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## 3.1W Stereo Filter-Free Class-D Audio Amplifier with 2 wire interface gain control

### 1 Description

The NAU8224 is a stereo high efficiency filter-free Class-D audio amplifier, which is capable of driving a 4Ω load with up to 3.1W output power. This device provides chip enable pin with extremely low standby current and fast start-up time of 3.4ms. The NAU8224 features a highly flexible 2 wire interface with many useful gain settings. The gain can be selected from 24dB to -62dB (plus mute) by using 2 wire interface and GS pin.

The NAU8224 is ideal for the portable applications of battery drive, as it has advanced features like 87dB PSRR, 91% efficiency, ultra low quiescent current (i.e. 2.1mA at 3.7V for 2 channels) and superior EMI performance. It has the ability to configure the inputs in either single-ended or differential mode. NAU8224 is available in Miniature QFN-20 package.

#### Key Features

- Low Quiescent Current:
  - 2.1mA at 3.7V for 2 channels
  - 3.2mA at 5V for 2 channels
- Gain Setting with 2 wire interface and GS pin
  - 24dB to -62dB (plus mute)
- Powerful Stereo Class-D Amplifier:
  - 2ch x 3.1W (4Ω @ 5V, 10% THD+N)
  - 2ch x 1.26W (4Ω @ 3.7V, 1% THD+N)
  - 2ch x 1.76W (8Ω @ 5V, 10% THD+N)
  - 2ch x 0.76W (8Ω @ 3.7V, 1% THD+N)
- Low Output Noise: 20 μV<sub>RMS</sub> @0dB gain
- 87dB 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

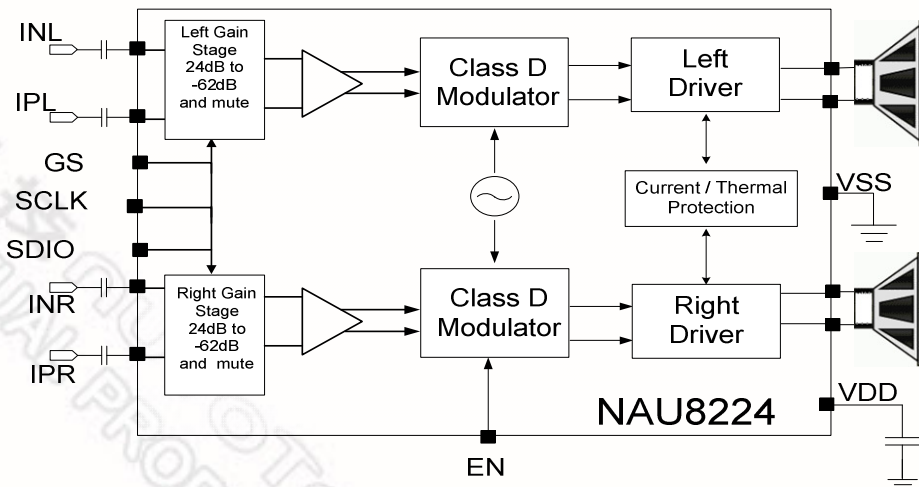
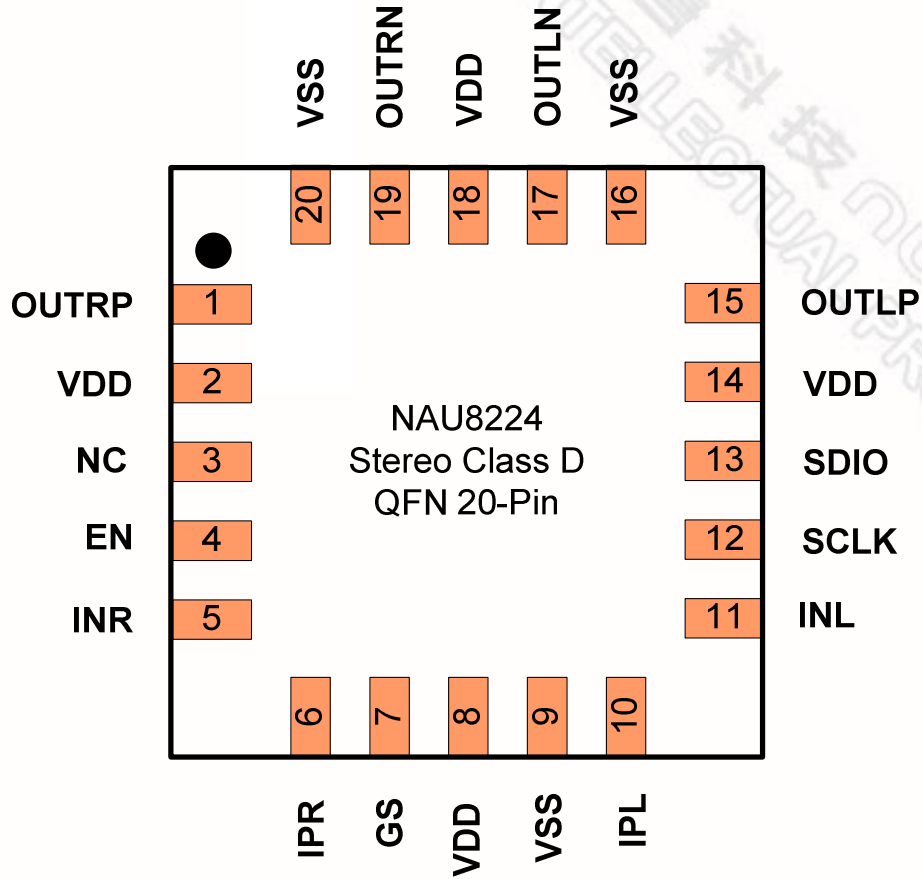


Figure 1: NAU8224Block Diagram

## 2 Pinout- QFN 20 (TOP VIEW)



Part Number	Dimension	Package	Package Material
NAU8224YG	4mm x 4mm	QFN-20	Pb-Free



### 3 Pin Descriptions

QFN	Name	Type	Functionality
1	OUTRP	Analog Output	Right Channel Positive BTL Output
2	VDD	Supply	Power Supply
3	NC	NC	No Connect
4	EN	Digital Input	Chip Enable (High = Enable; Low = PD)
5	INR	Analog Input	Right Channel Negative Input
6	IPR	Analog Input	Right Channel Positive Input
7	GS	Analog Input	5 Selectable Gain Setting (0dB / 6dB / 12dB / 18dB / 24dB)
8	VDD	Supply	Power Supply
9	VSS	Supply	Ground
10	IPL	Analog Input	Left Channel Positive Input
11	INL	Analog Input	Left Channel Negative Input
12	SCLK	Digital Input	I2C Serial Clock
13	SDIO	Digital I/O	I2C serial data Input & Output
14	VDD	Supply	Power Supply
15	OUTLP	Analog Output	Left Channel Positive BTL Output
16	VSS	Supply	Ground
17	OUTLN	Analog Output	Left Channel Negative BTL Output
18	VDD	Supply	Power Supply
19	OUTRN	Analog Output	Right Channel Negative BTL Output
20	VSS	Supply	Ground
21	Ex-Pad	Analog Input	Thermal Tab (must be connected to VSS, QFN-20 package, only)

#### Notes

1. Pins designated as NC (Not Internally Connected) should be left as no-connection

**Table 1: NAU8224 Pin description**

## 4 Electrical Characteristics

Conditions: EN = VDD = 5V, VSS = 0V, Av = 12dB ZL = ∞, Bandwidth = 20Hz to 22kHz, TA = 25 °C

Parameter	Symbol	Comments/Conditions	Min	Typ	Max	Units
<b>Power Delivered</b>						
Output Power (per channel)	P <sub>out</sub>	Z <sub>L</sub> = 4Ω + 33μH	VDD = 5.0V	3.1		W
		THD + N = 10%	VDD = 3.7V	1.57		
		Z <sub>L</sub> = 4Ω + 33μH	VDD = 5.0V	2.46		
		THD + N = 1%	VDD = 3.7V	1.26		
		Z <sub>L</sub> = 8Ω + 68μH	VDD = 5.0V	1.76		
		THD + N = 10%	VDD = 3.7V	0.95		
		Z <sub>L</sub> = 8Ω + 68μH	VDD = 5.0V	1.41		
		THD + N = 1%	VDD = 3.7V	0.76		

