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REFERENCE DESIGN 4320 INCLUDES: ✓Tested Circuit ✓Schematic ✓BOM ✓Description ✓Test Data ✓Layout

## Reference Design for a Class D, 2.1-Channel, Audio Amplifier for an MP3 Docking Station

Nov 11, 2011

*Abstract: This reference design demonstrates the use of the MAX98400 Class D audio amplifier in a stereo audio docking station application. The MAX98400 2.1 demo box is a complete powered speaker dock that uses two MAX98400 ICs to drive a 3-channel speaker system consisting of two 2in satellite speakers and one 5in subwoofer. The reference design is intended to be used with a portable audio player as its main music source. The overall solution size is very compact and features active equalization, power-supply monitoring, and dynamic equalization for the subwoofer.*

### Important Design Features

- Compact all-in-one design
- Operates from a single 12V to 20V DC power supply
- High SPL output from a small box
- High-efficiency Class-D design
- Active EQ, including dynamic bass equalization
- Excellent sound quality from cost-effective drivers



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### Bill of Materials

Designator	Qty	Description
U1, U2	2	Maxim MAX98400AETX+ (6mm x 6mm x 0.75mm, 36-pin TQFN), stereo high-power Class D amplifier
U3–U5, U100	4	Maxim MAX4234 (TSSOP-14), high-output-drive, 10MHz, 10V/μs, rail-to-rail I/O op amps
U6	1	Maxim MAX809LEUR (SOT-23), microprocessor reset circuit
U7	1	Fairchild™ H11F1SM, Opto-FET (DIP6-SMT)
U8	1	Maxim MAX5084ATT+ (6-TDFN-EP) 65V, 200mA, linear regulator
C1	1	560μF ±20% 35V aluminum electrolytic capacitor Panasonic® EEU-FM1V561L
C11, C15	2	220μF ±20% 35V aluminum electrolytic capacitor (10mm x 12.5mm) Panasonic EEUFM1V221

C16	1	10 $\mu$ F (1206), 50V
C80	2	10 $\mu$ F (1210), 50V
C2–C5, C10, C12–C14, C19, C305, C307, C321	12	0.1 $\mu$ F ceramic capacitor (0603), X7R, 50V
C8, C17–C18, C9, C122–C123, C222–C223, C309–C312	12	1 $\mu$ F ceramic capacitor (0603), X7R, 16V
C106, C109–C111, C114, C206, C209–C211, C214	10	OPEN
C117–C119, C217–C219	6	10nF ceramic capacitor (0603) X7R, 50V
C76	1	10 $\mu$ F ceramic capacitor (0805), X5R, 10V
C200–C201, C100–C101	4	2.2 $\mu$ F ceramic capacitor (0805), X7R, 25V
C204, C120–C121, C220–C221, C203, C301, C103–C104, C314–C315	11	100pF ceramic capacitor (0603), COG, 50V
C215, C208, C202, C112, C300, C102, C108, C212, C115, C322	10	33pF ceramic capacitor (0603), COG, 50V
C113, C213	2	4.7nF ceramic capacitor (0603), COG, 50V
C303	1	0.33 $\mu$ F ceramic capacitor (0603), X7R, 50V
C7	1	OPEN
C306, C308	2	15nF ceramic capacitor (0805), COG, 50V
C205, C105	2	68nF ceramic capacitor (0805), X7R, 25V
C107, C207	2	150pF ceramic capacitor (0603), COG, 50V
C302	1	0.47 $\mu$ F ceramic capacitor (0603), X7R, 50V
C316–C317	2	0.1 $\mu$ F ceramic capacitor (0603), X7R, 50V
R1	1	10k $\Omega$ (0805)
R27–R28	2	680 $\Omega$ (1206), 500mW
R2, R24, R317	3	1k $\Omega$ (0603)
R4	1	4.22k $\Omega$ (0603)
R5	1	220 $\Omega$ (0603)
R6, R8–R12, R14–R15, R17–R19, R22, R26, R100, R110, R113, R200, R210, R213	19	OPEN
R13, R20, R105, R21, R16, R23, R205, R25	8	0 $\Omega$ (0603)
R107, R109, R207, R209	4	1M $\Omega$ (0603)
R111, R112	2	10.5k $\Omega$ (0603)
R103–R104, R203–R204	4	39.2k $\Omega$ (0603)
R131–R132, R231–R232	4	3.32k $\Omega$ (0603)
R202, R101, R206, R108, R208, R102, R3, R106, R201, R300–R301, R318–R319	13	10k $\Omega$ (0603)

