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Piezo-ceramic SPS speakers
&
Piezo-ceramic Audio Amplifiers

SONITRON

November 2008

SONITRON N.V.
R&D DEPARTMENT

Sonitron's Piezo Audio Amplifiers & Piezo Speakers

Speakers are used in a wide range of applications going from small portable devices to complete audio systems. Today's market is mainly dominated by electromagnetic speakers which have a voice coil and a heavy permanent magnet. Portable devices however require small, light speakers which are also energy efficient in order to increase battery life. Piezoceramic speakers are the perfect solution for such applications. In this upcoming market Sonitron has developed the flat piezoceramic SPS-speakers which are based on a new composite membrane that ensures an even frequency response.

To drive these piezo speakers Sonitron also has developed a complete range of piezo audio amplifiers to increase the audio voltage. The sound pressure level generated by a piezospeaker is in direct relation with the audio voltage which is applied. Therefore the amplifier needs to be chosen carefully.

Figure 1 shows the possible combinations of the Piezo Speakers & Amplifiers .

With the specific integrated circuits of
Linear Technology, National Semiconductor, Maxim and Texas Instruments it was possible to satisfy the needs of small dimensions, little current consumption, quality sound performance and easy to build in design.

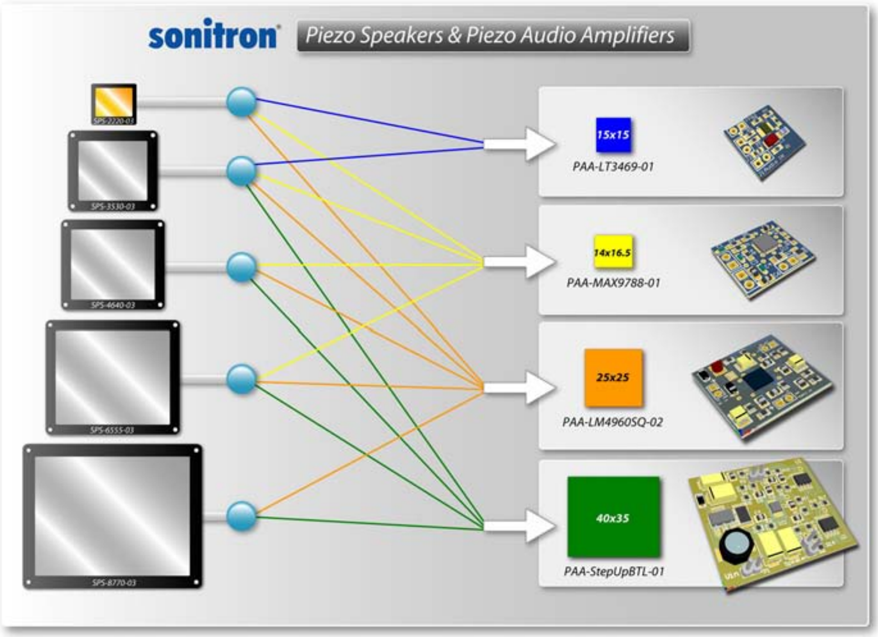

Figure 1: Combinations Sonitron Speaker & Amplifiers

	PAA-LT3469-01	PAA-MAX9788-01	PAA-LM4960-02	PAA-StepUpBTL-01
Measurements PCB(mm)	15 X15	14 X 16,5	25 X25	40 X 35
Voltage input (V)	5V	5V	5V	5V
MAX Capacitance Piezo Speaker	200nF	1µF	600nF	600nF
Max Voltage Output Vpp	33Vpp	20Vpp	24Vpp	60Vpp
Voltage Topology	Integrated step Up converter	Integrated step Up converter	Integrated step Up converter	Step Up converter
Amplifier classification	Class A	Class G	Class AB	Class AB
Used amplifier configuration	Single ended	Fully Differential	Bridge Tied Load	Bridge Tied Load
Average current consumption of speaker and amplifier (mA)	45mA	15mA	85mA	Not determined

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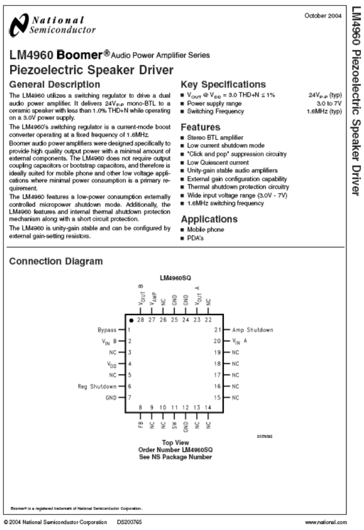
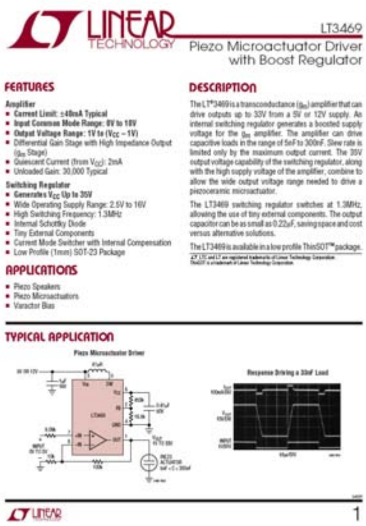
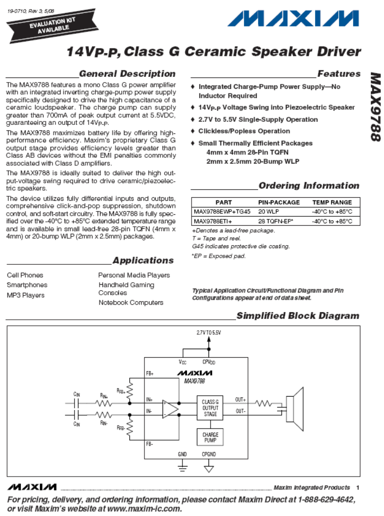
Piëzo Audio Amplifiers & Piëzo Speakers

Type	manufacter	Max Vout	Vin	ZL
LM4960	National Semiconductor	24Vpp	3V to 7V	800 nF + 20Ω
LM4961				
LM4962				
LM48555	National Semiconductor	15,7Vpp	3,2V	1µF + 10Ω (tested)
LT3469	Linear Technology	33Vpp	5V or 12V	5nF<C<300nF
MAX 9788	Maxim class G Ceramic Speaker Driver	14Vpp	2,7V to 5,5V	to 1µF + 10Ω
MAX 9738				
MAX668 OPA551	DC-DC converter (MAX668) with Bridge Tied Load (OPA551)	60Vpp	3V	







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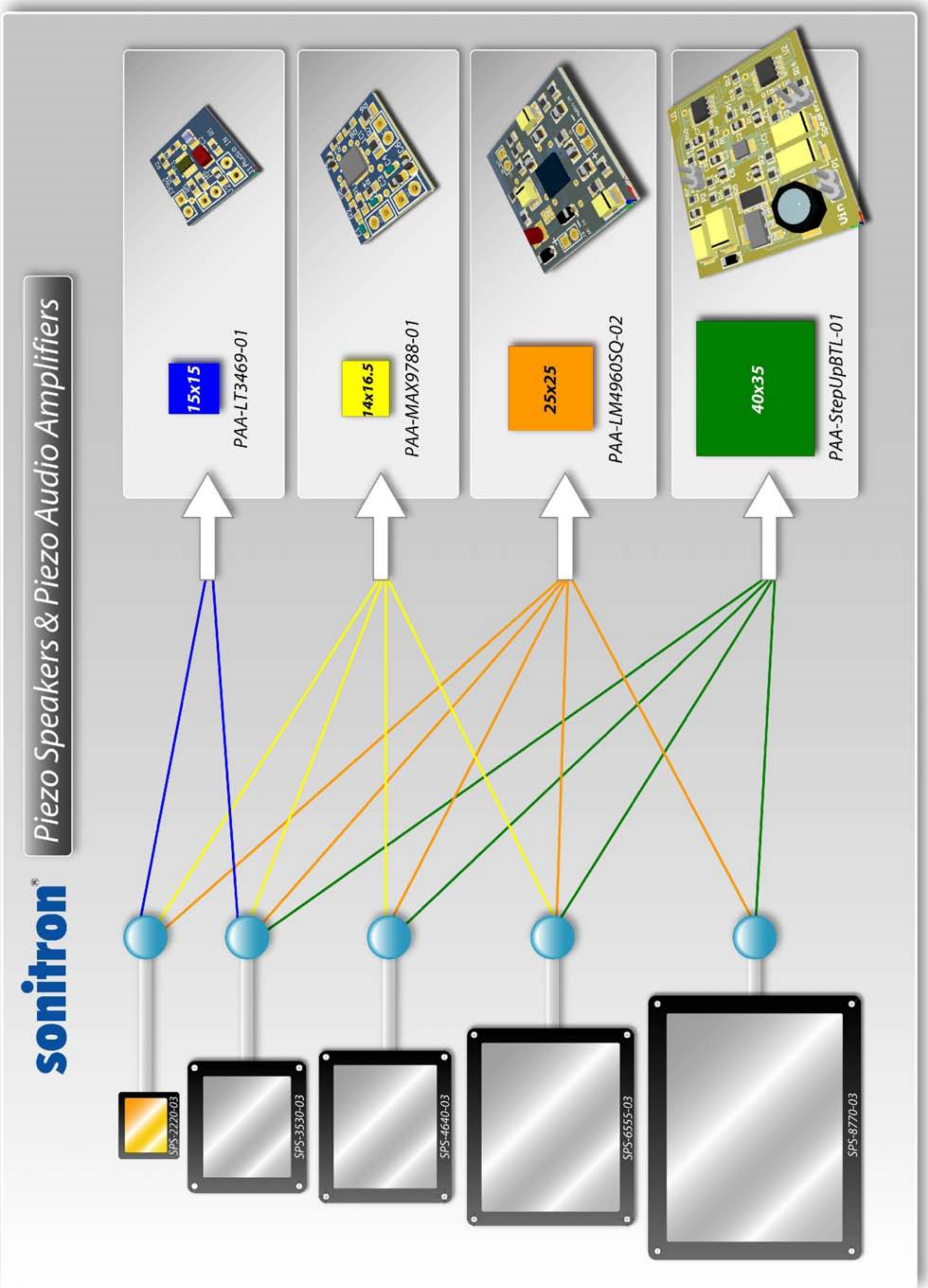

NEW

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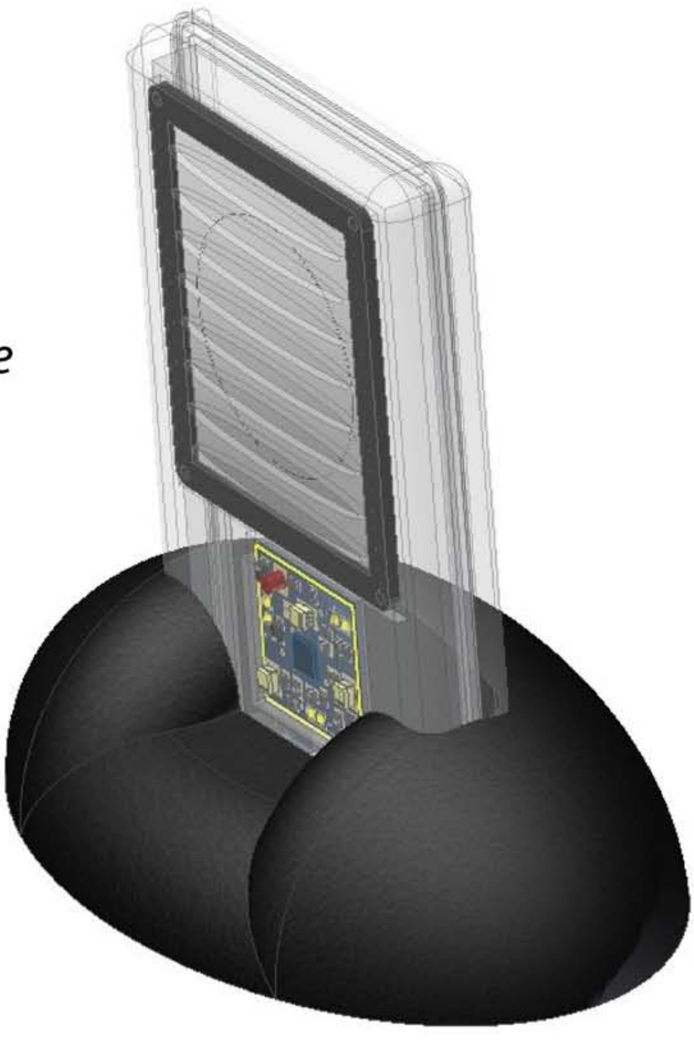
Application example
Pocketspeaker

SPS-6555-03
&
PAA-LM4960SQ-02

- *Easy to use and to demonstrate*
- *Powered by USB-connection cable*
- *Very light*
- *Small design*



Just put it in your pocket!

november 2008

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Piëzo-ceramic Audio Amplifiers
PAA-LT3469-01

SONITRON

October 2008

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R&D DEPARTMENT

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Sonitron PAA-LT3469-01 Amplifier

LINEAR TECHNOLOGY

LT3469

Piezo Microactuator Driver with Boost Regulator

FEATURES

Amplifier

- **Current Limit: ±40mA Typical**
- **Input Common Mode Range: 0V to 10V**
- **Output Voltage Range: 1V to (V_{CC} – 1V)**
- Differential Gain Stage with High Impedance Output (g_m Stage)
- Quiescent Current (from V_{CC}): 2mA
- Unloaded Gain: 30,000 Typical

Switching Regulator

- **Generates V_{CC} Up to 35V**
- Wide Operating Supply Range: 2.5V to 16V
- High Switching Frequency: 1.3MHz
- Internal Schottky Diode
- Tiny External Components
- Current Mode Switcher with Internal Compensation
- Low Profile (1mm) SOT-23 Package

APPLICATIONS

- Piezo Speakers
- Piezo Microactuators
- Varactor Bias

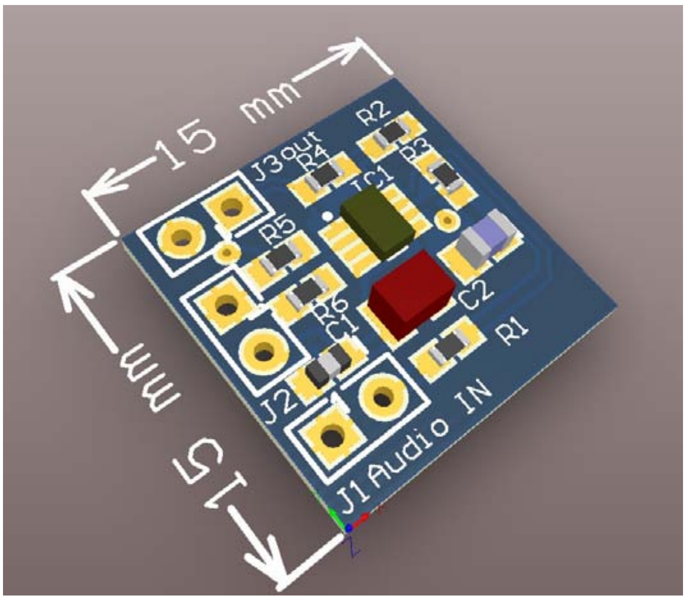
DESCRIPTION

The LT®3469 is a transconductance (g_m) amplifier that can drive outputs up to 33V from a 5V or 12V supply. An internal switching regulator generates a boosted supply voltage for the g_m amplifier. The amplifier can drive capacitive loads in the range of 5nF to 300nF. Slew rate is limited only by the maximum output current. The 35V output voltage capability of the switching regulator, along with the high supply voltage of the amplifier, combine to allow the wide output voltage range needed to drive a piezoceramic microactuator.

The LT3469 switching regulator switches at 1.3MHz, allowing the use of tiny external components. The output capacitor can be as small as 0.22µF, saving space and cost versus alternative solutions.

The LT3469 is available in a low profile ThinSOT™ package.

<u>Specifications:</u>
- Input Voltage: 2.5V to 16V
- Input Audio Signal: 0Vpp To 3.3Vpp
- Amplification ratio: 131
- Output Audio Signal: Max 33Vpp
- Dimensions: 15mm on 15mm



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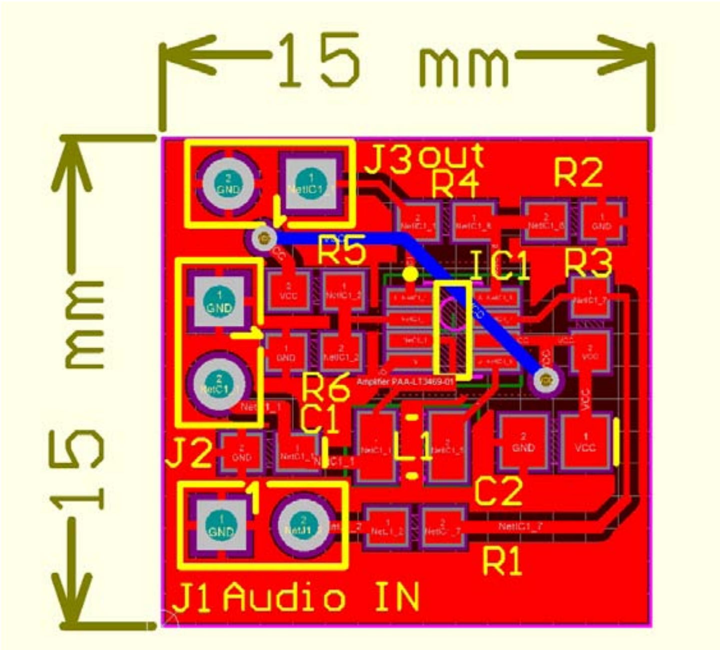
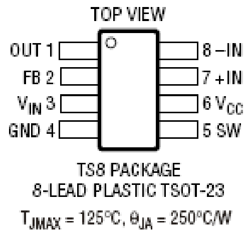
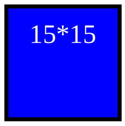






	Designator	Description	Package	Quantity
1	R1	Chip Resistor OR 1/16W 1%	R0603	1
2	R2	Chip Resistor 10K 1/16W 1%	R0603	1
3	R3	Chip Resistor 24K 1/16W 1%	R0603	1
4	R4	Chip Resistor 1M3 1/16W 1%	R0603	1
5	R5	Chip Resistor 430K 1/16W 1%	R0603	1
6	R6	Chip Resistor 16K 1/16W 1%	R0603	1
7	C1	Ceramic Capacitor 1µF/16V/X7R/10%	C0603	1
8	C2	Ceramic Capacitor 220nF/50V/X7R/10%	C0805	1
9	L1	47µH Taiyo Yuden TY LB2518-T470M	LB2518	1
10	U1	LT3469ETS8 Piëzo Audio Amplifier	TSOT 23-8	1

BLOCK DIAGRAM

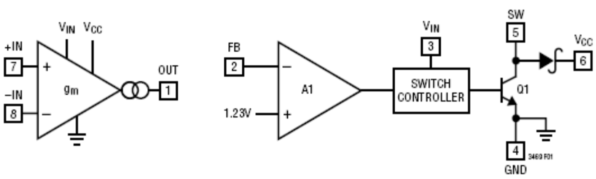
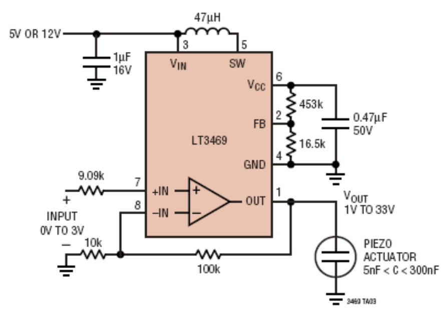


