

TI Designs: TIDA-01529

Cluster and eCall Audio With Diagnostics Reference Design



Description

This reference design is based on the TAS2505-Q1, which is a low-power class-D digital audio amplifier with both analog and digital input capabilities. This design allows a user to evaluate the TAS2505-Q1 class D speaker amplifier and the device's fault diagnostic capabilities. It shows the TAS2505-Q1 as suitable for automotive cluster and eCall applications by showcasing the device's ability to run on a single 5-V supply. The TAS2505-Q1 has the ability to detect short to ground, short to power, short between speaker terminals, and overtemperature. Two external circuit examples show how open load detection can be added with minimal cost.

Resources

TIDA-01529	Design Folder
TAS2505-Q1	Product Folder
TCA9406	Product Folder
SN74LVC1G126	Product Folder
SN74AVC4T774	Product Folder
TPS736	Product Folder
LM2903-Q1	Product Folder

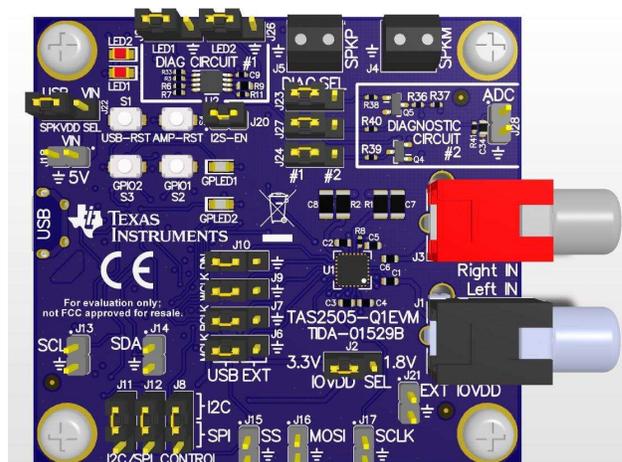
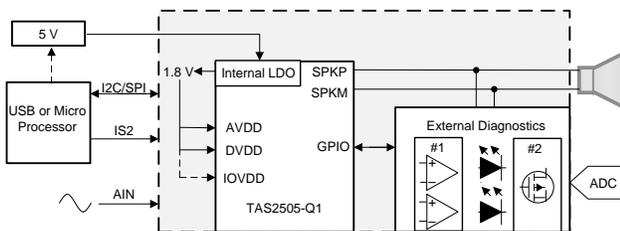


Features

- Mono Class-D BTL Speaker Amplifier
 - 2.6 W at 10% THD (4 Ω, 5.5 V)
 - 1.7 W at 10% THD (8 Ω, 5.5 V)
- Supports both Digital and Analog Input
- 92.3-dB SPL achieved at 1 W
- Load Diagnostic Functions:
 - Output-to-GND Short
 - Terminal-to-Terminal Short
 - Output-to-Power Short
 - Open Load
- Single Supply 2.7 V to 5.5 V
 - Integrated 1.8-V LDO can handle all internal analog and digital power needs
- Supports 9-kHz to 96-kHz Sample Rates
- I²C and SPI Control With Auto-Increment
- 24-Pin, VQFN Wettable Flank (Automotive Grade) Package for TAS2505-Q1

Applications

- [Emergency Call \(eCall\)](#)
- [Hybrid Cluster with Active Graphics Support](#)
- [Reconfigurable Digital Cluster](#)
- [Hybrid Cluster with Informational Graphics Support](#)
- [Telematics Control Unit](#)





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1 System Description

This reference design is based on the TAS2505-Q1, which is a low-power mono Class-D digital audio amplifier with analog and digital input capabilities. This design shows TAS2505-Q1 as suitable for automotive cluster and eCall applications. Direct I²S input removes the requirement for an external DAC in the audio signal path, and the integrated low-dropout (LDO) enables single supply operation. The chip's internal short-circuit detection natively includes the ability to detect speaker short to ground, speaker short to power, and short between the speaker terminals. Two external circuit examples show how open load detection can be added with minimal cost. The first external diagnostic circuit uses the LM2903-Q1 dual comparator to add open load detection and differentiation between different short conditions. Fault conditions can be monitored digitally using I²C commands or observed visually by looking at the LEDs when the amplifier is muted. The second diagnostic circuit adds open load detection with only two transistors and a few passive components but requires an external analog to digital converter (ADC) such as an analog input pin from a micro controller (MCU).

