDWN1_INT_DIS															OCP/OTP Shutdown Interrupt Disable 1 = Disable 0 = Enable		
		CLIP_INT_DIS															Clip Interrupt Disable 1 = Disable 0 = Enable		
		LOVDDDETB_INT_DIS															Low Voltage Detection Interrupt Disable 1 = Disable 0 = Enable		
		PWRUPEN_INT_DIS															Power Up Interrupt Disable 1 = Disable 0 = Enable		

#	Function	Name	Bit																Description
			15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
		Default	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0x007f
6	INT_CLR_STATUS	INT_CLR_STATUS																Interrupt Clear Status <u>Write Operation:</u> Write bits [6:0] 1s to clear the corresponding Interrupt Status. <u>Read Operation:</u> REG6 [6:0] --- RD_INT_STATUS Bit4 = Over Current/Over Temperature Shutdown Bit3 = Clip Bit2 = Low Voltage Detection Bit0 = Power Up	
		Default	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Read/Write
9	IRQOUT	IRQoutSEL																IRQ Output Function Select 0000 = IRQ (default) 0001 = SDB 0010 = OSC_CLK 0011 = MUTEB 0100 = SHUTDWNDVRR 0101 = PWRDOWN1B_D 0110 = PDOSCB 0111 = TMTALARM 1000 = SHUTDWNDVRL 1001 = MCLK 1010 = MCLKDET 1011 = TALARM 1100 = SHORTL 1101 = SHORTR 1110 = PWRUPEN 1111 = TMDT	
		DEM_DITH																Dither on SD integrator feedback 1 = 2x dither level (recommended setting)	
		GAINZI3																Gain of CRFB 3 rd integrator. Leave 0.	
		GAINZI2																Gain of O3 CRFB 2 nd integrator. Leave 0x000	
		Default	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0x0000 (Recommended 0x0080)
A	IO_CTRL	IRQ_PL																Default IRQ Logic 1 = Active High 0 = Active Low	
		IRQ_PS																IRQ Pin Pull Select 0 = Pull Down 1 = Pull Up	
		IRQ_PE																IRQ Pin Pull Enable 1 = Enable 0 = Disable	
		IRQ_DS																IRQ Current Drive Select 1 = High 0 = Low	
		IRQ_OE																IRQ Output Enable 1 = Enable 0 = Disable	
		IRQ_PIN_DEBUG_MODE																1: Enabled the test function that output the specific signal using IRQoutSEL to the IRQ pin 0: Disable this test function	
		BCLK_DS																Reserved. Keep at 0	
		LRC_DS																Reserved. Keep at 0	
Default	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0x0000		

#	Function	Name	Bit																Description
			15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
		DACEN_SM																	DACEN Soft Mute 1= enables DAC volume ramping up of a channel on a rising edge of when it is turned on.
		Reserved																	
		DAC_ZC_EN																	DAC Zero Crossing Enable
		UNMUTE_CTL																	Power-up soft unmute control x0: No soft digital unmute on PWRUPEN and MUTE_B events 01:512 MCLK per step soft unmute 11: 32 MCLK per step soft unmute
		ANA_MUTE																	Analog MUTE time on power up. 00: ~430us 01: ~860us 10: ~1.7ms 11: ~4ms
		AUTO_MUTE																	AUTO_MUTE 0: Enable Mute driver after detection of 2048 zero samples. 1: disables AUTO_MUTE function.
		Default	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0x2000	
13	DAC_VOLUME	DAC_VOLUME_R																DAC Right Channel Volume Control Expressed as gain or attenuation in 0.5 dB steps 0xff = +6 dB 0xfe = +5.5 dB 0xfd = +5dB ▼ 0xf3 = 0dB ▼ 0x53 = -80 dB 0x52 = Reserved ▼ 0x01 = Reserved 0x00 = Mute	
		DAC_VOLUME_L																DAC Left Channel Volume Control Expressed as gain or attenuation in 0.5 dB steps 0xff = +6 dB 0xfe = +5.5 dB 0xfd = +5dB ▼ 0xf3 = 0dB ▼ 0x53 = -80 dB 0x52 = Reserved ▼ 0x01 = Reserved 0x00 = Mute	
		Default	1	1	1	1	0	0	1	1	1	1	1	1	0	0	1	1	0xf3f3
1D	Debug Read 1	Reserved																Reserved	
		OSR100																	Reads '1' when OSR=100x
		MIPS500																	Indicates '1' when MCLK_SRC/FS=500
		SHUTDWND_RVRR																	
		SHUTDWND_RVRL																	
		MUTE_B																	
		PDOSCB																	