Figure 1. LT3469 Block Diagram

TYPICAL APPLICATION

Piezo Microactuator Driver



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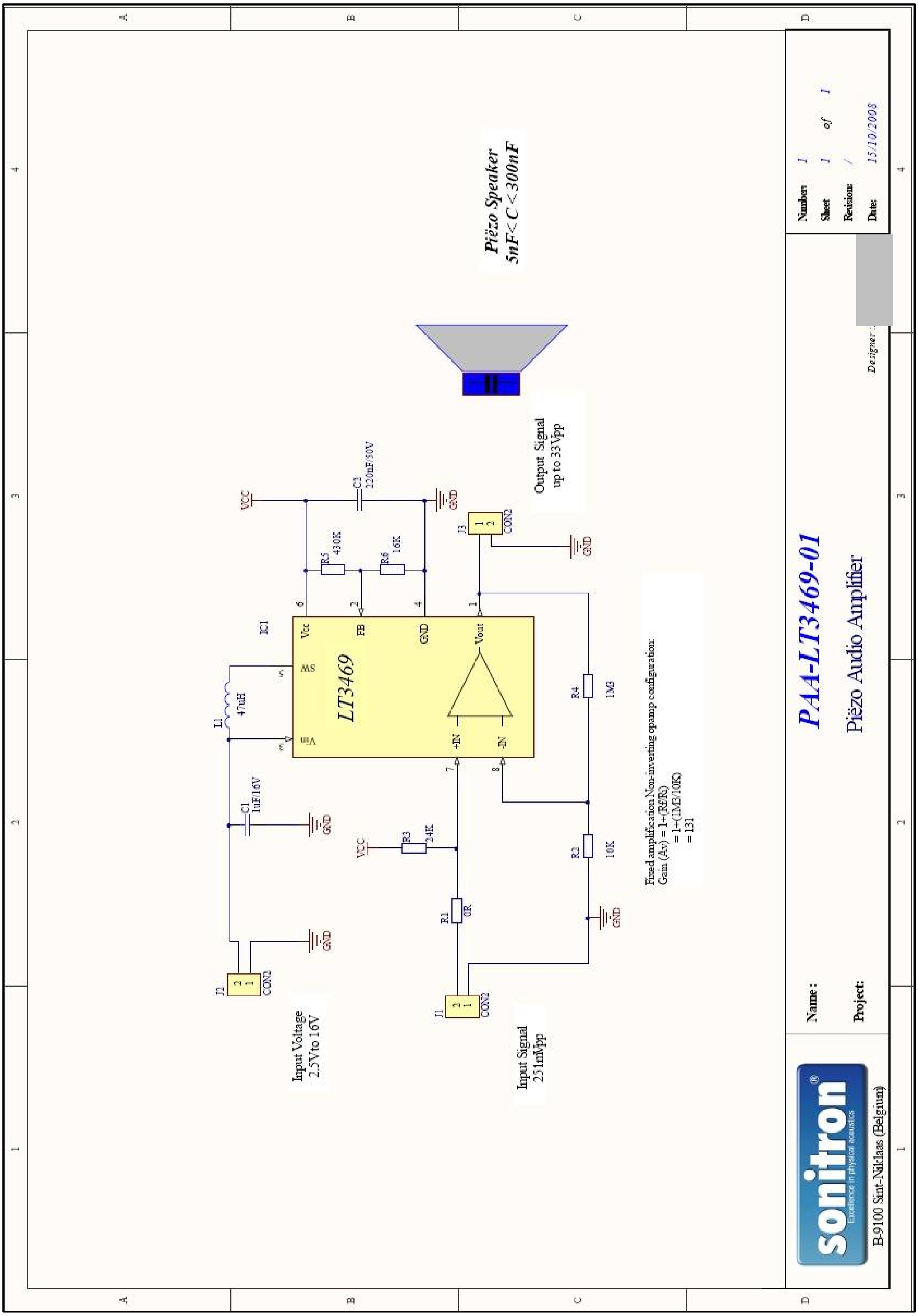
Electronic Schematic of PAA-LT3469-01

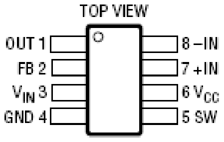


ABSOLUTE MAXIMUM RATINGS

(Note 1)

V_{IN} Voltage 16V
SW Voltage 40V
V_{CC} Voltage 38V
+IN, –IN Voltage 10V
FB Voltage 3V
Current Into SW Pin 1A
Operating Temperature Range (Note 2) .. –40°C to 85°C
Storage Temperature Range .... –65°C to 150°C
Lead Temperature (Soldering, 10 sec) .... 300°C

PACKAGE/ORDER INFORMATION



TS8 PACKAGE
8-LEAD PLASTIC TSOT-23
$T_{JMAX} = 125°C$, $\theta_{JA} = 250°C/W$

ORDER PART NUMBER
LT3469ETS8
TS8 PART MARKING
LTACA

Consult LTC Marketing for parts specified with wider operating temperature ranges.

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at $T_A = 25°C$. (Note 2) $V_{IN} = 5V$, $V_{CC} = 35V$, unless otherwise noted.

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
g_m Amplifier						
Input Offset Voltage	$V_{OUT} = V_{CC}/2$	●		3	10	mV
Input Offset Current		●		10	100	nA
Input Bias Current		●		150	500	nA
Input Resistance—Differential Mode				1		MΩ
Input Resistance—Common Mode				200		MΩ
Common Mode Rejection Ratio	V_{CM} = 0V to 10V		70	100		dB
Power Supply Rejection Ratio—V_{IN}	V_{IN} = 2.5V to 16V		80	120		dB
Power Supply Rejection Ratio—V_{CC}	V_{CC} = 15V to 35V		65	85		dB
Gain	No Load, V_{OUT} = 2V to 33V R_L = 200k, V_{OUT} = 2V to 33V		15 10	30 20		V/mV V/mV
Transconductance	I_{OUT} = ±100µA	 ●	160 140	220	260 300	µA/mV µA/mV
Maximum Output Current	$V_{OUT} = V_{CC}/2$	 ●	±30 ±23	±40	±55 ±58	mA mA
Maximum Output Voltage, Sourcing	V_{CC} = 35V, I_{OUT} = 10mA V_{CC} = 35V, I_{OUT} = 0mA		34.0 34.5	34.5 34.9		V V
Minimum Output Voltage, Sinking	I_{OUT} = –10mA I_{OUT} = 0mA			200 10	1000 500	mV mV
Output Resistance	V_{CC} = 35V, V_{OUT} = 2V to 33V			100		kΩ
Supply Current—V_{CC}	V_{CC} = 35V		1.5	2	2.5	mA
Switching Regulator						
Minimum Operating Voltage					2.5	V
Maximum Operating Voltage			16			V
Feedback Voltage		●	1.19	1.23	1.265	V
FB Pin Bias Current		●		45	200	nA
FB Line Regulation	$2.5V < V_{IN} < 16V$			0.03		%/V
Supply Current—V_{IN}				1.9	2.6	mA
Switching Frequency		●	0.8	1.3	1.7	MHz
Maximum Duty Cycle		●	88	91		%
Switch Current Limit (Note 3)		●	165	220		mA
Switch V_{CESAT}	I_{SW} = 100mA			350	500	mV

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. (Note 2) V_{IN} = 5V, V_{CC} = 35V, unless otherwise noted.

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Switch Leakage Current	V_{SW} = 5V			0.01	1	µA
Diode V_F	I_D = 100mA			740	1100	mV
Diode Reverse Leakage Current	V_R = 5V			0.1	1	µA

Note 1: Absolute Maximum Ratings are those values beyond which the life of a device may be impaired.

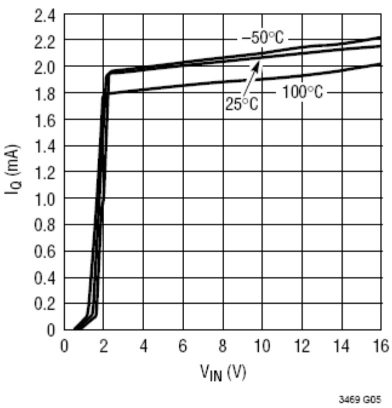
Note 2: The LT3469E is guaranteed to meet performance specifications from 0°C to 85°C. Specifications over the –40°C to 85°C operating temperature range are assured by design, characterization and correlation with statistical process controls.

Note 3: Current limit is guaranteed by design and/or correlation to static test. Slope compensation reduces current limit at higher duty cycles.

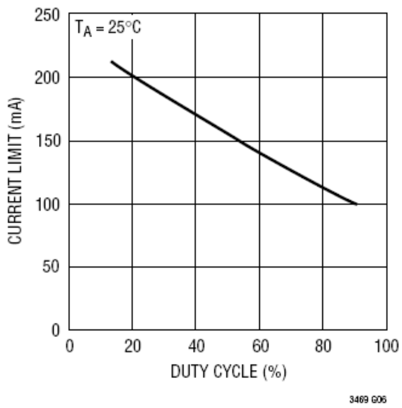
TYPICAL PERFORMANCE CHARACTERISTICS

(Switching Regulator)

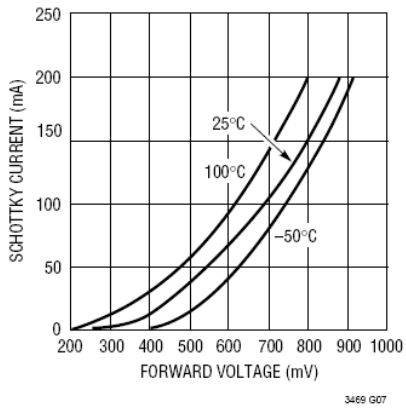
V_{IN} Quiescent Current



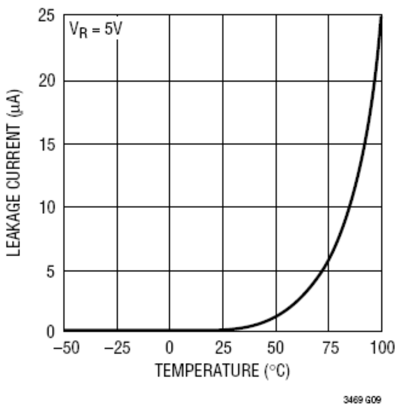
Current Limit vs Duty Cycle



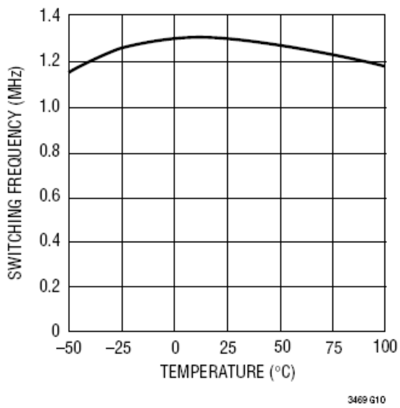
Schottky Forward Voltage



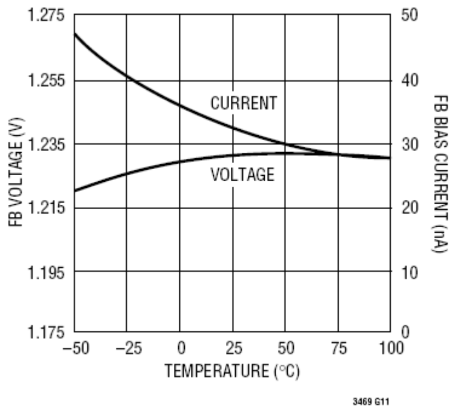
Schottky Reverse Leakage



Switching Frequency



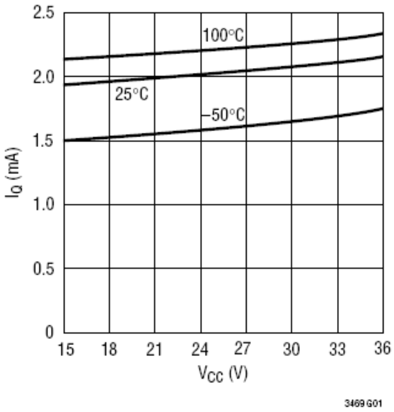
FB Pin Voltage and Bias Current



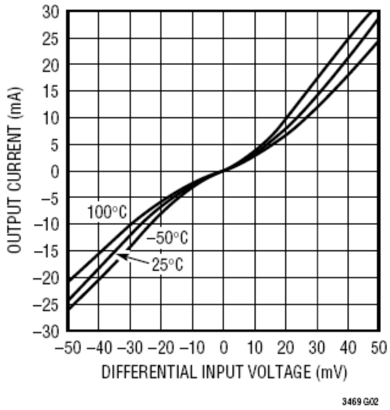
TYPICAL PERFORMANCE CHARACTERISTICS

(g_m Amplifier)

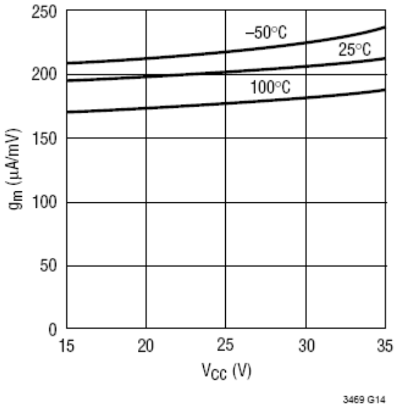
V_{CC} Quiescent Current



Output Current vs Differential Input Voltage



g_m vs V_{CC}



PIN FUNCTIONS

OUT (Pin 1): Output of the g_m Amplifier. There must be at least 5nF of capacitive load at the output in a gain of 10 configuration. Capacitive loads up to 300nF can be connected to this pin. Piezo actuators below 5nF can be driven if capacitance is placed in parallel to bring the total capacitance to 5nF.

FB (Pin 2): Feedback Pin. Reference voltage is 1.23V. Connect feedback resistor divider here.

V_{IN} (Pin 3): Input Supply Pin. Must be locally bypassed.

GND (Pin 4): Ground Pin. Connect directly to local ground plane.

SW (Pin 5): Switch Pin. Connect inductor here. Minimize trace area at this pin to reduce EMI.

V_{CC} (Pin 6): Output of Switching Regulator and Supply Rail for g_m Amp. There must be 0.22µF or more of capacitance here.

+IN (Pin 7): Noninverting Terminal of the g_m Amplifier.

–IN (Pin 8): Inverting Terminal of the g_m Amplifier.

BLOCK DIAGRAM

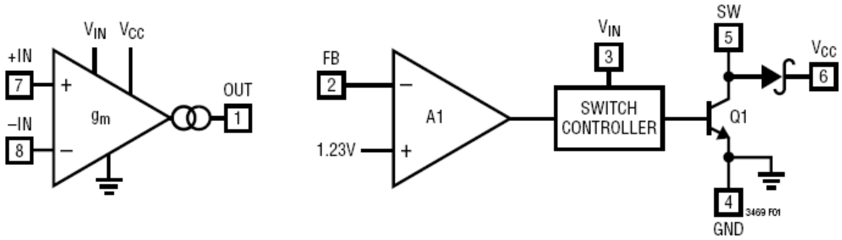


Figure 1. LT3469 Block Diagram

OPERATION

g_m Amplifier

The LT3469 is a wide output voltage range g_m amplifier designed to drive capacitive loads. Input common mode range extends from 10V to ground. The output current is proportional to the voltage difference across the input terminals. When the output voltage has settled, the input terminals will be at the same voltage; supply current of the amplifier will be low and power dissipation will be low. If presented with an input differential, however, the output current can increase significantly, up to the maximum output current (typically 40mA). The output voltage slew rate is determined by the maximum output current and the output capacitance, and can be quite high. With a 10nF load, the output slew rate will typically be 4V/µs. The capacitive load compensates the g_m amplifier and must be present for stable operation. The gain capacitance product of the amplifier must be at least 50nF. For example, if the amplifier is operated in a gain of 10 configuration, a minimum capacitance of 5nF is necessary. In a gain of 20 configuration, a minimum of 2.5nF is necessary. Closed loop –3dB bandwidth is set by the output capacitance. Typical closed loop bandwidth is approximately:

$$\frac{g_m}{2\pi \bullet A_V \bullet C_{OUT}}$$

where g_m = 200µA/mV

For example, an amplifier in a gain of 10 configuration with 10nF of output capacitance will have a closed loop –3dB bandwidth of approximately 300kHz. Figure 3 shows typical bandwidth of a gain of 10 configuration per output capacitance.

In applications where negative phase contributions below crossover frequency must be minimized, a phase boost capacitor can be added, as shown in Figure 4. Larger values of C_{BOOST} will further reduce the closed-loop negative phase contribution, however, the amplifier phase margin will be reduced. For an amplifier phase margin of approximately 55°, select C_{BOOST} as follows:

$$C_{BOOST} = \frac{C_{OUT}(R1/R2 + 1)}{g_m(R1 || R2)}$$

where g_m = 200µA/mV.

In a gain of 10 configuration, choosing C_{BOOST} as described will lead to nearly zero closed-loop negative phase contribution at 3kHz for values of C_{OUT} from 10nF to 200nF. The phase boost capacitor should not be used if C_{OUT} is less than twice the minimum for stable operation. The gain capacitance product should therefore be higher than 100nF if a phase boost capacitor is used.

Switching Regulator

The LT3469 uses a constant frequency, current mode control scheme to provide excellent line and load regulation. Operation can be best understood by referring to the Block Diagram in Figure 1. The switch controller sets the peak current in Q1 proportional to its input. The input to the switch controller is set by the error amplifier, A1, and is

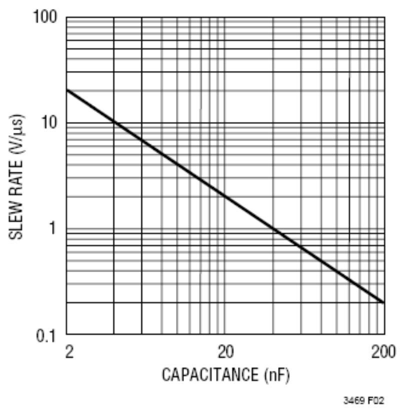


Figure 2. Slew Rate vs Capacitance

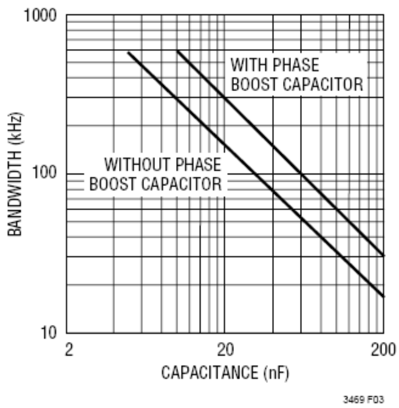


Figure 3. Closed Loop –3dB Bandwidth vs Capacitance in a Gain of 10 Configuration

OPERATION

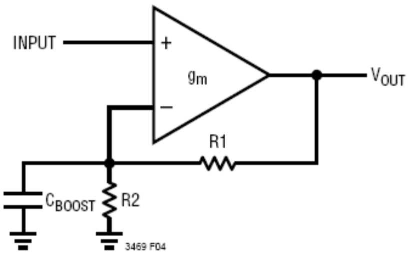


Figure 4. Boosting the Bandwidth of the g_m Amplifier with Capacitance On the Inverting Input

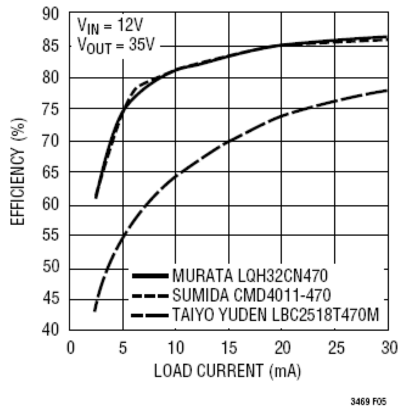


Figure 5. Efficiency Comparison of Different Inductors

simply an amplified version of the difference between the feedback voltage and the reference voltage of 1.23V. In this manner, the error amplifier sets the correct peak current level to keep the output in regulation. If the error amplifier's output increases, more current is delivered to the output; if it decreases, less current is delivered. The switching regulator provides the boosted supply voltage for the g_m amplifier.

Inductor Selection

A 47µH inductor is recommended for most LT3469 applications. Some suitable inductors with small size are listed in Table 1. The efficiency comparison of different inductors is shown in Figure 5.

Table 1. Recommended Inductors

PART NUMBER	DCR (Ω)	CURRENT RATING (mA)	MANUFACTURER
LQH32CN470	1.3	170	Murata 814-237-1431 www.murata.com
CMD4D11-470	2.8	180	Sumida 847-545-6700 www.Sumida.com
LBC2518T470M	1.9	150	Taiyo Yuden 408-573-4150 www.t-yuden.com

Capacitor Selection

The small size of ceramic capacitors makes them ideal for LT3469 applications. X5R and X7R types are recommended because they retain their capacitance over wider voltage and temperature ranges than other types such as Y5V or Z5U. A 1µF input capacitor is sufficient for most LT3469 applications. A 0.22µF output capacitor is sufficient for stable transient response, however, more output capacitance can help limit the voltage droop on V_{CC} during transients.

Table 2. Recommended Ceramic Capacitor Manufacturers

MANUFACTURER	PHONE	URL
Taiyo Yuden	408-573-4150	www.t-yuden.com
AVX	843-448-9411	www.avxcorp.com
Murata	814-237-1431	www.murata.com
Kemet	408-986-0424	www.kemet.com

Inrush Current Considerations When Hot Plugging

When the supply voltage is applied to V_{IN}, the voltage difference between V_{IN} and V_{CC} generates inrush current flowing from the input through the inductor, the SW pin, and the integrated Schottky diode to charge the output capacitor. Care should be taken not to exceed the LT3469 maximum SW pin current rating of 1A. Worst-case inrush current occurs when the application circuit is hot plugged into a live supply with a large output capacitance. The typical application circuit will maintain a peak SW pin current below 1A when it is hot plugged into a 5V supply. To keep SW pin current below 1A during a hot plug into a 12V supply, 4.7Ω must be added between the supply and the LT3469 input capacitor. During normal operation, the SW pin current remains significantly less than 1A.

Layout Hints

As with all switching regulators, careful attention must be paid to the PCB board layout and component placement. To maximize efficiency, switch rise and fall times are made

OPERATION

as short as possible. To prevent electromagnetic interference (EMI) problems, proper layout of the high frequency switching path is essential. The voltage signal of the SW pin has sharp rise and fall edges. The SW pin should be surrounded on three sides by metal connected to V_{CC} to shield +IN and –IN. Minimize the area of all traces connected to the SW pin and always use a ground plane under the switching regulator to minimize interplane coupling. In addition, the ground connection for the feedback resistor R1 should be tied directly to the GND pin and not shared with any other component, ensuring a clean, noise-free connection. The ground return of the piezoceramic microactuator should also have a direct and unshared connection to the GND pin. The GND connection to R5 should be tied directly to the ground of the source generating the INPUT signal to avoid error induced by voltage drops along the GND line. Recommended component placement is shown in Figure 6.

