ft6203

1.25W Fully Differential Audio Power Amplifier

GENERAL DESCRIPTION

The ft6203 is a mono fully differential audio amplifier designed to drive a speaker with 8Ω impedance while consuming minimum PCB area. The ft6203 operates from 2.5V to 5.5V, drawing only 1.9mA of quiescent current. It is available in DFN3X3-8L and MSOP-8L packages.

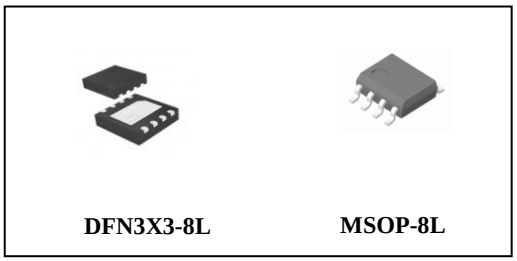
The ft6203 provides multiple features including 87dB PSRR from 90Hz to 5kHz, improved RF-rectification immunity, and a minimum number of external components required, which altogether make it ideal for mobile phones, PDAs, and other portable devices applications.

APPLICATIONS

- Mobile Phone
- Mini Sound Box
- PDA
- Portable electronic devices

FEATURES

- Output power: 1.25W (8Ω, 5V, 1% THD+N)
- Fully differential input to reduce RF rectification
- PSRR: 87dB (typical) at 217Hz
- THD+N: 0.06% at 1kHz (1W)
- Wide supply voltage range: 2.5V to 5.5V
- Quiescent current: 1.9mA
- Shutdown current: 0.1μA (typical)
- Available packages: DFN3X3-8L and MSOP-8L



APPLICATION CIRCUIT

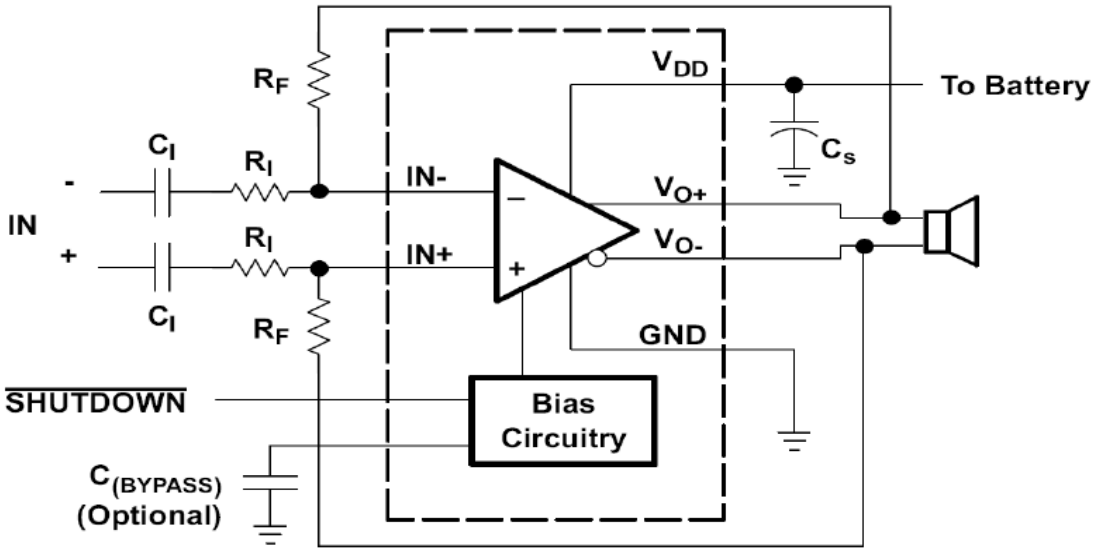
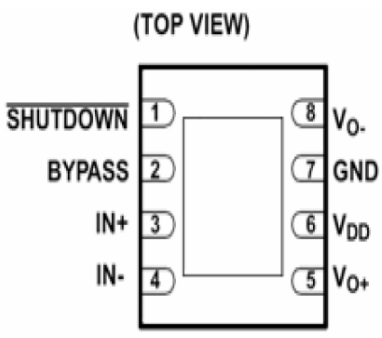


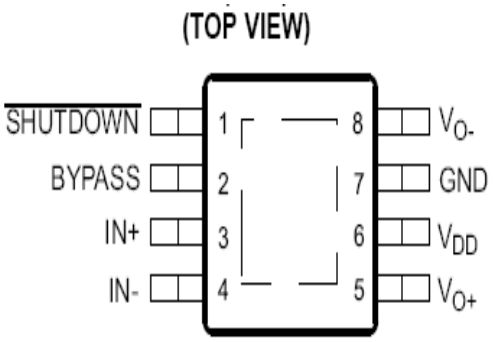
Figure 1: Typical Audio Amplifier Application Circuit

PIN CONFIGURATION AND DESCRIPTION



ft6203D

DFN3X3-8L



ft6203M

MSOP-8L

SYMBOL	DFN3X3-8L	MSOP-8L	DESCRIPTION
BYPASS	2	2	Mid-supply voltage. Adding a bypass capacitor improves PSRR.
GND	7	7	Ground
IN-	4	4	Negative differential input
IN+	3	3	Positive differential input
$\overline{\text{SHUTDOWN}}$	1	1	Shutdown terminal (active low logic)
V_{DD}	6	6	Power Supply
V_{O+}	5	5	Positive BTL output
V_{O-}	8	8	Negative BTL output
Thermal Pad			Connect to ground. Thermal pad must be soldered down in all applications to property secure device on the PCB.

