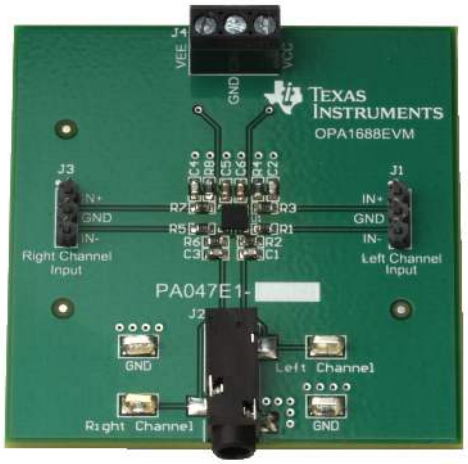
User's Guide
SBOU186–March 2017

OPA1688EVM SoundPlus™ Audio Operational Amplifier Evaluation Module



This user's guide contains information for the OPA1688 as well as support documentation for the OPA1688 evaluation module (EVM). Included are the performance specifications, set-up procedure, modifications, measured data, printed circuit board (PCB) layout, schematic, and bill of materials (BOM) of the OPA1688EVM.

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Trademarks

SoundPlus is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

1 Introduction

The OPA1688 is a low distortion, high-drive SoundPlus™ audio operational amplifier. For a full list of electrical characteristics of the OPA1688, refer to the OPA1688 product data sheet (SBOS724).

2 Performance Specification Summary

A summary of the OPA1688EVM performance specifications is provided in Table 1. Specifications are given for a supply voltage of V_s = ±5 V and at an ambient temperature of 25°C, unless otherwise noted.

Table 1. OPA1688EVM Measured Performance Summary

Specification	Test Conditions	Measured Performance
Total Harmonic Distortion Plus Noise (THD+N) at 1 kHz	V_{IN} = 1 V_{rms}, Load = 32 Ω, Measurement Bandwidth = 90 kHz	–105.6 dB
Second Harmonic	V_{IN} = 1 V_{rms}, Load = 32 Ω, F_{IN} = 1 kHz	–140 dBV
	V_{IN} = 1 V_{rms}, Load = 128 Ω, F_{IN} = 1 kHz	–136 dBV
	V_{IN} = 1 V_{rms}, Load = 250 Ω, F_{IN} = 1 kHz	–135.5 dBV

3 Modifications

This EVM is designed to provide access to the features of and measure the performance of the OPA1688. Modifications of the OPA1688EVM can be made and include; adjusting the gain, phase shift, and cut-off frequency. The schematic of the OPA1688EVM is displayed in Figure 1. For a full schematic of the OPA1688EVM, see Figure 10.

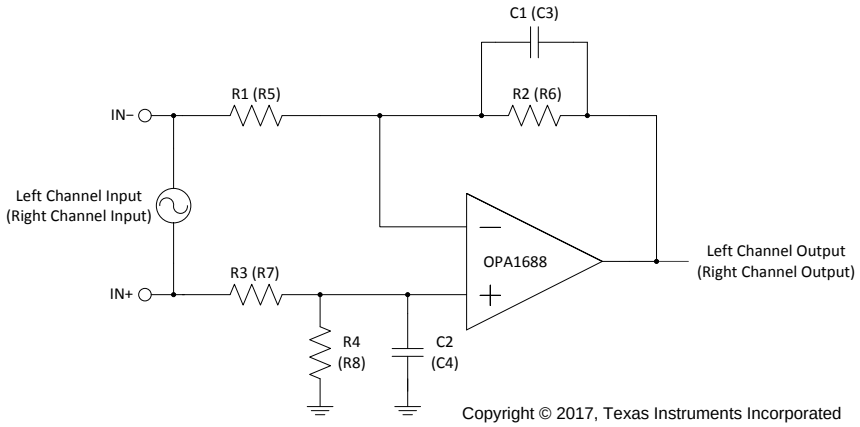

Figure 1. OPA1688EVM Schematic

3.1 Gain

Equation 1 and Equation 2 display the transfer function of the circuit shown in Figure 1.

$$V_{\text{Left Channel Output}} = \frac{R_4}{R_3 + R_4} \times \left(1 + \frac{R_2}{R_1}\right) \times (\text{IN}+) - \left(\frac{R_2}{R_1} \times (\text{IN}-)\right) \quad (1)$$

$$V_{\text{Right Channel Output}} = \frac{R_8}{R_7 + R_8} \times \left(1 + \frac{R_6}{R_5}\right) \times (\text{IN}+) - \left(\frac{R_6}{R5} \times (\text{IN}-)\right) \quad (2)$$

Most applications require the left and right channel to be balanced. Balancing the outputs is accomplished by setting R2 = R4 = R6 = R8 and R1 = R3 = R5 = R7. This simplifies Equation 1 and Equation 2 into Equation 3.