Thermal Considerations and Power Dissipation

The LT3469 combines large output drive with a small package. Because of the high supply voltage capability, it is possible to operate the part under conditions that exceed the maximum junction temperature. Maximum junction temperature (T_J) is calculated from the ambient temperature (T_A) and power dissipation (P_D) as follows:

$$T_J = T_A + (P_D \bullet 250°C/W)$$

Worst-case power dissipation occurs at maximum output swing, frequency, capacitance and V_{CC}. For a square wave input, power dissipation is calculated from the amplifier quiescent current (I_Q), input frequency (f), output swing ($V_{OUT(P-P)}$), capacitive load (C_L), amplifier supply voltage (V_{CC}) and switching regulator efficiency (η) as follows:

$$P_D = \frac{\left(I_Q + fV_{OUT(P-P)}C_L\right)\left(V_{CC}\right)}{\eta}$$

Example: LT3469 at T_A = 70°C, V_{CC} = 35V, C_L = 200nF, f = 3kHz, $V_{OUT(P-P)}$ = 4V, η = 80%:

$$P_D = \frac{\left(2.5mA + 3kHz \bullet 4V \bullet 200nF\right)\left(35V\right)}{0.80} = 214mW$$

$$T_J = 70°C + \left(214mW \bullet 250°C/W\right) = 124°C$$

Do not exceed the maximum junction temperature of 125°C.

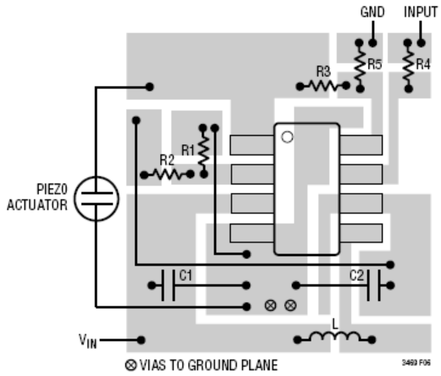
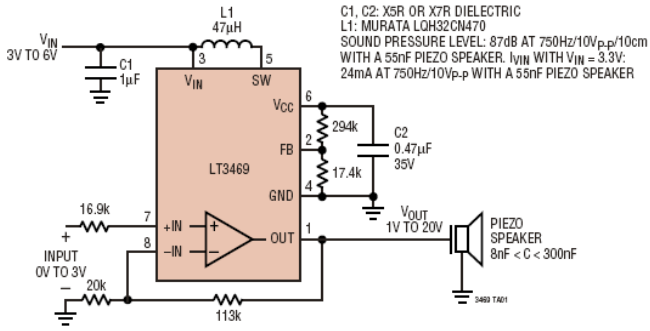


Figure 6. Recommended Component Placement

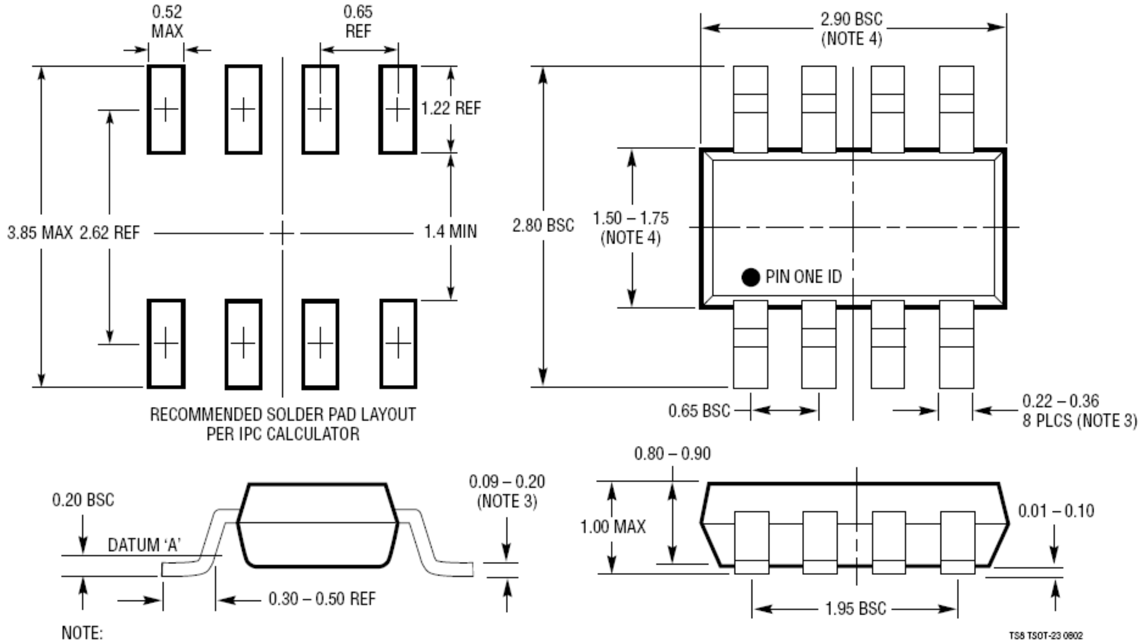
TYPICAL APPLICATION

Piezo Speaker Driver



PACKAGE DESCRIPTION

TS8 Package
8-Lead Plastic TSOT-23
(Reference LTC DWG # 05-08-1637)



NOTE:
1. DIMENSIONS ARE IN MILLIMETERS
2. DRAWING NOT TO SCALE
3. DIMENSIONS ARE INCLUSIVE OF PLATING
4. DIMENSIONS ARE EXCLUSIVE OF MOLD FLASH AND METAL BURR
5. MOLD FLASH SHALL NOT EXCEED 0.254mm
6. JEDEC PACKAGE REFERENCE IS MO-193

RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LT1611	550mA I_{SW}, 1.4MHz, High Efficiency Inverting DC/DC Converter	V_{IN}: 0.9V to 10V, $V_{OUT(MAX)}$: 34V, I_Q: 3mA, I_{SD}: <1µA, ThinSOT
LT1616	600mA I_{OUT}, 1.4MHz, High Efficiency Step-Down DC/DC Converter	V_{IN}: 3.6V to 25V, $V_{OUT(MIN)}$: 1.25V, I_Q: 1.9mA, I_{SD}: <1µA, ThinSOT
LTC1772B	550kHz, Current Mode Step-Down DC/DC Controller	V_{IN}: 2.5V to 9.8V, $V_{OUT(MIN)}$: 0.8V, I_Q: 270µA, I_{SD}: <8µA, ThinSOT
LT1931/LT1931A	1A I_{SW}, 1.2MHz/2.2MHz, High Efficiency Inverting DC/DC Converter	V_{IN}: 2.6V to 16V, $V_{OUT(MAX)}$: –34V, I_Q: 4.2mA, I_{SD}: <1µA, ThinSOT
LT1940 (Dual)	Dual Output 1.4A I_{OUT}, Constant 1.1MHz, High Efficiency Step-Down DC/DC Converter	V_{IN}: 3V to 25V, $V_{OUT(MIN)}$: 1.2V, I_Q: 2.5mA, I_{SD}: <1µA, TSSOP-16E
LTC3411	1.25A I_{OUT}, 4MHz Synchronous Step-Down DC/DC Converter	V_{IN}: 2.5V to 5.5V, $V_{OUT(MIN)}$: 0.8V, I_Q: 60µA, I_{SD}: <1µA, MS10, DFN
LT3464	85mA I_{SW}, Constant Off-Time, High Efficiency Step-Up DC/DC Converter with Integrated Schottky and Output Disconnect	V_{IN}: 2.3V to 10V, $V_{OUT(MAX)}$: 34V, I_Q: 25µA, I_{SD}: <0.5µA, ThinSOT

Linear Technology Corporation
1630 McCarthy Blvd., Milpitas, CA 95035-7417
(408) 432-1900 • FAX: (408) 434-0507 • www.linear.com
LT/TP 0304 1K • PRINTED IN USA

NOTES:

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Appnote PAA-MAX9788-01

Piëzo-ceramic audio amplifiers
PAA-MAX9788-01

SONITRON

November 2008

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Sonitron PAA-MAX9788-01 Amplifier

MAXIM

14VP-P, Class G Ceramic Speaker Driver

MAX9788

General Description

The MAX9788 features a mono Class G power amplifier with an integrated inverting charge-pump power supply specifically designed to drive the high capacitance of a ceramic loudspeaker. The charge pump can supply greater than 700mA of peak output current at 5.5VDC, guaranteeing an output of 14VP-P.

The MAX9788 maximizes battery life by offering high-performance efficiency. Maxim's proprietary Class G output stage provides efficiency levels greater than Class AB devices without the EMI penalties commonly associated with Class D amplifiers.

The MAX9788 is ideally suited to deliver the high output-voltage swing required to drive ceramic/piezoelectric speakers.

The device utilizes fully differential inputs and outputs, comprehensive click-and-pop suppression, shutdown control, and soft-start circuitry. The MAX9788 is fully specified over the -40°C to +85°C extended temperature range and is available in small lead-free 28-pin TQFN (4mm x 4mm) or 20-bump WLP (2mm x 2.5mm) packages.

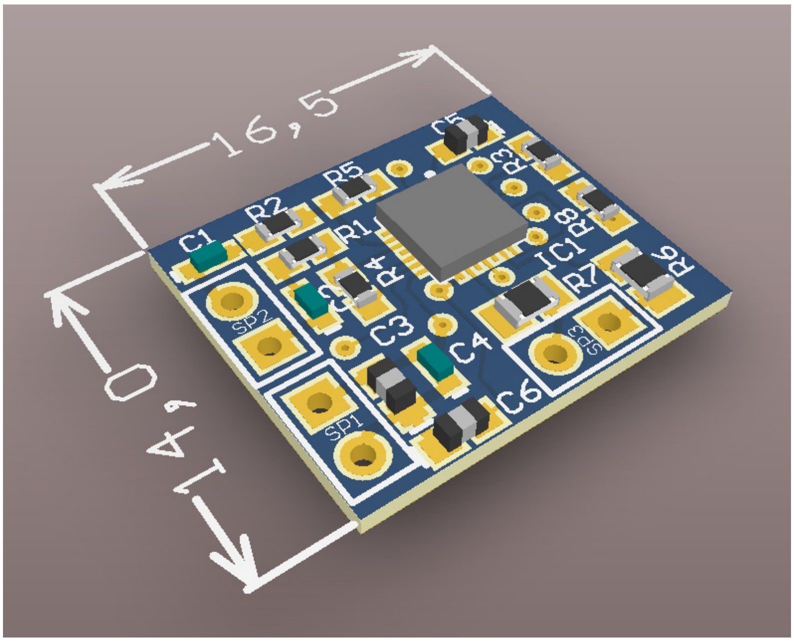
Features

- ♦ Integrated Charge-Pump Power Supply—No Inductor Required
- ♦ 14VP-P Voltage Swing into Piezoelectric Speaker
- ♦ 2.7V to 5.5V Single-Supply Operation
- ♦ Clickless/Popless Operation
- ♦ Small Thermally Efficient Packages
  - 4mm x 4mm 28-Pin TQFN
  - 2mm x 2.5mm 20-Bump WLP

Ordering Information

PART	PIN-PACKAGE	TEMP RANGE
MAX9788EWP+TG45	20 WLP	-40°C to +85°C
MAX9788ETI+	28 TQFN-EP*	-40°C to +85°C

+Denotes a lead-free package.
T = Tape and reel.
G45 indicates protective die coating.
**EP = Exposed pad.*



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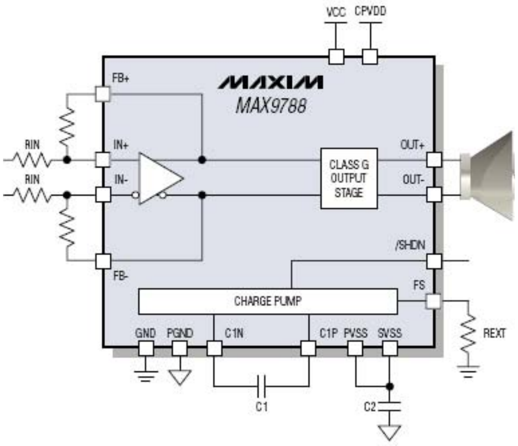
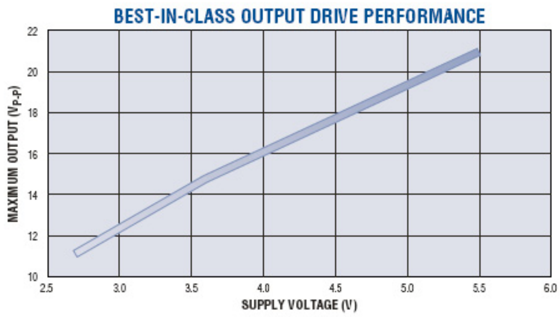
The MAX9788's Class G technology can deliver up to $20V_{P-P}$, ideal for driving ultra-thin piezoelectric and ceramic speakers, for portable applications such as cell phones, smartphones, and portable media players.

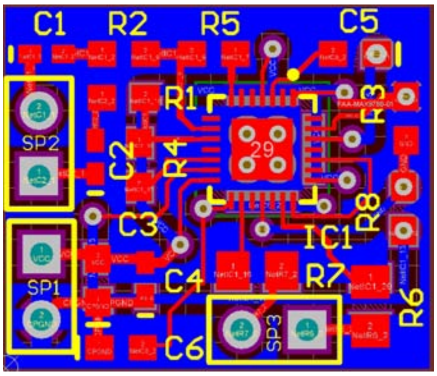




<u>Specifications:</u>

- **Class G amplifier** to drive a bridge-tied –load (BTL) Piëzo-ceramic speaker
- Input Voltage: 2.7V to 5.5V
- Input Audio Signal: 0V To 1.5Vpp
- Output Audio Signal: Max 20Vpp
- Capacitive load up to 1µF
- Dimensions: 14mm on 16.5mm

14*16.5



	Designator	Description	Package	Quantity
1	R1, R2	Chip Resistor 10k/1%	R0603	2
2	R3	Chip Resistor 0R/1%	R0603	1
3	R4,R5	Chip Resistor 200k/1%	R0603	2
4	R6,R7	Chip Resistor 10R/1%	R0805	2
5	R8	Chip Resistor 100K/1%	R0603	1
6	C1,C2	Ceramic Capacitor 68nF/16V/10%/X7R	C0402	2
7	C3,C6	Ceramic Capacitor 10uF/6,3V/20%/X5R	C0603	2
8	C4	Ceramic Capacitor 0,1uF/16V/10%/X5R	C0402	1
9	C5	Ceramic Capacitor 4,7uF/6,3V/10%/X5R	C0603	1
10	U1	MAX9788 Piezo Ceramic Speaker Amplifier	Thin QFN28	1

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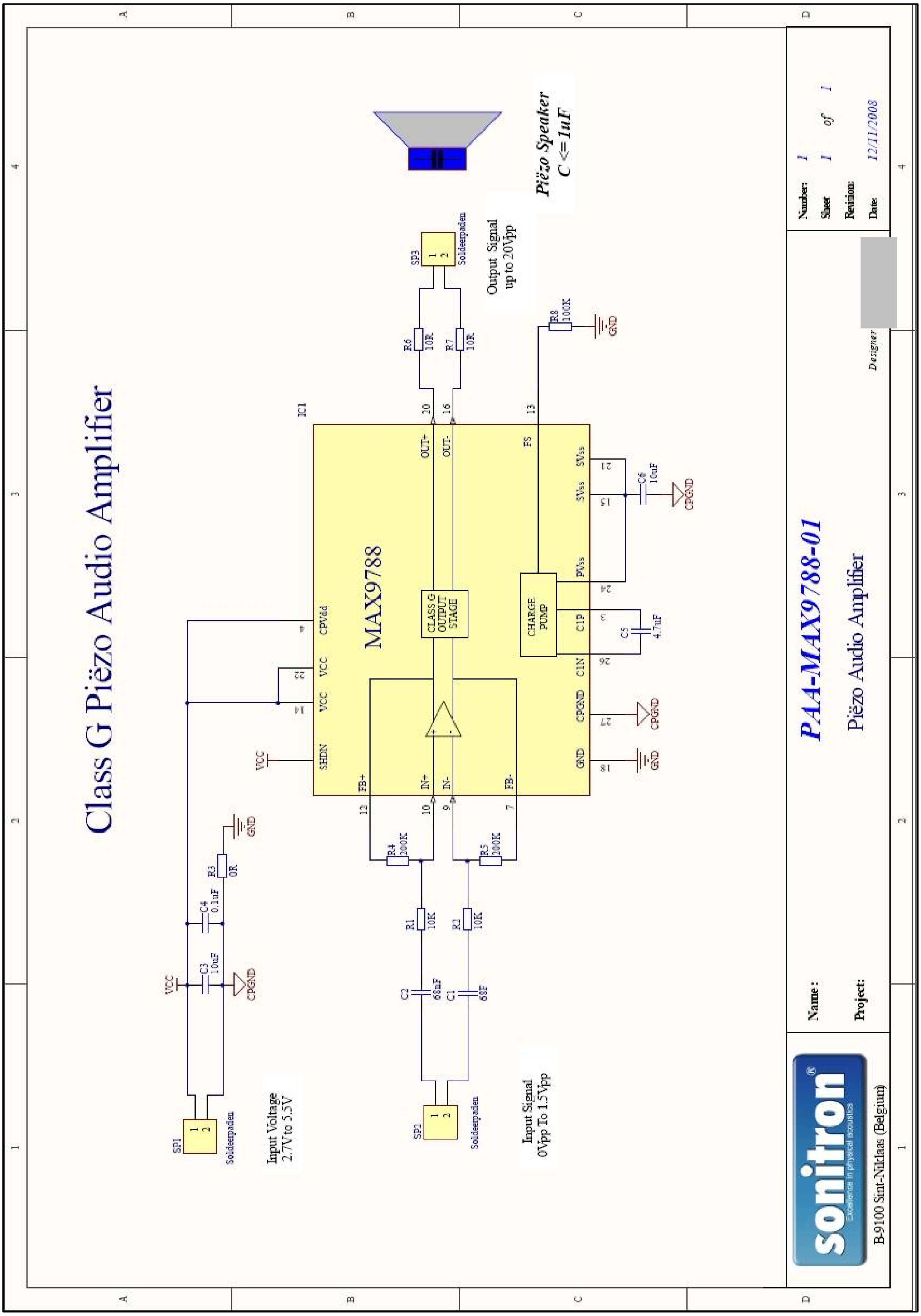
Electronic Schematic of PAA-MAX9788-01



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14VP-P, Class G Ceramic Speaker Driver

ABSOLUTE MAXIMUM RATINGS

(Voltages with respect to GND.)
V_{CC}, CPV_{DD} ....-0.3V to +6V
PV_{SS}, SV_{SS} ....-6V to +0.3V
CPGND....................-0.3V to +0.3V
OUT+, OUT-....................(SV_{SS} - 0.3V) to (V_{CC} + 0.3V)
IN+, IN-, FB+, FB- ....-0.3V to (V_{CC} + 0.3V)
C1N ....(PV_{SS} - 0.3V) to (CPGND + 0.3V)
C1P ....(CPGND - 0.3V) to (CPV_{DD} + 0.3V)
FS, $\overline{SHDN}$ ....-0.3V to (V_{CC} + 0.3V)
Continuous Current Into/Out of
OUT+, OUT-, V_{CC}, GND, SV_{SS} 800mA
CPV_{DD}, CPGND, C1P, C1N, PV_{SS}....................800mA
Any Other Pin 20mA
Continuous Power Dissipation (T_A = +70°C)
20-Bump WLP (derate 10.3mW/°C above +70°C) (Note 1)....................827mW
28-Pin TQFN (derate 20.8mW/°C above +70°C) 1667mW
Operating Temperature Range ....-40°C to +85°C
Storage Temperature Range ....-65°C to +150°C
Lead Temperature (soldering, 10s) ....+300°C
Bump Temperature (soldering) Reflow....................+235°C

Note 1: Package thermal resistances were obtained using the method described in JEDEC specification JESD51-7, using a four-layer board. For detailed information on package thermal considerations, see **www.maxim-ic.com/thermal-tutorial**.