Parameter	Symbol	Comments/Conditions	Min	Typ	Max	Units
<b>Chip Enable (EN)</b>						
Voltage Enable High	V <sub>EN_H</sub>	VDD = 2.5V to 5.5V	1.4			V
Voltage Enable Low	V <sub>EN_L</sub>	VDD = 2.5V to 5.5V			0.4	V
Input Leakage Current			-1		+1	μA
<b>Thermal and Current Protection</b>						
Thermal Shutdown Temperature				130		°C
Thermal Shutdown Hysteresis				15		°C
Short circuit Threshold	I <sub>LIMIT</sub>			2.1		A
<b>Gain Setting</b>						
Voltage Gain	A <sub>V</sub>	Tie GS to VSS		24		dB
		GS Connect VSS through 100k ± 5%		18		
		Tie GS pin to VDD		12		
		GS Connect VDD through 100k ± 5%		6		
		Floating Node		0		
Differential Input Resistance	R <sub>IN</sub>	A <sub>V</sub> = 24dB		35		kΩ
		A <sub>V</sub> = 18dB		70		
		A <sub>V</sub> = 12dB		140		
		A <sub>V</sub> = 6dB		280		
		A <sub>V</sub> = 0dB		558		

## Electrical Characteristics (continued)

Conditions: EN = VDD = 5V, VSS = 0V, Av = 12dB, ZL = ∞, Bandwidth = 20Hz to 22kHz, TA = 25 °C

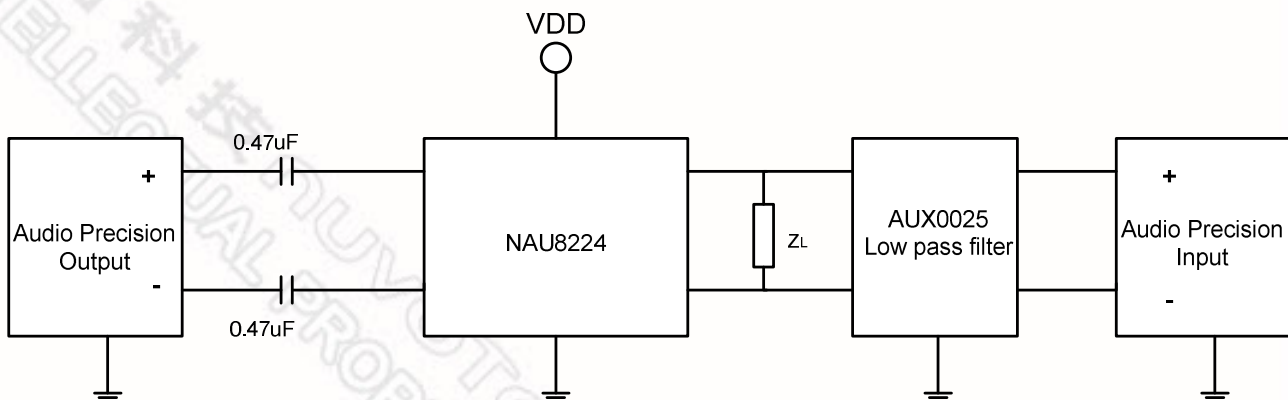
Parameter	Symbol	Comments/Conditions	Min	Typ	Max	Units
<b>Normal Operation</b>						
Quiescent Current Consumption	I <sub>QUI</sub>	VDD = 3.7V		2.1		mA
		VDD = 5V		3.17		mA
Shut Down Current	I <sub>OFF</sub>	EN = 0		0.1		μA
Oscillator Frequency	f <sub>OSC</sub>			300		kHz
Efficiency	η			91		%
Start Up Time	T <sub>start</sub>			3.4		msec
Output Offset Voltage	V <sub>OS</sub>			±1	±4	mV
Common Mode Rejection Ratio	CMRR	f <sub>IN</sub> = 1kHz		80		dB
Click-and-Pop Suppression		Into Shutdown (Z <sub>L</sub> =8Ω) A Weighted		-72		dBV
Power Supply Rejection Ratio	DC PSRR	VDD = 2.5V to 5.5V		98		dB
	AC PSRR*	V <sub>RIPPLE</sub> = 0.2Vpp@217Hz**		87		dB
		V <sub>RIPPLE</sub> = 0.2Vpp@1KHz V <sub>RIPPLE</sub> = 0.2Vpp@10KHz		74 54		
Channel Crosstalk		f <sub>IN</sub> = 1kHz, Z <sub>L</sub> = 8Ω + 68μH		-101		dB

\*Measured with 0.1uF capacitor on V<sub>DD</sub> and Battery supply

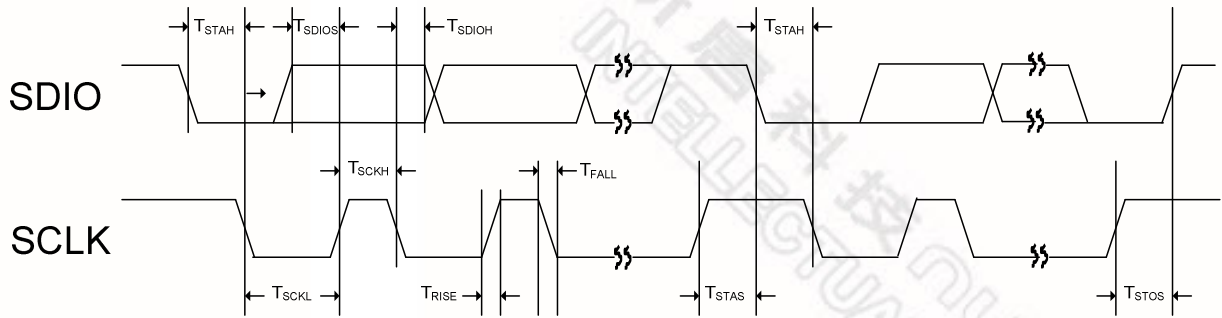
\*\* Measured with 2.2uF input capacitor.

Parameter	Symbol	Comments/Conditions	Min	Typ	Max	Units
<b>Noise Performance</b>						
		Av = 0dB (A-weighted)		20		μV <sub>RMS</sub>
		Av = 6dB (A-weighted)		21		
		Av = 12dB (A-weighted)		27		
		Av = 18dB (A-weighted)		36		
		Av = 24dB (A-weighted)		52		

The following setup is used to measure the above parameters



## Digital Serial Interface Timing



Two wire control mode timing

Symbol	Description	Min	Typ	Max	Unit
$T_{STAH}$	SDIO falling edge to SCLK falling edge hold timing in START / Repeat START condition	600	-	-	ns
$T_{STAS}$	SCLK rising edge to SDIO falling edge setup timing in Repeat START condition	600	-	-	ns
$T_{STOS}$	SCLK rising edge to SDIO rising edge setup timing in STOP condition	600	-	-	ns
$T_{SCKH}$	SCLK High Pulse Width	600	-	-	ns
$T_{SCKL}$	SCLK Low Pulse Width	1,300	-	-	ns
$T_{RISE}$	Rise Time for all 2-wire Mode Signals	-	-	300	ns
$T_{FALL}$	Fall Time for all 2-wire Mode Signals	-	-	300	ns
$T_{SDIOS}$	SDIO to SCLK Rising Edge DATA Setup Time	100	-	-	ns
$T_{SDIOH}$	SCLK falling Edge to SDIO DATA Hold Time	0	-	600	ns

## Digital Serial Interface Electrical Characteristics

Condition	Min	Typ.	Max.	Unit	Test Conditions
Input Leakage Current SCLK, SDIO	-1	-	+1	μA	VDD = 5.5V
Input High Voltage VIH	0.7 VDD		5.5	V	
Input low Voltage VIL	VSS		0.3 VDD	V	
VOH (SCLK, SDIO)	0.9 VDD			V	
VOL (SCLK, SDIO)			0.2 VDD	V	IOL = 1 mA
SDIO, SCLK; pull up resistor value		50k		Ohm	

## Absolute Maximum Ratings

Condition	Min	Max	Units
Analog supply	-0.50	+5.50	V
Industrial operating temperature	-40	+85	°C
Storage temperature range	-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 warranty.*

## Operating Conditions

Condition	Symbol	Min	Typical	Max	Units
Analog supply range	VDD	2.50	3.7	5.50	V
Ground	VSS		0		V



## 6 Special Feature Description

The NAU8224 offers excellent quantity performance as high efficiency, high output power and low quiescent current. It also provides the following special features.

### 6.1 Gain Setting with 2 wire interface control

The NAU8224 has a GS pin, which can control five selectable gain settings (i.e. 0dB / 6dB / 12dB / 18dB / 24dB).

