

## 3.1W Stereo Filter-Free Class-D Audio Amplifier

### 1 Description

The NAU8223 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. It has five selectable gain settings (i.e. 0dB, 6dB, 12dB, 18dB and 24dB), which can be controlled by a single gain pin.

The NAU8223 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.

NAU8223 is available in Miniature QFN-20 package and TSSOP-20 package.

#### Key Features

- Low Quiescent Current:
  - 2.1mA at 3.7V for 2 channels
  - 3.2mA at 5V for 2 channels
- 5 Selectable Gain Settings:
  - 0dB / 6dB / 12dB / 18dB / 24dB
- 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

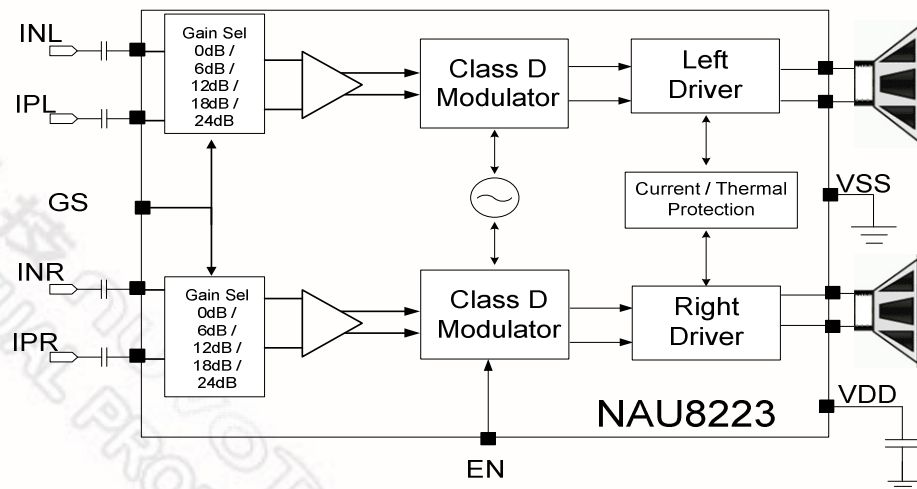
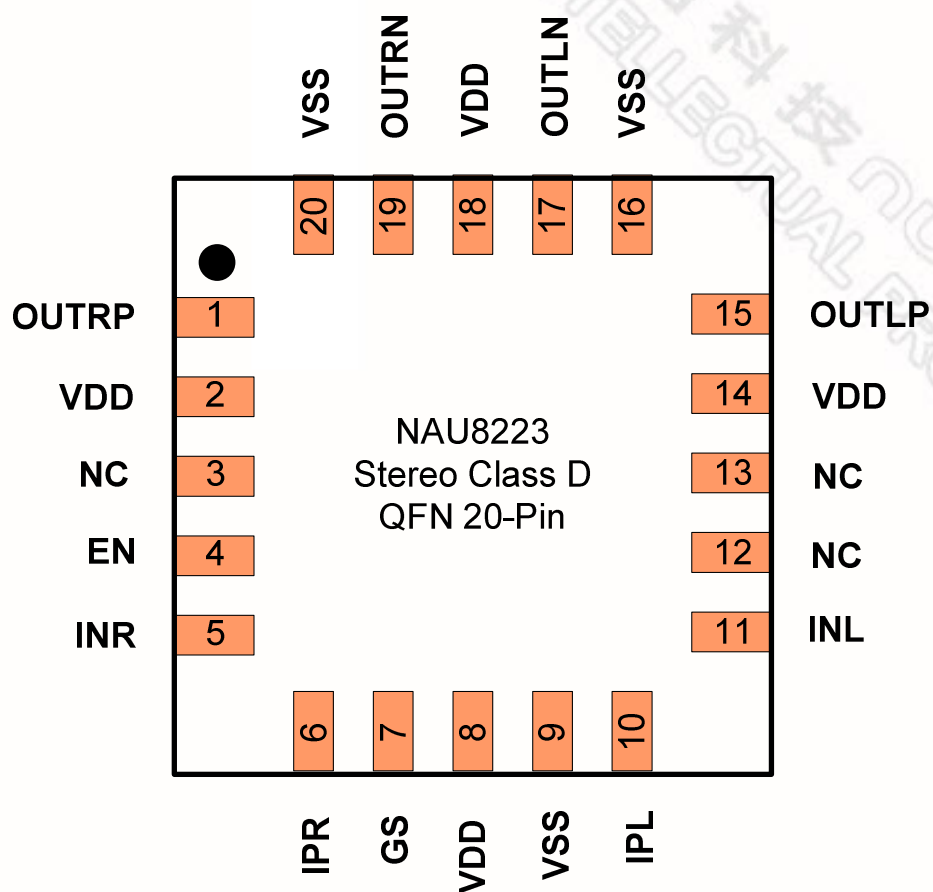


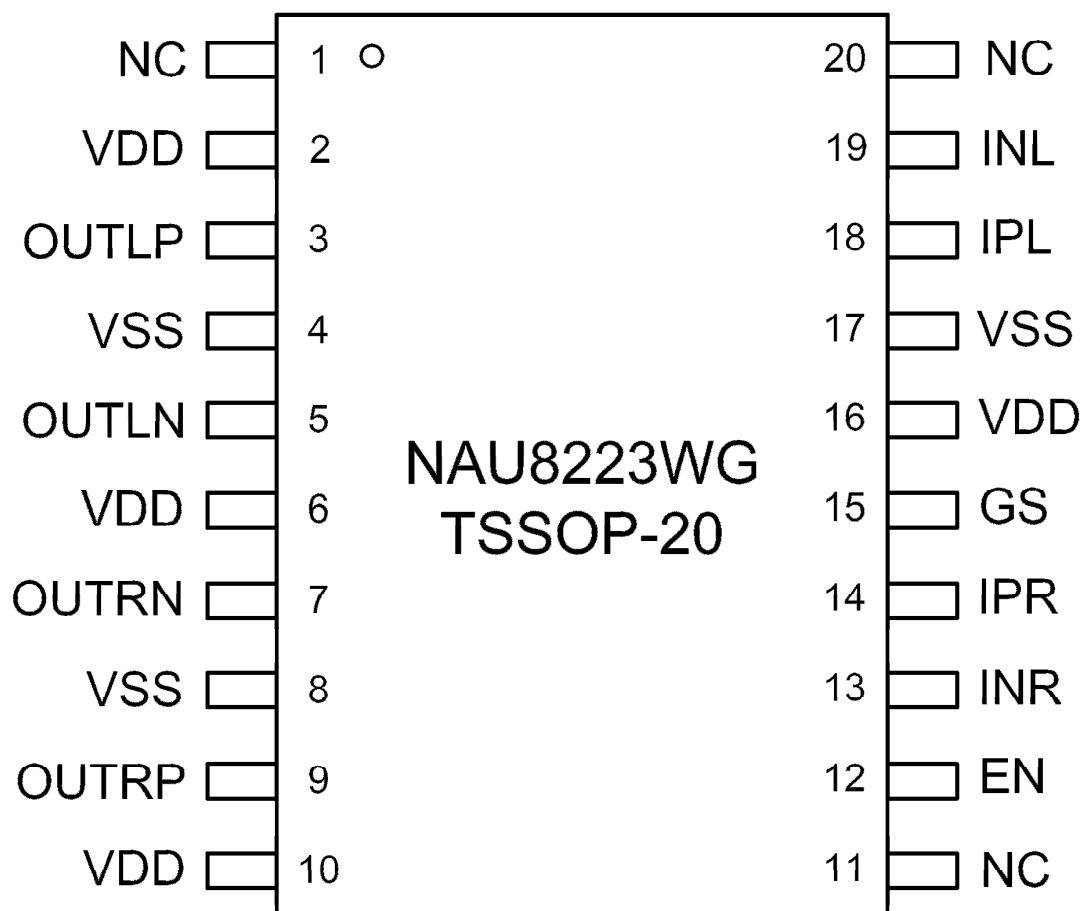
Figure 1: NAU8223Block Diagram

## 2 Pinout

### 2.1 NAU8223 QFN 20 (TOP VIEW)



## 2.2 TSSOP 20 (TOP VIEW)



| Part Number | Dimension     | Package  | Package Material |
|-------------|---------------|----------|------------------|
| NAU8223YG   | 4mm x 4mm     | QFN-20   | Pb-Free          |
| NAU8223WG   | 4.4mm x 6.5mm | TSSOP-20 | Pb-Free          |