#	Function	Name	Bit																Description	
			5	4	3	2	1	0	9	8	7	6	5	4	3	2	1	0		
		Default	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1001 = 512.00 msec 1010 - 1111 = 1000.00 msec 0x8400
2E	ALC_CTRL3	ALC_EN																		ALC Enable 0 = ALC/Limiter disabled (fixed gain) 1 = ALC/Limiter enabled
		Reserved																		Reserved, keep at '0'
	Reserved																			Reserved, keep at '0'
		Default	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0x0000
2F	ALC_CTRL4	DRVRPWR																		Class-D Driver Power Control Test '0' (default) uses low power at low output levels '1' uses full power at low output levels
		LPGAZC																		Channel Input Zero Cross Detection Enable 0 = Gain changes to PGA register happen immediately (default) 1 = Gain changes to PGA happen pending zero crossing logic
		CLIP_GAINADJUST																		Maximum Gain Adjustment during any clipping event 000 = (default) no adjustment 001 = 0.5dB (2 steps) 010 = 1dB (4 steps) 011 = 2dB (8 steps) 100 = 3dB (12 steps) 101 = 4dB (16 steps) 110 = 5dB (20 steps) 111 = 6dB (24 steps)
		Reserved																		Reserved, keep at '0'
		LPGAGAIN																		Channel Input PGA Volume Control Setting becomes active when allowed by zero crossing and/or update bit features. 00 0000 = -15.75 dB 00 0001 = -15.5 dB ▼ Volume increases in 0.25 dB steps 10 0000 = 0.0dB default setting ▼ 11 1110 = -0.25 dB 11 1111 = 0 dB
		Default	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0x003f
40	CLK_DET_CTRL	REG_APWRUPEN																		Power Up Enable 1 = Clock detection will require non-zero samples in order to enable to output power-up signal. 0 = DAC data does not gate power up signal.
		REG_CLKPWRUPEN																		Clock Detection Module Enable 1 = Disable 0 = Enable
		REG_PWRUP_DFT																		When the Clock Detection Module is disabled, this is the default value for the PWRUPEN

#	Function	Name	Bit																Description
			15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
57	Reserved																	Reserved	
60	BIAS_ADJ	TESTDAC																DAC Test only	
		VMID_SEL																VMIDEN Tie-Off Selection Options 00 = Open (default) 01 = 25 kOhm 10 = 125 kOhm 11 = 2.5 kOhm	
		BIASADJ																PGA Master Bias Current Power Options 00 = normal operation (default) 01 = 9% reduced bias current from default 10 = 17% reduced bias current from default 11 = 11% increased bias current from default	
		Default	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0x0000
61	ANALOG_CONTROL_1	VMIDEN															VMIDEN Reference Enable 00 = VMID reference disabled 01 = VMID reference enable gated by PWRUPEN signal 10 = VMID reference disabled 11 = VMID reference enabled		
		BIASEN															Current BIAS Reference Enable 00 = BIAS reference disabled 01 = BIAS reference enable gated by PWRUPEN signal 10 = BIAS reference disabled 11 = BIAS reference enabled		
		DACEN_Left															Left Channel DAC Enable 00 = DAC disabled 01 = DAC enable gated by PWRUPEN signal 10 = DAC disabled 11 = DAC enabled		
		DACCLKEN_Left															Left Channel DAC Clock Enable 00 = DAC Clock disabled 01 = DAC Clock enable gated by PWRUPEN signal 10 = DAC Clock disabled 11 = DAC Clock enabled		
		DACEN_Right															Right Channel DAC Enable 00 = DAC disabled 01 = DAC enable gated by PWRUPEN signal 10 = DAC disabled 11 = DAC enabled		
		DACCLKEN_Right															Right Channel DAC Clock Enable 00 = DAC Clock disabled 01 = DAC Clock enable gated by PWRUPEN signal 10 = DAC Clock disabled 11 = DAC Clock enabled		
		CLASSDEN															CLASS-D Enable 00 = CLASS-D disabled 01 = CLASS-D enable gated by PWRUPEN signal 10 = CLASS-D disabled 11 = CLASS-D enabled		