Stresses beyond those listed under "Absolute Maximum 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 in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS

(V_{CC} = V_{CPVDD} = $V_{\overline{SHDN}}$ = 3.6V, V_{GND} = V_{CPGND} = 0V, R_{IN+} = R_{IN-} = 10kΩ, R_{FB+} = R_{FB-} = 10kΩ, R_{FS} = 100kΩ, C1 = 4.7µF, C2 = 10µF; load connected between OUT+ and OUT-, Z_{LOAD} = 10Ω + 1µF, unless otherwise stated; T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.) (Notes 2, 3)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
GENERAL							
Supply Voltage Range	V_{CC}	Inferred from PSRR test		2.7		5.5	V
Quiescent Current	I_{CC}				8	12	mA
Shutdown Current	$I_{\overline{SHDN}}$	$\overline{SHDN}$ = GND			0.3	5	µA
Turn-On Time	t_{ON}	Time from shutdown or power-on to full operation			50		ms
Input DC Bias Voltage	V_{BIAS}	IN_ inputs (Note 4)		1.1	1.24	1.4	V
Charge-Pump Oscillator Frequency	f_{OSC}	I_{LOAD} = 0mA (slow mode)		55	83	110	kHz
		I_{LOAD} > 100mA (normal mode)		230	330	470	
$\overline{SHDN}$ Input Threshold (Note 5)		V_{IH}		1.4			V
		V_{IL}				0.4	
$\overline{SHDN}$ Input Leakage Current						±1	µA
SPEAKER AMPLIFIER							
Output Offset Voltage	V_{OS}	T_A = +25°C			±3	±15	mV
		$T_{MIN} \le T_A \le T_{MAX}$				±20	
Click-and-Pop Level	V_{CP}	Peak voltage into/out of shutdown A-weighted, 32 samples per second (Notes 6, 7)			-67		dBV
Voltage Gain	A_V	(Notes 4, 8)		11.5	12	12.5	dB
Output Voltage	V_{OUT}	f = 1kHz, 1% THD+N	V_{CC} = 5V		7.1		V_{RMS}
			V_{CC} = 4.2V		5.9		
			V_{CC} = 3.6V		5.1		
			V_{CC} = 3.0V		4.2		

ELECTRICAL CHARACTERISTICS (continued)

(V_{CC} = V_{CPVDD} = $V_{\overline{SHDN}}$ = 3.6V, V_{GND} = V_{CPGND} = 0V, R_{IN+} = R_{IN-} = 10kΩ, R_{FB+} = R_{FB-} = 10kΩ, R_{FS} = 100kΩ, C1 = 4.7µF, C2 = 10µF; load connected between OUT+ and OUT-, Z_{LOAD} = 10Ω + 1µF, unless otherwise stated; T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.) (Notes 2, 3)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Output Voltage	V_{OUT}	f = 10kHz, 1% THD+N, Z_L = 1µF + 10Ω, no load	V_{CC} = 5V		6.5		V_{RMS}
			V_{CC} = 4.2V		5.4		
			V_{CC} = 3.6V		4.7		
			V_{CC} = 3.0V		3.3		
Continuous Output Power	P_{OUT}	1% THD+N, f = 1kHz, R_L = 8Ω	V_{CC} = 5V		2.4		W
			V_{CC} = 4.2V		1.67		
			V_{CC} = 3.6V		1.25		
			V_{CC} = 3.0V		0.8		
Power-Supply Rejection Ratio (Note 4)	PSRR	V_{CC} = 2.7V to 5.5V		63	77		dB
		f = 217Hz, 200mVP-P ripple			77		
		f = 1kHz, 200mVP-P ripple			77		
		f = 20kHz, 200mVP-P ripple			58		
Total Harmonic Distortion Plus Noise	THD+N	Z_L = 1µF + 10Ω, V_{OUT} = 1kHz / 1.9V_{RMS}			0.002		%
		Z_L = 1µF + 10Ω, V_{OUT} = 1kHz / 4.0V_{RMS}			0.08		
Signal-to-Noise Ratio	SNR	V_{OUT} = 5.1V_{RMS}, A-weighted			108		dB
Common-Mode Rejection Ratio	CMRR	f_{IN} = 1kHz (Note 9)			68		dB
Dynamic Range	DR	A-weighted (Note 10)	V_{CC} = 5V		106		dB
			V_{CC} = 3.6V		105		

Note 2: All devices are 100% production tested at room temperature. All temperature limits are guaranteed by design.
Note 3: Testing performed with resistive and capacitive loads to simulate an actual ceramic/piezoelectric speaker load, Z_L = 1µF + 10Ω.
Note 4: Input DC bias voltage determines the maximum voltage swing of the input signal. Inputing a signal with a peak voltage of greater than the input DC bias voltage results in clipping.
Note 5: 1.8V logic compatible.
Note 6: Amplifier/inputs AC-coupled to GND.
Note 7: Testing performed at room temperature with 10Ω resistive load in series with 1µF capacitive load connected across the BTL output for speaker amplifier. Mode transitions are controlled by $\overline{SHDN}$. V_{CP} is the peak output transient expressed in dBV.
Note 8: Voltage gain is defined as: [V_{OUT+} - V_{OUT-}] / [V_{IN+} - V_{IN-}].
Note 9: PV_{SS} is forced to -3.6V to simulate boosted rail.
Note 10: Dynamic range is calculated by measuring the RMS voltage difference between a -60dBFS output signal and the noise floor, then adding 60dB. Full scale is defined as the output signal needed to achieve 1% THD+N.
$R_{IN\_}$ and $R_{FB\_}$ have 0.5% tolerance. The Class G output stage has 12dB of gain. Any gain or attenuation at the input stage will add to or subtract from the gain of the Class G output.

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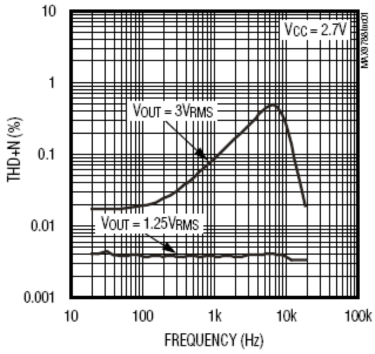
14VP-P, Class G Ceramic Speaker Driver

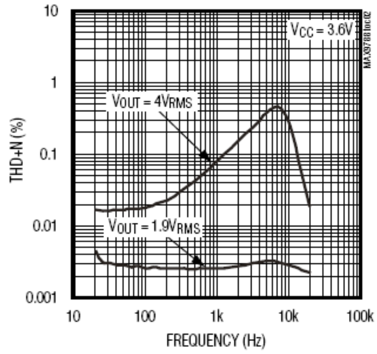
Typical Operating Characteristics

(V_{CC} = V_{CPVDD} = $V_{\overline{SHDN}}$ = 3.6V, V_{GND} = V_{CPGND} = 0V, R_{IN+} = R_{IN-} = 10kΩ, R_{FB+} = R_{FB-} = 10kΩ, R_{FS} = 100kΩ, C1 = 4.7µF, C2 = 10µF, Z_L = 1µF + 10Ω; load terminated between OUT+ and OUT-, unless otherwise stated; T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.) (Notes 1, 2)

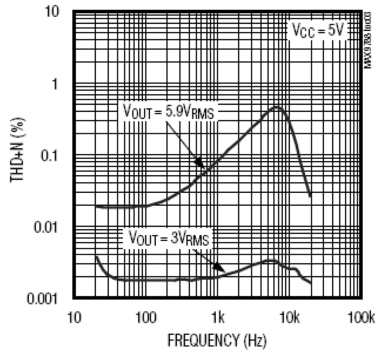
TOTAL HARMONIC DISTORTION PLUS NOISE vs. FREQUENCY



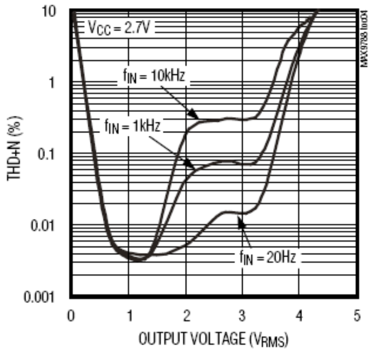
TOTAL HARMONIC DISTORTION PLUS NOISE vs. FREQUENCY



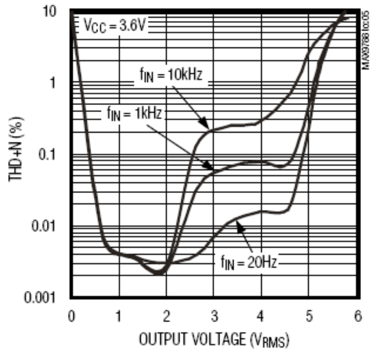
TOTAL HARMONIC DISTORTION PLUS NOISE vs. FREQUENCY



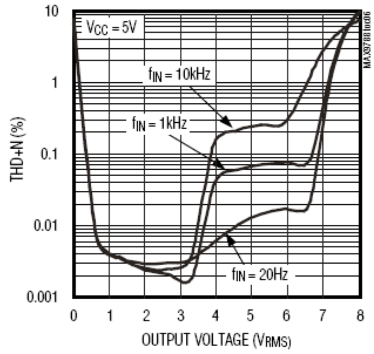
TOTAL HARMONIC DISTORTION PLUS NOISE vs. OUTPUT VOLTAGE



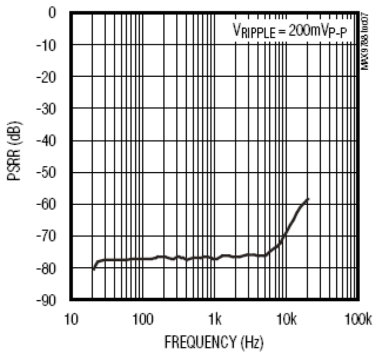
TOTAL HARMONIC DISTORTION PLUS NOISE vs. OUTPUT VOLTAGE



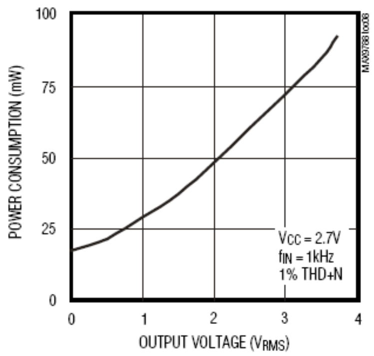
TOTAL HARMONIC DISTORTION PLUS NOISE vs. OUTPUT VOLTAGE



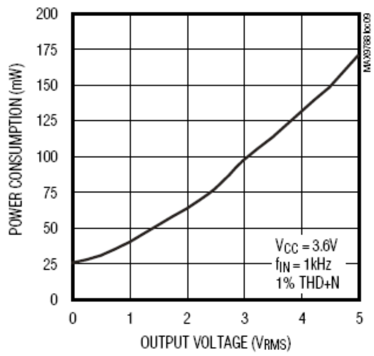
POWER-SUPPLY REJECTION RATIO vs. FREQUENCY



POWER CONSUMPTION vs. OUTPUT VOLTAGE



POWER CONSUMPTION vs. OUTPUT VOLTAGE

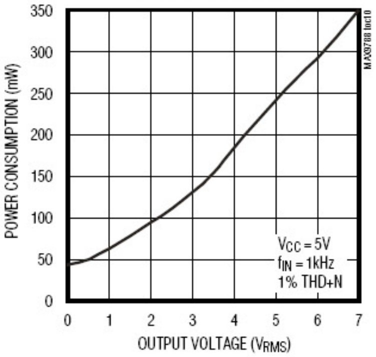


14VP-P, Class G Ceramic Speaker Driver

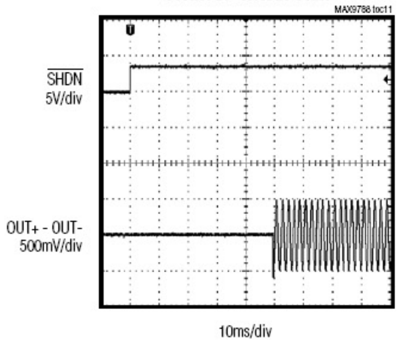
Typical Operating Characteristics (continued)

($V_{CC} = V_{CPVDD} = V_{\overline{SHDN}}$ = 3.6V, $V_{GND} = V_{CPGND}$ = 0V, $R_{IN+} = R_{IN-}$ = 10kΩ, $R_{FB+} = R_{FB-}$ = 10kΩ, R_{FS} = 100kΩ, C1 = 4.7µF, C2 = 10µF, Z_L = 1µF + 10Ω; load terminated between OUT+ and OUT-, unless otherwise stated; $T_A = T_{MIN}$ to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.) (Notes 1, 2)

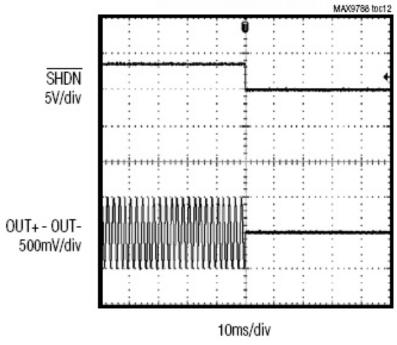
POWER CONSUMPTION vs. OUTPUT VOLTAGE



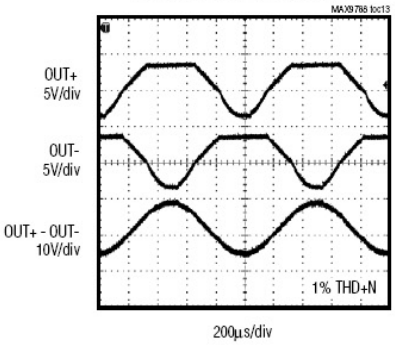
STARTUP WAVEFORM



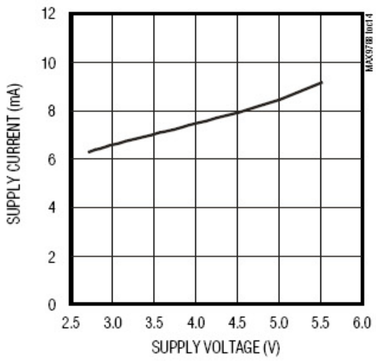
SHUTDOWN WAVEFORM



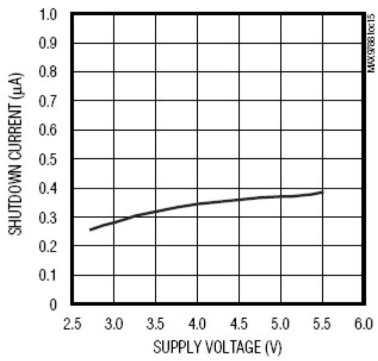
CLASS G OUTPUT WAVEFORM



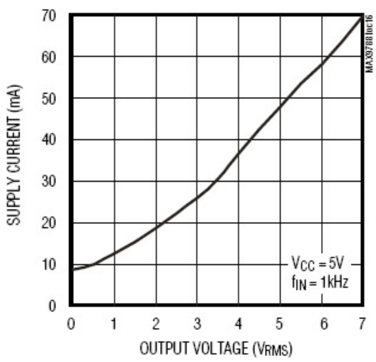
SUPPLY CURRENT vs. SUPPLY VOLTAGE



SHUTDOWN CURRENT vs. SUPPLY VOLTAGE



SUPPLY CURRENT vs. OUTPUT VOLTAGE

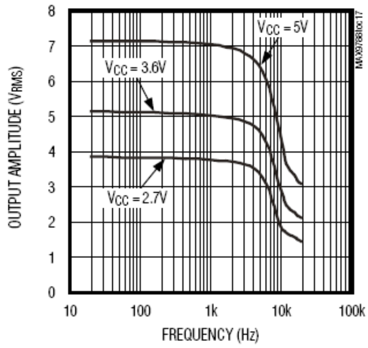


14VP-P, Class G Ceramic Speaker Driver

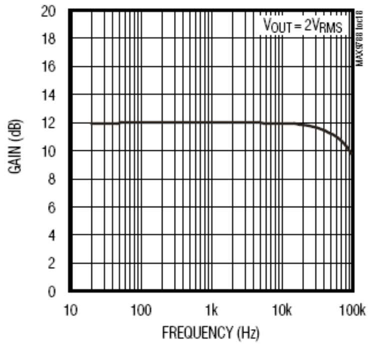
Typical Operating Characteristics (continued)

(V_{CC} = V_{CPVDD} = $V_{\overline{SHDN}}$ = 3.6V, V_{GND} = V_{CPGND} = 0V, R_{IN+} = R_{IN-} = 10kΩ, R_{FB+} = R_{FB-} = 10kΩ, R_{FS} = 100kΩ, C1 = 4.7µF, C2 = 10µF, Z_L = 1µF + 10Ω; load terminated between OUT+ and OUT-, unless otherwise stated; T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.) (Notes 1, 2)

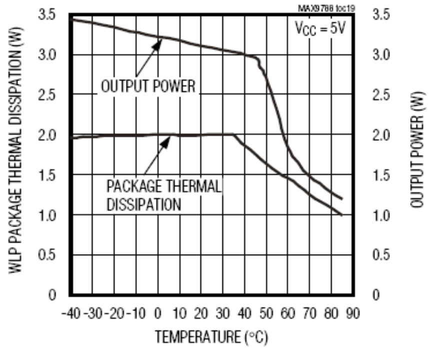
OUTPUT AMPLITUDE vs. FREQUENCY



FREQUENCY RESPONSE



WLP PACKAGE THERMAL DISSIPATION AND OUTPUT POWER vs. TEMPERATURE



Pin Description

PIN		NAME	FUNCTION
TQFN	WLP		
1	B2	$\overline{SHDN}$	Shutdown
2, 5, 6, 8, 11, 17, 19, 23, 25, 28	—	N.C.	No Connection. No internal connection.
3	A2	C1P	Charge-Pump Flying Capacitor, Positive Terminal. Connect a 4.7µF capacitor between C1P and C1N.
4	A3	CPV_{DD}	Charge-Pump Positive Supply
7	A4	FB-	Negative Amplifier Feedback
9	A5	IN-	Negative Amplifier Input
10	B5	IN+	Positive Amplifier Input
12	B4	FB+	Positive Amplifier Feedback
13	C5	FS	Charge-Pump Frequency Set. Connect a 100kΩ resistor from FS to GND to set the charge-pump switching frequency.
14, 22	D1, D5	V_{CC}	Supply Voltage. Bypass with a 10µF capacitor to GND.
15, 21	C2, C4	SV_{SS}	Amplifier Negative Power Supply. Connect to PV_{SS}.
16	D4	OUT-	Negative Amplifier Output
18	D3	GND	Ground
20	D2	OUT+	Positive Amplifier Output
24	C1	PV_{SS}	Charge-Pump Output. Connect a 10µF capacitor between PV_{SS} and CPGND.
26	B1	C1N	Charge-Pump Flying Capacitor, Negative Terminal. Connect a 4.7µF capacitor between C1N and C1P.
27	A1	CPGND	Charge-Pump Ground. Connect to GND.
EP	—	EP	Exposed Pad. Connect the TQFN EP to GND.

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Detailed Description

The MAX9788 Class G power amplifier with inverting charge pump is the latest in linear amplifier technology. The Class G output stage offers improved performance over a Class AB amplifier while increasing efficiency to extend battery life. The integrated inverting charge pump generates a negative supply capable of delivering greater than 700mA.

The Class G output stage and the inverting charge pump allow the MAX9788 to deliver a $14V_{P-P}$ voltage swing, up to two times greater than a traditional single-supply linear amplifier.

Class G Operation

The MAX9788 Class G amplifier is a linear amplifier that operates within a low (V_{CC} to GND) and high (V_{CC} to SV_{SS}) supply range. Figure 1 illustrates the transition from the low to high supply range. For small signals, the device operates within the lower (V_{CC} to GND) supply range. In this range, the operation of the device is identical to a traditional single-supply Class AB amplifier where:

$$I_{LOAD} = I_{N1}$$

As the output signal increases so a wider supply is needed, the device begins its transition to the higher supply range (V_{CC} to SV_{SS}) for the large signals. To ensure a seamless transition between the low and high supply ranges, both of the lower transistors are on so that:

$$I_{LOAD} = I_{N1} + I_{N2}$$

As the output signal continues to increase, the transition to the high supply is complete. The device then operates in the higher supply range, where the operation of the device is identical to a traditional dual-supply Class AB amplifier where:

$$I_{LOAD} = I_{N2}$$

During operation, the output common-mode voltage of the MAX9788 adjusts dynamically as the device transitions between supply ranges.

Utilizing a Class G output stage with an inverting charge pump allows the MAX9788 to realize a $20V_{P-P}$ output swing with a 5V supply.

