LM4665 Boomer® Audio Power Amplifier Series Filterless High Efficiency 1W Switching Audio Amplifier

Check for Samples: LM4665

FEATURES

- **No Output Filter Required for Inductive Transducers**
- **Selectable Gain of 6dB (2V/V) or 12dB (4V/V)**
- **Very Fast Turn On Time: 5ms (typ)**
- **User Selectable Shutdown High or Low Logic Level**
- **Minimum External Components**
- **"Click and Pop" Suppression Circuitry**
- **Micro-Power Shutdown Mode**
- **Short Circuit Protection**
- **DSBGA, WSON, and VSSOP Packages (No Heat Sink Required)**

APPLICATIONS

- **Mobile Phones**
- **PDAs**
- **Portable Electronic Devices**

KEY SPECIFICATIONS

- **Efficiency at 100mW into 8Ω Transducer 75%(typ)**
- **Efficiency at 400mW into 8Ω Transducer 80%(typ)**
- **Total Quiescent Power Supply Current (3V) 3mA(typ)**
- **Total Shutdown Power Supply Current (3V) 0.01µA(typ)**
- **Single Supply Range (VSSOP & WSON) 2.7V to 5.5V**
- **Single Supply Range (DSBGA) (Note 11) 2.7V to 3.8V**

DESCRIPTION

The LM4665 is a fully integrated single-supply high efficiency switching audio amplifier. It features an innovative modulator that eliminates the LC output filter used with typical switching amplifiers. Eliminating the output filter reduces parts count, simplifies circuit design, and reduces board area. The LM4665 processes analog inputs with a delta-sigma modulation technique that lowers output noise and THD when compared to conventional pulse width modulators.

The LM4665 is designed to meet the demands of mobile phones and other portable communication devices. Operating on a single 3V supply, it is capable of driving 8Ω transducer loads at a continuous average output of 400mW with less than 2%THD+N.

The LM4665 has high efficiency with an 8Ω transducer load compared to a typical Class AB amplifier. With a 3V supply, the IC's efficiency for a 100mW power level is 75%, reaching 80% at 400mW output power.

The LM4665 features a low-power consumption shutdown mode. Shutdown may be enabled by either a logic high or low depending on the mode selection. Connecting the Shutdown Mode pin to either V_{DD} (high) or GND (low) enables the Shutdown pin to be driven in a likewise manner to activate shutdown.

The LM4665 has fixed selectable gain of either 6dB or 12dB. The LM4665 has short circuit protection against a short from the outputs to V_{DD}, GND or across the outputs.

Typical Application

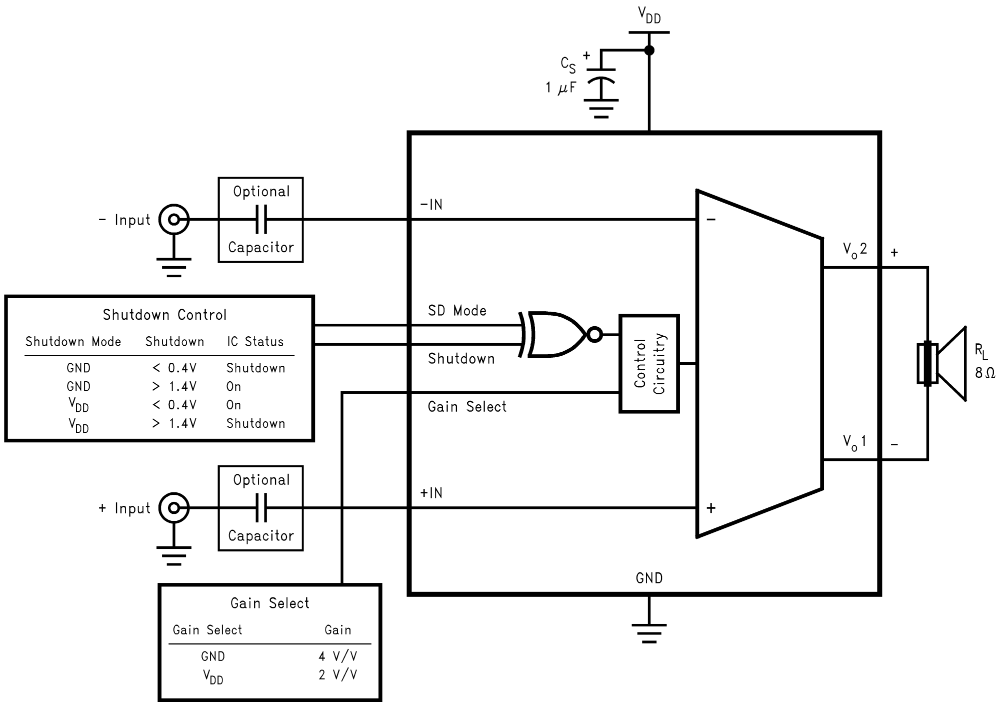


Figure 1. Typical Audio Amplifier Application Circuit

Connection Diagram

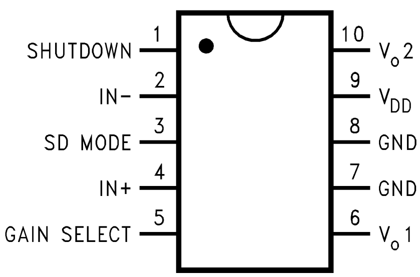


Figure 2. VSSOP Package – Top View
See Package Number DGS

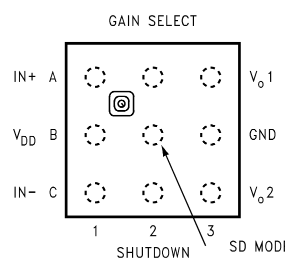


Figure 3. 9 Bump DSBGA Package – Top View
See Package Number YZR0009

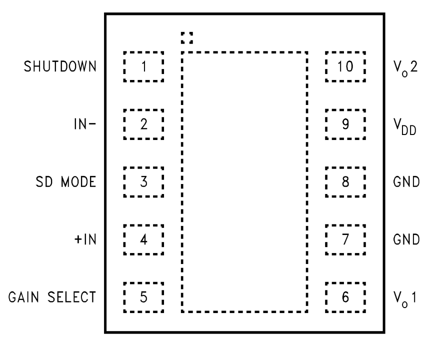


Figure 4. WSON Package – Top View
See Package Number NGZ

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

Absolute Maximum Ratings[(1)(2)(3)]

Supply Voltage[(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[(4)]		Internally Limited
ESD Susceptibility[(5)]		2.0kV
ESD Susceptibility[(6)]		200V
Junction Temperature (T_J)		150°C
Thermal Resistance	θ_{JA} (VSSOP)	190°C/W
	θ_{JC} (VSSOP)	56°C/W
	θ_{JA} (DSBGA)	180°C/W
	θ_{JA} (WSON)[(7)]	63°C/W
	θ_{JC} (WSON)[(7)]	12°C/W
Soldering Information		See the AN-1112 Application Report

(1) All voltages are measured with respect to the ground pin, unless otherwise specified.
(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 ensure specific performance limits. *Electrical Characteristics* state DC and AC electrical specifications under particular test conditions which ensure specific performance limits. This assumes that the device is within the Operating Ratings. Specifications are not ensured for parameters where no limit is given, however, the typical value is a good indication of device performance.
(3) If Military/Aerospace specified devices are required, please contact the TI Sales Office/ Distributors for availability and specifications.
(4) 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 LM4665, T_{JMAX} = 150°C. See the Efficiency and Power Dissipation versus Output Power curves for more information.
(5) Human body model, 100 pF discharged through a 1.5 kΩ resistor.
(6) Machine Model, 220 pF–240 pF discharged through all pins.
(7) The exposed-DAP of the LDA10B package should be electrically connected to GND.

Operating Ratings[(1)]

Temperature Range $T_{MIN} \le T_A \le T_{MAX}$	$-40°C \le T_A \le 85°C$
Supply Voltage (DGS & NGZ)	$2.7V \le V_{DD} \le 5.5V$
Supply Voltage (YZR0009) (Note11)	$2.7V \le V_{DD} \le 3.8V$

(1) *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 ensure specific performance limits. *Electrical Characteristics* state DC and AC electrical specifications under particular test conditions which ensure specific performance limits. This assumes that the device is within the Operating Ratings. Specifications are not ensured for parameters where no limit is given, however, the typical value is a good indication of device performance.

Electrical Characteristics V_{DD} = 5V[1][2][3]

The following specifications apply for V_{DD} = 5V, R_L = 8Ω + 33µH, measurement bandwidth is <10Hz - 22kHz unless otherwise specified. Limits apply for T_A = 25°C.

Symbol	Parameter	Conditions	LM4665 Typical[4]	LM4665 Limit[5][6]	Units (Limits)
I_{DD}	Quiescent Power Supply Current	V_{IN} = 0V, No Load V_{IN} = 0V, 8Ω + 22µH Load	14 14.5		mA mA
I_{SD}	Shutdown Current	$V_{SD} = V_{SD\ Mode}$[7]	0.1	5.0	µA (max)
V_{SDIH}	Shutdown Voltage Input High	$V_{SD\ Mode} = V_{DD}$	1.2	1.4	V (min)
V_{SDIL}	Shutdown Voltage Input Low	$V_{SD\ Mode} = V_{DD}$	1.1	0.4	V (max)
V_{SDIH}	Shutdown Voltage Input High	$V_{SD\ Mode}$ = GND	1.2	1.4	V (min)
V_{SDIL}	Shutdown Voltage Input Low	$V_{SD\ Mode}$ = GND	1.1	0.4	V (max)
V_{GSIH}	Gain Select Input High		1.2	1.4	V (min)
V_{GSIL}	Gain Select Input Low		1.1	0.4	V (max)
A_V	Closed Loop Gain	$V_{Gain\ Select} = V_{DD}$	6	5.5 6.5	dB (min) dB (max)
A_V	Closed Loop Gain	$V_{Gain\ Select}$ = GND	12	11.5 12.5	dB (min) dB (max)
V_{OS}	Output Offset Voltage		10		mV
T_{WU}	Wake-up Time		5		ms
P_o	Output Power	THD+N = 3% (max), f_{IN} = 1kHz	1.4		W
THD+N	Total Harmonic Distortion+Noise	P_O = 400mW$_{RMS}$, f_{IN} = 1kHz	0.8		%
R_{IN}	Differential Input Resistance	$V_{Gain\ Select} = V_{DD}$, Gain = 6dB	100		kΩ
		$V_{Gain\ Select}$ = GND, Gain = 12dB	65		kΩ
PSRR	Power Supply Rejection Ratio	V_{Ripple} = 100mV$_{RMS}$, f_{Ripple} = 217Hz, A_V = 6dB Inputs Terminated	52		dB
CMRR	Common Mode Rejection Ratio	V_{Ripple} = 100mV$_{RMS}$, f_{Ripple} = 217Hz, A_V = 6dB	43		dB
e_N	Output Noise Voltage	A-Weighted filter, V_{IN} = 0V	350		µV