#	Function	Name	Bit																Description
			15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
		VMDFASTENB																VMIDEN Reference Fast Power Up Circuit Disable 00 = VMIDEN reference fast power up circuit enabled with VMID reference enable 01 = VMIDEN reference fast power up circuit disabled with Class-D enable 10 = VMIDEN reference fast power up circuit enabled with VMID reference enable 11 = VMIDEN reference fast power up circuit disabled	
		Default	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0x0000	
62	ANALOG_CONTROL_2	DACREFCAP																DAC Reference Voltage Decoupling Capacitors 00 = 0 Capacitors 01 = 1 Capacitor 10 = 2 Capacitors 11 = 3 Capacitors Leave default.	
		DACTEST																DAC Test DC Input. Requires TESTDAC (Reg0x60) to be 1 00 = 0 V 01 = + Full Scale 10 = - Full Scale 11 = 0 V	
		PWMMOD																PWM Modulation Selection 0 = BDM Modulation 1 = Ternary Modulation	
		Default	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0x0000
63	ANALOG_CONTROL_3	GAIN_C															Class-D Coarse GAIN Sets the Class-D amplifier coarse gain '00001' = 0 dB '00010' = 6 dB '00100' = 12 dB '01000' = 17 dB '10000' = 22 dB $V_{out,pk} = V_{dcref} \times (300 / (6 + 0x63[0] \times 300 + 0x63[1] \times 150 + 0x63[2] \times 75 + 0x63[3] \times 37.5 + 0x63[4] \times 18.75))$, where V_{dcref} is set in register 0x73 $V_{out,pk} = 0.98 \times V_{dcref}$ at 0dB gain		

#	Function	Name	Bit													Description			
			15	14	13	12	11	10	9	8	7	6	5	4	3		2	1	0
		GAIN_F																	Class-D Fine GAIN adjust 0x63[6:0] Gain (dB) '1100001' -6.9 '1000001' -4.7 '0100001' -2.4 '0000001' 0.0 '1100010' -0.5 '1000010' 1.5 '0100010' 3.6 '0000010' 5.8 '1100100' 6.1 '1000100' 7.9 '0100100' 9.8 '0000100' 11.6 '1101000' 13.7 '1001000' 14.8 '0101000' 16.0 '0001000' 17.0 '0010000' 21.9 '1111111' = mute
		PD_R																	Reserved Right Channel Power down. 1=power down Right Channel. Should only be set in initialization to avoid pops.
		PD_L																	Left Channel Power down. 1=power down Left Channel. Should only be set in initialization to avoid pops.
																			Reserved
		Default	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	ANALOG_CONTROL_4	CLASSD SLEW																Class-D Driver Slew Rate Adjustment 00000000: Nominal Bit0=1: +25% for low signal levels Bit1=1: +25% for low signal levels Bit2=1: -25% for low signal levels Bit3=1: -25% for low signal levels Bit4=1: -25% for all signal levels Bit5=1: -25% for all signal levels Bit6=1: +25% for all signal levels Bit7=1: +25% for all signal levels	
		CLASSD OCPP																Class-D P-Driver Short Circuit Threshold Adjustment Leave at 0000	
		CLASSD OCPN																Class-D N-Driver Short Circuit Threshold Adjustment Leave at 0000	
		Default	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0x0000
65	ANALOG_CONTROL_5	MCLK4XEN																4x MCLK Enable. 1 = 4x MCLK Multiplier enabled 0 = 4x MCLK Multiplier disabled	
		MCLK8XEN																8x MCLK Enable. 1 = 8x MCLK Multiplier enabled (Requires 0x65[0] to be set to '1') 0 = 8x MCLK Multiplier disabled	
		MCLK_Range																Extend Clock Multiplier Input Range '0' = default range '1' = 2 x longer period (lower frequencies) Must be set to '1' if 8xMCLK is used	
		Reserved																Reserved	
		Default	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0x0000

