Analog Crossover Audio Plug-In Module

The TI Analog Crossover Audio Plug-in Module (SIDEGIG-XOVEREVM) turns TI Audio Class-D amplifier EVM's into a high quality, two-way speaker amplifier. The plug-in module makes it easy to remove the large and expensive passive crossover found in passive loudspeakers and create a bi-amped, two-way system with improved efficiency and reduced size. The board features a tunable active crossover with a high-pass filter, low-pass filter, baffle step, and delay to create two audio output signals for a tweeter and woofer. There are many advantages of designing active speakers including well-matched and well-tuned audio. This audio plug-in module plugs into an analog input Class-D audio evaluation module (EVM) with an audio interface board (AIB) connector. This document provides information including setup, operation, schematics, bill of materials (BOM) and printed-circuit board (PCB) layout. For questions and support, visit the E2E forums: www.e2e.ti.com.

The main contents of this document are:

- Hardware description
- Hardware implementations
- Design documents

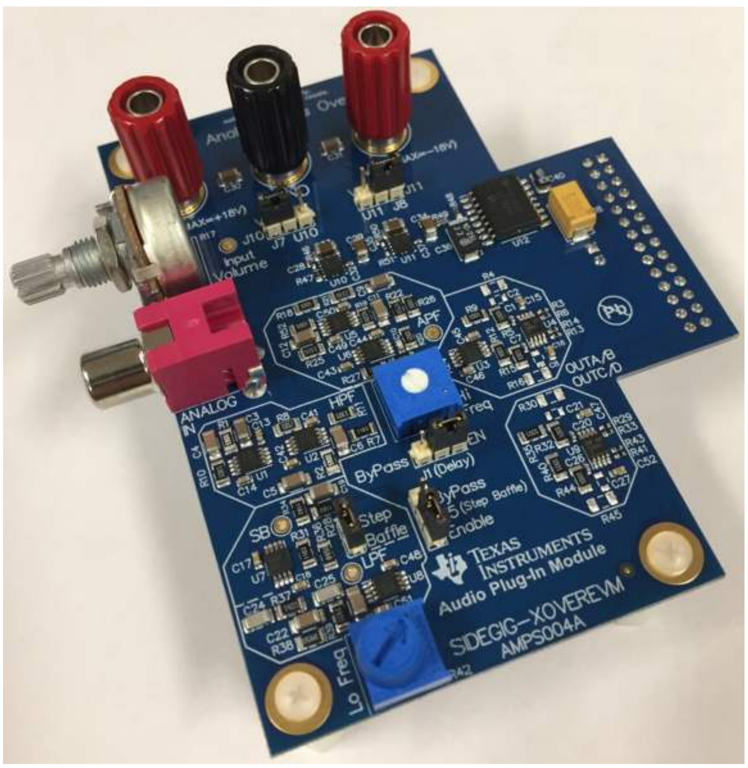

Figure 1. Analog Crossover Audio Plug-In Module

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1 Hardware Overview

The Analog Crossover Plug-in Module allows an audio Class-D amplifier to drive separate bass and tweeter channels from a single RCA input source.

The board includes an input volume control, high-pass filter, low-pass filter with optional baffle step compensation, optional all-pass filter for delay adjustment, as well as standard banana plug jacks for an external power supply (see Figure 2). A single RCA jack is used for input to the board.

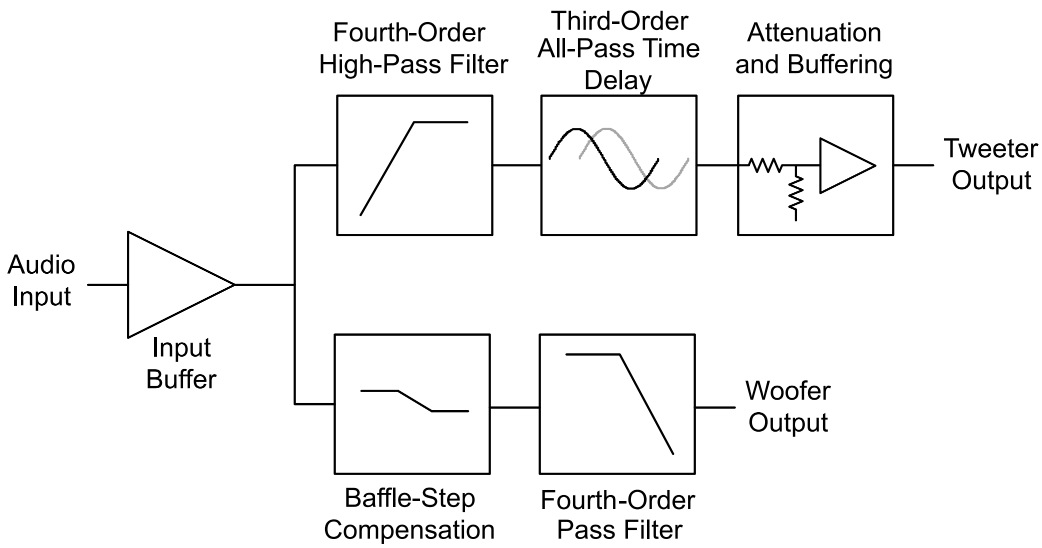

Figure 2. Analog Crossover Module Block Diagram

1.1 Features

The analog crossover module includes the following features:

- Compatible with the TI Audio Plug-in Module Ecosystem
- Standard RCA input jack
- Self-powered when connected to an audio Class-D EVM
- Differential outputs for both high and low channels which can directly drive the audio Class-D EVM
- Standard banana plug jacks for using an optional, external dual-rail supply for the board
- Potentiometers for input volume control as well as separate high- and low-channel volume control
- Fourth-order active high-pass filter
- Optional fourth-order active low-pass filter
- Optional baffle-step compensation
- Optional all-pass filter for delay adjustment
- Supports two-channel bridge-tied load (BTL) Class-D amplifier output

1.2 Class-D EVM Compatibility

The Analog Crossover Plug-in Module is compatible with analog input Class-D EVMs designed with the audio interface board (AIB) connector. See the SIDEGIG-XOVER tools folder on TI.com for a list of compatible Class-D EVMs.

Table 1. Plug-in Module Compatibility

PLUG-IN MODULE OUTPUT TYPE	CLASS-D EVM INPUT TYPE	SUPPORTED CLASS-D SPEAKER CONFIGURATIONS
2x differential analog	Analog	2x BTL

1.2.1 Audio Plug-In Module Output Types

The Analog Crossover Plug-in Module drives two differential analog outputs.

1.2.2 Class-D EVM Input Type

The Analog Crossover Plug-in Module is only compatible with analog input Class-D EVMs with the AIB connector.

1.2.3 Supported Class-D Speaker Configurations

Configure the connected Class-D EVM as a stereo BTL output because the Analog Crossover Plug-in Module has two differential outputs (see Figure 3).

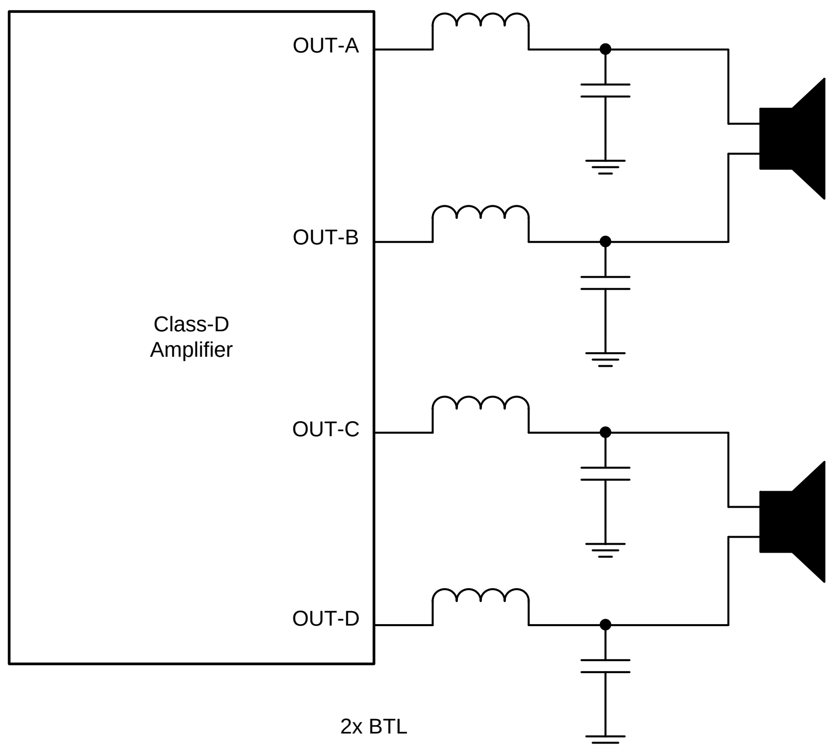

Figure 3. Class-D Output Drawings

NOTE: Consult the Class-D EVM user's guide for proper Class-D EVM configuration.

