TI Designs: TIDA-00724
車載緊急通話 (eCall) オーディオ・サブシステムのリファレンス・デザイン

TEXAS INSTRUMENTS

概要

車載緊急通報 (eCall) システムには効率性と診断機能が必要なため、オーディオ・サブシステムにもスピーカー診断機能や低消費電力など固有の要件が存在します。このデザインでは、TI 製の車載用 2 チャネル・オーディオ・コーデックと Class-D オーディオ・アンプを使用して eCall アプリケーションを作成する方法を紹介します。このリファレンス・デザインでは、TI 製ソリューションの重要な設計要素および利点として、低消費電力と高効率、大音量で明瞭なオーディオ出力、内蔵の診断および保護機能についても示します。

リソース

TIDA-00724	デザイン・フォルダ
TAS5411-Q1	プロダクト・フォルダ
TLV320AIC3104-Q1	プロダクト・フォルダ
TPD2E007	プロダクト・フォルダ
TPS709-Q1	プロダクト・フォルダ
TPS7B69-Q1	プロダクト・フォルダ

E2E™エキスパートに質問

特長

- CISPR-25 Class 5 放射エミッション制限に合格
- 4Ω負荷へ 8W の出力電力
- スピーカー診断および保護機能を内蔵
- TLV320AIC3104-Q1 用のレジスタ設定を内蔵

アプリケーション

- 緊急通話 (eCall)
- テレマティクス制御ユニット
- 車載用ゲートウェイ
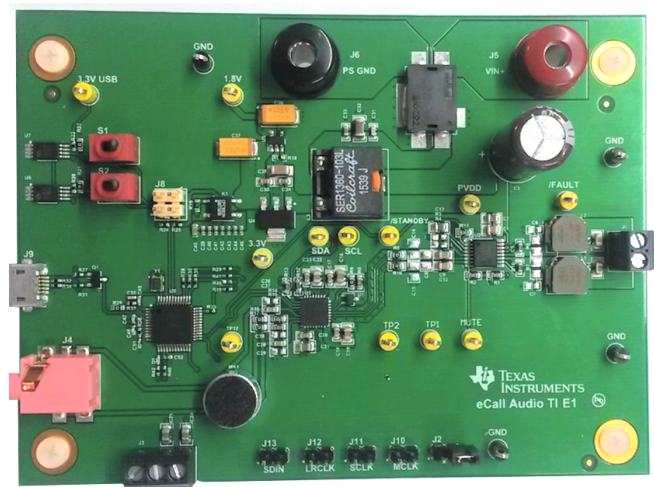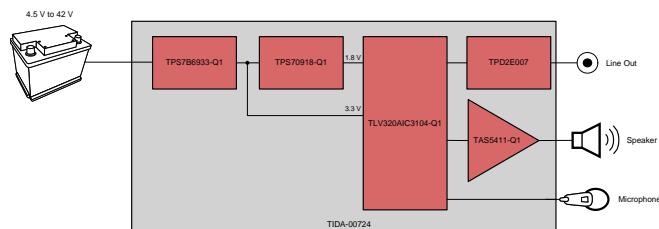
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1   System Description

## 1.1   Key System Specifications

表 1. Key System Specifications

PARAMETER	SPECIFICATIONS	MINIMUM	TYPICAL	MAXIMUM	UNIT
Input voltage	12-V car battery	4.5	14.4	40	V
Standby current	TAS5411-Q1 Standby mode, TLV320AIC3104-Q1 reset		6		uA
Speaker load		2	4	6	Ω
Output power	4-Ω Load			8	W
ESD protection on line out	IEC 61000-4-2 contact		±8		kV
	IEC 61000-4-2 air-gap		±15		
Audio input/output	Digital audio I²S input, speaker output microphone input, digital audio I²S output				
ESD protection	ESD protection needed on line output				
EMC/EMI requirements	CISPR-25 class 5 radiated emissions				
Operating temperature		-40		85	ºC
Form factor	3.35 in x 4.5 in				

2   System Overview

Governing bodies around the world have implemented specific legislation to require automotive companies to install emergency call (eCall) systems 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 図 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.

図 1. System Integration of eCall Subsystem
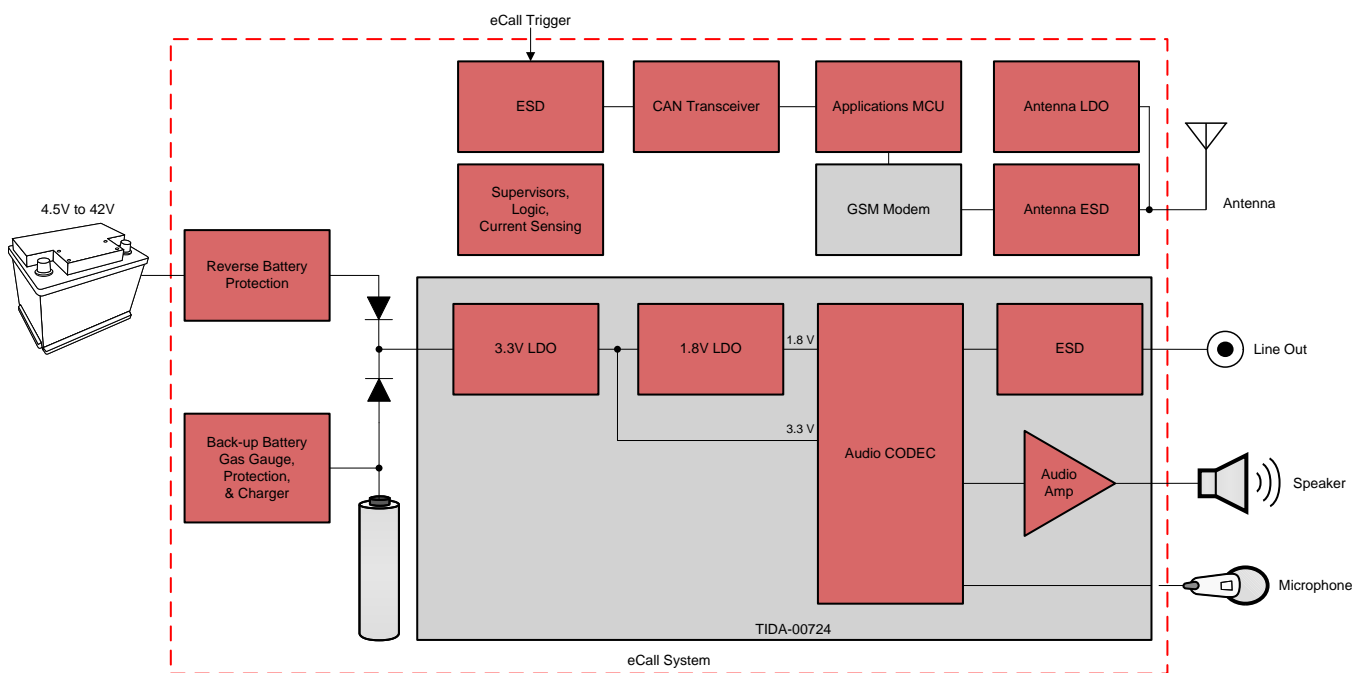
The audio subsystem consists of a class-D audio amplifier and an audio codec. The audio codec connects the digital audio input from the connectivity module to the class-D amplifier which drives the speaker. The codec must also convert the microphone inputs to a digital signal to communicate back to the connectivity module.