ORDERING INFORMATION

PART NUMBER	TEMPERATURE RANGE	PACKAGE
ft6203D	-40°C to +85°C	DFN3X3-8L
ft6203M	-40°C to +85°C	MSOP-8L

ABSOLUTE MAXIMUM RATINGS

PARAMETER	VALUE
Supply voltage, VDD	−0.3V to 6.0V
Input voltage SD	−0.3V to VDD+0.3V
Storage temperature	−65°C to +150°C
Total power dissipation	See Dissipation Rating Table
T_A	-40°C to +85°C
T_J	-40°C to +125°C

Note: Stresses beyond those listed under absolute maximun ratings may cause permanent damage to the device. These are stress ratings only,and functional operation of the device at these or any other conditions beyond those indicated under recommended operating conditions is not implied.Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

RECOMMENDED OPERATING CONDITIONS

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
Supply voltage，V_{DD}		2.5		5.5	V
$\overline{SD}$ High-level input voltage, V_{IH}		1.5			V
$\overline{SD}$ Low-level input voltage, V_{IL}				0.5	V
Common-mode input voltage, V_{IC}	V_{DD} = 2.5 V, 5.5 V, CMRR ≤ -60 dB	0.5		V_{DD}-0.8	V
Operating free-air temperature, T_A		-40		85	°C
Load impedance, Z_L			8		Ω

POWER DISSIPATION RATINGS

PART NUMBER	POWER RATING (TA ⩽ 25°C)	DERATING FACTOR	POWER RATING (TA ⩽ 70°C)	POWER RATING (TA ⩽ 85°C)
ft6203M	885mW	8.8mW /°C	486mW	354mW
ft6203D	2.7W	21.8mW /° C	1.7W	1.4W

ELECTRICAL CHARACTERISTICS

TA = 25**°C**, Gain = 1V/V unless otherwise noted

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNIT
$\lvert V_{OO} \rvert$	Output offset voltage (measured differentially)	V_I=0V, V_{DD}=2.5V to 5.5V			1		mV
PSRR	Power supply rejection ratio	V_{DD}=2.5V to 5.5V		70	90		dB
CMRR	Common mode rejection ratio	V_{DD} = 3.6V to 5.5V, V_{IC} = 0.5V to V_{DD}-0.8		65	70		dB
		V_{DD} = 2.5 V, V_{IC} =0.5V to 1.7V			55		
$\lvert I_{IH} \rvert$	High-level input current	V_{DD}=5.5V, V_I=5.8V				1.2	μA
$\lvert I_{IL} \rvert$	Low-level input current	V_{DD}=5.5V, V_I= - 0.3V				1.2	μA
I_{DD}	Supply current	V_{DD}=2.5V to 5.5V, no load V($\overline{SHOUTDOWN}$)=1.50V			1.9	3.0	mA
$I_{(SD)}$	Shutdown current	V_{DD}=2.5V to 5.5V V($\overline{SHOUTDOWN}$)=0.50V			0.01	0.1	μA
V_{OL}	Low-level output voltage	R_L = 8Ω, V_{IN+} =VDD, V_{IN-}=0V or V_{IN+}=0V, V_{IN-} =V_{DD}	V_{DD} = 5.5V		0.30	0.46	V
			V_{DD} = 3.6V		0.22		
			V_{DD} = 2.5V		0.19	0.26	
V_{OH}	High-level output voltage	R_L = 8Ω, V_{IN+} =VDD, V_{IN-}=0V or V_{IN+}=0V, V_{IN-} =V_{DD}	V_{DD} = 5.5V	4.8	5.12		V
			V_{DD} = 3.6V		3.28		
			V_{DD} = 2.5V	2.1	2.24		

ELECTRICAL CHARACTERISTICS

TA=25°C, Gain = 1V/V, RL=8Ω unless otherwise noted

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNIT
P_O	Output power	THD+N=1%, f=1kHz	V_{DD}=5V		1.25		W
			V_{DD}=3.6V		0.63		
			V_{DD}=2.5V		0.3		
THD+N	Total harmonic distortion plus noise	V_{DD}=5V, P_O=1W, f=1kHz			0.06		%
		V_{DD}=3.6V, P_O=0.5W, f=1kHz			0.07		
		V_{DD}=3.6V, P_O=200mW, f=1kHz			0.08		
PSRR	Supply ripple rejection ratio	C_{BYPASS}=0.47 μ F, V_{DD}=2.5V to 3.6V, Inputs ac-ground with C_i=2μF	f=217Hz, V_{RIPPLE}= 200mV_{pp}		87		dB
		C_{BYPASS}=0.47 μ F, V_{DD}=3.6V to 5.5V, Inputs ac-ground with C_i=2μF			82		
		C_{BYPASS}=0.47 μ F, V_{DD}=2.5V to 5.5V, Inputs ac-ground with C_i=2μF			74		
V_N	Output voltage noise	f=20Hz to 20kHz	No weighting		17		μV_{RMS}
			A weighting				
SNR	Signal-to-noise ratio	V_{DD}=5V, P_O=1W			104		dB
CMRR	Common mode rejection ratio	V_{DD}=2.5V to 5.5V, resistor tolerance=1%, gain=4V/V, V_{ICM}=200mV_{PP}	f=20Hz to 1kHz		85		dB
			f=20Hz to 20kHz		74		
ZO	Output impedance	Shutdown mode		10			kΩ
Z_I	Input impedance				2		MΩ
T_{WU}	Wake-up time	V_{DD}=5V, C_{BYPASS}=0.1uF			160		ms
	Shutdown attenuation	f=20Hz to 20kHz, R_F=R_I=20kΩ			80		dB

