National Semiconductor

March 3, 2008

LM4671 Boomer® Audio Power Amplifier Series
Filterless High Efficiency 2.5W Switching Audio Amplifier

General Description

The LM4671 is a single supply, high efficiency 2.5W switching audio amplifier. A low noise, filterless PWM architecture eliminates the output filter, reducing external component count, board area consumption, system cost, and simplifying design.

The LM4671 is designed to meet the demands of mobile phones and other portable communication devices. Operating on a single 5V supply, it is capable of driving a 4Ω speaker load at a continuous average output of 2.1W with less than 1% THD+N. Its flexible power supply requirements allow operation from 2.4V to 5.5V.

The LM4671 has high efficiency with speaker loads compared to a typical Class AB amplifier. With a 3V supply driving an 8Ω speaker, the IC's efficiency for a 100mW power level is 80%, reaching 88% at 400mW output power.

The LM4671 features a low-power consumption shutdown mode. Shutdown may be enabled by driving the Shutdown pin to a logic low (GND).

The gain of the LM4671 is externally configurable which allows independent gain control from multiple sources by summing the signals.

Key Specifications

- Efficiency @ 3.6V, 100mW into 8Ω speaker — 80% (typ)
- Efficiency @ 3.6V, 400mW into 8Ω speaker — 88% (typ)
- Efficiency @ 5V, 1W into 8Ω speaker — 86% (typ)
- Quiescent current, 3.6V supply — 2.8mA (typ)
- Total shutdown power supply current — 0.01µA (typ)
- Single supply range — 2.4V to 5.5V

Features

- No output filter required for inductive loads
- Externally configurable gain
- Very fast turn on time: 17µs (typ)
- Minimum external components
- "Click and pop" suppression circuitry
- Micro-power shutdown mode
- Available in space-saving microSMD package

Applications

- Mobile phones
- PDAs
- Portable electronic devices

Typical Application

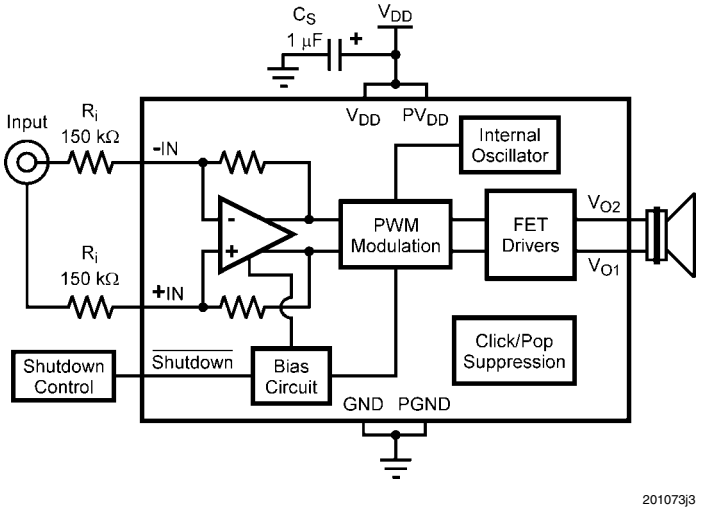

FIGURE 1. Typical Audio Amplifier Application Circuit

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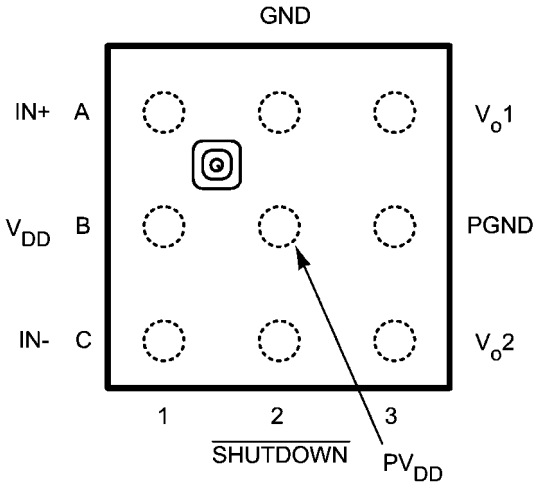
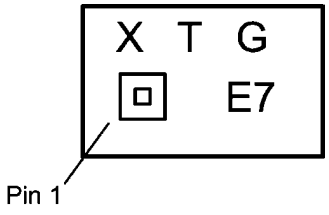
Connection Diagrams

9 Bump micro SMD Package



Top View
Order Number LM4671ITL, LM4671ITLX
See NS Package Number TLA09AAA

micro SMD Marking



Top View
X — Date Code
T— Die Traceability
G — Boomer Family
E7 — LM4671ITL

Absolute Maximum Ratings (Notes 1, 2)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Supply Voltage (Note 1)	6.0V
Storage Temperature	−65°C to +150°C
Voltage at Any Input Pin	V_{DD} + 0.3V ≥ V ≥ GND - 0.3V
Power Dissipation (Note 3)	Internally Limited
ESD Susceptibility, all other pins (Note 4)	2.0kV
ESD Susceptibility (Note 5)	200V
Junction Temperature (T_{JMAX})	150°C
Thermal Resistance	
θ_{JA} (micro SMD)	220°C/W
Soldering Information	
See AN-1112 "microSMD Wafers Level Chip Scale Package."	

Operating Ratings (Notes 1, 2)

Temperature Range	
$T_{MIN} \le T_A \le T_{MAX}$	−40°C ≤ T_A ≤ 85°C
Supply Voltage	2.4V ≤ V_{DD} ≤ 5.5V

Electrical Characteristics (Notes 1, 2)

The following specifications apply for A_V = 2V/V (R_I = 150kΩ), R_L = 15µH + 8Ω + 15µH unless otherwise specified. Limits apply for T_A = 25°C.

Symbol	Parameter	Conditions	LM4671 Typical (Note 6)	LM4671 Limit (Notes 7, 8)	Units (Limits)
$\lvert V_{OS} \rvert$	Differential Output Offset Voltage	V_I = 0V, A_V = 2V/V, V_{DD} = 2.4V to 5.0V	5		mV (max)
$PSRR_{GSM}$	GSM Power Supply Rejection Ratio	V_{DD} = 2.4V to 5.0V	61		dB (min)
$CMRR_{GSM}$	GSM Common Mode Rejection Ratio	V_{DD} = 2.4V to 5.0V V_{IC} = V_{DD}/2 to 0.5V, V_{IC} = V_{DD}/2 to V_{DD} − 0.8V	68		dB (min)
$\lvert I_{IH} \rvert$	Logic High Input Current	V_{DD} = 5.0V, V_I = 5.5V	17	100	µA (max)
$\lvert I_{IL} \rvert$	Logic Low Input Current	V_{DD} = 5.0V, V_I = −0.3V	0.9	5	µA (max)
I_{DD}	Quiescent Power Supply Current	V_{IN} = 0V, No Load, V_{DD} = 5.0V	6.4		mA (max)
		V_{IN} = 0V, No Load, V_{DD} = 3.6V	3.8	6.2	mA
		V_{IN} = 0V, No Load, V_{DD} =2.4V	2.0	3.0	mA (max)
I_{SD}	Shutdown Current	$V_{SHUTDOWN}$ = 0V V_{DD} = 2.4V to 5.0V	0.01	1	µA (max)
V_{SDIH}	Shutdown voltage input high		1.2	1.4	V (min)
V_{SDIL}	Shutdown voltage input low		1.1	0.4	V (max)
R_{OSD}	Output Impedance	$V_{SHUTDOWN}$ = 0.4V	100		kΩ
A_V	Gain		300kΩ/R_I	270kΩ/R_I 330kΩ/R_I	V/V (min) V/V (max)
R_{SD}	Resistance from Shutdown Pin to GND		300		kΩ
P_O	Output Power	R_L = 15µH + 4Ω + 15µH THD = 10% (max) f = 1kHz, 22kHz BW V_{DD} = 5V V_{DD} = 3.6V V_{DD} = 2.5V	 2.5 1.3 520		 W W mW
		R_L = 15µH + 4Ω + 15µH THD = 1% (max) f = 1kHz, 22kHz BW V_{DD} = 5V V_{DD} = 3.6V V_{DD} = 2.5V	 2.21 1.06 420		 W W mW