(1) All voltages are measured with respect to the ground pin, unless otherwise specified.
(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 ensure specific performance limits. *Electrical Characteristics* state DC and AC electrical specifications under particular test conditions which ensure specific performance limits. This assumes that the device is within the Operating Ratings. Specifications are not ensured for parameters where no limit is given, however, the typical value is a good indication of device performance.
(3) The LM4665 in the DSBGA package (NGZ) has an operating range of 2.7V - 3.8V for 8Ω speaker loads. The supply range may be increased as speaker impedance is increased. It is not recommended that 4Ω loads be used with the DSBGA package. To increase the supply voltage operating range, see Figure 31 and INCREASING SUPPLY VOLTAGE RANGE in the Application Information section for more information.
(4) Typical specifications are specified at 25°C and represent the parametric norm.
(5) Tested limits are specified to TI's AOQL (Average Outgoing Quality Level).
(6) Datasheet min/max specification limits are ensured by design, test, or statistical analysis.
(7) Shutdown current is measured in a normal room environment. Exposure to direct sunlight will increase I_{SD} by a maximum of 2µA. The Shutdown Mode pin should be connected to V_{DD} or GND and the Shutdown pin should be driven as close as possible to V_{DD} or GND for minimum shutdown current and the best THD performance in PLAY mode. See the Application Information section under SHUTDOWN FUNCTION for more information.

Electrical Characteristics V_{DD} = 3V[(1)(2)]

The following specifications apply for V_{DD} = 3V, and R_L = 8Ω + 33µH, measurement bandwidth is <10Hz - 22kHz unless otherwise specified. Limits apply for T_A = 25°C.

Symbol	Parameter	Conditions	LM4665		Units (Limits)
			Typical[(3)]	Limit[(4)(5)]	
I_{DD}	Quiescent Power Supply Current	V_{IN} = 0V, No Load V_{IN} = 0V, 8Ω + 22µH Load	3.0 3.5	7.0	mA (max) mA
I_{SD}	Shutdown Current	$V_{SD} = V_{SD\ Mode}$[(6)]	0.01	5.0	µA (max)
V_{SDIH}	Shutdown Voltage Input High	$V_{SD\ Mode} = V_{DD}$	1.0	1.4	V (min)
V_{SDIL}	Shutdown Voltage Input Low	$V_{SD\ Mode} = V_{DD}$	0.8	0.4	V (max)
V_{SDIH}	Shutdown Voltage Input High	$V_{SD\ Mode}$ = GND	1.0	1.4	V (min)
V_{SDIL}	Shutdown Voltage Input Low	$V_{SD\ Mode}$ = GND	0.8	0.4	V (max)
V_{GSIH}	Gain Select Input High		1.0	1.4	V (min)
V_{GSIL}	Gain Select Input Low		0.8	0.4	V (max)
A_V	Closed Loop Gain	$V_{Gain\ Select} = V_{DD}$	6	5.5 6.5	dB (min) dB (max)
A_V	Closed Loop Gain	$V_{Gain\ Select}$ = GND	12	11.5 12.5	dB (min) dB (max)
V_{OS}	Output Offset Voltage		10		mV
T_{WU}	Wake-up Time		5		ms
P_o	Output Power	THD+N = 2% (max), f_{IN} = 1kHz	400	350	mW (min)
THD+N	Total Harmonic Distortion+Noise	P_O = 100mW$_{RMS}$, f_{IN} = 1kHz	0.4		% (max)
R_{IN}	Differential Input Resistance	$V_{Gain\ Select} = V_{DD}$, Gain = 6dB	100		kΩ
		$V_{Gain\ Select}$ = GND, Gain = 12dB	65		kΩ
PSRR	Power Supply Rejection Ratio	V_{Ripple} = 100mV$_{RMS}$, f_{Ripple} = 217Hz, A_V = 6dB, Inputs Terminated	52		dB
CMRR	Common Mode Rejection Ratio	V_{Ripple} = 100mV$_{RMS}$, f_{Ripple} = 217Hz, A_V = 6dB	39		dB
e_N	Output Noise Voltage	A-Weighted filter, V_{IN} = 0V	350		µV

(1) All voltages are measured with respect to the ground pin, unless otherwise specified.
(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 ensure specific performance limits. *Electrical Characteristics* state DC and AC electrical specifications under particular test conditions which ensure specific performance limits. This assumes that the device is within the Operating Ratings. Specifications are not ensured for parameters where no limit is given, however, the typical value is a good indication of device performance.
(3) Typical specifications are specified at 25°C and represent the parametric norm.
(4) Tested limits are specified to TI's AOQL (Average Outgoing Quality Level).
(5) Datasheet min/max specification limits are ensured by design, test, or statistical analysis.
(6) Shutdown current is measured in a normal room environment. Exposure to direct sunlight will increase I_{SD} by a maximum of 2µA. The Shutdown Mode pin should be connected to V_{DD} or GND and the Shutdown pin should be driven as close as possible to V_{DD} or GND for minimum shutdown current and the best THD performance in PLAY mode. See the Application Information section under SHUTDOWN FUNCTION for more information.

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.

Typical Performance Characteristics

THD+N vs Frequency
V_{DD} = 5V, R_L = 8Ω + 33µH
P_{OUT} = 400mW, 30kHz BW

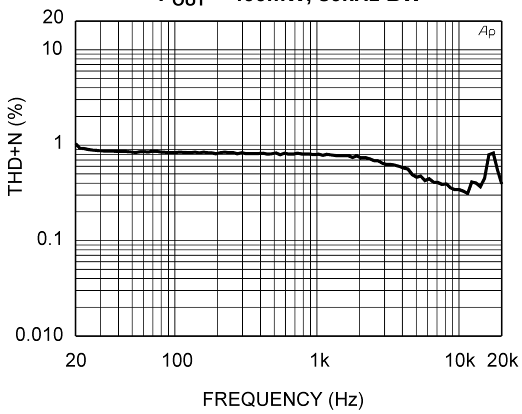


Figure 5.

THD+N vs Frequency
V_{DD} = 3V, R_L = 8Ω + 33µH
P_{OUT} = 100mW, 30kHz BW

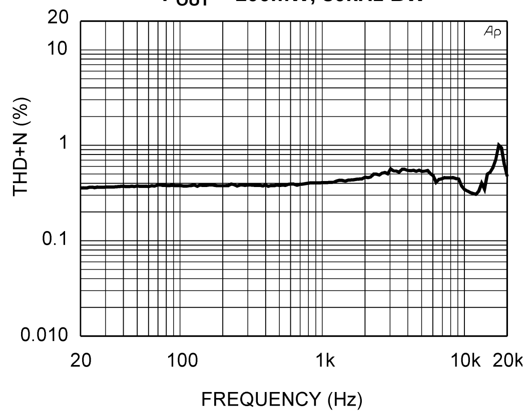


Figure 6.

THD+N vs Frequency
V_{DD} = 3.3V, R_L = 4Ω + 33µH
P_{OUT} = 300mW, 30kHz BW

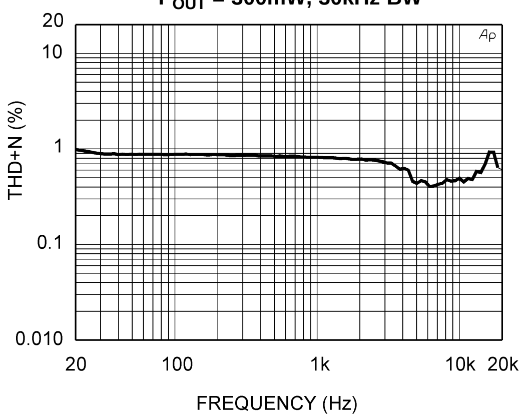


Figure 7.

THD+N vs Power Out
V_{DD} = 5V, R_L = 8Ω + 33µH
f = 1kHz, 22kHz BW

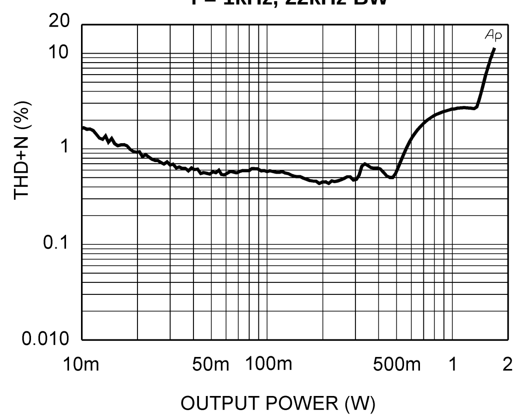


Figure 8.

THD+N vs Power Out
V_{DD} = 3V, R_L = 8Ω + 33µH
f = 1kHz, 22kHz BW

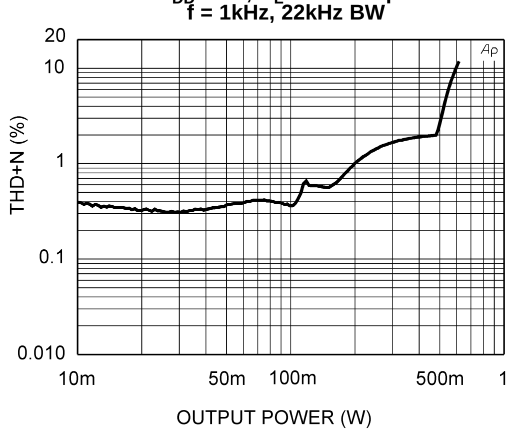


Figure 9.