$$V_{\text{Left Channel Output}} = V_{\text{Right Channel Output}} = \frac{R_2}{R_1} \times \left((\text{IN}+) - (\text{IN}-)\right) \quad (3)$$

If the channels require unbalanced gain, the gain of each channel can be calculated using Equation 4 and Equation 5.

$$\text{Gain}_{\text{Left Channel}} = \frac{R_2}{R_1}$$

given

- $R_2 = R_4$ and $R_1 = R_3$ (4)

$$\text{Gain}_{\text{Right Channel}} = \frac{R_6}{R_5}$$

given

- $R_6 = R_8$ and $R_5 = R_7$ (5)

3.2 Cutoff Frequency

This EVM provides the ability to filter the output of the OPA1688. The cutoff frequency of the filter can be calculated using Equation 6 and Equation 7.

$$f_{c-\text{left}} = \frac{1}{2\pi \times R_2 \times C_1}$$

given

- $R_2 = R_4$, $R_1 = R_3$, and $C_1 = C_2$ (6)

$$f_{c-right} = \frac{1}{2\pi \times R_6 \times C_3}$$

given

- $R_6 = R_8$, $R_5 = R_7$, and $C_3 = C_4$ (7)

3.3 Phase Shift

The phase shift, θ, is calculated using Equation 8.

$$\Theta = -\tan^{-1}\left(\frac{f}{f_c}\right)$$

where

- f is the maximum frequency of interest within the audio band
- f_c is the cutoff frequency discussed in Section 3.2 (8)

4 Test Setup and Results

This section describes how to properly connect, set up, and use the OPA1688EVM. This section also includes measured data of the OPA1688EVM to display typical performance of the OPA1688EVM.

Measurements include:

- *THD+N vs. Frequency* for a 32-, 128-, and 250-Ω load
- *THD+N vs. Amplitude* for a 32-, 128-, and 250-Ω load
- *Fast-Fourier Transform* (FFT) for a 32-, 128-, and 250-Ω load

The *THD+N vs. Frequency*, *THD+N vs. Amplitude*, and FFT measurements were taken using an *Audio Precision* APx555. All measurements were taken using ±5-V supplies at an ambient temperature of 25 °C, unless otherwise noted.

4.1 Power Supply Connections

The power supply connections for the OPA1688EVM are provided through the use of connector J4 located at the top of the EVM. The positive power supply connection is labeled VCC, the negative power supply connection is labeled VEE, and the ground connection is labeled GND. To connect power to the OPA1688EVM, insert wires into each terminal of J4 and then tighten the screws to make the connection. Figure 2 displays the proper way to connect power to the OPA1688EVM. For the minimum and maximum supply voltages of the OPA1688EVM, refer to the OPA1688 product data sheet (SBOS724).

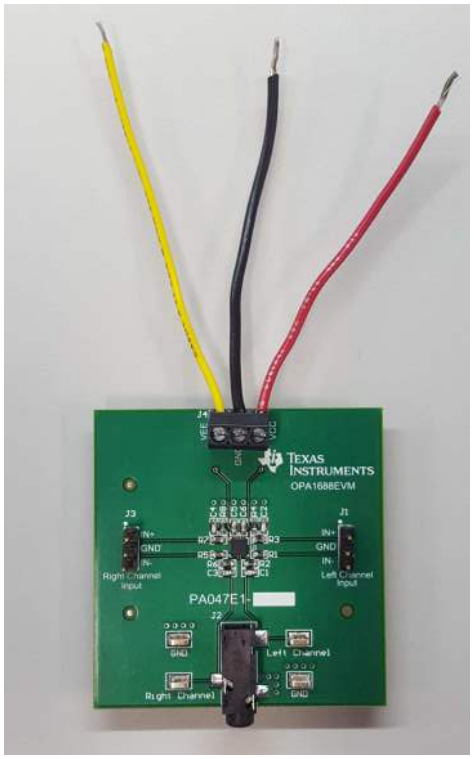

Figure 2. Power Supply Connections

4.2 Input Connections

Signals for the left channel and right channel input are applied to the OPA1688EVM through connectors J1 and J3, respectively. Connect wires to J1 and J3 to provide an input signal from a source such as an audio analyzer or audio digital-to-analog converter (DAC). The positive input from the source connects to the pin labeled IN+ (upper pin), the negative input from the source connects to the pin labeled IN– (lower pin), and the ground connection from the source connects to the center pin of J1 and J3, labeled GND.

4.3 Output Connections

Output connections are provided through the use of the audio jack, J2, and two test points labeled *Left Channel* and *Right Channel* near the bottom of the OPA1688EVM. The audio jack provides a way to connect headphones or a resistive load to the output of the OPA1688 while testing the performance of the OPA1688EVM. Test points labeled *Left Channel* and *Right Channel* provide a connection to measure the performance of the left and right channels of the OPA1688EVM.