GS Pin Configuration	Internal Gain (dB)
GS tie to VSS	24
GS connect to VSS through 100kΩ ± 5% resistor	18
GS tie to VDD	12
GS connect to VDD through 100kΩ ± 5% resistor	6
Floating (open node)	0

The NAU8224 provides 2 wire register programmable volume control in addition to the GS pin selectable gain selection. The possible gain values by using these two controls are listed in the table below:

VLCRTL[5:0] Reg 0x1B	GAINDEC[4:0]=0x01 (GS pin set to 0dB position)	GAINDEC[4:0]=0x02 (GS pin set to 6dB position)	GAINDEC[4:0]=0x04 (GS pin set to 12dB position)	GAINDEC[4:0]=0x08 (GS pin set to 18dB position)	GAINDEC[4:0]=0x10 (GS pin set to 24dB position)
0x0	0 dB	6 dB	12 dB	18 dB	24 dB
0x1	-2 dB	4.1 dB	10.4 dB	17 dB	Not used
0x2	-4 dB	2.2dB	8.8 dB	16 dB	Not used
0x3	-6 dB	0.4 dB	7.1dB	15 dB	Not used
0x4	-8 dB	-1.6 dB	5.4 dB	13.7 dB	Not used
0x5	-10 dB	-3.5 dB	3.6 dB	12.4 dB	Not used
0x6	-12 dB	-5.6 dB	1.7 dB	10.9 dB	Not used
0x7	-14 dB	-7.5 dB	-0.2 dB	9.4 dB	Not used
0x8	-16 dB	-9.5 dB	-2 dB	7.9 dB	Not used
0x9	-18dB	-11.4 dB	-3.9 dB	6.2 dB	Not used
0xA	-20dB	-13.4 dB	-5.8 dB	4.5 dB	Not used
0xB	-22dB	-15.4 dB	-7.8 dB	2.7 dB	Not used
0xC	-24dB	-17.3 dB	-9.7 dB	0.9 dB	Not used
0xD	-26 dB	-19.3 dB	-11.7 dB	-0.9 dB	Not used
0xE	-28 dB	-21.3 dB	-13.6 dB	-2.8 dB	Not used
0xF	-30 dB	-23.3 dB	-15.6 dB	-4.7 dB	Not used
0x10	-32 dB	-25.3 dB	-17.6 dB	-6.6 dB	Not used
0x11	-34 dB	-27.3 dB	-19.3 dB	-7.3 dB	Not used
0x12	-36 dB	-29.1 dB	-20.4 dB	-7.3 dB	Not used
0x13	-38 dB	-30.7 dB	-20.5 dB	-7.2 dB	Not used
0x14	-40 dB	-32.2 dB	-20.2 dB	-7.1 dB	Not used
0x15	-42 dB	-33.7 dB	-20 dB	-7.1 dB	Not used
0x16	-44 dB	-35.1 dB	-19.8 dB	-7.1 dB	Not used
0x17	-46 dB	-36.6 dB	-19.7 dB	-7.1 dB	Not used
0x18	-48 dB	-36 dB	-19.6 dB	-7.0 dB	Not used
0x19	-50 dB	-35.2 dB	-19.5 dB	-7.0 dB	Not used
0x1A	-52 dB	-34.6 dB	-19.5 dB	-7.0 dB	Not used
0x1B	-54 dB	-34.2 dB	-19.4 dB	-7.0 dB	Not used
0x1C	-56 dB	-33.9 dB	-19.4 dB	-7.0 dB	Not used
0x1D	-58 dB	-33.7 dB	-19.4 dB	-7.0 dB	Not used
0x1E	-60dB	-33.5 dB	-19.4 dB	-7.0 dB	Not used
0x1F	-62 dB	-33.4 dB	-19.3 dB	-7.0 dB	Not used
0x3F	Mute	Mute	Mute	Mute	Mute

## 6.1.1 2-Wire-Serial Control and Data Bus (I<sup>2</sup>C Style Interface)

The serial interface provides a 2-wire bidirectional read/write data interface similar to and typically compatible with standard I2C protocol. This protocol defines any device that sends CLK onto the bus as a master, and the receiving device as slave. The NAU8224 can function only as a slave device.

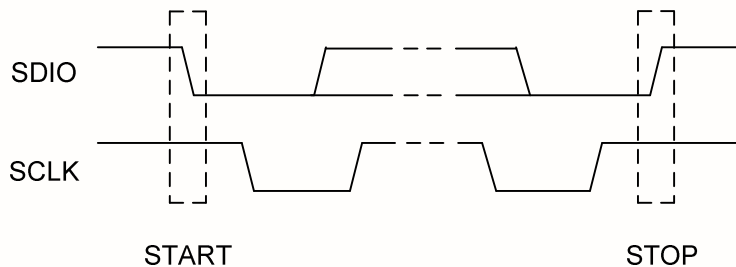
An external clock drives the device, and in accordance with the protocol, data is sent to or from the device accordingly. All functions are controlled by means of a register control interface in the device.

## 6.1.2 2-Wire Protocol Convention

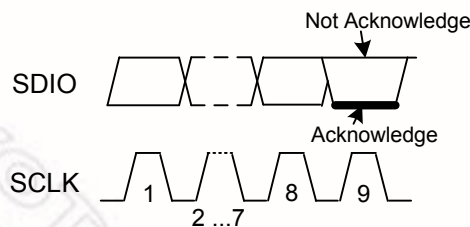
All 2-Wire interface operations must begin with a START condition, which is a HIGH-to-LOW transition of SDIO while SCLK is HIGH. All 2-Wire interface operations are terminated by a STOP condition, which is a LOW to HIGH transition of SDIO while SCLK is HIGH. A STOP condition at the end of a read or write operation places the serial interface in standby mode.

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

Following a START condition, the master must output a device address byte. This consists of a 7-bit device address, and the LSB of the device address byte is the R/W (Read/Write) control bit. When R/W= 1, this indicates the master is initiating a read operation from the slave device, and when R/W=0, the master is initiating a write operation to the slave device. If the device address matches the address of the slave device, the slave will output an ACK during the period when the master allows for the ACK signal.



**START and STOP signals**



**Acknowledge and NOT Acknowledge**

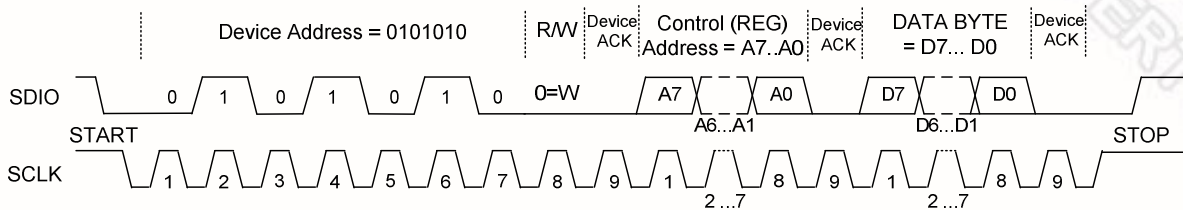
0	1	0	1	0	1	0	R/W	Device Address Byte
A7	A6	A5	A4	A3	A2	A1	A0	Control Address Byte
D7	D6	D5	D4	D3	D2	D1	D0	Data Byte

### Slave Address Byte, Control Address Byte, and Data Byte

#### 6.1.3 2-Wire Write Operation

A Write operation consists of a two-byte instruction followed by a Data Byte. A Write operation requires a START condition, followed by a valid device address byte with R/W= 0, a valid control address byte, data byte, and a STOP condition.

The NAU8224 is permanently programmed with “010 1010” (0x2A) as the Device Address. If the Device Address matches this value, the NAU8224 will respond with the expected ACK signaling as it accepts the data being transmitted into it.