THD+N vs Power Out
V_{DD} = 3.3V, R_L = 4Ω + 33µH
f = 1kHz, 22kHz BW

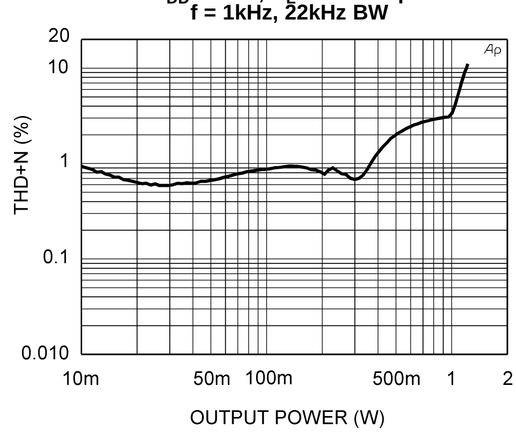


Figure 10.

Typical Performance Characteristics (continued)

THD+N vs Common-Mode Voltage
V_{DD} = 5V, R_L = 8Ω + 33µH, f = 1kHz
P_{OUT} = 400mW, 22kHz BW

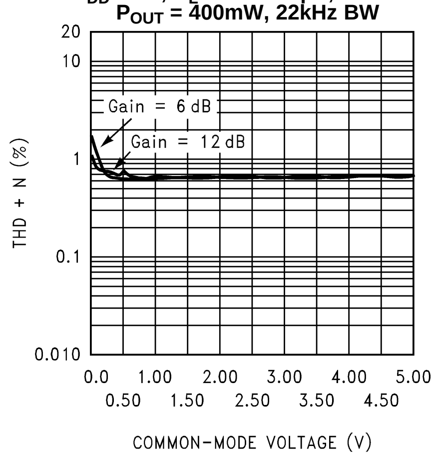


Figure 11.

THD+N vs Common-Mode Voltage
V_{DD} = 3V, R_L = 8Ω + 33µH, f = 1kHz
P_{OUT} = 100mW, 22kHz BW

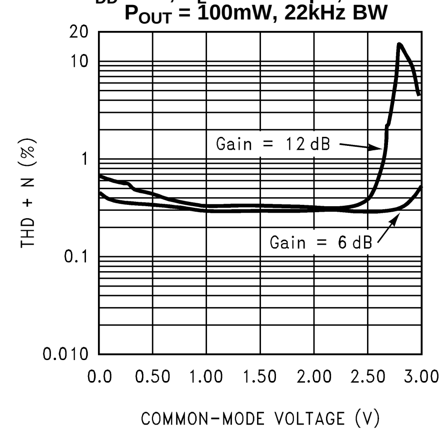


Figure 12.

CMRR vs Frequency
V_{DD} = 5V, R_L = 8Ω + 33µH
V_{CM} = 100mV_{RMS} Sine Wave, 80kHz BW

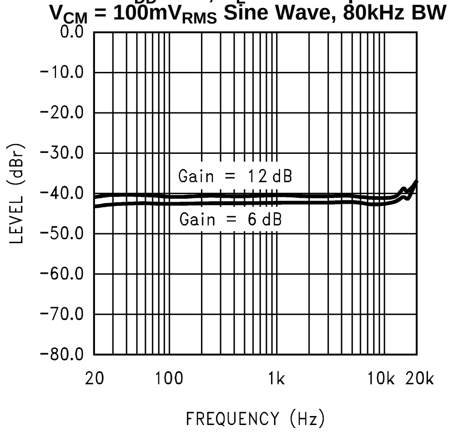


Figure 13.

CMRR vs Frequency
V_{DD} = 3V, R_L = 8Ω + 33µH
V_{CM} = 100mV_{RMS} Sine Wave, 80kHz BW

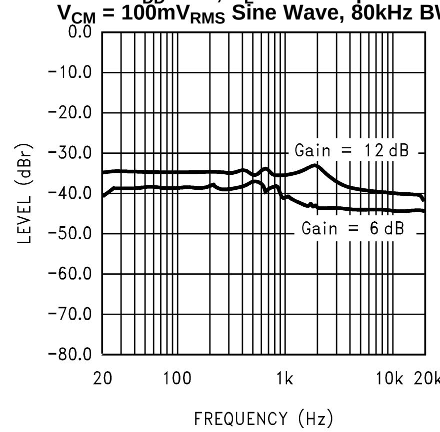


Figure 14.

PSRR vs DC Common-Mode Voltage
V_{DD} = 5V, R_L = 8Ω + 33µH
V_{Ripple} = 100mV_{RMS}, f_{Ripple} = 217Hz Sine Wave

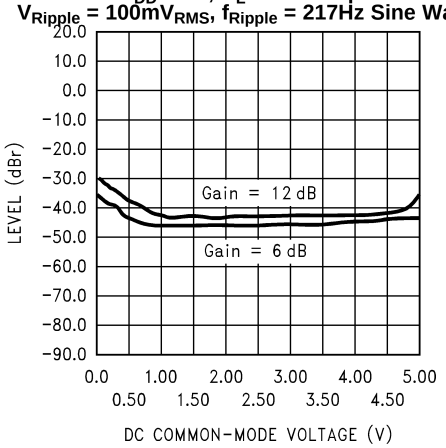


Figure 15.

PSRR vs DC Common-Mode Voltage
V_{DD} = 3V, R_L = 8Ω + 33µH
V_{Ripple} = 100mV_{RMS}, f_{Ripple} = 217Hz Sine Wave

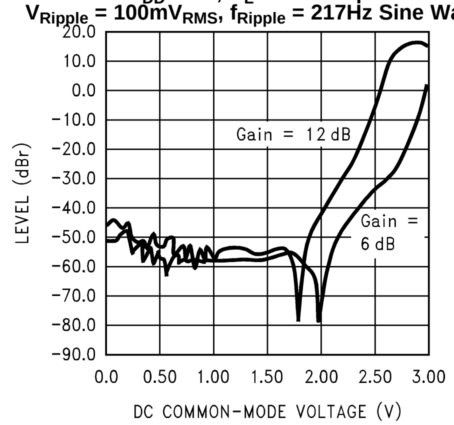


Figure 16.

Typical Performance Characteristics (continued)

PSRR vs Frequency
V_{DD} = 5V, R_L = 8Ω + 33µH
V_{CM} = 100mV_{RMS}Sine Wave, 22kHz BW

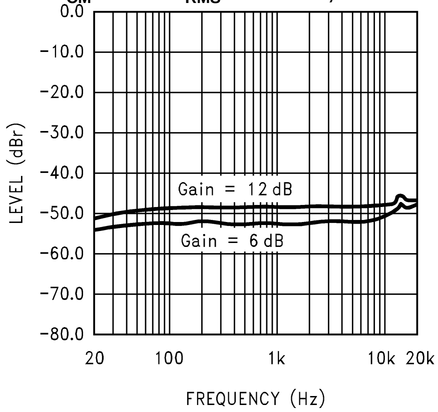


Figure 17.

PSRR vs Frequency
V_{DD} = 3V, R_L = 8Ω + 33µH
V_{CM} = 100mV_{RMS}Sine Wave, 22kHz BW

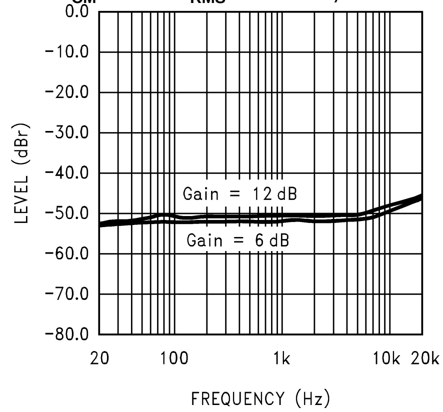


Figure 18.

Efficiency (top trace) and
Power Dissipation (bottom trace) vs Output Power
V_{DD} = 5V, R_L = 8Ω + 33µH, f = 1kHz, THD < 3%

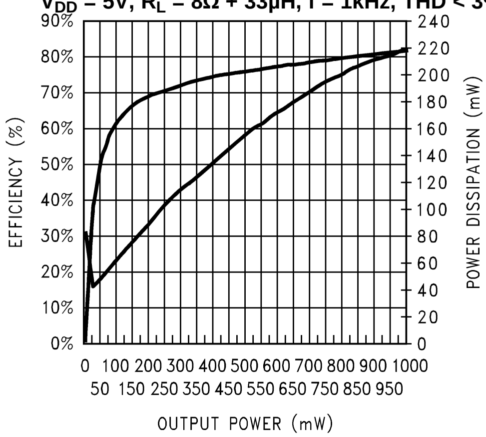


Figure 19.

Efficiency (top trace) and
Power Dissipation (bottom trace) vs Output Power
V_{DD} = 3V, R_L = 8Ω + 33µH, f = 1kHz, THD < 2%

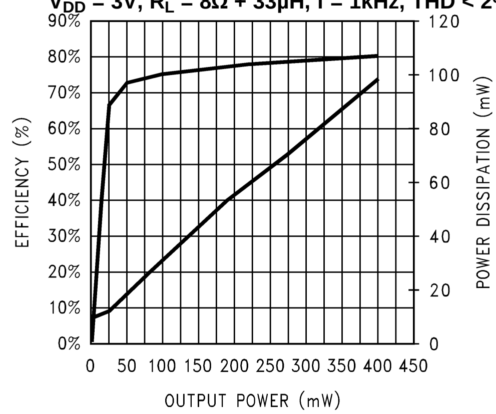


Figure 20.

Efficiency (top trace) and
Power Dissipation (bottom trace) vs Output Power
V_{DD} = 3.3V, R_L = 4Ω + 33µH, f = 1kHz, THD < 2%

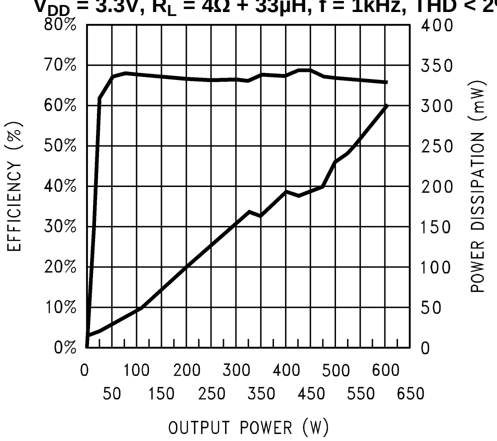


Figure 21.