Symbol	Parameter	Conditions	LM4671		Units (Limits)
			Typical (Note 6)	Limit (Notes 7, 8)	
P_O	Output Power	R_L = 15µH + 8Ω + 15µH THD = 10% (max) f = 1kHz, 22kHz BW			
		V_{DD} = 5V	1.7		W
		V_{DD} = 3.6V	870		mW
		V_{DD} = 2.5V	425		mW
		R_L = 15µH + 8Ω + 15µH THD = 1% (max) f = 1kHz, 22kHz BW			
		V_{DD} = 5V	1.19		W
		V_{DD} = 3.6V	700	600	mW
		V_{DD} = 2.5V	350		mW
THD+N	Total Harmonic Distortion + Noise	V_{DD} = 5V, P_O = 0.1W_{RMS}, f = 1kHz	0.09		%
		V_{DD} = 3.6V, P_O = 0.1W_{RMS}, f = 1kHz	0.04		%
		V_{DD} = 3.6V, P_O = 0.1W_{RMS}, f = 5kHz	0.12		%
		V_{DD} = 3.6V, P_O = 0.1W_{RMS}, f = 10kHz	0.05		%
PSRR	Power Supply Rejection Ratio	V_{DD} = 3.6V, 5V V_{Ripple} = 200mV_{PP} Sine, f_{Ripple} = 217Hz Inputs to AC GND, C_I = 2µF	61.8		dB
		V_{DD} = 3.6V, 5V V_{Ripple} = 200mV_{PP} Sine, f_{Ripple} = 1kHz Inputs to AC GND, C_I = 2µF	59.8		dB
		V_{DD} = 3.6V, 5V V_{Ripple} = 200mV_{PP} Sine, f_{Ripple} = 10kHz Inputs to AC GND, C_I = 2µF	48.7		dB
		V_{DD} = 3.6V, 5V V_{Ripple} = 200mV_{PP} Sine, f_{Ripple} = 217Hz f_{IN} = 1kHz, P_O = 10mW_{RMS}	65.7		dB
SNR	Signal to Noise Ratio	V_{DD} = 5V, P_O = 1W_{RMS}	93		dB
ε_{OUT}	Output Noise	V_{DD} = 3.6V, f = 20Hz – 20kHz Inputs to AC GND, C_I = 2µF No Weighting	58		µV_{RMS}
		V_{DD} = 3.6V, Inputs to AC GND C_I = 2µF, A Weighted	38		µV_{RMS}
CMRR	Common Mode Rejection Ratio	V_{DD} = 3.6V, V_{Ripple} = 1V_{PP} Sine f_{Ripple} = 217Hz	68.3		dB
T_{WU}	Wake-up Time	V_{DD} = 3.6V	17	49	µs (max)
T_{SD}	Shutdown Time		140		µs

Note 1: All voltages are measured with respect to the ground pin, unless otherwise specified.

Note 2: *Absolute Maximum Ratings* indicate limits beyond which damage to the device may occur. *Operating Ratings* indicate conditions for which the device is functional, but do not guarantee specific performance limits. *Electrical Characteristics* state DC and AC electrical specifications under particular test conditions which guarantee specific performance limits. This assumes that the device is within the Operating Ratings. Specifications are not guaranteed for parameters where no limit is given, however, the typical value is a good indication of device performance.

Note 3: The maximum power dissipation must be derated at elevated temperatures and is dictated by T_{JMAX}, θ_{JA}, and the ambient temperature T_A. The maximum allowable power dissipation is $P_{DMAX} = (T_{JMAX}–T_A)/\theta_{JA}$ or the number given in Absolute Maximum Ratings, whichever is lower. For the LM4671, T_{JMAX} = 150°C. The typical θ_{JA} is 220°C/W for the microSMD package.

Note 4: Human body model, 100pF discharged through a 1.5kΩ resistor.

Note 5: Machine Model, 220pF–240pF discharged through all pins.

Note 6: Typical specifications are specified at 25°C and represent the parametric norm.

Note 7: Tested limits are guaranteed to National's AOQL (Average Outgoing Quality Level).

Note 8: Datasheet min/max specification limits are guaranteed by design, test, or statistical analysis.

Note 9: Shutdown current is measured in a normal room environment. Exposure to direct sunlight will increase I_{SD} by a maximum of 2µA. The Shutdown pin should be driven as close as possible to GND for minimal shutdown current and to V_{DD} for the best THD performance in PLAY mode. See the **Application Information** section under SHUTDOWN FUNCTION for more information.

Note 10: The performance graphs were taken using the Audio Precision AUX-0025 Switching Amplifier measurement Filter in series with the LC filter on the demo board.

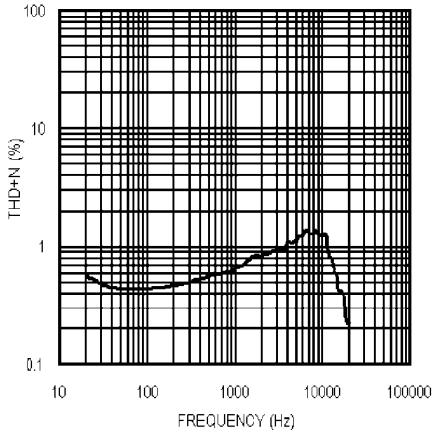
External Components Description

(*Figure 1*)

Components		Functional Description
1.	C_S	Supply bypass capacitor which provides power supply filtering. Refer to the **Power Supply Bypassing** section for information concerning proper placement and selection of the supply bypass capacitor.
2.	C_I	Input AC coupling capacitor which blocks the DC voltage at the amplifier's input terminals.

Typical Performance Characteristics

THD+N vs Frequency
V_{DD} = 2.4V, R_L = 15µH+4Ω+15µH,
P_O = 375mW, 22kHz BW



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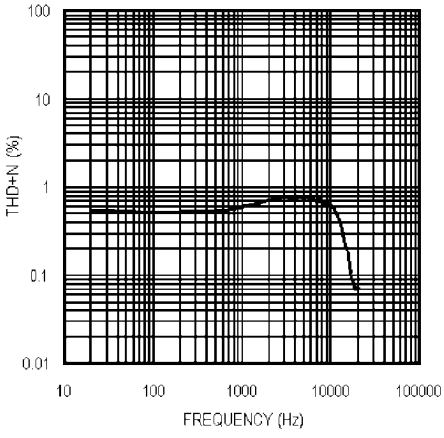
THD+N vs Frequency
V_{DD} = 3.6V, R_L = 15µH+4Ω+15µH,
P_O = 750mW, 22kHz BW



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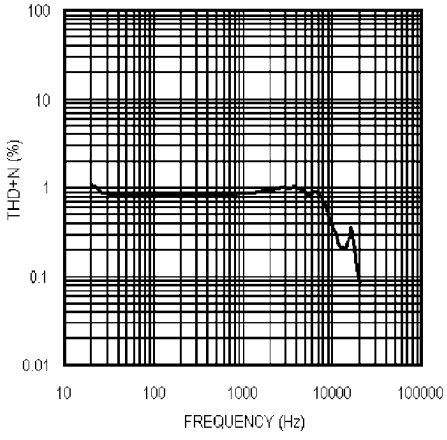
THD+N vs Frequency
V_{DD} = 5V, R_L = 15µH+4Ω+15µH,
P_O = 1.5mW, 22kHz BW