Write Sequence

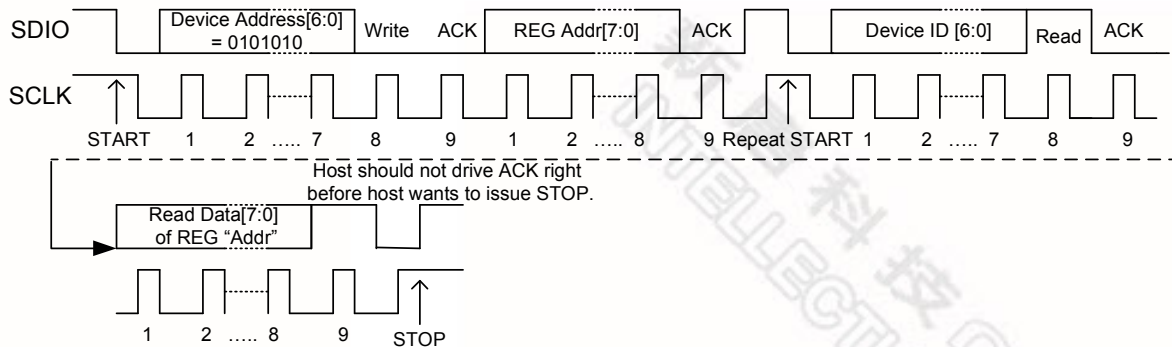
#### 6.1.4 2-Wire Single Read Operation

A Read operation consists of a three-byte Write instruction followed by a Read instruction of data byte. 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 slave device which of its control registers is to be accessed.

The NAU8224 is permanently programmed with “010 1010” (0x2A) as its device address. If the device address matches this value, the NAU8224 will respond with the expected ACK signaling as it accepts the Control Register Address being transmitted into it. After this, the master transmits a second START condition, and a second instantiation of the same device address, but now with R/W=1.

After again recognizing its device address, the NAU8224 transmits an ACK, followed by a one byte value containing the data from the selected control register inside the NAU8224. During this phase, the master generates the ACK signaling with byte transferred from the NAU8224.





## Read Sequence

### 6.1.5 2-Wire Timing

The NAU8224 is compatible with serial clock speeds defined as “standard mode” with SCLK 0 - 100 kHz, and “fast mode” with SCLK 0 - 400 kHz. At these speeds, the total bus line capacitance load is required to be 400 pF or less.

Open collector drivers are required for the serial interface. Therefore, the bus line rise time is determined by the total serial bus capacitance and the VDD pull-up resistors. The NAU8224 defaults to a weak pull up (typical 50 k ohm) for applications with no external pull up resistor.

## 6.2 Register Map

The NAU8223 contains the registers as shown in the table below.

Addr (Hex)	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0	Default (Hex)	Note
04				GAINDEC[4:0]					01	RO
1B			VOLCTRL[5]	VOLCTRL[4]	VOLCTRL[3]	VOLCTRL[2]	VOLCTRL[1]	VOLCTRL[0]	00	RW

### 6.3 Register Map Details

#### 0x04:REGGAIN

This register is a read only register and can be used to check the function of the GAIN pin.

Bit	Default	Function when read '1'
GAINDEC[4]	0	24 dB Gain setting enabled
GAINDEC[3]	0	18 dB Gain setting enabled
GAINDEC[2]	0	12 dB Gain setting enabled
GAINDEC[1]	0	6 dB Gain setting enabled
GAINDEC[0]	0	0 dB Gain setting enabled

#### 0x1B: VOLCTRL[5:0]

This register can be used to adjust the output volume.

Bit	Default	Function when set to '1'
VOLCTRL[5]	0	Adjust Output Volume
VOLCTRL[4]	0	Adjust Output Volume
VOLCTRL[3]	0	Adjust Output Volume
VOLCTRL[2]	0	Adjust Output Volume
VOLCTRL[1]	0	Adjust Output Volume
VOLCTRL[0]	0	Adjust Output Volume

### 6.4 Device Protection

The NAU8224 includes device protection for three operating scenarios. They are

1. Thermal Overload
2. Short circuit
3. Supply under voltage

#### 6.4.1 Thermal Overload Protection

When the device internal junction temperature reaches 130°C, the NAU8224 will disable the output drivers. When the device cools down and a safe operating temperature of 115°C has been reached for at least about 47ms, the output drivers will be enabled again.

#### 6.4.2 Short Circuit Protection

If a short circuit is detected on any of the pull-up or pull-down devices on the output drivers for at least 14µs, the output drivers will be disabled for 47ms. The output drivers will then be enabled again and check for the short circuit. If the

short circuit is still present, the output drivers are disabled after 14 $\mu$ s. This cycle will continue until the short circuit is removed. The short circuit threshold is set at 2.1A.

### 6.4.3 Supply under Voltage Protection

If the supply voltage drops under 2.1V, the output drivers will be disabled while the NAU8224 control circuitry still operates. This will avoid the battery supply to drag down too low before the host processor can safely shut down the devices on the system. If the supply drops further below 1.0V the internal power on reset activated and puts the entire device in power down state.

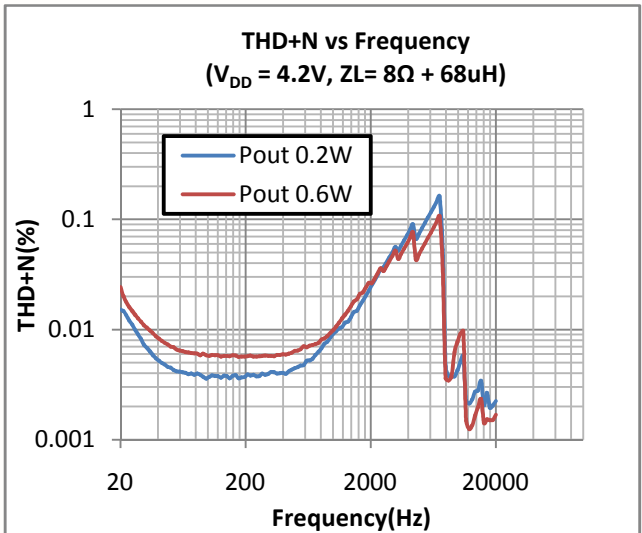
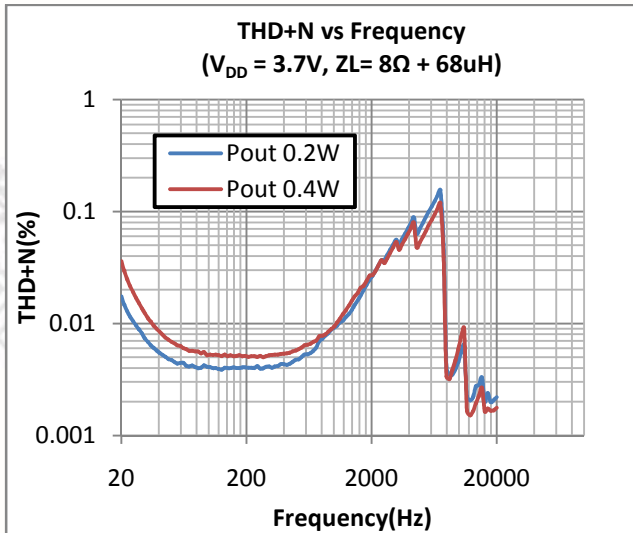
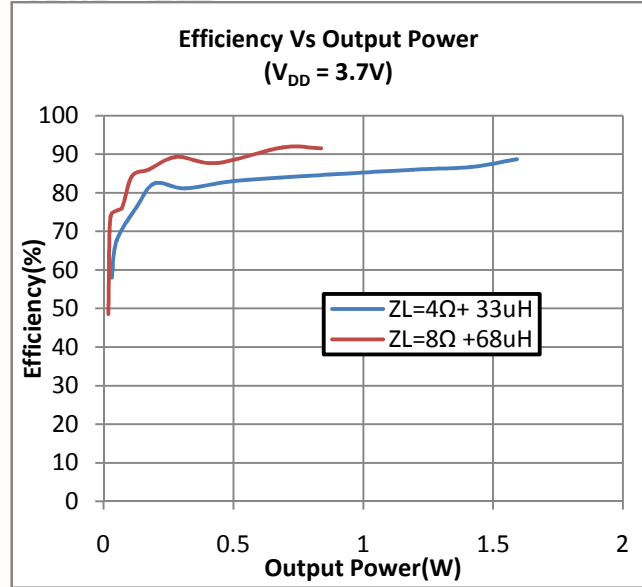
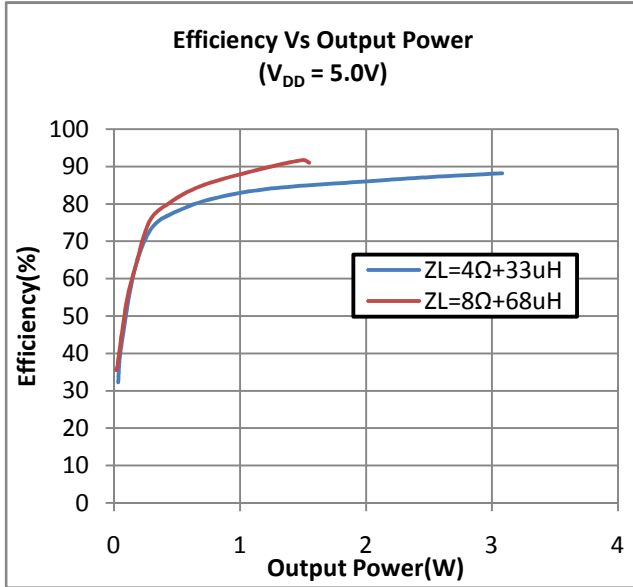
### 6.5 Power up and Power down Control

When the supply voltage ramps up, the internal power on reset circuit gets triggered. At this time all internal circuits will be set to power down state. The device can be enabled by setting the EN pin high. Upon setting the EN pin high, the device will go through an internal power up sequence in order to minimize 'pops' on the speaker output. The complete power up sequence will take about 3.4ms. The device will power down in about 30 $\mu$ s, when the EN pin is set low.

