TI Designs
TIDA-00724 Automotive Emergency Call (eCall) Audio Subsystem Reference Design

Design Overview

The efficiency and diagnostics necessary for automotive Emergency Call (eCall) systems generate unique requirements for the audio subsystem, such as speaker diagnostics and low power consumption. This TI design shows how to use Texas Instruments' automotive two-channel audio codec and a class-D audio amplifier for eCall applications. The reference design also highlights critical design factors and benefits of TI's solution such as: low power consumption and efficiency, loud and clear audio output, and integrated diagnostics/protection.

Design Features

- Passes CISPR-25 Class 5 Radiated Emissions Limits
- 8W through a 4 ohm load output power
- Integrated speaker diagnostics and protection
- Register settings included for the TLV320AIC3104-Q1

Featured Applications

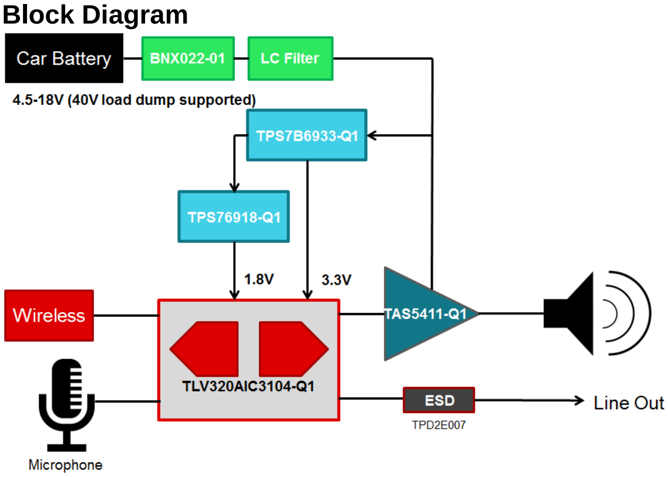
- Automotive Emergency Call (eCall)
- Automotive Telematics
- Automotive Connected Gateway

Design Resources

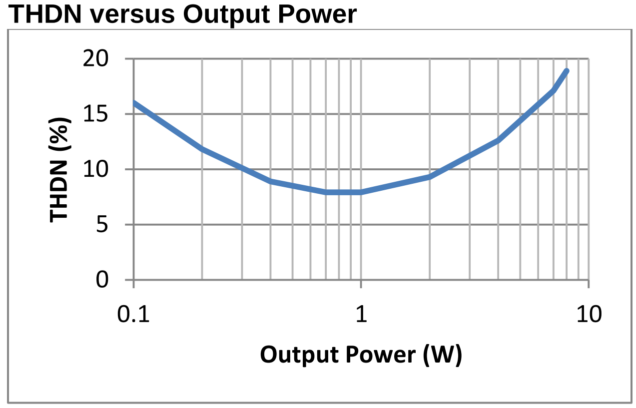
TIDA-00724	Design Folder
TAS5411-Q1	Product Folder
TLV320AIC3104-Q1	Product Folder
TPS7B6933-Q1	Product Folder
TPS76918-Q1	Product Folder
TPD2E007	Product Folder
TIDA-00159	Tools Folder

Board Image

Block Diagram



THDN versus Output Power



1 Key System Specifications

Table 1: Key System Specifications

Parameter	Conditions	Min	Typ	Max	Details
Input Voltage	12V car battery	4.5-V	14.4-V	18-V (40-V load dump)	2.3
Standby Current[1]	TAS5411 standby mode, AIC3104 reset		6 uA		
Speaker Load		2-Ω	4-Ω	16-Ω	4.1
Output Power	4 ohm load			8-W	2.1
ESD Protection on line out	IEC 61000-4-2 Contact		±8-kV		2.4
	IEC 61000-4-2 Air-Gap		±15-kV		2.4
Audio Inputs/Outputs	Digital audio I2S input –> speaker output Microphone Input -> Digital audio I2S output				4.2
ESD protection	ESD protection needed on line output				
EMC/EMI Requirements	CISPR-25 Class 5 Radiated Emissions				4.4
Operating Temperature		-40°C		85°C	

1. **Standby current only includes TAS5411-Q1 and TLV320AIC3104-Q1**

2 System Description

Governing bodies around the world have implemented specific legislation to require automotive companies to install Emergency Call (eCall) systems in order to reduce emergency response times and save lives. eCall systems are activated during a collision or emergency situation and automatically facilitate a call to emergency services. The state of a vehicle after a collision is difficult to predict and could include a disconnected battery, trapped passengers, and a noisy environment. For this reason, the eCall module must have its own battery power source and be able to sustain a hands-free call for approximately ten minutes (depending on specific regional legislation) Therefore, the audio devices selected for this reference design are optimal for low power consumption while still enabling a loud and clear conversation with an emergency operator. In addition, the TAS5411-Q1 includes integrated diagnostics and protection which allows for easier design of these features.

The entire block diagram as seen in Figure 1 contains power management, an MCU, a connectivity module, and audio. The MCU receives inputs from the rest of the vehicle and activates the call if an accident occurs. The power management is able to run off of the car's main battery or a smaller back-up battery integrated into the eCall module. The wireless module makes the call and uses a full duplex digital audio signal to interface with the audio subsystem. The audio subsystem drives the speakers and handles the microphone input.

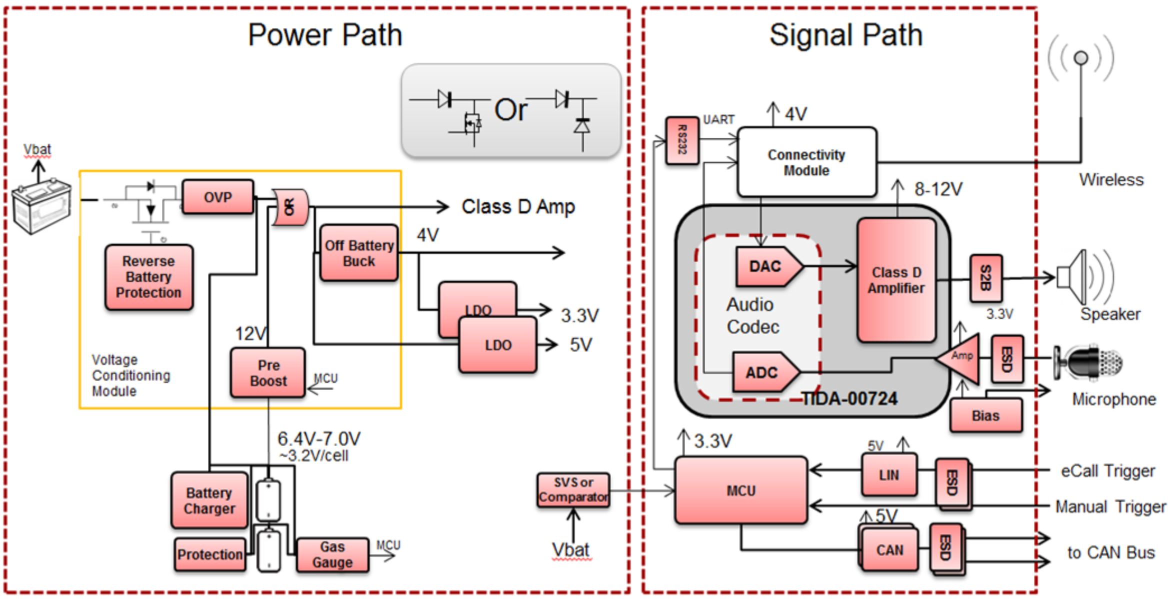


Figure 1: Block Diagram of eCall System

The audio subsystem consists of a class-D audio amplifier and an audio codec. The audio codec connects the digital audio input from the connectivity module to the class-D amplifier which drives the speaker. The codec must also convert the microphone inputs to digital to communicate back to the connectivity module.

2.1 Class-D Amplifier

The class-D amplifier must maintain sufficient output power to drive the speaker to the specified audio level with sufficient audio quality. It must also have high efficiency and good EMI/EMC performance. In addition, many eCall systems require speaker diagnostics and IC protection circuitry.

Class-D amplifiers are used because of their excellent efficiency, which is critical in the eCall application. The high efficiency is achieved by using MOSFETs that switch to drive a bridge tied load; however the switching causes more electromagnetic radiation than other classes of amplifiers. Texas Instruments has several class-D amplifiers that use BD mode modulation, which reduces the ripple current that flows through the inductor. This improves the EMC performance and uses smaller components. This TI design was tested for radiated emissions according to CISPR-25; contact a local TI representative to request the EMC test report.

Diagnostic and protection coverage is needed for eCall applications because of the unknown nature of the environment after a collision. If a speaker is faulty after a collision, the information can be sent to the call center so they know that the speaker does not work. It also helps to have load diagnostics before there is a collision so that any problems with the system can be fed back to the driver for maintenance.

Within the eCall module itself, it is unlikely for there to be an exposure to a high-voltage event; however, the connectors leaving the eCall module are in danger. Specifically, the speaker cables that connect the speaker to the eCall module could be connected to ground or battery during installation, maintenance, or during an accident. While no class-D amplifier can operate while such a condition is maintained on the output lines, without protection even a momentary incident could damage a class-D amplifier. The TAS5411-Q1 has integrated protection for these events, reducing the need for external components, and it can report problems over I^2C.

Damage can also occur to the class-D amplifier on its power supply input. Because it has to drive several Watts on the output speaker, it is beneficial to power an audio amplifier directly from the battery; however, most class-D amplifiers cannot survive common battery conditions that can occur on the battery line. The TAS5411-Q1 integrates the protection necessary to survive a 40V load dump, which means that the only external protection necessary when operating off of the battery is a reverse battery protection diode.

Texas Instruments has several AEC-Q100 options depending on the specific requirements of the eCall system. Table XX shows a comparison between three popular class-D amplifiers for eCall. For most applications that require speaker diagnostic and integrated protection, the TAS5411-Q1 is the clear choice. Eight Watts is usually enough for the eCall application, but for higher power requirements, the TAS5421-Q1 is the recommended device. For those lower-end applications that do not require integrated load diagnostics or protection, the TPA3111D1-Q1 remains a good choice.

Table 2 - Comparison of Audio Class-D Amplifiers for eCall

	TAS5411-Q1	TAS5421-Q1	TPA3111D1-Q1
Output Power	8W	22W	10W
Open and Shorted Load Diagnostics	Yes	Yes	External Diagnostics needed
Output to power and ground short diagnostics	Yes	Yes	External Diagnostics needed
40V load dump protection	Yes	Yes	External Protection needed
Output short to power, ground, and output-output protection	Yes	Yes	Yes, short to battery not supported
Over-temperature protection	Yes	Yes	Yes
Cost	Middle	Highest	Lowest
Collateral about eCall	TIDA-00754	TIDA-00159	Upcoming

2.2 Audio Codec

The audio codec in the eCall system must be able to support full duplex communication between the digital audio source from the wireless module, the microphone input, and the speaker output. By using a two channel device, stereo inputs and outputs can be used. The TLV320AIC3104 is a two channel audio codec that meets the low power requirements and has the inputs and outputs necessary for the eCall application.

Sometimes, the audio codec is re-used for other non eCall applications in the car. In this case, the second channel is routed to the head unit. ESD protection is needed because the extra codec analog output leaves the eCall module and could be exposed to ESD events.

For this design, it is assumed that the wireless module communicates to the audio codec through I2S.

2.3 Power

The power management design is critical to achieve high efficiency and at the same time meeting EMI/EMC requirements. It must also have the capability of operating from the car battery or a small separate battery. For the audio subsystem, the power requirements are simpler. The input power will come from a lab power supply; this mimics the car battery voltage or the boosted smaller battery voltage. This battery input directly powers the class-D amplifier. The codec requires two voltage rails, 3.3V with a typical current draw of 6mA and 1.8V with a typical current draw of 3.5mA.

Because the current consumption is low and the audio quality can be impacted by switching noise on the power inputs, LDOs were chosen for this design. When designing the full power management system, there will be more design considerations and possibly more devices will be using the 3.3V and 1.8V rails, such as the microcontroller. Other TI Designs explore this aspect in more detail (TIDA-00159).

The power architecture used in this TI design are two cascaded LDOs as can be seen in Figure 2. The first LDO must accept a wide input voltage range and output 3.3V. The TPS7B6933-Q1 was chosen for this LDO because it can accept 4V to 40V input, has a low Iq of 15uA, a small package size, and a low price. The second LDO does not need as wide of an input range, so the TPA76918-Q1 was chosen for its low IQ of 17uA, small package size, and low price.

2.4 ESD protection

The extra differential output pair from the codec should be protected from ESD events. The device chosen, the TPD2E007, protects from 8kV contact discharge and 15kV air gap discharge. It also has a breakdown voltage of 14V, which is well above the operating range of the TLV320AIC3104-Q1.