Gain Threshold Voltages
V_{DD} = 3V - 5V

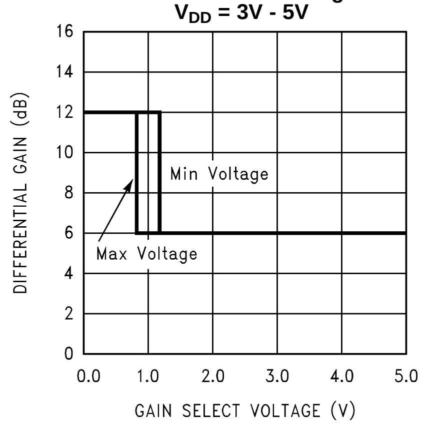


Figure 22.

Typical Performance Characteristics (continued)

Output Power vs Supply Voltage
R_L = 16Ω + 33µH, f = 1kHz

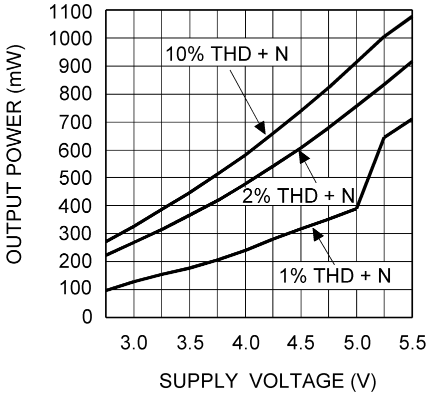


Figure 23.

Output Power vs Supply Voltage
R_L = 8Ω + 33µH, f = 1kHz

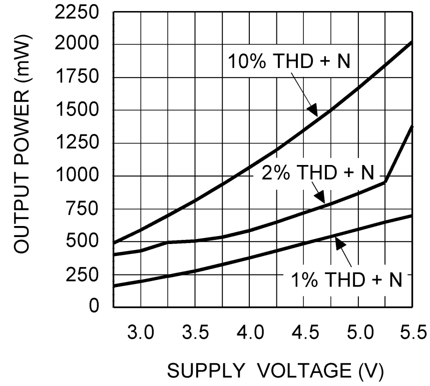


Figure 24.

Output Power vs Supply Voltage
R_L = 4Ω + 33µH, f = 1kHz

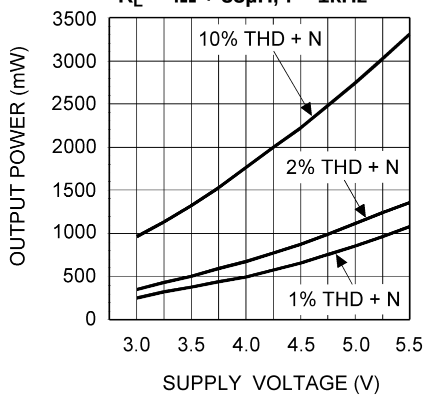


Figure 25.

Shutdown Hysteresis Voltage
V_{DD} = 5V, SD Mode = GND (SD Low)

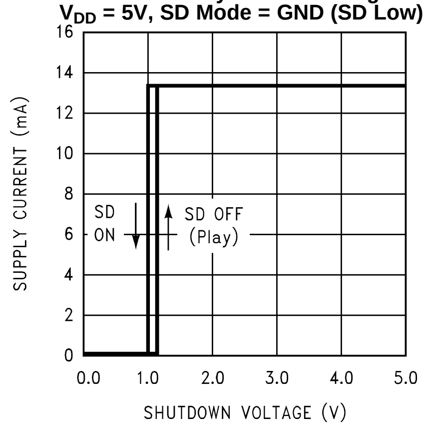


Figure 26.

Shutdown Hysteresis Voltage
V_{DD} = 3V, SD Mode = GND (SD Low)

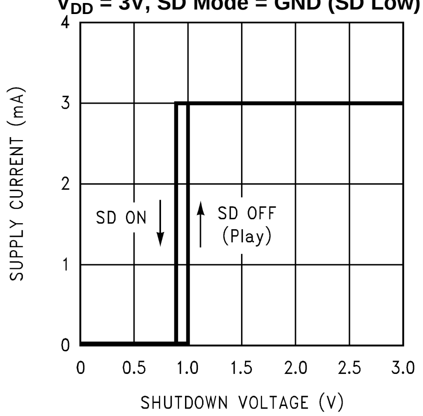


Figure 27.

Shutdown Hysteresis Voltage
V_{DD} = 5V, SD Mode = GND (SD High)

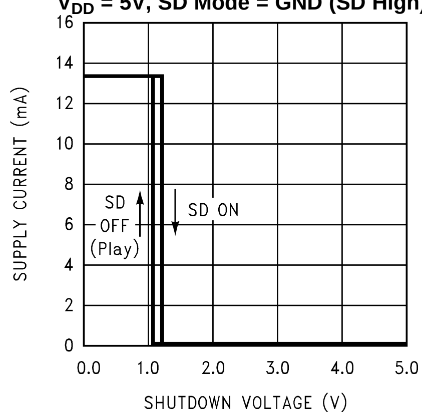


Figure 28.

Typical Performance Characteristics (continued)

Shutdown Hysteresis Voltage
V_{DD} = 3V, SD Mode = GND (SD High)

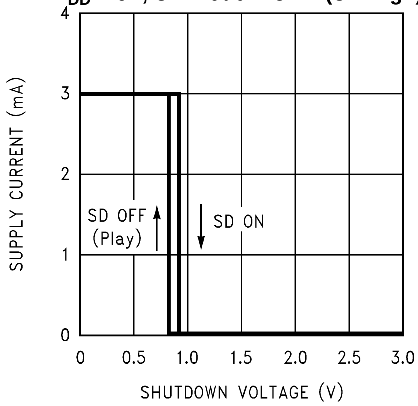


Figure 29.

Supply Current vs Supply Voltage
R_L = 8Ω + 33µH

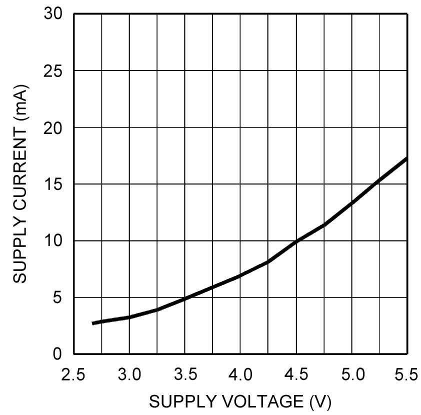


Figure 30.

APPLICATION INFORMATION

GENERAL AMPLIFIER FUNCTION

The output signals generated by the LM4665 consist of two, BTL connected, output signals that pulse momentarily from near ground potential to V_{DD}. The two outputs can pulse independently with the exception that they both may never pulse simultaneously as this would result in zero volts across the BTL load. The minimum width of each pulse is approximately 160ns. However, pulses on the same output can occur sequentially, in which case they are concatenated and appear as a single wider pulse to achieve an effective 100% duty cycle. This results in maximum audio output power for a given supply voltage and load impedance. The LM4665 can achieve much higher efficiencies than class AB amplifiers while maintaining acceptable THD performance.

The short (160ns) drive pulses emitted at the LM4665 outputs means that good efficiency can be obtained with minimal load inductance. The typical transducer load on an audio amplifier is quite reactive (inductive). For this reason, the load can act as it's own filter, so to speak. This "filter-less" switching amplifier/transducer load combination is much more attractive economically due to savings in board space and external component cost by eliminating the need for a filter.

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 LM4665 and in the transducer load. The amount of power dissipation in the LM4665 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 LM4665 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 LM4665 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 LM4665 also offers the possibility of DC input coupling which eliminates the two external AC coupling, DC blocking capacitors. The LM4665 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 LM4665 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 LM4665 and the load results is lower output power and decreased efficiency. Higher trace resistance between the supply and the LM4665 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 rising and falling edges are necessarily short in relation to the minimum pulse width (160ns), having approximately 2ns rise and fall times, typical, depending on parasitic output capacitance. 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 interference. 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.

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 LM4665. 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 LM4665. A 1µF tantalum capacitor is recommended.

SHUTDOWN FUNCTION

In order to reduce power consumption while not in use, the LM4665 contains shutdown circuitry that reduces current draw to less than 0.01µA. In addition, the LM4665 contains a Shutdown Mode pin allowing the designer to designate whether the shutdown circuitry is activated by either a High level logic signal or a Low level logic signal. The Shutdown Mode pin should be permanently connected to either GND (Low) or V_{DD} (High). The LM4665 may then be placed into shutdown by toggling the Shutdown pin to the same state as the Shutdown Mode pin. For simplicity's sake, this is called "Shutdown same", as the LM4665 enters into a shutdown state whenever the two pins are in the same logic state. The trigger point for either shutdown high or shutdown low 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 LM4665 may be disabled with shutdown voltages in between ground and supply, the idle current will be greater than the typical 0.01µA value. Increased THD may also be observed with voltages greater than GND and less than V_{DD} on the Shutdown pin when in PLAY mode.

The LM4665 has an internal resistor connected between the Shutdown Mode and Shutdown pins. The purpose of this resistor is to eliminate any unwanted state changes when the Shutdown pin is floating, as long as the Shutdown Mode pin is connected to GND or V_{DD}. When the Shutdown Mode pin is properly connected, the LM4665 will enter the shutdown state when the Shutdown pin is left floating or if not floating, when the shutdown voltage has crossed the corresponding threshold for the logic level assigned by the Shutdown Mode pin voltage. To minimize the supply current while in the shutdown state, the Shutdown pin should be driven to the same potential as the Shutdown Mode pin or left floating. The amount of additional current due to the internal shutdown resistor can be found by Equation 1 below.

$$(V_{SD\ MODE} - V_{SD}) / 60k\Omega \tag{1}$$

With only a 0.5V difference between the Shutdown Mode voltage and the Shutdown voltage an additional 8.3µA of current will be drawn while in the shutdown state.

GAIN SELECTION FUNCTION

The LM4665 has fixed selectable gain to minimize external components, increase flexibility and simplify design. For a differential gain of 6dB (2V/V), the Gain Select pin should be permanently connected to V_{DD} or driven to a logic high level. For a differential gain of 12dB (4V/V), the Gain Select pin should be permanently connected to GND or driven to a logic low level. The gain of the LM4665 can be switched while the amplifier is in PLAY mode driving a load with a signal without damage to the IC. The voltage on the Gain Select pin should be switched quickly between GND (logic low) and V_{DD} (logic high) to eliminate any possible audible artifacts from appearing at the output. For typical threshold voltages for the Gain Select function, refer to the Gain Threshold Voltages graph in the Typical Performance Characteristics section.