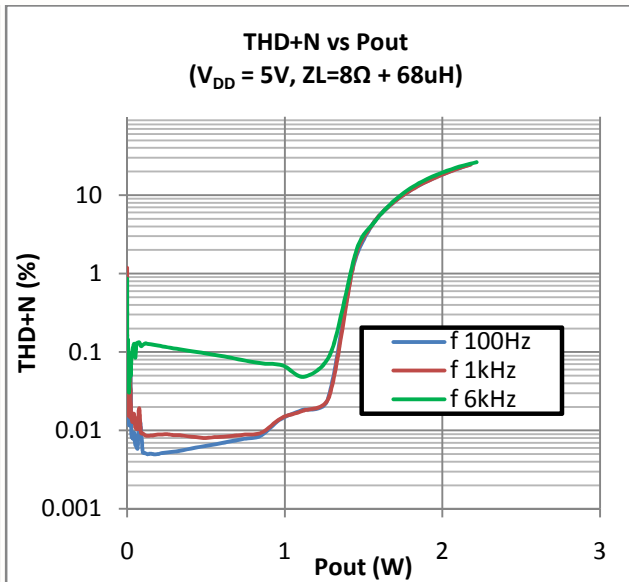
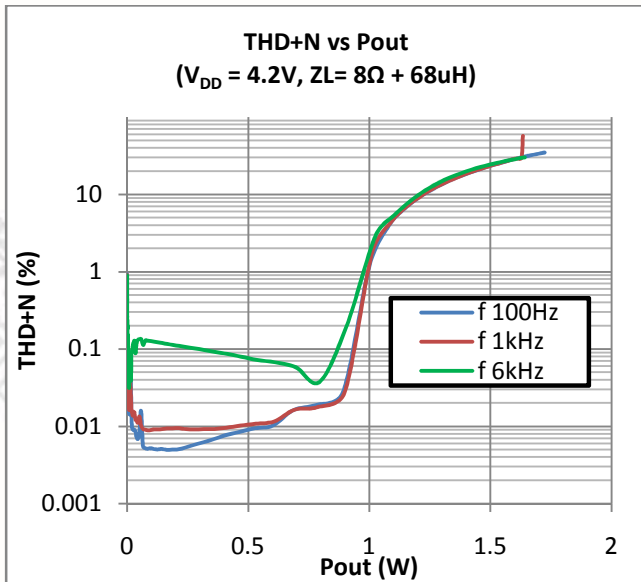
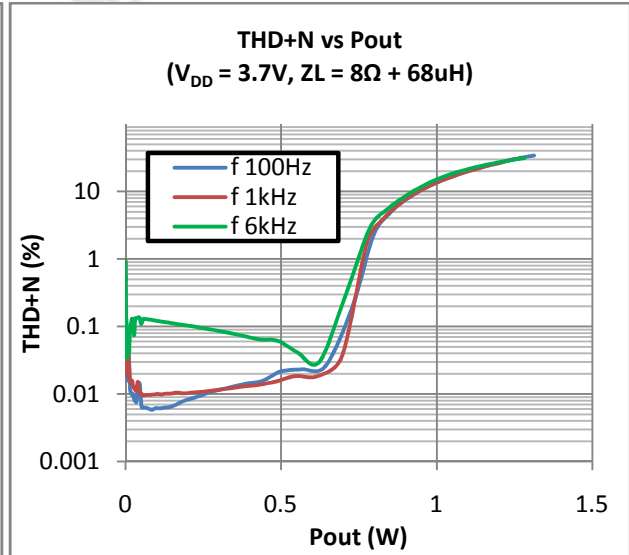
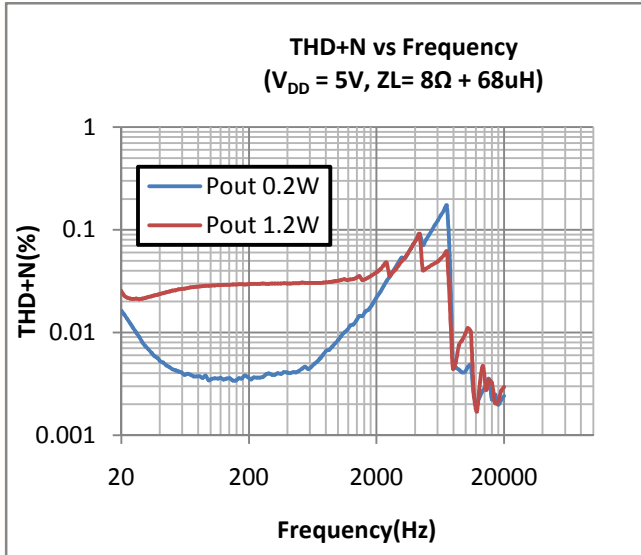
It is important to keep the input signal at zero amplitude or enable the mute condition in order to minimize the 'pops' when the EN pin is toggled.

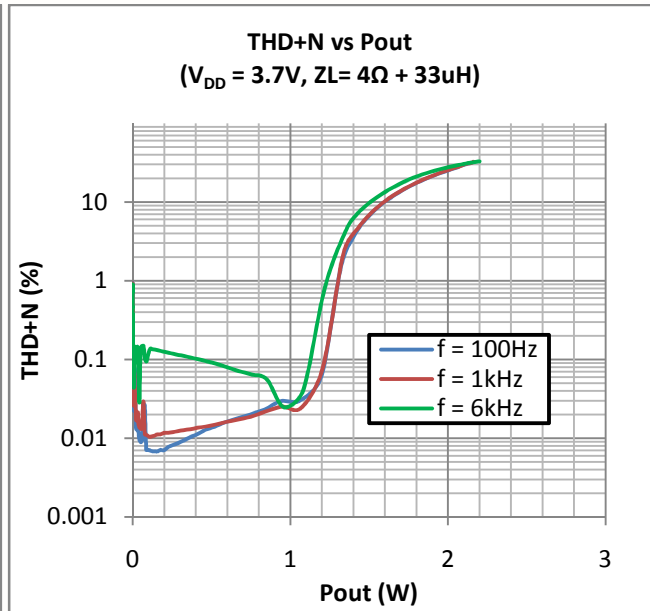
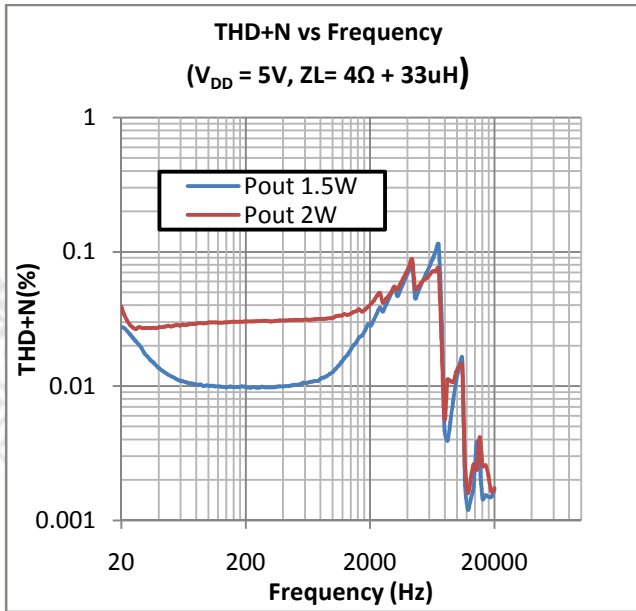
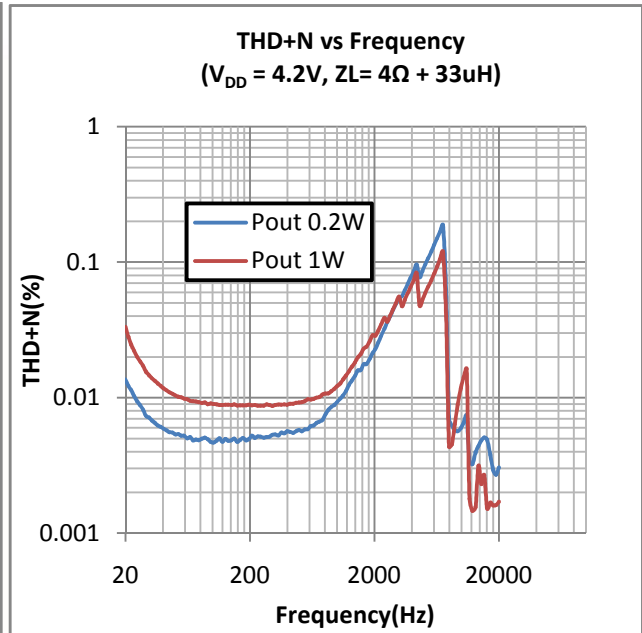
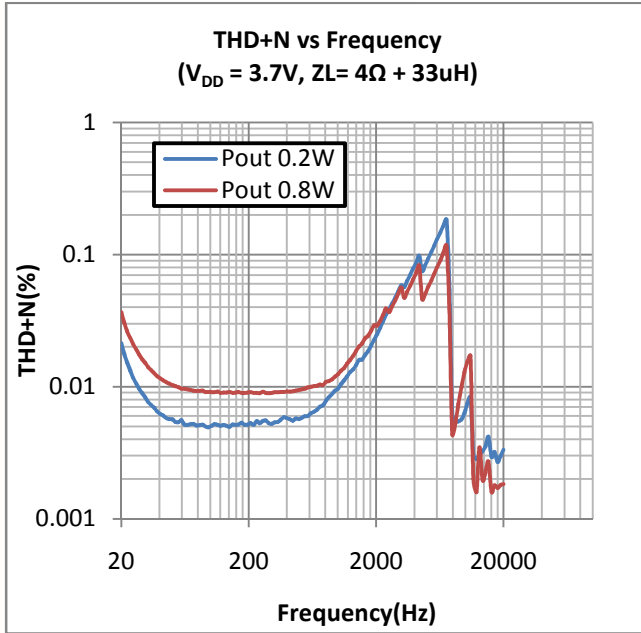
## 7 Typical Operating Characteristics