TYPICAL PERFORMANCE CHARACTERISTICS

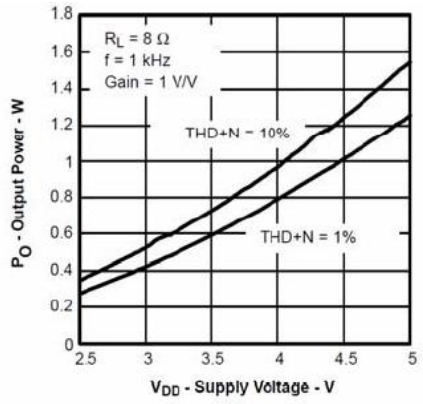


Figure 2: Output Power vs. Supply Voltage

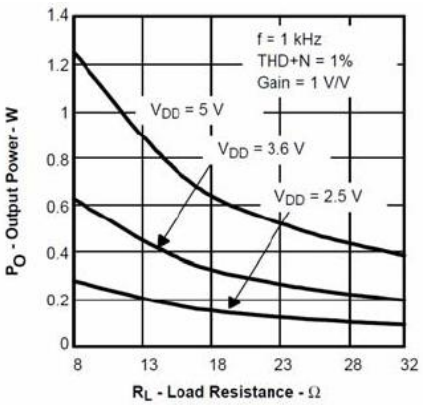


Figure 3: Output Power vs. Load Resistance

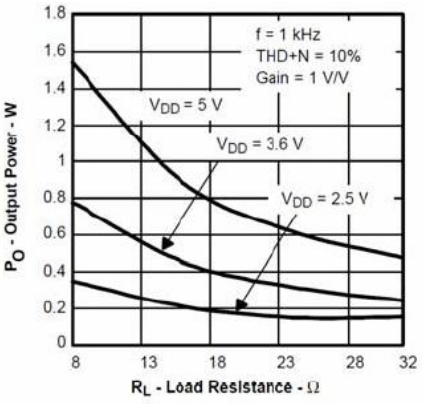


Figure 4: Output Power vs. Load Resistance

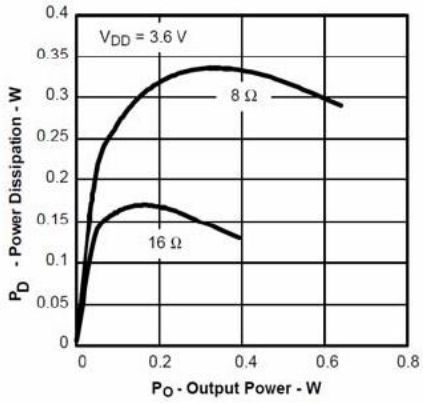


Figure 5: Power Dissipation vs. Output Power

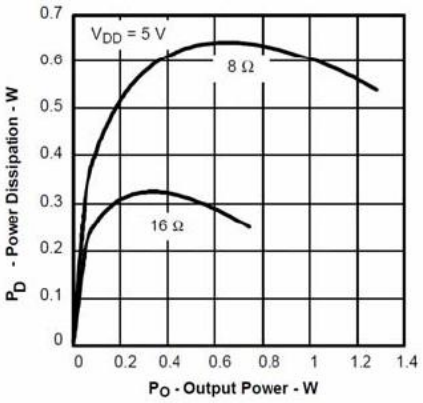


Figure 6: Power Dissipation vs. Output Power

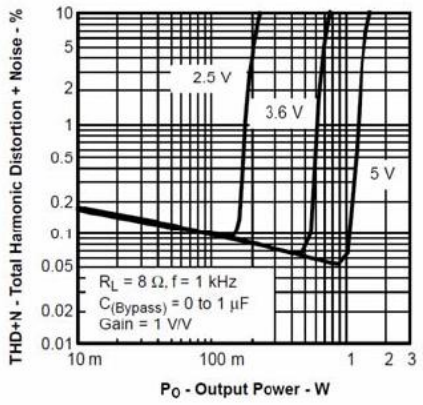


Figure 8: THD+N vs. Output Power

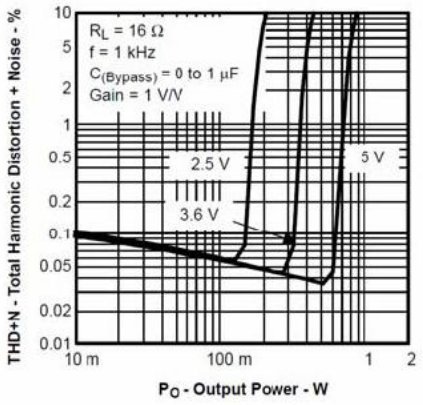


Figure 9: THD+N vs. Output Power

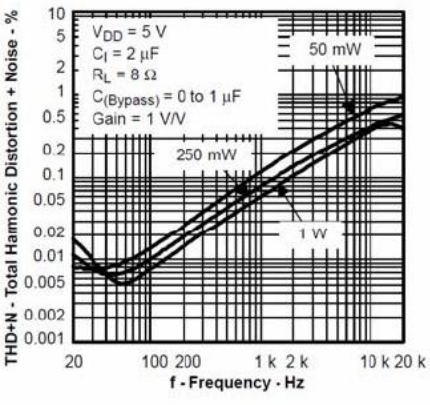


Figure 10: THD+N vs. Frequency

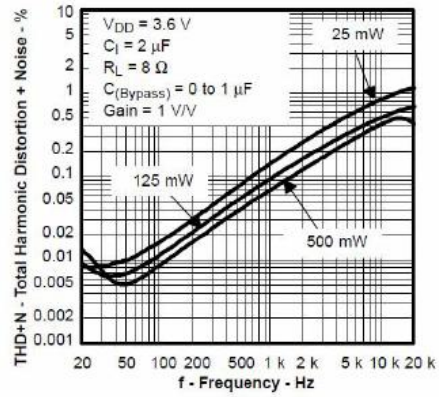


Figure 11: THD+N vs. Frequency

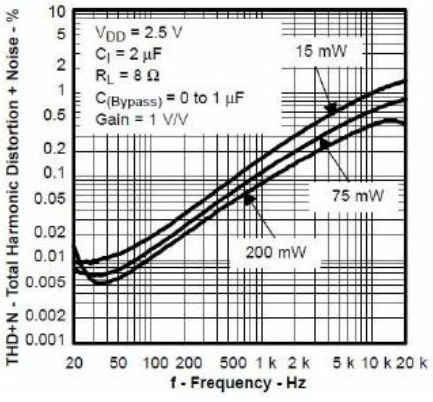


Figure 12: THD+N vs. Frequency

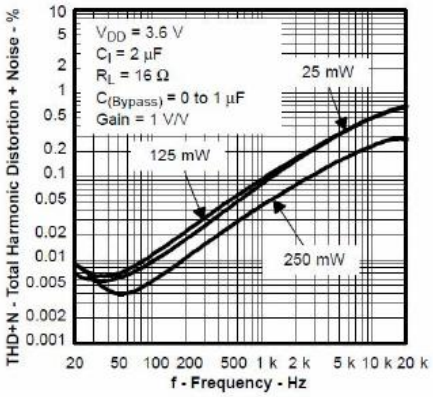


Figure 13: THD+N vs. Frequency

TYPICAL PERFORMANCE CHARACTERISTICS

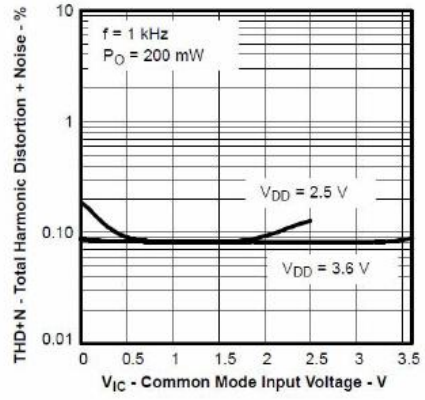


Figure 14: THD+N vs. V_{IC}

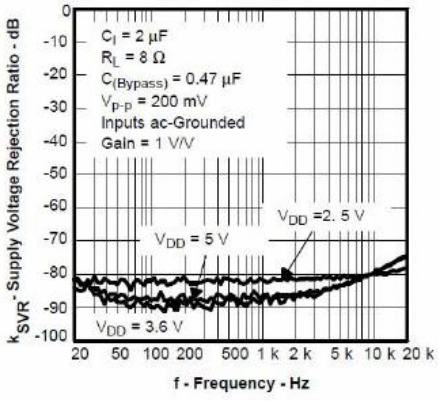


Figure 15: PSRR vs. Frequency

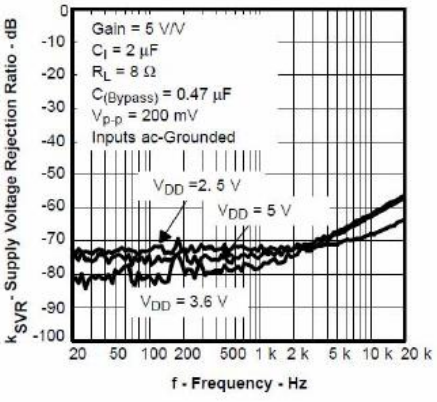


Figure 16: PSRR vs. Frequency

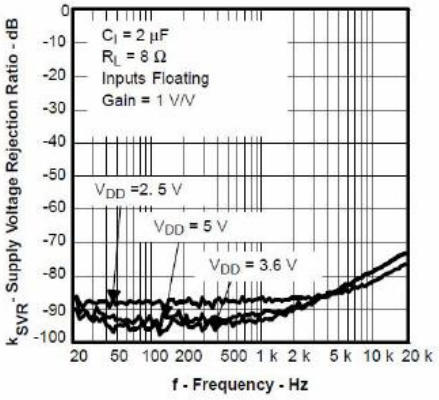


Figure 17: PSRR vs. Frequency

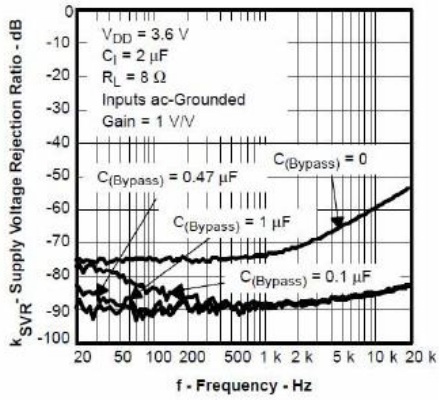


Figure 18: PSRR vs. Frequency

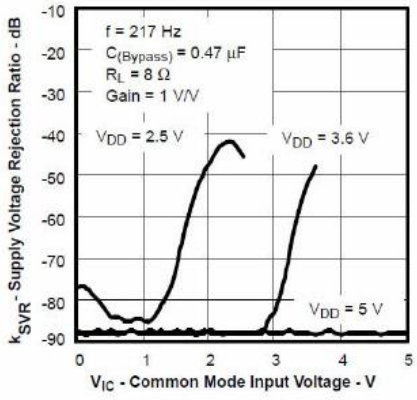


Figure 19: PSRR vs. Frequency

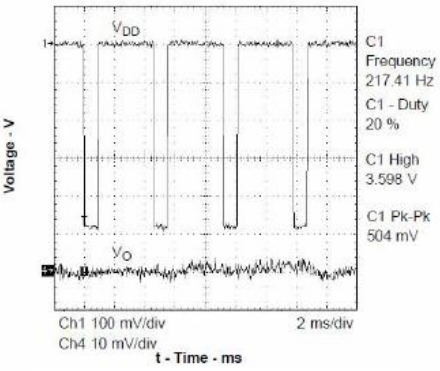


Figure 20: GSM Power Supply Rejection vs. Time

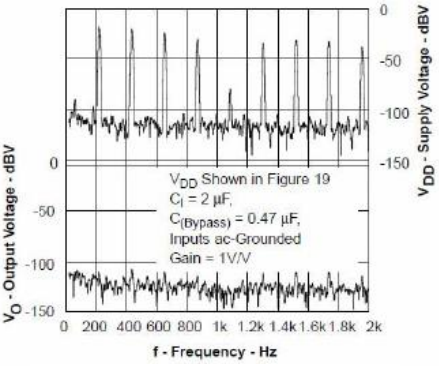


Figure 21: GSM Power Supply Rejection vs. Frequency

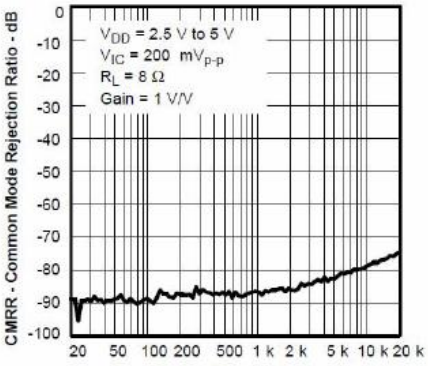


Figure 22: Common Mode Rejection vs. Frequency