### 3 Pin Descriptions

| QFN | TSSOP | Name   | Type          | Functionality                                                |
|-----|-------|--------|---------------|--------------------------------------------------------------|
| 1   | 9     | OUTRP  | Analog Output | Right Channel Positive BTL Output                            |
| 2   | 10    | VDD    | Supply        | Power Supply                                                 |
| 3   | 11    | NC     | NC            | No Connect                                                   |
| 4   | 12    | EN     | Digital Input | Chip Enable (High = Enable; Low = PD)                        |
| 5   | 13    | INR    | Analog Input  | Right Channel Negative Input                                 |
| 6   | 14    | IPR    | Analog Input  | Right Channel Positive Input                                 |
| 7   | 15    | GS     | Analog Input  | 5 Selectable Gain Setting (0dB / 6dB / 12dB / 18dB / 24dB)   |
| 8   | 16    | VDD    | Supply        | Power Supply                                                 |
| 9   | 17    | VSS    | Supply        | Ground                                                       |
| 10  | 18    | IPL    | Analog Input  | Left Channel Positive Input                                  |
| 11  | 19    | INL    | Analog Input  | Left Channel Negative Input                                  |
| 12  | 20    | NC     | NC            | No Connect                                                   |
| 13  | 1     | NC     | NC            | No Connect                                                   |
| 14  | 2     | VDD    | Supply        | Power Supply                                                 |
| 15  | 3     | OUTLP  | Analog Output | Left Channel Positive BTL Output                             |
| 16  | 4     | VSS    | Supply        | Ground                                                       |
| 17  | 5     | OUTLN  | Analog Output | Left Channel Negative BTL Output                             |
| 18  | 6     | VDD    | Supply        | Power Supply                                                 |
| 19  | 7     | OUTRN  | Analog Output | Right Channel Negative BTL Output                            |
| 20  | 8     | 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: NAU8223 Pin description**

## 4 Electrical Characteristics

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

| Parameter                     | Symbol    | Comments/Conditions       | Min | Typ  | Max | Units |
|-------------------------------|-----------|---------------------------|-----|------|-----|-------|
| <b>Power Delivered</b>        |           |                           |     |      |     |       |
| Output Power<br>(per channel) | $P_{out}$ | $Z_L = 4\Omega + 33\mu H$ |     | 3.1  |     | W     |
|                               |           | THD + N = 10%             |     | 1.57 |     |       |
|                               |           | $Z_L = 4\Omega + 33\mu H$ |     | 2.46 |     |       |
|                               |           | THD + N = 1%              |     | 1.26 |     |       |
|                               |           | $Z_L = 8\Omega + 68\mu H$ |     | 1.76 |     |       |
|                               |           | THD + N = 10%             |     | 0.95 |     |       |
|                               |           | $Z_L = 8\Omega + 68\mu H$ |     | 1.41 |     |       |
|                               |           | THD + N = 1%              |     | 0.76 |     |       |

| Parameter                             | Symbol      | Comments/Conditions                   | Min | Typ | Max | Units      |
|---------------------------------------|-------------|---------------------------------------|-----|-----|-----|------------|
| <b>Chip Enable (EN)</b>               |             |                                       |     |     |     |            |
| Voltage Enable High                   | $V_{EN\_H}$ | $V_{DD} = 2.5V$ to $5.5V$             | 1.4 |     |     | V          |
| Voltage Enable Low                    | $V_{EN\_L}$ | $V_{DD} = 2.5V$ to $5.5V$             |     |     | 0.4 | V          |
| Input Leakage Current                 |             |                                       | -1  |     | +1  | $\mu A$    |
| <b>Thermal and Current Protection</b> |             |                                       |     |     |     |            |
| Thermal Shutdown Temperature          |             |                                       |     | 130 |     | $^\circ C$ |
| Thermal Shutdown Hysteresis           |             |                                       |     | 15  |     | $^\circ C$ |
| Short circuit Threshold               | $I_{LIMIT}$ |                                       |     | 2.1 |     | A          |
| <b>Gain Setting</b>                   |             |                                       |     |     |     |            |
| Voltage Gain                          | $A_v$       | Tie GS to VSS                         |     | 24  |     | dB         |
|                                       |             | GS Connect VSS through $100k \pm 5\%$ |     | 18  |     |            |
|                                       |             | Tie GS pin to VDD                     |     | 12  |     |            |
|                                       |             | GS Connect VDD through $100k \pm 5\%$ |     | 6   |     |            |
|                                       |             | Floating Node                         |     | 0   |     |            |
| Differential Input Resistance         | $R_{IN}$    | $A_v = 24dB$                          |     | 35  |     | $k\Omega$  |
|                                       |             | $A_v = 18dB$                          |     | 70  |     |            |
|                                       |             | $A_v = 12dB$                          |     | 140 |     |            |
|                                       |             | $A_v = 6dB$                           |     | 280 |     |            |
|                                       |             | $A_v = 0dB$                           |     | 558 |     |            |

## Electrical Characteristics (continued)

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

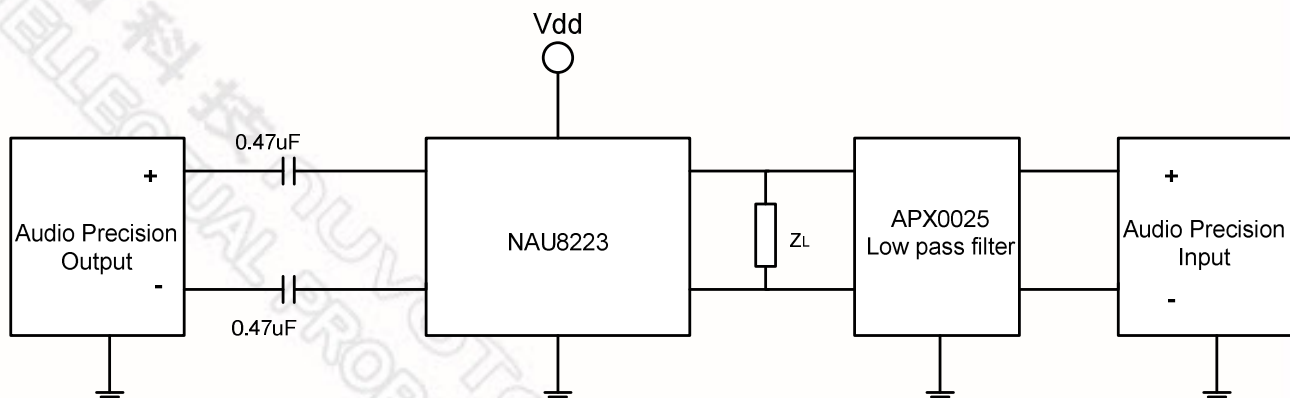
| Parameter                     | Symbol             | Comments/Conditions                                   | Min | Typ  | Max | Units |
|-------------------------------|--------------------|-------------------------------------------------------|-----|------|-----|-------|
| <b>Normal Operation</b>       |                    |                                                       |     |      |     |       |
| 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)<br>A Weighted      |     | -72  |     | dBV   |
| Power Supply Rejection Ratio  | DC PSRR            | VDD = 2.5V to 5.5V                                    |     | 98   |     | dB    |
|                               | AC PSRR*           | V <sub>RIPPLE</sub> =<br>0.2V <sub>pp</sub> @217Hz**  |     | 87   |     | dB    |
|                               |                    | V <sub>RIPPLE</sub> = 0.2V <sub>pp</sub> @1KHz        |     | 74   |     |       |
|                               |                    | V <sub>RIPPLE</sub> =<br>0.2V <sub>pp</sub> @10KHz    |     | 54   |     |       |
| Channel Crosstalk             |                    | f <sub>IN</sub> = 1kHz,<br>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



## 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 NAU8223 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

The NAU8223 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 100k $\Omega$ $\pm$ 5% resistor | 18                 |
| GS tie to VDD                                             | 12                 |
| GS connect to VDD through 100k $\Omega$ $\pm$ 5% resistor | 6                  |
| Floating (open node)                                      | 0                  |

### 6.2 Device Protection

The NAU8223 includes device protection for three operating scenarios. They are

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

#### 6.2.1 Thermal Overload Protection

When the device internal junction temperature reaches 130°C, the NAU8223 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 47mSec, the output drivers will be enabled again.