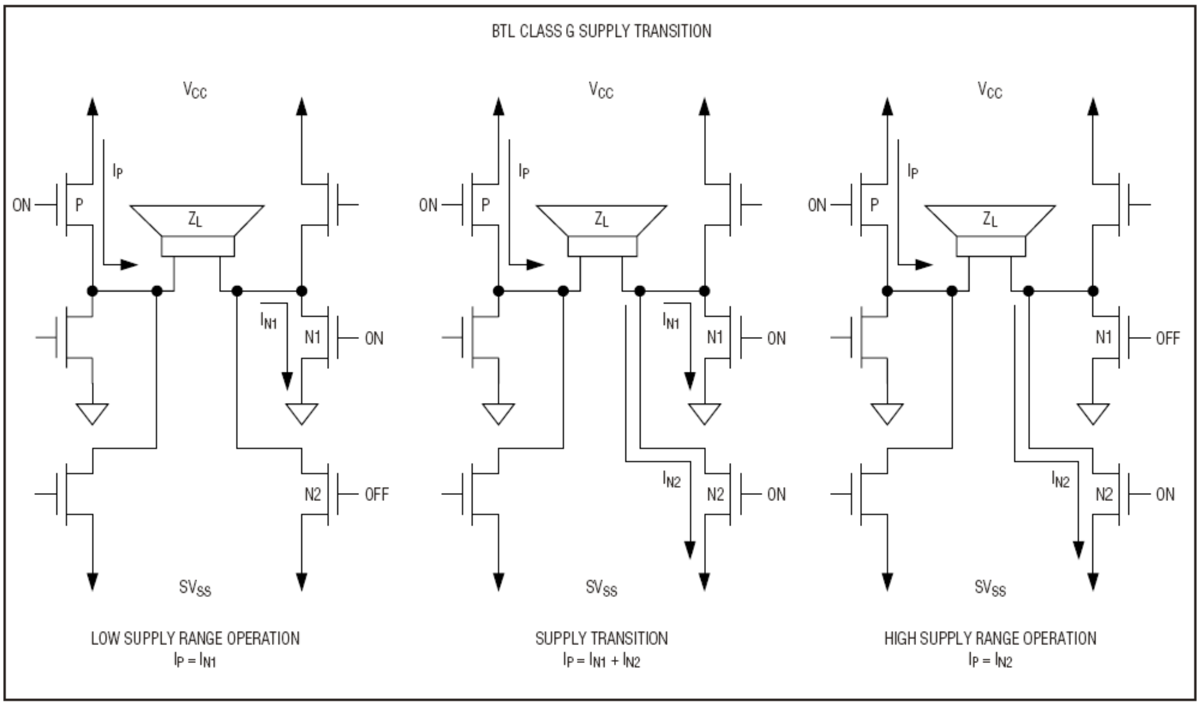

Figure 1. Class G Supply Transition

14VP-P, Class G Ceramic Speaker Driver

Inverting Charge Pump

The MAX9788 features an integrated charge pump with an inverted supply rail that can supply greater than 700mA over the positive 2.7V to 5.5V supply range. In the case of the MAX9788, the charge pump generates the negative supply rail (PV_{SS}) needed to create the higher supply range, which allows the output of the device to operate over a greater dynamic range as the battery supply collapses over time.

Shutdown Mode

The MAX9788 has a shutdown mode that reduces power consumption and extends battery life. Driving $\overline{SHDN}$ low places the MAX9788 in a low-power (0.3µA) shutdown mode. Connect $\overline{SHDN}$ to V_{CC} for normal operation.

Click-and-Pop Suppression

The MAX9788 Class G amplifier features Maxim's comprehensive, industry-leading click-and-pop suppression. During startup, the click-and-pop suppression circuitry eliminates any audible transient sources internal to the device.

Applications Information

Differential Input Amplifier

The MAX9788 features a differential input configuration, making the device compatible with many CODECs, and offering improved noise immunity over a single-ended input amplifier. In devices such as PCs, noisy digital signals can be picked up by the amplifier's input traces. The signals appear at the amplifier's inputs as common-mode noise. A differential input amplifier amplifies the difference of the two inputs and signals common to both inputs are canceled out. When configured for differential inputs, the voltage gain of the MAX9788 is set by:

$$A_V = 20\log\left[4 \times \left(\frac{R_{FB\_}}{R_{IN\_}}\right)\right] \text{(dB)}$$

where A_V is the desired voltage gain in dB. R_{IN+} should be equal to R_{IN-}, and R_{FB+} should be equal to R_{FB-}. The Class G output stage has a fixed gain of 4V/V (12dB). Any gain or attenuation set by the external input stage resistors will add to or subtract from this fixed gain. See Figure 2.

In differential input configurations, the common-mode rejection ratio (CMRR) is primarily limited by the external resistor and capacitor matching. Ideally, to achieve the highest possible CMRR, the following external components should be selected where:

$$\frac{R_{FB+}}{R_{IN+}} = \frac{R_{FB-}}{R_{IN-}}$$

and

$$C_{IN+} = C_{IN-}$$

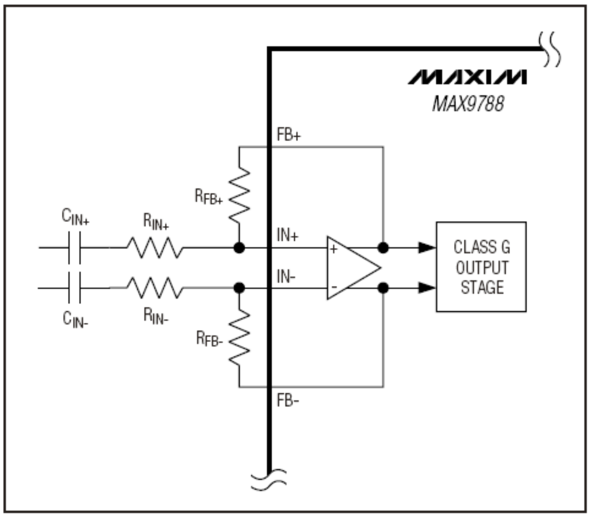

Figure 2. Gain Setting

14VP-P, Class G Ceramic Speaker Driver

Driving a Ceramic Speaker

Applications that require thin cases, such as today's mobile phones, demand that external components have a small form factor. Dynamic loudspeakers that use a cone and voice coil typically cannot conform to the height requirements. The option for these applications is to use a ceramic/piezoelectric loudspeaker.

Ceramic speakers are much more capacitive than a conventional loudspeaker. Typical capacitance values for such a speaker can be greater than 1µF. High peak-to-peak voltage drive is required to achieve acceptable sound pressure levels. The high output voltage requirement coupled with the capacitive nature of the speaker demand that the amplifier supply much more current at high frequencies than at lower frequencies. Above 10kHz, the typical speaker impedance can be less than 16Ω.

The MAX9788 is ideal for driving a capacitive ceramic speaker. The high charge-pump current limit allows for a flat frequency response out to 20kHz while maintaining high output voltage swings. See the Frequency Response graph in the *Typical Operating Characteristics*. Figure 3 shows a typical circuit for driving a ceramic speaker.

A 10Ω series resistance is recommended between the amplifier output and the ceramic speaker load to ensure the output of the amplifier sees some fixed resistance at high frequencies when the speaker is essentially an electrical short.

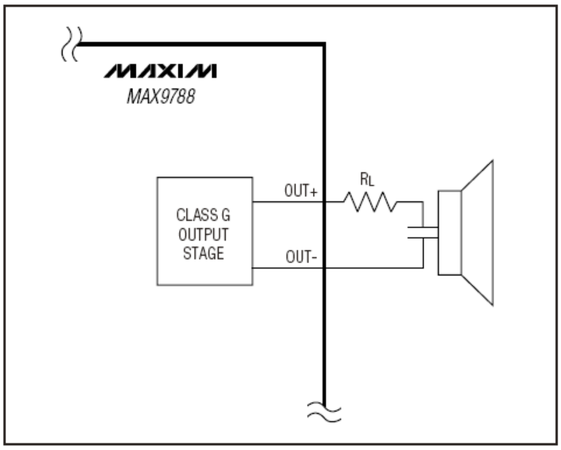

Figure 3. Driving a Ceramic Speaker

Component Selection

Input-Coupling Capacitor

The AC-coupling capacitors ($C_{IN\_}$) and input resistors ($R_{IN\_}$) form highpass filters that remove any DC bias from an input signal (see the *Functional Diagram/ Typical Operating Circuit*). $C_{IN\_}$ blocks DC voltages from the amplifier input. The -3dB point of the highpass filter, assuming zero source impedance due to the input signal source, is given by:

$$f_{-3dB} = \frac{1}{2\pi \times R_{IN\_} \times C_{IN\_}} (Hz)$$

Ceramic speakers generally perform best at frequencies greater than 1kHz. Low frequencies can deflect the piezoelectric speaker element so that high frequencies cannot be properly reproduced. This can cause distortion in the speaker's usable frequency band. Select a C_{IN} so the f_{-3dB} closely matches the low frequency response of the ceramic speaker. Use capacitors with low-voltage coefficient dielectrics. Aluminum electrolytic, tantalum, or film dielectric capacitors are good choices for AC-coupling capacitors. Capacitors with high-voltage coefficients, such as ceramics (non-C0G dielectrics), can result in increased distortion at low frequencies.

Charge-Pump Capacitor Selection

Use capacitors with an ESR less than 50mΩ for optimum performance. Low-ESR ceramic capacitors minimize the output resistance of the charge pump. For best performance over the extended temperature range, select capacitors with an X7R dielectric.

Flying Capacitor (C1)

The value of the flying capacitor (C1) affects the load regulation and output resistance of the charge pump. A C1 value that is too small degrades the device's ability to provide sufficient current drive. Increasing the value of C1 improves load regulation and reduces the charge-pump output resistance to an extent. Above 1µF, the on-resistance of the switches and the ESR of C1 and C2 dominate. A 4.7µF capacitor is recommended.

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14VP-P, Class G Ceramic Speaker Driver

Hold Capacitor (C2)

The output capacitor value and ESR directly affect the ripple at PV_{SS}. Increasing C2 reduces output ripple. Likewise, decreasing the ESR of C2 reduces both ripple and output resistance. A 10µF capacitor is recommended.

Charge-Pump Frequency Set Resistor (R_{FS})

The charge pump operates in two modes. When the charge pump is loaded below 100mA, it operates in a slow mode where the oscillation frequency is reduced to 1/4 of its normal operating frequency. Once loaded, the charge-pump oscillation frequency returns to normal operation. In applications where the design may be sensitive to the operating charge-pump oscillation frequency, the value of the external resistor R_{FS} can be changed to adjust the charge-pump oscillation frequency shown in Figure 4. A 100kΩ resistor is recommended.

Ceramic Speaker Impedance Characteristics

A 1µF capacitor is a good model for the ceramic speaker as it best approximates the impedance of a ceramic speaker over the audio band. When selecting a capacitor to simulate a ceramic speaker, the voltage rating or the capacitor must be equal to or higher than the expected output voltage swing. See Figure 5.

Series Load Resistor

The capacitive nature of the ceramic speaker results in very low impedances at high frequencies. To prevent the ceramic speaker from shorting the MAX9788 output at high frequencies, a series load resistor must be used. The output load resistor and the ceramic speaker create a lowpass filter. To set the rolloff frequency of the output filter, the approximate capacitance of the speaker must be known. This information can be obtained from bench testing or from the ceramic speaker manufacturer. A series load resistor greater than 10Ω is recommended. Set the lowpass filter cutoff frequency with the following equation:

$$f_{LP} = \frac{1}{2\pi \times R_L \times C_{SPEAKER}} (Hz)$$

WLP Applications Information

For the latest application details on WLP construction, dimensions, tape carrier information, PCB techniques, bump-pad layout, and recommended reflow temperature profile, as well as the latest information on reliability testing results, go to the Maxim website at www.maxim-ic.com/ucsp for the application note, *UCSP—A Wafer-Level Chip-Scale Package*.

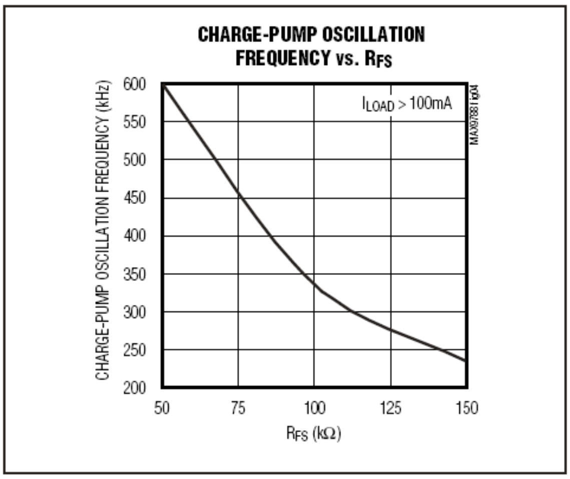


Figure 4. Charge-Pump Oscillation Frequency vs. R_{FS}

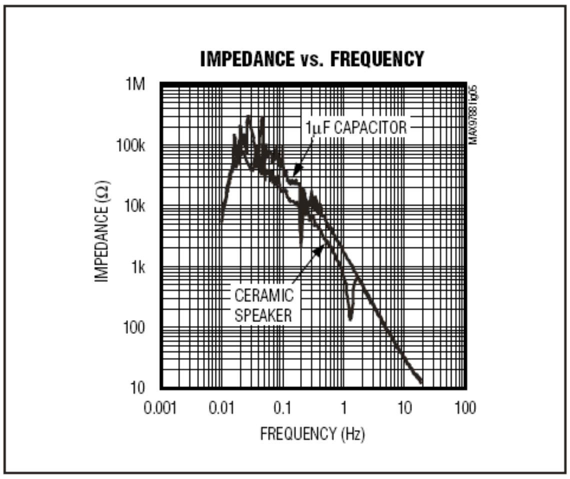
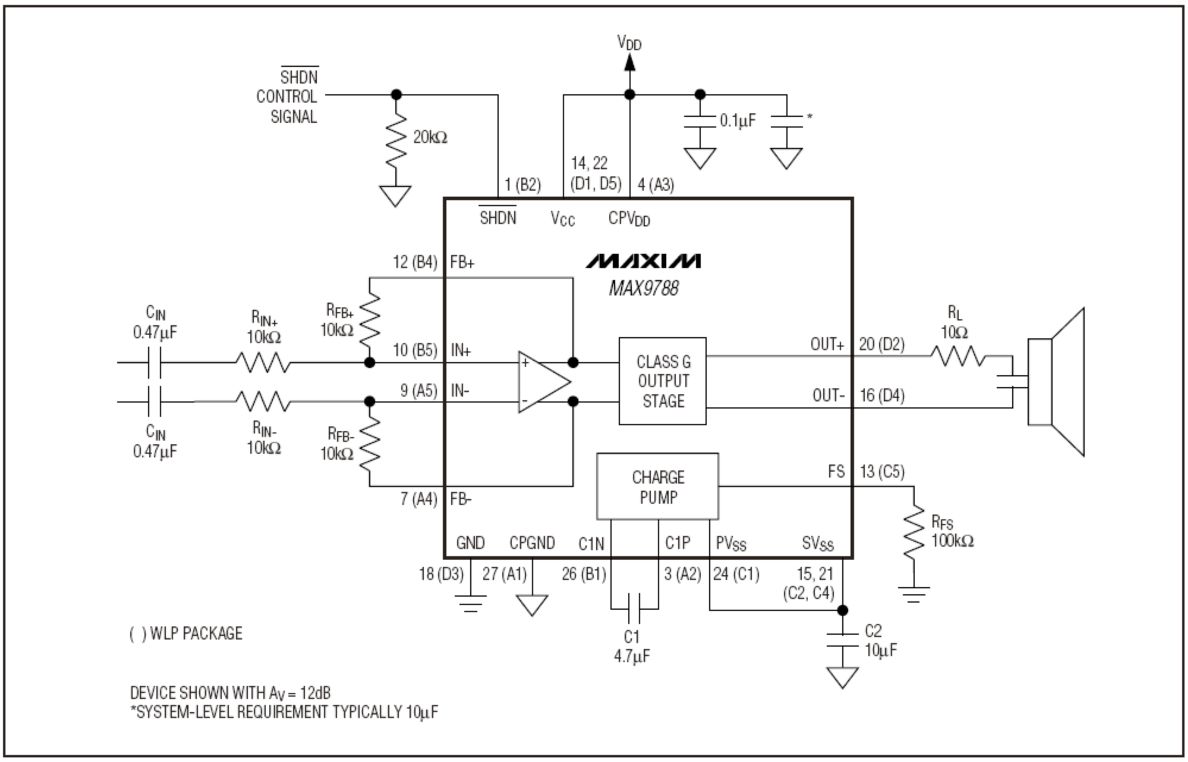


Figure 5. Ceramic Speaker and Capacitor Impedance

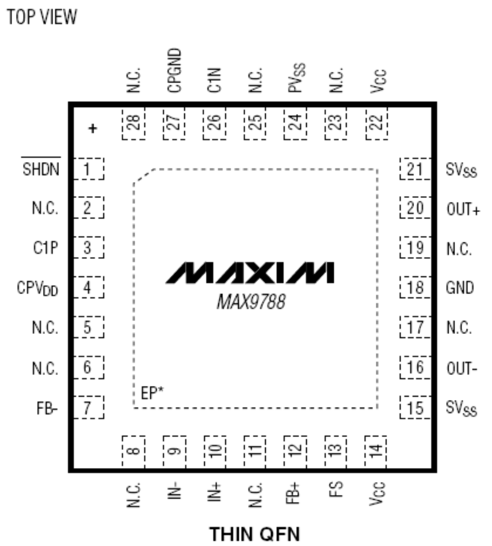
14VP-P, Class G Ceramic Speaker Driver

Typical Application Circuit/Functional Diagram

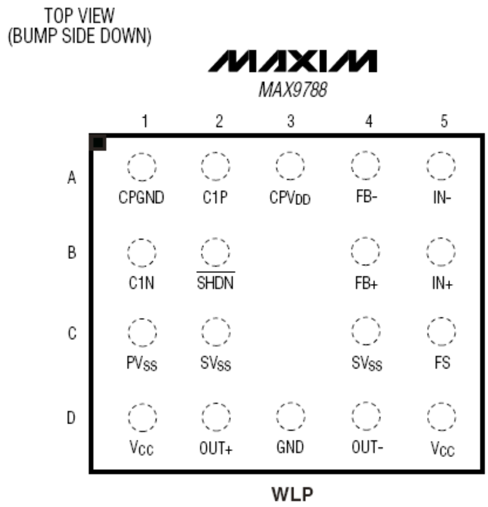


14VP-P, Class G Ceramic Speaker Driver

Pin Configurations



*EXPOSED PAD.



Package Information

For the latest package outline information and land patterns, go to **www.maxim-ic.com/packages**.

PACKAGE TYPE	PACKAGE CODE	DOCUMENT NO.
20 WLP	W202A2+1	21-0059
28 TQFN	T2844-1	21-0139

Chip Information

PROCESS: BiCMOS

NOTES:

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Appnote PAA-LM4960SQ-02

Piëzo-ceramic Audio Amplifiers
Sonitron PAA-LM4960SQ-02

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September 2008

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R&D DEPARTMENT

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Sonitron PAA-LM4960SQ-02 Amplifier

LM4960 Boomer® Audio Power Amplifier Series
Piezoelectric Speaker Driver

General Description

The LM4960 utilizes a switching regulator to drive a dual audio power amplifier. It delivers $24V_{P-P}$ mono-BTL to a ceramic speaker with less than 1.0% THD+N while operating on a 3.0V power supply.

The LM4960's switching regulator is a current-mode boost converter operating at a fixed frequency of 1.6MHz.

Boomer audio power amplifiers were designed specifically to provide high quality output power with a minimal amount of external components. The LM4960 does not require output coupling capacitors or bootstrap capacitors, and therefore is ideally suited for mobile phone and other low voltage applications where minimal power consumption is a primary requirement.

The LM4960 features a low-power consumption externally controlled micropower shutdown mode. Additionally, the LM4960 features and internal thermal shutdown protection mechanism along with a short circuit protection.

The LM4960 is unity-gain stable and can be configured by external gain-setting resistors.