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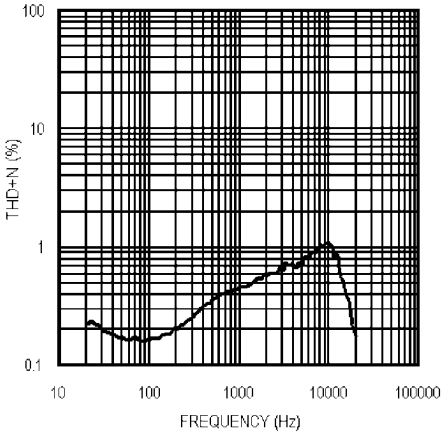
THD+N vs Frequency
V_{DD} = 2.4V, R_L = 15µH+8Ω+15µH,
P_O = 200mW, 22kHz BW



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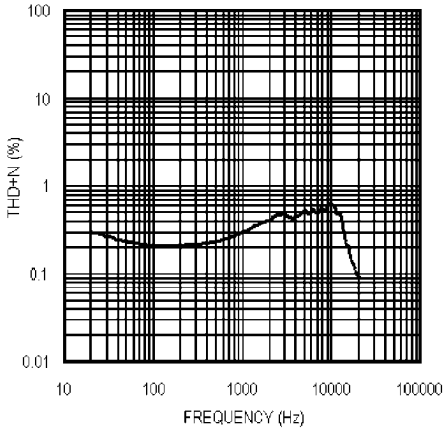
THD+N vs Frequency
V_{DD} = 3.6V, R_L = 15µH+8Ω+15µH,
P_O = 500mW, 22kHz BW



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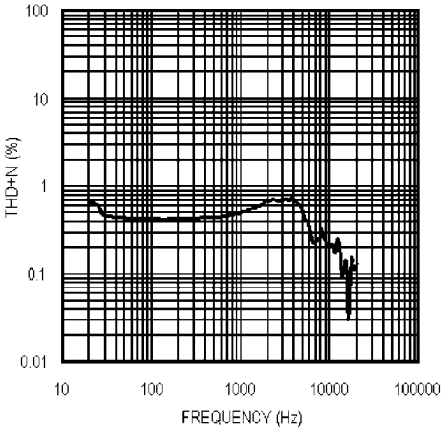
THD+N vs Frequency
V_{DD} = 5V, R_L = 15µH+8Ω+15µH,
P_O = 1W, 22kHz BW



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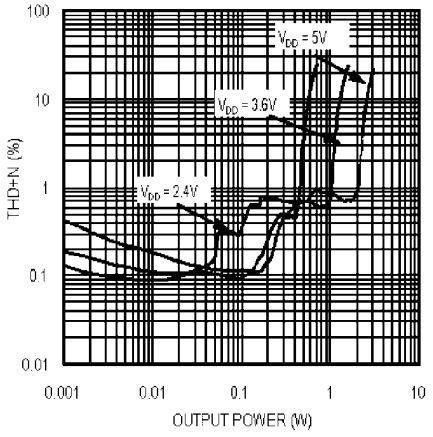
THD+N vs Output Power
V_{DD} = 5V, R_L = 15µH+4Ω+15µH,
f = 1kHz, 22kHz BW



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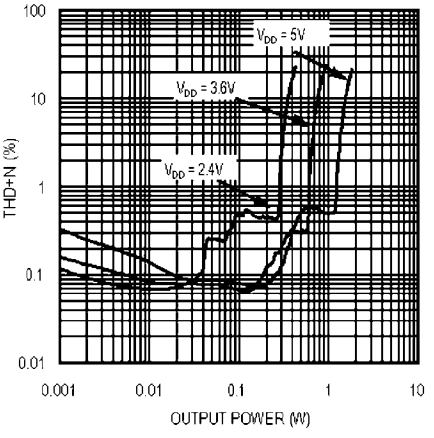
THD+N vs Output Power
V_{DD} = 5V, R_L = 15µH+8Ω+15µH,
f = 1kHz, 22kHz BW



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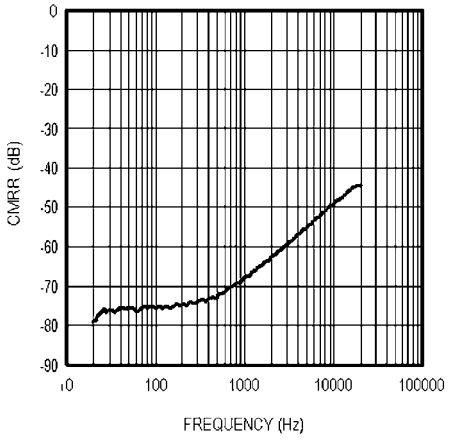
CMRR vs Frequency
V_{DD} = 3.6V, R_L = 15µH+8Ω+15µH,
V_{ripple} = $1V_{p-p}$, 22kHz BW



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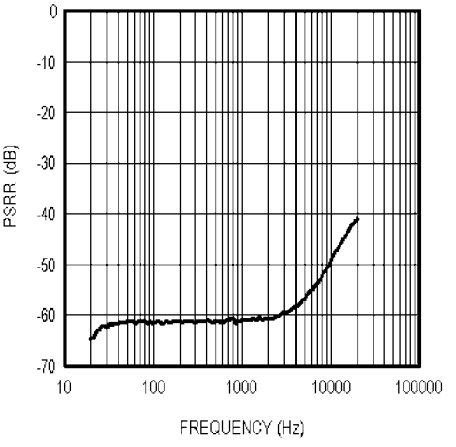
PSRR vs Frequency
V_{DD} = 3.6V, R_L = 15µH+8Ω+15µH,
V_{ripple} = $200mV_{p-p}$, 22kHz BW



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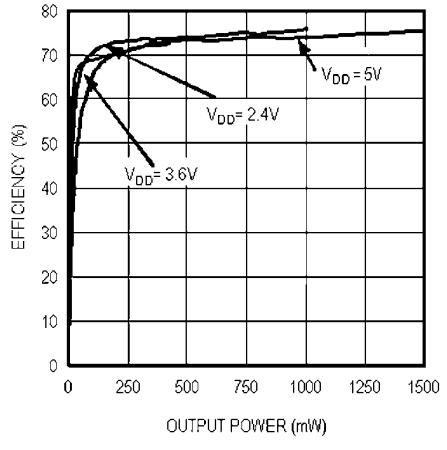
Efficiency vs Output Power
R_L = 15µH+4Ω+15µH,
f = 1kHz, 22kHz BW



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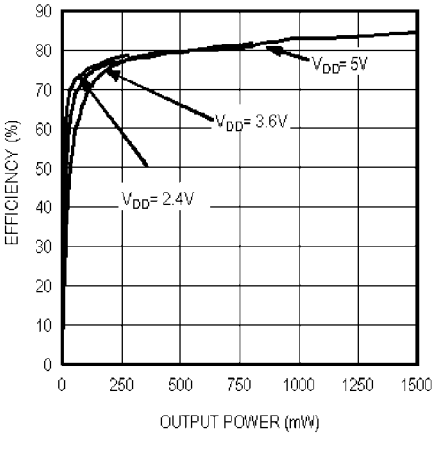
Efficiency vs Output Power
R_L = 15µH+8Ω+15µH,
f = 1kHz, 22kHz BW