2.1 Block Diagram

図 2. TIDA-00724 Block Diagram
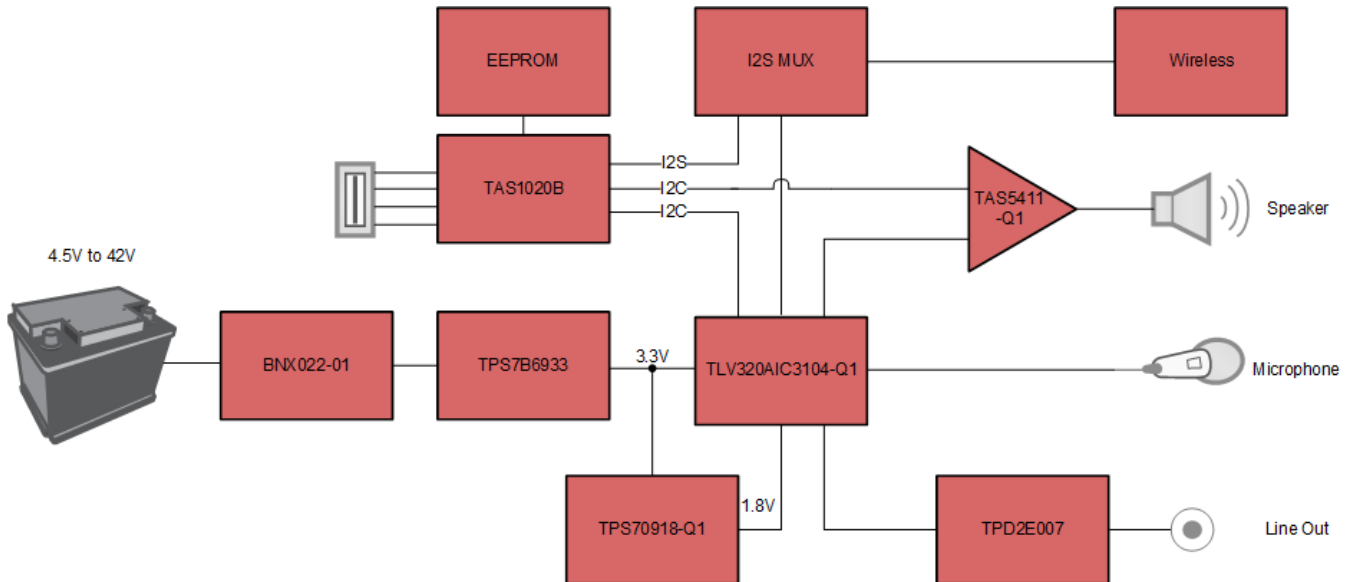
2.2 Design Considerations

2.3 Highlighted Products

2.3.1 TAS5411-Q1 8-W Mono Automotive Class-D Audio Amplifier With Load Dump and I2C Diagnostics

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 8 W 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 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 through I2C register read. The load diagnostic function runs on deassertion of STANDBY or when the device is in a fault state such as 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. The load diagnostic test takes approximately 229 ms to run. 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 event. The load diagnostic for open load only has I2C reporting. All other faults have I2C and FAULT pin assertion.
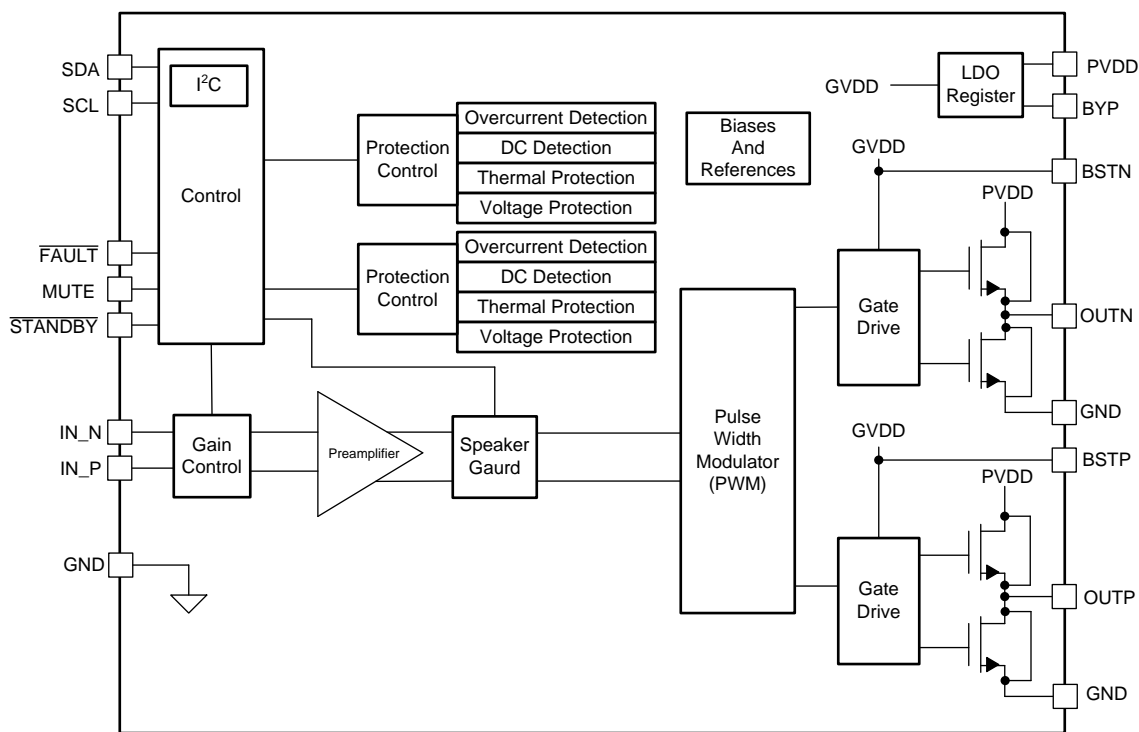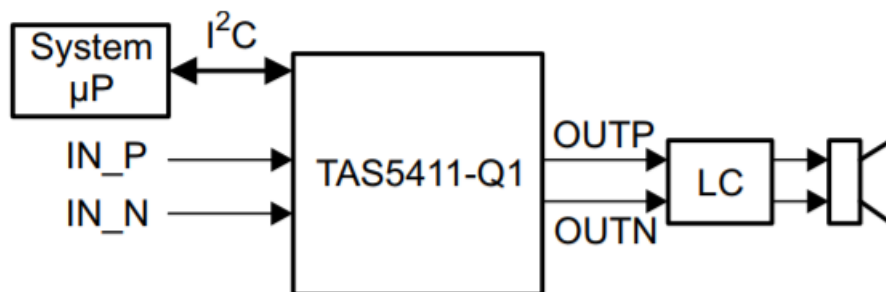
図 3. TAS5411-Q1 Functional Block Diagram

図 4. TAS5411-Q1 Simplified Block Diagram

2.3.2 TLV320AIC3104-Q1 Low-Power Stereo Audio Codec for Infotainment and Cluster

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 headphones using AC-coupling capacitors, or stereo 16-Ω headphones, in a capless output configuration. These parameters enable the TLV320AIC3104-Q1 to act as an interface between the MCU and speaker amplifiers, such as the TPA3111D1-Q1, in various audio applications in the infotainment and cluster fields.

The stereo audio DAC supports sampling rates from 8 kHz to 96 kHz and includes programmable digital filtering in the DAC path for 3D, bass, treble, midrange effects, speaker equalization, and de-emphasis for 32-kHz, 44.1-kHz, and 48-kHz sample rates. The stereo audio ADC supports sampling rates from 8 kHz to 96 kHz and is preceded by programmable gain amplifiers (PGA) or an automatic gain control (AGC) circuit that can provide up to 59.5-dB analog gain for low-level microphone inputs. The TLV320AIC3104-Q1 provides an extremely high range of programmability for both attack (8 ms to 1,408 ms) and for decay (0.05 s to 22.4 s). This extended AGC range allows the AGC to be tuned for many types of applications.