R115, R215	2	30.1k $\Omega$ (0603)
R114, R214	2	137k $\Omega$ (0603)
R130, R230	2	100 $\Omega$ (0603)
R112, R212	2	150 $\Omega$ (0603)
R302	1	2k $\Omega$ (0603)
R304	1	7.15k $\Omega$ (0603)
R305	1	14.7k $\Omega$ (0603)
R306	1	12k $\Omega$ (0603)
R307	1	3.3k $\Omega$ (0603)
R308	1	3.24k $\Omega$ (0603)
R309, R311–R312, R314	4	11k $\Omega$ (0603)
R313, R310	2	24.3k $\Omega$ (0603)
R315–R316	2	2.2k $\Omega$ (0603)
R7	1	100k $\Omega$ , PVG3A104C01R00, surface mount potentiometer, 3mm
R303	1	20k $\Omega$ , PVG3A203C01R00, surface mount potentiometer, 3mm
L100–L101, L200–L201, L300–L301	6	Ferrite bead (1206), 3A
FB1	1	Ferrite bead (1206), 6A
J1	1	Power jack, right angle, Switchcraft® 722RA
J2	1	Dual RCA® jack, 161-4220-E
J3	1	6-pin male header
J4	1	Header, Hirose DF3A-2P-2DSA
J10, J20, J30	3	Header, 26-60-4020
D1	1	Green LED (0603)
D3	1	Zener diode (SOT23), BZX84C5V6
D5	1	Blue LED (0603)
D6	1	Dual diode (SOT23), common cathode, MMBD4148CC
Q2	1	NPN transistor, MMBT3904
X1–X2	2	Screw terminal
SPK1, SPK2	2	2in full-range loudspeaker Tymphany® Peerless Gold PLS-P830970 830970
SPK3	1	5.25in subwoofer loudspeaker Tymphany Peerless Gold SLS-P830945

## Detailed Design Description

The reference design consists of a single, carefully tuned box enclosure containing all of the electronics and speaker hardware. Only an external power supply and a signal source are required to complete the system.

The design features two 2in loudspeaker drivers for the left and right channels, and a 5in loudspeaker for the subwoofer. A single MAX98400A is used in stereo mode for the left/right channels and another MAX98400A is used in mono mode for the subwoofer channel. The detailed description here is divided into two sections: the electronic circuit description and the speakers/physical enclosure description.

## Electronic Circuit Description

The electronics of the reference design comprise two sections, the left/right and subwoofer. Each section has three stages: input, EQ, and power. See **Figure 1**.