#	Function	Name	Bit																Description
			15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
66	ANALOG_CONTROL_6																	VDDSPK Clip Limiter Threshold. VBATLOW='1' when VDDSPK goes below: '000' = 4.1V '001' = 3.9V '010' = 3.7V '011' = 3.5V '100' = 3.3V '101' = 3.1V '110' = 2.9V '111' = 2.7V	
																		VDDSPK Limiter Threshold Enable Enables comparator with threshold set in VBATTHRES 0 = Disable 1 = Enable	
																		Sets VBATLOW when VBATTHREN is disabled (VBATTHREN = '0') 0 = VBATLOW = '0' 1 = VBATLOW = '1'	
																		Reserved	
		Default	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0x0000
69	CLIP_CTRL	ANTI_CLIP_ENABLE															Clip Function Enable 1 = Enable Clip detection 0 = Disable Clip detection		
		Default	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0x0000	
71	Reserved	Reserved															Reserved		
73	RDAC	Reserved															Reserved		
		Reserved															Reserved		
		CLK_DAC_DELAY															DAC Clock Delay Setting DAC clock delay setting (010 suggested value) 000 delay 0 nsec 100 delay 4 nsec 001 delay 1 nsec 101 delay -3 nsec 010 delay 2nsec 110 delay -2 nsec 011 delay 3 nsec 111 delay -1 nsec		
		DACVREFSEL															DAC Reference Voltage Setting. Can be used for minor tuning of the output level. 0 0 VDDA (unregulated) 0 1 VDDA x 1.5/1.8 V 1 0 default: VDDA x 1.6/1.8 V 1 1 VDDA x 1.7/1.8 V		
Default	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0x0008			

9 Electrical Characteristics

The tables in this chapter provide the various electrical parameters for the NAU8325 and their values.

9.1 Absolute Maximum Ratings

Parameter	Min	Max	Units
IO_VDD Digital I/O Supply Range	-0.3	4.0	V
SPK_VDD Battery Supply Range	-0.3	6.0	V
A_VDD Analog Supply Range	-0.3	2.2	V
Voltage Input Analog Range	A_GND - 0.3	A_VDD + 0.3	V
Voltage Input I/O Range	IO_GND - 0.3	IO_VDD + 0.3	V
Junction Temperature, T _J	-40	+150	°C
Storage Temperature	-65	+150	°C

CAUTION: Do not operate at or near the maximum ratings listed for extended periods of time. Exposure to such conditions may adversely influence product reliability and result in failures not covered by the warranty.

9.2 Operating Conditions

Recommended Operating Conditions

Condition	Symbol	Min	Typical	Max	Units
Battery Supply Range	SPK_VDD	2.50	4.2	5.50	V
Analog Supply Range	A_VDD	1.62	1.8	1.98	V
Digital I/O Supply Range	IO_VDD	1.62	3.0	3.6	V
Ground	A_GND/IO_GND		0		V
Industrial Operating Temperature		-40		+85	°C

CAUTION: The following conditions needed to be followed for regular operation: SPK_VDD > A_VDD - 1.2V; IO_VDD > A_VDD - 0.6V.