3 Block Diagram

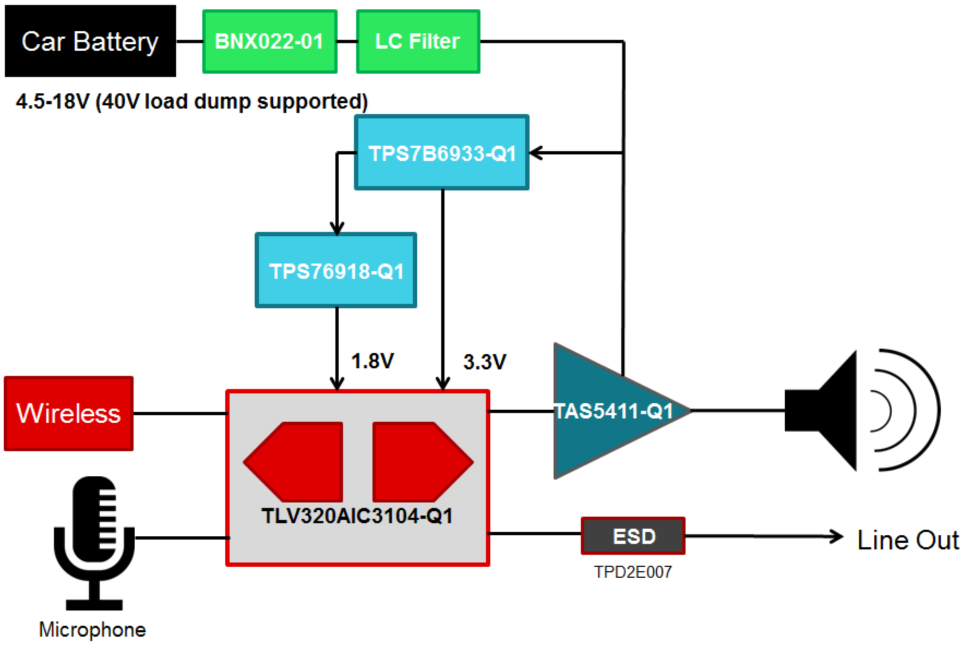


Figure 2: Audio eCall Block Diagram

3.1 Highlighted Products

The audio eCall TI design features the following devices:

- TLV320AIC3104-Q1: Automotive Low-Power Stereo Audio Codec
- TAS5411-Q1: Automotive 10W Mono Digital Audio Amplifier
- TPS7B6933-Q1: Automotive High-Voltage LDO
- TPS76918-Q1: Automotive 10-V LDO
- TPD2E007: 2-Channel ESD Protection Array

3.1.1 TAS5411-Q1

The TAS5411-Q1 is a mono digital audio amplifier, ideal for use in automotive emergency call (eCall), telematics, instrument cluster, and infotainment applications. The device provides up to 8W into 4 Ω at less than 10% THD+N from a 14.4-Vdc automotive battery. The wide operating voltage range and excellent efficiency make the device ideal for start-stop support or running from a backup battery when required. The integrated load-dump protection reduces external voltage clamp cost and size, and the onboard load diagnostics report the status of the speaker through I2C.

The design uses an ultra-efficient class-D technology developed by Texas Instruments, but with features added for the automotive industry. This technology allows for reduced power consumption, reduced heat, and reduced peak currents in the electrical system. The device realizes an audio sound system design with smaller size and lower weight than traditional class-AB solutions.

The device incorporates load diagnostic circuitry designed for detecting and determining the status of output connections. The device supports the following diagnostics:

- Short to GND
- Short to PVDD
- Short across load
- Open load

The device reports the presence of any of the short or open conditions to the system via I2C register read. Load Diagnostics—The load diagnostic function runs on de-assertion of STANDBY or when the device is in a fault state (dc detect, overcurrent, overvoltage, undervoltage, and overtemperature). During this test, the outputs are in a Hi-Z state. The device determines whether the output is a short to GND, short to PVDD, open load, or shorted load. The load diagnostic biases the output, which therefore requires limiting the capacitance value for proper functioning; see the Recommended Operating Conditions. The load diagnostic test takes approximately 229 ms to run. Note that the check phase repeats up to 5 times if a fault is present or a large capacitor to GND is present on the output. On detection of an open load, the output still operates.
On detection of any other fault condition, the output goes into a Hi-Z state, and the device checks the load continuously until removal of the fault condition. After detection of a normal output condition, the audio output starts. The load diagnostics run after every other overvoltage (OV) event. The load diagnostic for open load only has I2C reporting. All other faults have I2C and FAULT pin assertion.

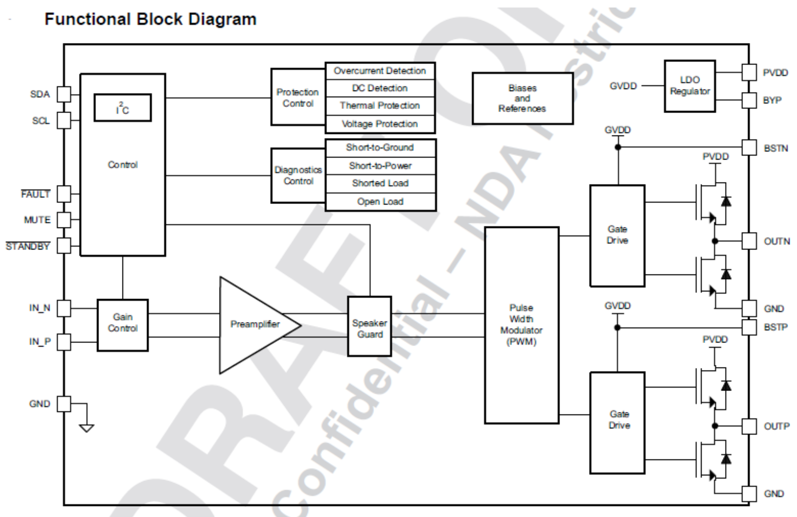


Figure 3: TAS5411-Q1 Functional Block Diagram

3.1.2 TLV320AIC3104-Q1

The TLV320AIC3104-Q1 is a low-power stereo audio codec with stereo pre-amplifier, as well as multiple inputs and outputs that are programmable in single-ended or fully differential configurations.

The record path of the TLV320AIC3104-Q1 contains integrated microphone bias, digitally controlled stereo microphone preamplifier, and automatic gain control (AGC), with mix/mux capability among the multiple analog inputs. The playback path includes mix/mux capability from the stereo DAC and selected inputs, through programmable volume controls, to the various outputs.

The TLV320AIC3104-Q1 contains four high-power output drivers as well as two fully differential output drivers. The high-power output drivers are capable of driving a variety of load configurations, including up to four channels of single-ended 16-Ω speakers using ac-coupling capacitors, or stereo 16-Ω speakers in a capacitor-free output configuration.

A special low-power analog signal pass-through mode is available when neither analog nor digital signal processing is required. This mode significantly reduces power consumption, as most of the device is powered down during this pass-through operation.

The serial control bus supports the I2C protocol, whereas the serial audio data bus is programmable for I2S, left/right-justified, DSP, or TDM modes. A highly programmable PLL is included for flexible clock generation and support for all standard audio rates from a wide range of available MCLKs, varying from 512 kHz to 50 MHz, with special attention paid to the most-popular cases of 12-MHz, 13-MHz, 16-MHz, 19.2-MHz, and 19.68-MHz system clocks.

The TLV320AIC3104 operates from an analog supply of 2.7 V–3.6 V, a digital core supply of 1.525 V–1.95 V, and a digital I/O supply of 1.1 V–3.6 V. The device is available in a 5-mm × 5-mm 32-pin QFN package.

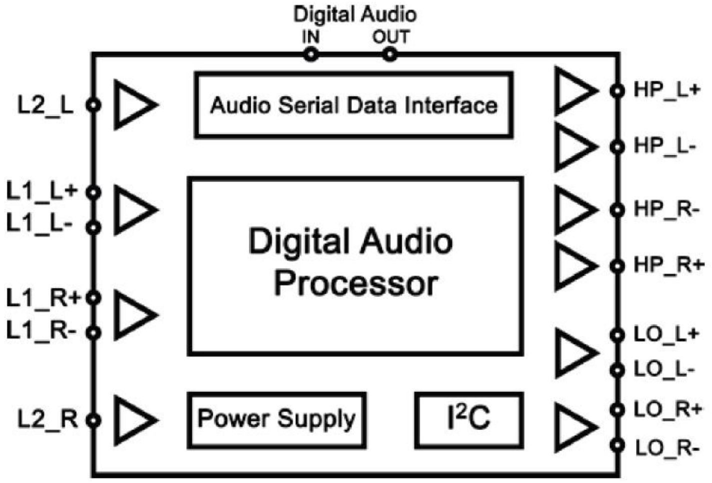


Figure 4: TLV320AIC3104-Q1 Block Diagram

Features:

- Qualified for Automotive Applications
- Stereo Audio DAC
    - 102-dBA Signal-to-Noise Ratio

- 16/20/24/32-Bit Data
- Supports Sample Rates From 8 kHz to 96 kHz
- 3D/Bass/Treble/EQ/De-Emphasis Effects
- Flexible Power Saving Modes and Performance are Available

- Stereo Audio ADC
  - 92-dBA Signal-to-Noise Ratio
  - Supports Sample Rates From 8 kHz to 96 kHz
  - Digital Signal Processing and Noise Filtering Available During Record
- Six Audio Input Pins
  - One Stereo Pair of Single-Ended Inputs
  - **One Stereo Pair of Fully Differential Inputs**
- Six Audio Output Drivers
  - Stereo Fully Differential or Single-Ended Headphone Drivers
  - **Fully Differential Stereo Line Outputs**
- **Low Power: 14-mW Stereo 48-kHz Playback With 3.3-V Analog Supply**
- Ultralow-Power Mode with Passive Analog Bypass
- Programmable Input/Output Analog Gains
- Automatic Gain Control (AGC) for Record
- Programmable Microphone Bias Level
- **Programmable PLL for Flexible Clock Generation**
- I^2C Control Bus
- Audio Serial Data Bus Supports I^2S, Left/Right-Justified, DSP, and TDM Modes
- Extensive Modular Power Control
- Power Supplies:
  - Analog: 2.7 V–3.6 V.
  - Digital Core: 1.525 V–1.95 V
  - Digital I/O: 1.1 V–3.6 V
- Package: 5-mm × 5-mm 32-Pin QFN

3.1.3 TPS7B6933-Q1

The TPS7B69xx-Q1 device is a low-dropout linear regulator designed for up to 40-V VI operations. With only 15-µA (typical) quiescent current at light load, the device is suitable for standby microcontrol-unit systems especially in automotive applications.

The devices feature an integrated short-circuit and overcurrent protection. The TPS7B69xx-Q1 device operates over a –40°C to 125°C temperature range. Because of these features, the TPS7B6925-Q1, TPS7B6933-Q1, and TPS7B6950-Q1 devices are well suited in power supplies for various automotive applications.

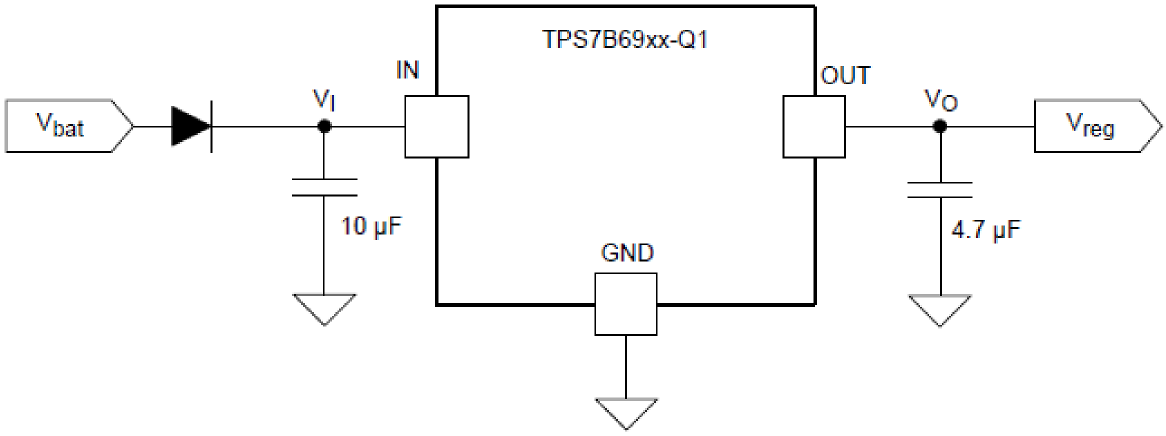


Figure 5: TPS7B6933-Q1 Block Diagram

Features:

- Qualified for Automotive Applications
- AEC-Q100 Qualified With the Following Results:
  - Device Temperature Grade 1: –40°C to 125°C Ambient Operating Temperature Range
  - Device HBM ESD Classification Level 2
  - Device CDM ESD Classification Level C4B
- 4 to 40-V Wide V_I Input Voltage Range With up to 45-V Transient
- Maximum Output Current: 150 mA
- Low Quiescent Current (I_Q):
  - 15 µA Typical at Light Loads
  - 25 µA Maximum Under Full Temperature
- 450-mV Typical Low Dropout Voltage at 100 mA Load Current
- Stable With Low ESR Ceramic Output Capacitor (2.2 to 100 µF)
- Fixed 2.5-V, 3.3-V, and 5-V Output Voltage Options
- Integrated Fault Protection:
  - Thermal Shutdown
  - Short-Circuit Protection
- Packages:
  - 4-Pin SOT-223 Package
  - 5-Pin SOT-23 Package

3.1.4 TPS76918-Q1

The TPS769xx-Q1 family of low-dropout (LDO) voltage regulators offers the benefits of low-dropout voltage, ultralow-power operation, and miniaturized packaging. These regulators feature low-dropout voltages and ultralow quiescent current compared to conventional LDO regulators. Offered in a 5-pin small outline integrated-circuit SOT-23 package, the TPS769xx-Q1 series devices are ideal for micropower operations and where board space is at a premium.

A combination of new circuit design and process innovation has enabled the usual PNP pass transistor to be replaced by a PMOS pass element. Because the PMOS pass element behaves as a low-value resistor, the dropout voltage is very low, typically 71 mV at 100 mA of load current (TPS76950-Q1), and is directly proportional to the load current. Since the PMOS pass element is a voltage-driven device, the quiescent current is ultralow (28 µA maximum) and is stable over the entire range of output load current (0 mA to 100 mA). The ultralow-dropout voltage feature and ultralow-power operation result in a significant increase in system battery operating life, making this device suitable for use in automotive applications.