#### 6.2.2 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 14uSec, the output drivers will be disabled for 47mSec. 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 14uSec. This cycle will continue until the short circuit is removed. The short circuit threshold is set at 2.1A.

#### 6.2.3 Supply under Voltage Protection

If the supply voltage drops under 2.1V, the output drivers will be disabled while the NAU8223 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.



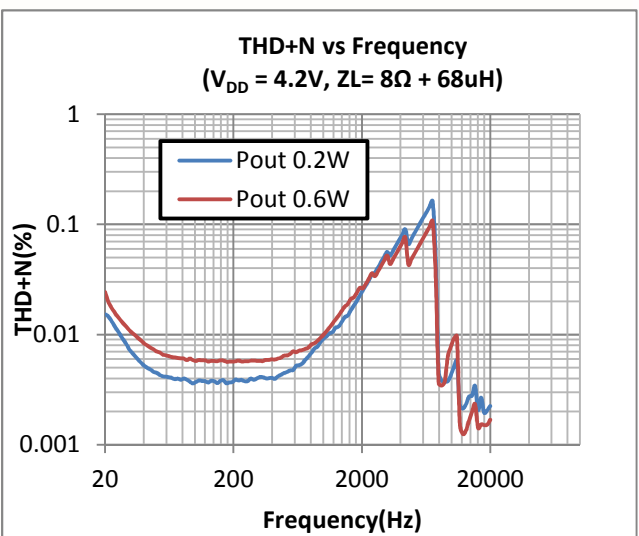
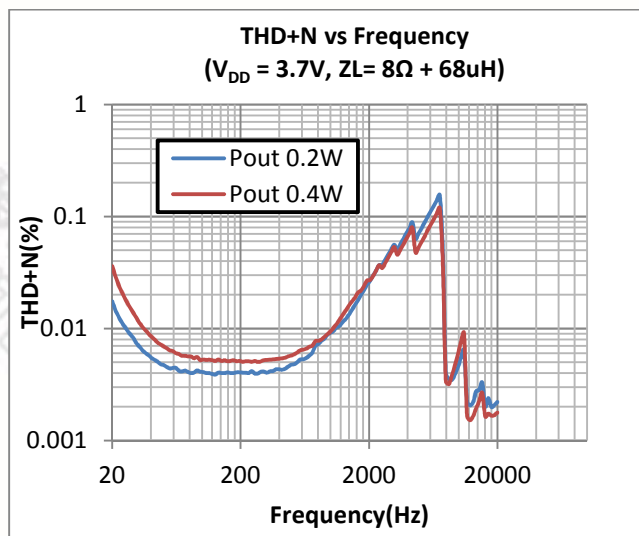
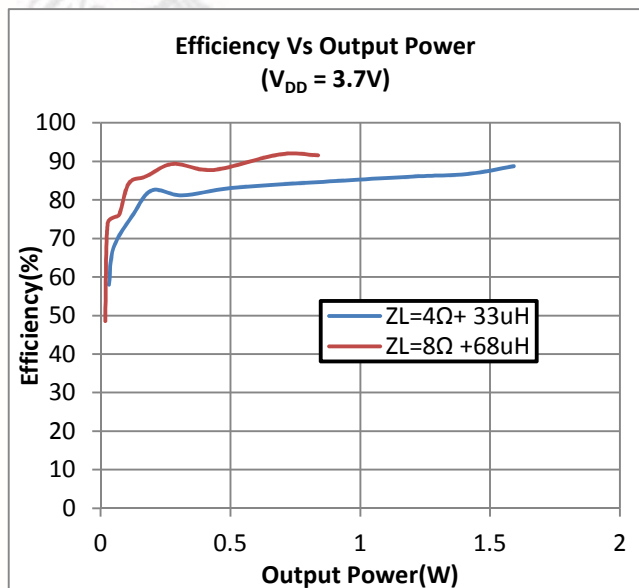
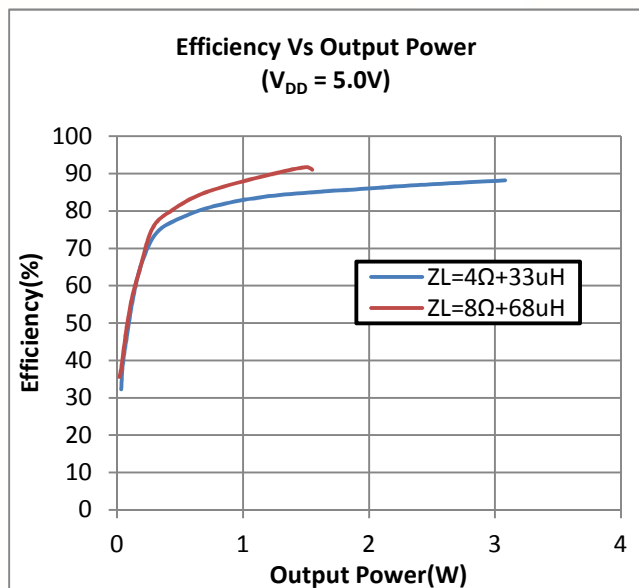
## 6.3 Power up and Power down Control

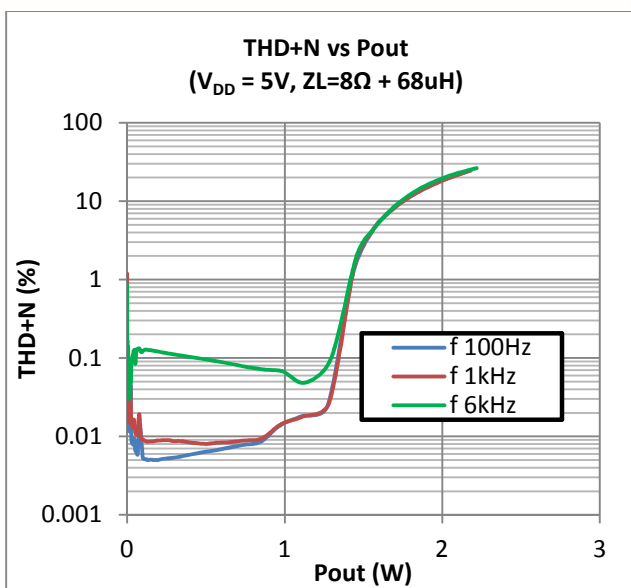
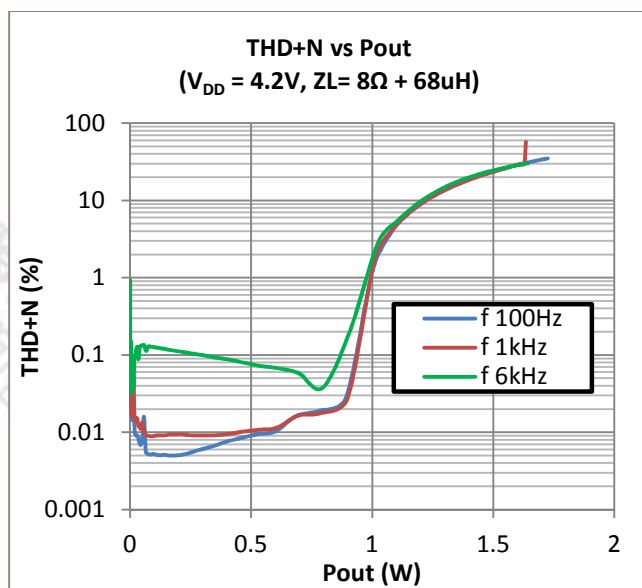
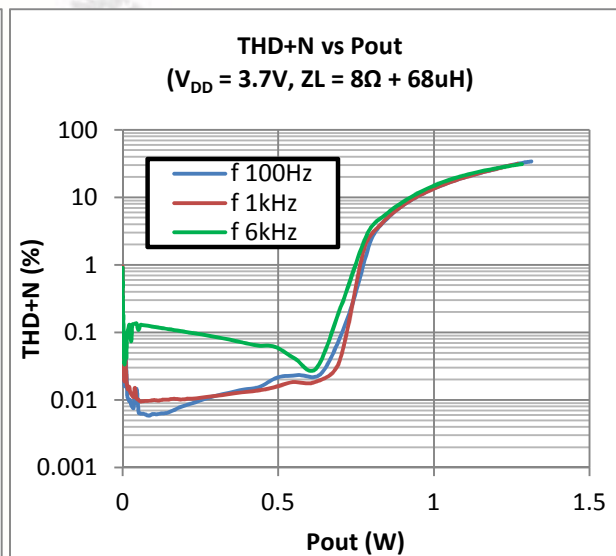
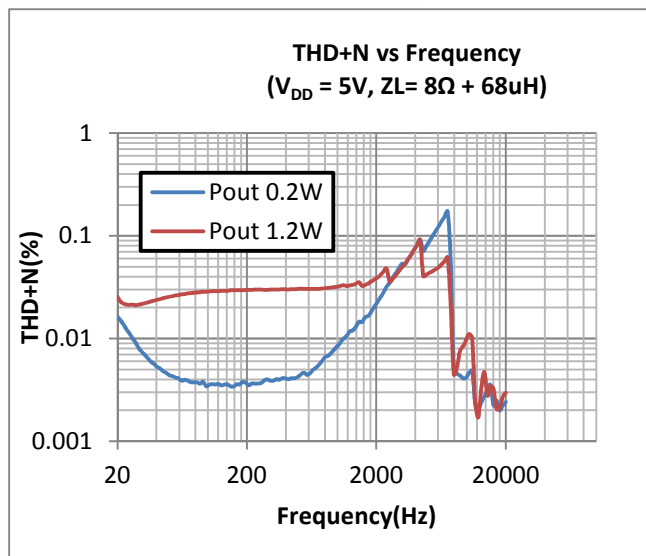
When the supply voltage ramps up, the internal power on reset circuit gets triggered. At this time all internal circuits will be set to power down state. The device can be enabled by setting the EN pin high. Upon setting the EN pin high, the device will go through an internal power up sequence in order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