4.4 THD+N vs. Frequency

For all *THD+N vs. Frequency* measurements, the input signal frequency was swept from 20 Hz to 20 kHz and had an amplitude of 1 V_{rms} on the output of the OPA1688 with the measurement bandwidth of the *Audio Precision* set to 90 kHz. A small variation in the THD+N performance between amplifier channels is normal. Figure 3 shows the *THD+N vs. Frequency* for a 32-, 128-, and 250-Ω load.

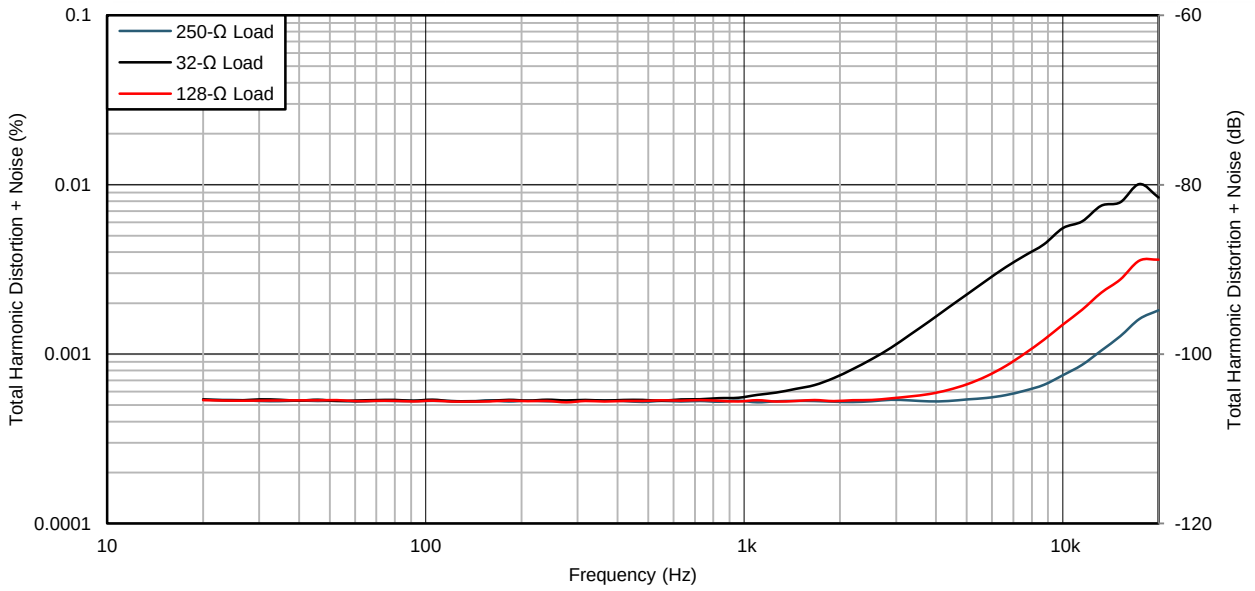

Figure 3. THD+N vs. Frequency for a 32-, 128-, and 250-Ω Load

4.5 THD+N vs. Amplitude

For all *THD+N vs. Amplitude* measurements, the output amplitude was swept from 10 mV_{rms} to 3 V_{rms} at a frequency of 1 kHz. The measurement bandwidth of the *Audio Precision* was set to 22 kHz.

NOTE: Power supply voltages larger than ±5 V may cause the output of the OPA1688 to clip at a lower output amplitude than what is shown in the measurements because the increased power dissipation in the amplifier will trigger the thermal protection circuitry.

Figure 4 shows the *THD+N vs. Amplitude* for a 32-, 128-, and 250-Ω load.