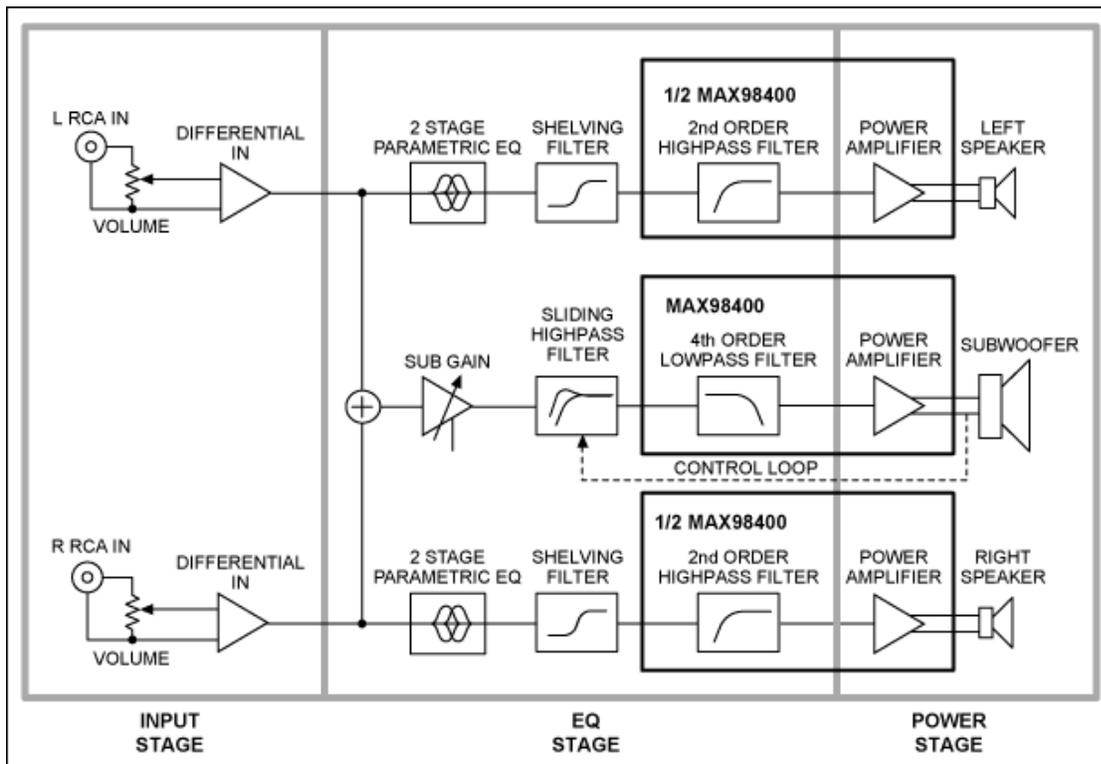


Figure 1. Electrical circuit block diagram features the MAX98400 Class D audio amplifier. The design has an input, EQ, and power stage.

### Input Stage

The input stage is common to both the left/right and subwoofer sections. A stereo, log-taper potentiometer (digipot) is used as a volume control to adjust the signal level to the preamplifier. To avoid ground loops, the input is sensed differentially and the RCA input connectors are not directly connected to the system ground. A 100Ω resistor is used to reduce the common-mode voltage; U3-A and U3-D (see schematics below) perform differential-to-single-ended conversion with a gain of 2. The outputs of the input stage are referred to  $V_{REF}$ , the reference voltage of power amplifier U2 which is buffered using U100-A.

### EQ Stage

After the input stage, the left and right signals are passed to a two-stage parametric EQ built around U3-B (for left)

and U3-C (for right). Each parametric EQ uses an op-amp gyrator to simulate an inductor in an LC-series resonant circuit. The series circuit has two access points for either attenuation or boost, and the access points are realized by two different capacitors. C105 and C106, for example, are the boost and attenuation points for the first parametric EQ band for the left channel. If only C106 is used (and C105 is not stuffed), the resonant circuit forms a voltage-divider in combination with the series resistor R105 (10k $\Omega$ ), and the resonant frequency is attenuated. Conversely, if only C105 is used, the feedback is reduced, resulting in a boost at the resonant frequency. If neither of the capacitors is used, then the band is disabled.

The resonant frequency,  $f_0$ , can be calculated using the equation:

$$f_0 = 1/(2 \times \pi \times \sqrt{L_0 \times C_0})$$

Where:

$$L_0 = R108 \times C107 \times R107$$

$$C_0 = C105$$

And the Q is:

$$Q_0 = \sqrt{L_0/(C_0 \times R_0^2)}$$

A third EQ band is added that realizes a shelving filter and only needs an RC: one capacitor (C113 for boost; C114 for attenuation) and one resistor (R111).

In this reference design, op amps U100-B and U100-C are used to build a second-order highpass filter for the left/right channels.

## Power Stage

The design features three channels of speaker power amplification. A MAX98400A is configured in stereo mode to drive the left and right speakers, and can provide  $2 \times 20W$  into 8 $\Omega$ . For the third channel, a MAX98400A is configured as a mono subwoofer amplifier.

In mono mode, the two Class D outputs of the MAX98400A are connected in parallel to allow for higher output power. In mono mode, the subwoofer channel can deliver 44W into 4 $\Omega$  ( $V_{DD} = 18V$ ). The input stage for the subwoofer channel is the same as that used for the left and right channels. After the input stage, the left and right signals are then summed using U5-B to create the mono subwoofer channel. R303 is used to set the subwoofer channel gain at the summing amp.