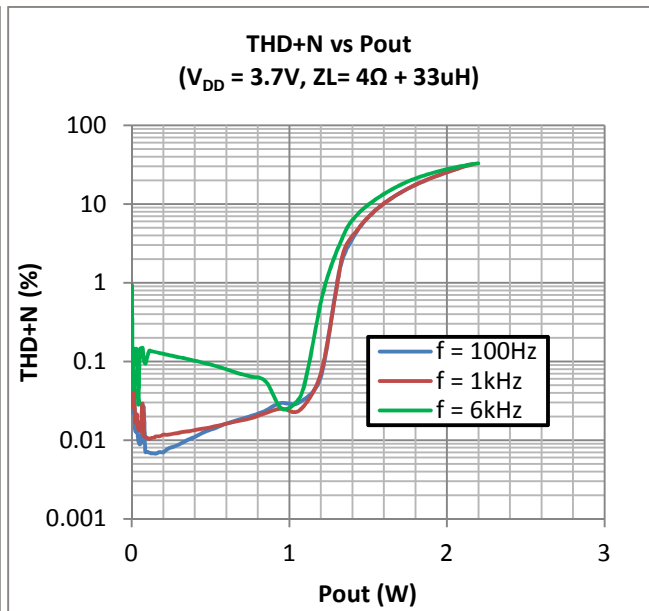
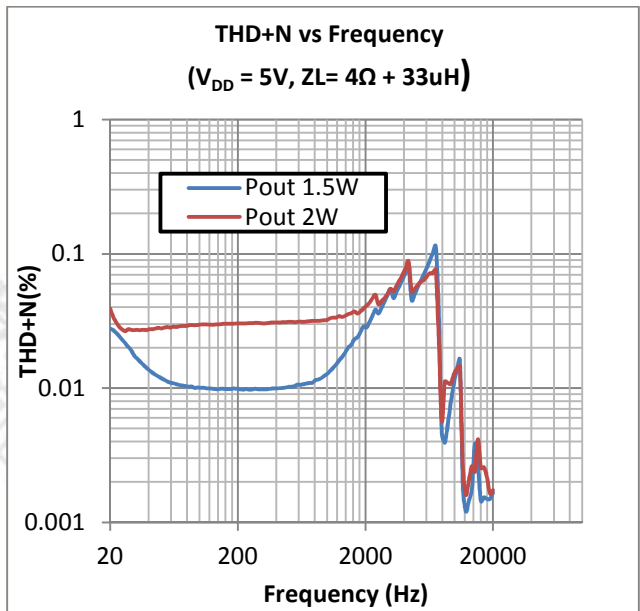
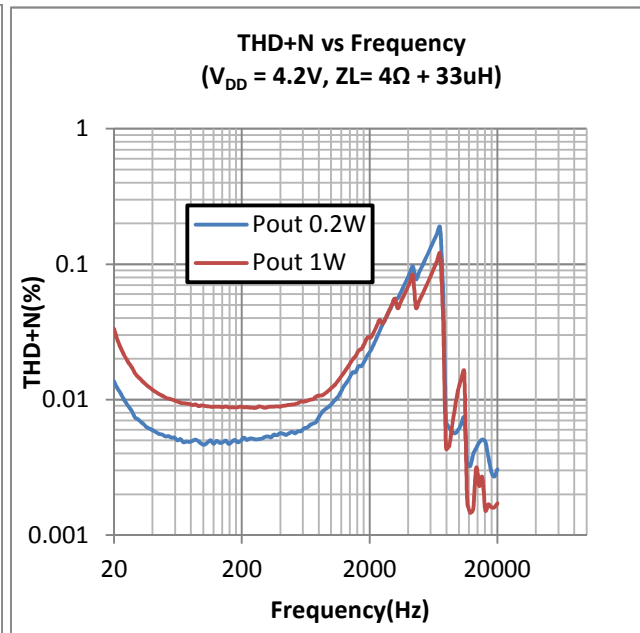
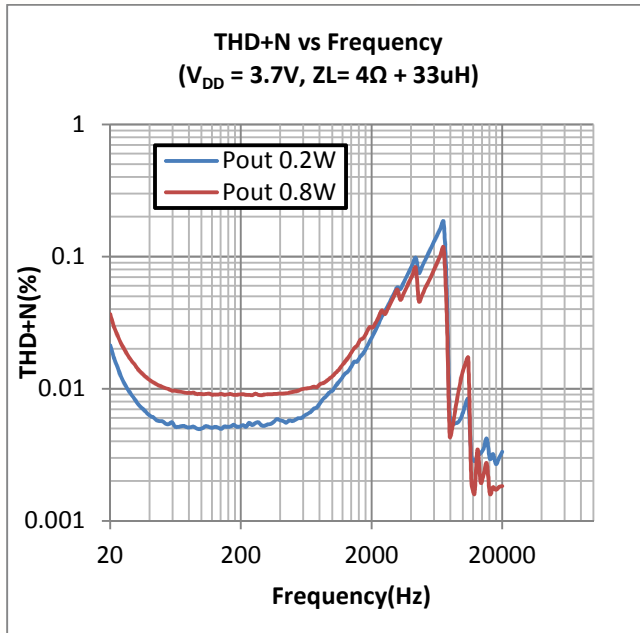
It is important to keep the input signal at zero amplitude or enable the mute condition in order to minimize the 'pops' when the EN pin is toggled.