1.3 AIB Pinout

This section shows the AIB connector pinout used by the Analog Crossover Audio Plug-in Module (see Figure 4). Any pin names not listed in Table 2 are unused by this plug-in module.

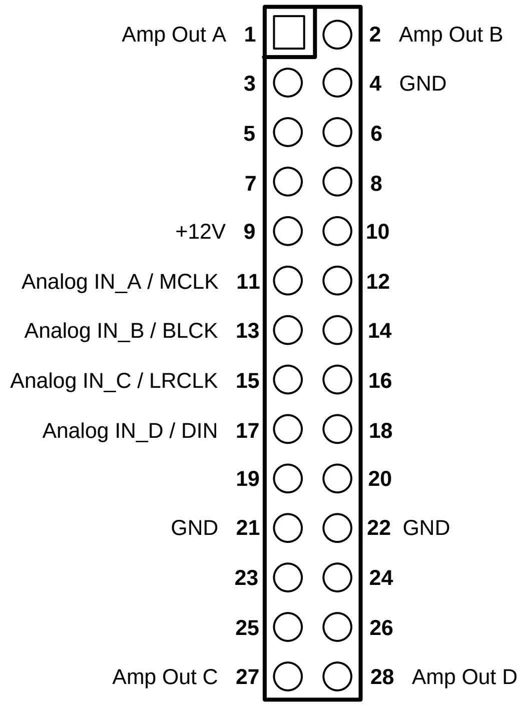

Figure 4. AIB Connector Pinout

Table 2. AIB Connector Pin Descriptions

PIN NUMBER	FUNCTION	DESCRIPTION	AUDIO EVM INPUT/OUTPUT	AUDIO PLUG-IN MODULE INPUT/OUTPUT
1	AMP-INA	Speaker-level output from audio Class-D EVM (single-ended (SE) or one side of BTL); used for post-filter feedback	O	I
2	AMP-INB	Speaker-level output from audio Class-D EVM (SE or one side of BTL); used for post-filter feedback	O	I
4	GND	Ground reference between audio plug-in module and audio Class-D EVM	—	—
9	12V	12-V supply from EVM; used for powering audio plug-in module	O	I
11	Analog IN_A	Positive (+) analog input Class-D EVM (IN_A and IN_B are driven differentially by the Analog Crossover Plug-in Module)	I	O
13	Analog IN_B	Negative (–) analog input for high-frequency channel to audio Class-D EVM (IN_A and IN_B are driven differentially by the Analog Crossover Plug-in Module)	I	O
15	Analog IN_C	Postive (+) analog input for low-frequency channel to audio Class-D EVM (IN_C and IN_D are driven differentially by the Analog Crossover Plug-in Module)	I	O
17	Analog IN_D	Negative (–) analog input for low-frequency channel to audio Class-D EVM (IN_C and IN_D are driven differentially by the Analog Crossover Plug-in Module)	I	O

Table 2. AIB Connector Pin Descriptions (continued)

PIN NUMBER	FUNCTION	DESCRIPTION	AUDIO EVM INPUT/OUTPUT	AUDIO PLUG-IN MODULE INPUT/OUTPUT
21	GND	Ground reference between audio plug-in module and audio Class-D EVM	—	—
22	GND	Ground reference between audio plug-in module and audio Class-D EVM	—	—
27	AMP-INC	Speaker-level output from audio Class-D EVM (SE or one side of BTL); used for post-filter feedback	O	I
28	AMP-IND	Speaker-level output from audio Class-D EVM (SE or one side of BTL); used for post-filter feedback	O	I

2 Analog Crossover Plug-In Module Setup

This section describes the setup and use of the Analog Crossover Audio Plug-in Module.

2.1 Preparation and First Steps for Setup

The Analog Crossover Audio Plug-in Module plugs into an analog input audio Class-D EVM using the AIB connector.

To plug the board in, simply align the AIB connector on the Analog Crossover Plug-in Module and the audio EVM and press into place. No additional setup is required. The plug-in module automatically powers up when the Class-D EVM is powered.

1. Configure the Class-D amplifier EVM in BTL output mode to support the analog crossover module.
2. While the Class-D amplifier EVM is not powered, connect the analog crossover module to the AIB connector (see Figure 5). Take care not to misalign the connector, otherwise damage to the plug-in module or Class-D EVM can occur.
3. Connect the EVM A/AB BTL channel to a tweeter or mid-range speaker channel.
4. Connect the EVM C/CD BTL channel to a bass speaker channel.
5. Make sure that J10 (“VCC SEL”) is connected to the U10 pin and that J11 (“VEE SEL”) is connected to the U11 pin. Power the Class-D EVM and the plug-in module is automatically powered. The plug-in module provides its own +10-V and –10-V supply rails. However, if the designer wishes to increase the supply rails with an external supply to increase the maximum output available from the plug-in module, follow steps 5a through 5f; otherwise, proceed to step 6.
    1. Connect the ground of the external supply to the banana jack labeled “GND” on the plug-in module.
    2. Connect the positive supply line of the external supply to the banana jack labeled “Vcc” on the plug-in module. Note the absolute maximum voltage of 18 V on this pin. Do not exceed this level; otherwise, damage may occur to the plug-in module.
    3. Connect the negative supply line of the external supply to the banana jack labeled “Vee” on the plug-in module. Note the absolute minimum voltage of –18 V on this pin. Do not exceed this level; otherwise, damage may occur to the plug-in module.
    4. Move the jumper on VCC SEL to the J7 pin.
    5. Move the jumper on VEE SEL to the J8 pin.
    6. Turn on the external power supply.
6. Plug in a standard RCA cable into the plug-in module.
7. Adjust the potentiometers for each channel to set the overall desired volume.

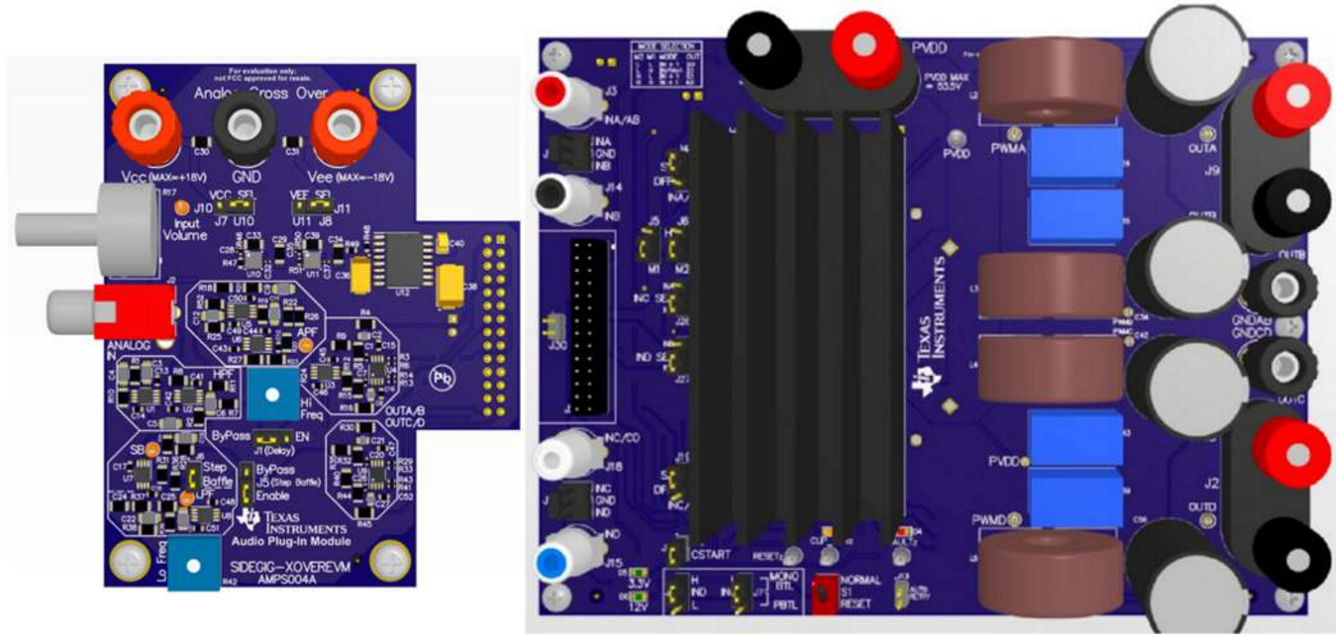

Figure 5. Connecting Audio Crossover Plug-in Module

2.2 Analog Crossover Plug-In Module Controls and Circuits

This subsection describes the controls and use of the Analog Crossover Audio Plug-in Module. Figure 6 shows the Analog Crossover Plug-in Module controls.