To enable a maximally flat response down to very low frequencies, the system is configured with a sixth-order filtered alignment for the subwoofer. This approach means that the fourth-order highpass response of the vented speaker is supplemented with a second-order electrical highpass in the active circuitry. U5-B is used to realize the noninverting Sallen-Key, second-order highpass filter for the subwoofer.

This system requires a high Q, which leads to 13dB of boost at 40Hz (**Figure 2**). To avoid overloading the speaker and amplifier, the Sallen-Key filter is set up to act as a sliding highpass; the filter acts dynamically as the amplifier output reaches its limit. The value of input resistor R305 is designed to reduce automatically (using the opto-coupled FET, U7) to a value so that the filter Q is lowered to 0.5, resulting in no boost at all.

The peak output voltage of the subwoofer amplifier, U2, controls the signal to the opto-FET. D6 and C16 form a peak detector, which senses the output peak level with a fast attack time. The operating threshold for the peak detector can be adjustable or fixed, depending on whether R7 is stuffed or R8/R9 are stuffed. The LED D5 turns on when this control circuit is active.

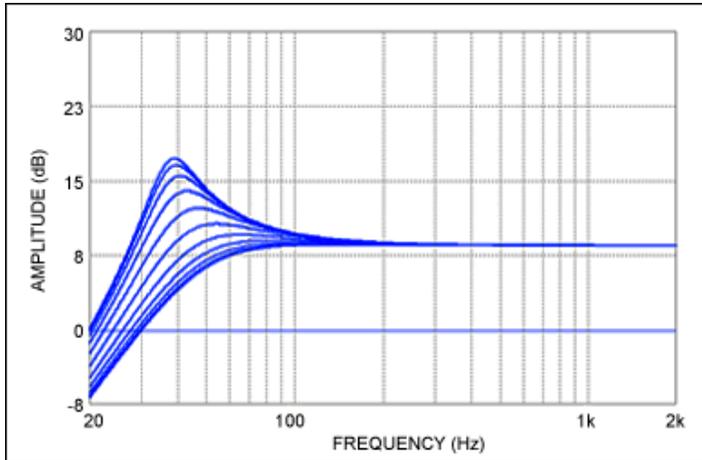


Figure 2. Simulation results of the dynamic bass boost from the subwoofer channel. The Q of the highpass filter is reduced while the cutoff frequency is also increased, as the subwoofer level approaches its limit.

The two op amps U5-C and U5-D are configured into a fourth-order lowpass subwoofer filter that complements the highpass filter used for the left/right channels.

J1 is the power-supply input connector chosen to be a standard laptop-type coaxial socket. A typical laptop power supply has an average output voltage of around 19V and serves as a good power source for the docking system. After some filtering through C1 and C2, the voltage is labelled PVDD and D1 is set to light green when power is attached.

A simple reset circuit (through U6) is used put the IC's into shutdown on power-up and power-down for both amplifier chips. This step avoids output transient noises due to input circuitry settling. The shutdown control threshold is programmed to approximately 10V with the R3 and R4 resistor-divider.

The MAX98400 features a patented filter-less modulation method, which eliminates the need for bulky inductor-based filters. Only simple ferrite beads (L100 to L301) are required at the output.

## Speakers and Physical Enclosure

The loudspeaker used for the subwoofer is a 5in-diameter model from Tymphany, SLS-P830945, with a  $4\Omega$  nominal impedance and a resonance frequency of 47.4Hz. The 2in loudspeakers used for the left and right channels are model PLS-P830970, also from Tymphany. These loudspeakers have  $4\Omega$  nominal impedance and a resonance frequency of 147.5Hz.

A low  $f_3$  of 35Hz is targeted for the acoustic system, so a sixth-order alignment is used. That alignment includes a second-order highpass filter within the active crossover. The overall system is housed in a single box enclosure with the three loudspeakers, tuned port, and circuit PCB. The subwoofer is mounted as down-firing to minimize the box size and to help increase efficiency by compression loading. The resulting box volume is approximately 3.79l and the vented port is tuned to 54Hz. The outside overall box dimensions are approximately 355mm x 180mm x 120mm. The speaker crossover equalization is designed as a fourth-order Linkwitz-Riley at 250Hz; the speaker equalization for the satellites consists of a parametric EQ with  $f = 500\text{Hz}$ ,  $\text{gain} = +6\text{dB}$ ,  $Q = 0.5$ , and a shelving filter with  $f_3 = 3.8\text{kHz}$  and a gain of +5.8dB. **Figure 3** shows the system's response.