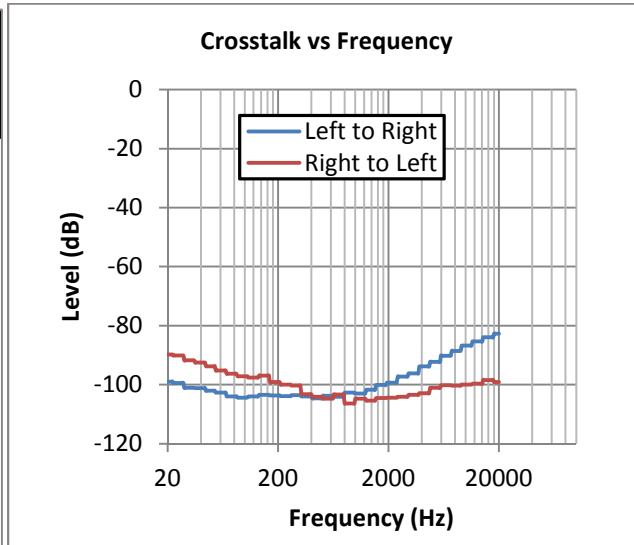
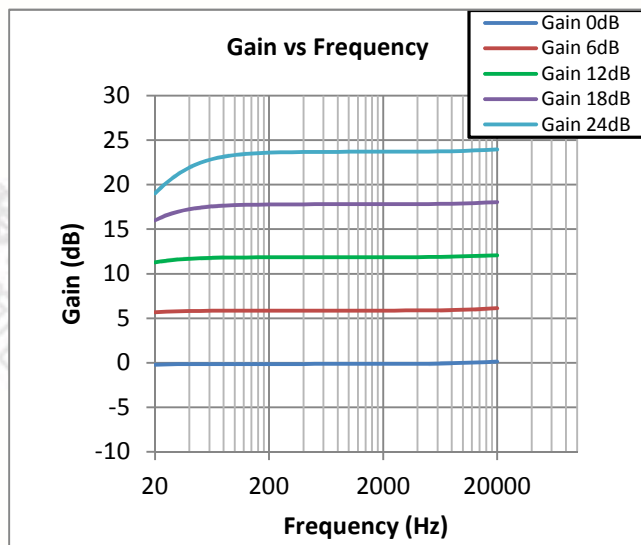
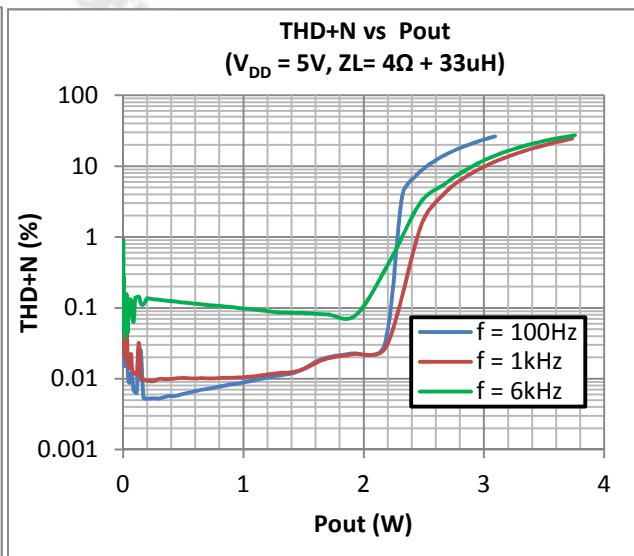
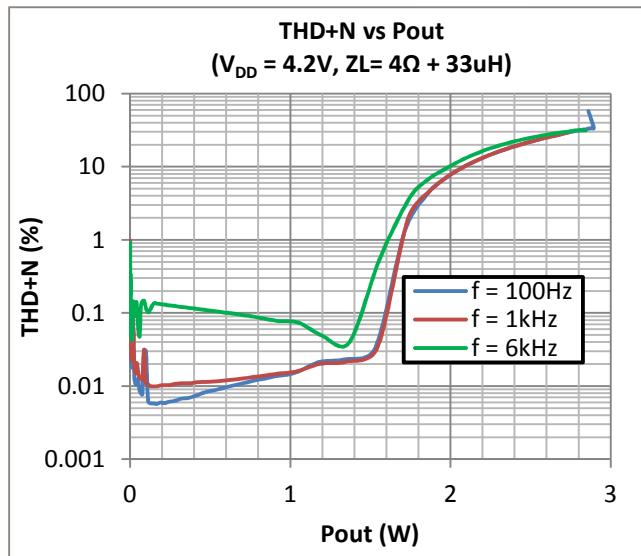
## 7 Typical Operating Characteristics

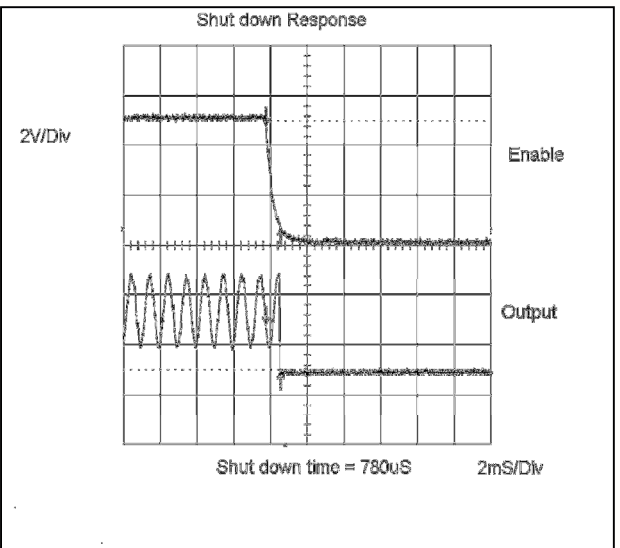
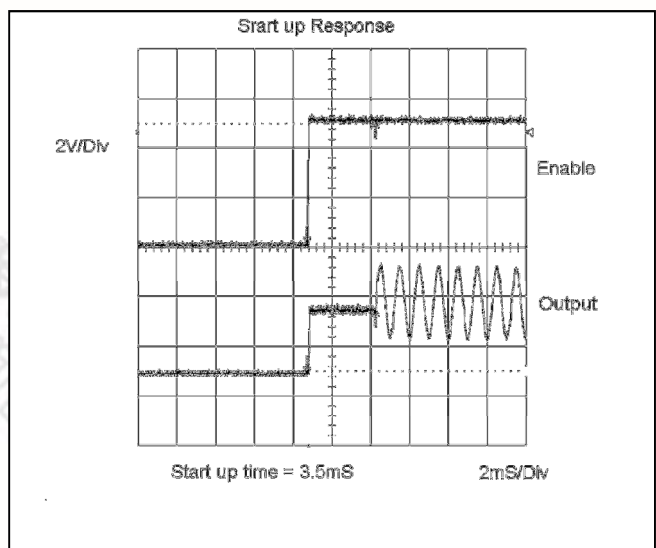
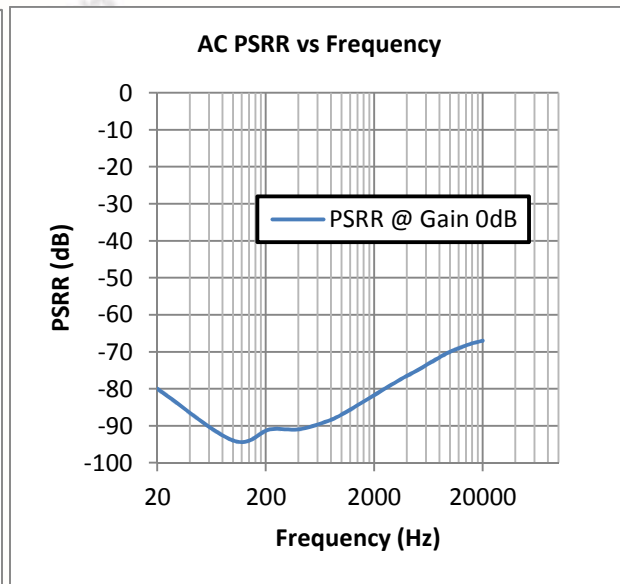
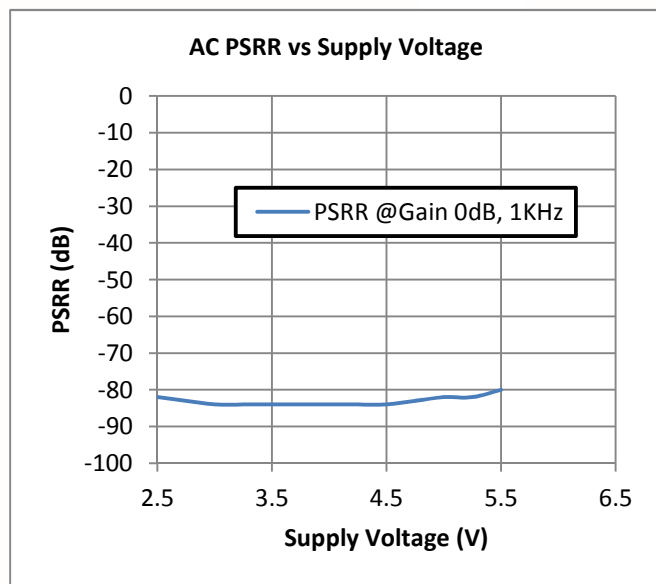
Conditions:  $V_{DD} = 5V$ ,  $V_{SS} = 0V$ ,  $A_v = 12dB$ ,  $Z_L = \infty$ , Bandwidth = 20Hz to 22kHz,  $T_A = 25^\circ C$ , unless otherwise noted