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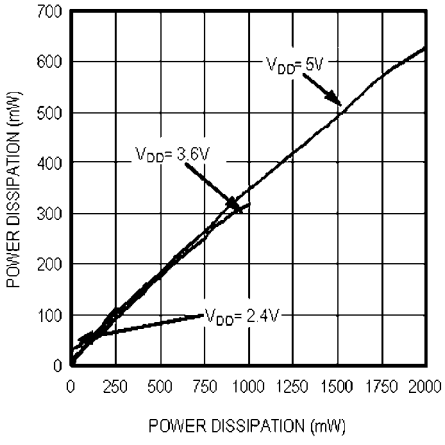
Power Dissipation vs Output Power
R_L = 15µH+4Ω+15µH,
f = 1kHz, 22kHz BW



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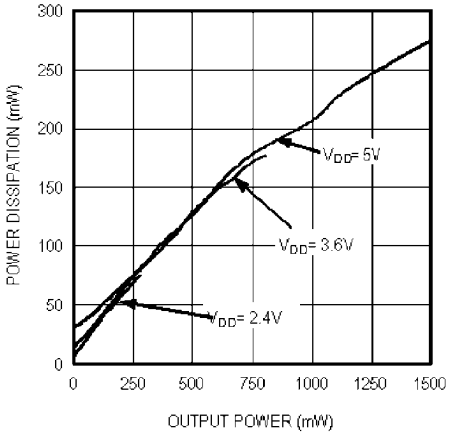
Power Dissipation vs Output Power
R_L = 15µH+8Ω+15µH,
f = 1kHz, 22kHz BW



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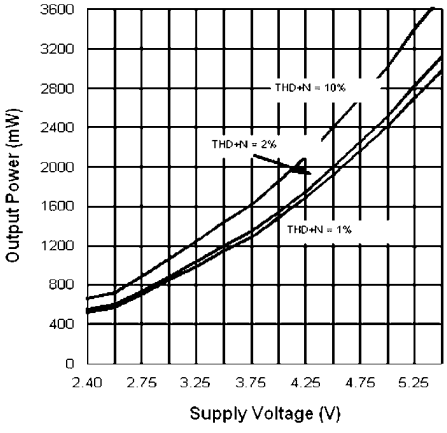
Output Power vs Supply Voltage
R_L = 15µH+4Ω+15µH,
V_{DD} = 3.6V



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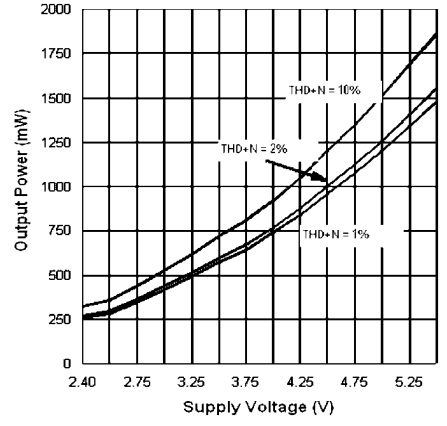
Output Power vs Supply Voltage
R_L = 15µH+8Ω+15µH,
V_{DD} = 3.6V



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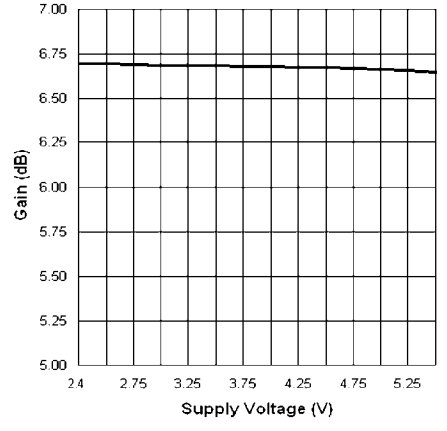
Gain vs Supply Voltage
R_{in} = 150kΩ



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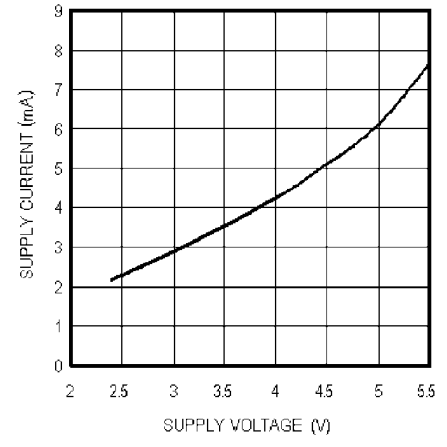
Supply Current vs Supply Voltage
R_L = 15µH+8Ω+15µH



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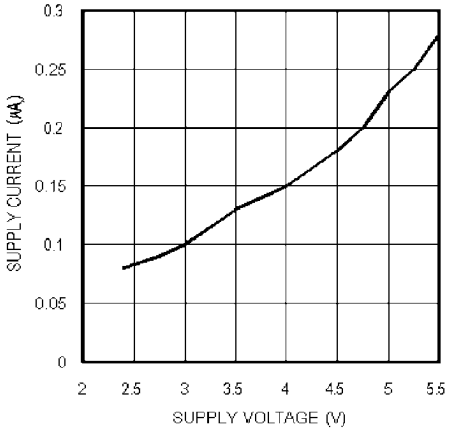
Shutdown Current vs Supply Voltage
R_L = 15µH+8Ω+15µH



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Application Information

GENERAL AMPLIFIER FUNCTION

The LM4671 features a filterless modulation scheme. The differential outputs of the device switch at 300kHz from V_{DD} to GND. When there is no input signal applied, the two outputs (V_O1 and V_O2) switch with a 50% duty cycle, with both outputs in phase. Because the outputs of the LM4671 are differential, the two signals cancel each other. This results in no net voltage across the speaker, thus there is no load current during an idle state, conserving power.

With an input signal applied, the duty cycle (pulse width) of the LM4671 outputs changes. For increasing output voltages, the duty cycle of V_O1 increases, while the duty cycle of V_O2 decreases. For decreasing output voltages, the converse occurs, the duty cycle of V_O2 increases while the duty cycle of V_O1 decreases. The difference between the two pulse widths yields the differential output voltage.

POWER DISSIPATION AND EFFICIENCY

In general terms, efficiency is considered to be the ratio of useful work output divided by the total energy required to produce it with the difference being the power dissipated, typically, in the IC. The key here is “useful” work. For audio systems, the energy delivered in the audible bands is considered useful including the distortion products of the input signal. Sub-sonic (DC) and super-sonic components (>22kHz) are not useful. The difference between the power flowing from the power supply and the audio band power being transduced is dissipated in the LM4671 and in the transducer load. The amount of power dissipation in the LM4671 is very low. This is because the ON resistance of the switches used to form the output waveforms is typically less than 0.25Ω. This leaves only the transducer load as a potential "sink" for the small excess of input power over audio band output power. The LM4671 dissipates only a fraction of the excess power requiring no additional PCB area or copper plane to act as a heat sink.

DIFFERENTIAL AMPLIFIER EXPLANATION

As logic supply voltages continue to shrink, designers are increasingly turning to differential analog signal handling to preserve signal to noise ratios with restricted voltage swing.

The LM4671 is a fully differential amplifier that features differential input and output stages. A differential amplifier amplifies the difference between the two input signals. Traditional audio power amplifiers have typically offered only single-ended inputs resulting in a 6dB reduction in signal to noise ratio relative to differential inputs. The LM4671 also offers the possibility of DC input coupling which eliminates the two external AC coupling, DC blocking capacitors. The LM4671 can be used, however, as a single ended input amplifier while still retaining it's fully differential benefits. In fact, completely unrelated signals may be placed on the input pins. The LM4671 simply amplifies the difference between the signals. A major benefit of a differential amplifier is the improved common mode rejection ratio (CMRR) over single input amplifiers. The common-mode rejection characteristic of the differential amplifier reduces sensitivity to ground offset related noise injection, especially important in high noise applications.