INCREASING SUPPLY VOLTAGE RANGE

When using the DSBGA package (YZR0009), the operating supply voltage range is 2.7V - 3.8V with an 8Ω speaker load. To increase the operating supply voltage range, four Schottky diodes (D_1 - D_4) can be used to control the over and undershoot of the output pulse waveform (See Figure 31 below). To reduce THD+N, small value capacitors in the range of 10pF - 33pF (C_{N1} & C_{N2}) can also be added as needed. The diodes should be placed as close to the DSBGA package as possible.

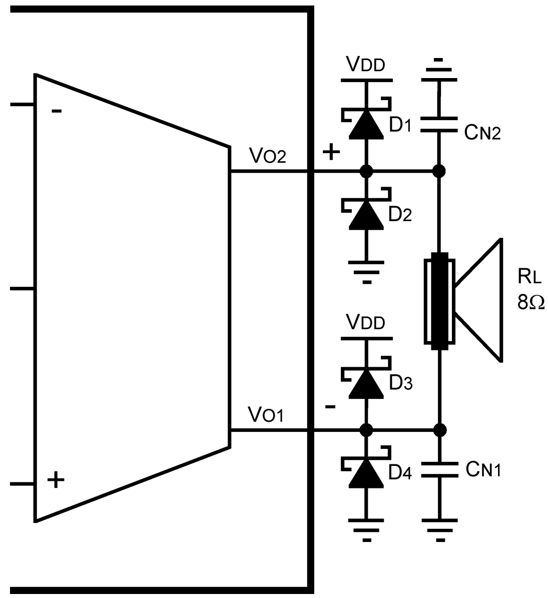


Figure 31. Increased Supply Voltage Operating Range for the DSBGA Package

SINGLE-ENDED CIRCUIT CONFIGURATIONS

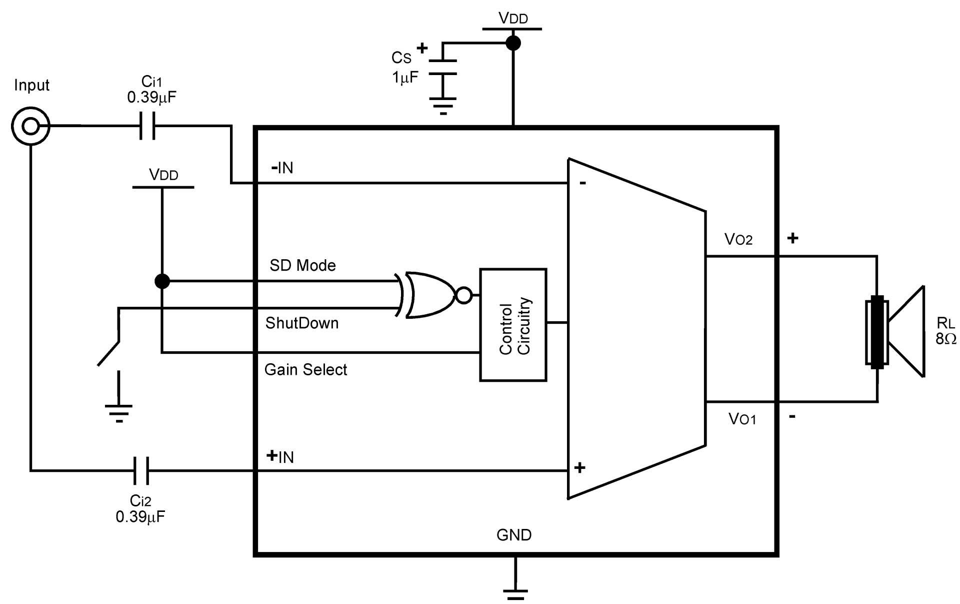


Figure 32. Single-Ended Input, Shutdown High and Gain of 6dB Configuration

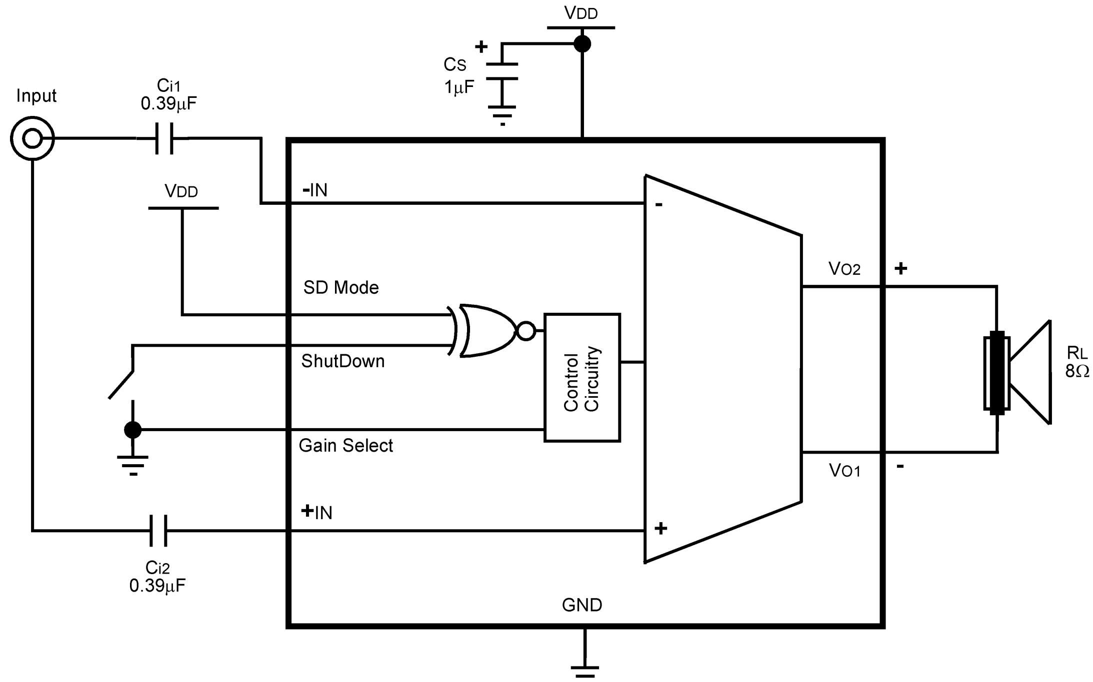