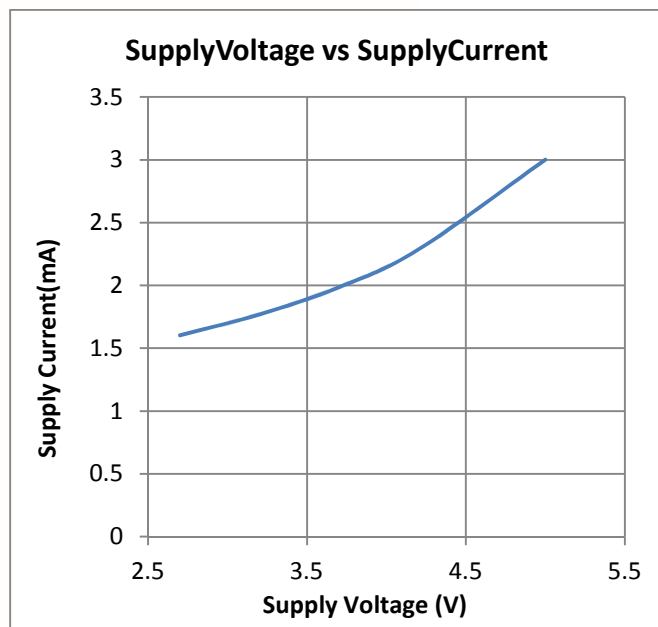






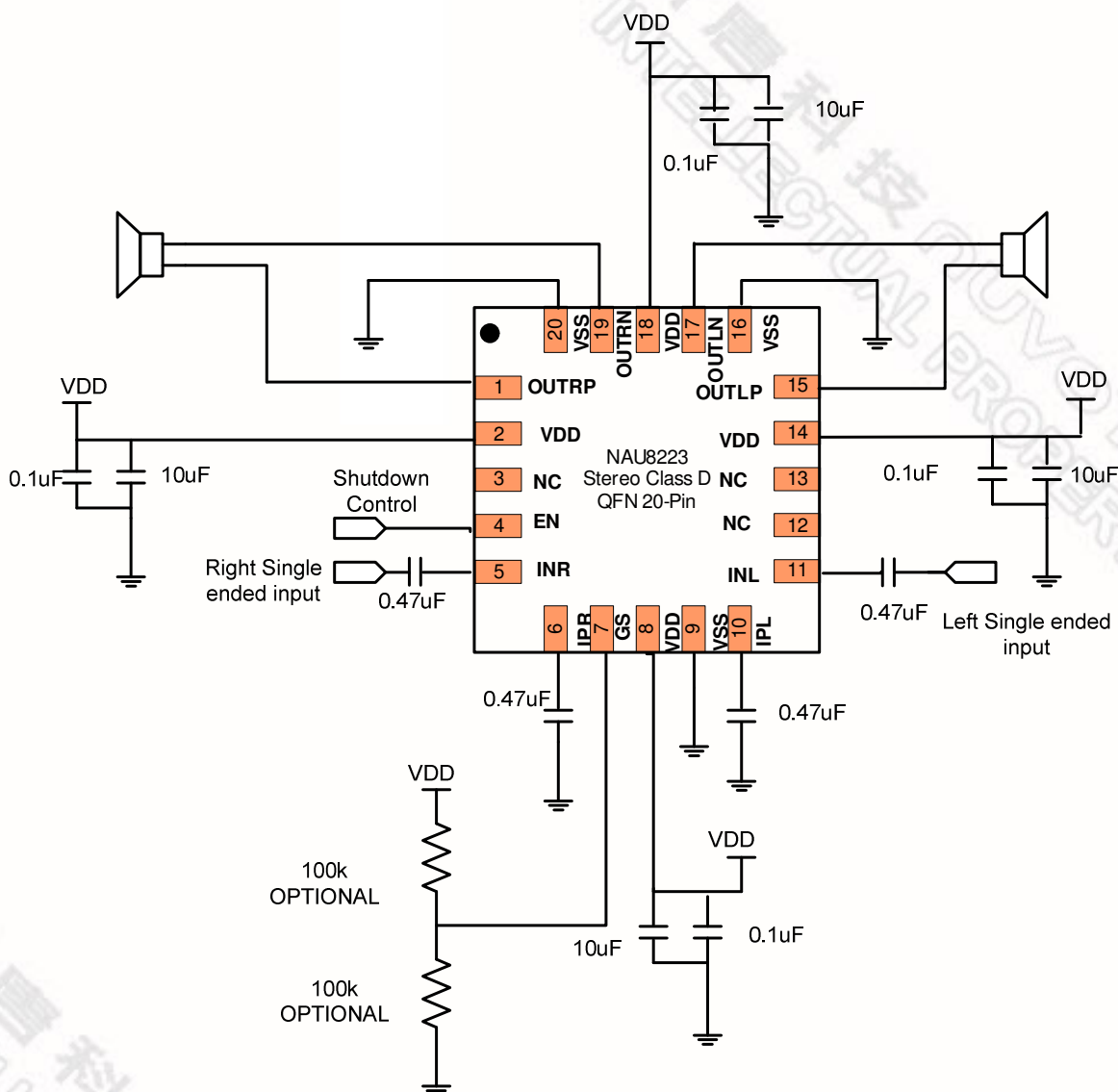






## 8 Application Information

### 8.1 Application diagram



**P.S.** GS Pin – The 100k $\Omega$  resistors are optional. GS can be floating for internal gain setting = 0dB. Please refer Section 2.1 (Gain Setting) for the detailed explanation.

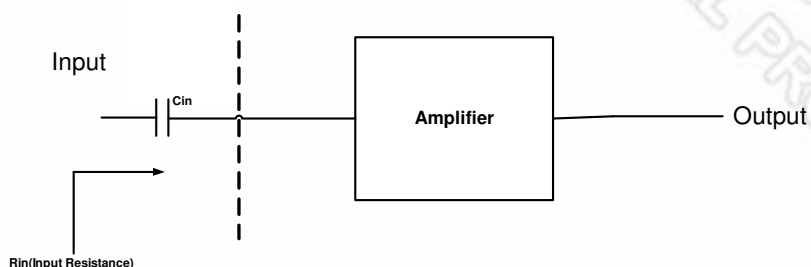


## 8.2 Component selection

### 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

Where  $f_c$  is the desired cut off frequency of the High pass filter.

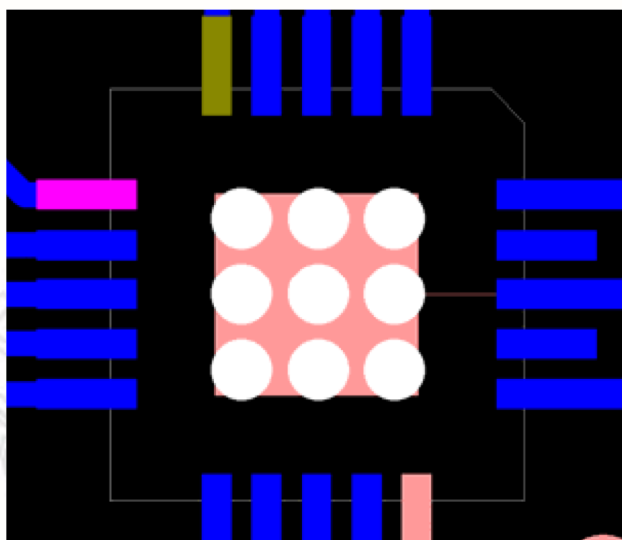


### Bypass Capacitors

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 NAU8223 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 NAU8223. This pad is internally connected to Vss. A typical layout is shown below.