PCB LAYOUT CONSIDERATIONS

As output power increases, interconnect resistance (PCB traces and wires) between the amplifier, load and power supply create a voltage drop. The voltage loss on the traces between the LM4671 and the load results is lower output power and decreased efficiency. Higher trace resistance between the supply and the LM4671 has the same effect as a poorly regulated supply, increase ripple on the supply line also reducing the peak output power. The effects of residual trace resistance increases as output current increases due to higher output power, decreased load impedance or both. To maintain the highest output voltage swing and corresponding peak output power, the PCB traces that connect the output pins to the load and the supply pins to the power supply should be as wide as possible to minimize trace resistance.

The use of power and ground planes will give the best THD +N performance. While reducing trace resistance, the use of power planes also creates parasite capacitors that help to filter the power supply line.

The inductive nature of the transducer load can also result in overshoot on one or both edges, clamped by the parasitic diodes to GND and V_{DD} in each case. From an EMI standpoint, this is an aggressive waveform that can radiate or conduct to other components in the system and cause inter-

ference. It is essential to keep the power and output traces short and well shielded if possible. Use of ground planes, beads, and micro-strip layout techniques are all useful in preventing unwanted interference.

As the distance from the LM4671 and the speaker increase, the amount of EMI radiation will increase since the output wires or traces acting as antenna become more efficient with length. What is acceptable EMI is highly application specific. Ferrite chip inductors placed close to the LM4671 may be needed to reduce EMI radiation. The value of the ferrite chip is very application specific.

POWER SUPPLY BYPASSING

As with any power amplifier, proper supply bypassing is critical for low noise performance and high power supply rejection ratio (PSRR). The capacitor (C_S) location should be as close as possible to the LM4671. Typical applications employ a voltage regulator with a 10µF and a 0.1µF bypass capacitors that increase supply stability. These capacitors do not eliminate the need for bypassing on the supply pin of the LM4671. A 1µF tantalum capacitor is recommended.

SHUTDOWN FUNCTION

In order to reduce power consumption while not in use, the LM4671 contains shutdown circuitry that reduces current draw to less than 0.01µA. The trigger point for shutdown is shown as a typical value in the Electrical Characteristics Tables and in the Shutdown Hysteresis Voltage graphs found in the **Typical Performance Characteristics** section. It is best to switch between ground and supply for minimum current usage while in the shutdown state. While the LM4671 may be disabled with shutdown voltages in between ground and supply, the idle current will be greater than the typical 0.01µA value.

The LM4671 has an internal resistor connected between GND and Shutdown pins. The purpose of this resistor is to eliminate any unwanted state changes when the Shutdown pin is floating. The LM4671 will enter the shutdown state when the Shutdown pin is left floating or if not floating, when the shutdown voltage has crossed the threshold. To minimize the supply current while in the shutdown state, the Shutdown pin should be driven to GND or left floating. If the Shutdown pin is not driven to GND, the amount of additional resistor current due to the internal shutdown resistor can be found by Equation (1) below.

$$(V_{SD} - GND) / 60k\Omega \quad (1)$$

With only a 0.5V difference, an additional 8.3µA of current will be drawn while in the shutdown state.

PROPER SELECTION OF EXTERNAL COMPONENTS

The gain of the LM4671 is set by the external resistors, Ri in Figure 1, The Gain is given by Equation (2) below. Best THD +N performance is achieved with a gain of 2V/V (6dB).

$$A_V = 2 * 150\ k\Omega / R_i\ (V/V) \quad (2)$$

It is recommended that resistors with 1% tolerance or better be used to set the gain of the LM4671. The Ri resistors should be placed close to the input pins of the LM4671. Keeping the input traces close to each other and of the same length in a high noise environment will aid in noise rejection due to the good CMRR of the LM4671. Noise coupled onto input traces which are physically close to each other will be common mode and easily rejected by the LM4671.

Input capacitors may be needed for some applications or when the source is single-ended (see Figures 3, 5). Input capacitors are needed to block any DC voltage at the source so that the DC voltage seen between the input terminals of the LM4671 is 0V. Input capacitors create a high-pass filter with the input resistors, R_i. The –3dB point of the high-pass filter is found using Equation (3) below.

$$f_C = 1 / (2\pi R_i C_i)\ (Hz) \quad (3)$$

The input capacitors may also be used to remove low audio frequencies. Small speakers cannot reproduce low bass frequencies so filtering may be desired . When the LM4671 is using a single-ended source, power supply noise on the ground is seen as an input signal by the +IN input pin that is capacitor coupled to ground (See Figures 5 – 7). Setting the high-pass filter point above the power supply noise frequencies, 217Hz in a GSM phone, for example, will filter out this noise so it is not amplified and heard on the output. Capacitors with a tolerance of 10% or better are recommended for impedance matching.

DIFFERENTIAL CIRCUIT CONFIGURATIONS

The LM4671 can be used in many different circuit configurations. The simplest and best performing is the DC coupled, differential input configuration shown in Figure 2. Equation (2) above is used to determine the value of the R_i resistors for a desired gain.

Input capacitors can be used in a differential configuration as shown in Figure 3. Equation (3) above is used to determine the value of the C_i capacitors for a desired frequency response due to the high-pass filter created by C_i and R_i. Equation (2) above is used to determine the value of the R_i resistors for a desired gain

The LM4671 can be used to amplify more than one audio source. Figure 4 shows a dual differential input configuration. The gain for each input can be independently set for maximum design flexibility using the R_i resistors for each input and Equation (2). Input capacitors can be used with one or more sources as well to have different frequency responses depending on the source or if a DC voltage needs to be blocked from a source.

SINGLE-ENDED CIRCUIT CONFIGURATIONS

The LM4671 can also be used with single-ended sources but input capacitors will be needed to block any DC at the input terminals. Figure 5 shows the typical single-ended application configuration. The equations for Gain, Equation (2), and frequency response, Equation (3), hold for the single-ended configuration as shown in Figure 5.

When using more than one single-ended source as shown in Figure 6, the impedance seen from each input terminal should be equal. To find the correct values for C_{i3} and R_{i3} connected to the +IN input pin the equivalent impedance of all the single-ended sources are calculated. The single-ended sources are in parallel to each other. The equivalent capacitor and resistor, C_{i3} and R_{i3}, are found by calculating the parallel combination of all $C_i$values and then all R_i values. Equations (4) and (5) below are for any number of single-ended sources.

$$C_{i3} = C_{i1} + C_{i2} + C_{in} \ldots (\mu F) \quad (4)$$

$$R_{i3} = 1 / (1/R_{i1} + 1/R_{i2} + 1/R_{in} ...) (\Omega) \quad (5)$$

The LM4671 may also use a combination of single-ended and differential sources. A typical application with one single-ended source and one differential source is shown in Figure 7. Using the principle of superposition, the external component values can be determined with the above equations corresponding to the configuration.