Where neither analog nor digital signal processing are required, the device can be put in a special analog signal passthrough mode. This mode significantly reduces power consumption, as most of the device is powered down during this passthrough operation.

The serial control bus supports the I2C protocol, whereas the serial audio data bus is programmable for I 2S, 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-Q1 operates from an analog supply of 2.7 V to 3.6 V, a digital core supply of 1.525 V to 1.95 V, and a digital I/O supply of 1.1 V to 3.6 V.

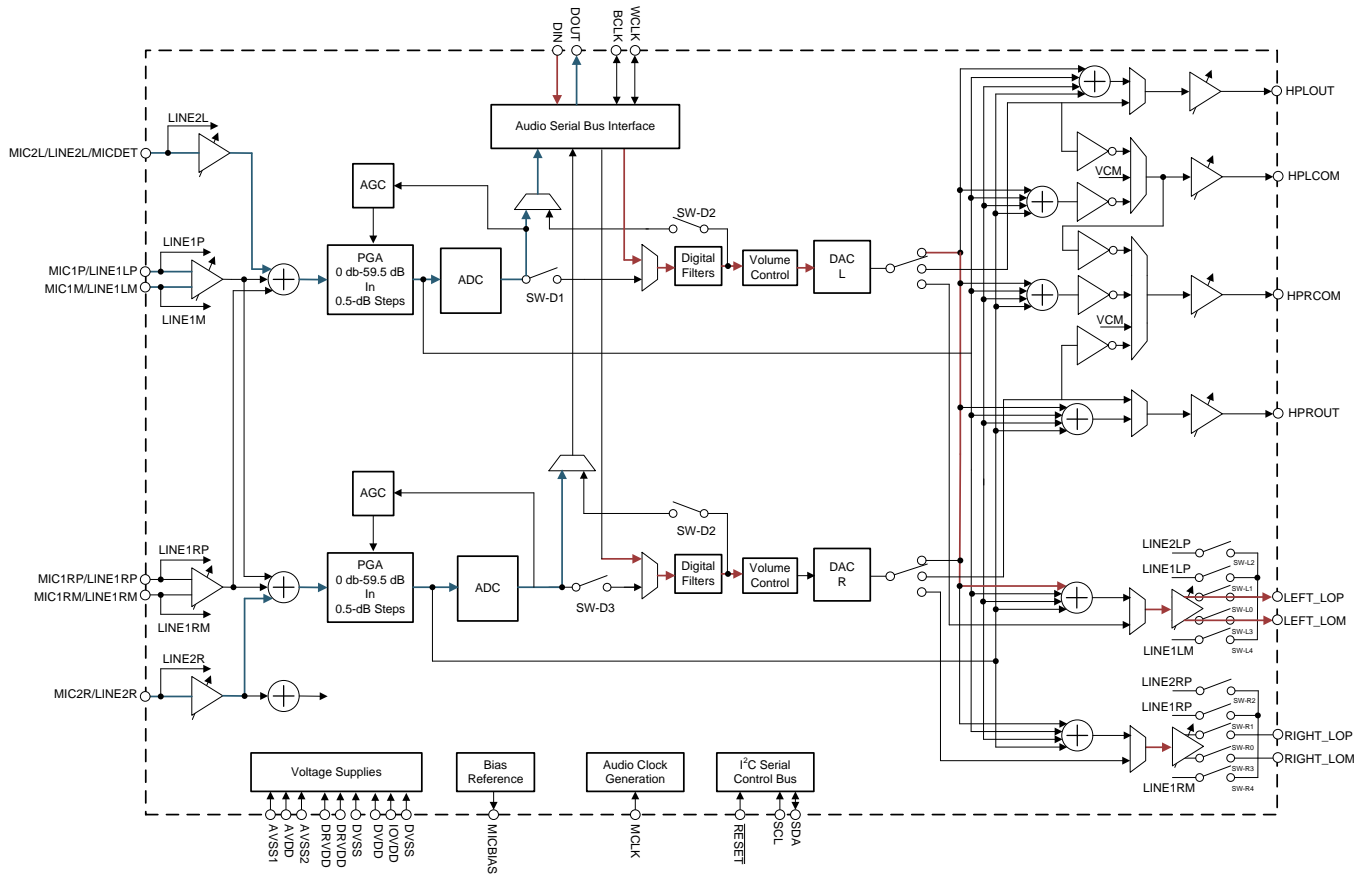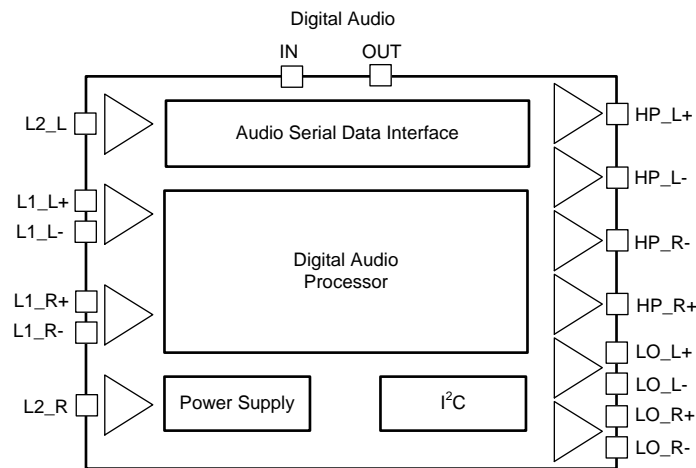## 図 5. TLV320AIC3104-Q1 Functional Block Diagram

図 5. TLV320AIC3104-Q1 Functional Block Diagram

図 6. TLV320AIC3104-Q1 Simplified Diagram

図 6. TLV320AIC3104-Q1 Simplified Diagram

2.3.3 TPS7B69-Q1 High-Voltage Ultra-Low IQ Low-Dropout Regulator

The TPS7B69xx-Q1 high-voltage linear regulator operates over a 4-V to 40-V input voltage range. With only 15-µA (typical) quiescent current at light load, the device is suitable for standby microcontrol-unit systems especially in automotive applications. The device has an output current capability of 150 mA and offers fixed output voltages of 2.5 V (TPS7B6925-Q1), 3.3 V (TPS7B69-Q1) or 5 V (TPS7B6950-Q1). The device features a thermal shutdown and short-circuit protection to prevent damage during overtemperature and overcurrent conditions.