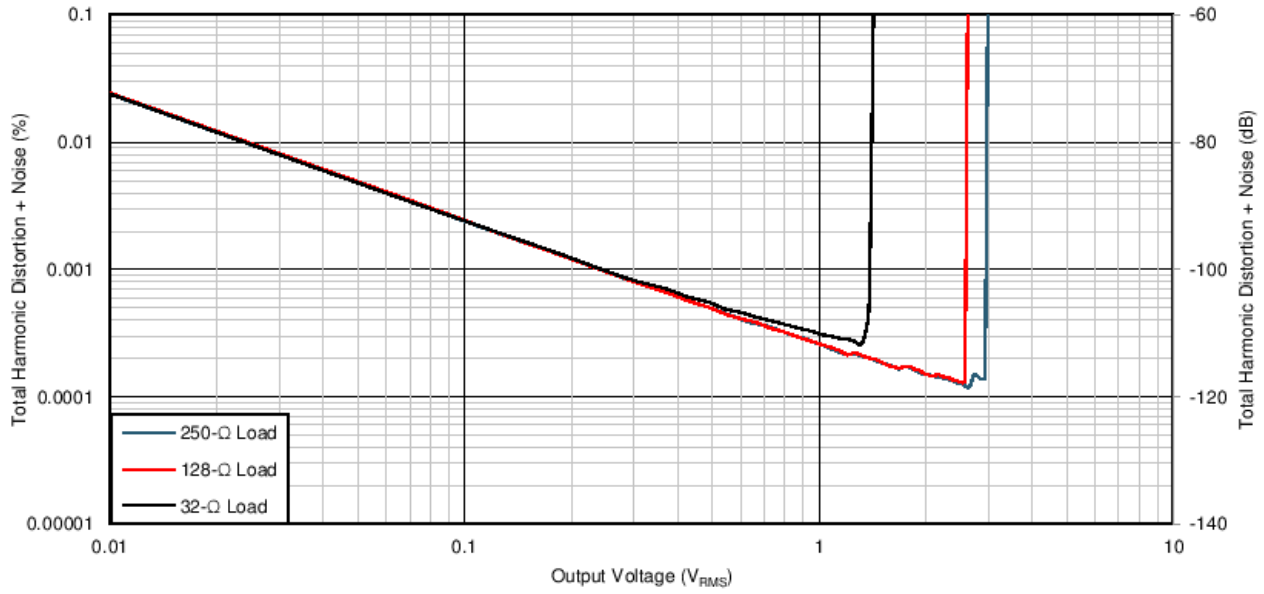

Figure 4. THD+N vs. Amplitude for a 32-, 128-, and 250-Ω Load

4.6 Fast Fourier Transforms

For all FFT measurements, a frequency of 1 kHz and amplitude of 1 V_{rms} on the output was used. The 1 V_{rms} fundamental corresponds to 0 dBV in all FFT measurements. Figure 5 shows an FFT with a 32-Ω load.

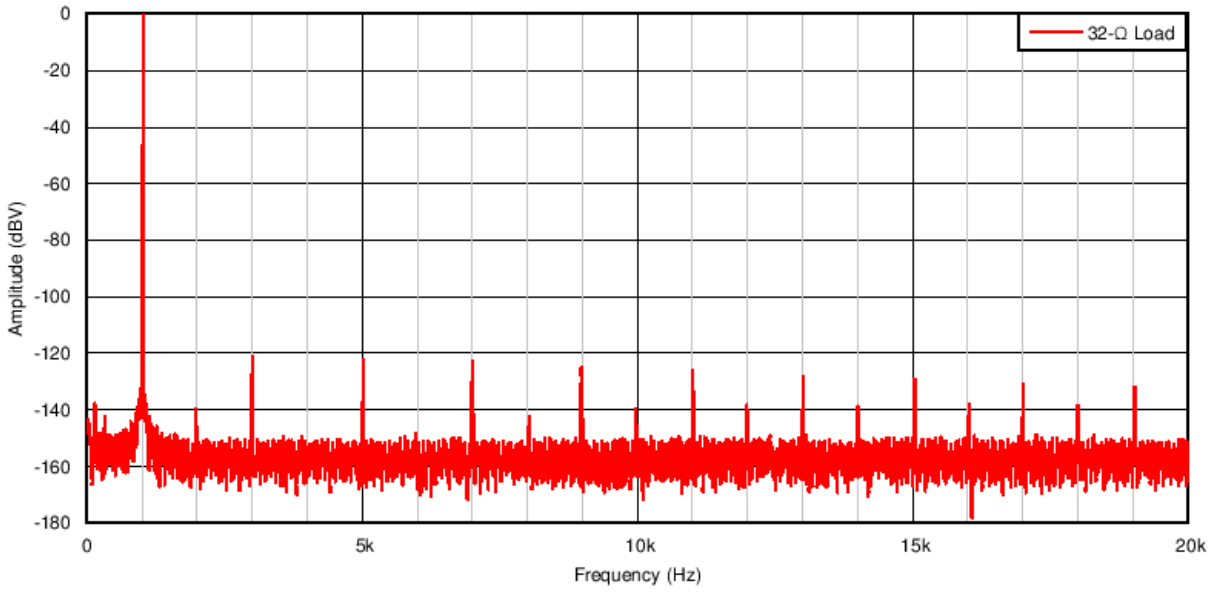

Figure 5. FFT With a 32-Ω Load

Figure 6 shows an FFT with a 128-Ω load.