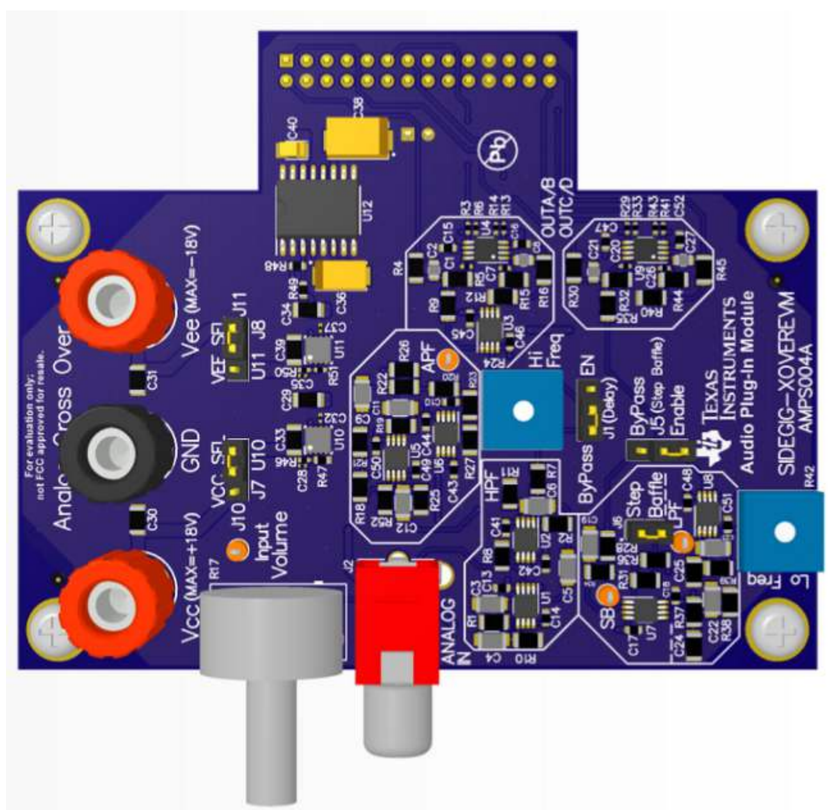

Figure 6. Analog Crossover Plug-in Module Controls

2.2.1 Low-Pass Filter

The optional fourth-order low-pass filter attenuates all signals with frequencies above a certain cutoff, which is determined by the component values. The low-pass filter circuit also includes R42 for its own separate volume control. Connect the jumper on J5 to "Bypass" instead of "Enable" to bypass the low-pass filter together with the BSC circuit.

Figure 7 shows the schematic of the low-pass filter.

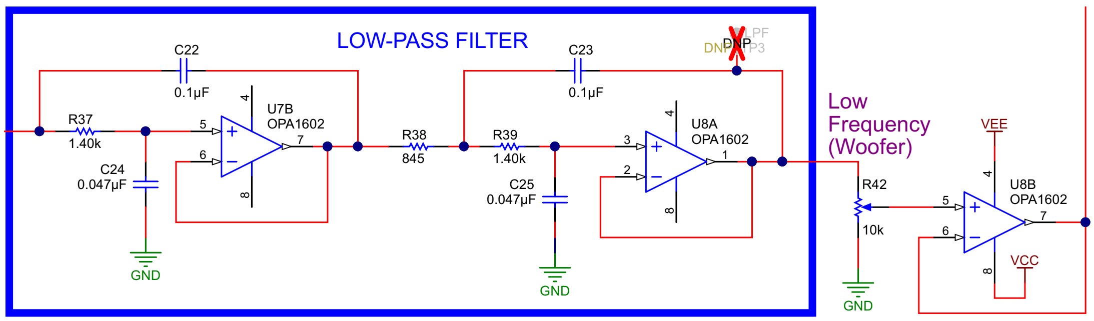

Figure 7. Low-Pass Filter Schematic

Tthe low-pass filter circuit comprises two second-order Sallen-Key low-pass filters (U7B and U8A), which combine together to produce a fourth-order low-pass filter. R36 = R38, R37 = R39, C22 = C23, and C24 = C25; therefore, the transfer function for the low-pass filter can be written as follows in Equation 1.

$$H(s) = \left(\frac{1}{1 + sC_{24}\left(R_{36} + R_{37}\right) + s^2 R_{36} R_{37} C_{22} C_{24}} \right)^2 \tag{1}$$

The following Equation 2 gives the cutoff frequency for the low-pass filter.

$$f_c = \frac{1}{2\pi\sqrt{R_{36} R_{37} C_{22} C_{24}}} \tag{2}$$

When using the component values as shown in the Figure 7 schematic, the low-pass filter has a cutoff frequency of approximately 2.1 kHz. As is the case with the high-pass filter, change the corresponding components on each filter if a change to the cutoff frequency is desired. So, if changing the value of R37, then be sure to also change R39 to the same value.

Just like the previous high-pass filter, each of the second-order filters in the low-pass filter circuit has a Q factor, which determines how much peaking occurs in the frequency response of the circuit around the cutoff frequency. As before, the value of the Q factor must be kept below 1 and roughly above 0.5, but should preferably be around 0.7. The current value of the Q factor for each second-order low-pass filter is 0.707. The following Equation 3 gives the Q factor.

$$Q = \frac{\sqrt{R_{37} C_{22} C_{24}}}{\left(C_{22} + C_{24}\right)\sqrt{R_{36}}} \tag{3}$$

Figure 8 shows the frequency response of the low-pass filter on the plug-in module.

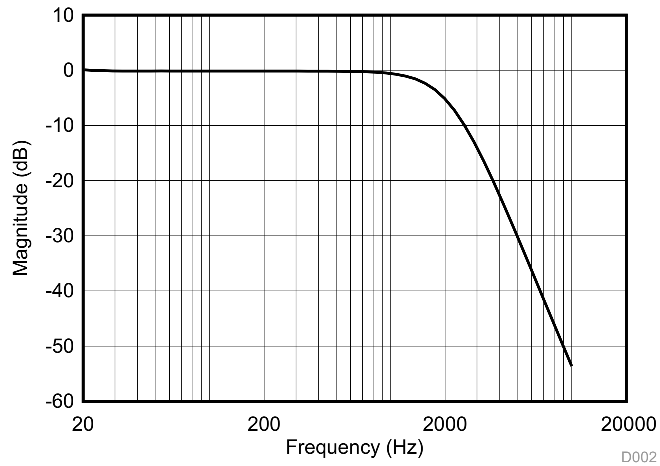

Figure 8. Low-Pass Filter Frequency Response

Table 3 shows some of the suggested component values for different cutoff frequencies for the low-pass filter.

Table 3. Component Values for Different Low-Pass Filter Cutoff Frequencies

APPROXIMATE CUTOFF FREQUENCY	HIGH-PASS FILTER COMPONENT VALUES			
	R36 AND R38	R37 AND R39	C22 AND C23	Cx4 AND C25
300 Hz	6.01 kΩ	10.00 kΩ	100 nF	47 nF
600 Hz	3.01 kΩ	4.99 kΩ	100 nF	47 nF
900 Hz	2.00 kΩ	3.32 kΩ	100 nF	47 nF
1200 Hz	1.50 kΩ	2.49 kΩ	100 nF	47 nF
1500 Hz	1.21 kΩ	2.00 kΩ	100 nF	47 nF
1800 Hz	1.00 Ω	1.65 kΩ	100 nF	47 nF
2100 Hz	866 Ω	1.43 kΩ	100 nF	47 nF

2.2.2 Baffle-Step Compensation

The optional baffle-step compensation (BSC) circuit allows correction of the frequency response of the woofer. Due to the physical construction of loud speakers, high frequencies are directed forward to the listener, while low frequencies are not only directed forward, but also pass around the speaker to the rear. This relationship causes higher frequencies to sound louder. Baffle-step compensation is required in loud speakers to reduce the sound pressure of those higher frequencies compared with lower frequencies. The BSC flattens the sound pressure level across frequencies for a better listening experience. The BSC is optional and the designer can disable this by removing the jumper across J6 (labeled “Baffle Step”), in which case the circuit becomes a unity-gain inverting amplifier.