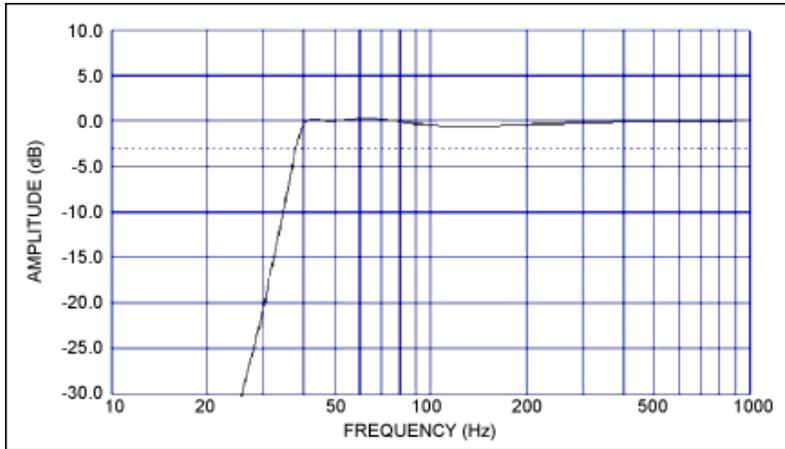
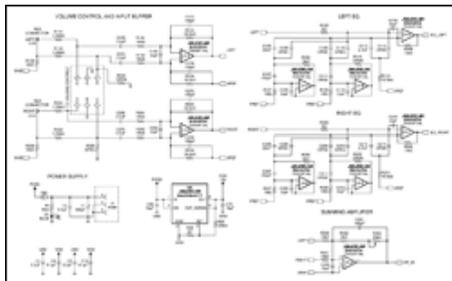


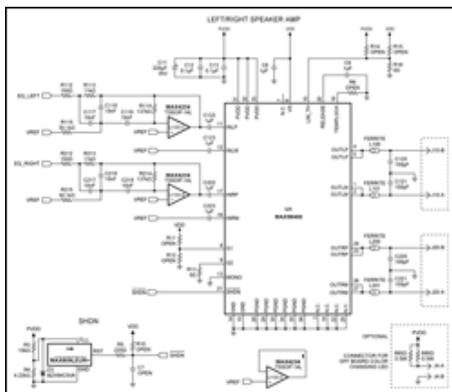
Figure 3. Total system simulated response shows maximally flat down to 40Hz.

The mechanical drawings included in this document are copies of those used to construct the prototype model. The prototype was built using 1/4in clear acrylic plastic and assembled with drilled/tapped screws and acrylic adhesive and an 8.5in x 2.5in port tube. A consumer product version might be constructed using a more cost-effective material such as wood, MDF, ABS, etc.

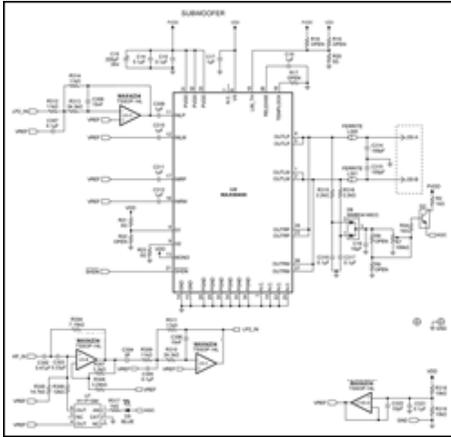
## Circuit Schematics



[More detailed image \(PDF, 335kB\)](#)