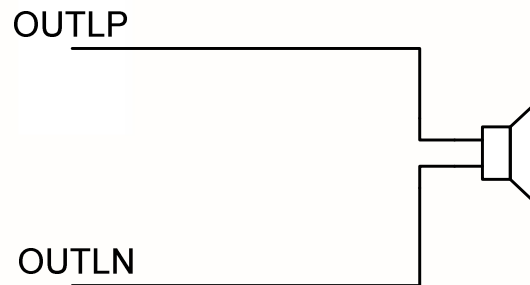


The PCB has to be designed in such a manner that it should have nine vias in 3x3 grid under NAU8223. The vias should have hole size of 12mil and a spacing of 30mils. The pad size of the vias is 24mils. The vias on the top side of the board should be connected with a copper pour that has an area of 2mm x 2mm, centered underneath the NAU8223. 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 NAU8223 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.



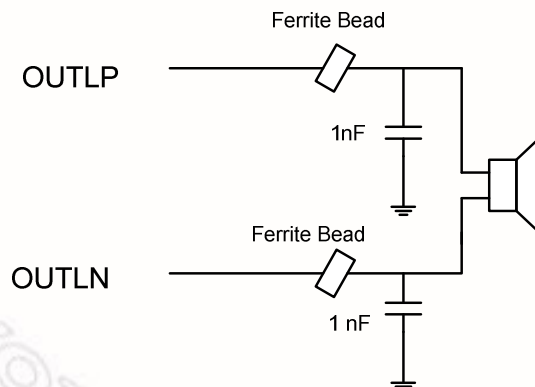
**NAU8223 outputs connected to speaker without filter circuit**

## 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.

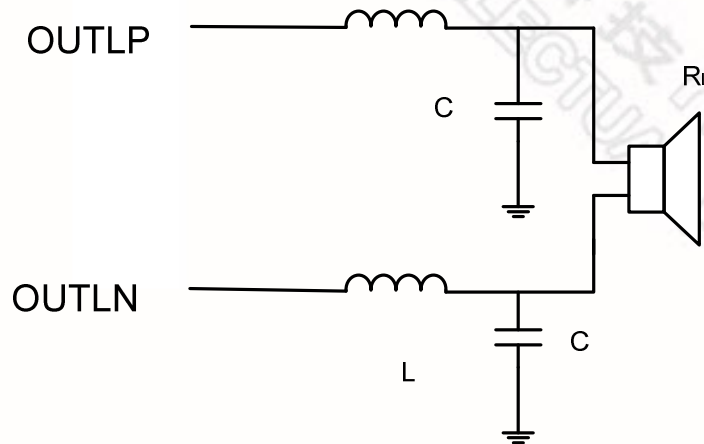


**NAU8223 outputs connected to speaker with Ferrite Bead filter**

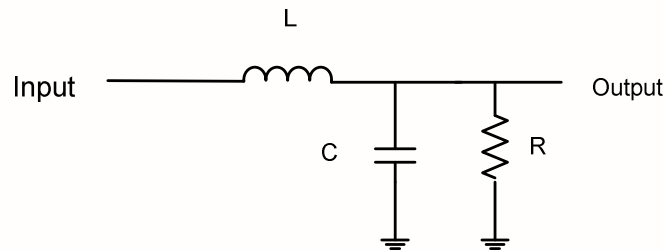
The characteristic of ferrite bead is such that it offers higher impedance at high frequencies. For better EMI performance select ferrite bead which offers highest impedance at high frequencies, so that it will attenuate the signals at higher frequencies. Usually the ferrite beads have low impedance 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 NAU8223 outputs connected to the speaker with LC filter circuit.  $R_L$  is the resistance of the speaker coil.



NAU8223 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

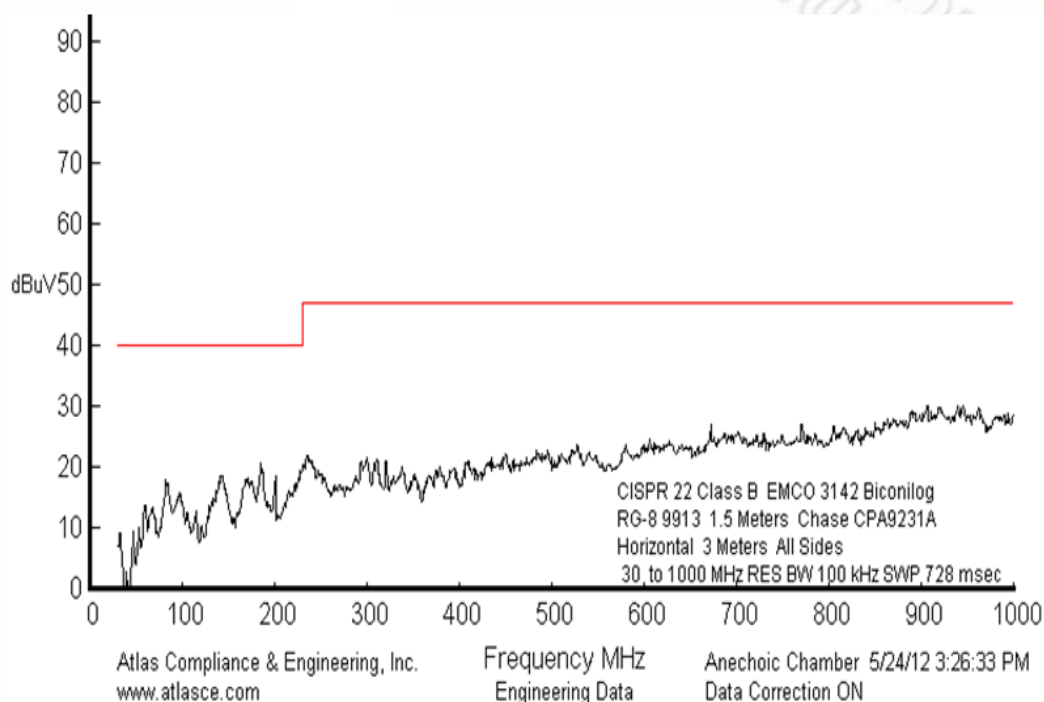
$$2\pi f_c = \frac{1}{\sqrt{LC}} \quad f_c \text{ is the cutoff frequency}$$

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

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

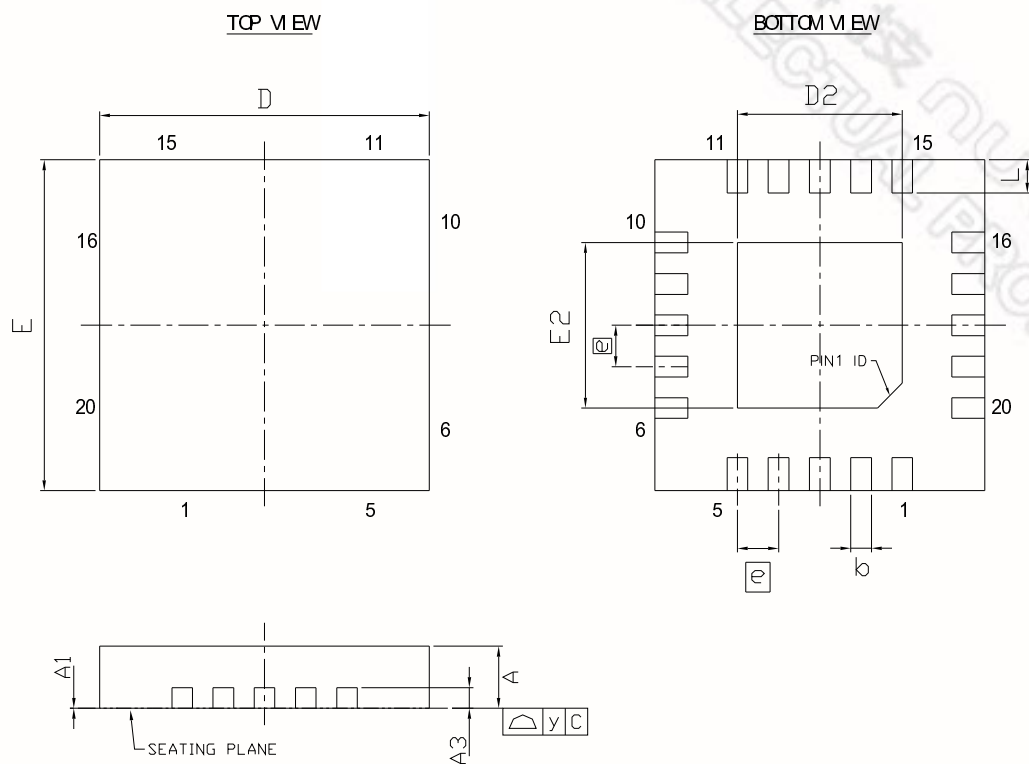
## 8.6 NAU8223 EMI performance

The NAU8223 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 NAU8223 with ferrite beads and speaker cable length of 30cm.