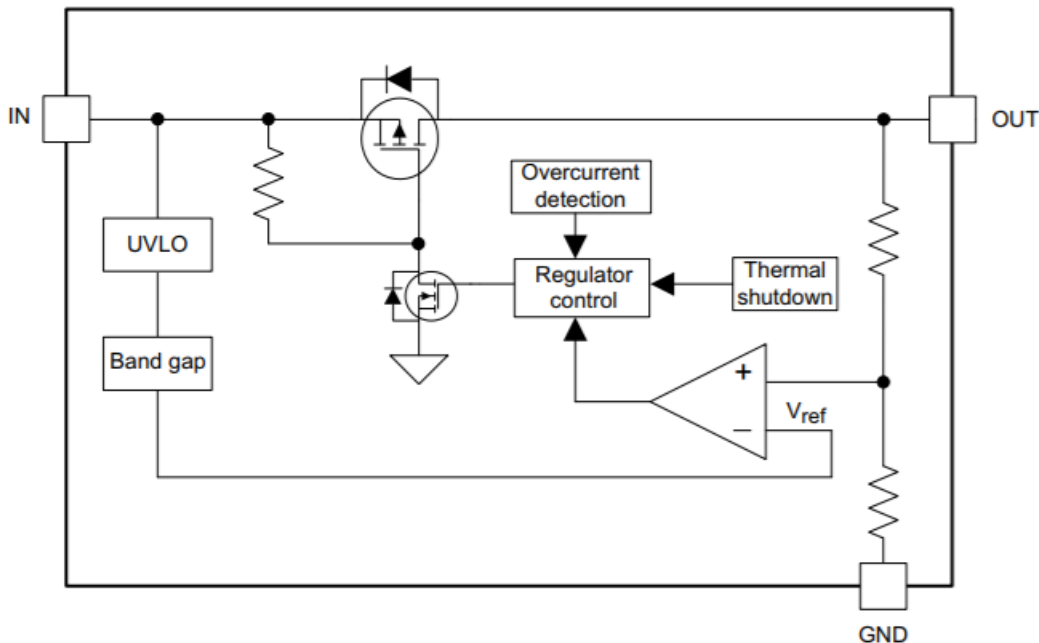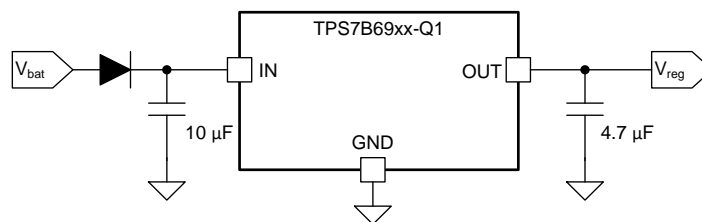図 7. TPS7B69-Q1 Functional Diagram

図 8. TPS7B69-Q1 Simplified Schematic

2.3.4 TPS709-Q1 150-mA 30-V Ultra-Low-IQ Wide-Input Low-Dropout (LDO) Regulator With Reverse Current Protection

The TPS709 series of linear regulators are ultra-low, quiescent current devices designed for power-sensitive applications. A precision band-gap and error amplifier provides 2% accuracy over temperature. Quiescent current of only 1 µA makes these devices ideal solutions for battery-powered, always-on systems that require very little idle-state power dissipation. These devices have thermal-shutdown, current-limit, and reverse-current protections for added safety.

Shutdown mode is enabled by pulling the EN pin low. The shutdown current in this mode goes down to 150 nA, typical.

The TPS709 series is available in WSON-6 and SOT-23-5 packages.

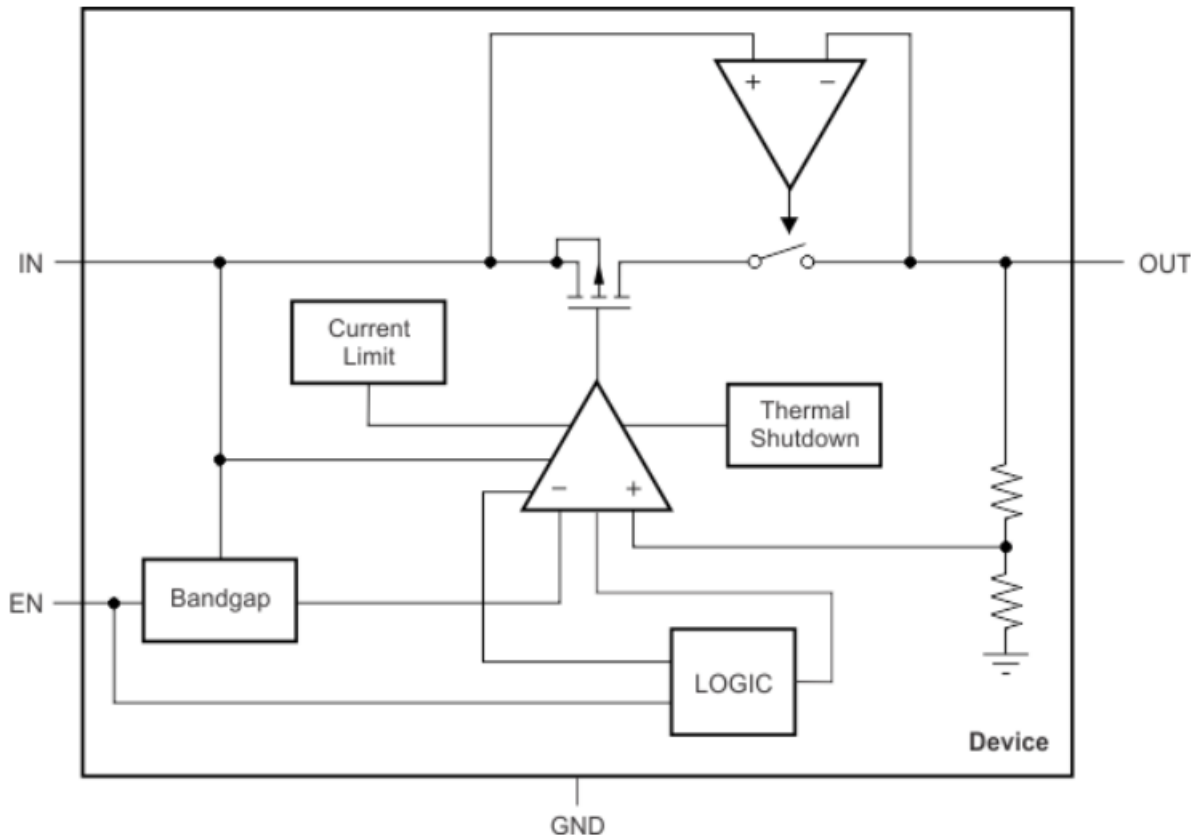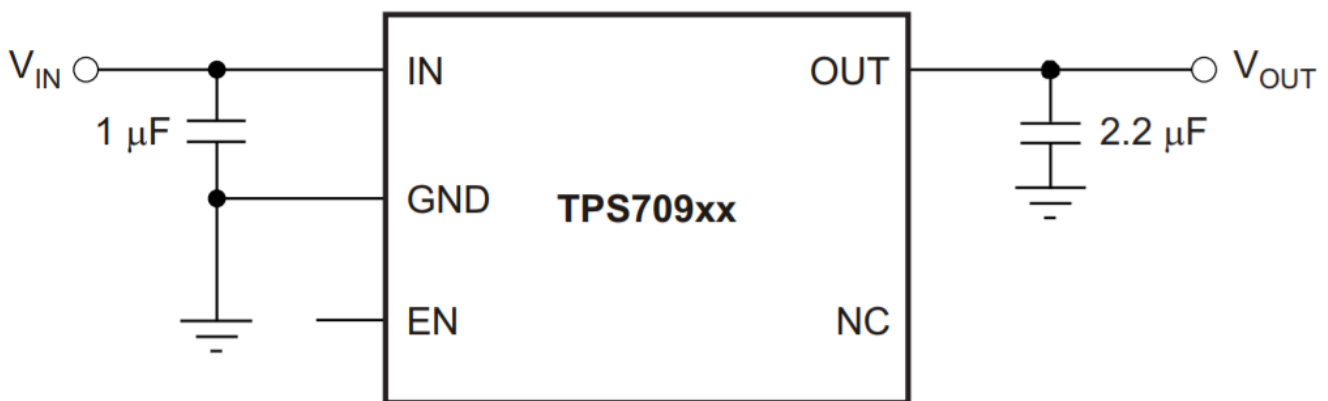図 9. TPS709-Q1 Functional Block Diagram

図 10. TPS709-Q1 Simplified Schematic

2.3.5　TPD2E007 2-Channel ESD Protection Array for AC-Coupled and Negative-Rail Data Interfaces

This device is a transient voltage suppressor (TVS) based electrostatic discharge (ESD) protection device designed to offer system-level ESD solutions for a 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, and so forth) 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 (YFM), with only a 0.15-mm (maximum) package height, is recommended for ultra space-saving applications where the package height is a key concern. The PicoStar package can be used in either embedded printed-circuit board (PCB) applications or in surface-mount applications. The industry standard SOT package offers a straightforward board layout option in legacy designs.