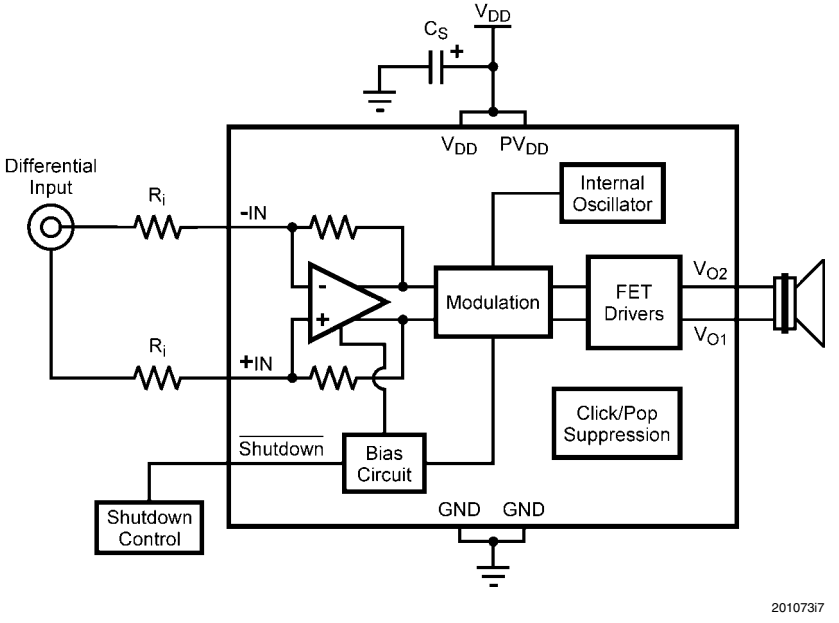


FIGURE 2. Differential input configuration

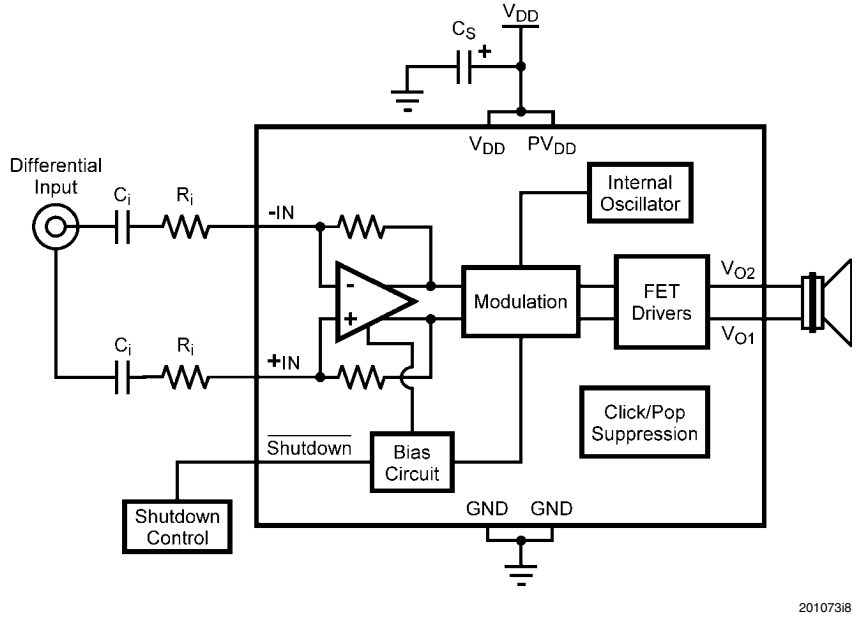


FIGURE 3. Differential input configuration with input capacitors

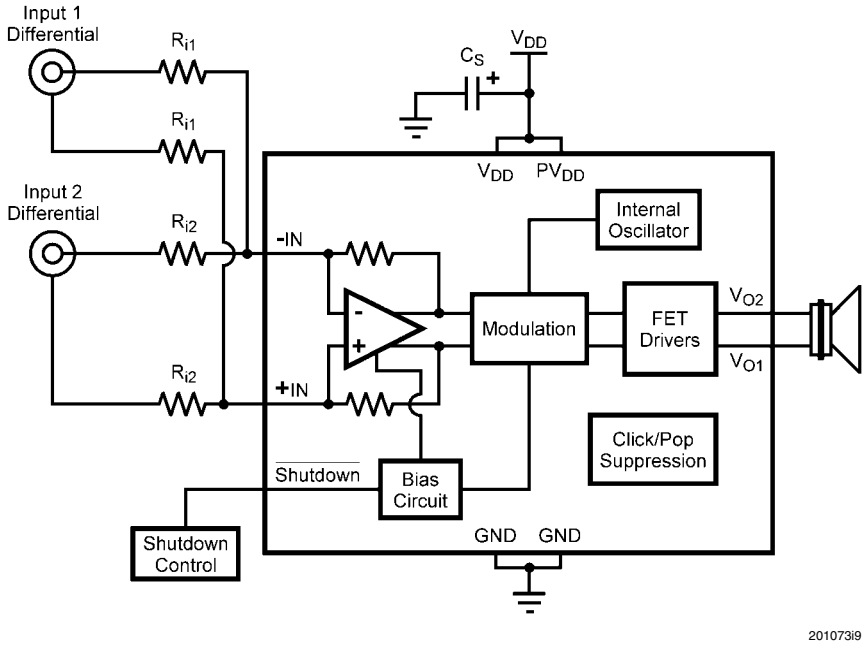


FIGURE 4. Dual differential input configuration

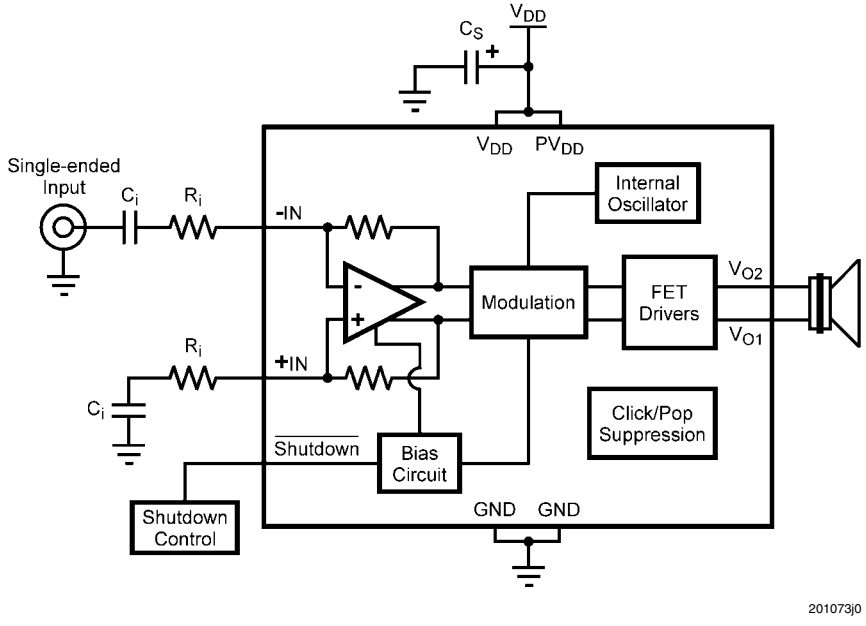


FIGURE 5. Single-ended input configuration

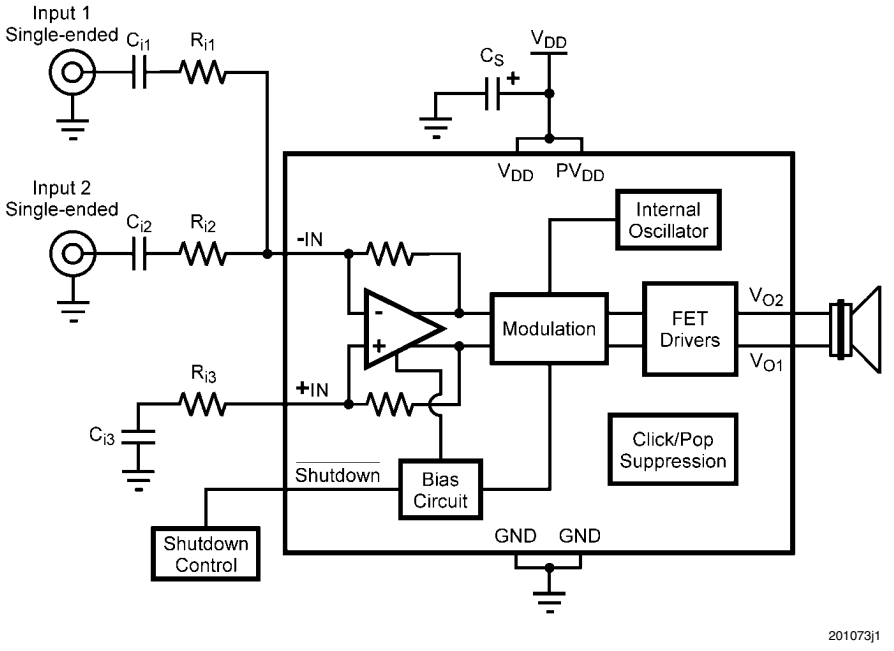


FIGURE 6. Dual single-ended input configuration

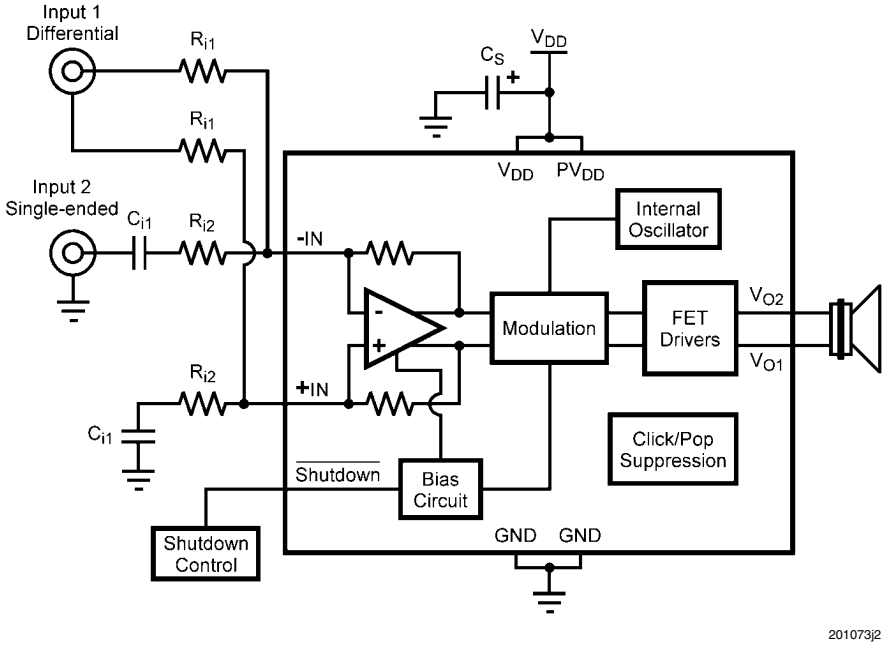


FIGURE 7. Dual input with a single-ended input and a differential input

REFERENCE DESIGN BOARD SCHEMATIC

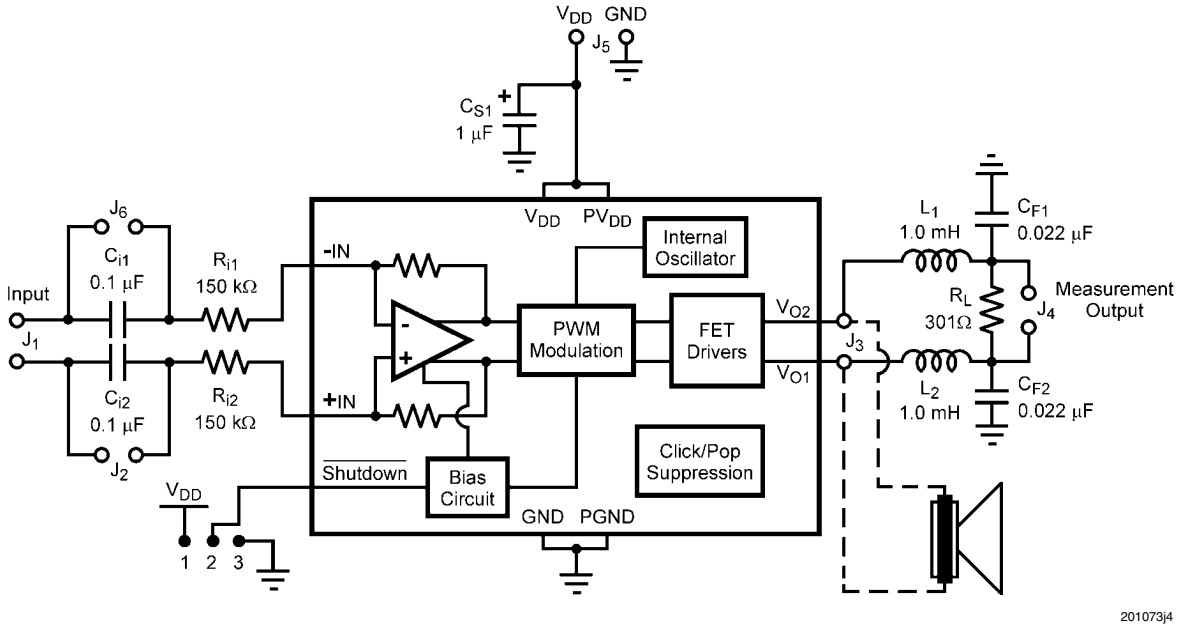


FIGURE 8.

In addition to the minimal parts required for the application circuit, a measurement filter is provided on the evaluation circuit board so that conventional audio measurements can be conveniently made without additional equipment. This is a balanced input, grounded differential output low pass filter with a 3dB frequency of approximately 35kHz and an on board termination resistor of 300Ω (see schematic). Note that the capacitive load elements are returned to ground. This is not optimal for common mode