9.3 Electrical Parameters

Conditions: A_VDD = IO_VDD = 1.8V; SPK_VDD= 4.2V. R_L = 8 Ω + 33 μH, f = 1kHz, 48kHz sample rate, MCLK=12.288MHz, unless otherwise specified. Limits apply for T_A = 25°C

Symbol	Parameter	Conditions	Typical	Limit	Units
ISD	Shutdown Supply Current	A_VDD, all clocks off	2.0	10	μA
		IO_VDD, all clocks off	0.1	2	
		SPK_VDD, all clocks off	0.2	4	
ISB	Standby Mode Supply Current	A_VDD, clocks off, clock gating on	2.0		μA
		IO_VDD, clocks off, clock gating on	0.1		μA
		SPK_VDD, clocks off, clock gating on	0.2		μA

Symbol	Parameter	Conditions	Typical	Limit	Units
IDD	Operating Mode Supply Current (stereo operation)	A_VDD, idle Channel	3.8		mA
		IO_VDD, idle Channel	0.1		mA
		SPK_VDD, idle Channel	2.8		mA
IDDm	Operating Mode Supply Current (mono operation)	A_VDD, idle Channel	3.0		mA
		IO_VDD, idle Channel	0.1		mA
		SPK_VDD, idle Channel	1.6		mA
Class-D Channel					
Po	Output Power	SPK_VDD=4.2V RL = 8 Ohm + 33 μ H and Total Harmonic Distortion+Noise (THD+N) = 1%, Gain=12dB	0.98		W
		SPK_VDD=5V RL = 8 Ohm + 33 μ H and Total Harmonic Distortion+Noise (THD+N) = 10%, Gain=18dB	1.72		W
		SPK_VDD=4.2V RL = 4 Ohm + 33 μ H and Total Harmonic Distortion+Noise (THD+N) = 1%, Gain=12dB	1.77		W
		SPK_VDD=5V RL = 4 Ohm + 33 μ H and Total Harmonic Distortion+Noise (THD+N) = 10%, Gain=12dB	3.08		W
THD+N	Total Harmonic Distortion + Noise	RL = 8 Ω + 33 μ H, f=1kHz, Po = 0.5 W, Gain=12dB	0.01		%
eos	Output Noise	A-Weighted, 20Hz-20kHz, no Auto Mute or zero detection, no DAC input signal, gain = 0dB	18		μ Vrms
		A-Weighted, 20Hz-20kHz, no Auto Mute or zero detection, no DAC input signal, gain = 6dB	22		μ Vrms
PSRR	Power Supply Rejection Ratio (Note 1)	DC, SPK_VDD = 3.2V – 4.2V, amplifier voltage GAIN = 6dB	82		dB
		f _{RIPPLE} = 1020Hz, V _{RIPPLE} = 100mV _{P-P} amplifier voltage GAIN = 6dB	82	60	dB
		f _{RIPPLE} = 4kHz, V _{RIPPLE} = 100mV _{P-P} amplifier voltage GAIN = 6dB	77		dB
Fres	Frequency Response	F = 20Hz ~ 20KHz, 1Watt, RL = 8 Ω + 33 μ H	+0.8/-0.3		dB
Vos	Output Offset Voltage	Idle Channel, Gain= 0dB	\pm 1	\pm 5	mV
Kpop	Pop and Click Noise	A-weighted, Idle DAC input, Clock Gating, toggling clocks on/off, Gain= 6dB	0.03		mVrms

Symbol	Parameter	Conditions	Typical	Limit	Units
		A-weighted, Idle DAC input, toggling between -120dBFS DAC In & 2048 zero samples, Gain= 6dB	0.03		mVrms
Fsw	Switching Frequency	Average	300	400	kHz
Class-D					
Neff	Power Efficiency	Output Power = 2 x 1W, SPK_VDD = 4.2 V	90		%

Note 1 : $PSRR = 20 \times \text{LOG}_{10}(\text{GAIN} \times \Delta\text{SPK_VDD} / \Delta(\text{SPKP-SPKN})) \text{ dB}$