図 11. TPD2E007 Simplified Schematic
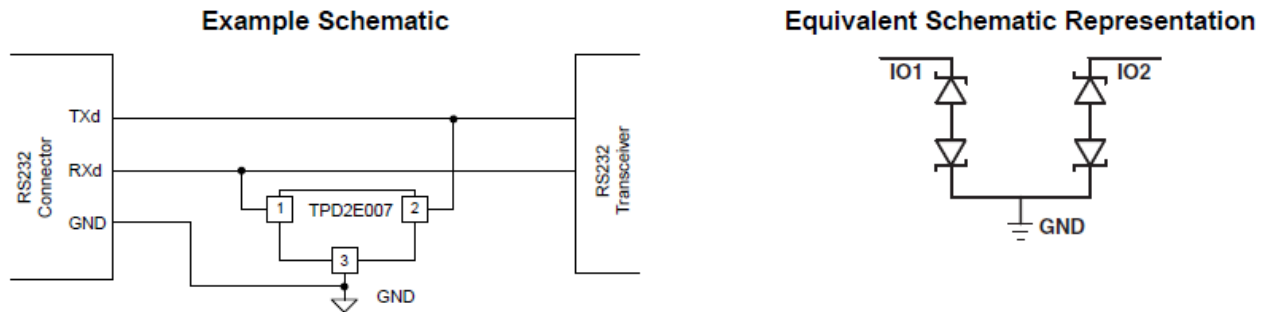
2.4 System Design Theory

2.4.1 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 design was tested for radiated emissions according to CISPR-25.

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 that they know that the speaker does not work. This coverage also helps to retrieve 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 I2C. 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 40-V load dump, which means that the only external protection necessary when operating off of the battery is a reverse battery protection diode.

2.4.2 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, 図 12 shows an LC reconstruction filter with common-mode and differential capacitors and RC snubbers.

図 12. Class-D Amplifier LC Filter With RC Snubber
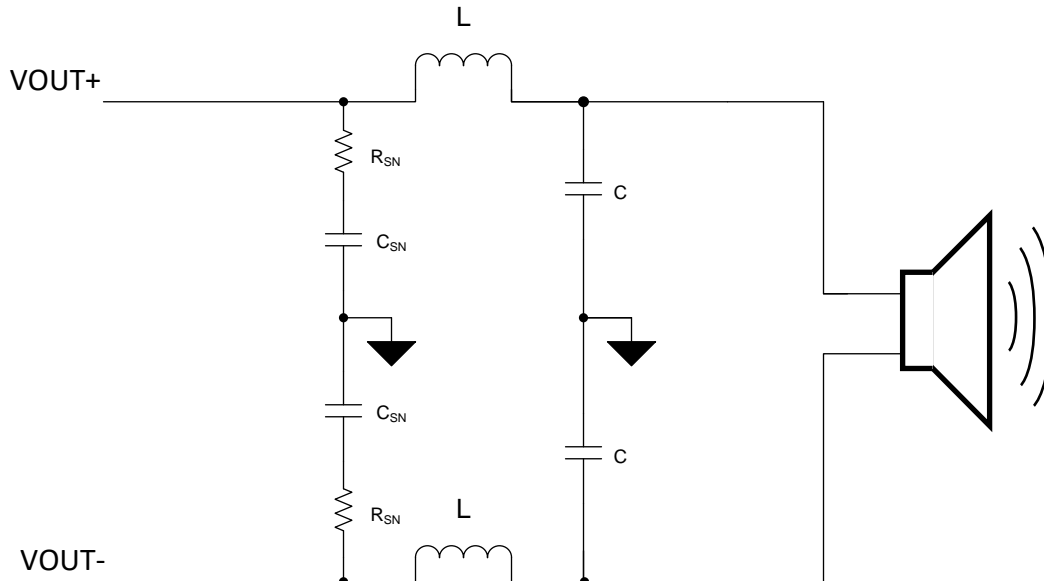
The RC snubbers help reduce electromagnetic emissions, however, they are not needed for many applications. The radiated emissions testing done on this design did not use the RC snubbers. 図 13 shows the output filter without the RC snubber network.

図 13. Class-D Amplifier LC Filter
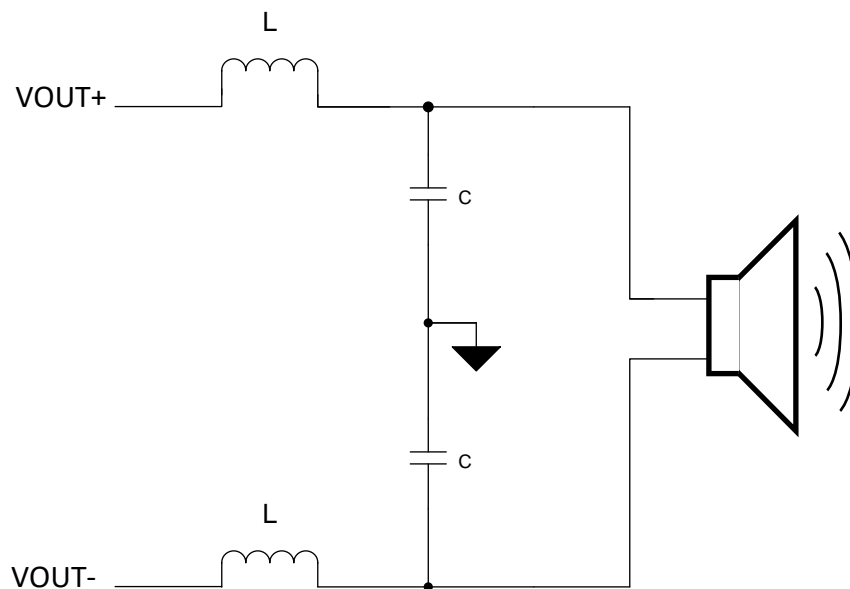
When designing the output filter, consider the filter as two single-ended outputs. For this reason, R_L is considered to be 2-Ω instead of 4-Ω in the following design equations. A second order Butterworth filter provides a flat passband response and a reasonable sharp roll off. The filter should be critically damped, which occurs when:

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

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

$$Q = R_L \times \sqrt{\frac{C}{L}}$$
(2)

$$\omega_c^2 = \frac{1}{C \times L}$$
(3)

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

$$L = \frac{R_L \times \sqrt{2}}{\omega_c}$$
(4)

$$L = \frac{2\Omega \times \sqrt{2}}{2 \times \pi \times 30kHz} = 15\mu H$$
(5)

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 2.4 A. 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 design is the DFEG7030D-150M which is magnetically shielded, has low DC resistance, and has a typical saturation current of 3.2 A.

The capacitors should be chosen using the following equation:

$$C = \frac{1}{\omega_c \times R_L \times \sqrt{2}}$$
(6)

$$C = \frac{1}{2 \times \pi \times 30kHz \times 4 \times \sqrt{2}} = 1.88\mu F$$
(7)

To improve EMC performance, the cutoff frequency can be lowered slightly more by raising the capacitor slightly. For this design, a capacitor of 2.2 μF was used, which results in the frequency response shown in 図 14.