The TPS769xx-Q1 devices also feature a logic-enabled sleep mode to shut down the regulator, reducing quiescent current to 1 µA typical at TJ = 25°C. The TPS769xx-Q1 devices are offered in 1.2-V, 1.5-V, 1.8-V, 2.5-V, 2.7-V, 2.8-V, 3-V, 3.3-V, and 5-V fixed-voltage versions and in a variable version (programmable over the range of 1.2 V to 5.5 V).

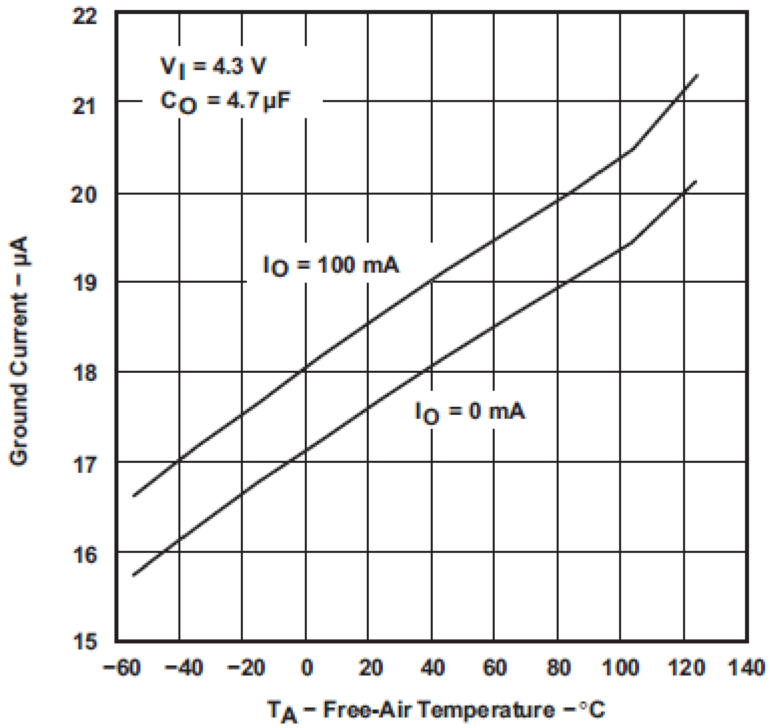


Figure 6: TPS76918-Q1 Ground Current vs Temperature

Features:

- Qualified for Automotive Applications
- 100-mA Low-Dropout Regulator

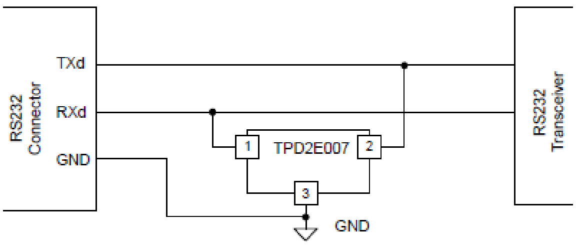
- Available in 1.2-V, 1.5-V, 1.8-V, 2.5-V, 2.7-V, 2.8-V, 3-V, 3.3-V and 5-V Fixed-Output and Adjustable Versions
- Only 17-µA Quiescent Current at 100 mA
- 1-µA Quiescent Current in Standby Mode
- Dropout Voltage Typically 71 mV at 100 mA
- Over Current Limitation
- −40°C to 125°C Operating Junction Temperature Range
- 5-Pin SOT-23 (DBV) Package

3.1.5 TPD2E007

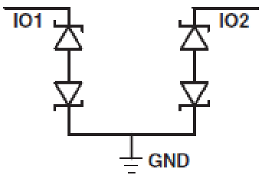
This device is a Transient Voltage Suppressor (TVS) based Electrostatic Discharge (ESD) protection device designed to offer system level ESD solutions for wide range of portable and industrial applications. The back-to-back diode array allows AC-coupled or negative-going data transmission (audio interface, LVDS, RS-485, RS-232, etc.) without compromising signal integrity. This device exceeds the IEC 61000-4-2 (Level 4) ESD protection and is ideal for providing system level ESD protection for the internal ICs when placed near the connector.

The TPD2E007 is offered in a 4-bump PicoStar and 3-pin SOT (DGK) packages. The PicoStar package (YFMG4), with only 0.15 mm (Max) package height, is recommended for ultra space saving application where the package height is a key concern. The PicoStar package can be used in either embedded PCB board applications or in surface mount applications. The industry standard SOT package offers straightforward board layout option in legacy designs.

Example Schematic



Equivalent Schematic Representation



Features:

- IEC 61000-4-2 Level 4 ESD Protection
  - ±8-kV IEC 61000-4-2 Contact Discharge
  - ±15-kV IEC 61000-4-2 Air-Gap Discharge
- IEC 61000-4-5 Surge Protection
  - 4.5-A Peak Pulse Current (8/20 µs Pulse)
- IO Capacitance 15pF (max)
- Low 50-nA Leakage Current
- Space-Saving PicoStar and SOT Package
- APPLICATIONS
  - Cell Phones
  - Audio Interface Connections
  - Consumer Electronics (DVR, Set-Top Box, TV)
  - Industrial Interfaces (RS-232, RS-485, RS-422, LVDS)

4 System Design Theory

4.1 Audio Filter Design

To improve the audio quality and to reduce electromagnetic emissions, an output filter is needed for the TAS5411-Q1. These output filters can use many components; for instance, Figure 7 shows an LC reconstruction filter with common mode and differential capacitors, and RC snubbers.

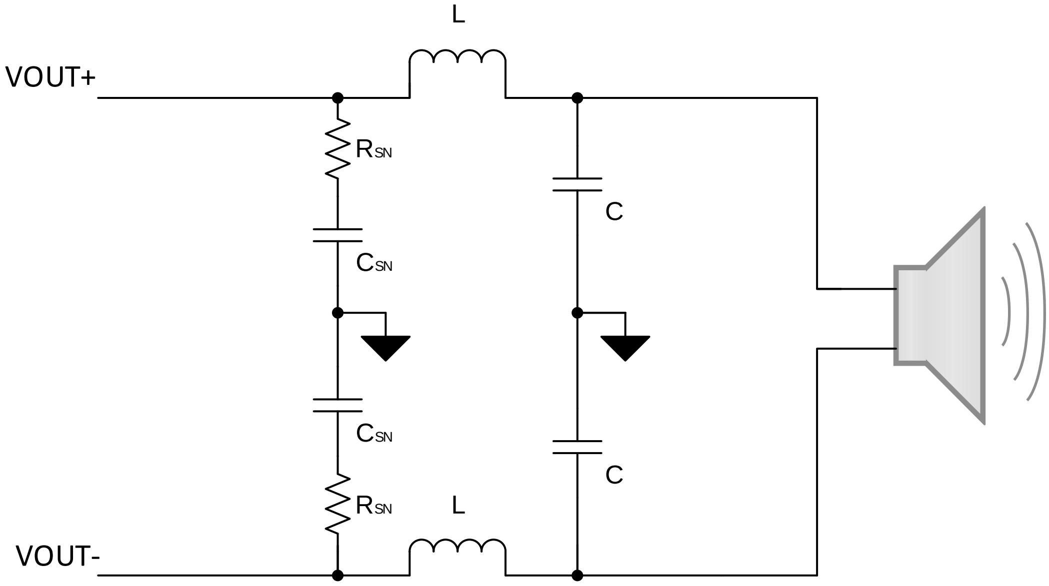


Figure 7: Class-D Amplifier LC Filter with RC Snubber

The RC snubbers help reduce electromagnetic emissions; however, they are not needed for many applications. The radiated emissions testing done on this TI Design did not use the RC Snubbers. Figure 8 shows the output filter without the RC snubber network.

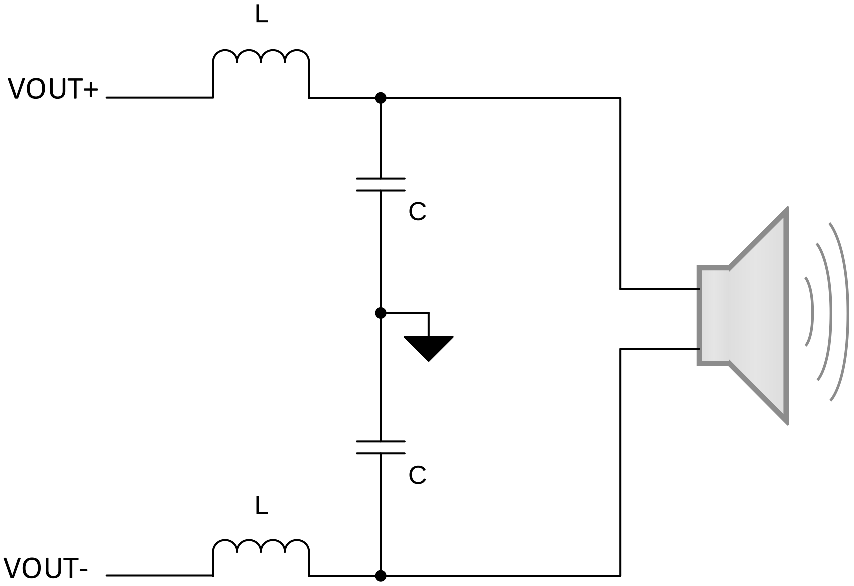


Figure 8: Class-D Amplifier LC Filter

When designing the output filter, it is helpful to consider the filter as two single-ended outputs. For this reason, R_L is considered to be 2 ohms instead of 4 ohms in the design equations below. A second order Butterworth filter provides a flat passband response and a reasonable sharp roll off. The filter should be critically damped, which occurs when:

$$Q = \frac{1}{\sqrt{2}}$$

The equations for C and L can be derived from the following two equations.

$$Q = R_L * \sqrt{\frac{C}{L}}$$

$$\omega_c^2 = \frac{1}{L * C}$$

Both the inductor and capacitor are chosen by choosing the cutoff frequency of the filter. For audio voice applications, 30kHz is a reasonable number. The equation to choose the inductance is:

$$L = \frac{R_L * \sqrt{2}}{\omega_c}$$

$$L = \frac{2\ ohms * \sqrt{2}}{2 * \pi * 30kHz} = 15uH$$

Further considerations for the inductor include shielding to improve EMC performance, saturation current, and low core losses. The TAS5411-Q1 overcurrent shutdown protection is typically 2.4A. Reaching the saturation current of an inductor lowers the inductance, so choosing the saturation level to be around or above the shutdown current is a safe choice. The inductor chosen for this TI design is the DFEG7030D-150M which is magnetically shielded, has low DC resistance, and has a typical saturation current of 3.2A.

The capacitors should be chosen using the following equation:

$$C = \frac{1}{\omega_c * R_L * \sqrt{2}}$$

$$C = \frac{1}{2 * \pi * 30kHz * 4 * \sqrt{2}}$$

$$C = 1.88\ uF$$

To improve EMC performance, the cut off frequency can be lowered slightly more by raising the capacitor slightly. For this design a capacitor of 2.2uF was used, which results in the frequency response shown in Figure 9.

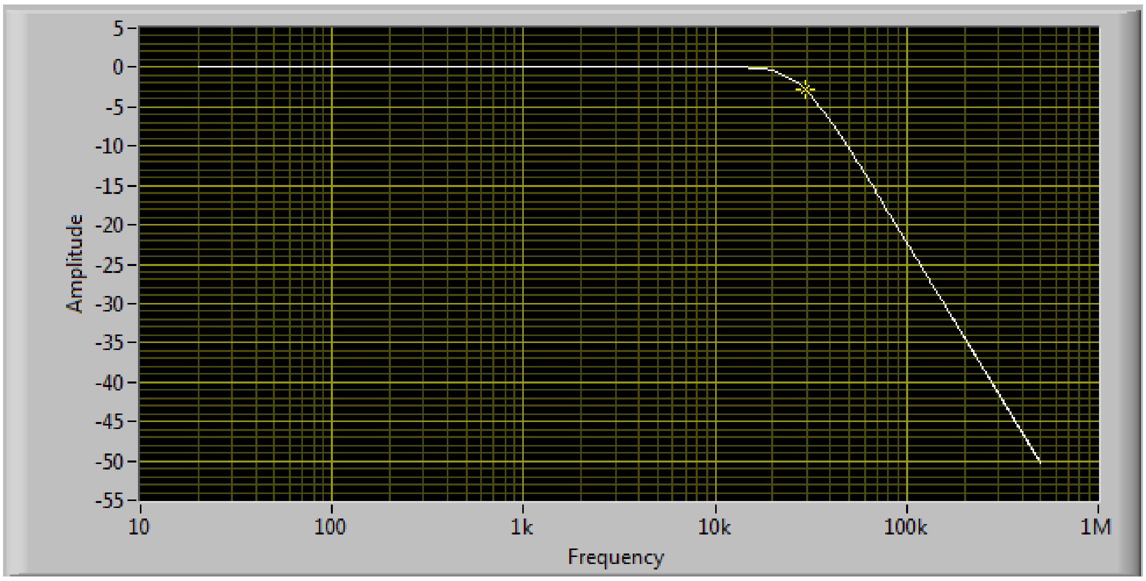


Figure 9: Frequency Response of LC Filter, L = 15uH, C = 2.2uH, R = 2 ohms Single Ended

While this change assists with EMC performance, it does drop the gain at 20kHz to 2dB instead of 1dB. Tradeoffs must be made between audio quality and EMC testing.

For improved EMC performance, the RC snubbers can be added back in, but this TI design was tested without them.

For a full derivation of the design equations refer to the app note, Class-D LC Filter Design.

4.2 Codec Settings

The TLV320AIC3104-Q1 must route two inputs and two outputs. The wireless module communicates through I2S and both transmits and receives audio data from the codec. An analog microphone input allows the user to speak to the emergency operator, and the analog output is the input to the audio amplifier which drives a speaker, allowing the user to listen to the emergency operator. Figure 10 shows the signal paths needed inside the TLV320AIC3104-Q1 to enable these inputs and outputs. The blue lines show the signal from the microphone inputs to the ADC and then out to I2S. The pink lines show the signal from I2S to the DAC and then out to the left channel outputs.