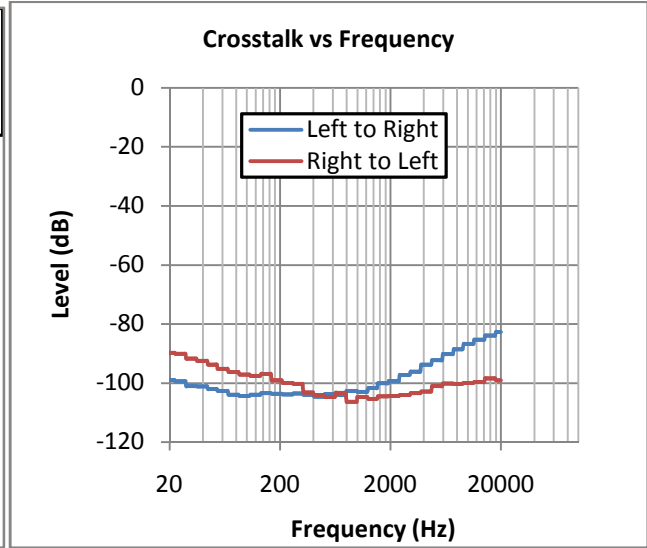
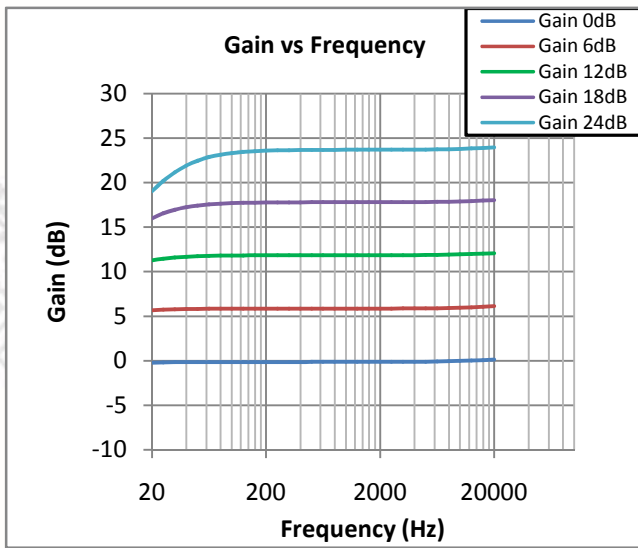
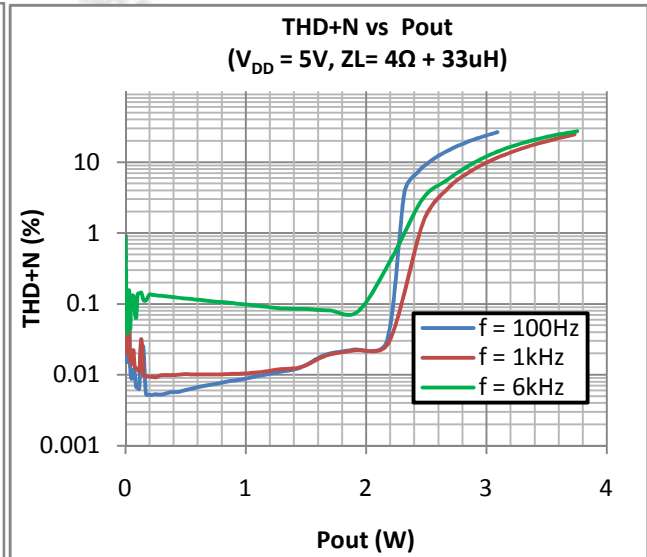
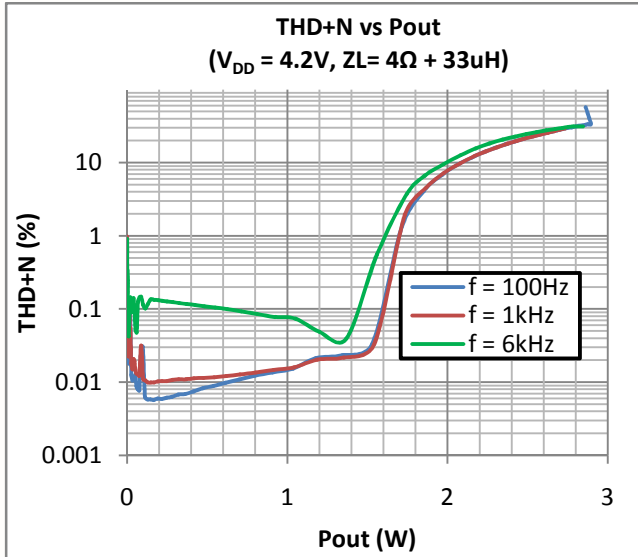
Conditions:  $V_{DD} = 5V$ ,  $V_{SS} = 0V$ ,  $A_v = 12dB$ ,  $Z_L = \infty$ , Bandwidth = 20Hz to 22kHz,  $T_A = 25^\circ C$ , unless otherwise noted