図 14. Frequency Response of LC Filter, L = 15 μH, C = 2.2 μF, R = 2-Ω Single Ended
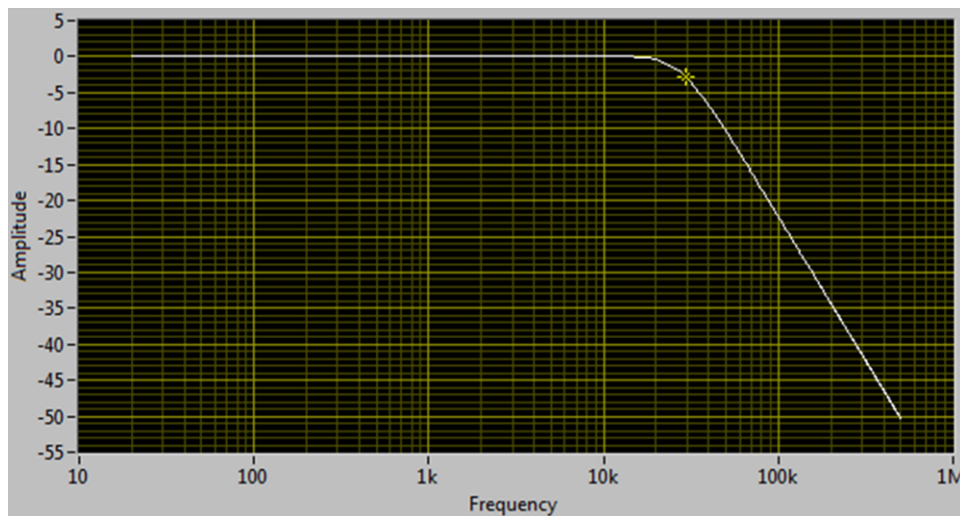
While this change assists with EMC performance, it does drop the gain at 20 kHz to 2 dB instead of 1 dB. Tradeoffs must be made between audio quality and EMC testing.

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

For the full derivation of the design equations see the LC filter design application report.

2.4.3 Codec Design

2.4.4 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 TPS7B69-Q1 recommends that an input capacitor of at least 1 µF is used, so a 10-µF capacitor was used in this design. The voltage rating must be higher than the maximum input, so a 50-V capacitor was used. The recommended output capacitor is between 2.2 µF and 100 µF with an equivalent series resistance (ESR) between 1 mΩ and 2 Ω. The 4.7-µF tantalum TPSC475K035R0600 capacitor was chosen for this design. The TPS7B69-Q1 has two package options. If the 40-V input specification is needed, then the DCY package should be chosen.

The TPS709-Q1 does not require an input capacitor, but TI recommends that at least a 0.1-µF to 2.2-µF capacitor be used to improve noise rejection and transient response. For this design, a 0.1-µF input capacitor was used. The output capacitor minimum is 1.5 µF for output voltages greater than 1.5 V and must have an ESR between 0 Ω and 200 mΩ. The same output capacitor was used for this LDO, the 4.7-µF tantalum TPSC475K035R0600.

2.4.5 EMC/EMI Design Considerations

The layout must be designed with EMC considerations. See 4.3 for more information. Additionally, the TAS5411-Q1 switching frequency can be programmed to be either 400 kHz or 500 kHz. 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.

3 Hardware, Testing Requirements, and Test Results

3.1 Getting Started Hardware

3.1.1 Board Connection

The hardware design includes the blocks discussed previously 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. 図 15 shows the block diagram of the 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.

**図 15. TIDA-00724 Full Block Diagram**
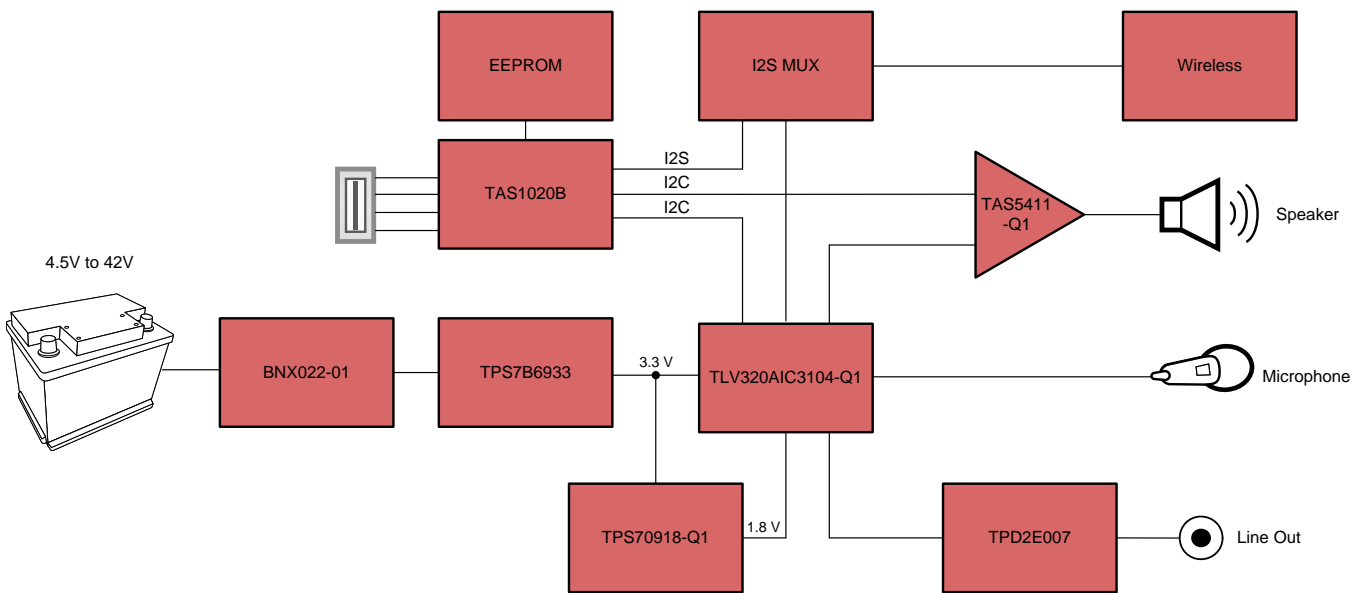
3.1.1.1 Connectors

DESIGNATOR	NAME	DESCRIPTION
J1	Speaker output	Connect the speaker load across pins 1 and 2 of J1
J2	Codec reset	Open (default) - reset signal will be pulled high, allowing the TLV320AIC3104-Q1 to operate normally
J3	Channel 1 inputs	Pin 1 - MIC1RM/LINE1RM Pin 2 - MIC1RP/LINE1RP Pin 3 - MIC1LM/LINE1LM Pin 4 - MIC1LP/LINE1LP
J4	External microphone input	To use an external microphone, remove R16 and R17
J5	VIN+	Power supply input (4.5 - 18-V)
J6	PS GND	Power supply ground
J8	I²C	Connect to an external I²C bus MCLK
J9	USB	USB cable connects here
J10	MCLK	I²S bus MCLK
J11	BCLK	I²S bus BCLK
J12	WCLK	I²S bus WCLK

DESIGNATOR	NAME	DESCRIPTION
J13	SDIN	I²S bus SDIN

3.1.2 Configuring the Board

Either the onboard 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. 図 16 shows the schematic for the microphone input.