Figure 9 shows the schematic for the BSC circuit.

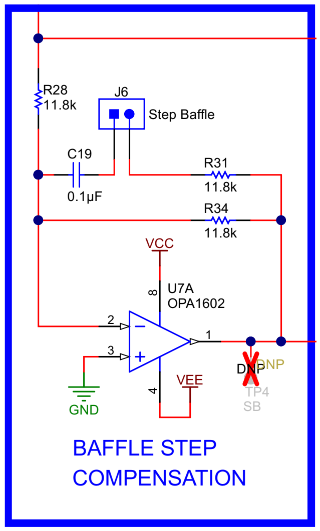

Figure 9. Baffle-Step Compensation (BSC) Schematic

The BSC circuit has the following transfer function shown in Equation 4.

$$H(s) = -\frac{R_{34}}{R_{28}}\left(\frac{1 + sR_{31}C_{19}}{1 + s(R_{34}R_{31})C_{19}}\right) \quad (4)$$

Equation 5 and Equation 6 give the pole and zero frequencies, respectively.

$$f_p = \frac{1}{2\pi(R_{34} + R_{31})C_{19}} \quad (5)$$

$$f_z = \frac{1}{2\pi R_{31}C_{19}} \quad (6)$$

When using the current component values, as shown in Figure 9, the pole and zero frequencies of the BSC are 67.4 Hz and 134.9 Hz, respectively.

Figure 10 and Figure 11 show the frequency response with and without the BSC.

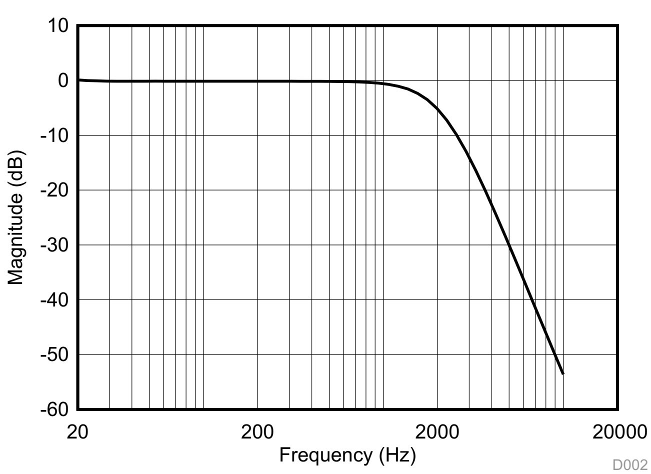

Figure 10. Low-Pass Filter Frequency Response Without Baffle-Step Compensation

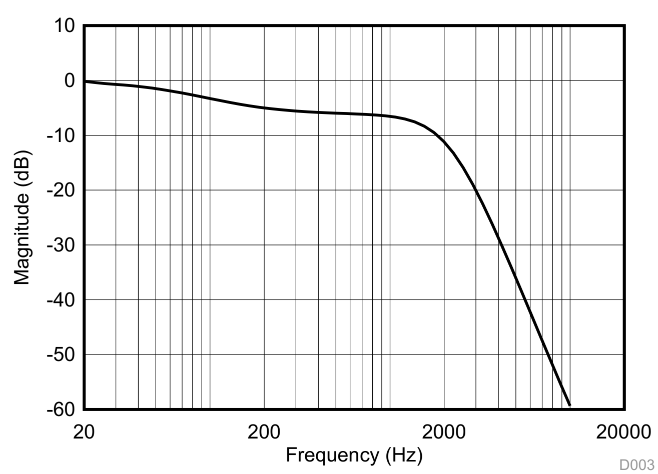

Figure 11. Low-Pass Filter Frequency Response With Baffle-Step Compensation

2.2.3 High-Pass Filter

The fourth-order high-pass filter attenuates all signals with frequencies below a certain cutoff, which is determined by the filter component values.

The high-pass filter schematic in Figure 12 comprises two second-order Sallen-Key high-pass filters (U1B and U2A), which combine to create a fourth-order filter and provide a rapid attenuation at frequencies below the cutoff. R1 = R2, R10 = R11, C3 = C5, and C4 = C6; therefore, the transfer function for the high-pass filter can be written as follows in Equation 7.

$$H(s) = \left(\frac{s^2 R_1 R_{10} C_3 C_4}{1 + sR_1 (C_3 + C_4) + s^2 R_1 R_{10} C_3 C_4} \right)^2 \quad (7)$$

The following Equation 8 gives the cutoff frequency of the filter.

$$fc = \frac{1}{2\pi\sqrt{R_1 R_{10} C_3 C_4}} \quad (8)$$

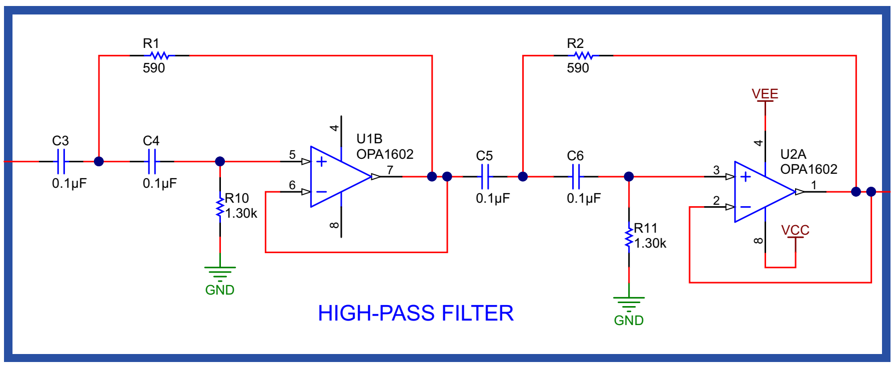

Figure 12. High-Pass Filter Schematic

Using the component values as shown in the previous Figure 12 schematic, the filter has a cutoff frequency of approximately 1.8 kHz. The designer can modify the cutoff frequency if desired by changing one of the components on the first filter and the corresponding component on the second filter. For example, if changing the value of R10, then be sure to change R11 to the same value.

Figure 13 shows the frequency response of the high-pass filter.

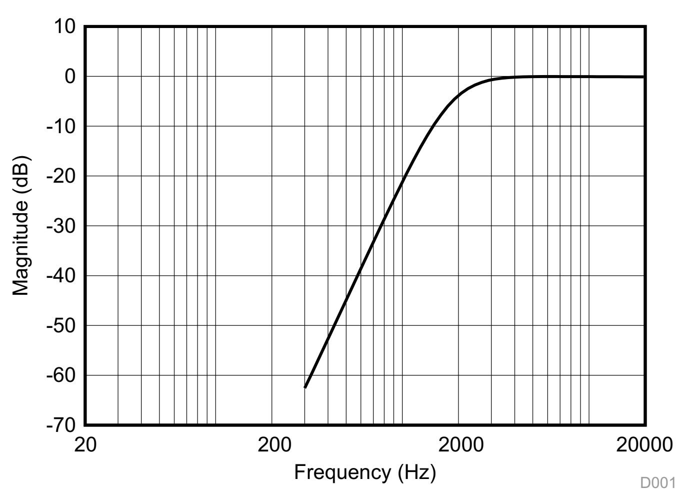

Figure 13. High-Pass Filter Frequency Response

The Q factor for each second-order filter is another value that is important to the filter functionality and it determines how much and how sharply the frequency response of the filter peaks around the cutoff frequency. The Q factor must be less than 1 to reduce this peaking, but it must also be kept above 0.5. Keeping the Q factor around 0.7 is preferable and the current Q factor for the high-pass filter is 0.742. Equation 9 shows the Q factor of each second-order filter.

$$Q = \frac{\sqrt{R_1 R_{10} C_3}}{(R_1 + R_{10})\sqrt{C_4}} \tag{9}$$

Table 4 shows some suggested component values for different cutoff frequencies for the high-pass filter.

Table 4. Component Values for Different High-Pass Filter Cutoff Frequencies

APPROXIMATE CUTOFF FREQUENCY (Hz)	HIGH-PASS FILTER COMPONENT VALUES			
	R1 AND R2	R10 AND R11	C3 AND C5	C4 AND C6
300	3.57 kΩ	7.87 kΩ	100 nF	100 nF
600	1.75 kΩ	3.92 kΩ	100 nF	100 nF
900	1.18 kΩ	2.61 kΩ	100 nF	100 nF
1200	887 Ω	1.96 kΩ	100 nF	100 nF
1500	715 Ω	1.58 kΩ	100 nF	100 nF
1800	590 Ω	1.3 kΩ	100 nF	100 nF
2100	511 Ω	1.1 kΩ	100 nF	100 nF

2.2.4 All-Pass Filter

Use the optional all-pass filter to add a specific time delay to the high-frequency signal path so that the high-channel and low-channel sounds can be matched in time to compensate for any delay that results from distance offsets between the tweeter and the woofer transducers. Figure 14 shows a physical representation of this alignment difference.