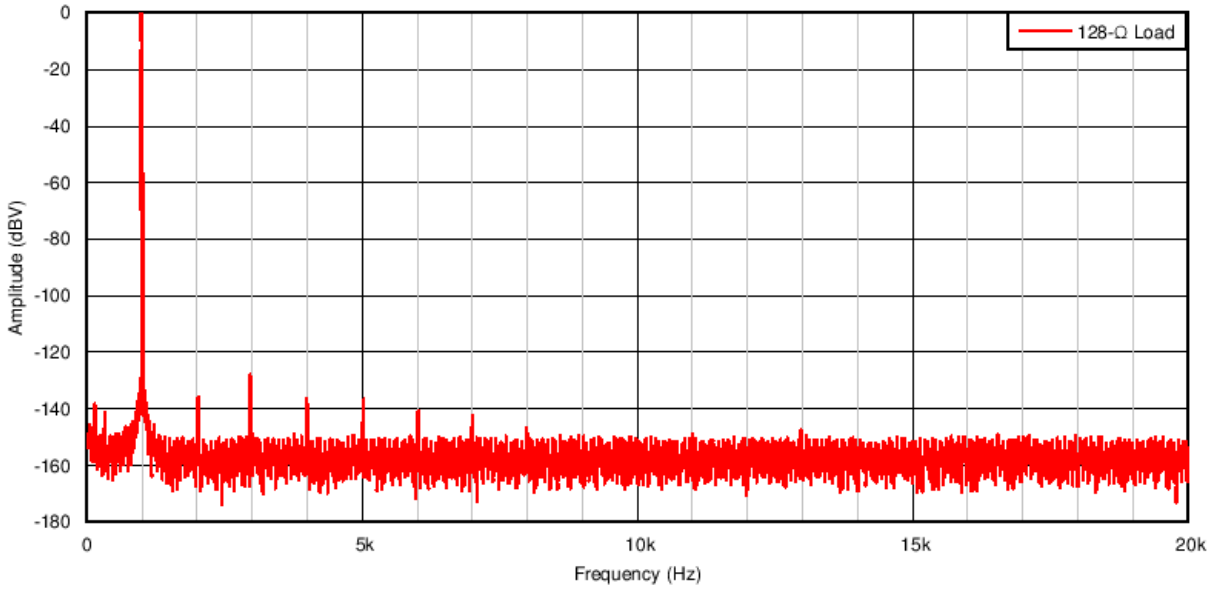

Figure 6. FFT With a 128-Ω Load

Figure 7 shows an FFT with a 250-Ω load.

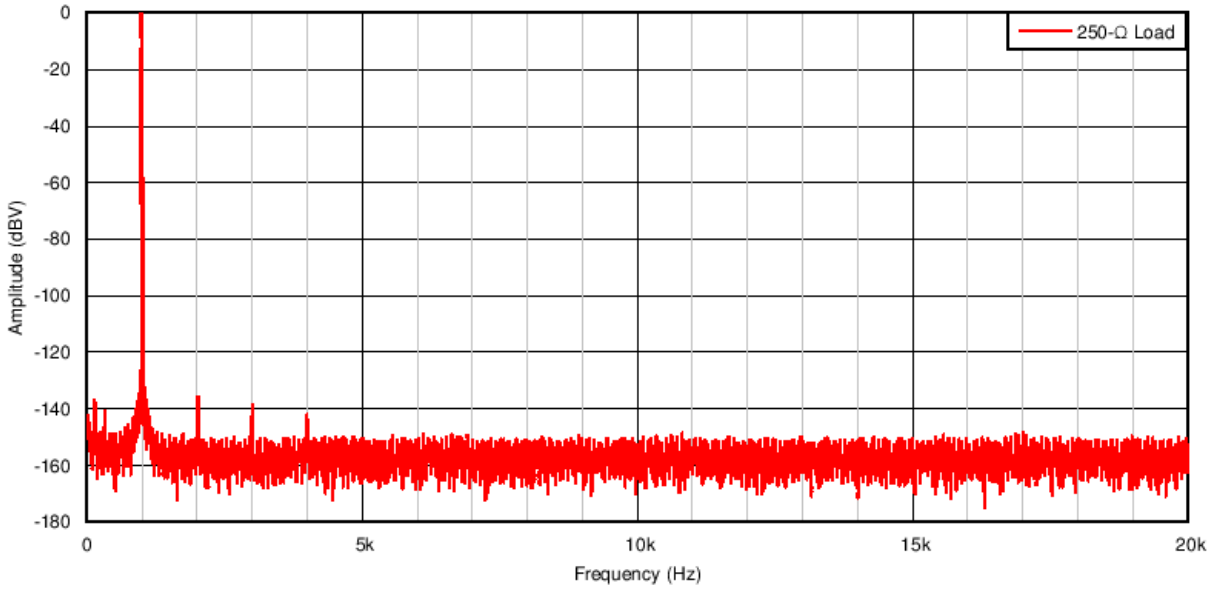

Figure 7. FFT With a 250-Ω Load

5 Board Layout

This section provides a description of the OPA1688EVM board layout and includes layer illustrations.