9.4 Digital I/O Parameters

Digital I/O

Parameter	Symbol	Comments/Conditions	Min	Max	Units
Input LOW level	V _{IL}	IO_VDD = 1.8V		0.33*IO_VDD	V
		IO_VDD = 3.3V		0.37*IO_VDD	
Input HIGH level	V _{IH}	IO_VDD = 1.8V	0.67*IO_VDD		V
		IO_VDD = 3.3V	0.63*IO_VDD		
Output HIGH level	V _{OH}	I _{Load} = 1mA	IO_VDD=1.8V	0.9*IO_VDD	V
			IO_VDD = 3.3V	0.95*IO_VDD	
Output LOW level	V _{OL}	I _{Load} = 1mA	IO_VDD = 1.8V	0.1*IO_VDD	V
			IO_VDD=3.3V	0.05*IO_VDD	

10 Package Specification

The NAU8325 Stereo Class-D Amplifier is available in a small, QFN20L 4x4mm package, using 0.5 mm pitch, as shown in **Figure 29**.

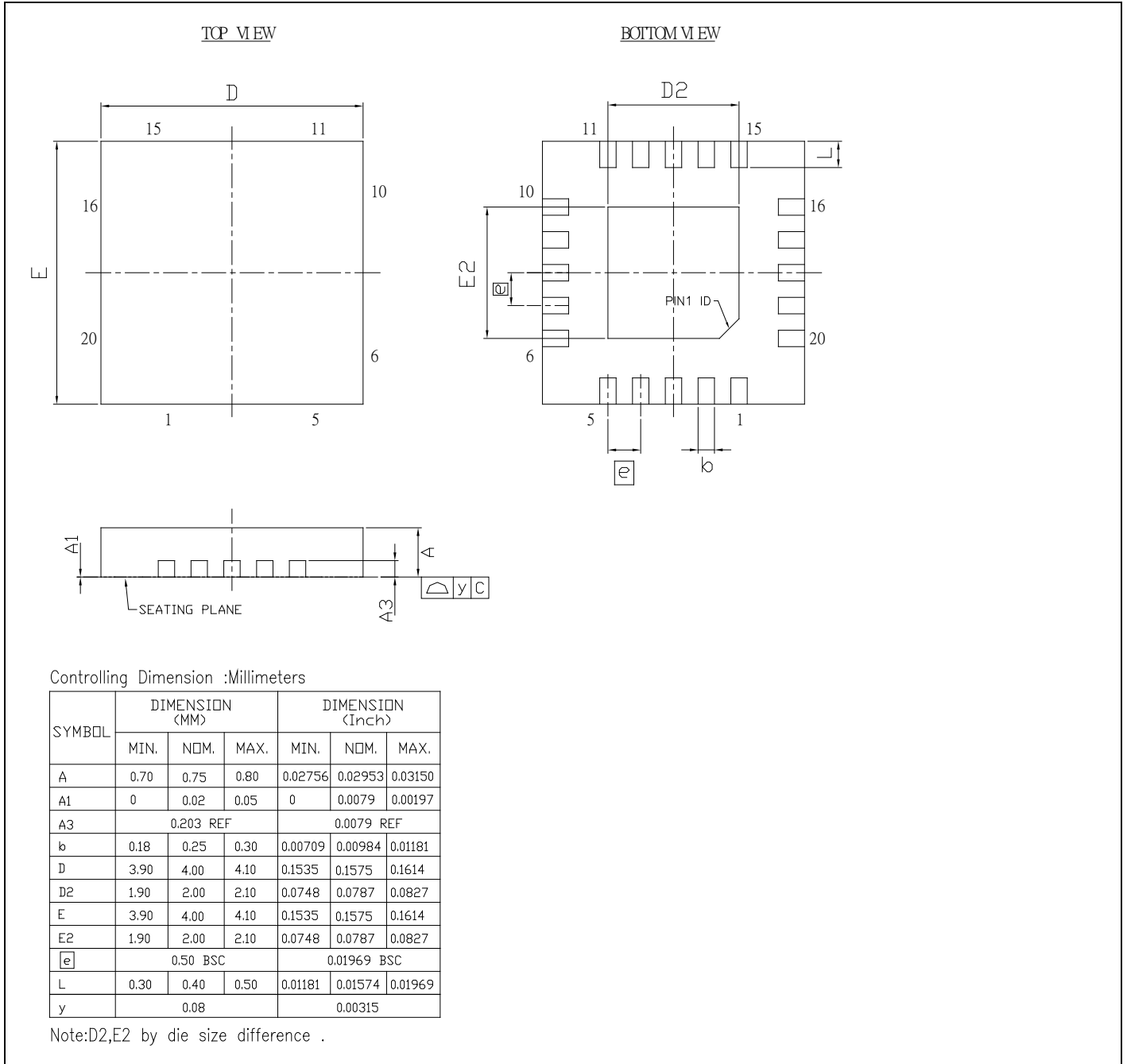
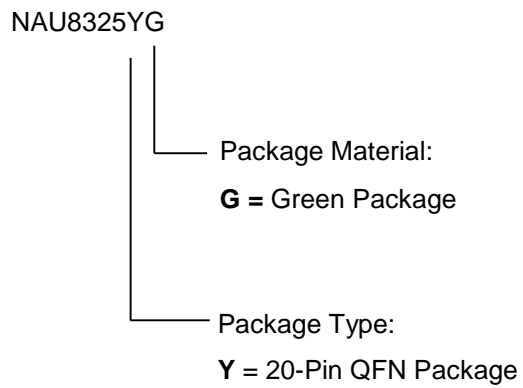