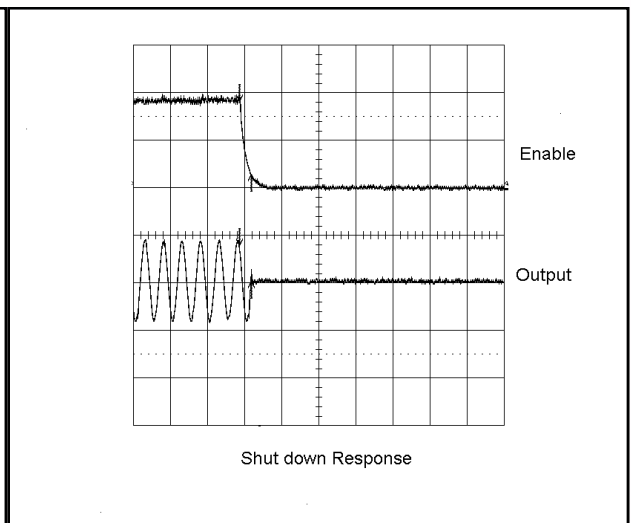
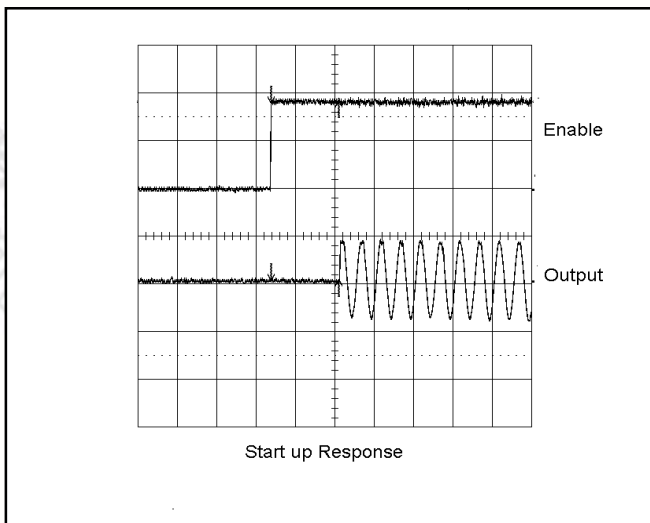
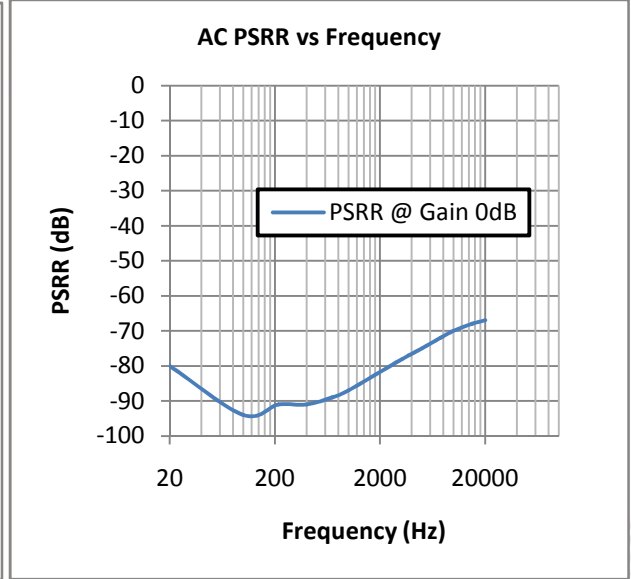
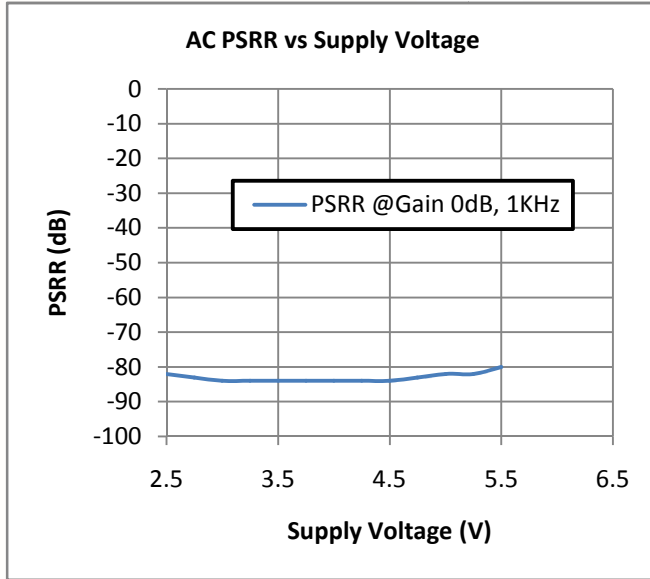




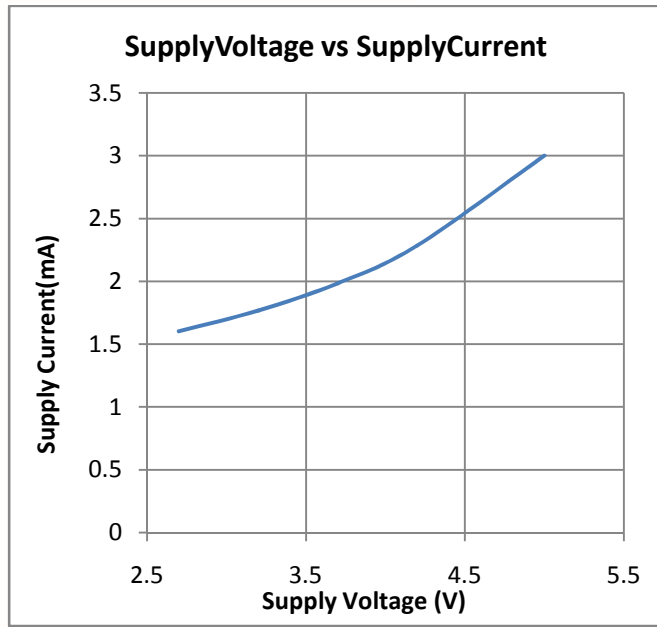










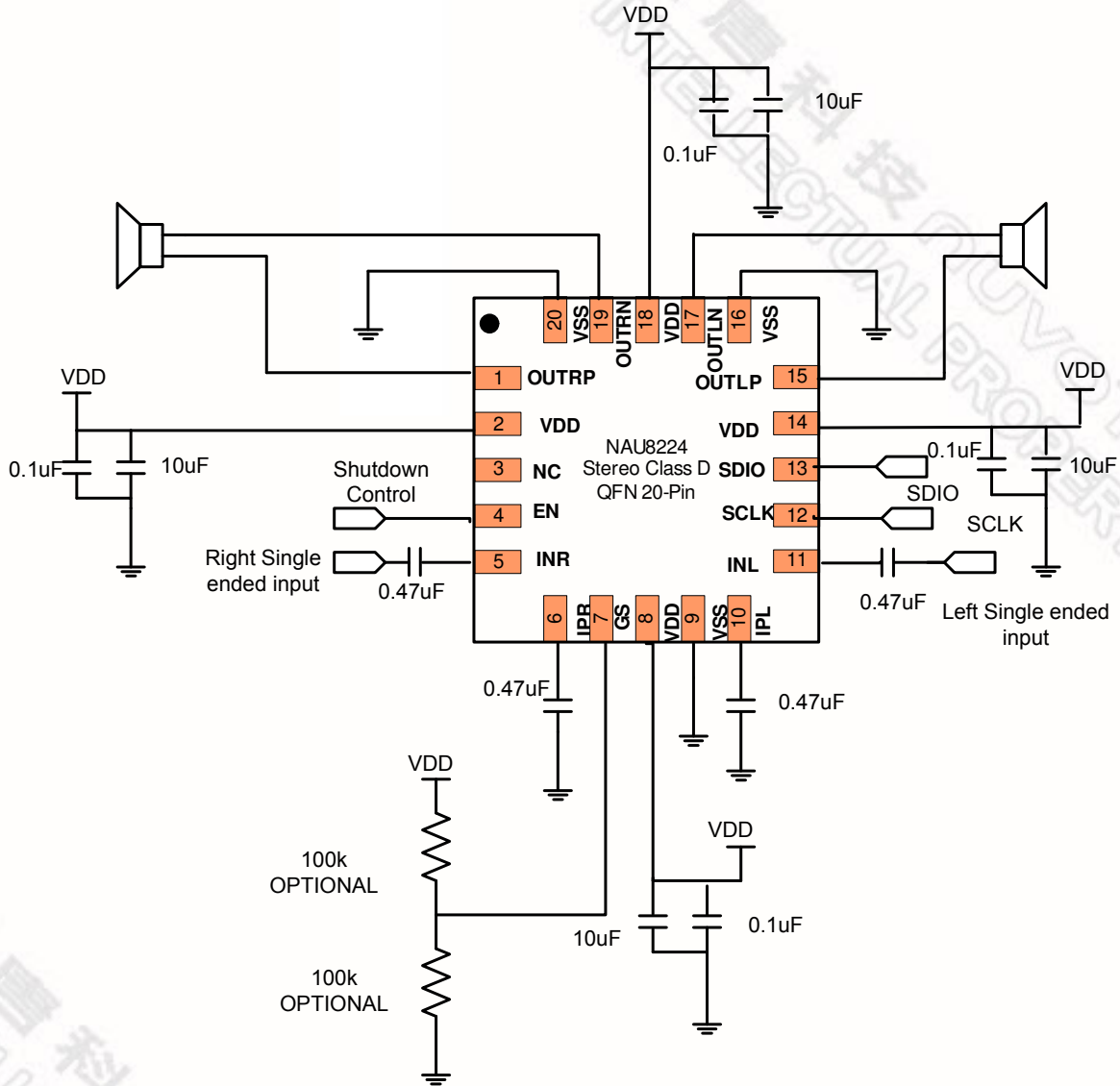


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## 8 Application Information