5.1 Layout

The board layout for the OPA1688EVM is shown in Figure 8 and Figure 9. The top layer consists of all signal traces and is poured with a solid ground plane. The traces of the positive input (IN+) and negative input (IN–) for both the left and right channel were kept as balanced as possible to eliminate any impedance mismatch due to trace impedance. The decoupling capacitors, C5 and C6, were positioned as close as possible to the power supply pins of the device. Vias were placed at the ground connection of every component to provide a low impedance path on the bottom layer back to the supply ground. It is important to provide a very clean, low impedance return path for the audio jack (J2); therefore, multiple stitching vias were placed around the ground connection of the audio jack. Also, the connection to the thermal pad of the OPA1688 on the bottom layer was kept to a minimum to ensure currents from the audio jack ground to the supply ground have a clean return path. Note that due to the size of the copper pour for the thermal pad on the bottom layer, the thermal performance specified in the OPA1688 data sheet may not be met on the OPA1688EVM. Refer to the application report, *PowerPAD™ Thermally Enhanced Package* (SLMA002), for more information.

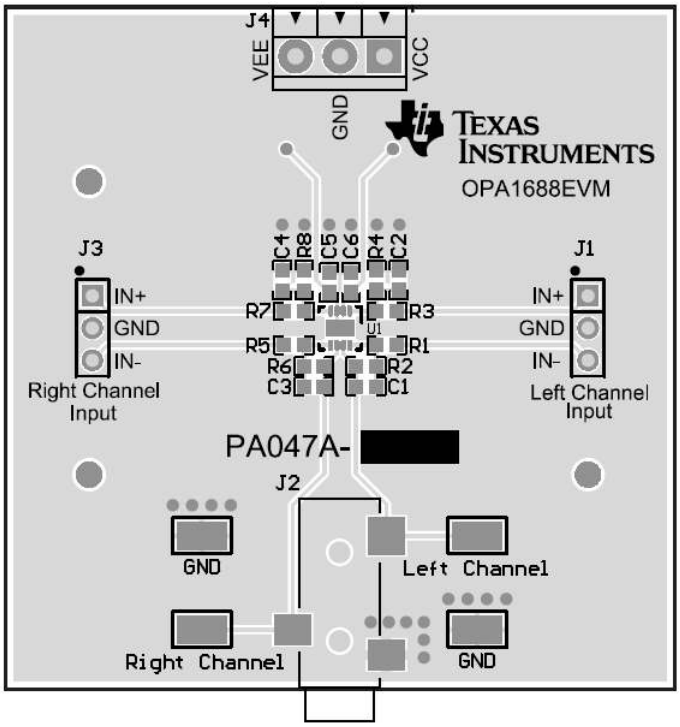

Figure 8. Top Layer PCB Layout

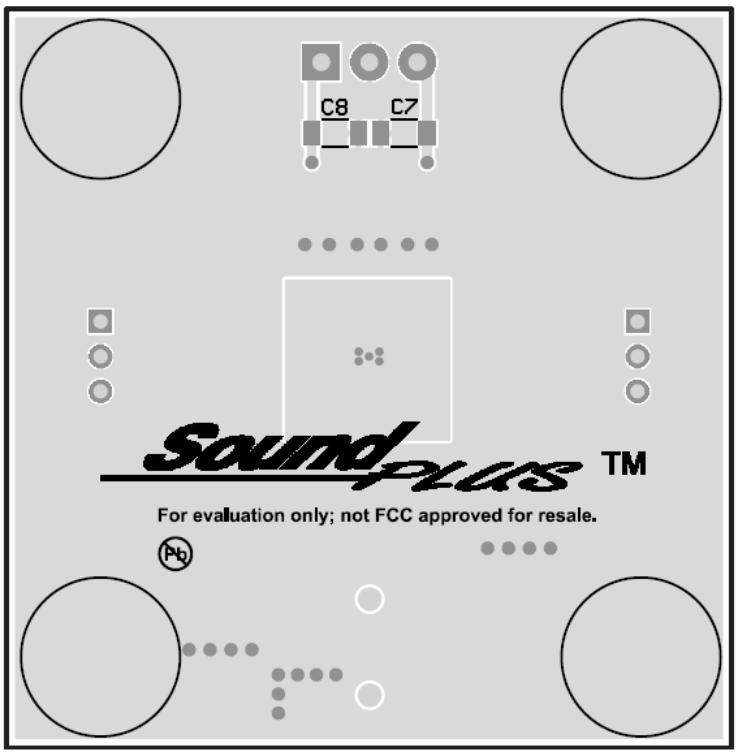

Figure 9. Bottom Layer PCB Layout

6 Schematic, Bill of Materials, and Reference

This section contains the schematics, the bill of materials, and a list of reference documents.

6.1 Schematic

Figure 10 illustrates the EVM schematics.