Key Specifications

- V_{OUT} @ V_{DD} = 3.0 THD+N ≤ 1% — $24V_{P-P}$ (typ)
- Power supply range — 3.0 to 7V
- Switching Frequency — 1.6MHz (typ)

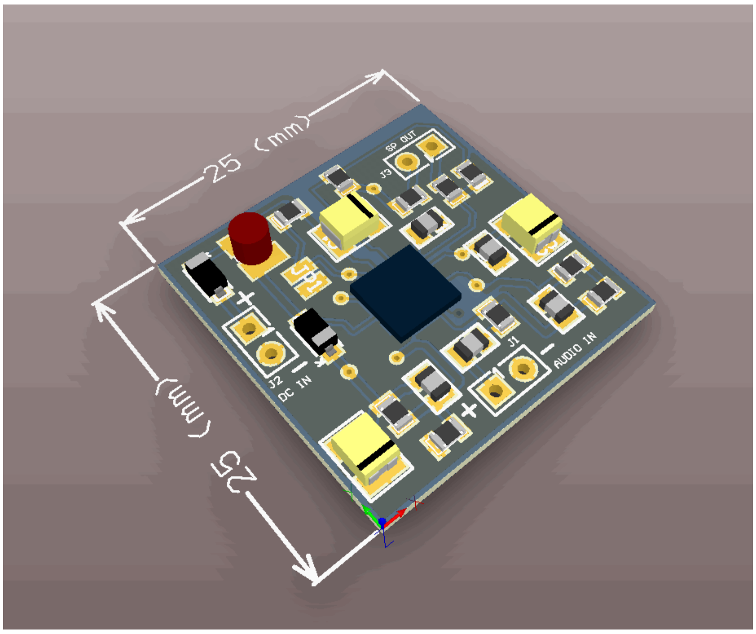
Features

- Stereo BTL amplifier
- Low current shutdown mode
- "Click and pop" suppression circuitry
- Low Quiescent current
- Unity-gain stable audio amplifiers
- External gain configuration capability
- Thermal shutdown protection circuitry
- Wide input voltage range (3.0V - 7V)
- 1.6MHz switching frequency

Applications

- Mobile phone
- PDA's

Specifications:
- Input Voltage: 3V to 7V
- Input Audio Signal: Max 325mVpp
- Output Audio Signal: Max 24Vpp
- Dimensions: 25mm on 25mm



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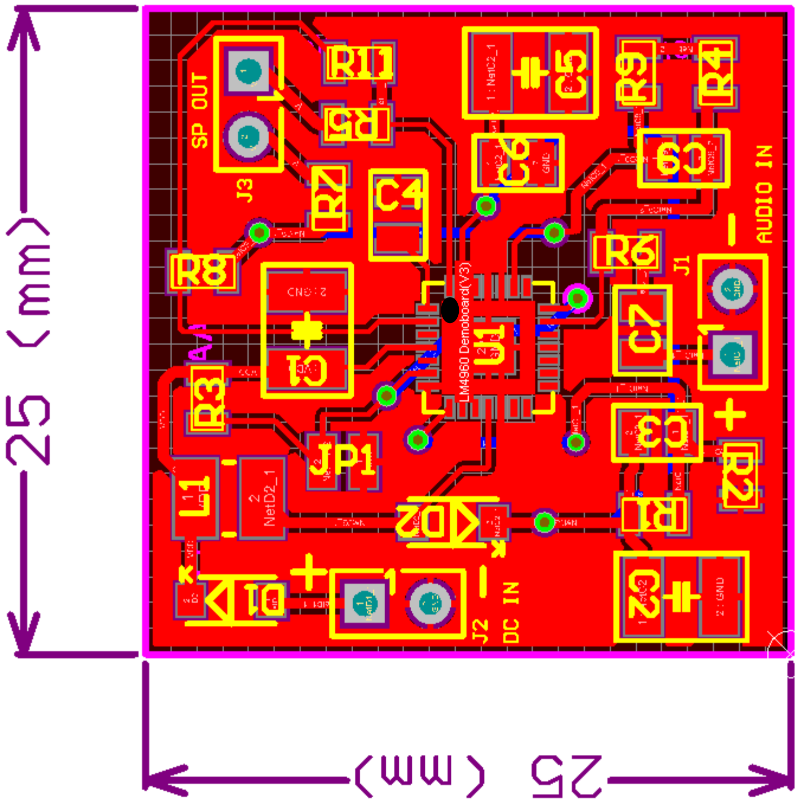
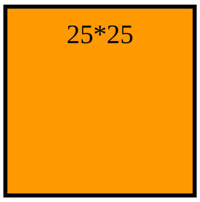
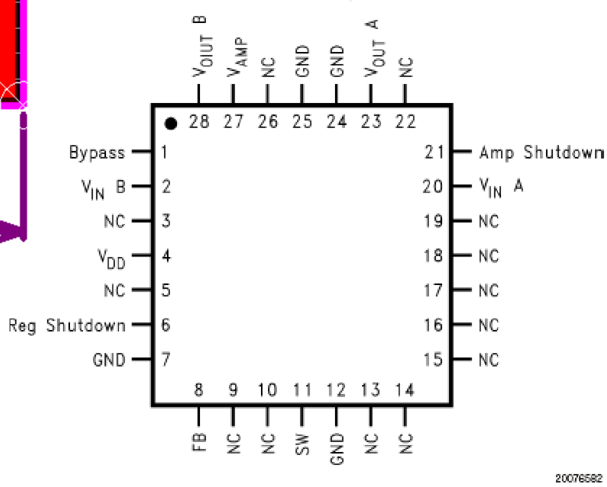




LM4960SQ



Top View
Order Number LM4960SQ
See NS Package Number

	Designator	Description	Package	Quantity
1	R1, R9	Chip Resistor 270k/5%	R0805	2
2	R2	Chip Resistor 30k/5%	R0805	1
3	R3	Chip Resistor 10k/5%	R0805	1
4	R4	Chip Resistor 470k/5%	R0805	1
5	R5, R7	Chip Resistor 10R/5%	R0805	2
6	R6, R8, R11	Chip Resistor 20k/5%	R0805	3
7	C1, C2, C5	Ceramic Capacitor 4.7µF/25V/X5R	C1210	3
8	C3	Ceramic Capacitor 220pF/100V/X7R	C0805	1
9	C4	Ceramic Capacitor 220nF/16V/X7R	C0805	1
10	C6	Ceramic Capacitor 100nF/50V/X7R	C0805	1
11	C7	Ceramic Capacitor 33nF/50V/X7R	C0805	1
12	C9	Ceramic Capacitor 10pF/100V/X7R (opt)	C0805	1
13	L1	SDR0302-100ML SMD Power Inductor	SDR0302	1
14	D1, D2	MBR0520LT1 20V, 0.5A shottky diode	SOD-123	2
12	U1	LM4960SQ Piezo Ceramic Speaker Amplifier	LLP28	1

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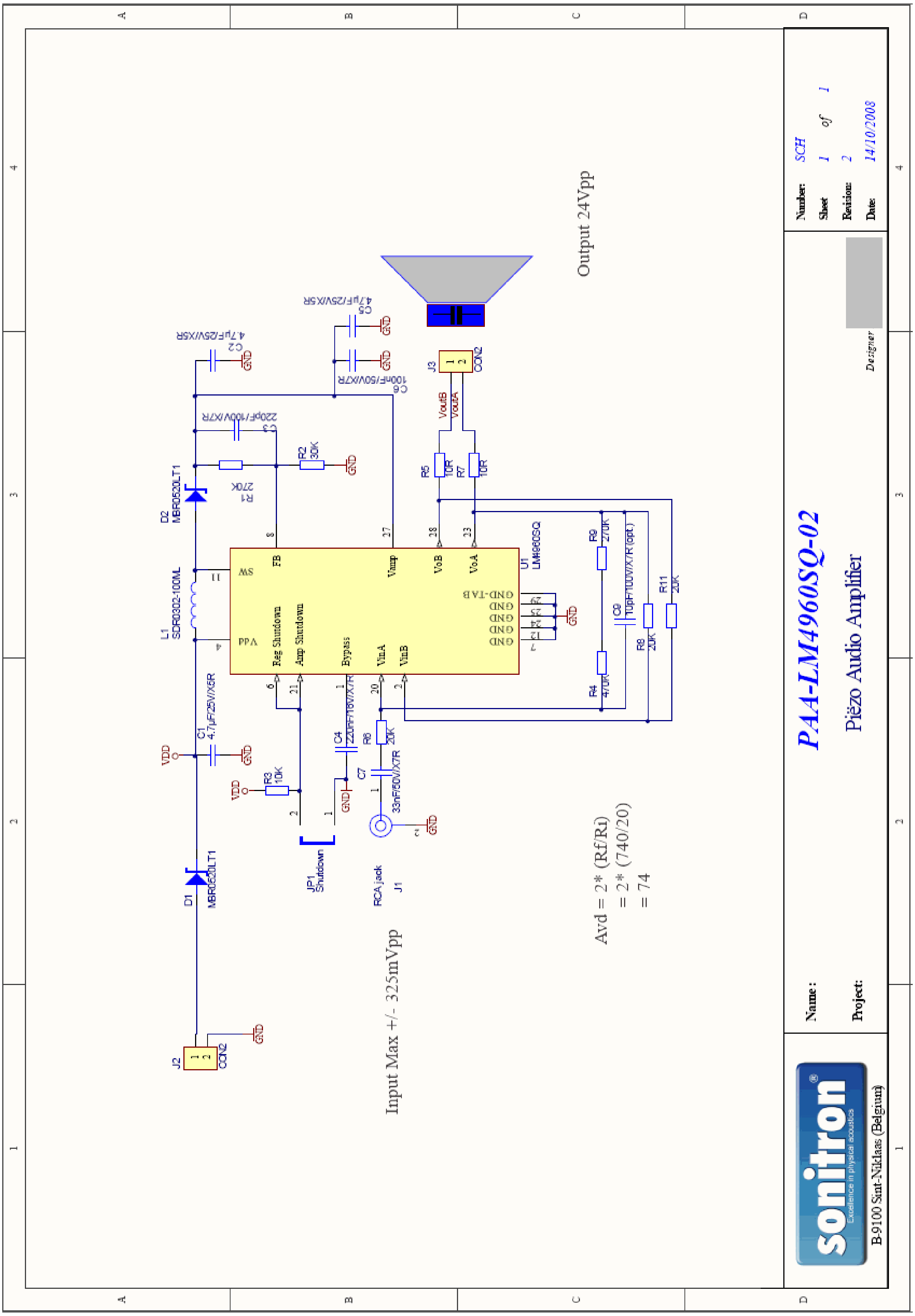
Electronic Schematic of PAA-LM4960SQ-02



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 (V_{DD})	8.5V
Supply Voltage (V1) (Pin 27 referred to GND)	18V
Storage Temperature	−65°C to +150°C
Input Voltage	−0.3V to V_{DD} + 0.3V
Power Dissipation (Note 3)	Internally limited
ESD Susceptibility (Note 4)	2000V
ESD Susceptibility (Note 5)	200V
Junction Temperature	150°C
Thermal Resistance	
θ_{JA} (LLP)	°C/W

See AN-1187 'Leadless Leadframe Packaging (LLP).'

Operating Ratings

Temperature Range $T_{MIN} \le T_A \le T_{MAX}$	$-40°C \le T_A \le +85°C$
Supply Voltage (V_{DD})	$3.0V \le V_{DD} \le 7V$
Supply Voltage (V1)	$9.6V \le V_1 \le 16V$

Electrical Characteristics V_{DD} = 3.0V (Notes 1, 2)

The following specifications apply for V_{DD} = 3V, A_V = 10, R_L = 800nF+20Ω, V1 = 12V unless otherwise specified. Limits apply for T_A = 25°C.

Symbol	Parameter	Conditions	LM4960 Typical (Note 6)	LM4960 Limit (Notes 7, 8)	Units (Limits)
I_{DD}	Quiescent Power Supply Current	V_{IN} = GND, No Load	85	150	mA (max)
I_{SD}	Shutdown Current	$V_{SHUTDOWN}$ = GND (Note 9)	30	100	µA (max)
V_{OS}	Output Offset Voltage		5	40	mV (max)
V_{SDIH}	Shutdown Voltage Input High			2	V (max)
V_{SDIL}	Shutdown Voltage Input Low			0.4	V (min)
T_{WU}	Wake-up Time	C_B = 0.22µF	50		ms
TSD	Thermal Shutdown Temperature		170	150 190	°C (min) °C (max)
V_O	Output Voltage	THD = 1% (max); f = 1kHz	24	20	V_{P-P} (min)
THD+N	Total Harmonic Distortion + Noise	V_O = 3Wrms; f = 1kHz	0.04		%
ϵ_{OS}	Output Noise	A-Weighted Filter, V_{IN} = 0V	90		µV
PSRR	Power Supply Rejection Ratio	V_{RIPPLE} = 200mV_{p-p}, f = 1kHz	55	50	dB (min)
V_{FB}	Feedback Pin Reference Voltage		1.23		V (max)

Electrical Characteristics V_{DD} = 5.0V (Notes 1, 2)

The following specifications apply for V_{DD} = 5V, A_V = 10, R_L = 800nF+20Ω unless otherwise specified. Limits apply for T_A = 25°C.

Symbol	Parameter	Conditions	LM4960 Typical (Note 6)	LM4960 Limit (Notes 7, 8)	Units (Limits)
I_{DD}	Quiescent Power Supply Current	V_{IN} = GND, No Load	45		mA (max)
I_{SD}	Shutdown Current	$V_{SHUTDOWN}$ = GND (Note 9)	55	100	µA (max)
V_{SDIH}	Shutdown Voltage Input High			2	V (max)
V_{SDIL}	Shutdown Voltage Input Low			0.4	V (min)
T_{WU}	Wake-up Time	C_B = 0.22µF	50		s
TSD	Thermal Shutdown Temperature		170	150 190	°C (min) °C (max)
V_O	Output Voltage	THD = 1% (max); f = 1kHz R_L = Ceramic Speaker	24	20	V_{P-P} (min)
THD+N	Total Harmonic Distortion + Noise	V_O = 3Wrms; f = 1kHz	0.04		%
ϵ_{OS}	Output Noise	A-Weighted Filter, V_{IN} = 0V	90		µV
PSRR	Power Supply Rejection Ratio	V_{RIPPLE} = 200mV_{p-p}, f = 1kHz	60		dB (min)
V_{FB}	Feedback Pin Reference Voltage		1.23		V (max)

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

Application Information

BRIDGE CONFIGURATION EXPLANATION

The Audio Amplifier portion of the LM4960 has two internal amplifiers allowing different amplifier configurations. The first amplifier's gain is externally configurable, whereas the second amplifier is internally fixed in a unity-gain, inverting configuration. The closed-loop gain of the first amplifier is set by selecting the ratio of Rf to Ri while the second amplifier's gain is fixed by the two internal 20kΩ resistors. Figure 1 shows that the output of amplifier one serves as the input to amplifier two. This results in both amplifiers producing signals identical in magnitude, but out of phase by 180°. Consequently, the differential gain for the Audio Amplifier is

$$A_{VD} = 2 *(Rf/Ri)$$

By driving the load differentially through outputs Vo1 and Vo2, an amplifier configuration commonly referred to as "bridged mode" is established. Bridged mode operation is different from the classic single-ended amplifier configuration where one side of the load is connected to ground.

A bridge amplifier design has a few distinct advantages over the single-ended configuration. It provides differential drive to the load, thus doubling the output swing for a specified supply voltage. Four times the output power is possible as compared to a single-ended amplifier under the same conditions. This increase in attainable output power assumes that the amplifier is not current limited or clipped. In order to choose an amplifier's closed-loop gain without causing excessive clipping, please refer to the **Audio Power Amplifier Design** section.

The bridge configuration also creates a second advantage over single-ended amplifiers. Since the differential outputs, Vo1 and Vo2, are biased at half-supply, no net DC voltage exists across the load. This eliminates the need for an output coupling capacitor which is required in a single supply, single-ended amplifier configuration. Without an output coupling capacitor, the half-supply bias across the load would result in both increased internal IC power dissipation and also possible loudspeaker damage.

AMPLIFIER POWER DISSIPATION

Power dissipation is a major concern when designing a successful amplifier, whether the amplifier is bridged or single-ended. A direct consequence of the increased power delivered to the load by a bridge amplifier is an increase in internal power dissipation. Since the amplifier portion of the LM4960 has two operational amplifiers, the maximum internal power dissipation is 4 times that of a single-ended amplifier. The maximum power dissipation for a given BTL application can be derived from Equation 1.

$$P_{DMAX(AMP)} = 4(V_{DD})^2 / (2\pi^2 Z_L) \qquad (1)$$

where

$$Z_L = R_o1 + R_o2 + 1/2\pi fc$$

BOOST CONVERTER POWER DISSIPATION

At higher duty cycles, the increased ON-time of the switch FET means the maximum output current will be determined by power dissipation within the LM2731 FET switch. The switch power dissipation from ON-time conduction is calculated by Equation 2.

$$P_{DMAX(SWITCH)} = DC \times I_{IND}(AVE)^2 \times R_{DS}(ON) \qquad (2)$$

where DC is the duty cycle.

There will be some switching losses as well, so some derating needs to be applied when calculating IC power dissipation.

TOTAL POWER DISSIPATION

The total power dissipation for the LM4960 can be calculated by adding Equation 1 and Equation 2 together to establish Equation 3:

$$P_{DMAX(TOTAL)} = [4*(V_{DD})^2/2\pi^2 Z_L] + [DC \times I_{IND}(AVE)^2 \times R_{DS}(ON)] \qquad (3)$$

The result from Equation 3 must not be greater than the power dissipation that results from Equation 4:

$$P_{DMAX} = (T_{JMAX} - T_A) / \theta JA \qquad (4)$$

For the LQA28A, θ_{JA} = 59°C/W. T_{JMAX} = 125°C for the LM4960. Depending on the ambient temperature, T_A, of the system surroundings, Equation 4 can be used to find the maximum internal power dissipation supported by the IC packaging. If the result of Equation 3 is greater than that of Equation 4, then either the supply voltage must be increased, the load impedance increased or T_A reduced. For the typical application of a 3V power supply, with V1 set to 12V and a 800nF + 20Ω load, the maximum ambient temperature possible without violating the maximum junction temperature is approximately 118°C provided that device operation is around the maximum power dissipation point. Thus, for typical applications, power dissipation is not an issue. Power dissipation is a function of output power and thus, if typical operation is not around the maximum power dissipation point, the ambient temperature may be increased accordingly. Refer to the Typical Performance Characteristics curves for power dissipation information for lower output levels.

EXPOSED-DAP PACKAGE PCB MOUNTING CONSIDERATIONS

The LM4960's exposed-DAP (die attach paddle) package (LD) provides a low thermal resistance between the die and the PCB to which the part is mounted and soldered. The low thermal resistance allows rapid heat transfer from the die to the surrounding PCB copper traces, ground plane, and surrounding air. The LD package should have its DAP soldered to a copper pad on the PCB. The DAP's PCB copper pad may be connected to a large plane of continuous unbroken copper. This plane forms a thermal mass, heat sink, and radiation area. Further detailed and specific information concerning PCB layout, fabrication, and mounting an LD (LLP) package is found in National Semiconductor's Package Engineering Group under application note AN1187.

Application Information (Continued)

SHUTDOWN FUNCTION

In many applications, a microcontroller or microprocessor output is used to control the shutdown circuitry to provide a quick, smooth transition into shutdown. Another solution is to use a single-pole, single-throw switch, and a pull-up resistor. One terminal of the switch is connected to GND. The other side is connected to the two shutdown pins and the terminal of the pull-up resistor. The remaining resistance terminal is connected to V_{DD}. If the switch is open, then the external pull-up resistor connected to V_{DD} will enable the LM4960. This scheme guarantees that the shutdown pins will not float thus preventing unwanted state changes.

PROPER SELECTION OF EXTERNAL COMPONENTS

Proper selection of external components in applications using integrated power amplifiers, and switching DC-DC converters, is critical for optimizing device and system performance. Consideration to component values must be used to maximize overall system quality.

The best capacitors for use with the switching converter portion of the LM4960 are multi-layer ceramic capacitors. They have the lowest ESR (equivalent series resistance) and highest resonance frequency, which makes them optimum for high frequency switching converters.

When selecting a ceramic capacitor, only X5R and X7R dielectric types should be used. Other types such as Z5U and Y5F have such severe loss of capacitance due to effects of temperature variation and applied voltage, they may provide as little as 20% of rated capacitance in many typical applications. Always consult capacitor manufacturer's data curves before selecting a capacitor. High-quality ceramic capacitors can be obtained from Taiyo-Yuden, AVX, and Murata.

POWER SUPPLY BYPASSING

As with any amplifier, proper supply bypassing is critical for low noise performance and high power supply rejection. The capacitor location on both V1 and V_{DD} pins should be as close to the device as possible.

SELECTING INPUT CAPACITOR FOR AUDIO AMPLIFIER

One of the major considerations is the closedloop bandwidth of the amplifier. To a large extent, the bandwidth is dictated by the choice of external components shown in Figure 1. The input coupling capacitor, C_I, forms a first order high pass filter which limits low frequency response. This value should be chosen based on needed frequency response for a few distinct reasons.

High value input capacitors are both expensive and space hungry in portable designs. Clearly, a certain value capacitor is needed to couple in low frequencies without severe attenuation. But ceramic speakers used in portable systems, whether internal or external, have little ability to reproduce signals below 100Hz to 150Hz. Thus, using a high value input capacitor may not increase actual system performance.

In addition to system cost and size, click and pop performance is affected by the value of the input coupling capacitor, C_I. A high value input coupling capacitor requires more charge to reach its quiescent DC voltage (nominally 1/2 V_{DD}). This charge comes from the output via the feedback and is apt to create pops upon device enable. Thus, by minimizing the capacitor value based on desired low frequency response, turn-on pops can be minimized.

SELECTING BYPASS CAPACITOR FOR AUDIO AMPLIFIER

Besides minimizing the input capacitor value, careful consideration should be paid to the bypass capacitor value. Bypass capacitor, C_B, is the most critical component to minimize turn-on pops since it determines how fast the amplifer turns on. The slower the amplifier's outputs ramp to their quiescent DC voltage (nominally 1/2 V_{DD}), the smaller the turn-on pop. Choosing C_B equal to 1.0µF along with a small value of C_I (in the range of 0.039µF to 0.39µF), should produce a virtually clickless and popless shutdown function. Although the device will function properly, (no oscillations or motorboating), with C_B equal to 0.1µF, the device will be much more susceptible to turn-on clicks and pops. Thus, a value of C_B equal to 1.0µF is recommended in all but the most cost sensitive designs.

SELECTING FEEDBACK CAPACITOR FOR AUDIO AMPLIFIER

The LM4960 is unity-gain stable which gives the designer maximum system flexability. However, to drive ceramic speakers, a typical application requires a closed-loop differential gain of 10. In this case a feedback capacitor (C_f2) will be needed as shown in Figure 2 to bandwidth limit the amplifier.