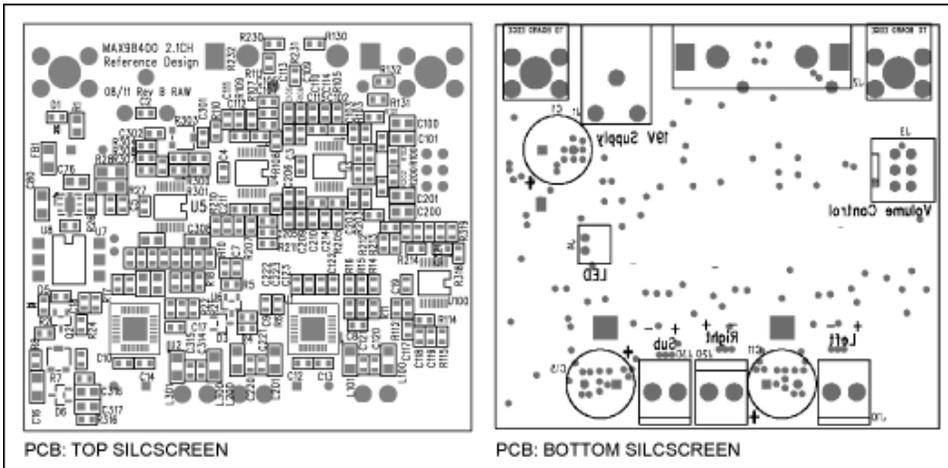


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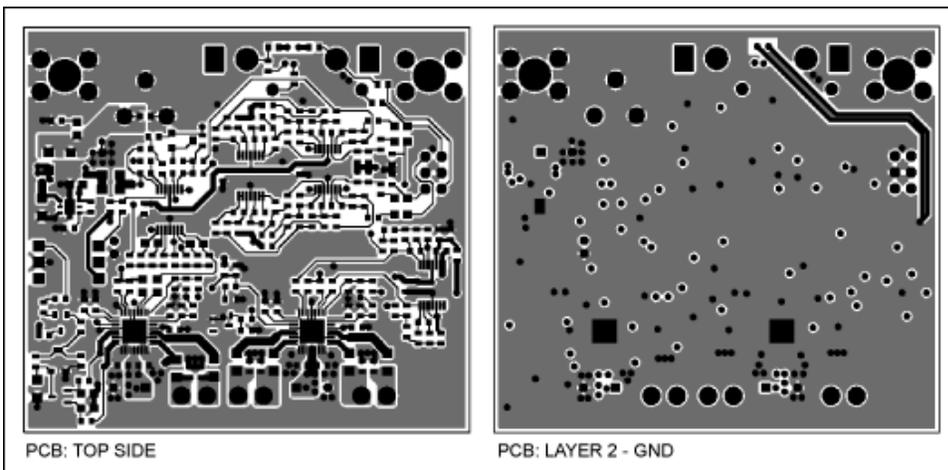


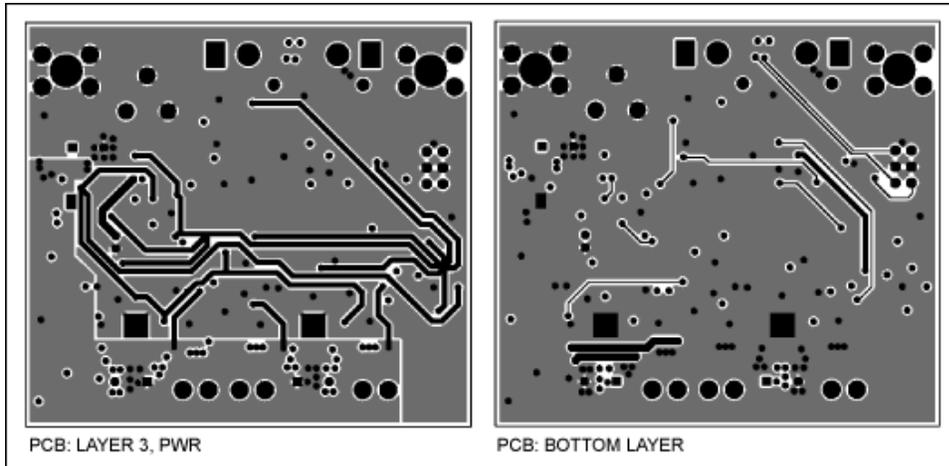
[More detailed image \(PDF, 343kB\)](#)

## PCB Layout

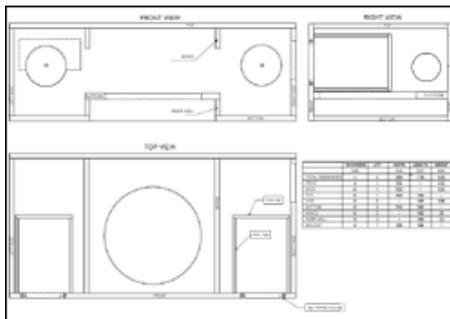


[More detailed image of the Top Silkscreen \(PDF, 296kB\)](#)