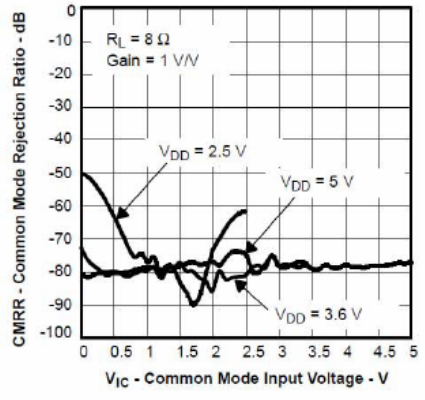


Figure 23: Common Mode Rejection vs. V_{IC}

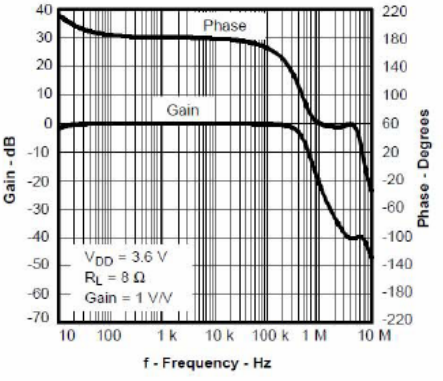


Figure 24: Closed Loop Gain / Phase vs. Frequency

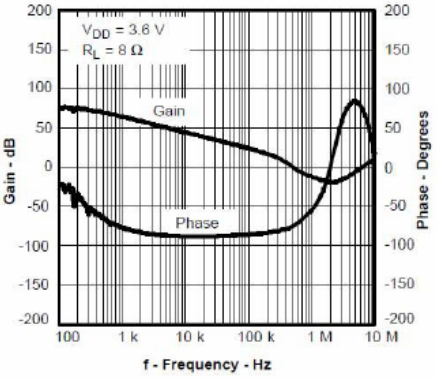


Figure 25: Open Loop Gain / Phase vs. Frequency

TYPICAL PERFORMANCE CHARACTERISTICS

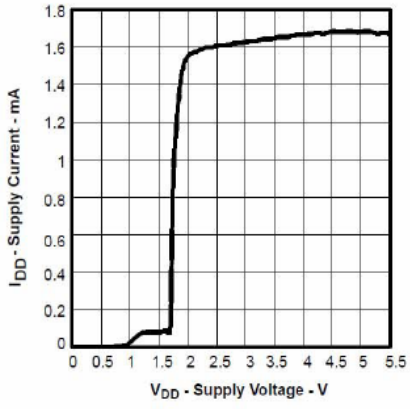


Figure 26: Supply Current vs. Supply Voltage

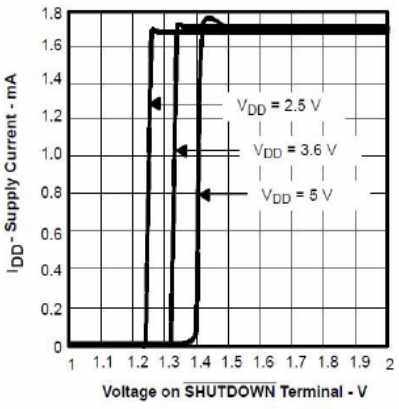


Figure 27: Supply Current vs. Shutdown Voltage

APPLICATION INFORMATION

FULLY DIFFERENTIAL AMPLIFIER

The ft6203 is a fully differential audio amplifier with differential inputs and outputs. The fully differential amplifier consists of a differential amplifier and a common-mode amplifier. The differential amplifier ensures that the amplifier outputs a differential voltage that is equal to the differential input times the gain. The common-mode feedback ensures that the common-mode voltage at the output is biased around VDD/2 regardless of the common-mode voltage at the input.

ADVANTAGES OF FULLY DIFFERENTIAL AMPLIFIERS

- Input coupling capacitors not required: A fully differential amplifier with good CMRR, like the ft6203, allows the inputs to be biased at voltage other than mid-supply. For example, if a DAC has mid-supply lower than the mid-supply of the ft6203, the common-mode feedback circuit adjusts for that, and the ft6203 outputs are still biased at mid-supply of the ft6203. The inputs of the ft6203 can be biased from 0.5V to VDD-0.8V. If the inputs are biased outside of that range, input coupling capacitors are required.