## 9 Package Dimensions

### 9.1 QFN20L 4X4 MM<sup>2</sup>, Pitch:0.50 MM

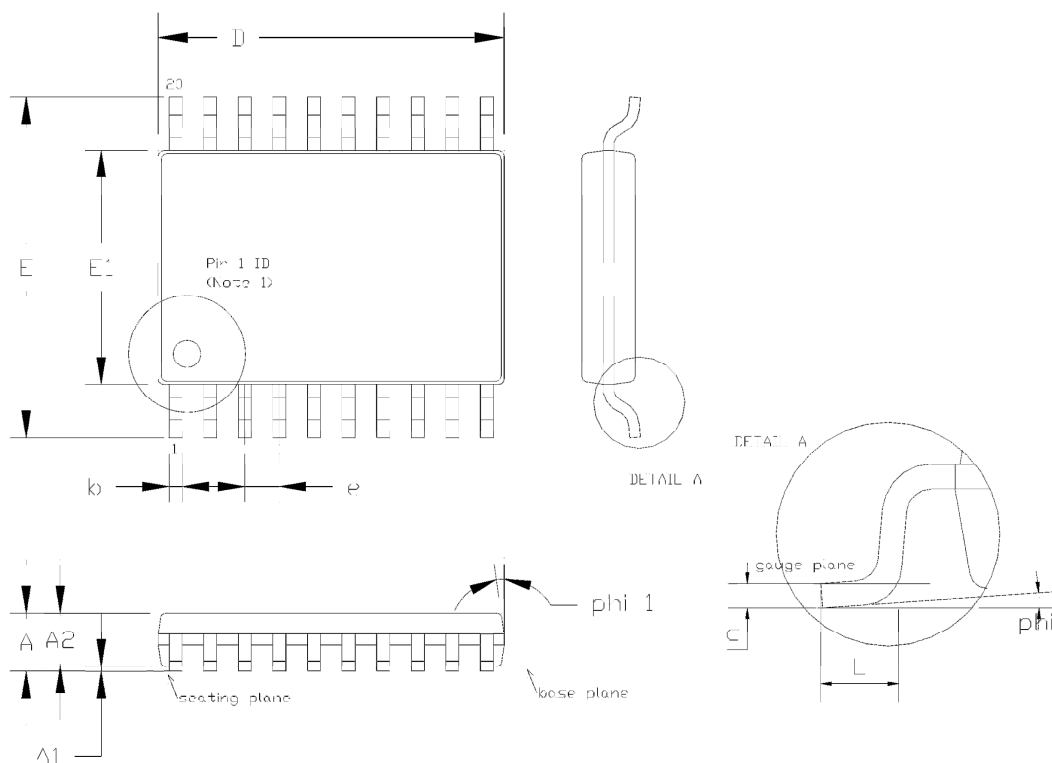


Controlling Dimension :Millimeters

| SYMBOL | DIMENSION (MM) |      |      | DIMENSION (Inch) |         |         |
|--------|----------------|------|------|------------------|---------|---------|
|        | MIN.           | NOM. | MAX. | MIN.             | NOM.    | MAX.    |
| A      | 0.70           | 0.75 | 0.80 | 0.02756          | 0.02953 | 0.03150 |
| A1     | 0              | 0.02 | 0.05 | 0                | 0.0079  | 0.00197 |
| A3     | 0.203 REF      |      |      | 0.0079 REF       |         |         |
| b      | 0.18           | 0.25 | 0.30 | 0.00709          | 0.00984 | 0.01181 |
| D      | 3.90           | 4.00 | 4.10 | 0.1535           | 0.1575  | 0.1614  |
| D2     | 1.90           | 2.00 | 2.10 | 0.0748           | 0.0787  | 0.0827  |
| E      | 3.90           | 4.00 | 4.10 | 0.1535           | 0.1575  | 0.1614  |
| E2     | 1.90           | 2.00 | 2.10 | 0.0748           | 0.0787  | 0.0827  |
| e      | 0.50 BSC       |      |      | 0.01969 BSC      |         |         |
| L      | 0.30           | 0.40 | 0.50 | 0.01181          | 0.01574 | 0.01969 |
| y      | 0.08           |      |      | 0.00315          |         |         |

Note:D2,E2 by die size difference .

## 9.2 TSSOP20L 4.4X6.5 MM<sup>2</sup>, Pitch:0.65 MM



| Description                                        | Symbol   | mm       |      |      | inch      |       |       |
|----------------------------------------------------|----------|----------|------|------|-----------|-------|-------|
|                                                    |          | min      | typ  | max  | min       | typ   | max   |
| Package height                                     | A        | --       | --   | 1.20 | --        | --    | 0.047 |
| Stand off                                          | A1       | 0.05     | --   | 0.15 | 0.002     | --    | 0.006 |
| Package body thickness                             | A2       | 0.80     | 1.00 | 1.05 | 0.031     | 0.039 | 0.041 |
| Width of terminal leads, inclusive lead finish     | b        | 0.19     | --   | 0.30 | 0.007     | --    | 0.012 |
| Thickness of terminal leads, inclusive lead finish | c        | 0.09     | --   | 0.20 | 0.004     | --    | 0.008 |
| Package length                                     | D        | 6.40     | 6.50 | 6.60 | 0.252     | 0.256 | 0.260 |
| Package width                                      | E        | 6.40 BSC |      |      | 0.252 BSC |       |       |
| Package body width                                 | E1       | 4.30     | 4.40 | 4.50 | 0.169     | 0.173 | 0.177 |
| Lead pitch                                         | e        | 0.65 BSC |      |      | 0.026 BSC |       |       |
| Length of terminal for soldering to substrate      | L        | 0.45     | 0.60 | 0.75 | 0.018     | 0.024 | 0.030 |
| Angle of lead mounting area                        | phi [°]  | 0        | --   | 8    | 0         | --    | 8     |
| mold release angle                                 | phi1 [°] | 12 REF   |      |      | 12 REF    |       |       |
| Number of terminal positions                       | N        | 20       |      |      | 20        |       |       |

**Note:** the mm values are valid, the inch values contains rounding errors

## 10 Ordering Information

Nuvoton Part Number Description

NAU8223 \_G

**Package Material:**

**G** = Pb-free Package

**Package Type:**

**Y** = 20-Pin QFN Package

**W** = 20-Pin TSSOP Package

## Version History

| VERSION | DATE         | PAGE                   | DESCRIPTION                                                                                                                     |
|---------|--------------|------------------------|---------------------------------------------------------------------------------------------------------------------------------|
| Rev1.0  | March, 2012  | P.8, P.9               | Preliminary Revision<br>Updated typical characteristics                                                                         |
| Rev1.1  | March, 2012  | P.2, P.10              | Updated Pin No.<br>Added application diagrams                                                                                   |
| Rev1.2  | May, 2012    | NA                     | Updated Electrical Characteristics                                                                                              |
| Rev1.3  | July, 2012   | P.4, P.5,<br>P.10-P.18 | Added Application information section<br>Added/Modified Typical operating Characteristics<br>Updated Electrical Characteristics |
| Rev1.4  | August, 2013 | P.4, P.5,<br>P.22,P.23 | Added TSSOP20 Package information section                                                                                       |

Table 1: Version History

### Important Notice

Nuvoton products are not designed, intended, authorized or warranted for use as components in systems or equipment intended for surgical implantation, atomic energy control instruments, airplane or spaceship instruments, transportation instruments, traffic signal instruments, combustion control instruments, or for other applications intended to support or sustain life. Furthermore, Nuvoton products are not intended for applications wherein failure of Nuvoton products could result or lead to a situation wherein personal injury, death or severe property or environmental damage could occur.

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