Figure 33. Single-Ended Input, Shutdown High and Gain of 12dB Configuration

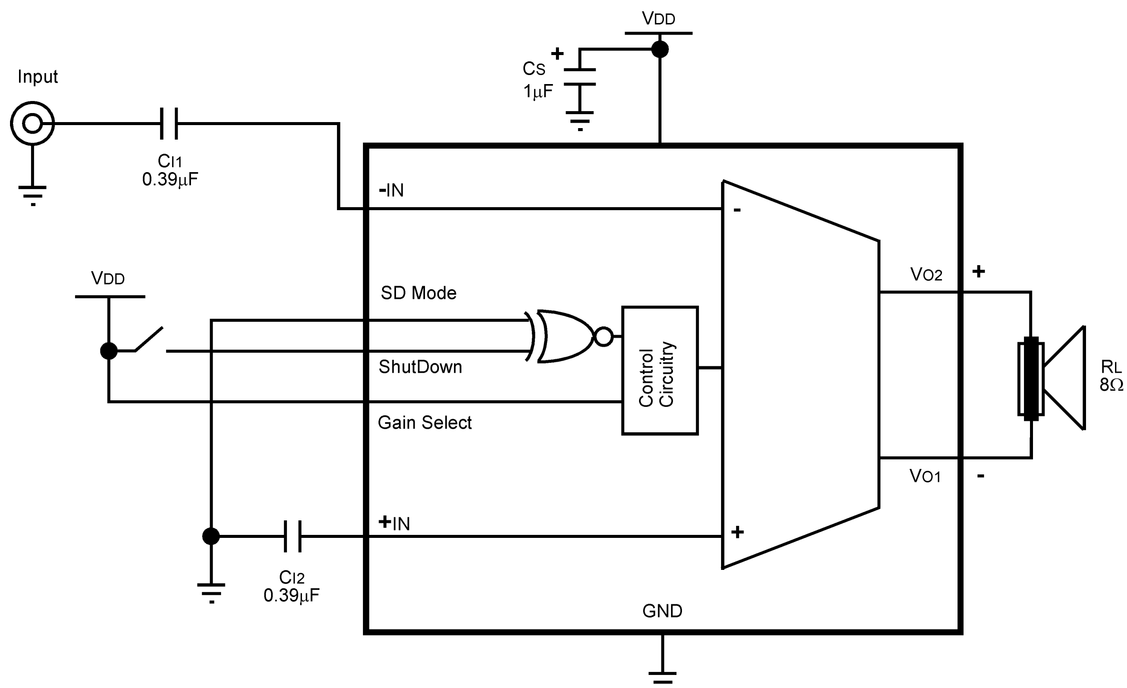


Figure 34. Single-Ended Input, Shutdown Low and Gain of 6dB Configuration

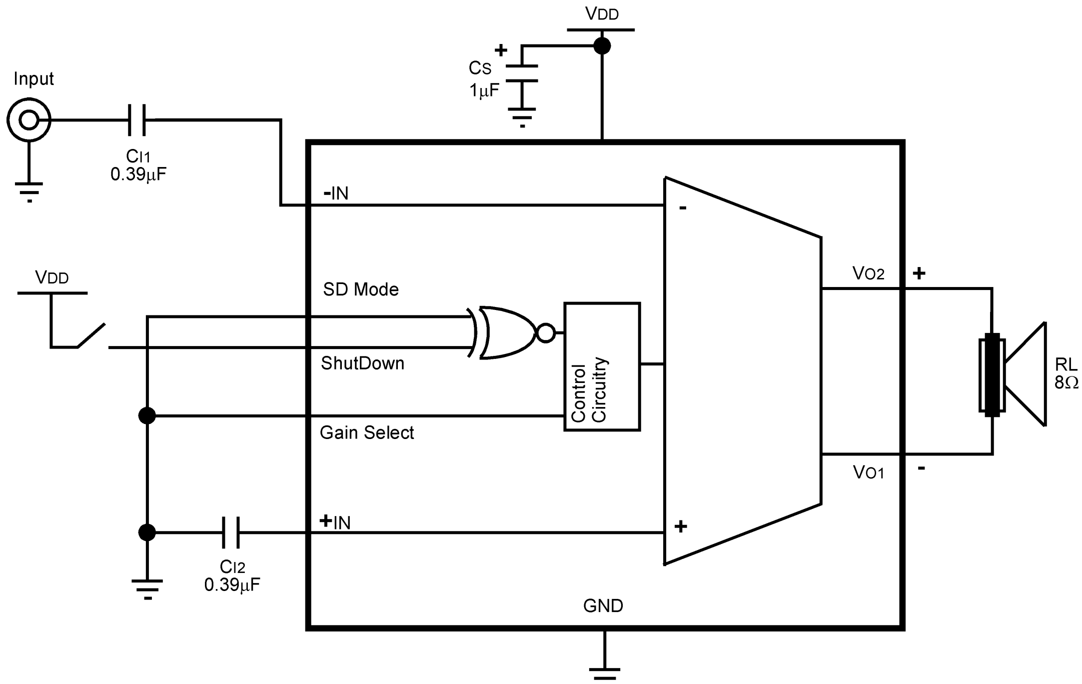
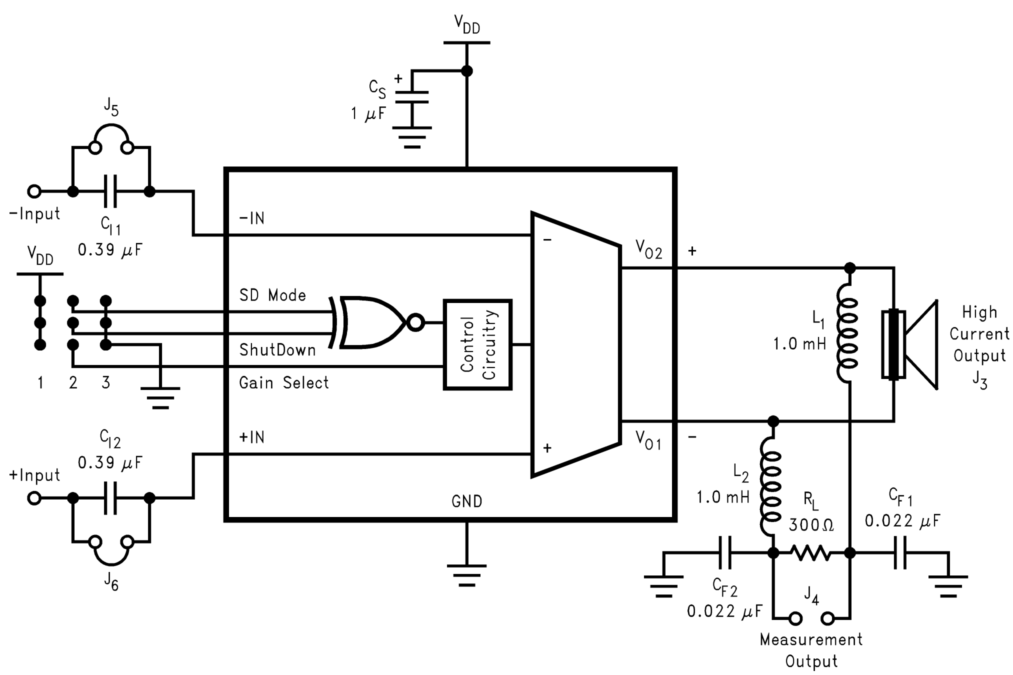


Figure 35. Single-Ended Input, Shutdown Low and Gain of 12dB Configuration

REFERENCE DESIGN BOARD SCHEMATIC



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 fast pulses of 160nS width 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 -0.35dB (4%). 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.

LM4665 VSSOP BOARD ARTWORK

Figure 36. Composite View

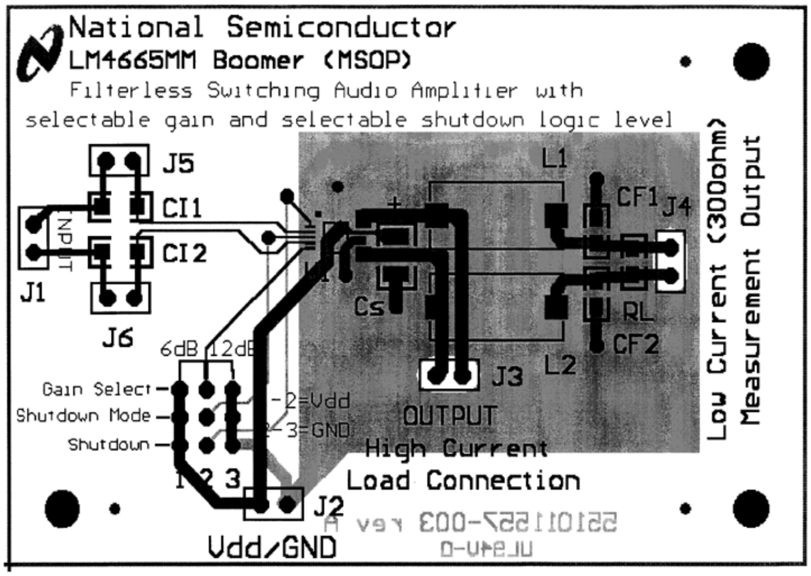


Figure 37. Silk Screen

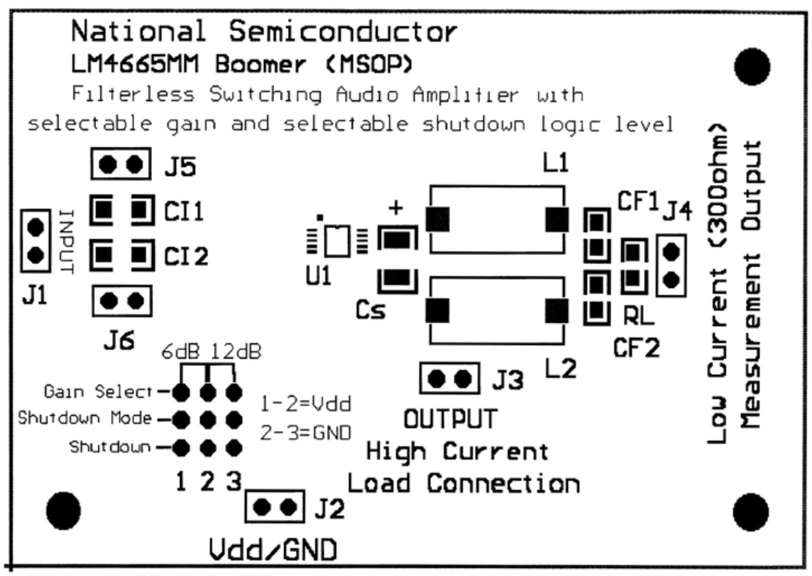


Figure 38. Top Layer

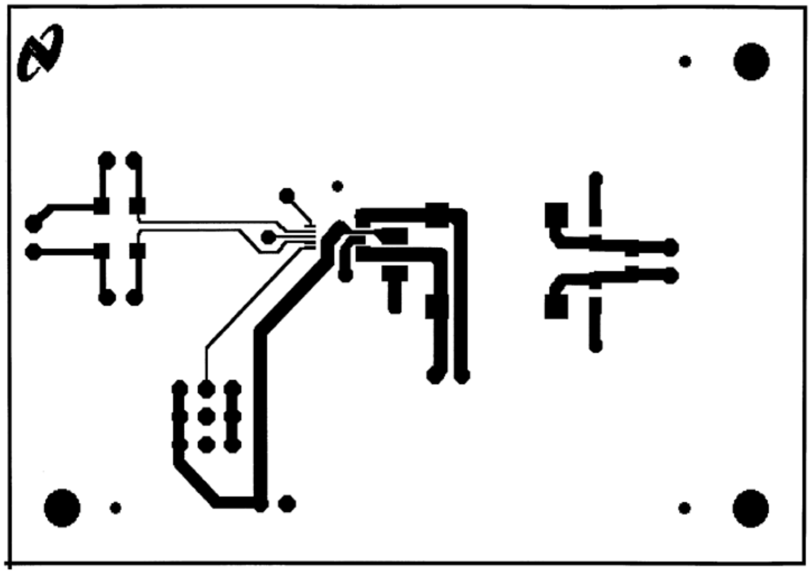
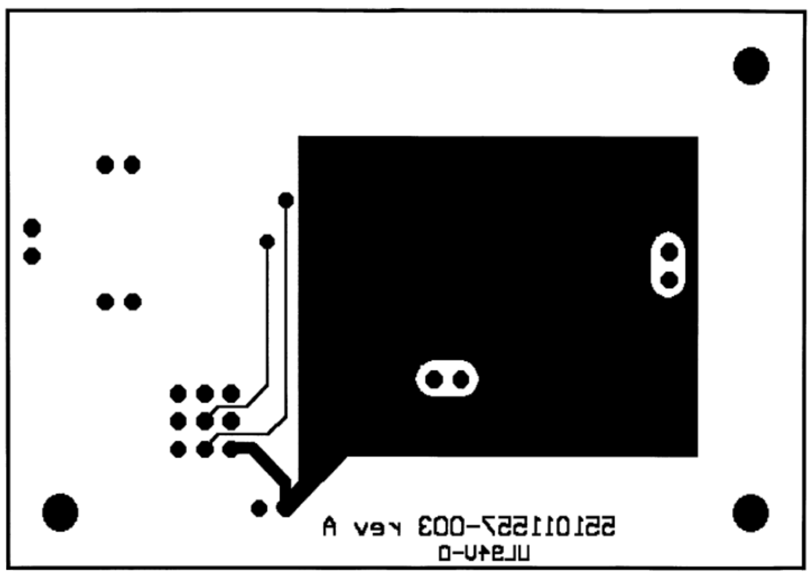