- Mid-supply bypass capacitor, $C_{(BYPASS)}$, not required: The fully differential amplifier does not required a bypass capacitor. This is because any shift in the mid-supply affects both positive and negative channels equally and cancels at the differential output. However, removing the bypass capacitor slightly worsens power supply rejection ratio (PSRR), but a slight decrease of PSRR may be acceptable when an additional component can be eliminated.
- Better RF-immunity: GSM handsets save power by turning on and shutting off the RF transmitter at a rate of 217Hz. The transmitted signal is picked-up on input and output traces. The fully differential amplifier cancels the signal much better than the typical audio amplifier.

APPLICATION SCHEMATICS

Figure 28 through Figure 29 show application schematics for differential and single-ended inputs. Typical values are shown in the following Table1.

COMPONENT	VALUE
R_I	10 kΩ
R_F	10 kΩ
C_{BYPASS} (*)	0.22 μF
C_S	1 μF
C_I	0.22 μF
* $C_{(BYPASS)}$ is optional in typical design.	

Table1

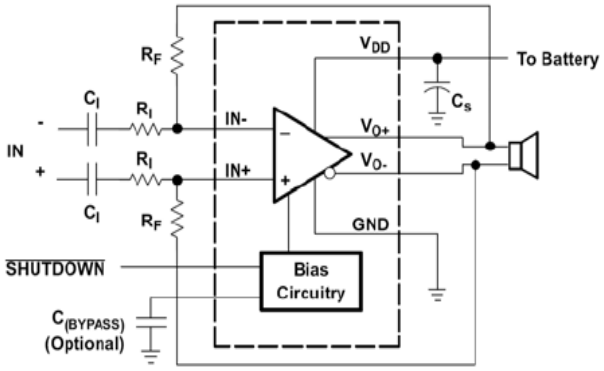


Figure 28: Differential Input Schematic

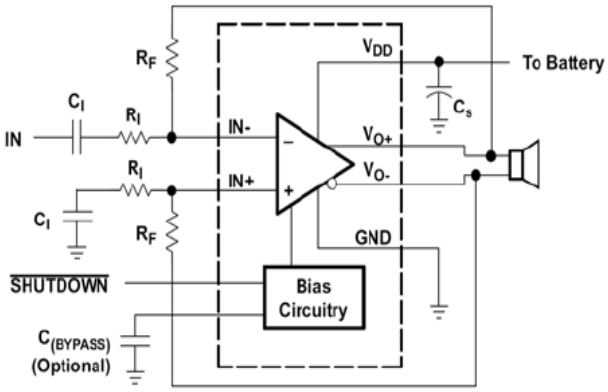


Figure 29: Single-end Input Schematic

SELECTING COMPONENTS

RESISTORS (R_F AND R_I)

The input (R_I) and feedback resistors (R_F) set the gain of the amplifier according to Equation 1.

Gain = R_F/R_I (1)

R_F and R_I should range from 1kΩ to 100kΩ. Most graphs were taken with R_F=R_I=20kΩ.

Resistor matching is very important in fully differential amplifiers. The balance of the output on the reference voltage depends on matched ratios of the resistors. CMRR, PSRR, and the cancellation of the second harmonic distortion diminish if resistor mismatch occurs. Therefore, it is recommended to use 1% tolerance resistors or better to keep the performance optimized.