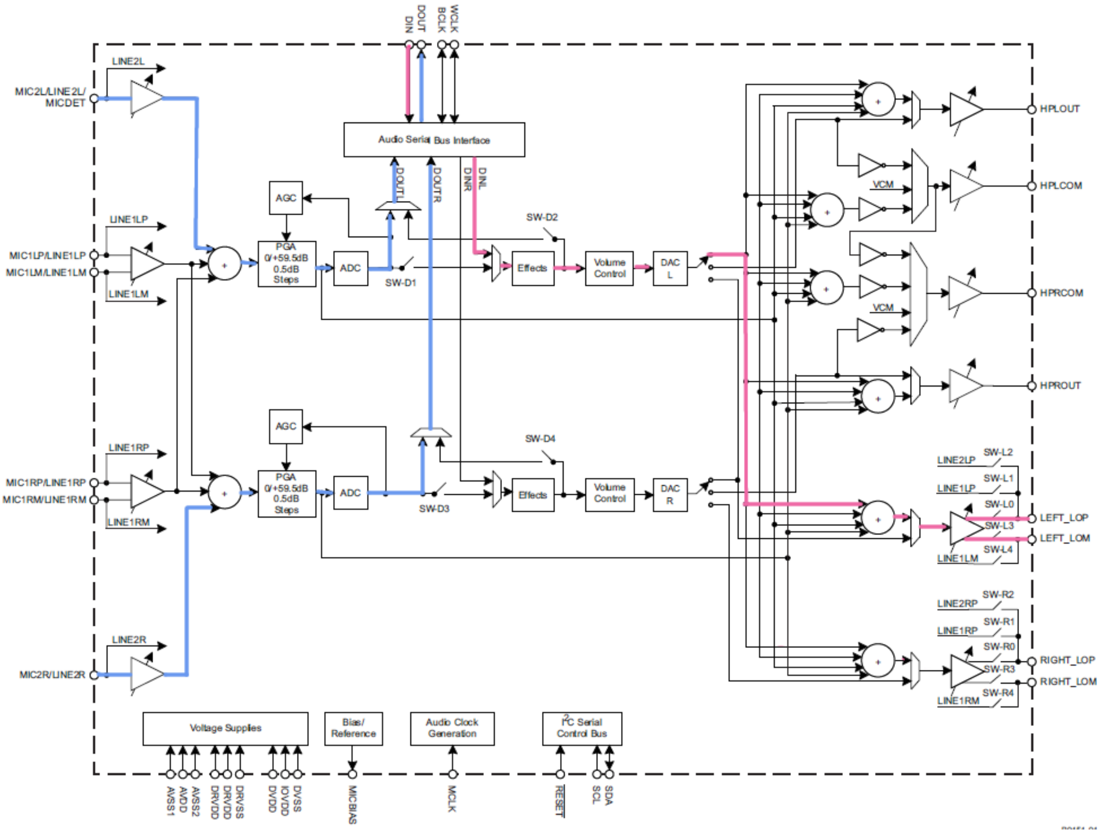


Figure 10: TLV320AIC3104-Q1 Signal Path

The AIC3104 start-up sequence is important to ensure proper operation. The reset pin should be held low until all voltage rails are stable. Once they are stable, the reset pin can be raised high and programming can begin.

4.3 Power Design

The only external components necessary for the two LDOs are input and output capacitors. Input capacitors improve transient performance and can improve noise rejection. Output capacitors are necessary for stability.

The TPS7B6933-Q1 recommends that an input capacitor of at least 1uF is used, so a 10uF capacitor was used in this design. The voltage rating must be higher than the maximum input, so a 50V capacitor was used. The recommended output capacitor is between 2.2uF and 100uF with an equivalent series resistance (ESR) between 1mohm and 2 ohms. The 4.7uF tantalum TPSC475K035R0600 capacitor was chosen for this design. The TPS7B6933-Q1 has two package options. If the 40V input spec is needed, then the DCY package should be chosen.

The TPS76918-Q1 does not require an input capacitor, but recommends that at least a 0.047uF capacitor be used to improve noise rejection and transient response. For this design, a 0.1uF input capacitor was used. The output capacitor minimum is 4.7uF and must have an ESR between 0.2 and 10 ohms. The same output capacitor was used for this LDO, the 4.7uF tantalum TPSC475K035R0600 capacitor.

4.4 Special Considerations for EMC/EMI Design

The layout must be designed with EMC considerations. See the "Layout Recommendations" section for more information. Additionally, the TAS5411-Q1 switching frequency can be programmed to be either 400kHz or 500kHz. Changing the switching frequency is useful to shift where the emissions occur. If multiple devices in the system operate at the same frequency, then it is more difficult to pass the radiated emissions limits.

5 Getting Started Hardware

5.1 Architecture of TI Design Board

The hardware design includes the blocks discussed earlier as well as a USB controller to send I2C commands to the TAS5411-Q1 and the TLV320AIC3104-Q1. In the final system, this USB controller would be replaced with an automotive compatible MCU. Figure 11 shows the block diagram of the TI Design with the USB controller. When evaluating this design however, using the I2C bus is all that is needed, so any I2C controller can be used.

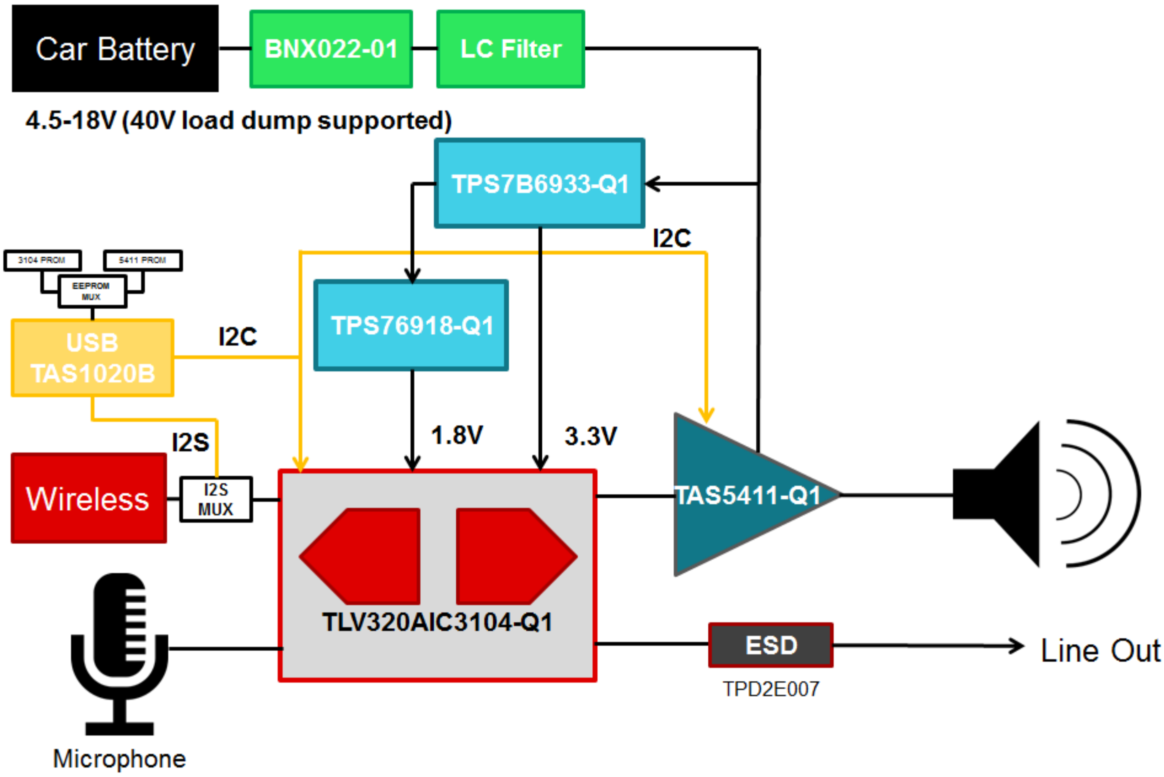


Figure 11: TIDA-00724 Block Diagram with USB Controller

5.2 Connectors

Table 3: Connector Descriptions

Designator	Name	Description
J1	Speaker Output	Connect the speaker load across pins 1 and 2 of J1
J2	Codec Reset Jumper	Open (default) – Reset signal will be pulled high, allowing the TLV320AIC3104-Q1 to operate normally Closed – Puts the TLV320AIC3104-Q1 into the reset state
J3	Channel 1 Inputs	Pin 1 – MIC1RM/LINE1RM Pin 2 – MIC1RP/LINE1RP Pin 3 – MIC1LM/LINE1LM Pin 4 – MIC1LP/LINE1LP
J4	External Mic Input	To use an external microphone, remove R16 and R17.
J5	VIN+	Power supply input (4.5-18V)
J6	PS GND	Power supply ground
J8	I2C	Connect to an external I2C bus
J9	USB	USB cable connects here
J10	MCLK	I2S bus MCLK
J11	BCLK	I2S bus BCLK
J12	WCLK	I2S bus WCLK
J13	SDIN	I2S bus SDIN

5.3 Configuring the Board

Either the on-board microphone (MK1) or an external microphone (J4) can be used with this design. If using the external microphone, R16 and R17 should be removed from the board. C26, C29, and C30 can be installed to reduce noise from the microphone but are not necessary for normal operation. Figure 12 shows the schematic for the microphone input.

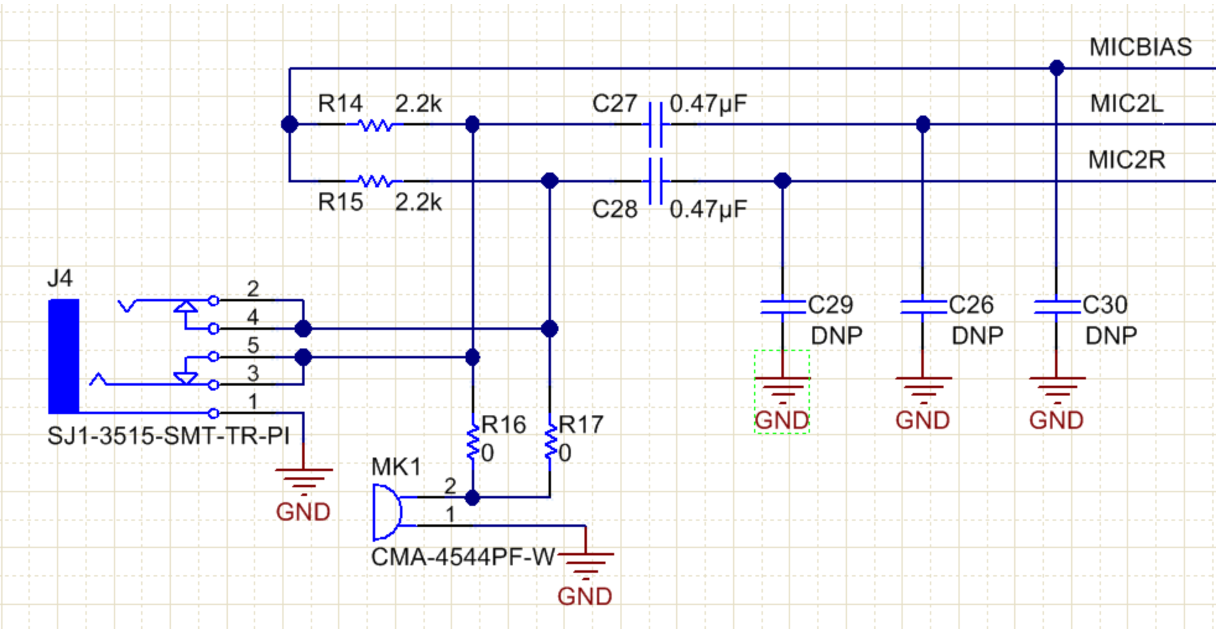


Figure 12: Schematic of Microphone Input

6 Getting Started Firmware

The PCM3070-K GUI was used to send the I2C commands. The format of the scripts is:
R/W I2C Address Register Address Data

6.1 Firmware for Bench Tests

I2C commands below show how to configure the TLV320AIC3104-Q1 for the signal path shown in Figure 10. This assumes that the master clock is 12.2880 MHz, so the PLL is not needed.

```
# MCLK = 12.2880 MHz
# reset
W 30 01 08

#connect MICBIAS to AVDD
W 30 19 C0

# Route Line2L to the Left ADC, then Power up Left ADC
W 30 11 0F
W 30 13 04

# Route Line2R to the Right ADC, then Power up Right ADC
W 30 12 F0
W 30 16 04

# Unmute Left PGA, set gain to 0 dB
W 30 0F 00
# Unmute Right PGA, set gain to 0dB
W 30 10 00

# Route Left data to Left DAC, Route Right data to Right DAC
W 30 07 0A
# Power up Left and Right DAC's
W 30 25 C0

# Unmute Left digital volume control, set gain to 0 dB
W 30 2B 00
# Unmute Right digital volume control, set gain to 0 dB
W 30 2C 00

# Route Left DAC output to Left line outs
W 30 52 80
# Route Right DAC output to Right Line outs
# W 30 5C 80

# Power up Left line out ± (differential), set gain to 0dB
W 30 56 09
# Power up Right line out ± (differential), set gain to 0 dB
#W 30 5D 09
```

7 Test Setup

Equipment:

- Audio Precision - AP2722 and PSIA
- Power Supply – 4.5V to 18V, 2.5A
- 4 ohm load, 10W
- Two multimeters

Bench Test Set-Up:

- PVDD = 14.4V
- 4 ohm load
- TLV320AIC3104-Q1 settings as shown in Section 6.1

CISPR-25 Radiated Emissions Test Set-Up:

- PVDD = 14.4V
- 1W output across 4 ohm load
- CISPR-25 Class 5 Radiated emissions set-up
- Request EMC test report from local TI representative.