Figure 29 NAU8325 Package Specification

11 Ordering Information

Nuvoton Part Number Description:

Part Number	Dimension	Package	Package Material
NAU8325YG	4mm x 4mm	QFN-20	Green



12 Revision History

Version			Description
#	Date	Page(s)	
1.0 Preliminary Draft 1	Apr 04, 2018		
1.1 Preliminary	Apr 10, 2018		Internal review. Expand clock detection/auto power-down description. Final register map.
1.2 Preliminary	Apr 13, 2018		Release to Alpha
1.3	May 18, 2018		Removing unused right-justified PCM modes. Modified digital gain settings to 6dB -- -80dB Expand AUTO_MUTE description Update clock source description
1.4	June, 2018	17	Update MCLK_SRC/LRCK possible ratios to include 400/500
1.5	July, 2018		Update I2C Slave Address to 0x21 Update electrical parameters
1.6	Oct, 2018		Update PDM description Update CLK_CTRL reg MCLK off. Update reg 0x02, 0x03, 0x4A, 0x63, 0x65 descriptions Update PSRR limits & gain
1.7	Oct, 2018		Update reg 0x0C, 0x0D for PCM options.
1.8	Jan, 2019		Update 7.5 POR ANALOG_CTRL_3 PD bits for mono operation. Silicon Rev to xF2
1.9	Feb, 2019		Update 9.3 Electrical characteristics for mono.
2.0	Aug, 2019		Correct digits in I2C slave address in table. Changed VSS to GND consistent with pin names.
2.1	Jun 16, 2020		Update format.
2.2	June 1, 2021	39	Register 0x9 [7] description
2.3	June 21, 2021	38,39	Register 0x4 0x5 format correction; Reg0x9 default setting value

Important Notice

Nuvoton Products are neither intended nor warranted for usage in systems or equipment, any malfunction or failure of which may cause loss of human life, bodily injury or severe property damage. Such applications are deemed, "Insecure Usage".

Insecure usage includes, but is not limited to: equipment for surgical implementation, atomic energy control instruments, airplane or spaceship instruments, the control or operation of dynamic, brake or safety systems designed for vehicular use, traffic signal instruments, all types of safety devices, and other applications intended to support or sustain life.

All Insecure Usage shall be made at customer's risk, and in the event that third parties lay claims to Nuvoton as a result of customer's Insecure Usage, customer shall indemnify the damages and liabilities thus incurred by Nuvoton.

*Please note that all data and specifications are subject to change without notice.
All the trademarks of products and companies mentioned in this datasheet belong to their respective owners.*