Figure 39. Bottom Layer



LM4665 WSON BOARD ARTWORK

Figure 40. Composite View

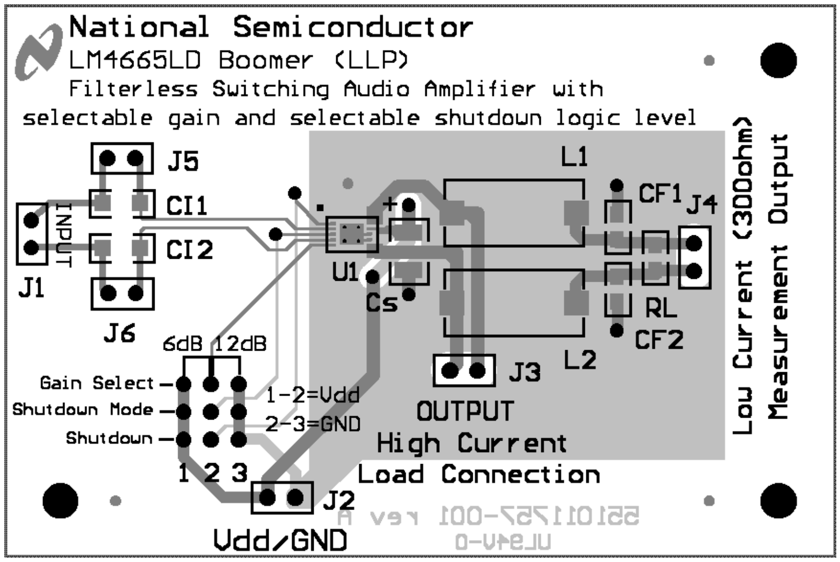


Figure 41. Silk Screen

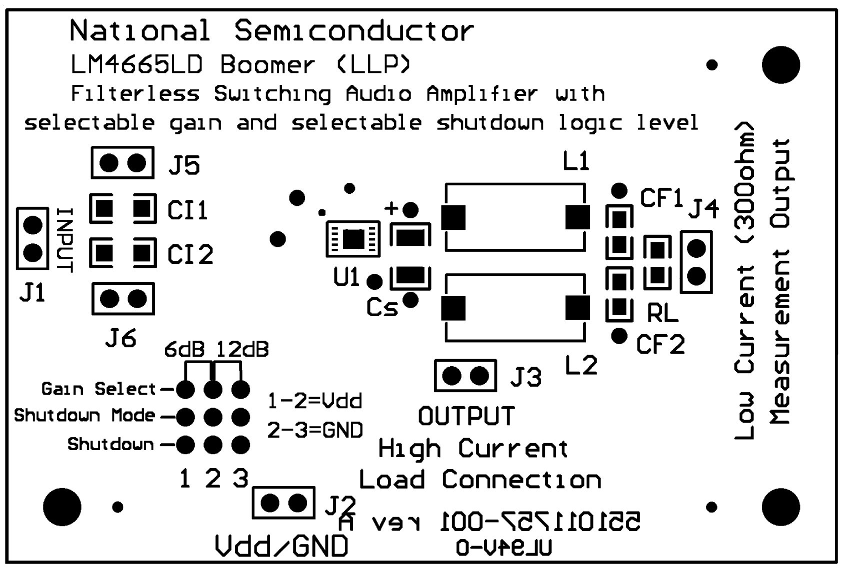


Figure 42. Top Layer

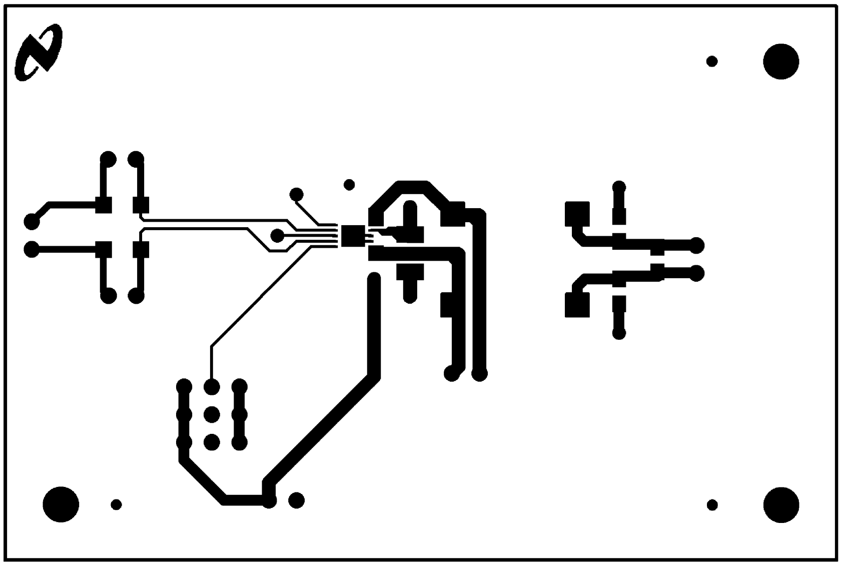
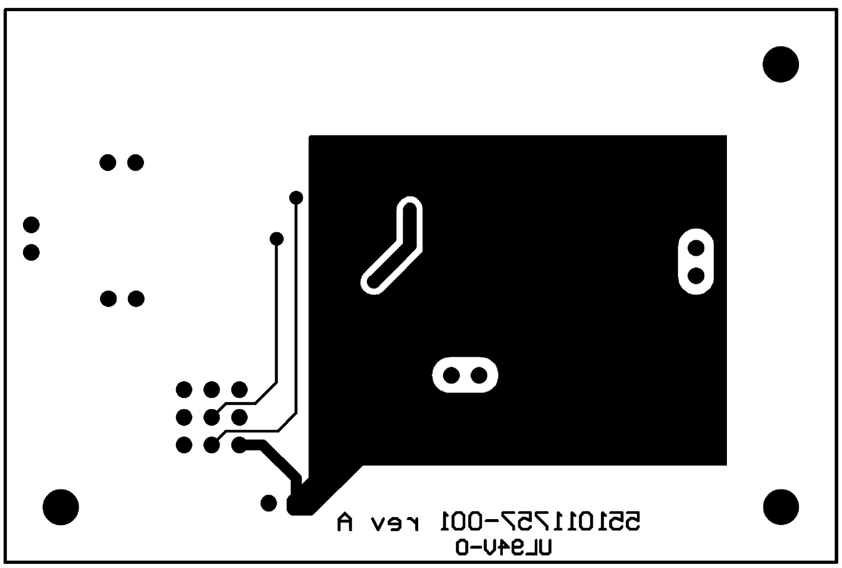