8 Test Data

8.1 Audio Performance

THDN (Total Harmonic Distortion + Noise) is a measurement of how ideal a sine wave is. The 1kHz sine wave is generated by the Audio Precision instrument and sent over I2S to the TLV320AIC3104-Q1. The Audio Precision then measures the THDN of the analog signal across the 4 ohm load. Figure 13 shows the THDN versus output power across a 4 ohm load.

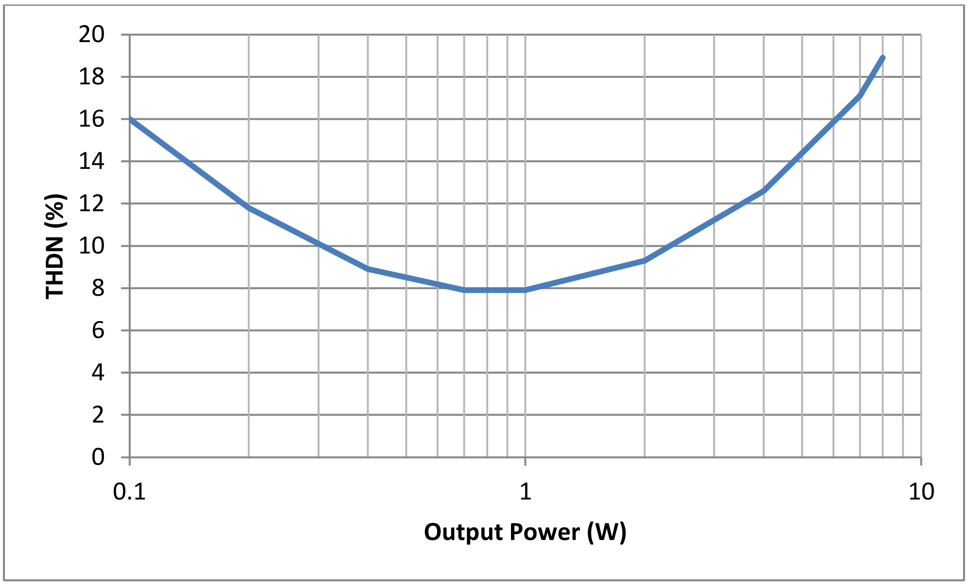
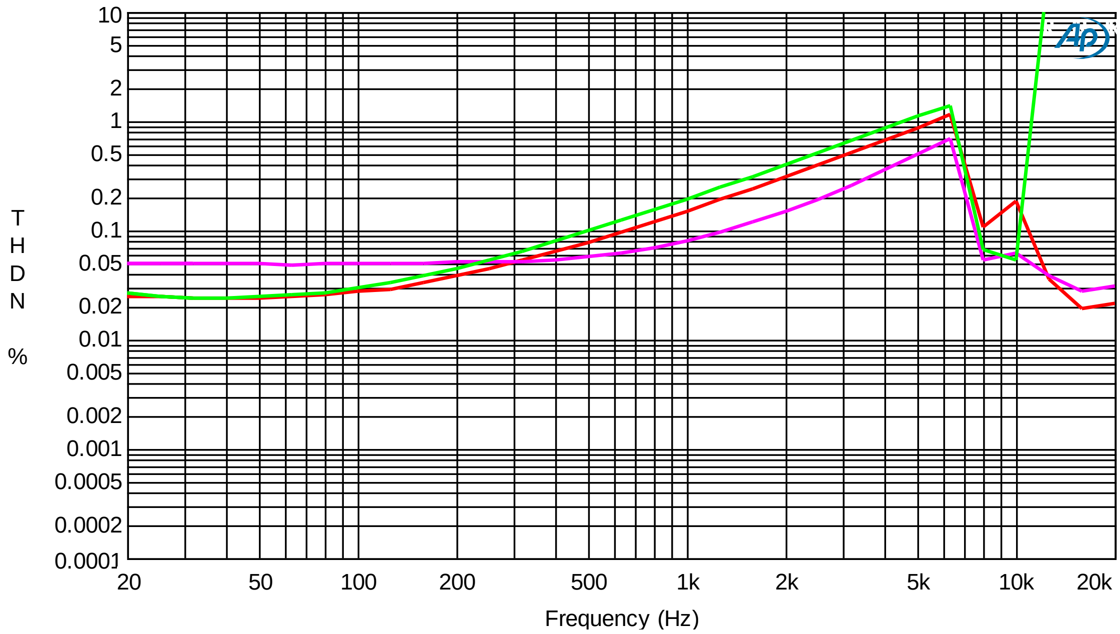


Figure 13: THDN vs Output Power, 4 Ohm Load, PVDD = 14.4V, 1kHz Sine Wave

THDN also varies with frequency. Figure 14 shows the THDN across frequency for three different output powers.



Sweep	Trace	Color	Line Style	Thick	Data	Axis	Comment
1	1	Green	Solid	2	Anlr.THD+N Ratio	Left	8W
2	1	Red	Solid	2	Anlr.THD+N Ratio	Left	5W
3	1	Magenta	Solid	2	Anlr.THD+N Ratio	Left	1W

Figure 14: THDN vs Frequency, 4 Ohm Load, PVDD = 14.4V

8.2 Power Tests

Class-D amplifiers are designed for efficiency at higher output powers. The switching losses and device current consumption remain about the same regardless of output power which results in low efficiency at low output power and higher efficiency as the output power increases. Figure 15 shows the efficiency versus output power for TIDA-00724.

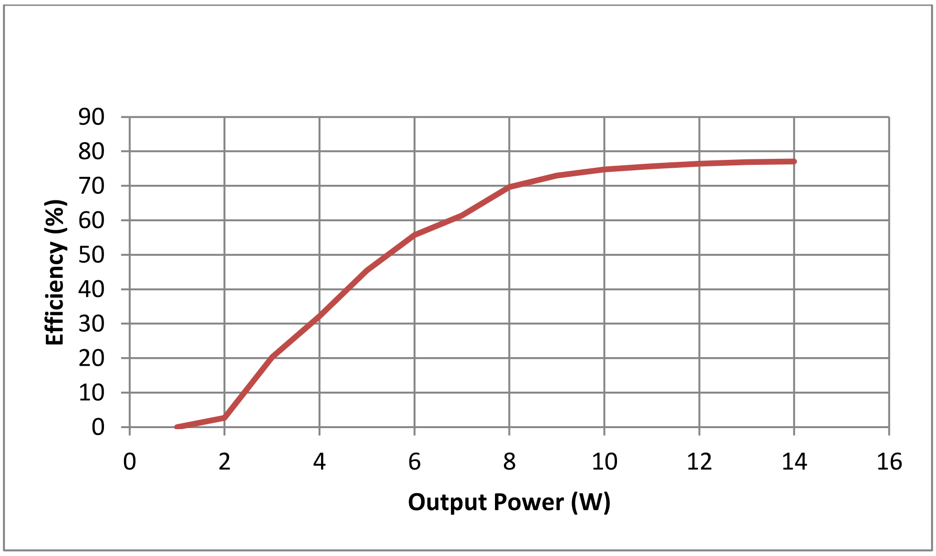


Figure 15: Efficiency vs Output Power, 4 Ohm Load, PVDD = 14.4V

At lower input voltage levels, the output signal can clip at higher output powers. This affects the THDN. Figure 16 shows the maximum output power versus the input voltage to achieve 1% or 10% THDN. Above 10V, 8W of output power is achievable at less than 1% THDN.

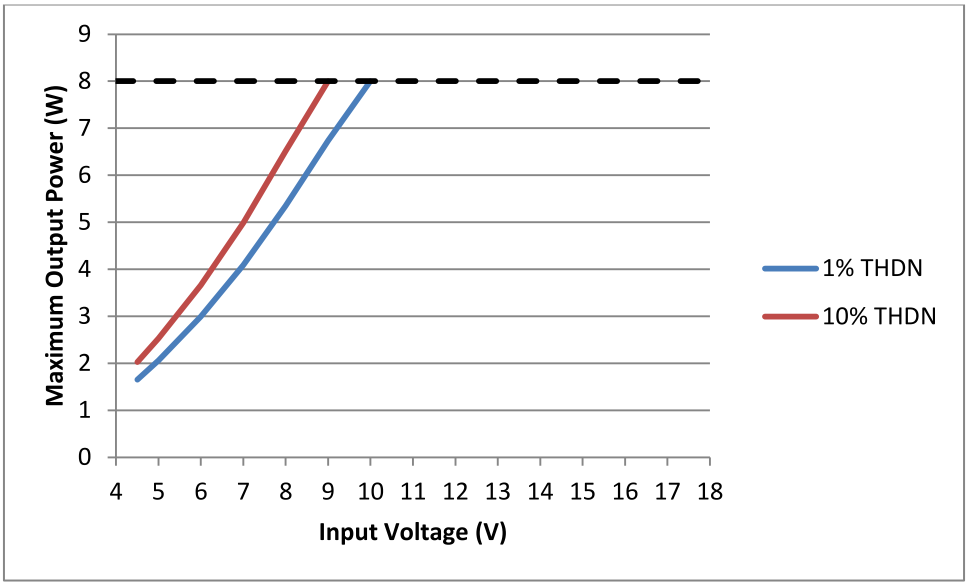


Figure 16: Maximum Output Power vs Input Voltage, 4 Ohm Load

8.3 EMC Results

The TIDA-00724 passes CISPR-25 Class 5 radiated emissions. Please contact local TI representative for a full EMC report.

9 Design Files

9.1 Schematics

To download the Schematics for each board, see the design files at http://www.ti.com/tool/TIDA-00724.