rejection purposes, but due to the independent pulse format at each output there is a significant amount of high frequency common mode component on the outputs. The grounded capacitive filter elements attenuate this component at the board to reduce the high frequency CMRR requirement placed on the analysis instruments.

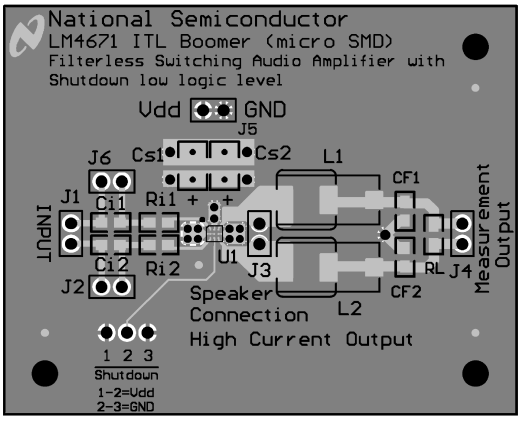
Even with the grounded filter the audio signal is still differential, necessitating a differential input on any analysis instrument connected to it. Most lab instruments that feature BNC connectors on their inputs are **NOT** differential responding because the ring of the BNC is usually grounded.

The commonly used Audio Precision analyzer is differential, but its ability to accurately reject high frequency signals is questionable necessitating the on board measurement filter. When in doubt or when the signal needs to be single-ended, use an audio signal transformer to convert the differential output to a single ended output. Depending on the audio transformer's characteristics, there may be some attenuation of the audio signal which needs to be taken into account for correct measurement of performance.