This feedback capacitor creates a low pass filter that eliminates possible high frequency oscillations. Care should be taken when calculating the -3dB frequency because an incorrect combination of R_f and C_f2 will cause rolloff before the desired frequency

SELECTING OUTPUT CAPACITOR (C_O) FOR BOOST CONVERTER

A single 4.7µF to 10µF ceramic capacitor will provide sufficient output capacitance for most applications. If larger amounts of capacitance are desired for improved line support and transient response, tantalum capacitors can be used. Aluminum electrolytics with ultra low ESR such as Sanyo Oscon can be used, but are usually prohibitively expensive. Typical Al electrolytic capacitors are not suitable for switching frequencies above 500 kHz because of significant ringing and temperature rise due to self-heating from ripple current. An output capacitor with excessive ESR can also reduce phase margin and cause instability.

In general, if electrolytics are used, we recommended that they be paralleled with ceramic capacitors to reduce ringing, switching losses, and output voltage ripple.

SELECTING INPUT CAPACITOR (Cs1) FOR BOOST CONVERTER

An input capacitor is required to serve as an energy reservoir for the current which must flow into the coil each time the switch turns ON. This capacitor must have extremely low ESR, so ceramic is the best choice. We recommend a nominal value of 4.7µF, but larger values can be used. Since this capacitor reduces the amount of voltage ripple seen at the input pin, it also reduces the amount of EMI passed back along that line to other circuitry.

Application Information (Continued)

SETTING THE OUTPUT VOLTAGE (V_1) OF BOOST CONVERTER

The output voltage is set using the external resistors R1 and R2 (see Figure 1). A value of approximately 13.3kΩ is recommended for R2 to establish a divider current of approximately 92µA. R1 is calculated using the formula:

$$R1 = R2 \times (V_2/1.23 - 1) \quad (5)$$

FEED-FORWARD COMPENSATION FOR BOOST CONVERTER

Although the LM4960's internal Boost converter is internally compensated, the external feed-forward capacitor C_f is required for stability (see Figure 1). Adding this capacitor puts a zero in the loop response of the converter. The recommended frequency for the zero fz should be approximately 6kHz. C_f1 can be calculated using the formula:

$$C_f1 = 1 / (2 \times R1 \times fz) \quad (6)$$

SELECTING DIODES

The external diode used in Figure 1 should be a Schottky diode. A 20V diode such as the MBR0520 is recommended.

The MBR05XX series of diodes are designed to handle a maximum average current of 0.5A. For applications exceeding 0.5A average but less than 1A, a Microsemi UPS5817 can be used.

DUTY CYCLE

The maximum duty cycle of the boost converter determines the maximum boost ratio of output-to-input voltage that the converter can attain in continuous mode of operation. The duty cycle for a given boost application is defined as:

$$\text{Duty Cycle} = V_{OUT} + V_{DIODE} - V_{IN} / V_{OUT} + V_{DIODE} - V_{SW}$$

This applies for continuous mode operation.

INDUCTANCE VALUE

The first question we are usually asked is: "How small can I make the inductor." (because they are the largest sized component and usually the most costly). The answer is not simple and involves trade-offs in performance. Larger inductors mean less inductor ripple current, which typically means less output voltage ripple (for a given size of output capacitor). Larger inductors also mean more load power can be delivered because the energy stored during each switching cycle is:

$$E = L/2 \times (Ip)2$$

Where "Ip" is the peak inductor current. An important point to observe is that the LM4960 will limit its switch current based on peak current. This means that since Ip(max) is fixed, increasing L will increase the maximum amount of power available to the load. Conversely, using too little inductance may limit the amount of load current which can be drawn from the output.

Best performance is usually obtained when the converter is operated in "continuous" mode at the load current range of interest, typically giving better load regulation and less output ripple. Continuous operation is defined as not allowing the inductor current to drop to zero during the cycle. It should be noted that all boost converters shift over to discontinuous operation as the output load is reduced far enough, but a larger inductor stays "continuous" over a wider load current range.

To better understand these trade-offs, a typical application circuit (5V to 12V boost with a 10µH inductor) will be analyzed. We will assume:

$$V_{IN} = 5V,\ V_{OUT} = 12V,\ V_{DIODE} = 0.5V,\ V_{SW} = 0.5V$$

Since the frequency is 1.6MHz (nominal), the period is approximately 0.625µs. The duty cycle will be 62.5%, which means the ON-time of the switch is 0.390µs. It should be noted that when the switch is ON, the voltage across the inductor is approximately 4.5V. Using the equation:

$$V = L\ (di/dt)$$

We can then calculate the di/dt rate of the inductor which is found to be 0.45 A/µs during the ON-time. Using these facts, we can then show what the inductor current will look like during operation:

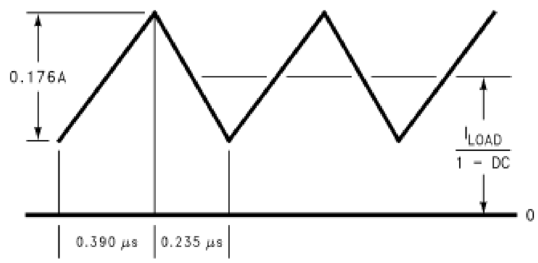


FIGURE 2. 10µH Inductor Current 5V - 12V Boost (LM4960)

During the 0.390µs ON-time, the inductor current ramps up 0.176A and ramps down an equal amount during the OFF-time. This is defined as the inductor "ripple current". It can also be seen that if the load current drops to about 33mA, the inductor current will begin touching the zero axis which means it will be in discontinuous mode. A similar analysis can be performed on any boost converter, to make sure the ripple current is reasonable and continuous operation will be maintained at the typical load current values.

MAXIMUM SWITCH CURRENT

The maximum FET switch current available before the current limiter cuts in is dependent on duty cycle of the application. This is illustrated in a graph in the typical performance characterization section which shows typical values of switch current as a function of effective (actual) duty cycle.

Application Information (Continued)

CALCULATING OUTPUT CURRENT OF BOOST CONVERTER (I_{AMP})

As shown in Figure 2 which depicts inductor current, the load current is related to the average inductor current by the relation:

$$I_{LOAD} = I_{IND}(AVG) \times (1 - DC) \quad (7)$$

Where "DC" is the duty cycle of the application. The switch current can be found by:

$$I_{SW} = I_{IND}(AVG) + 1/2\ (I^{RIPPLE}) \quad (8)$$

Inductor ripple current is dependent on inductance, duty cycle, input voltage and frequency:

$$I_{RIPPLE} = DC \times (V_{IN}\text{-}V_{SW}) / (f \times L) \quad (9)$$

combining all terms, we can develop an expression which allows the maximum available load current to be calculated:

$$I_{LOAD}(max) = (1-DC)x(I_{SW}(max)-DC(V_{IN}\text{-}V_{SW}))/fL \quad (10)$$

The equation shown to calculate maximum load current takes into account the losses in the inductor or turn-OFF switching losses of the FET and diode.

DESIGN PARAMETERS V_{SW} AND I_{SW}

The value of the FET "ON" voltage (referred to as V_{SW} in equations 7 thru 10) is dependent on load current. A good approximation can be obtained by multiplying the "ON Resistance" of the FET times the average inductor current.

FET on resistance increases at V_{IN} values below 5V, since the internal N-FET has less gate voltage in this input voltage range (see Typical Performance Characteristics curves). Above V_{IN} = 5V, the FET gate voltage is internally clamped to 5V.

The maximum peak switch current the device can deliver is dependent on duty cycle. For higher duty cycles, see Typical Performance Characteristics curves.

INDUCTOR SUPPLIERS

Recommended suppliers of inductors for the LM4960 include, but are not limited to Taiyo-Yuden, Sumida, Coilcraft, Panasonic, TDK and Murata. When selecting an inductor, make certain that the continuous current rating is high enough to avoid saturation at peak currents. A suitable core type must be used to minimize core (switching) losses, and wire power losses must be considered when selecting the current rating.

PCB LAYOUT GUIDELINES

High frequency boost converters require very careful layout of components in order to get stable operation and low noise. All components must be as close as possible to the LM4802 device. It is recommended that a 4-layer PCB be used so that internal ground planes are available.

Some additional guidelines to be observed:

1. Keep the path between L1, D1, and Co extremely short. Parasitic trace inductance in series with D1 and Co will increase noise and ringing.

2. The feedback components R1, R2 and C_f 1 must be kept close to the FB pin of U1 to prevent noise injection on the FB pin trace.

3. If internal ground planes are available (recommended) use vias to connect directly to ground at pin 2 of U1, as well as the negative sides of capacitors C_s1 and Co.

GENERAL MIXED-SIGNAL LAYOUT RECOMMENDATION

This section provides practical guidelines for mixed signal PCB layout that involves various digital/analog power and ground traces. Designers should note that these are only "rule-of-thumb" recommendations and the actual results will depend heavily on the final layout.

Power and Ground Circuits

For 2 layer mixed signal design, it is important to isolate the digital power and ground trace paths from the analog power and ground trace paths. Star trace routing techniques (bringing individual traces back to a central point rather than daisy chaining traces together in a serial manner) can have a major impact on low level signal performance. Star trace routing refers to using individual traces to feed power and ground to each circuit or even device. This technique will take require a greater amount of design time but will not increase the final price of the board. The only extra parts required may be some jumpers.

Single-Point Power / Ground Connection

The analog power traces should be connected to the digital traces through a single point (link). A "Pi-filter" can be helpful in minimizing high frequency noise coupling between the analog and digital sections. It is further recommended to place digital and analog power traces over the corresponding digital and analog ground traces to minimize noise coupling.

Placement of Digital and Analog Components

All digital components and high-speed digital signals traces should be located as far away as possible from analog components and circuit traces.

Avoiding Typical Design / Layout Problems

Avoid ground loops or running digital and analog traces parallel to each other (side-by-side) on the same PCB layer. When traces must cross over each other do it at 90 degrees. Running digital and analog traces at 90 degrees to each other from the top to the bottom side as much as possible will minimize capacitive noise coupling and crosstalk.

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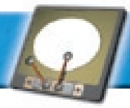
NOTES:

SPS-2220-03



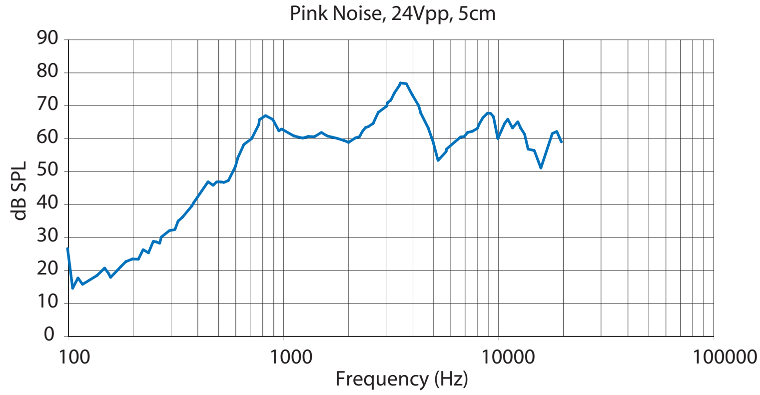
Sonitron's latest slim line profile speaker, the SPS-2220-03, is the result of ten years intensive research and development work. With a thickness of only 1 mm and dimensions of 20x22 mm this small multifunctional speaker/microphone is ideal for use in GPS, MP3, camera's, mobile phones,... It is distortion free and has excellent sound reproduction. Considering its extremely good voice clarity it definitely is the new speaker generation for the mobile phone industry.

SPECIFICATIONS

Frequency Range :	700 Hz-20 kHz
Max SPL @ 10 cm, 24Vpp: (average at 4-point)	85 dB
Distortion (%THD): (80dB at 5 cm, average at 4-point)	≤1%
Sensitivity: (SPL @ 10cm for 1Vrms, average at 4-point : 800Hz, 1kHz, 1.5kHz, 2kHz)	63 dB
Capacitance (+/- 20%):	70 nF
Impedance @ 1kHz (+/-20%):	2.16 kohm
Operating Voltage:	1Vpp-24Vpp
Weight:	0.4g
Operating Temperature:	-20°C to 60°C
Storage Temperature:	-40°C to 60°C
Case material:	PBT
Standard color:	Black

speaker mounted on plexi plate of 5 x 5cm in closed box of 40 x 15 x 5cm

FREQUENCY RESPONSE

Model	*Sound pressure level vs. frequency*
SPS-2220-03	

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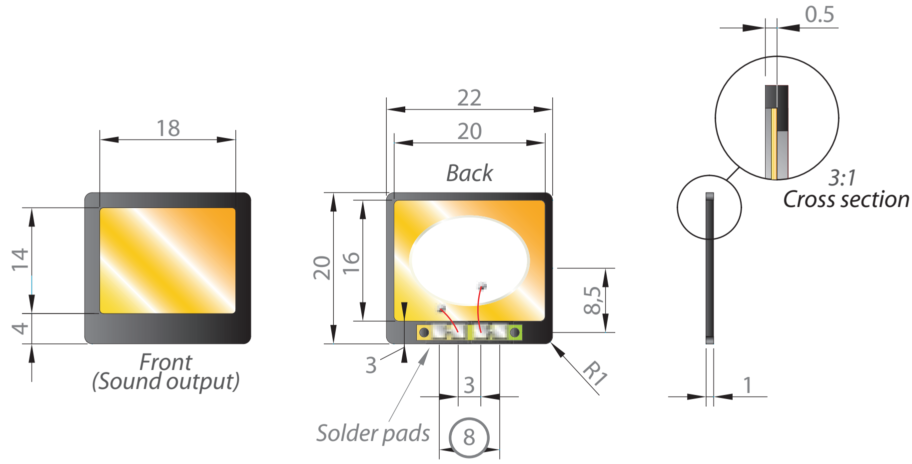
DIMENSIONS (all dimensions are in mm)

SPS-2220-03



Tolerance: +/- 0.2mm

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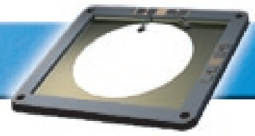
SPS-3530-03



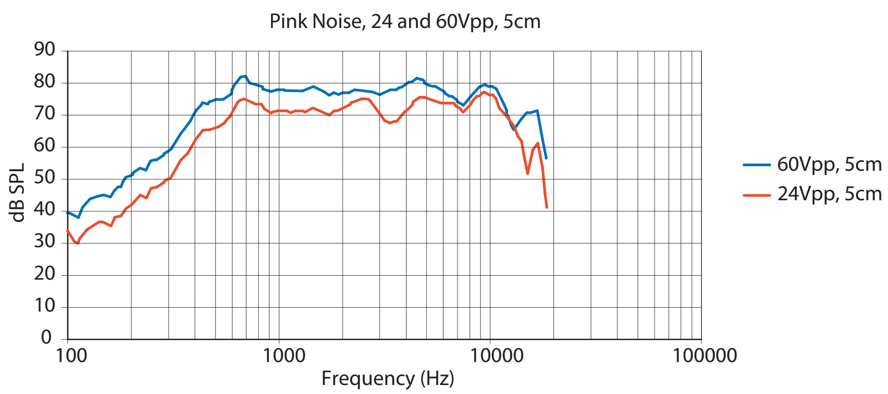
The electronics industry still is a very demanding industry which requires more and more flat and small components. Therefore Sonitron developed this new flat piezoceramic speaker.
With a thickness of only 2 mm and dimensions of 39x43.5 mm, this small multifunctional speaker/microphone is ideal for use in portable electronic devices (PDA, GPS, MP3,...), notebooks and consumer products.

SPECIFICATIONS

Frequency Range :	700 Hz - 20 kHz
Max SPL @ 1 m, 60 Vpp: (average at 4-point)	81 dB
Distortion (%THD): (80dB @ 0.5m, average @ 4-point)	≤1.5%
Sensitivity: (SPL @ 10cm for 1Vrms, average @ 4-point : 800Hz, 1kHz, 1.5kHz, 2kHz)	73 dB
Capacitance (+/- 20%):	220 nF
Impedance @ 1kHz (+/-20%):	603 ohm
Operating Voltage:	5-60 Vpp
Weight:	2.4g
Operating Temperature:	-20°C to 60°C
Storage Temperature:	-40°C to 60°C
Case material:	PBT
Standard color:	Black

speaker mounted in closed box of 40 x 15 x 5cm

FREQUENCY RESPONSE

Model	Sound pressure level vs. frequency
SPS-3530-03	

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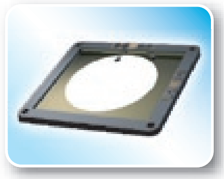
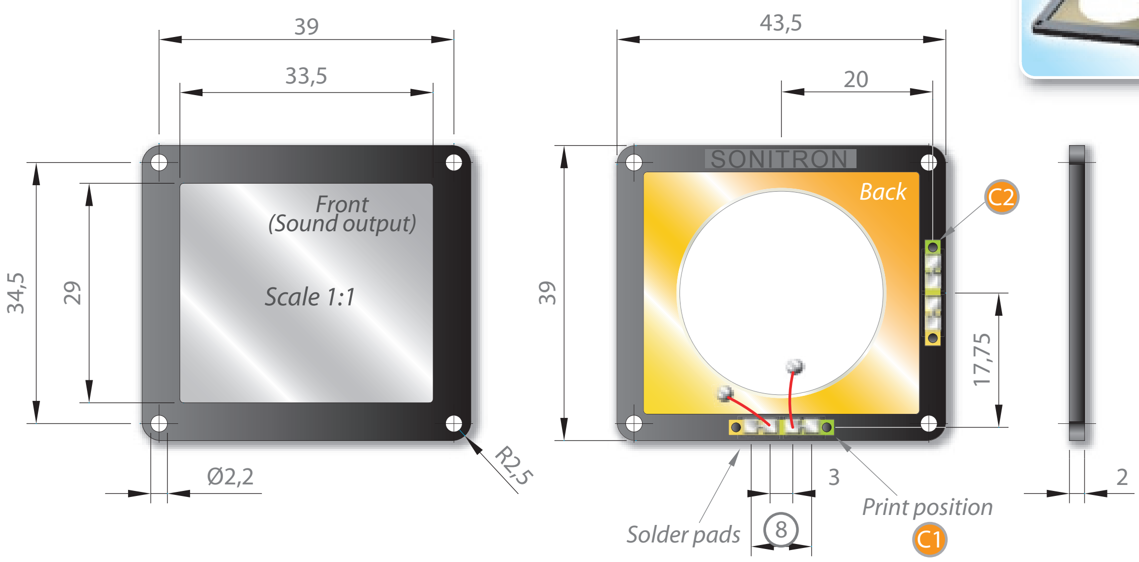
DIMENSIONS (all dimensions are in mm)

SPS-3530-03





Tolerance: +/- 0.2mm

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SPS-4640-03

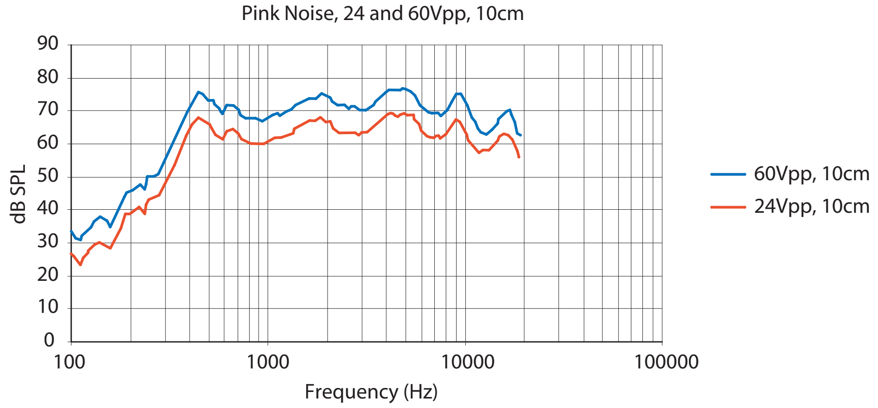
The electronics industry still is a very demanding industry which requires more and more flat and small components. Therefore Sonitron developed this new flat piezoceramic speaker.
With a thickness of only 2 mm and dimensions of 43.6x50 mm this small multifunctional speaker/microphone is ideal for use in portable electronic devices (PDA, GPS, MP3,...), notebooks and consumer products.