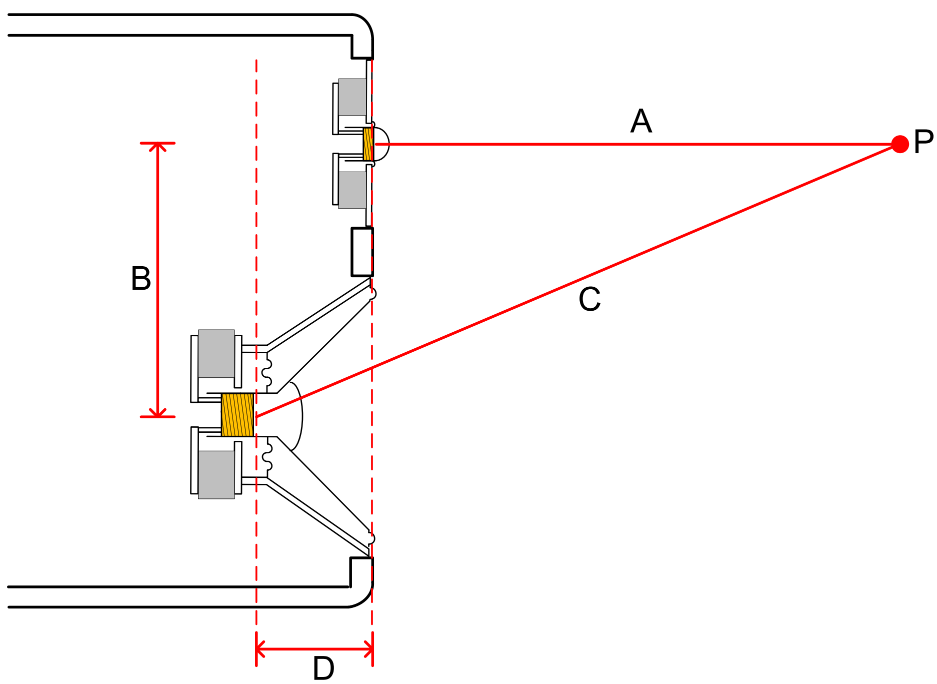

Figure 14. Cross Section of Two-Way Loudspeaker Requiring Delay Compensation

Enable the all-pass filter by connecting the jumper on J1 (labeled “Delay”) to the “EN” pin. If the J1 Delay jumper remains connected to the “Bypass” pin, the all-pass filter is skipped, no delay is added, and the output from the high-pass filter functions as the only output for the high channel. Control the level of the high-pass output through the potentiometer R24 at the output of the all-pass filter.

Figure 15 shows the schematic of the all-pass filter.

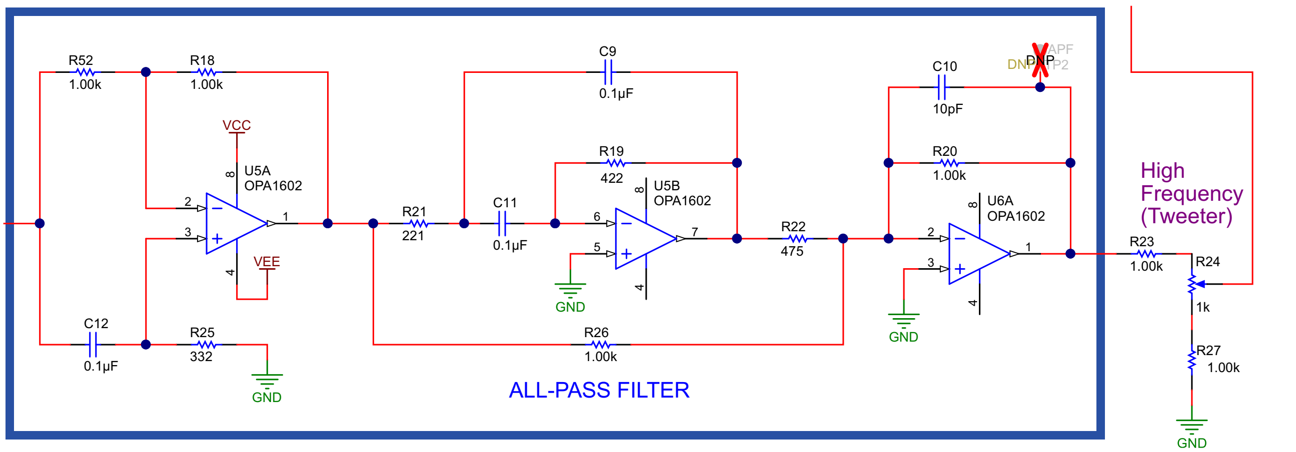

Figure 15. All-Pass Filter Schematic

The transfer function of the all-pass filter is a third-order function. The all-pass filter passes the signal with a constant gain. However, for the gain on the all-pass filter to stay at unity, R52 must equal R18 and R20 must equal R26.

The purpose of the all-pass filter is to add in a time delay to the high-frequency signal; therefore, the formula for the time delay added by the all-pass filter as a function of frequency is given in Equation 10. To simplify the equation, first make a few assumptions about the circuit. Assume that R52 and R18 are always the same value, C9 and C11 are always the same value, R26 and R20 are the same value as well, and that R26 and R20 remain unchanged. Also, the first-order low-pass filter created by U6A has a cutoff frequency of approximately 16 MHz; therefore, assume that it remains unmodified and that its contribution to the time delay is negligible and can be ignored. After making these assumptions, simplify the time delay function to the following Equation 10.

$$\tau(f) = \frac{2R_{25}C_{12}}{1+\left(2\pi R_{25}C_{12}f\right)^2} + \frac{1}{1+\left(\dfrac{4\pi R_{21}C_9 f}{1-4\pi^2 R_{21}R_{19}C_9^2 f^2}\right)^2}\left(\frac{2R_{21}C_9}{1-4\pi^2 R_{21}R_{19}C_9^2 f^2} + \frac{16\pi^2 R_{21}^2 R_{19} C_9^3 f^2}{\left(1-4\pi^2 R_{21}R_{19}C_9^2 f^2\right)^2}\right)$$
$$\frac{1}{1+\left(\dfrac{2\pi\left[2R_{21}-\dfrac{R_{26}}{R_{22}}R_{19}\right]C_9 f}{1-4\pi^2 R_{21}R_{19}C_9^2 f^2}\right)^2}\left(\frac{\left[2R_{21}-\dfrac{R_{26}}{R_{22}}R_{19}\right]C_9}{1-4\pi^2 R_{21}R_{19}C_9^2 f^2} + \frac{8\pi^2\left[2R_{21}-\dfrac{R_{26}}{R_{22}}R_{19}\right]R_{21}R_{19}C_9^3 f^2}{\left(1-4\pi^2 R_{21}R_{19}C_9^2 f^2\right)^2}\right) \quad (10)$$

Find the approximate value for the low-frequency time delay by setting f = 0 in Equation 10. Using the current component values as shown in Figure 15, the all-pass filter has a delay of approximately 155 µs. Table 5 also provides a few suggested component values for varying amounts of delay.

Table 5. Approximate Additional Time Delays With Corresponding Component Values and Approximate Frequency When Delay Decreases by 10%

APPROXIMATE TIME DELAY	COMPONENT VALUES								ESTIMATED FREQUENCY FOR 10% DROP IN DELAY
	R52 AND R18	C12	R25	R21	C9 AND C11	R19	R22	R26 AND R20	
30 µS	1000 Ω	10 nF	649 Ω	422 Ω	10 nF	806 Ω	475 Ω	1000 Ω	20300 Hz
60 µS	1000 Ω	22 nF	590 Ω	383 Ω	22 nF	732 Ω	475 Ω	1000 Ω	10100 Hz
90 µS	1000 Ω	47 nF	412 Ω	576 Ω	22 nF	1100 Ω	475 Ω	1000 Ω	6750 Hz
120 µS	1000 Ω	47 nF	549 Ω	365 Ω	47 nF	698 Ω	475 Ω	1000 Ω	5050 Hz
150 µS	1000 Ω	100 nF	324 Ω	453 Ω	47 nF	866 Ω	475 Ω	1000 Ω	4050 Hz
180 µS	1000 Ω	100 nF	442 Ω	287 Ω	100 nF	456 Ω	499 Ω	1000 Ω	4300 Hz
210 µS	1000 Ω	100 nF	499 Ω	324 Ω	100 nF	549 Ω	499 Ω	1000 Ω	3450 Hz
240 µS	1000 Ω	100 nF	604 Ω	383 Ω	100 nF	604 Ω	499 Ω	1000 Ω	3200 Hz
270 µS	1000 Ω	100 nF	681 Ω	432 Ω	100 nF	681 Ω	499 Ω	1000 Ω	2850 Hz

Figure 16 shows an example of added phase delay by the all-pass filter block to the high-frequency channel.