図 16. Schematic of Microphone Input Configuration
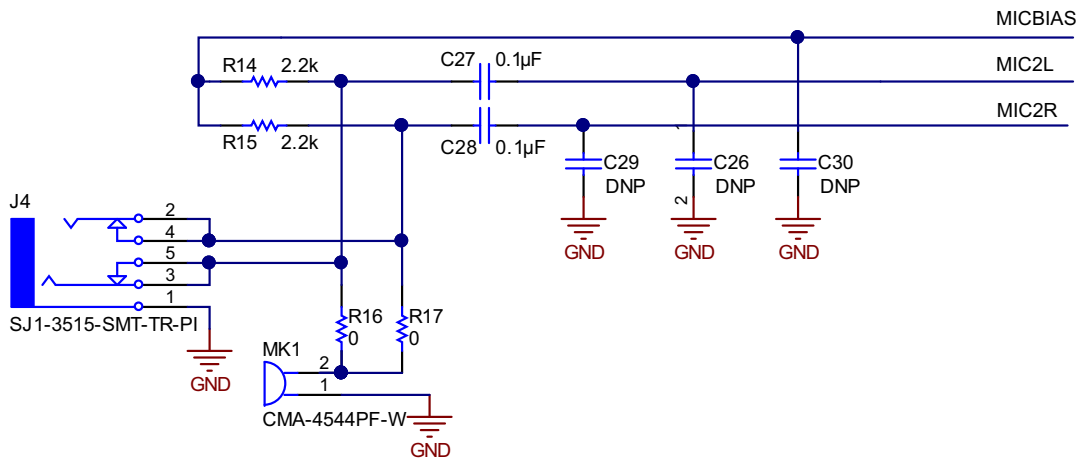
3.2 Getting Started Firmware