SPECIFICATIONS

Frequency Range :	400 Hz - 20 kHz
Max SPL @ 1 m, 60 Vpp: (average @ 4-point)	83 dB
Distortion (%THD): (80dB @ 1m, average @ 4-point)	≤1.5%
Sensitivity: (SPL @ 10cm for 1Vrms, average @ 4-point : 800Hz, 1kHz, 1.5kHz, 2kHz)	72 dB
Capacitance (+/- 20%):	225 nF
Impedance @ 1kHz (+/-20%):	680 ohm
Operating Voltage:	5-60 Vpp
Weight:	2.8g
Operating Temperature:	-20°C to 60°C
Storage Temperature:	-40°C to 60°C
Case material:	PBT
Standard color:	Black

speaker mounted in closed box of 40 x 15 x 5cm

FREQUENCY RESPONSE

Model	Sound pressure level vs. frequency
SPS-4640-03	

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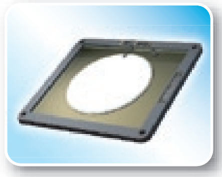
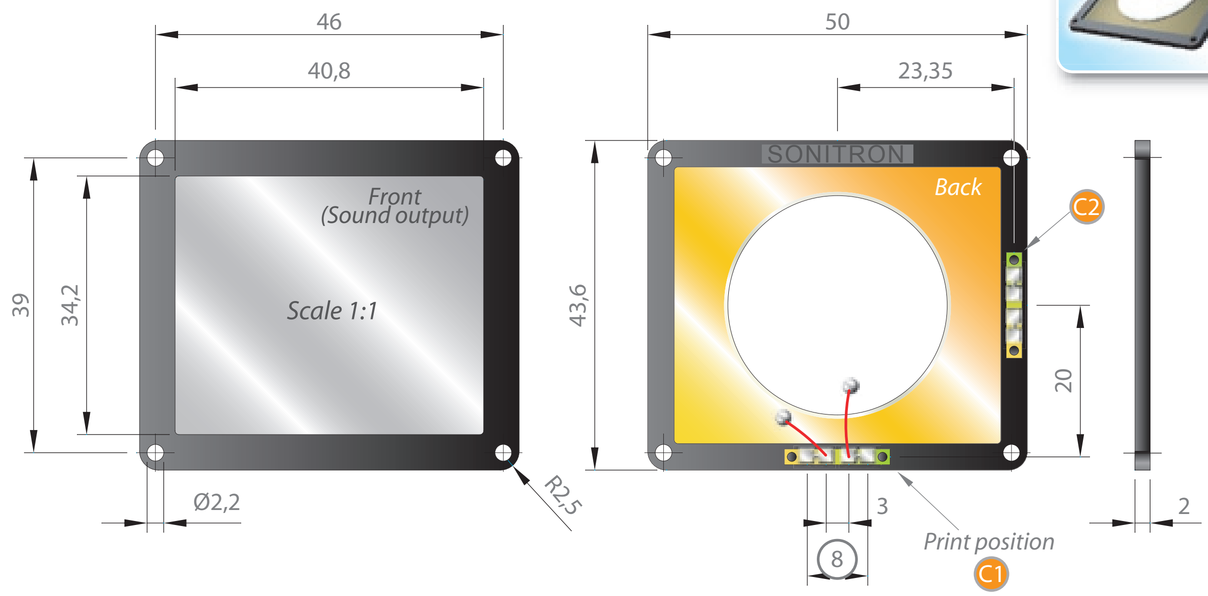
DIMENSIONS (all dimensions are in mm)

SPS-4640-03





Tolerance: +/- 0.2mm

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SPS-6555-03

The new SPS-6555-03 is designed for applications where the space is limited and a high sound quality is required. This new speaker model features a broad frequency range combined with small dimensions which makes them ideal for multimedia applications.

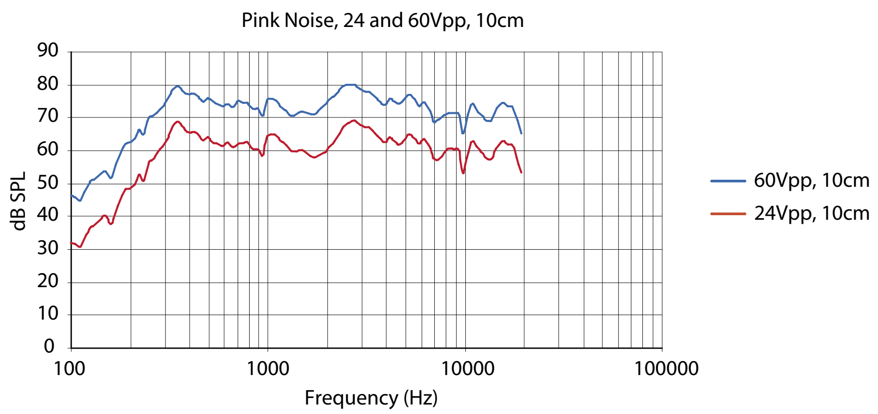
SPECIFICATIONS

Frequency Range :	300 Hz - 20 kHz
Max SPL @ 1 m, 60 Vpp: (average @ 4-point)	83 dB
Distortion (%THD): (80dB @ 1m, average @ 4-point)	≤1.5%
Sensitivity: (SPL @ 10cm for 1Vrms, average @ 4-point : 800Hz, 1kHz, 1.5kHz, 2kHz)	73 dB
Capacitance (+/- 20%):	480 nF
Impedance @ 1kHz (+/-20%):	333 ohm
Operating Voltage:	5-60 Vpp
Weight:	5g
Operating Temperature:	-20°C to 60°C
Storage Temperature:	-40°C to 60°C
Case material:	PBT
Standard color:	Black

speaker mounted in closed box of 40 x 15 x 5cm

FREQUENCY RESPONSE

Model	*Sound pressure level vs. frequency*
SPS-6555-03	



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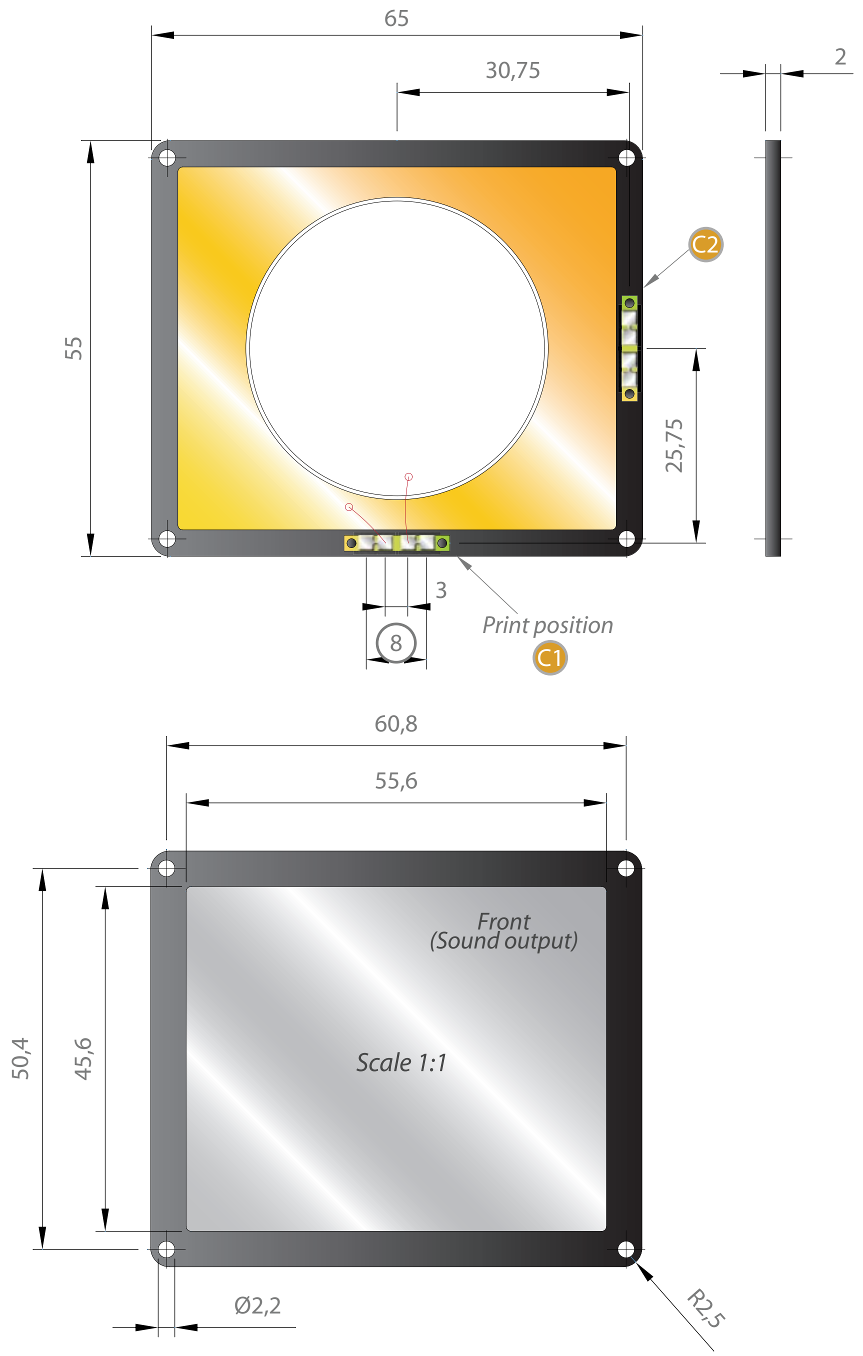
DIMENSIONS (all dimensions are in mm)

SPS-6555-03



Tolerance: +/- 0.2mm

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SPS-8770-03

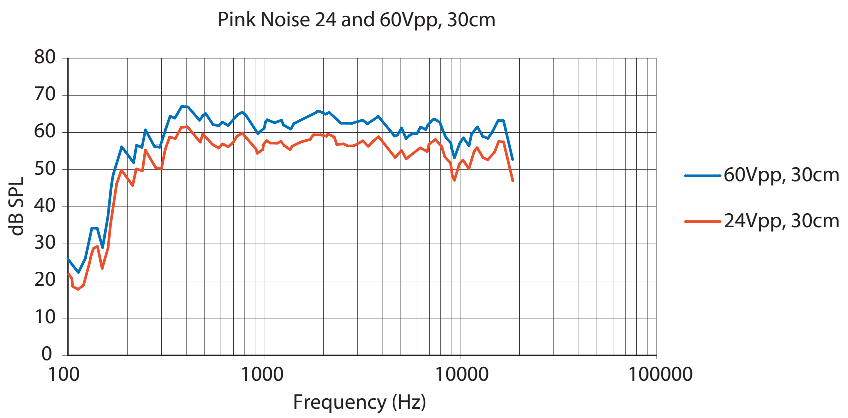
The SPS-8770-03 is the largest version of our piezo speakers, with a thickness of only 2 mm. This model is extremely suitable for flat devices when high sound output and broad frequency range are required. Low weight and easy mounting requirements are the extreme advantages of this speaker. Compared with conventionel designs the speaker also has less current consumption.

SPECIFICATIONS

Frequency Range :	200 Hz - 20 kHz
Max SPL @ 1 m, 60 Vpp: (average @ 4-point)	84 dB
Distortion (%THD): (80dB @ 1m, average @ 4-point)	≤1.5%
Sensitivity: (SPL @ 10cm for 1Vrms, average @ 4-point : 800Hz, 1kHz, 1.5kHz, 2kHz)	74 dB
Capacitance (+/- 20%):	580 nF
Impedance @ 1kHz (+/-20%):	266 ohm
Operating Voltage:	5-60 Vpp
Weight:	7.3g
Operating Temperature:	-20°C to 60°C
Storage Temperature:	-40°C to 60°C
Case material:	PBT
Standard color:	Black

speaker mounted in closed box of 40 x 15 x 5cm

FREQUENCY RESPONSE

Model	Sound pressure level vs. frequency
SPS-8770-03	

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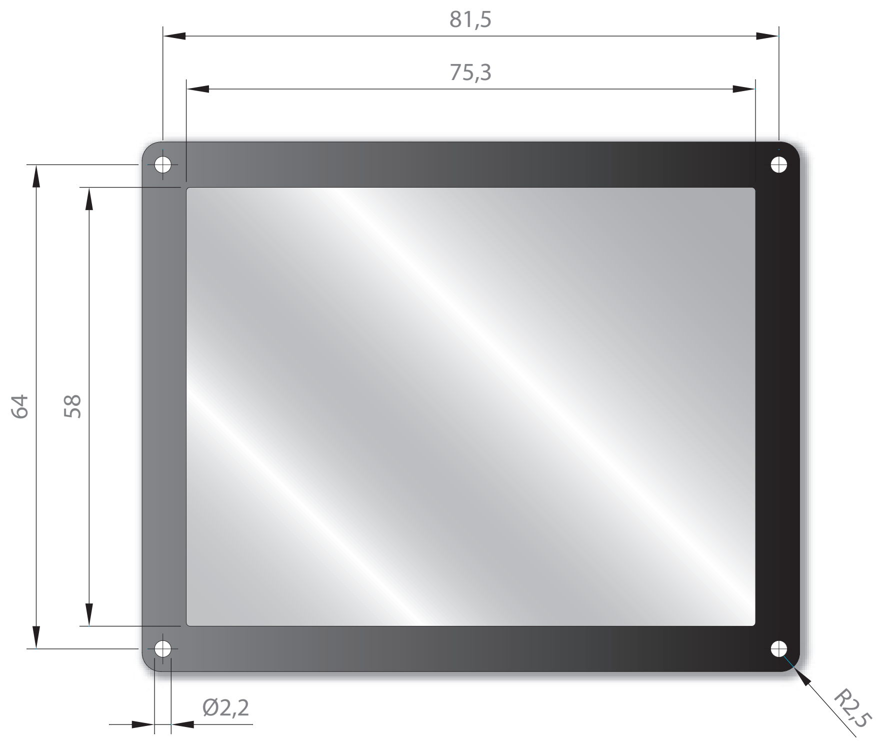
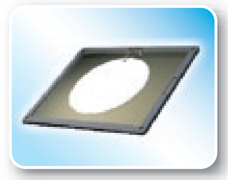
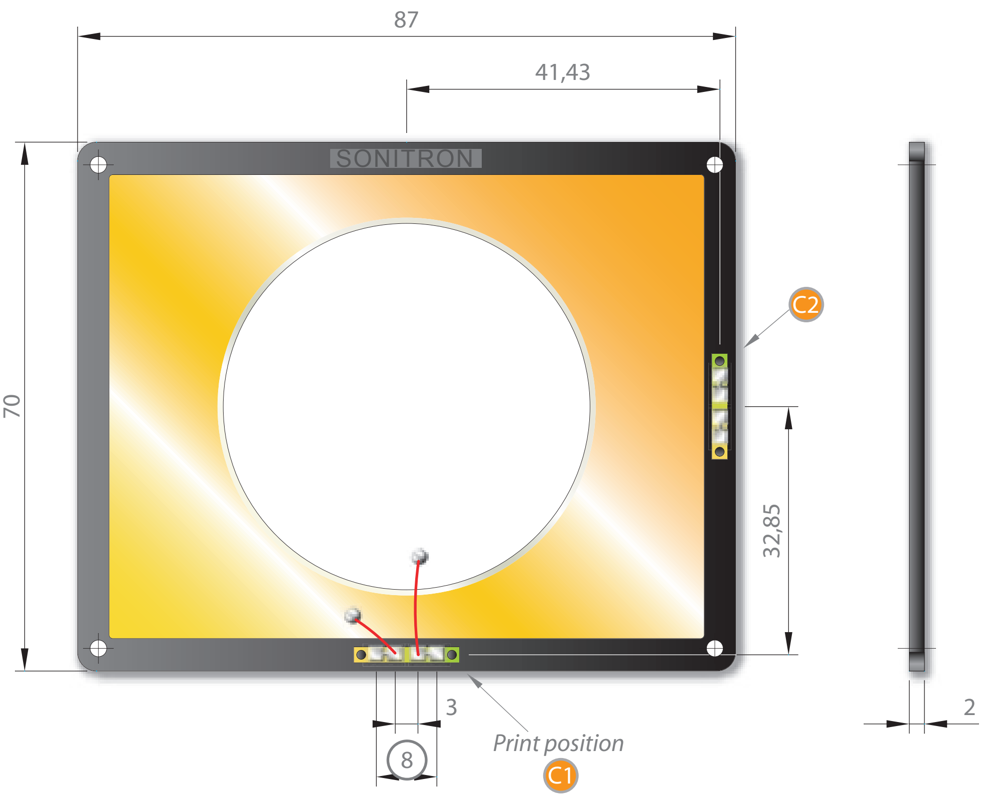
DIMENSIONS (all dimensions are in mm)

SPS-8770-03







Tolerance: +/- 0.2mm

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SPS-8770-UW

INTRODUCTION

Based on the in-house expertise in vibration characteristics of piezoceramic material and microacoustics, Sonitron successfully developed the first flat piezoceramic speaker for underwater applications. This speaker is based on a completely new principle of piezoceramics and composite metal/polymer layer. The composite membrane reduces unwanted resonance peaks to provide a more even frequency response than can be achieved with conventional designs.

ADVANTAGES & APPLICATIONS

ADVANTAGES :

- Light but solid construction
- Easily mountable
- Small dimensions
- IP68: dust tight, totally protected against dust.
  Protected against long periods of immersion under pressure.

APPLICATIONS :

- Diving communications
- Swimming pool music
- Instruction in underwater training, and or during surf training
- Warning signals
- Shark alerts
- Boat alarms
- Outdoor applications
- Carwash
- Fridges
- Whirlpools
- Bathroom
- Etc,...

SPECIFICATIONS

Operating voltage:	5 to 60Vpp
Frequency range:	600 Hz-20 kHz
Max. SPL @1m: (60Vpp input, average @ 4-point)	90 dB
Distortion (%THD): (80dB @ 1m, average @ 4-point)	<3.5%
Terminals:	50 cm cable, other lengths on request
Operating temperature:	-20°C to +70°C
Storage temperature:	-40°C to +85 °C
Case material:	ABS (UL rating: 94 HB)
Case color:	blue
Weight:	42g
Capacitance (±20%):	660nF
Impedance @1kHz (±20%):	220 ohm

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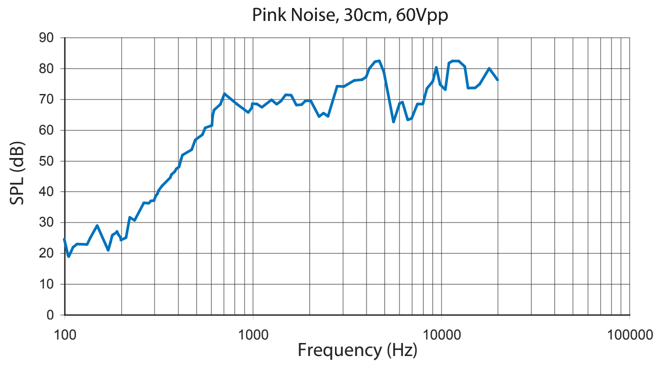
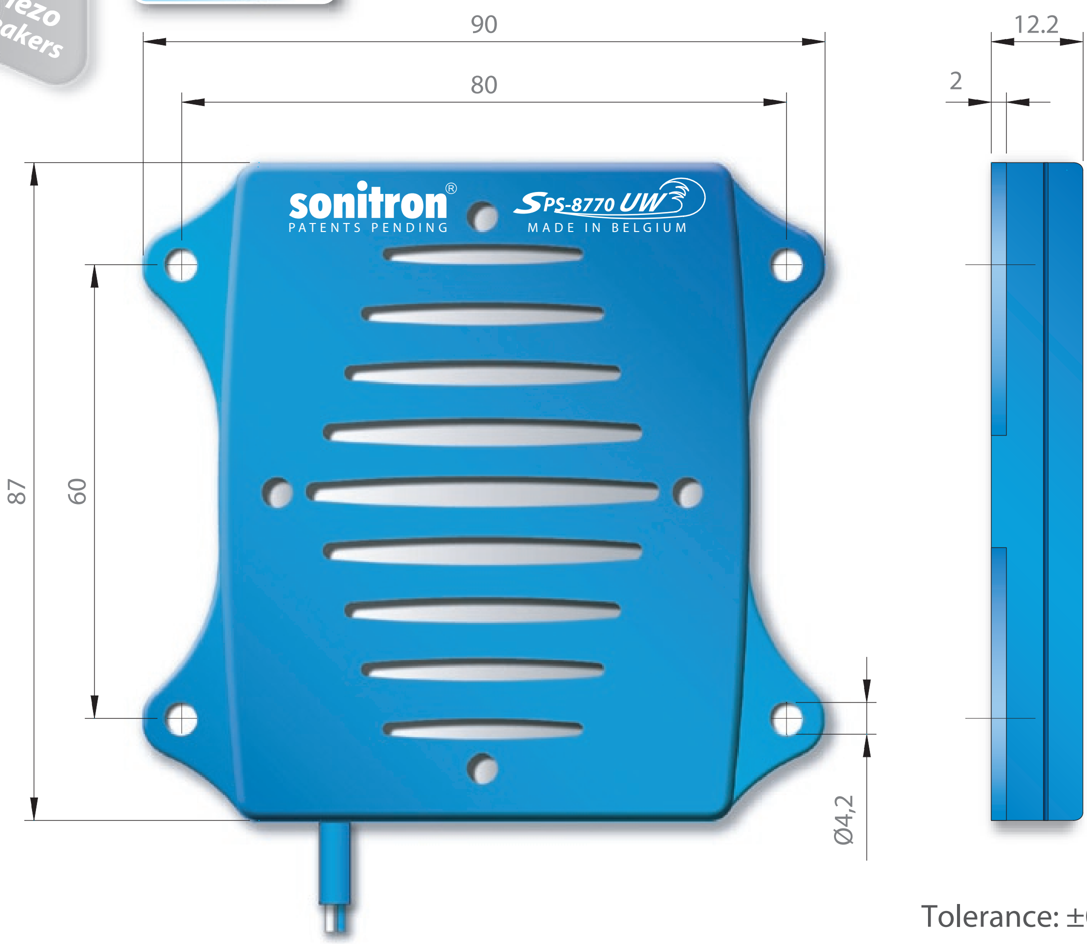
FREQUENCY RESPONSE

Model	Frequency response curve
SPS-8770-UW	

DIMENSIONS (All dimensions are in mm)



Tolerance: ±0.2mm

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