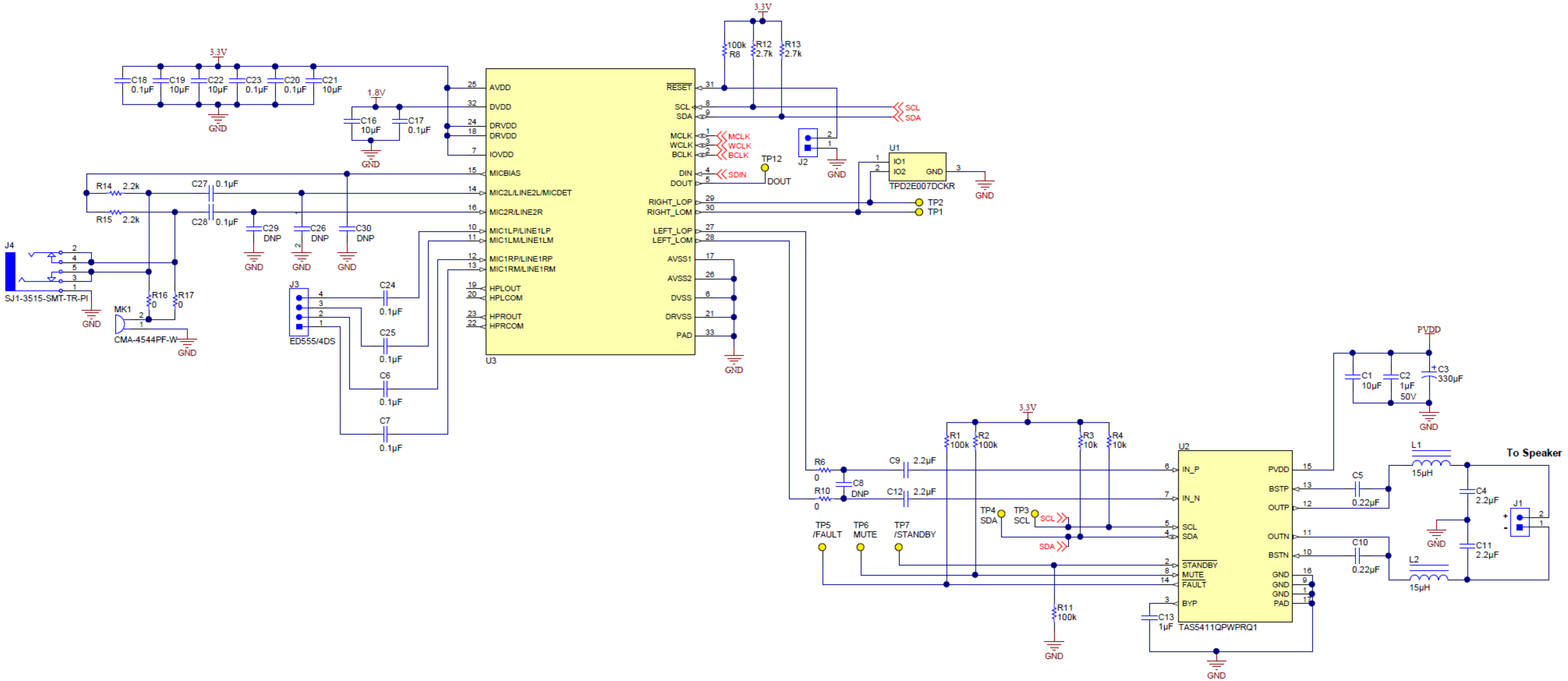


Figure 17: Audio Subsystem Schematic

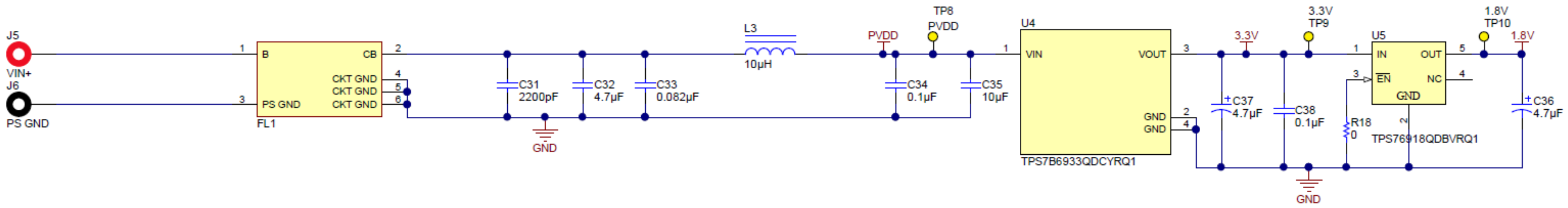


Figure 18: Power Schematic

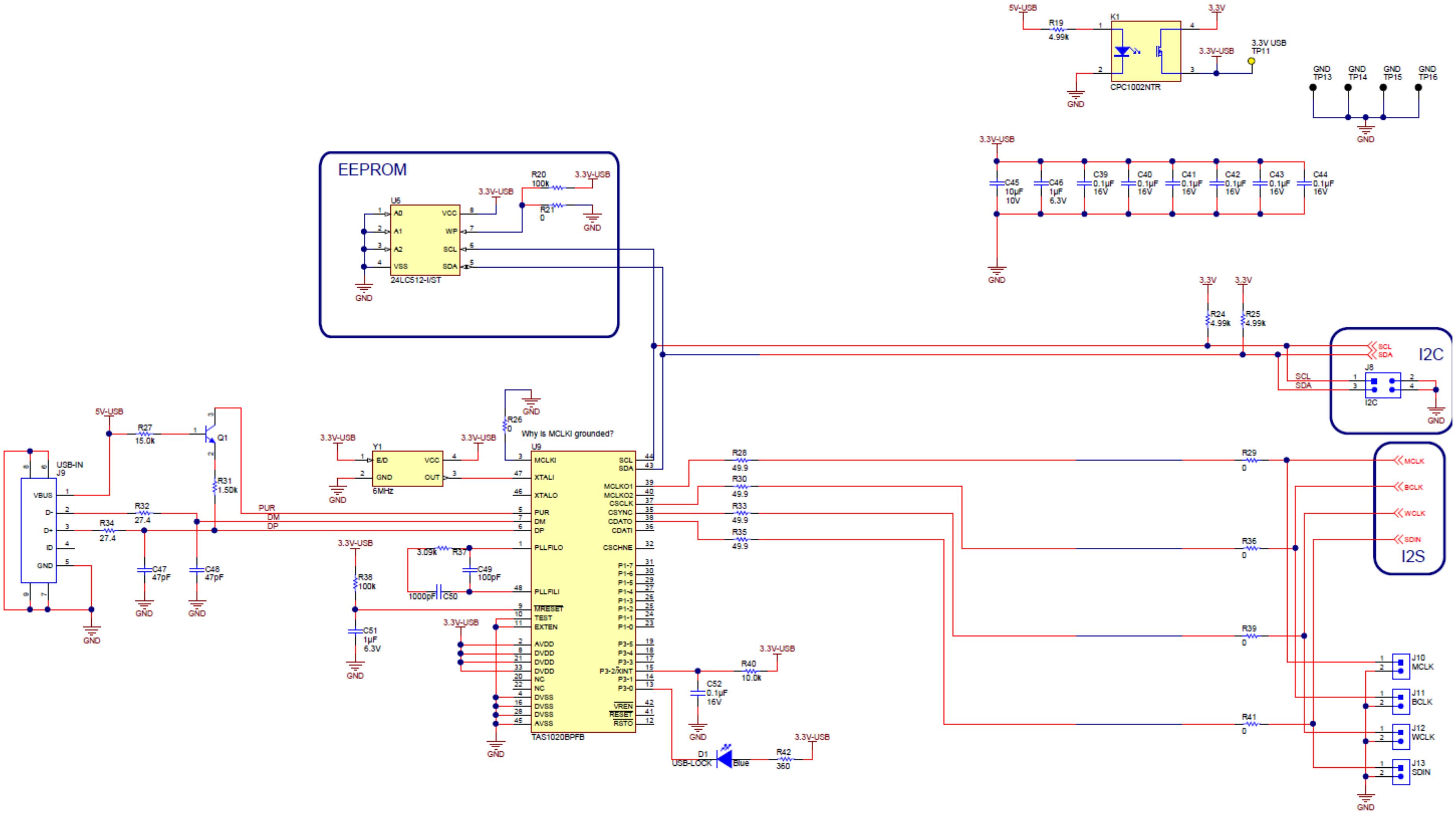


Figure 19: USB Controller Schematic

9.2 Bill of Materials

To download the Bill of Materials for this board, see the design files at http://www.ti.com/tool/TIDA-00724.

Table 4: TIDA-00724 Bill of Materials

Qty	Reference	Value	Part Description	Manufacturer	Manufacturer Part Number	PCB Footprint
1	!PCB1		Printed Circuit Board	Any	TIDA-00724	
5	C1, C16, C19, C21, C22	10uF	CAP, CERM, 10 µF, 6.3 V, +/- 10%, X5R, 0805	Kemet	C0805C106K9PAC	0805
2	C2, C13	1uF	CAP, CERM, 1uF, 50V, +/-10%, X7R, 0805	MuRata	GRM21BR71H105KA12L	0805
1	C3	330uF	CAP, AL, 330 µF, 50 V, +/- 20%, 0.028 ohm, TH	Chemi-Con	EKZE500ELL331MJ25S	D10xL25mm
4	C4, C9, C11, C12	2.2uF	CAP, CERM, 2.2uF, 16V, +/-10%, X7R, 0805	Taiyo Yuden	EMK212B7225KG-T	0805
2	C5, C10	0.22uF	CAP, CERM, 0.22 µF, 50 V, +/- 10%, X7R, 0603	TDK	C1608X7R1H224K080AB	0603
6	C6, C7, C24, C25, C27, C28	0.1uF	CAP, CERM, 0.1 µF, 100 V, +/- 10%, X7R, 0805	TDK	C2012X7R2A104K	0805
4	C17, C18, C20, C23	0.1uF	CAP, CERM, 0.1 µF, 16 V, +/- 10%, X7R, 0603	TDK	C1608X7R1C104K	0603
1	C31	2200pF	CAP, CERM, 2200 pF, 50 V, +/- 10%, X7R, 0603	MuRata	GRM188R71H222KA01D	0603
1	C32	4.7uF	CAP, CERM, 4.7 µF, 25 V, +/- 10%, X7R, 1206	MuRata	GRM31CR71E475KA88L	1206
1	C33	0.082uF	CAP, CERM, 0.082 µF, 25 V, +/- 10%, X7R, 0603	MuRata	GRM188R71E823KA01D	0603
2	C34, C38	0.1uF	CAP, CERM, 0.1 µF, 25 V, +/- 10%, X7R, 0603	MuRata	GRM188R71E104KA01D	0603
1	C35	10uF	CAP, CERM, 10 µF, 50 V, +/- 10%, X5R, 1206_190	MuRata	GRM31CR61H106KA12L	1206_190
2	C36, C37	4.7uF	CAP, TA, 4.7 µF, 35 V, +/- 10%, 0.6 ohm, SMD	AVX	TPSC475K035R0600	6032-28
7	C39, C40, C41, C42, C43, C44, C52	0.1uF	CAP, CERM, 0.1uF, 16V, +/-10%, X7R, 0402	MuRata	GRM155R71C104KA88D	0402
1	C45	10uF	CAP, CERM, 10uF, 10V, +/-20%, X5R, 0603	TDK	C1608X5R1A106M	0603
2	C46, C51	1uF	CAP, CERM, 1uF, 6.3V, +/-20%, X5R, 0402	TDK	C1005X5R0J105M	0402
2	C47, C48	47pF	CAP, CERM, 47pF, 25V, +/-5%, C0G/NP0, 0402	MuRata	GRM1555C1E470JA01D	0402
1	C49	100pF	CAP, CERM, 100pF, 50V, +/-5%, C0G/NP0, 0402	MuRata	GRM1555C1H101JA01D	0402
1	C50	1000pF	CAP, CERM, 1000pF, 50V, +/-5%, C0G/NP0, 0402	MuRata	GRM1555C1H102JA01D	0402
1	D1	Blue	LED, Blue, SMD	Rohm	SMLP12BC7TT86	Blue LED

1	FL1	1MHZ-1GHZ	Filter, EMI, 10A 50V 1MHZ-1GHZ SMD	MuRata	BNX022-01L	12.1x3.1x9.1
4	H1, H2, H3, H4		Machine Screw, Round, #4-40 x 1/4, Nylon, Philips panhead	B&F Fastener Supply	NY PMS 440 0025 PH	Screw
4	H5, H6, H7, H8		Standoff, Hex, 0.5"L #4-40 Nylon	Keystone	1902C	Standoff
1	J1		Terminal Block, 6A, 3.5mm Pitch, 2-Pos, TH	On-Shore Technology	ED555/2DS	7.0x8.2x6.5mm
5	J2, J10, J11, J12, J13		Header, 100mil, 2x1, Gold, TH	Sullins Connector Solutions	PBC02SAAN	Sullins 100mil, 1x2, 230 mil above insulator
1	J3		Terminal Block, 6A, 3.5mm Pitch, 4-Pos, TH	On-Shore Technology	ED555/4DS	14x8.2x6.5mm
1	J4		Audio Jack, 3.5mm, Stereo, R/A, Pink, SMT	CUI Inc.	SJ1-3515-SMT-TR-PI	Audio Jack, 15x5x9.5mm SMT
1	J5		BANANA JACK, SOLDER LUG, RED, TH	Tenma	SPC15363	Red Insulated Banana Jack
1	J6		BANANA JACK, SOLDER LUG, BLACK, TH	Tenma	SPC15354	Black Insulated Banana Jack
1	J8		Header, 100mil, 2x2, Tin, TH	Sullins Connector Solutions	PEC02DAAN	Header, 2x2, 2.54mm, TH
1	J9		Connector, Receptacle, Micro-USB Type AB, R/A, Bottom Mount SMT	JAE Electronics	DX4R205JJAR1800	Connector, USB Micro AB
1	K1		Relay, SPST-NO (1 Form A), 0.7 A, , SMD	IXYS	CPC1002NTR	4.089x3.81mm
2	L1, L2	15uH	Inductor, Shielded, Metal Composite, 15 µH, 2.7 A, 0.179 ohm, AEC-Q200 Grade 1, SMD	Toko	DFEG7030D-150M	7x6.6mm
1	L3	10uH	Inductor, Shielded E Core, Ferrite, 10 µH, 7.2 A, 0.01 ohm, SMD	Coilcraft	SER1360-103KLB	SER1360
1	MK1		Microphone, Electret Condenser, Omnidirectional, -44 dB, TH	CUI Inc.	CMA-4544PF-W	THD, 2-Leads, Dia 9.85mm, Pin Spacing

						2.54mm
1	Q1	0.3V	Transistor, NPN, 40V, 0.15A, SOT-23	Fairchild Semiconductor	MMBT2222A	SOT-23
4	R1, R2, R8, R11	100k	RES, 100k ohm, 5%, 0.1W, 0603, RES, 100k ohm, 5%, 0.1W, 0603, RES, 100 k, 5%, 0.1 W, 0603, RES, 100k ohm, 5%, 0.1W, 0603	Vishay-Dale	CRCW0603100KJNEA	0603
2	R3, R4	10k	RES, 10k ohm, 5%, 0.1W, 0603	Vishay-Dale	CRCW060310K0JNEA	0603
4	R6, R10, R16, R17	0	RES, 0, 5%, 0.1 W, 0603	Rohm	MCR03EZPJ000	0603
2	R12, R13	2.7k	RES, 2.7 k, 5%, 0.1 W, 0603	Yageo America	RC0603JR-072K7L	0603
2	R14, R15	2.2k	RES, 2.2 k, 5%, 0.1 W, 0603	Yageo America	RC0603JR-072K2L	0603
1	R18	0	RES, 0, 5%, 0.063 W, 0402	Panasonic	ERJ-2GE0R00X	0402
1	R19	4.99k	RES, 4.99 k, 1%, 0.1 W, 0603	Vishay-Dale	CRCW06034K99FKEA	0603
2	R20, R38	100k	RES, 100k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW0402100KFKED	0402
2	R21, R26	0	RES, 0, 5%, 0.1 W, 0603	Vishay-Dale	CRCW06030000Z0EA	0603
2	R24, R25	4.99k	RES, 4.99k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04024K99FKED	0402
1	R27	15.0k	RES, 15.0k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW040215K0FKED	0402
4	R28, R30, R33, R35	49.9	RES, 49.9 ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW040249R9FKED	0402
4	R29, R36, R39, R41	0	RES, 0, 5%, 0.063 W, 0402	Vishay-Dale	CRCW04020000Z0ED	0402
1	R31	1.50k	RES, 1.50k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04021K50FKED	0402
2	R32, R34	27.4	RES, 27.4 ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW040227R4FKED	0402
1	R37	3.09k	RES, 3.09k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04023K09FKED	0402
1	R40	10.0k	RES, 10.0 k, 1%, 0.063 W, 0402	Vishay-Dale	CRCW040210K0FKED	0402
1	R42	360	RES, 360 ohm, 5%, 0.063W, 0402	Vishay-Dale	CRCW0402360RJNED	0402
12	TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP8, TP9, TP10, TP11, TP12	Yellow	Test Point, Compact, Yellow, TH	Keystone	5009	Yellow Compact Testpoint
4	TP13, TP14, TP15, TP16	Black	Test Point, Compact, Black, TH	Keystone	5006	Black Compact Testpoint
1	U1		ESD Protection Array for AC Signal Data Interface, 2	Texas	TPD2E007DCKR	DCK0003A

			Channels, -40 to +85 degC, 3-pin SC70 (DCK), Green (RoHS & no Sb/Br)	Instruments		
1	U2		8-W Mono Automotive Digital-Audio Amplifier With Load Dump and I2C Diagnostics, PWP0016B	Texas Instruments	TAS5411QPWPRQ1	PWP0016B
1	U3		LOW-POWER STEREO AUDIO CODEC, RHB0032E	Texas Instruments	6PAIC3104IRHBRQ1	RHB0032E
1	U4		High Voltage Ultra Low Iq - Low Drop Out Regulator, DCY0004A	Texas Instruments	TPS7B6933QDCYRQ1	DCY0004A
1	U5		Single Output Automotive LDO, 100 mA, Fixed 1.8 V Output, 2.7 to 10 V Input, 5-pin SOT-23 (DBV), -40 to 125 degC, Green (RoHS & no Sb/Br)	Texas Instruments	TPS76918QDBVRQ1	DBV0005A
1	U6		EEPROM, 512KBIT, 400KHZ, 8TSSOP	Microchip	24LC512-I/ST	TSSOP-8
1	U9	TAS1020BPFB	IC, USB Streaming Controller	TI	TAS1020BPFB	PQFP48
1	Y1		Oscillator, 6MHz, 3.3V, SMD	CTS Electrocomponents	625L3I006M00000	2.5x1x2.5mm

9.3 PCB Layout Recommendations

There are three things to consider when layout out the PCB: thermal dissipation, electromagnetic emissions, and signal integrity. All three of these considerations are especially critical when designing the layout around the TAS5411-Q1.