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

3.2.1 Firmware for Bench Tests

The following I2C commands show how to configure the TLV320AIC3104-Q1 for the signal path shown in 2.4.3.

```
# 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

3.3 Testing and Results

3.3.1 Test Setup

Equipment:

- Audio precision - AP2722 and PSI
- Power supply - 4.5 V to 18 V, 2.5 A
- 4-Ω load
- Two multi-meters

Bench test setup:

- PVDD = 14.4 V
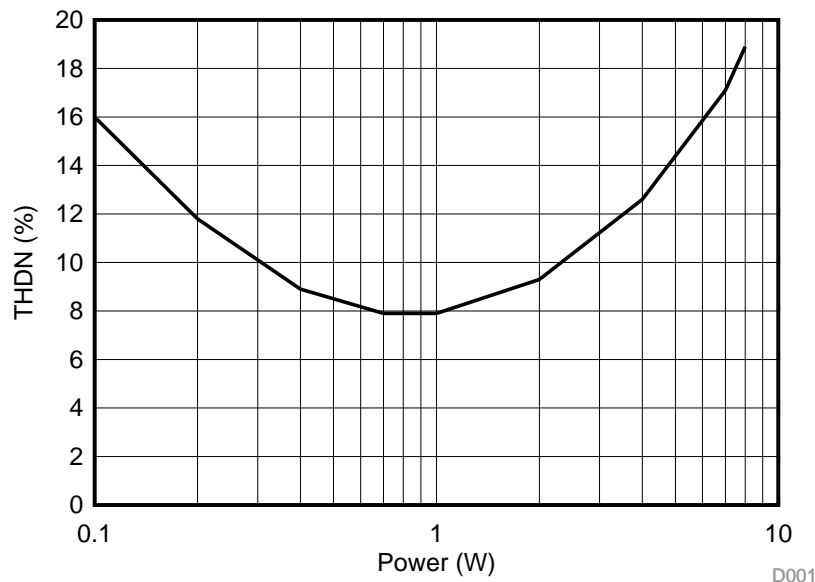- 4-Ω load

CISPR-25 radiated emissions test setup:

- PVDD = 14.4 V
- 1-W output across 4-Ω load
- CISPR-25 class 5 radiated emissions setup

3.3.2 Test Results

3.3.2.1 Audio Performance

THD+N (Total Harmonic Distortion + Noise) is a measurement of how ideal a sine wave is. The 1-kHz sine wave is generated by the audio precision instrument and sent over I^{2}S to the TLV320AIC3104-Q1. The audio precision then measures the THD+N of the analog signal across the 4-Ω load. 図 17 shows the THD+N versus output power across the load.

図 17. THD+N Versus Output Power, 4-Ω Load, PVDD = 14.4 V, 1-kHz Sine Wave

THD+N also varies with frequency. 図 18 shows the THD+N across frequency for three different power levels.

図 18. THD+N Versus Frequency, 4-Ω Load, PVDD = 14.4 V
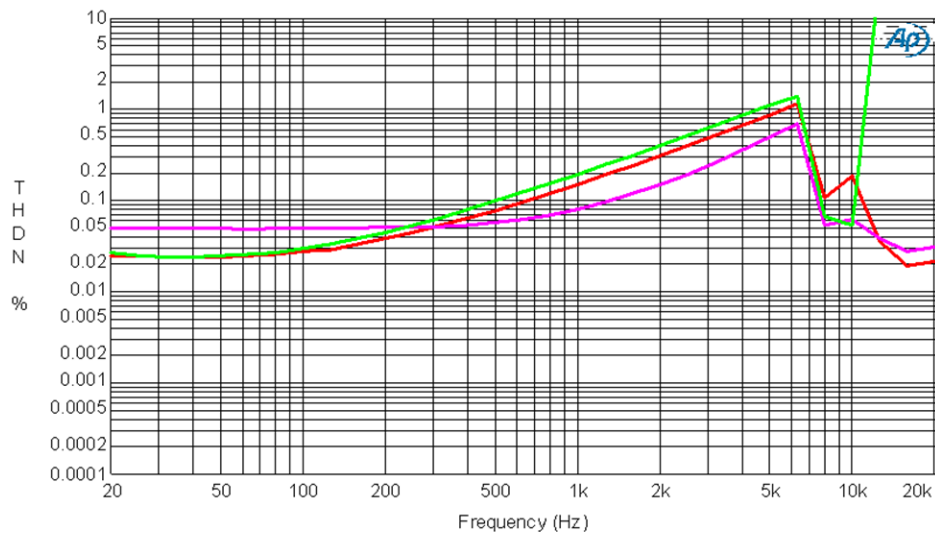
Sweep	Trace	Color	Line Style	Thick	Data	Axis	Comment
1	1	Green	Solid	2	Anlr.THD+N Ratio	Left	8W
2	1	Red	Solid	2	Anlr.THD+N Ratio	Left	5W
3	1	Magenta	Solid	2	Anlr.THD+N Ratio	Left	1W

3.3.2.2 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. 図 19 shows the efficiency versus output power for the TIDA-00724.

図 **19. Efficiency Versus Output Power, 4-Ω Load, PVDD = 14.4 V**
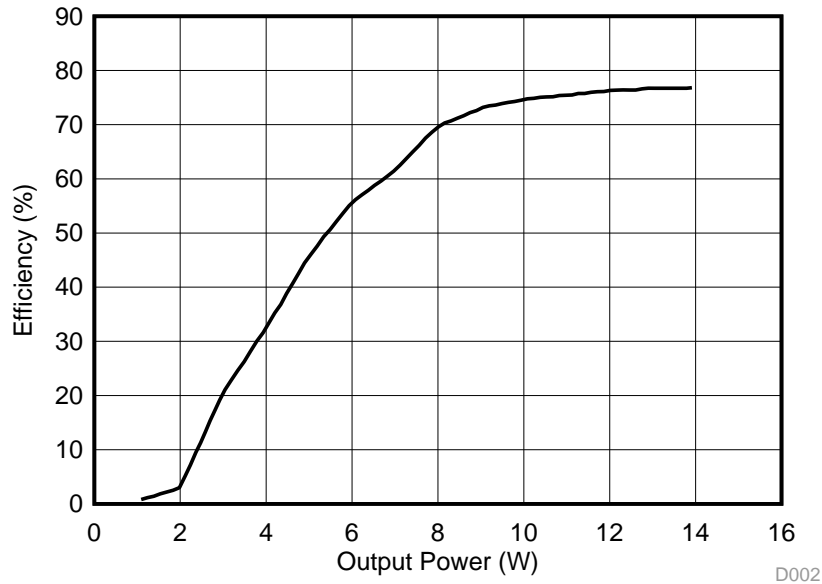
At lower-input voltage levels, the output signal can clip at higher output powers. This affects the THDN. 図 20 shows the maximum output power versus the input voltage to achieve 1% or 10% THDN. At over 10 V, 8 W of output power is achievable at less than 1% THDN.

図 **20. Maximum Output Power Versus Input Voltage, 4-Ω Load**
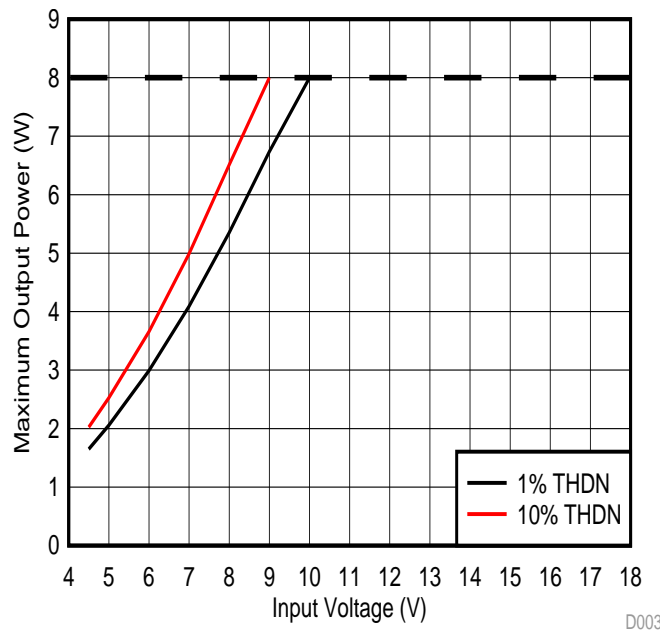

3.3.2.3   *EMI/EMC Test Results*

This design was built and tested with the goal to pass CISPR 25 class 5 standards, the strictest of the CISPR classification standards. This CISPR EMI testing was done with a third-party facility and follows the international standard "to protect on-board receivers from disturbances produced by conducted and radiate emissions arising in a vehicle" (CISPR 25 Ed. 3.0 b: 2008, pg. 7) meaning that this particular TI Design is tested to make sure that it does not interfere with other equipment in the vehicle. As outlined in

the standard, that radiated disturbances do not disrupt the broadcast and mobile service or band. For this particular TI Design, Broadcast standards were tested at Peak, Quasi-Peak, and Average ratings. For this test, a car battery or a 14.4-V power supply was used in conjunction with short cables in order to test at optimized performance. Additionally, resistive load 4Ω to generate 1W was used. The setup and results of the CISPR 25 Class 5 testing are shown below.

図 21. CISPR 25 Class 5 Test Setup for the TIDA-00724

図 22. Radiated CISPR 25 Class 5 Testing Results for the TIDA-00724
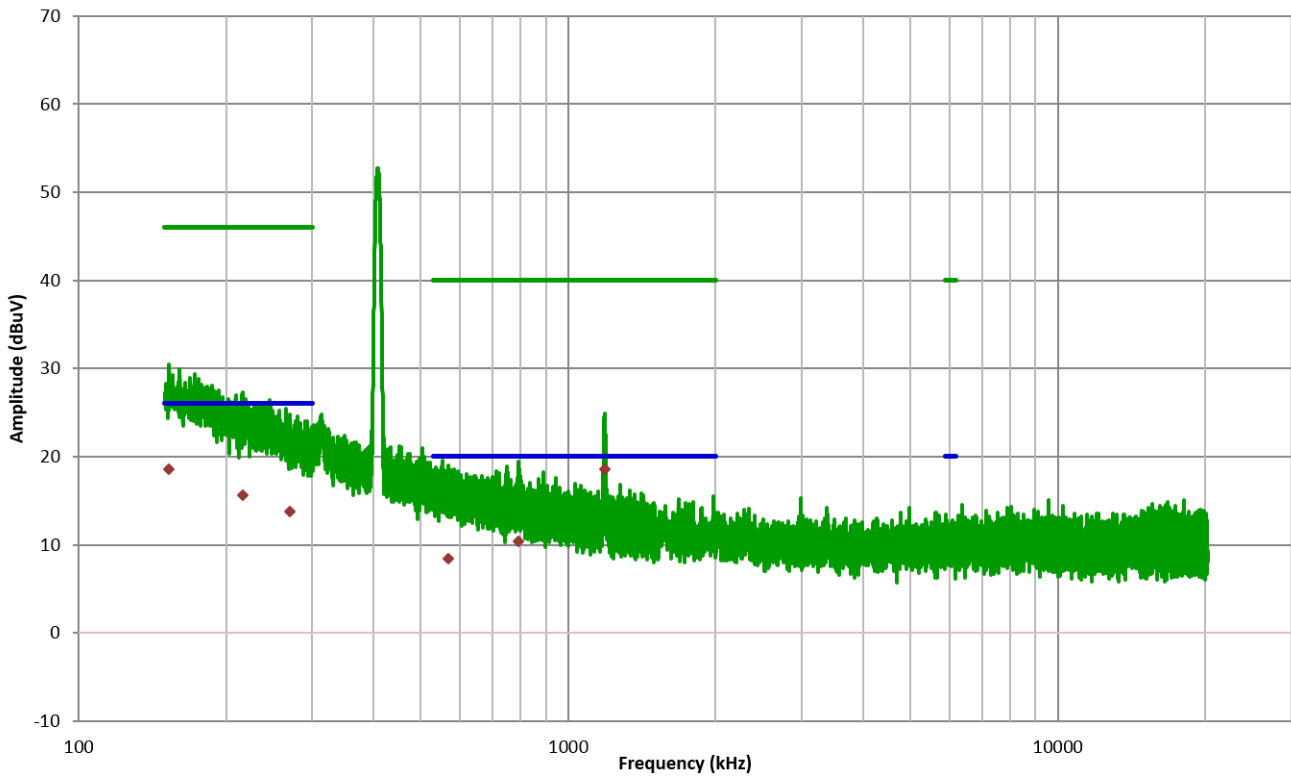
4　Design Files

4.1　Schematics

To download the schematics, see the design files at TIDA-00724.

4.2　Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00724.

4.3　PCB Layout Recommendations

There are three things to consider with 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 10 W 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.

4.3.1　Layout Prints

To download the layer plots, see the design files at TIDA-00724.

4.4　Altium Project

To download the Altium Designer® project files, see the design files at TIDA-00724.

4.5　Gerber Files

To download the Gerber files, see the design files at TIDA-00724.

4.6　Assembly Drawings

To download the assembly drawings, see the design files at TIDA-00724.

5　Related Documentation

1. Texas Instruments, LC filter design application report
2. Texas Instruments, TLV320AIC3104 programming made easy application report

5.1 商標

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