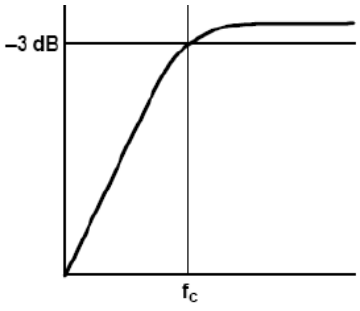
BYPASS CAPACITOR (C_{BYPASS})

Bypass capacitor in ft6203 application filters noise and increases the PSRR. The bigger the capacitance is, the better noise filtering can be achieved. However, big capacitance slows down the rise time of the amplifier during the power-up or reactivation from SHUTDOWN mode. Therefore, it should be weighed between the noise filtering requirement and the rise time consideration to find out the optimum capacitor specification.

INPUT CAPACITOR (C_I)

In the differential and single-ended input application an input capacitor, C_I, is required to allow the amplifier to bias the input signal to the proper dc level. In this case, C_I and R_I form a high-pass filter with the corner frequency determined in Equation 2.

$$f_C = \frac{1}{2\pi R_I C_I} \qquad (2)$$



The value of C_I is important to consider as it directly affects the bass (low frequency) performance of the circuit. Consider the example where R_I is 10kΩ and the specification calls for a flat bass response down to 100Hz.

Equation 2 is reconfigured as Equation 3.

$$C_I = \frac{1}{2\pi R f c} \qquad (3)$$

In this example, C_I is 0.16 μF, so one would likely choose a value in the range of 0.22 μF to 0.47 μF. A further consideration for this capacitor is the leakage path from the input source through the input network (R_I, C_I) and the feedback resistor (R_F) to the load. This leakage current creates a dc offset voltage at the input to the amplifier that reduces useful headroom, especially in high gain applications. For this reason, a ceramic capacitor is the best choice. When polarized capacitors are used, the positive side of the capacitor should face the amplifier input in most applications, as the dc level there is held at $V_{DD}/2$, which is likely higher than the source dc level. It is important to confirm the capacitor polarity in the application.

DECOUPLING CAPACITOR (C_S)

The ft6203 is a high-performance CMOS audio amplifier that requires adequate power supply decoupling to ensure the output total harmonic distortion (THD) is as low as possible. Power supply decoupling also prevents oscillations for long lead lengths between the amplifier and the speaker. For higher frequency transients, spikes, or digital hash on the line, a good low equivalent-series – resistance (ESR) ceramic capacitor, typically 0.1 μF to 1 μF, placed as close as possible to the device V_{DD} lead works best. For filtering lower frequency noise signals, a 10 μF or greater capacitor placed near the audio power amplifier also helps, but is not required in most applications because of the high PSRR of this device.

USING LOW-ESR CAPACITORS

LOW-ESR capacitors are recommended throughout this applications section. A real (as opposed to ideal) capacitor can be modeled simply as a resistor in series with an ideal capacitor. The voltage drop across this resistor minimizes the beneficial effects of the capacitor in the circuit. The lower the equivalent value of this resistance the more the real capacitor behaves like ideal capacitor.

DIFFERENTIAL OUTPUT VERSUS SINGLE-ENDED OUTPUT

Figure 30 shows a Class-AB audio power amplifier (APA) in a fully differential configuration. The ft6203 amplifier has differential outputs driving both ends of the load. There are several potential benefits to this differential drive configuration, but initially consider power to the load. The differential drive to the speaker means that as one side is slewing up, the other side is slewing down, and vice versa. This in effect doubles the voltage swing on the load as compared to a ground referenced load. Plugging $2xV_{O(PP)}$ into the power equation, where voltage is squared, yields 4x the output power from the same supply rail and load impedance (see Equation 4)

$$V_{(rms)} = \frac{V_{O(PP)}}{2\sqrt{2}}$$

$$Power = \frac{V_{(rms)}^2}{R_L} \qquad (4)$$

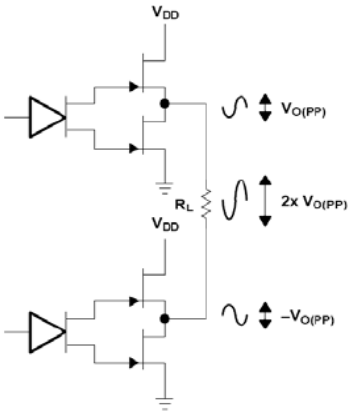


Figure 30: Differential Output Configuration

In a typical wireless handset operation at 3.6V, bridging raises the power into an 8Ω speaker from a singled-ended (SE, ground reference) limit of 200mW to 800mW. In sound power that is a 6dB improvement −which is loudness that can be here. In addition to increased power there are frequency response concerns. Consider the single-supply SE configuration shown in Figure 31. A coupling capacitor is required to block the dc offset voltage from reaching the load. This capacitor can be quite large (approximately 33μF to 1000μF) so it tends to be expensive, heavy, occupy valuable PCB area, and have the additional drawback of limiting low-frequency performance of the system. This frequency-limiting effect is due to the high pass filter network created with the speaker impendence and the coupling capacitance and is calculated with Equation 5.

$$f_C = \frac{1}{2\pi R_L C_C} \qquad (5)$$

For example, a 68μF capacitor with a 8Ω speaker would attenuate low frequencies below 293Hz. The BTL configuration cancels the dc offsets, which eliminates the need for the blocking capacitors. Low-frequency performance is then limited only by the input network and speaker response. Cost and PCB space are also minimized by eliminating the bulky coupling capacitor.