The TAS5411-Q1 can drive up to 10W of power through a load. While the TAS5411-Q1 is efficient, some losses will dissipate as heat. The thermal pad on the bottom of the TAS5411-Q1 must be connected to a ground plane through vias directly below the thermal pad. Additionally, there should be a ground plane on the top layer with enough space around the TAS5411-Q1 to help dissipate the heat.

Electromagnetic emissions can occur because of the switching waveforms of the Class-D amplifier output drivers. Reducing the area of these switching nodes and providing low inductance current paths will reduce unwanted emissions. In particular, the traces from the outputs to the LC filter should be kept short, with a compact route back to ground.

Signal integrity is important in the path from the audio codec to the class-D amplifier inputs. This is a differential analog signal. To protect it from unwanted noise, it is best if the traces from the audio codec can be kept short and for the traces to be routed directly above a ground plane, without any digital signals crossing on the other layers.

9.3.1 Layout Prints

To download the Layout Prints for each board, see the design files at http://www.ti.com/tool/TIDA-00724.

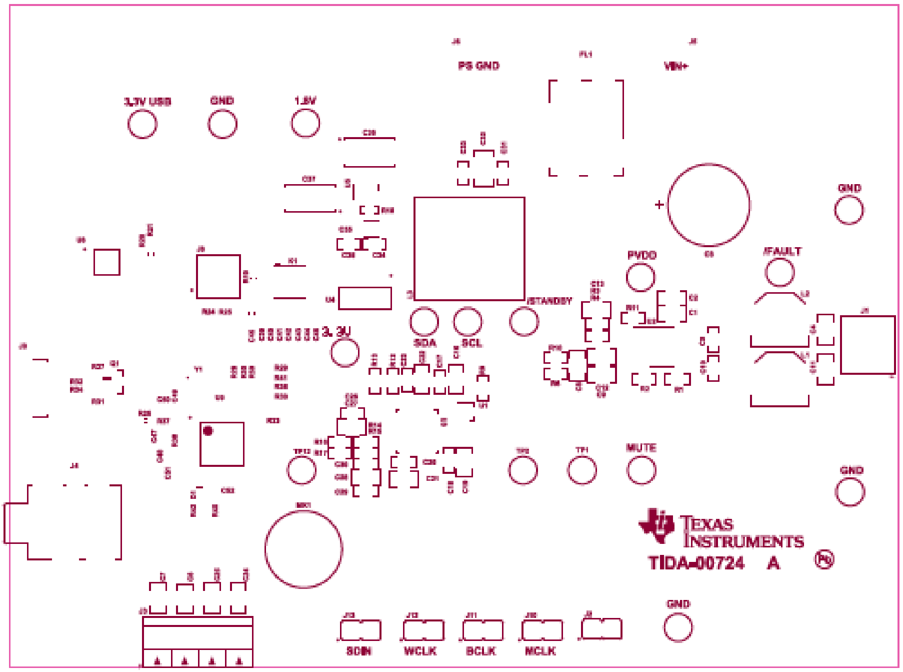


Figure 20: Top Silk Screen

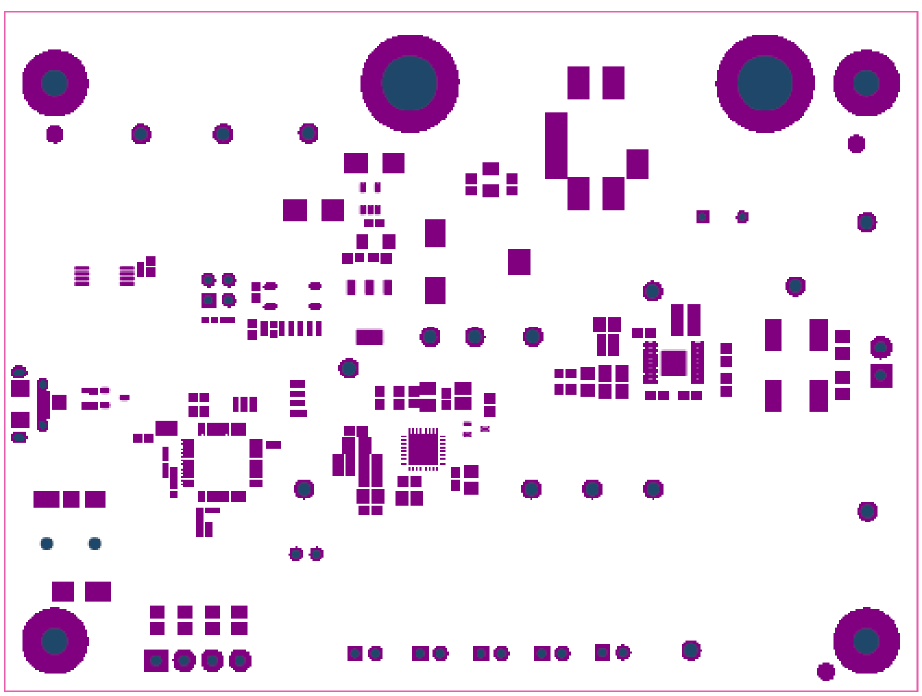


Figure 21: Top Solder Mask

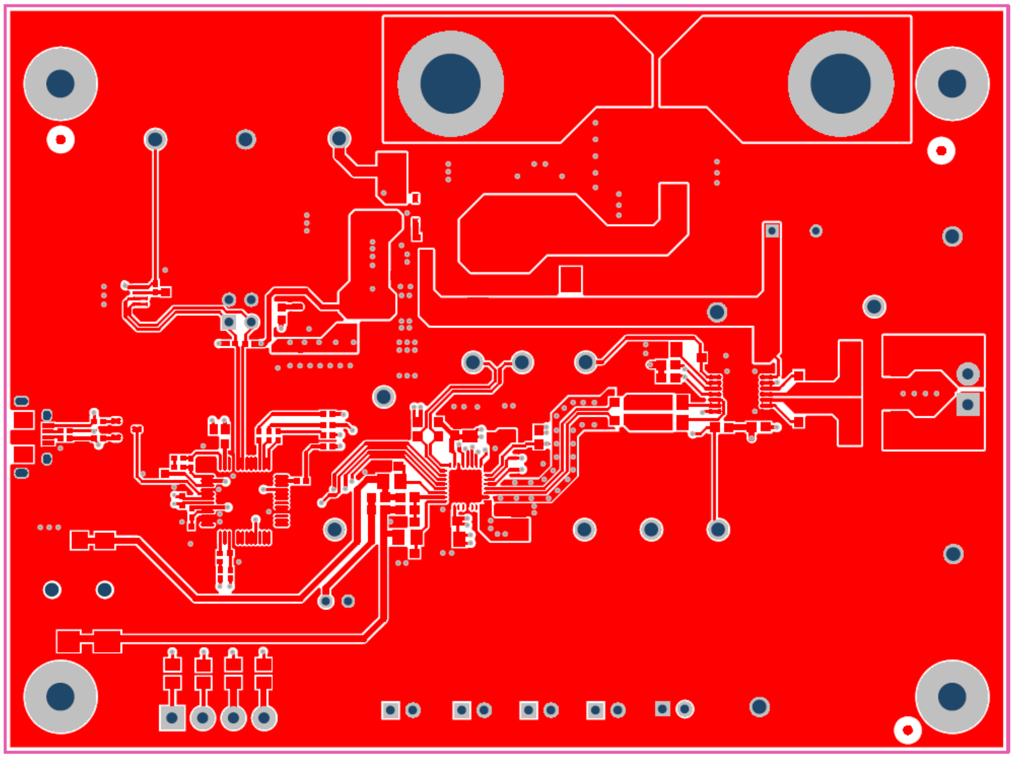


Figure 22: Top Layer

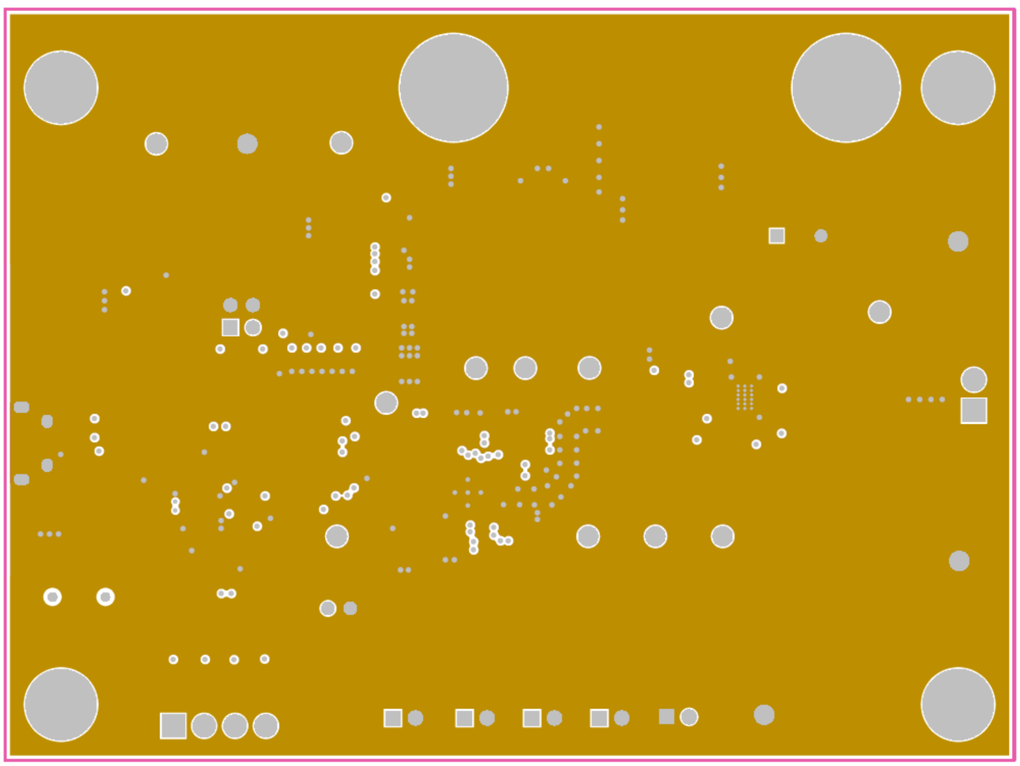


Figure 23: Signal Layer 1

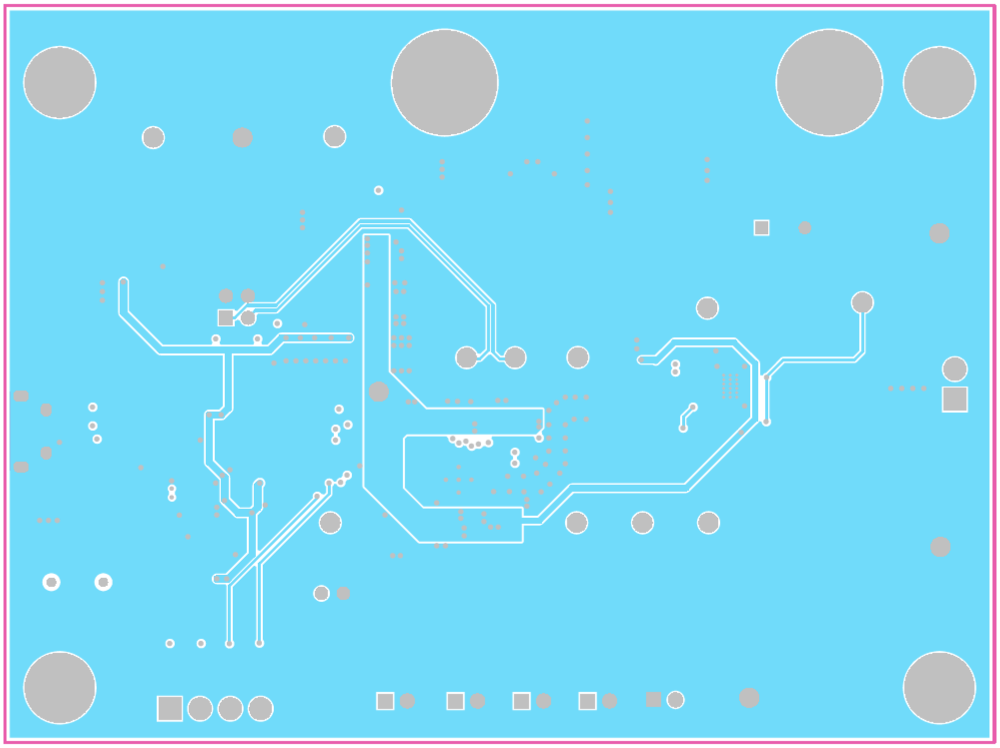