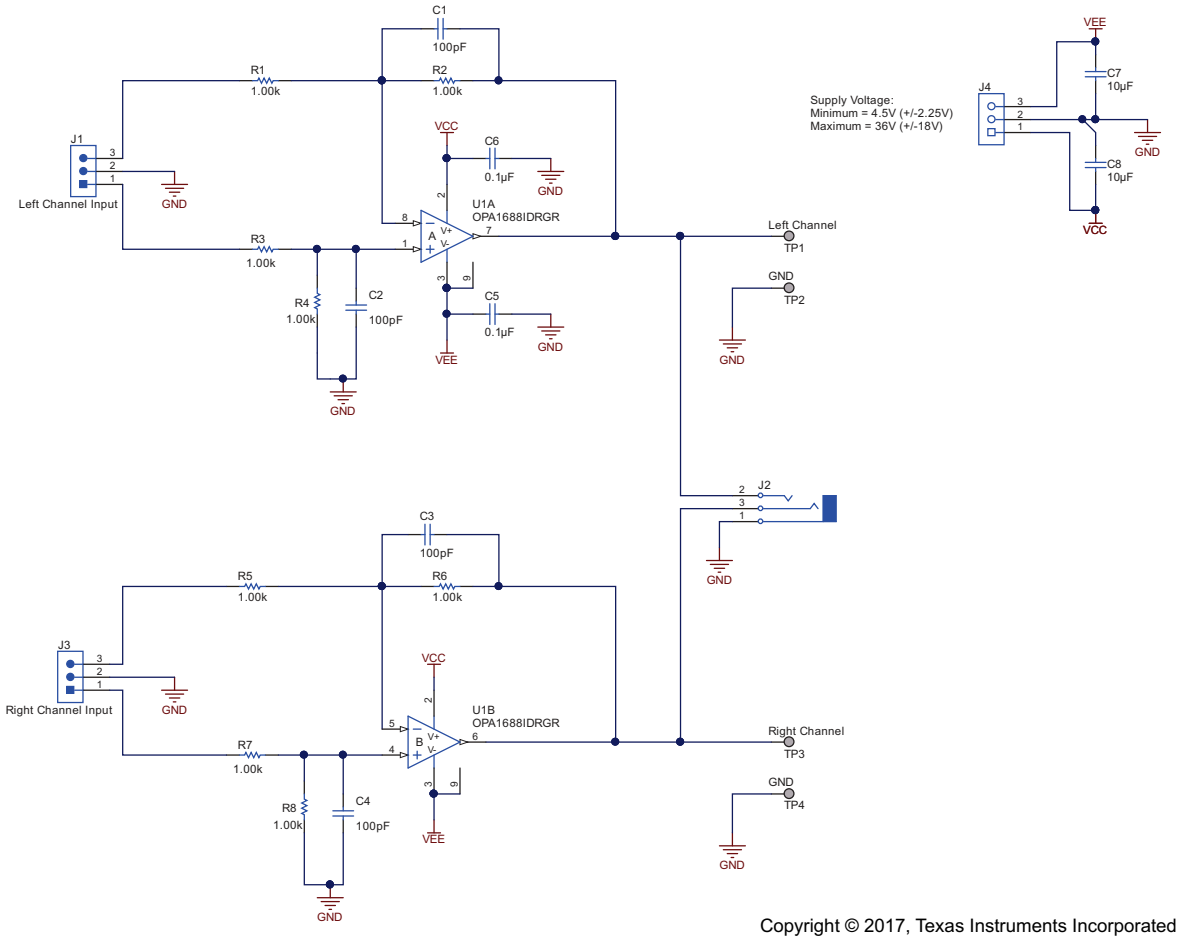

Figure 10. OPA1688EVM Schematic

6.2 Bill of Materials

Table 2 lists the EVM BOM.

Table 2. OPA1688EVM Bill of Materials

Designator	Qty	Value	Description	Package Reference	Part Number	Manufacturer
PCB	1		Printed-Circuit Board		PA047	Any
C1, C2, C3, C4	4	100pF	CAP, CERM, 100pF, 50V, +/-1%, C0G/NP0, 0603	0603	06035A101FAT2A	AVX
C5, C6	2	0.1uF	CAP, CERM, 0.1uF, 16V, +/-5%, X7R, 0603	0603	0603YC104JAT2A	AVX
C7, C8	2	10uF	CAP, CERM, 10uF, 50V, +/-10%, X5R, 1206_190	1206_190	CGA5L3X5R1H106K160AB	TDK
H1, H2, H3, H4	4		Bumpon, Hemisphere, 0.44 X 0.20, Clear	Transparent Bumpon	SJ-5303 (CLEAR)	3M
J1, J3	2		Header, 100mil, 3x1, Tin, TH	Header, 3 PIN, 100mil, Tin	PEC03SAAN	Sullins Connector Solutions
J2	1		Audio Jack, 3.5mm, Stereo, R/A, SMT	Audio Jack SMD	SJ-3523-SMT	CUI Inc,
J4	1		Terminal Block, 3.5mm Pitch, 3x1, TH	10.5x8.2x6.5mm	ED555/3DS	On-Shore Technology
J5	1		Header, 100mil, 2x1, Tin, TH	Header 2x1	90120-0122	Molex
R1, R2, R3, R4, R5, R6, R7, R8	8	1.00k	RES, 1.00 k, 0.1%, 0.1 W, 0603	0603	RT0603BRB071KL	Yageo America
TP1, TP2, TP3, TP4	4		Test Point, Miniature, SMT	Test Point, Miniature, SMT	5019	Keystone
U1	1		SoundPlus 36-V, Single-Supply, 10-MHz, Rail-to-Rail Output Operational Amplifiers, DRG0008A (WSON-8	DRG0008A	OPA1688IDRGT	Texas Instruments