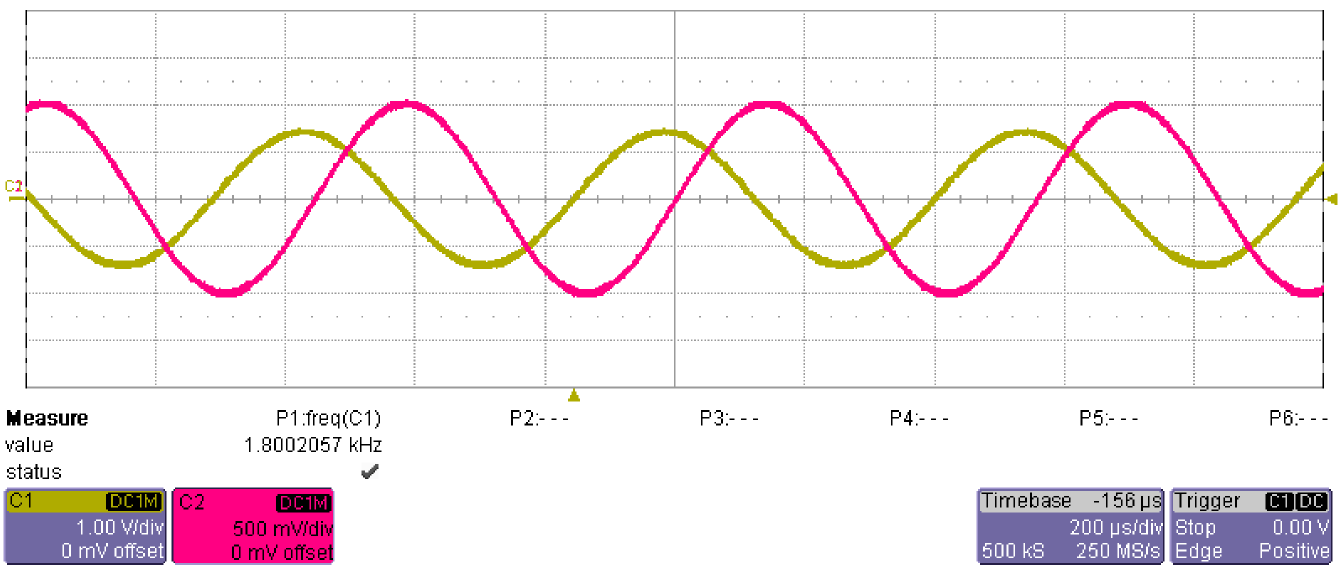

Figure 16. Example of All-Pass Filter Delay

NOTE: The input signal (yellow) is a 1.8-kHz sine wave and the output from the analog crossover module is shown in pink.

See more information about how to determine the necessary time delay, as well as more information about the analog crossover module, in *Analog, Active Crossover Circuit for Two-Way Loudspeakers* (TIDU035).

2.2.5 Input

The input to the Analog Crossover Plug-in Module is a single channel, single-ended audio source.

2.2.6 Volume Knob

Control the master volume on the analog crossover module with R17, which is the potentiometer next to the RCA input jack.

3 Design Files

3.1 Schematic

Figure 17 and Figure 18 show the SIDEGIG-XOVEREVM schematics.