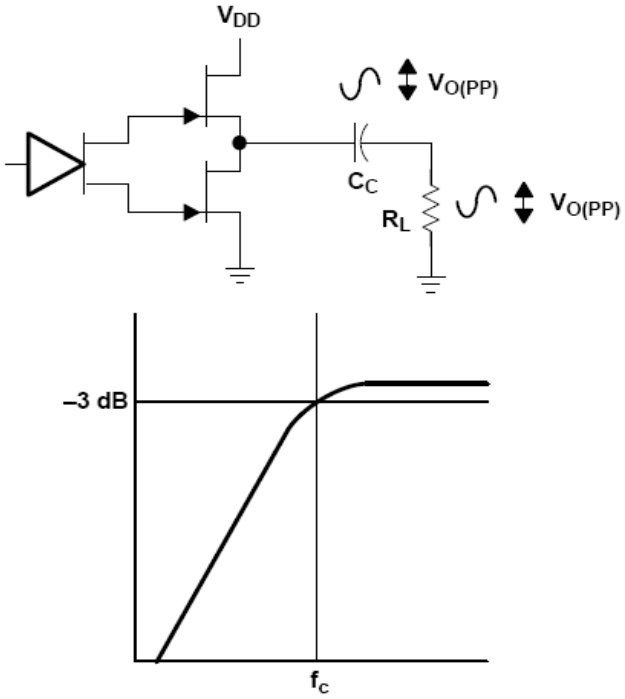


Figure 31: Single-Ended Output and Frequency Response

FULLY DIFFERENTIAL AMPLIFIER EFFICIENCY AND THERMAL INFORMATION

Class-AB amplifiers are inefficient. The primary cause of these inefficiencies is voltage drop across the output stage transistors. There are two components of the internal voltage drop. One is the headroom or dc voltage drop that varies inversely to output power. The second component is due to the sine wave nature of the output. The total voltage drop can be calculated by subtracting the RMS value of the output voltage from V_{DD}. The internal voltage drop multiplied by the average value of the supply current, I_{DD}(avg), determines the internal power dissipation of the amplifier.

An easy-to-use equation to calculate efficiency starts out as being equal to the ratio of power from the power supply to the power delivered to the load. To accurately calculate the RMS and average values of power in the load and in the amplifier, the current and voltage waveform shapes must first be understood (see Figure 32).

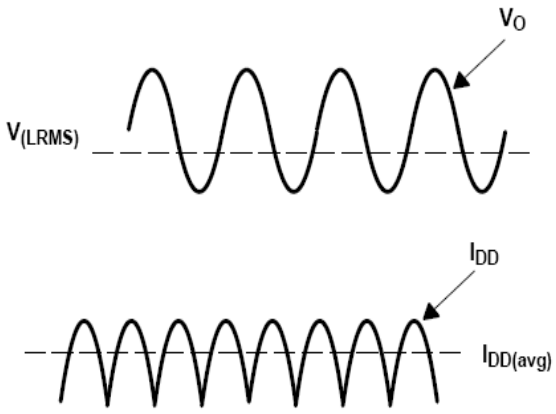


Figure 32: Voltage and Current Waveforms for BTL Amplifiers

Although the voltages and currents for SE and BTL are sinusoidal in the load, currents from the supply are very different between SE and BTL configurations. In an SE application the current waveform is a half-wave rectified shape, whereas in BTL it is a full-wave rectified waveform. This means RMS conversion factors are different. Keep in mind that for most of the waveform both the push and pull transistors are not on at the same time, which supports the fact that each amplifier in the BTL device only draws current from the supply for half the waveform. The following equations are the basis for calculating amplifier efficiency.

$$\text{Efficiency of a BTL amplifier} = \frac{P_L}{P_{SUP}}$$

Where:

$$P_L = \frac{V_{Lrms}^2}{R_L}, \text{ and } V_{LRMS} = \frac{V_P}{\sqrt{2}}, \text{ therefore, } P_L = \frac{V_P^2}{2R_L}$$

And $P_{SUP} = V_{DD} I_{DD}avg$ and $I_{DD}avg = \frac{1}{\pi}\int_0^{\pi} \frac{V_P}{R_L}\sin(t)dt = \frac{1}{\pi} \times \frac{V_P}{R_L}\left[\cos(t)\right]_0^{\pi} = \frac{2V_P}{\pi R_L}$

Therefore,

$$P_{SUP} = \frac{2V_{DD}V_P}{\pi R_L}$$

substituting P_L and P_{SUP} into equation 6,

$$\text{Efficiency of a BTL amplifier} = \frac{\frac{V_P^2}{2R_L}}{\frac{2V_{DD}V_P}{\pi R_L}} = \frac{\pi V_P}{4V_{DD}}$$

where:

$$V_P = \sqrt{2P_L R_L} \qquad (6)$$

Therefore,

$$\eta_{BTL} = \frac{\pi\sqrt{2P_L R_L}}{4V_{DD}} \qquad (7)$$

P_L = Power delivered to load

P_{SUP} = Power drawn from power supply

V_{LRMS} = RMS voltage on BTL load

R_L = Load resistance

V_P = Peak voltage on BTL load

$I_{DD}avg$ = Average current drawn from the power supply

V_{DD} = Power supply voltage

η_{BTL} = Efficiency of a BTL amplifier

OUTPUT POWER (W)	EFFICIENCY (%)	INTERNAL DISSIPATION (W)	POWER FROM SUPPLY (W)	MAX AMBIENT TEMPERATURE (°C)
0.25	31.4	0.55	0.75	62
0.50	44.4	0.62	1.12	54
1.00	62.8	0.59	1.59	58
1.25	70.2	0.53	1.78	65

Table2: Efficiency and Maximum Ambient Temperature vs. Output Power in 5V 8Ω BTL System

Table 2 employs Equation 7 to calculate efficiencies for four different output power levels. Note that the efficiency of the amplifier is quite low for lower power levels and rises sharply as power to the load is increased resulting in a nearly flat internal power dissipation over the normal operating range. Note that the internal dissipation at full output power is less than in the half power range. Calculating the efficiency for a specific system is the key to proper power supply design. For a 1.25W audio system with 8Ω loads and a 5V supply, the maximum draw on the power supply is almost 1.8W.

A final point to remember about Class-AB amplifiers is how to manipulate the terms in the efficiency equitation to the utmost advantage when possible. Note that in Equation 7, V_{DD} is in the denominator. This indicates that as V_{DD} goes down, efficiency goes up.

A simple formula for calculating the maximum power dissipated, P_{Dmax}, may be used for a differential output application:

$$P_{D\,max} = \frac{2\,V_{DD}^2}{\pi^2 R_L} \qquad (8)$$

P_{Dmax} for a 5V, 8Ω system is 634mW.