6.3 Reference

- *OPA1688 SoundPlus™ Audio Operational Amplifier* data sheet (SBOS724)
- *PowerPAD™ Thermally Enhanced Package* (SLMA002)

STANDARD TERMS FOR EVALUATION MODULES

1. *Delivery:* TI delivers TI evaluation boards, kits, or modules, including any accompanying demonstration software, components, and/or documentation which may be provided together or separately (collectively, an “EVM” or “EVMs”) to the User (“User”) in accordance with the terms set forth herein. User's acceptance of the EVM is expressly subject to the following terms.

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   1.2 EVMs are not intended for consumer or household use. EVMs may not be sold, sublicensed, leased, rented, loaned, assigned, or otherwise distributed for commercial purposes by Users, in whole or in part, or used in any finished product or production system.

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   2.1 These terms do not apply to Software. The warranty, if any, for Software is covered in the applicable Software License Agreement.

   2.2 TI warrants that the TI EVM will conform to TI's published specifications for ninety (90) days after the date TI delivers such EVM to User. Notwithstanding the foregoing, TI shall not be liable for a nonconforming EVM if (a) the nonconformity was caused by neglect, misuse or mistreatment by an entity other than TI, including improper installation or testing, or for any EVMs that have been altered or modified in any way by an entity other than TI, (b) the nonconformity resulted from User's design, specifications or instructions for such EVMs or improper system design, or (c) User has not paid on time. Testing and other quality control techniques are used to the extent TI deems necessary. TI does not test all parameters of each EVM. User's claims against TI under this Section 2 are void if User fails to notify TI of any apparent defects in the EVMs within ten (10) business days after delivery, or of any hidden defects with ten (10) business days after the defect has been detected.

   2.3 TI's sole liability shall be at its option to repair or replace EVMs that fail to conform to the warranty set forth above, or credit User's account for such EVM. TI's liability under this warranty shall be limited to EVMs that are returned during the warranty period to the address designated by TI and that are determined by TI not to conform to such warranty. If TI elects to repair or replace such EVM, TI shall have a reasonable time to repair such EVM or provide replacements. Repaired EVMs shall be warranted for the remainder of the original warranty period. Replaced EVMs shall be warranted for a new full ninety (90) day warranty period.

3 *Regulatory Notices:*

   3.1 *United States*

      3.1.1 *Notice applicable to EVMs not FCC-Approved:*

      FCC NOTICE: This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

      3.1.2 *For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:*

      CAUTION

      This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

      Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

      FCC Interference Statement for Class A EVM devices

      NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- *Reorient or relocate the receiving antenna.*
- *Increase the separation between the equipment and receiver.*
- *Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.*
- *Consult the dealer or an experienced radio/TV technician for help.*

3.2 *Canada*

3.2.1 *For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210 or RSS-247*

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSSs. Operation is subject to the following two conditions:

(1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur

3.3 *Japan*

3.3.1 *Notice for EVMs delivered in Japan:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。
http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page

3.3.2 *Notice for Users of EVMs Considered "Radio Frequency Products" in Japan:* EVMs entering Japan may not be certified by TI as conforming to Technical Regulations of Radio Law of Japan.

If User uses EVMs in Japan, not certified to Technical Regulations of Radio Law of Japan, User is required to follow the instructions set forth by Radio Law of Japan, which includes, but is not limited to, the instructions below with respect to EVMs (which for the avoidance of doubt are stated strictly for convenience and should be verified by User):

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry's Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

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3.4 *European Union*

3.4.1 *For EVMs subject to EU Directive 2014/30/EU (Electromagnetic Compatibility Directive)*:

This is a class A product intended for use in environments other than domestic environments that are connected to a low-voltage power-supply network that supplies buildings used for domestic purposes. In a domestic environment this product may cause radio interference in which case the user may be required to take adequate measures.

4 *EVM Use Restrictions and Warnings:*

4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.

4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.

4.3 *Safety-Related Warnings and Restrictions:*

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