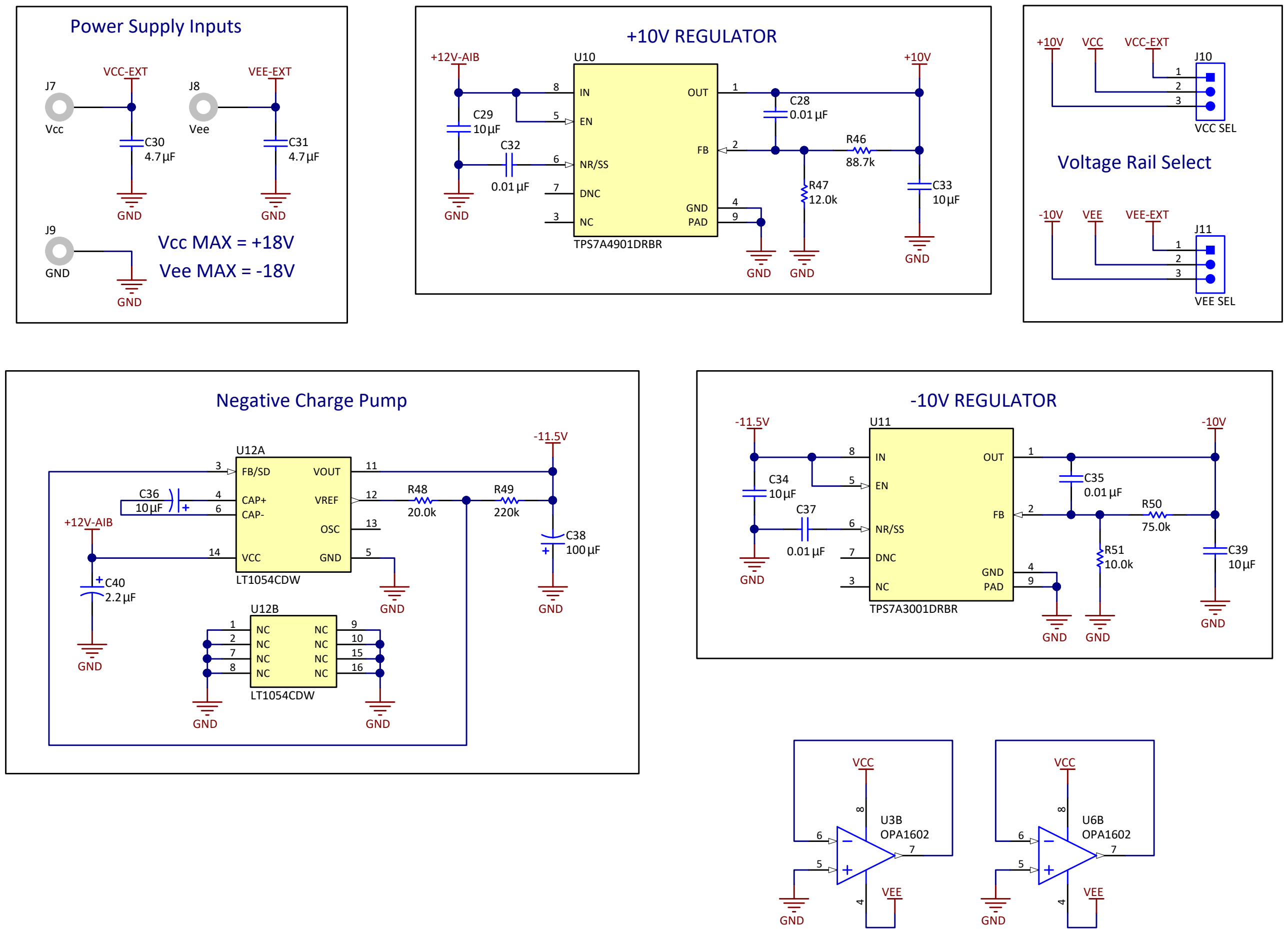

Figure 17. SIDEGIG-XOVEREVM Schematic Page 1

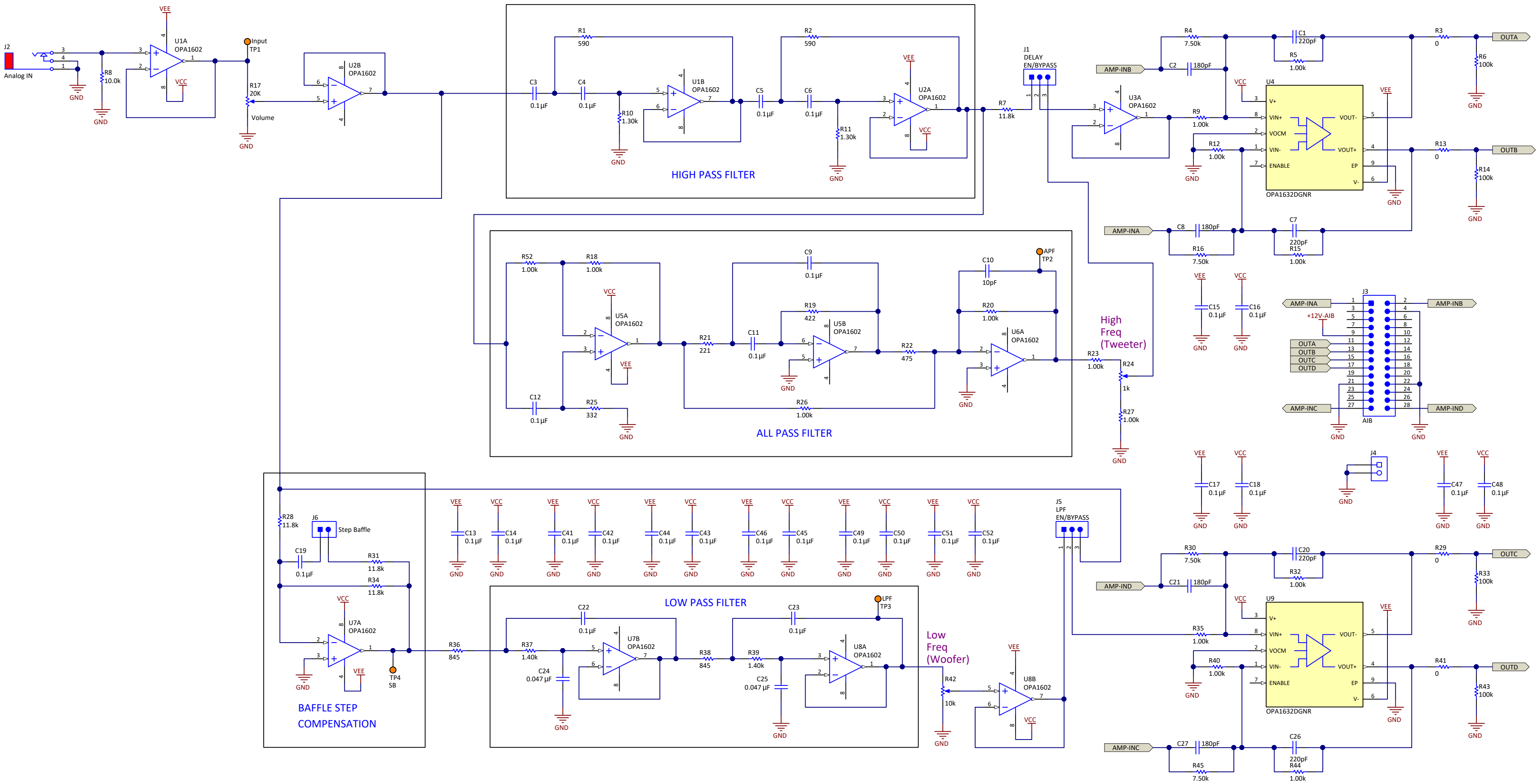

Figure 18. SIDEGIG-XOVEREVM Schematic Page 2

3.2 Board Layouts

Figure 19 and Figure 20 show the SIDEGIG-XOVEREVM layout images.

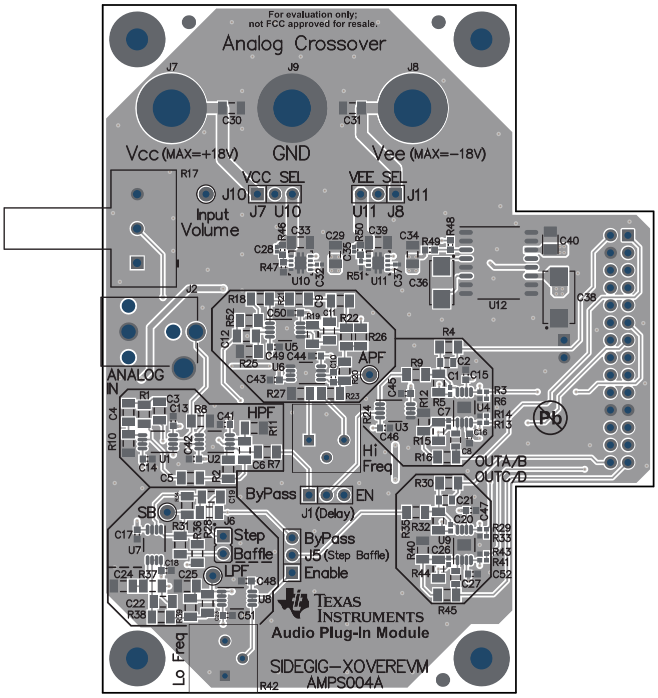

Figure 19. Top Overlay

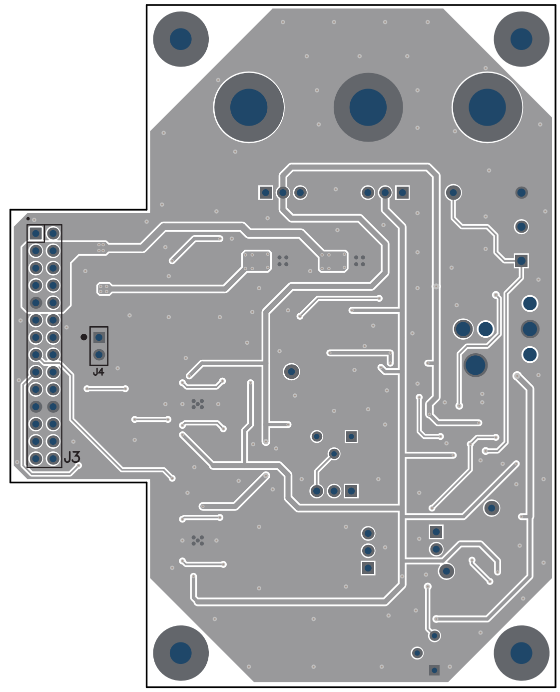

Figure 20. Bottom Overlay

3.3 Board Dimensions

Figure 21 shows the SIDEGIG-XOVEREVM board dimensions.

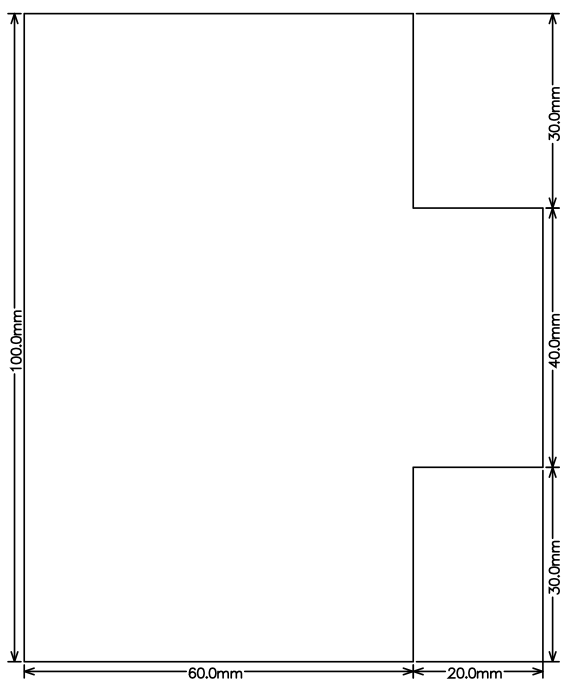

Figure 21. SIDEGIG-XOVEREVM Board Dimensions

3.4 Bill of Materials

Table 6 shows the SIDEGIG-XOVEREVM BOM.