The maximum ambient temperature depends on the heat sinking ability of the PCB system. The derating factor for the 2mm x 2mm BGA package is shown in the dissipation rating table. Converting this to θ_{JA}:

$$\theta_{JA} = \frac{1}{\text{Derating Factor}} = \frac{1}{0.0088} = 113°C/W \qquad (9)$$

Given θ_{JA}, the maximum allowable junction temperature, and the maximum internal dissipation, the maximum ambient temperature can be calculated with the following equation. The maximum recommended junction temperature for the ft6203 is 125℃.

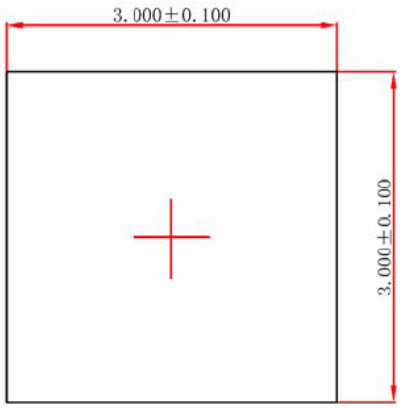
T_A Max = T_J Max – θ_{JA} PDmax = 125 – 113(0.634) = 53.3℃ (10)

Equation 10 shows that the maximum ambient temperature is 53.5℃ at maximum power dissipation with a 5V supply.

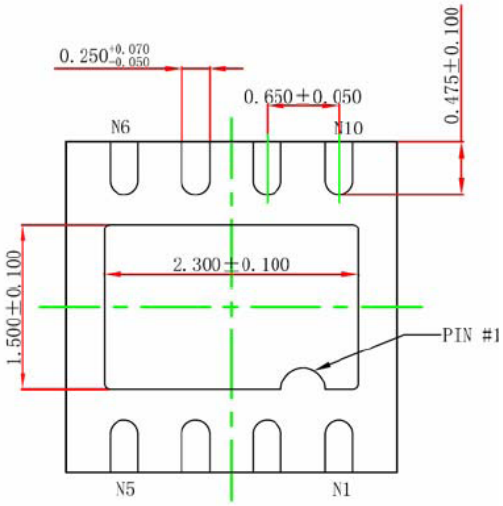
Table 2 shows that for most applications no airflow is required to keep junction temperatures in the specified range. The ft6203 is designed with thermal protection that turns the device off when the junction temperature surpasses 150℃ to prevent damage to the IC. Also, using more resistive than 8Ω speakers dramatically increases the thermal performance by reducing the output current.

PHYSICAL DIMENSIONS

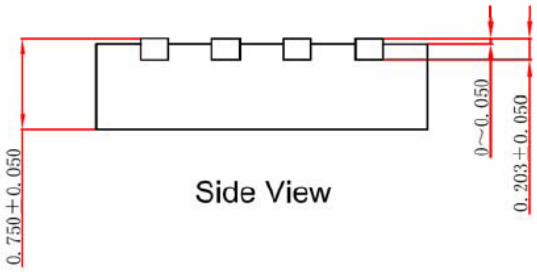
DFN3mmX3mm-8L Package



Top View



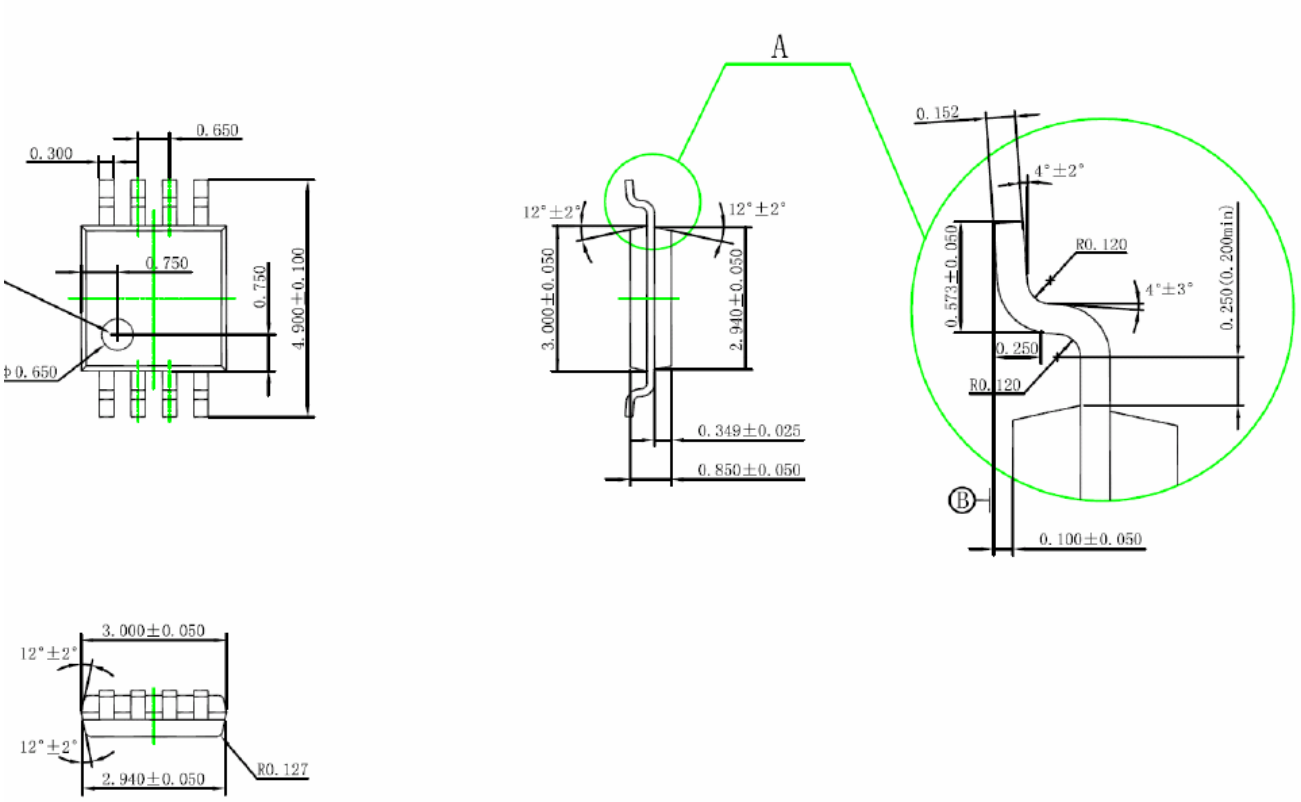
Bottom View



Side View

Unit: millimeters.

MSOP-8L Package



Unit: millimeters.

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