Measurements made at the output of the measurement filter suffer attenuation relative to the primary, unfiltered outputs even at audio frequencies. This is due to the resistance of the inductors interacting with the termination resistor (300Ω) and is typically about -0.25dB (3%). In other words, the voltage levels (and corresponding power levels) indicated through the measurement filter are slightly lower than those that actually occur at the load placed on the unfiltered outputs. This small loss in the filter for measurement gives a lower output power reading than what is really occurring on the unfiltered outputs and its load.

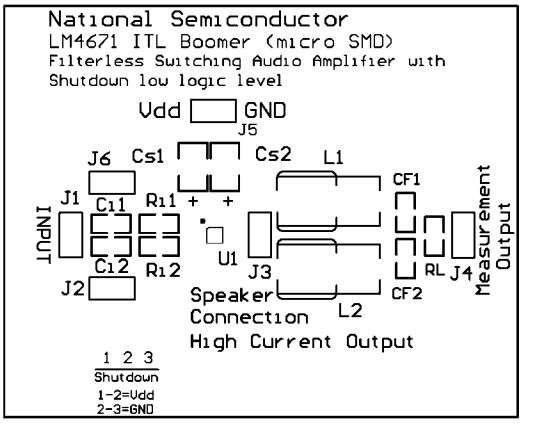
LM4671 micro SMD BOARD ARTWORK

Composite View



201073j6

Silk Screen



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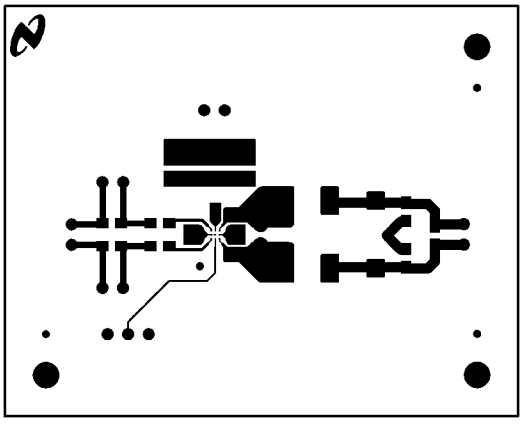
Top Layer



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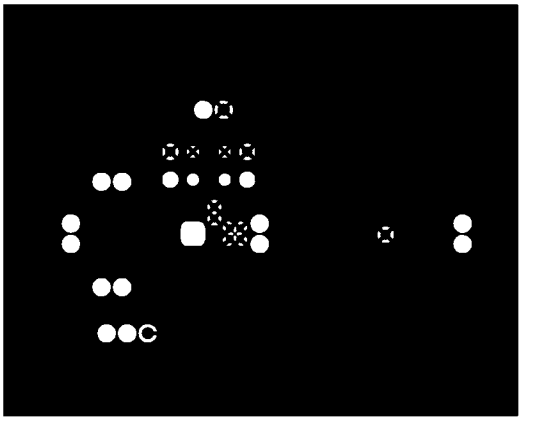

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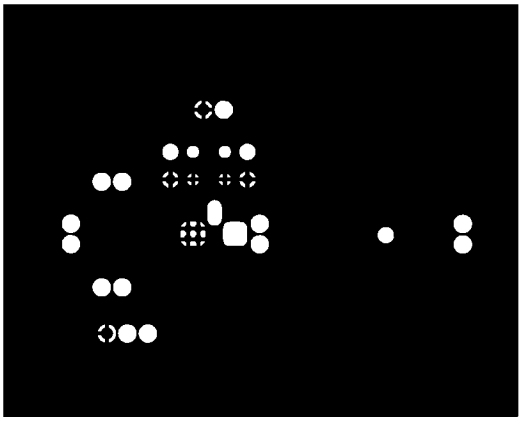
Internal Layer 2, GND



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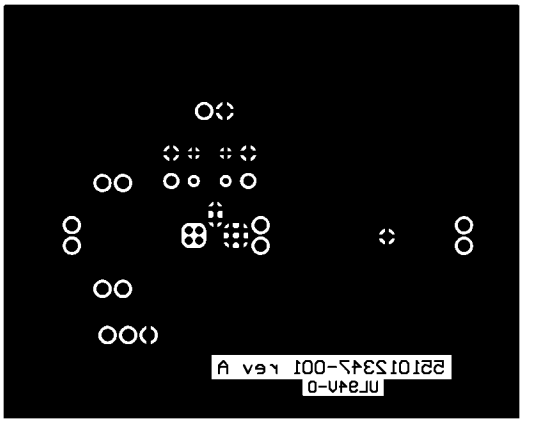
Bottom Layer

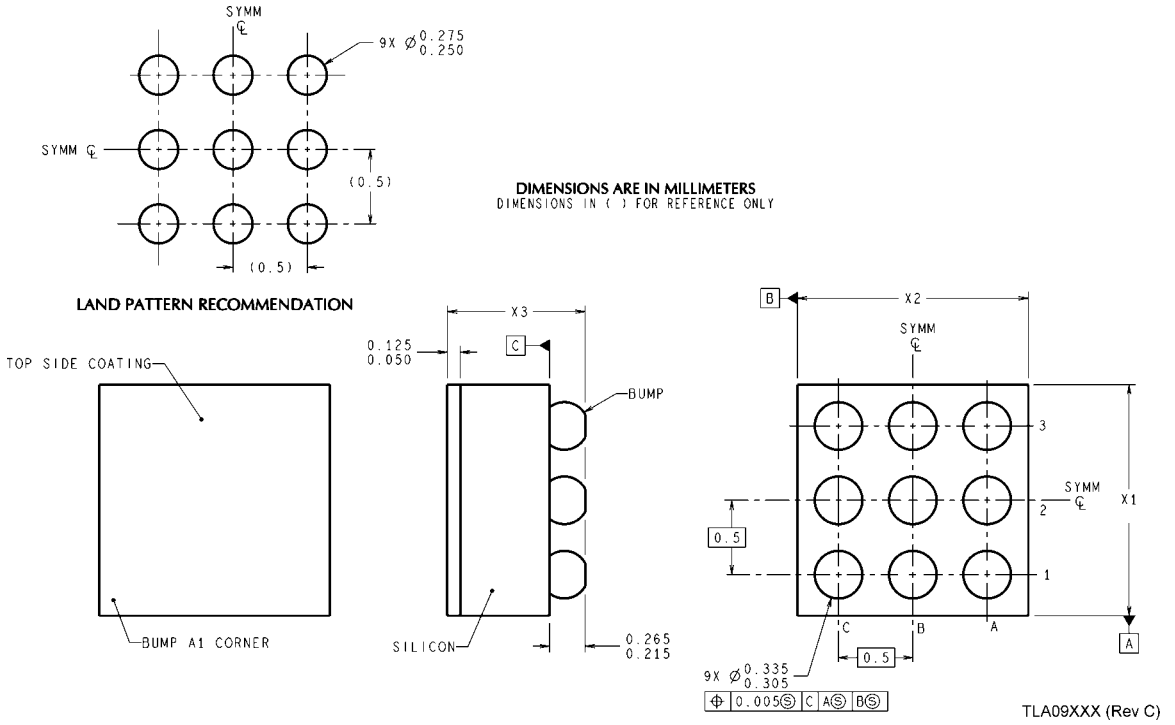


201073j5

Revision History

Rev	Date	Description
1.0	03/16/05	Initial release.
1.01	12/17/07	Some text edits.
1.02	03/03/08	Edited the SHUTDOWN FUNCTION section (under Application Information).

Physical Dimensions inches (millimeters) unless otherwise noted



9 Bump micro SMD
Order Number LM4671ITL, LM4671ITLX
NS Package Number TLA09AAA
X1 = 1.514 X2 = 1.514 X3 = 0.600

Notes

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