Figure 43. Bottom Layer



LM4665 DSBGA BOARD ARTWORK

Figure 44. Composite View

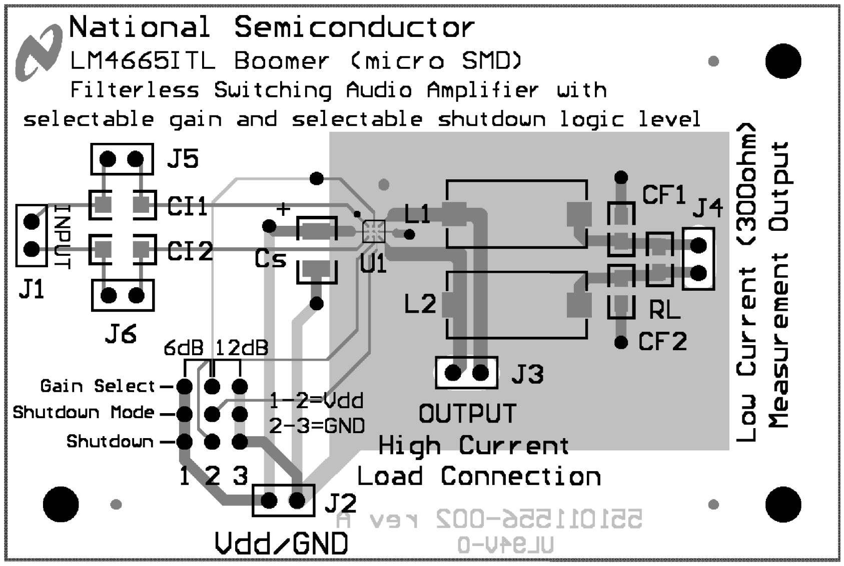


Figure 45. Silk Screen

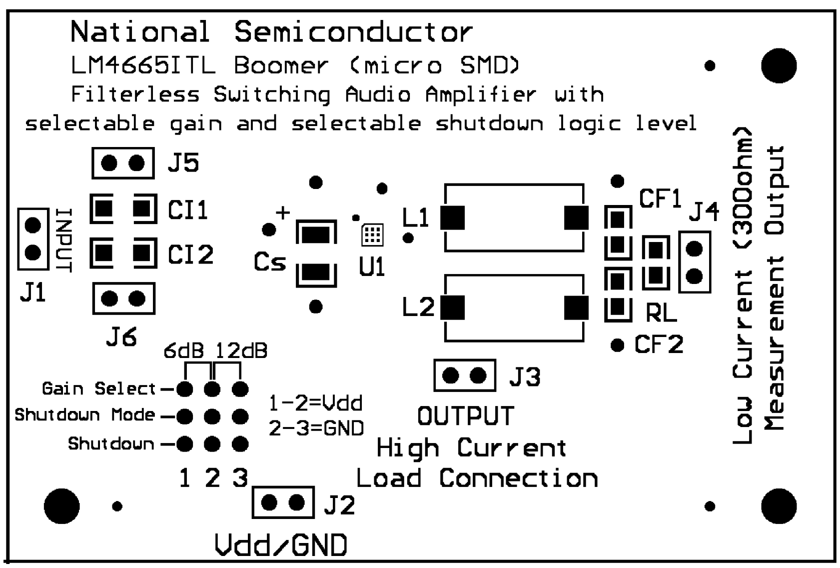


Figure 46. Top Layer

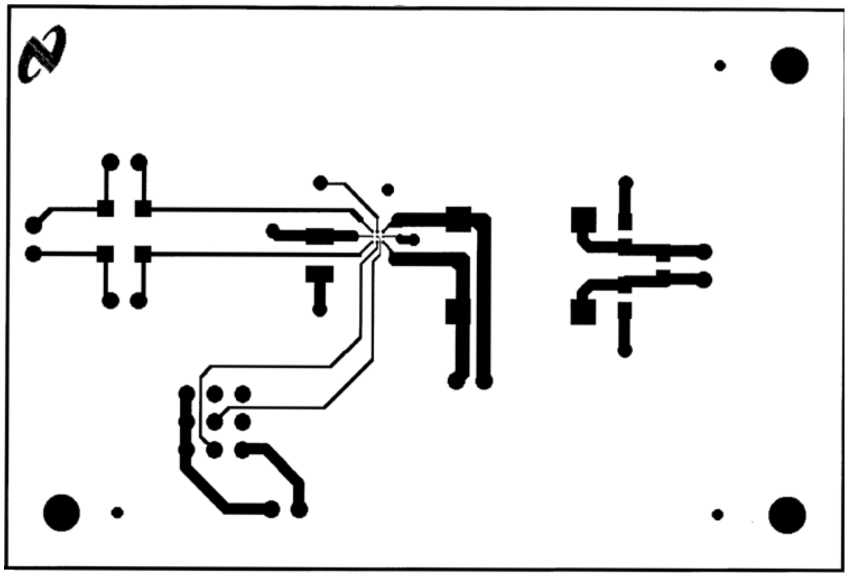
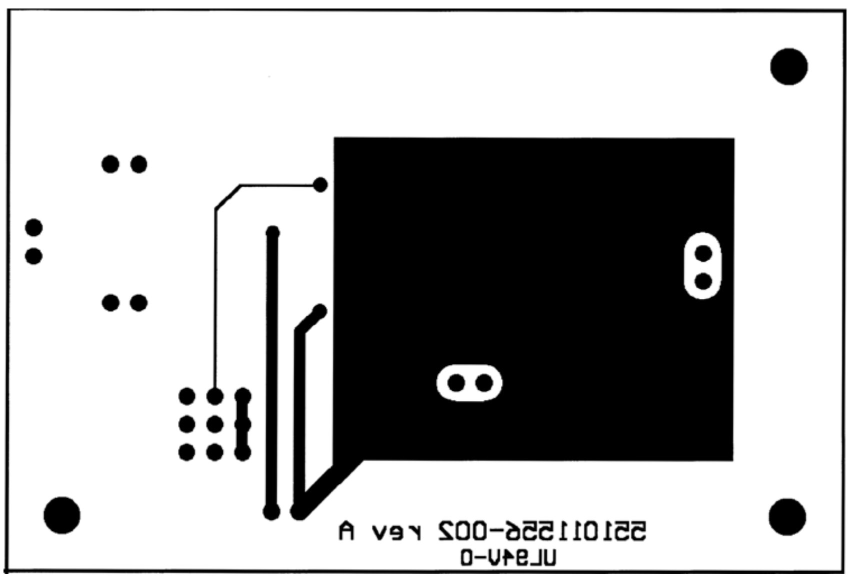


Figure 47. Bottom Layer



REVISION HISTORY

Changes from Revision D (May 2013) to Revision E	Page
• Changed layout of National Data Sheet to TI format	22

PACKAGING INFORMATION

Orderable part number	Status (1)	Material type (2)	Package | Pins	Package qty | Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
LM4665ITL/NOPB	Active	Production	DSBGA (YZR) | 9	250 | SMALL T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 85	G A2
LM4665ITL/NOPB.A	Active	Production	DSBGA (YZR) | 9	250 | SMALL T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 85	G A2

(1) **Status:** For more details on status, see our product life cycle.

(2) **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

(3) **RoHS values:** Yes, No, RoHS Exempt. See the TI RoHS Statement for additional information and value definition.

(4) **Lead finish/Ball material:** Parts may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

(5) **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

(6) **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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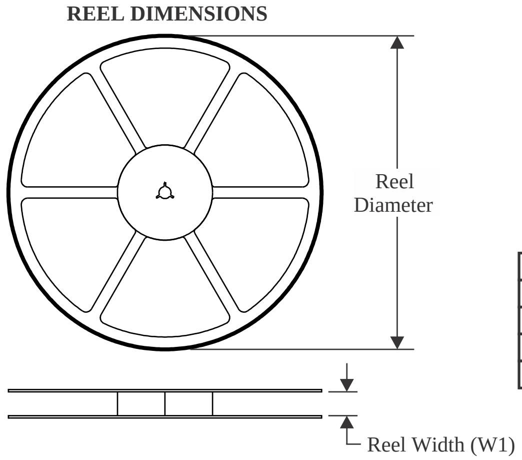
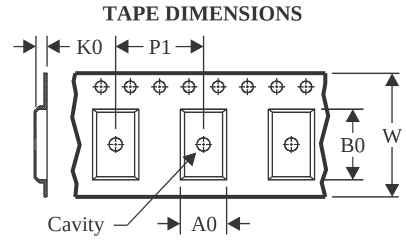
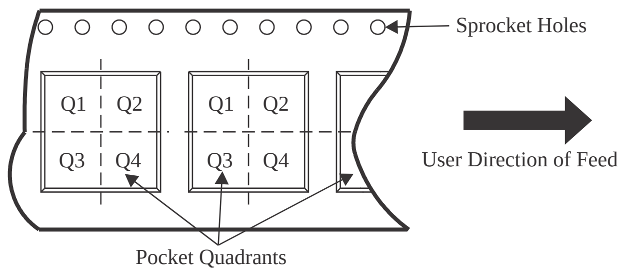
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

TAPE AND REEL INFORMATION





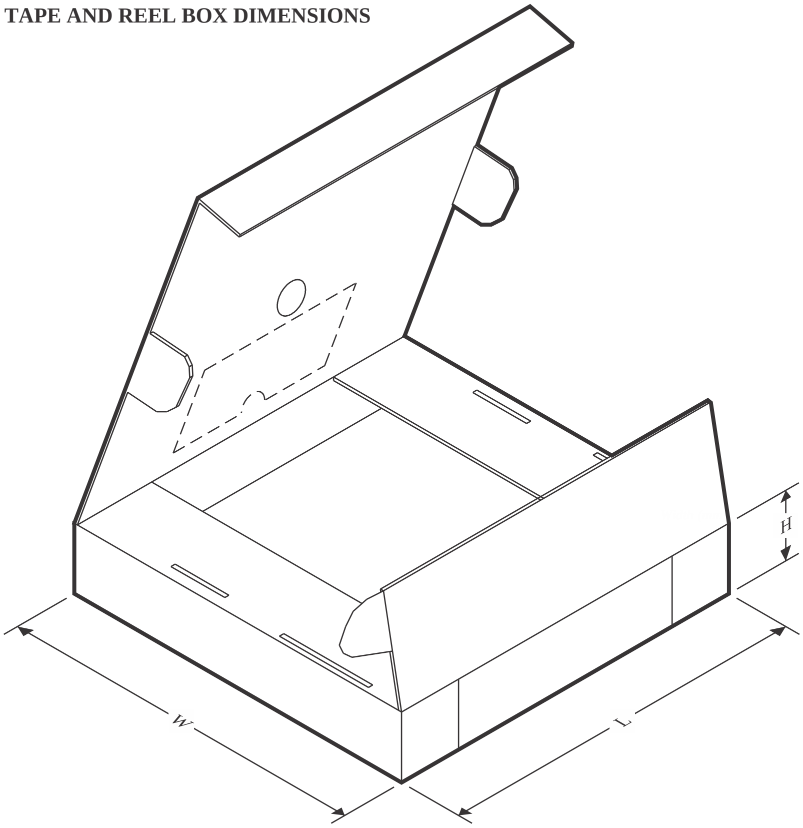
A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers



*All dimensions are nominal

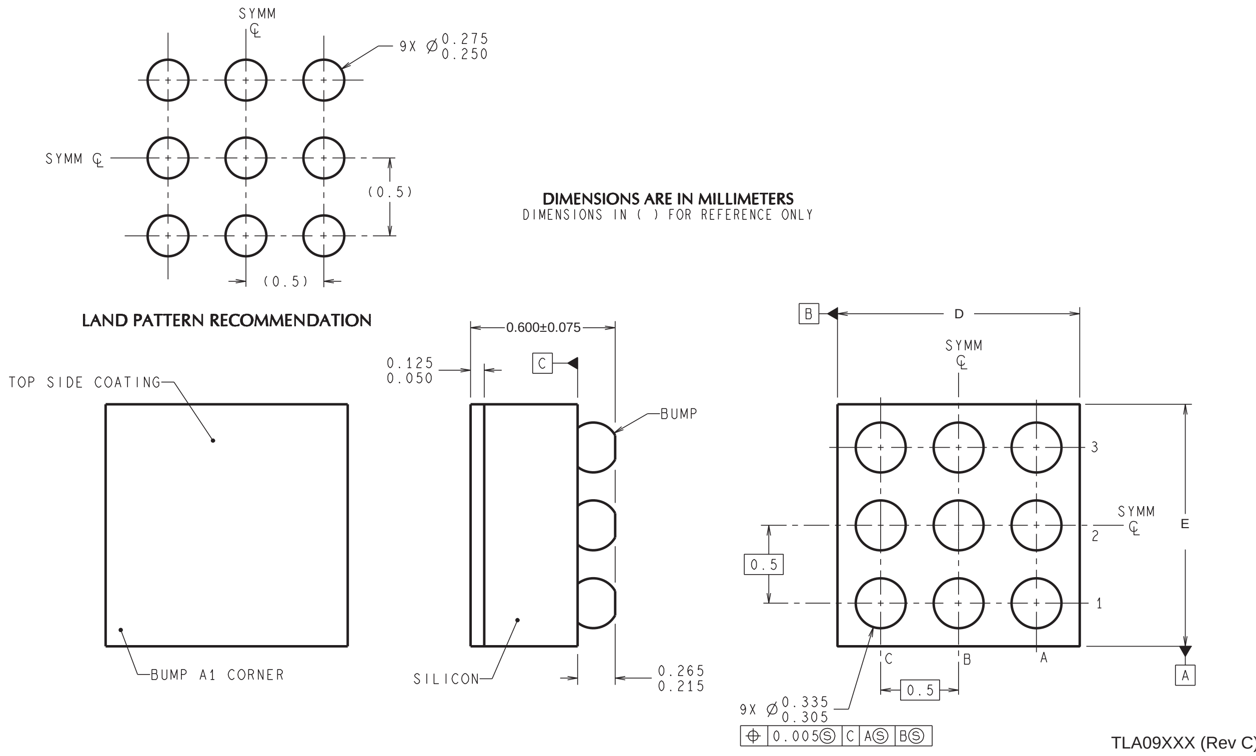
Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LM4665ITL/NOPB	DSBGA	YZR	9	250	178.0	8.4	1.7	1.7	0.76	4.0	8.0	Q1

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM4665ITL/NOPB	DSBGA	YZR	9	250	208.0	191.0	35.0



D: Max = 1.545 mm, Min =1.484 mm

E: Max = 1.545 mm, Min =1.484 mm

4215046/A 12/12

NOTES: A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
B. This drawing is subject to change without notice.