Figure 24: Signal Layer 2

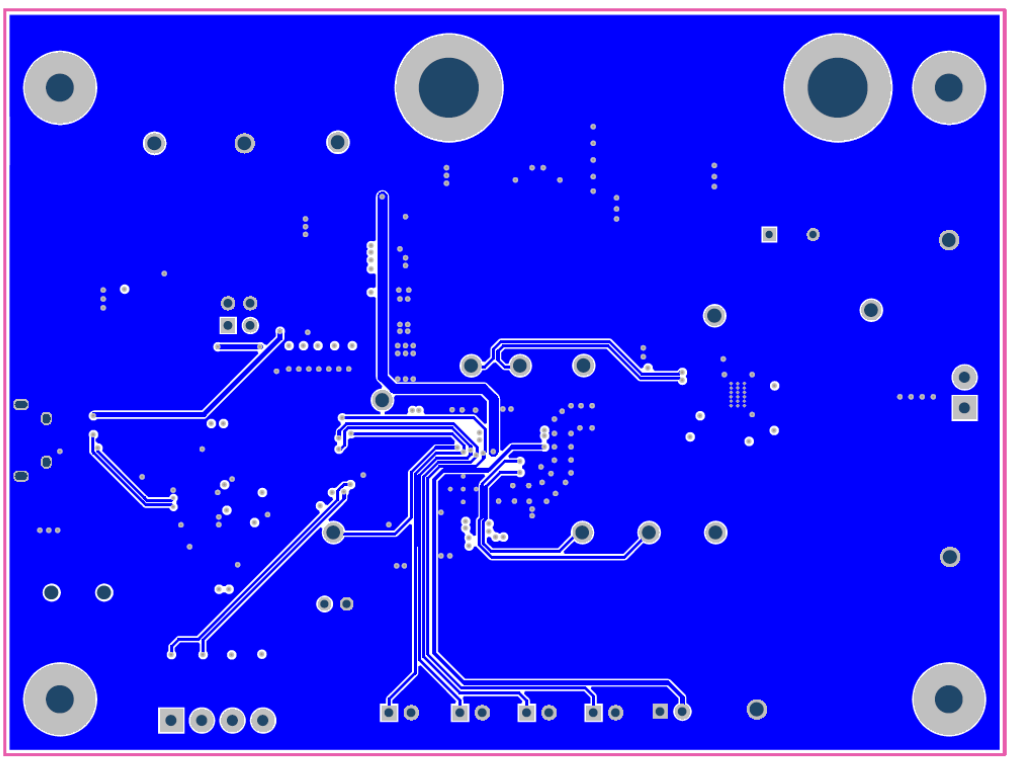


Figure 25: Bottom Layer

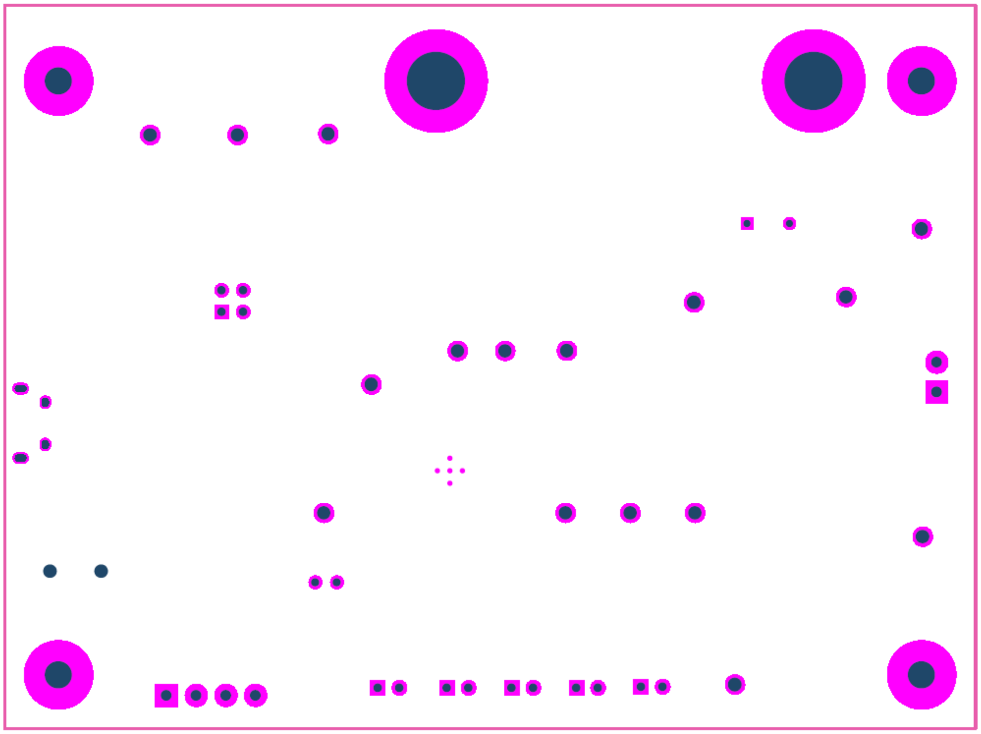


Figure 26: Bottom Solder Mask

Figure 27: Board Dimensions

9.4 Altium Project

To download the Altium project files for each board, see the design files at http://www.ti.com/tool/TIDA-00724.

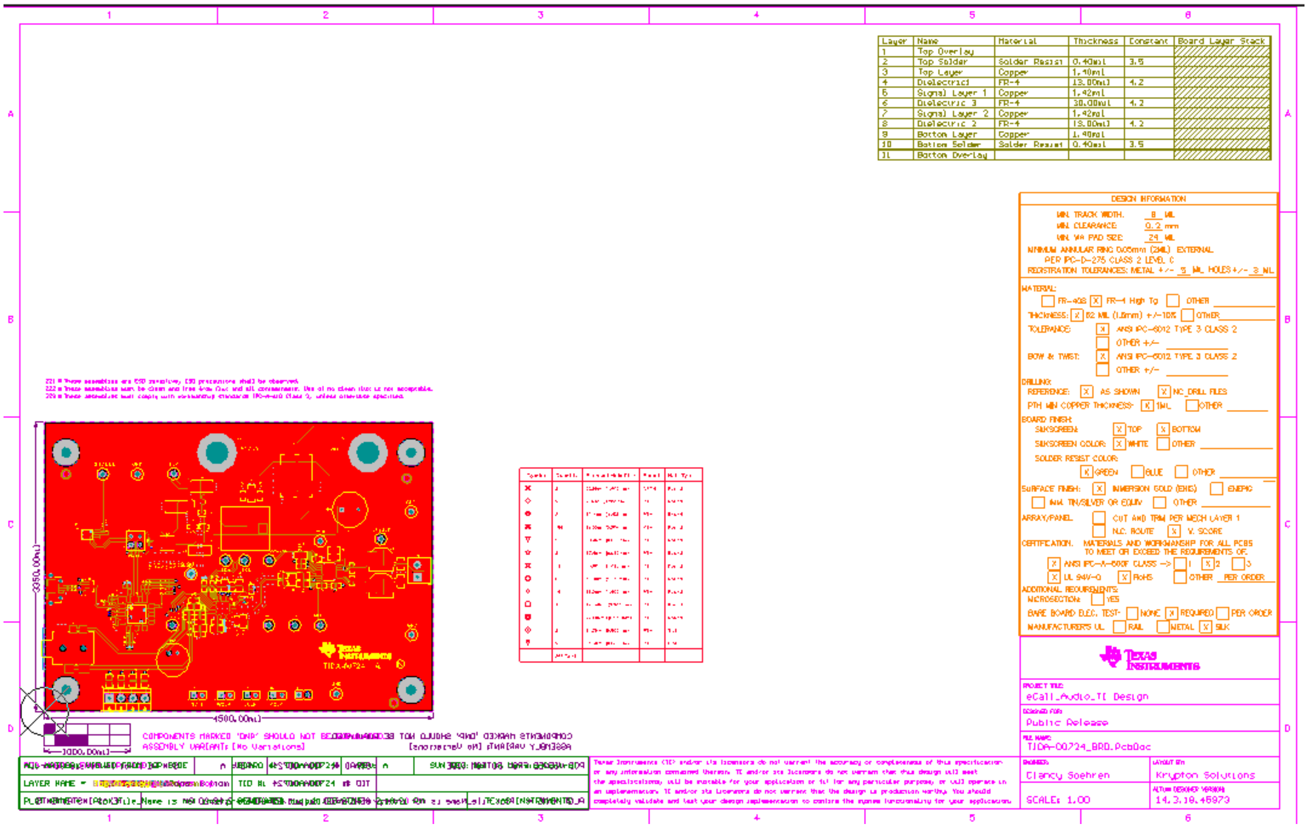


Figure 28: Altium Project

9.5 Gerber files

To download the Gerber files for each board, see the design files at http://www.ti.com/tool/TIDA-00724

9.6 Assembly Drawings

To download the Assembly Drawings for each board, see the design files at http://www.ti.com/tool/TIDA-00724.

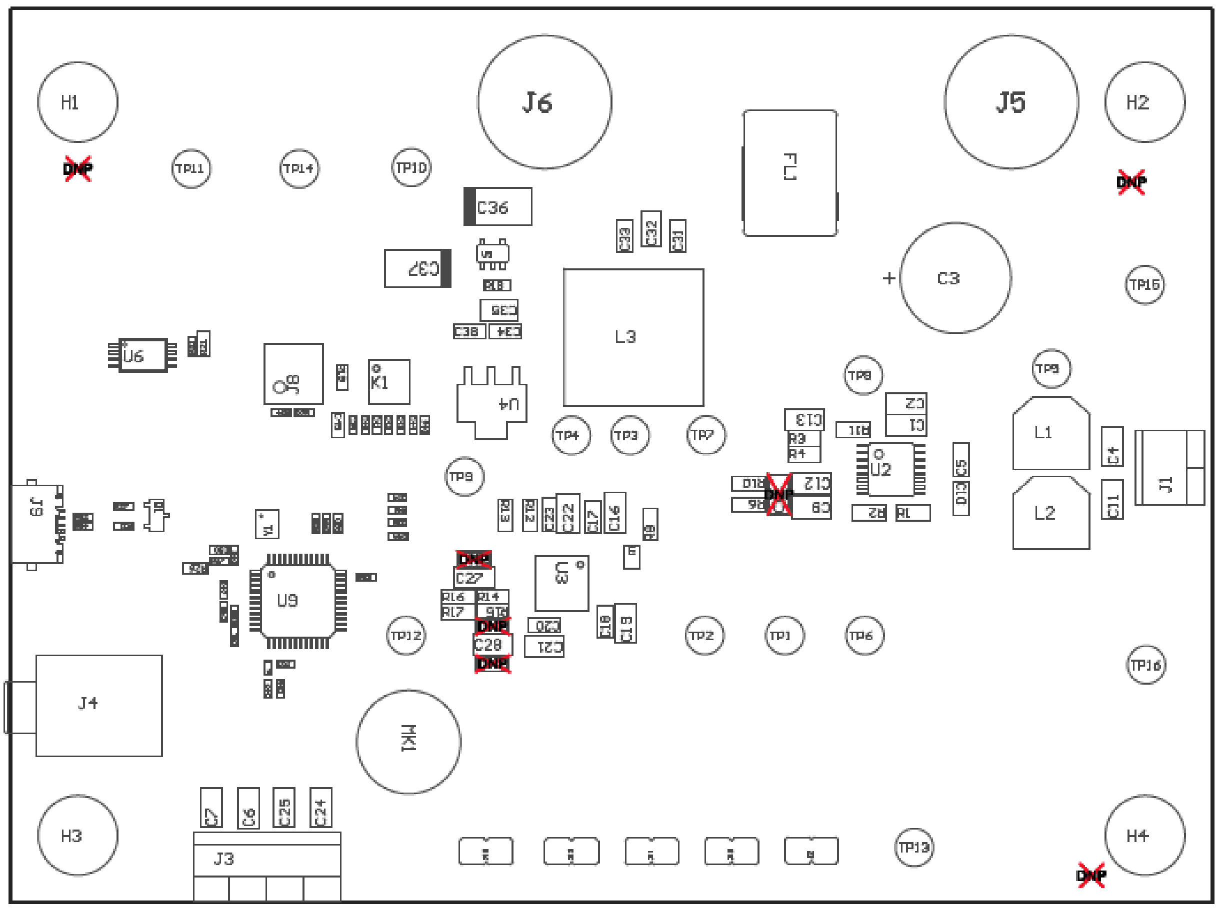


Figure 29: Assembly Drawing

10 References

1. Class-D LC Filter Design, SLOA119B
2. TLV320AIC3104 Programming Made Easy, SLAA403
3. Texas Instruments E2E Community, http://e2e.ti.com/

11 Terminology

THDN: Total Harmonic Distortion + Noise

12 About the Author

Brian Rodriguez is a Product Marketing Engineer at Texas Instruments where he is responsible for automotive amplifiers and data converters. Brian earned his BS in Industrial Engineering at Texas A&M University in College Station, TX.

Clancy Soehren is an Applications Engineer at Texas Instruments, where she is responsible for automotive amplifiers and data converters. Clancy earned her Master of Electrical and Computer Engineering (MECE) from Rose Hulman Institute of Technology in Terre Haute, IN.

IMPORTANT NOTICE FOR TI REFERENCE DESIGNS