Table 6. BOM

DESIGNATOR	QTY	VALUE	DESCRIPTION	PACKAGE REFERENCE	PART NUMBER	MANUFACTURER	ALTERNATE PART NUMBER	ALTERNATE MANUFACTURER
!PCB1	1		Printed Circuit Board		AMPS004	Any		
C1, C7, C20, C26	4	220pF	CAP, CERM, 220 pF, 50 V,+/- 1%, C0G/NP0, 0402	0402	C1005C0G1H221F050BA	TDK		
C3, C4, C5, C6, C9, C11, C12, C19, C22, C23	10	0.1uF	CAP, CERM, 0.1 µF, 25 V,+/- 5%, C0G/NP0, 1206	1206	C1206C104J3GACTU	Kemet		
C10	1	10pF	CAP, CERM, 10 pF, 50 V,+/- 5%, C0G/NP0, 0603	0603	06035A100JAT2A	AVX		
C13, C14, C15, C16, C17, C18, C41, C42, C43, C44, C45, C46, C47, C48, C49, C50, C51, C52	18	0.1uF	CAP, CERM, 0.1 µF, 16 V,+/- 5%, X7R, 0603	0603	0603YC104JAT2A	AVX		
C24, C25	2	0.047uF	CAP, CERM, 0.047 µF, 50 V,+/- 5%, C0G/NP0, 1206	1206	GRM31M5C1H473JA01L	MuRata		
C28, C35	2	0.01uF	CAP, CERM, 0.01 µF, 10 V,+/- 10%, X7R, AEC-Q200 Grade 1, 0201	0201	CGA1A2X7R1A103K030BA	TDK		
C29, C33, C34, C39	4	10uF	CAP, CERM, 10 µF, 25 V,+/- 10%, X7R, 1206	1206	885012208069	Wurth Elektronik		
C30, C31	2	4.7uF	CAP, CERM, 4.7 µF, 16 V,+/- 10%, X5R, 1206	1206	C1206C475K4PACTU	Kemet		
C32, C37	2	0.01uF	CAP, CERM, 0.01 µF, 6.3 V,+/- 10%, X5R, 0201	0201	GRM033R60J103KA01D	MuRata		
C36	1	10uF	CAP, TA, 10 µF, 25 V, +/- 10%, 1.5 ohm, SMD	6032-28	293D106X9025C2TE3	Vishay-Sprague		
C38	1	100uF	CAP, TA, 100 µF, 20 V, +/- 10%, 0.5 ohm, SMD	7343-43	293D107X9020E2TE3	Vishay-Sprague		
C40	1	2.2uF	CAP, TA, 2.2 µF, 25 V, +/- 10%, 6.3 ohm, SMD	3216-18	293D225X9025A2TE3	Vishay-Sprague		
H1, H2, H3, H4	4		Machine Screw, Round, #4-40 x 1/4, Nylon, Philips panhead	Screw	NY PMS 440 0025 PH	B&F Fastener Supply		
H5, H6, H7, H8	4		Standoff, Hex, 1"L #4-40 Nylon	Standoff	1902E	Keystone		
J1, J5, J10, J11	4		Header, 100mil, 3x1, Gold, TH	PBC03SAAN	PBC03SAAN	Sullins Connector Solutions		
J2	1		RCA Jack, Red, R/A, TH	PC Mount Phono Jack- Red, TH	971	Keystone		
J3	1		Header, 100mil, 14x2, Gold, TH	14x2 Header	TSW-114-07-G-D	Samtec		
J4	1		Receptacle, 100mil, 2x1, Tin, TH	Receptacle, 2x1, 100mil, Tin	PPTC021LFBN-RC	Sullins Connector Solutions		
J6	1		Header, 100mil, 2x1, Gold, TH	Sullins 100mil, 1x2, 230 mil above insulator	PBC02SAAN	Sullins Connector Solutions		
J7, J8, J9	3		Standard Banana Jack, Uninsulated, 5.5mm	Keystone_575-4	575-4	Keystone		
R1, R2	2	590	RES, 590, 1%, 0.25 W, 1206	1206	RC1206FR-07590RL	Yageo America		
R3, R13, R29, R41	4	0	RES, 0, 5%, 0.063 W, 0402	0402	RC0402JR-070RL	Yageo America		
R5, R9, R12, R15, R18, R20, R23, R26, R27, R32, R35, R40, R44, R52	14	1.00k	RES, 1.00 k, 1%, 0.25 W, 1206	1206	RC1206FR-071KL	Yageo America		
R6, R14, R33, R43	4	100k	RES, 100 k, 0.1%, 0.063 W, 0402	0402	RG1005P-104-B-T5	Susumu Co Ltd		
R7, R28, R31, R34	4	11.8k	RES, 11.8 k, 1%, 0.25 W, 1206	1206	RC1206FR-0711K8L	Yageo America		
R8	1	10.0k	RES, 10.0 k, 1%, 0.25 W, 1206	1206	RC1206FR-0710KL	Yageo America		

Table 6. BOM (continued)

DESIGNATOR	QTY	VALUE	DESCRIPTION	PACKAGE REFERENCE	PART NUMBER	MANUFACTURER	ALTERNATE PART NUMBER	ALTERNATE MANUFACTURER
R10, R11	2	1.30k	RES, 1.30 k, 1%, 0.25 W, 1206	1206	RC1206FR-071K3L	Yageo America		
R17	1	20K	Potentiometer 20K 20% 16MM ROTARY POT, TH	17x24.5mm	P160KN-0QC15B20K	TT-Electronics-BI-Technologies		
R19	1	422	RES, 422, 1%, 0.25 W, 1206	1206	RC1206FR-07422RL	Yageo America		
R21	1	221	RES, 221, 1%, 0.25 W, 1206	1206	RC1206FR-07221RL	Yageo America		
R22	1	475	RES, 475, 1%, 0.25 W, 1206	1206	RC1206FR-07475RL	Yageo America		
R24	1	1k	TRIMMER, 1k ohm, 0.5W, TH	375x190x375mil	3386P-1-102LF	Bourns		
R25	1	332	RES, 332, 1%, 0.25 W, 1206	1206	RC1206FR-07332RL	Yageo America		
R36, R38	2	845	RES, 845, 1%, 0.25 W, 1206	1206	RC1206FR-07845RL	Yageo America		
R37, R39	2	1.40k	RES, 1.40 k, 1%, 0.25 W, 1206	1206	RC1206FR-071K4L	Yageo America		
R42	1	10k	TRIMMER, 10k ohm, 0.5W, TH	375x190x375mil	3386P-1-103LF	Bourns		
R46	1	88.7k	RES, 88.7 k, 1%, 0.1 W, 0603	0603	RC0603FR-0788K7L	Yageo America		
R47	1	12.0k	RES, 12.0 k, 1%, 0.1 W, 0603	0603	RC0603FR-0712KL	Yageo America		
R48	1	20.0k	RES, 20.0 k, 1%, 0.1 W, 0603	0603	RC0603FR-0720KL	Yageo America		
R49	1	220k	RES, 220 k, 1%, 0.1 W, 0603	0603	RC0603FR-07220KL	Yageo America		
R50	1	75.0k	RES, 75.0 k, 1%, 0.1 W, 0603	0603	RC0603FR-0775KL	Yageo America		
R51	1	10.0k	RES, 10.0 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	RMCF0402FT10K0	Stackpole Electronics Inc		
SH-J1, SH-J2, SH-J3, SH-J4, SH-J5	5	1x2	Shunt, 100mil, Gold plated, Black	Shunt	969102-0000-DA	3M	SNT-100-BK-G	Samtec
U1, U2, U3, U5, U6, U7, U8	7		Sound Plus High-Performance, Bipolar-Input Audio Operational Amplifier, 4.5 to 36 V, -40 to 85 degC, 8-pin SOP (DGK0008A), Green (RoHS & no Sb/Br)	DGK0008A	OPA1602AIDGK	Texas Instruments	Equivalent	Texas Instruments
U4, U9	2		Fully Differential I/O Audio Amplifier, DGN0008D (VSSOP-8)	DGN0008D	OPA1632DGNR	Texas Instruments	OPA1632DGN	Texas Instruments
U10	1		Vin 3V to 36V, 150mA, Ultra-Low Noise, High PSRR, Low-Dropout Linear Regulator, DRB0008A (VSON-8)	DRB0008A	TPS7A4901DRBR	Texas Instruments	TPS7A4901DRBT	Texas Instruments
U11	1		Vin -3V to -36V, -200mA, Ultra-Low Noise, High PSRR, Low-Dropout Linear Regulator, DRB0008A (VSON-8)	DRB0008A	TPS7A3001DRBR	Texas Instruments	TPS7A3001DRBT	Texas Instruments
U12	1		-5 V, Buck / Boost Charge Pump, 100 mA, 3.5 to 15 V Input, 0 to 70 degC, 16-pin SOIC (DW16), Green (RoHS & no Sb/Br)	DW0016A	LT1054CDW	Texas Instruments	Equivalent	Texas Instruments
C2, C8, C21, C27	0	180pF	CAP, CERM, 180 pF, 50 V,+/- 5%, C0G/NP0, 0805	0805	C0805C181J5GACTU	Kemet		
FID1, FID2, FID3	0		Fiducial mark. There is nothing to buy or mount.	N/A	N/A	N/A		
R4, R16, R30, R45	0	7.50k	RES, 7.50 k, 1%, 0.25 W, 1206	1206	RC1206FR-077K5L	Yageo America		
TP1, TP2, TP3, TP4	0		Test Point, Miniature, Orange, TH	Orange Miniature Testpoint	5003	Keystone		

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