### 8.1 Application diagram



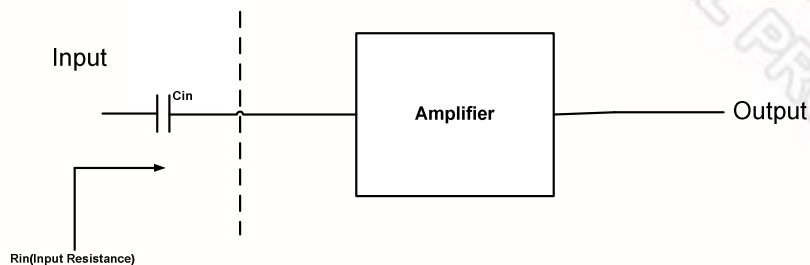
**P.S.** GS Pin – The 100kΩ resistors are optional. GS can be floating for internal gain setting = 0dB. Please refer Section 6.1 (Gain Setting) for the detailed explanation.

## 8.2 Component selection

### Coupling Capacitors

An ac coupling capacitor ( $C_{in}$ ) is used to block the dc content from the input source. The input resistance of the amplifier ( $R_{in}$ ) together with the  $C_{in}$  will act as a high pass filter. So depending on the required cut off frequency the  $C_{in}$  can be calculated by using the following formula

$C_{in} = 1/2\pi R_{in}f_c$  Where  $f_c$  is the desired cut off frequency of the High pass filter.

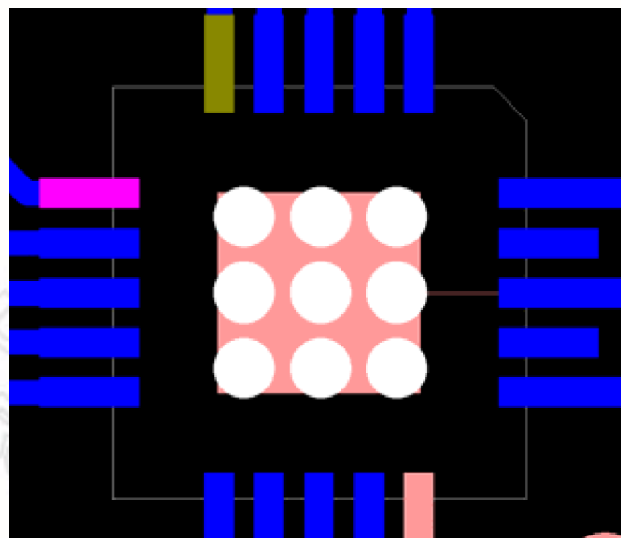


### Bypass Capacitors

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, 10uF and 0.1uF are enough to get the good performance.

## 8.3 Layout considerations

The NAU8224 QFN package uses an exposed pad on the bottom side of the package to dissipate excess power from the output drivers. This pad must be soldered carefully to the PCB for proper operation of the NAU8224. This pad is internally connected to Vss. A typical layout is shown below.

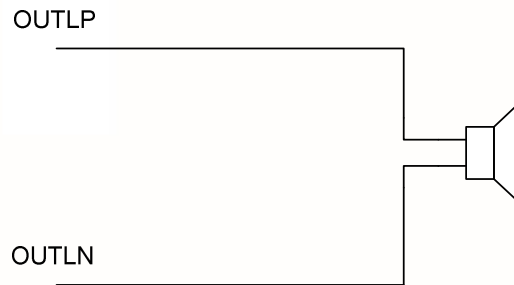


The PCB has to be designed in such a manner that it should have nine vias in 3x3 grid under NAU8224. The vias should have hole size of 12mil and a spacing of 30mils. The pad size of the vias is 24mils. The vias on the top side of the board should be connected with a copper pour that has an area of 2mm x 2mm, centered underneath the NAU8224. The nine vias should connect to copper pour area on the bottom of the PCB. It is preferred to pour the complete bottom side of the board with Vss.

Also good PCB layout and grounding techniques are essential to get the 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.

## 8.4 Class D without filter

The NAU8224 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. The following diagram shows this simple configuration.



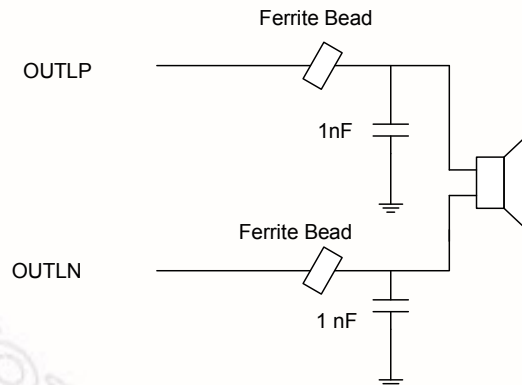
**NAU8224 outputs connected to speaker without filter circuit**

## 8.5 Class D with filter

In some applications, the shorter trace lengths are not possible because of speaker size limitations and other layout reasons. In these applications, the long traces will cause EMI issues. There are two types of filter circuits available to reduce the EMI effects. These are ferrite bead and LC filters.

### Ferrite Bead filter

The ferrite bead filters are used to reduce the high frequency emissions. The typical circuit diagram is shown in the figure.

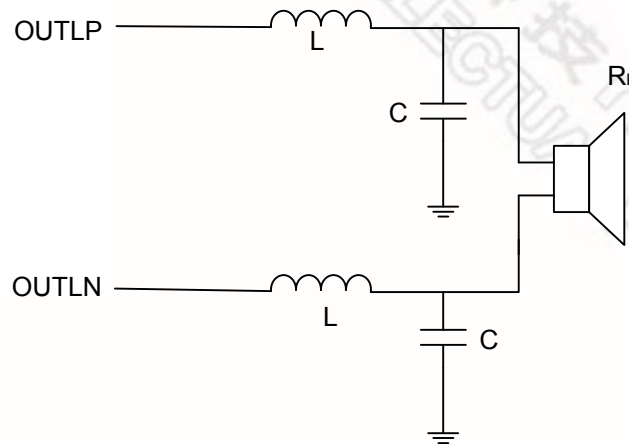


**NAU8224 outputs connected to speaker with Ferrite Bead filter**

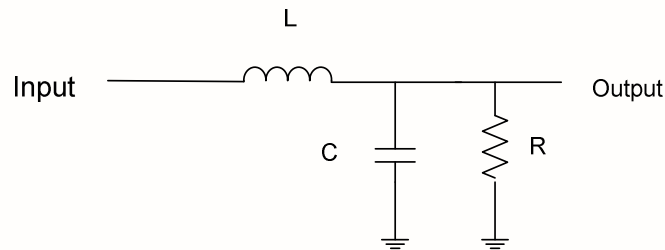
The characteristic of ferrite bead is such that it offers higher impedance at high frequencies. For better EMI performance select ferrite bead which offers highest impedance at high frequencies, so that it will attenuate the signals at higher frequencies. Usually the ferrite beads have low impedance in the audio range, so it will act as a pass through filter in the audio frequency range.

## LC filter

The LC filter is used to suppress the low frequency emissions. The following diagram shows the NAU8224 outputs connected to the speaker with LC filter circuit.  $R_L$  is the resistance of the speaker coil.



NAU8224 outputs connected to speaker with LC filter



## Standard Low pass LCR filter

The following are the equations for the critically damped ( $\zeta = 0.707$ ) standard low pass LCR filter

$$2\pi f_c = \frac{1}{\sqrt{LC}} \quad f_c \text{ is the cutoff frequency}$$

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

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

## 8.6 NAU8224 EMI performance

The NAU8224 includes a spread spectrum oscillator for reduced EMI. The PWM oscillator frequency typically sweeps in a range of 300 kHz +/- 15 kHz in order to spread the energy of the PWM pulses over a larger frequency band. In addition, slew rate control on the output drivers allows the application of 'filter less' loads, while suppressing EMI at high frequencies. The below graph shows the EMI performance of NAU8224 with ferrite beads and speaker cable length of 30cm.