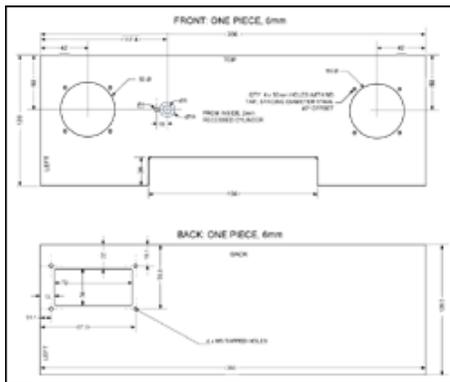




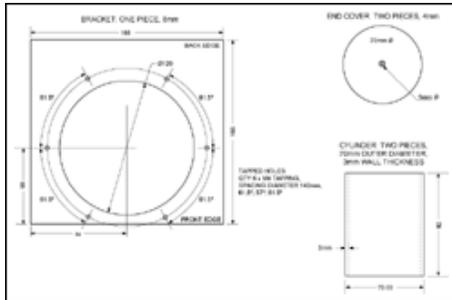
## Mechanical Drawings



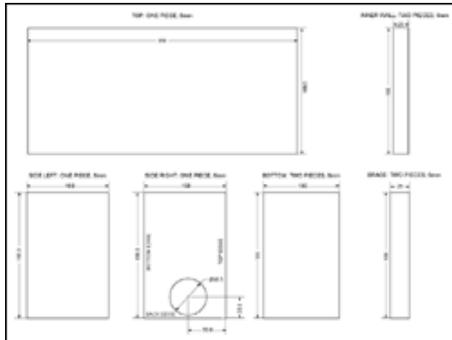
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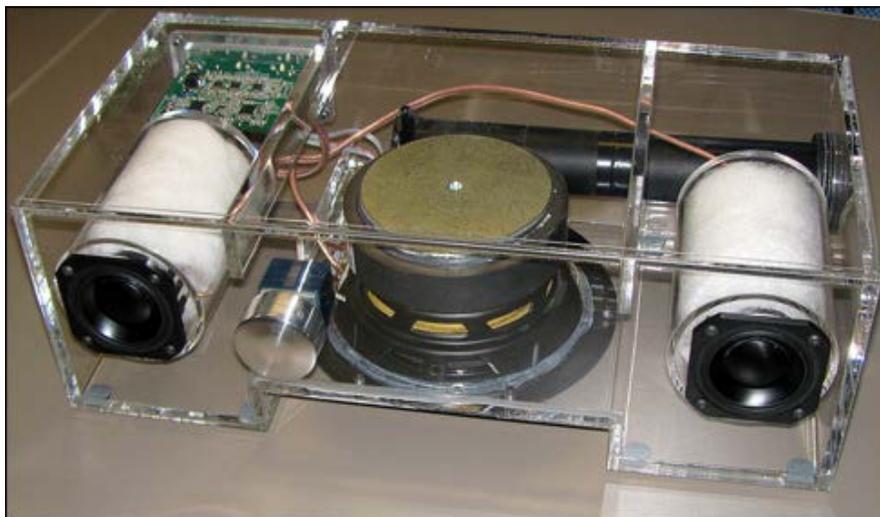


[More detailed image \(PDF, 52kB\)](#)



[More detailed image \(PDF, 48kB\)](#)

## Picture of System



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## Related Parts

<a href="#">MAX4234</a>	High-Output-Drive, 10MHz, 10V/ $\mu$ s, Rail-to-Rail I/O Op Amps with Shutdown in SC70	<a href="#">Free Samples</a>
<a href="#">MAX5084</a>	65V, 200mA, Low-Quiescent-Current Linear Regulators in TDFN	<a href="#">Free Samples</a>
<a href="#">MAX809L</a>	3-Pin Microprocessor Reset Circuits	<a href="#">Free Samples</a>

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REFERENCE DESIGN 4320, AN4320, AN 4320, APP4320, Appnote4320, Appnote 4320

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