1.1 Key System Specifications

Table 1. Typical Operating Conditions

PARAMETER	SPECIFICATIONS
Input power	External 2.7 V to 5.5 V or USB
Input signal	Two channel analog (RCA), I2S through USB or external pins
Output power	2.6 W into 4 Ω with 10% THD+N
Universal serial bus (USB), USB class audio	Micro-USB
Operating temperature	0°C to +70°C
Form factor	2.36 × 2.56 × 1.1 in

2 System Overview

2.1 Block Diagrams

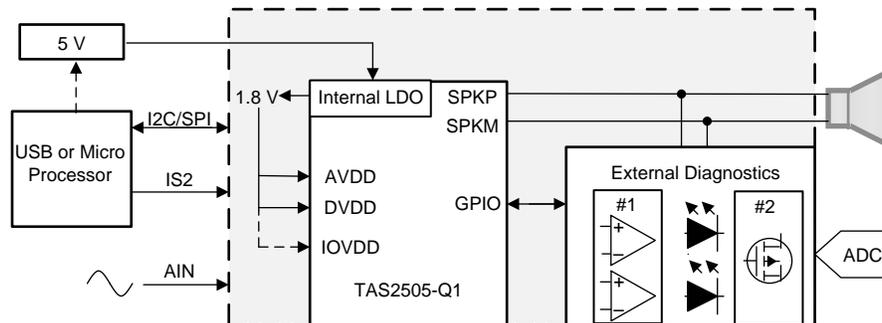


Figure 1. TIDA-01529 Block Diagram

2.2 Design Considerations

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

The TAS2505-Q1 addresses these concerns by providing high quality audio output from either a digital or analog audio input. The TAS2505-Q1's direct I2S input removes the requirement for an external DAC in the audio signal path, and the integrated LDO enables single supply operation by providing the 1.8-V rail necessary for IOVDD, DVDD, and AVDD. If a short to ground, short to power, short between speaker terminals, or an over-temperature fault is detected, then the amplifier is automatically muted. This reference design provides two simple external circuits that can add open load fault detection.

In the reference design, both power and audio can be provided externally or through the USB. If providing power externally, the input voltage range is 2.7 V to 5.5 V. If communicating through the USB, Codec Control software helps facilitate communication between the PC and the speaker, so the user can supply digital audio and customize the register settings with ease. IOVDD sets the logic levels of the I2C, SPI, and I2S communication, and two most common values for IOVDD are 1.8 V and 3.3 V. Both options are configurable on the TIDA-01529 reference design, and IOVDD can also be provided externally if another value is necessary. The TAS2505-Q1 contains a built-in LDO that can generate the analog supply (AVDD) and the digital supply (DVDD) at 1.8 V and this can also be used for IOVDD. If 3.3 V is necessary for the communication, the TAS2505-Q1 requires an external LDO to power IOVDD at 3.3 V. This 5-V to 3.3-V LDO has been provided on the bottom of the board.

2.3 Highlighted Products

2.3.1 TAS2505-Q1

The TAS2505-Q1 is a mono Class-D speaker amplifier that supports both digital and analog inputs. The device is ideal for automotive instrument cluster, emergency call (eCall), and telematics applications. Direct I²S input removes the requirement for an external DAC in the audio signal path, and the integrated LDO enables single supply operation. In addition to integration, the device features programmable audio processing. The onboard DSP supports bass boost, treble, and EQ (up to 6 biquads). An on-chip phase lock loop (PLL) provides the high-speed clock needed by the DSP. The volume level is register controlled.

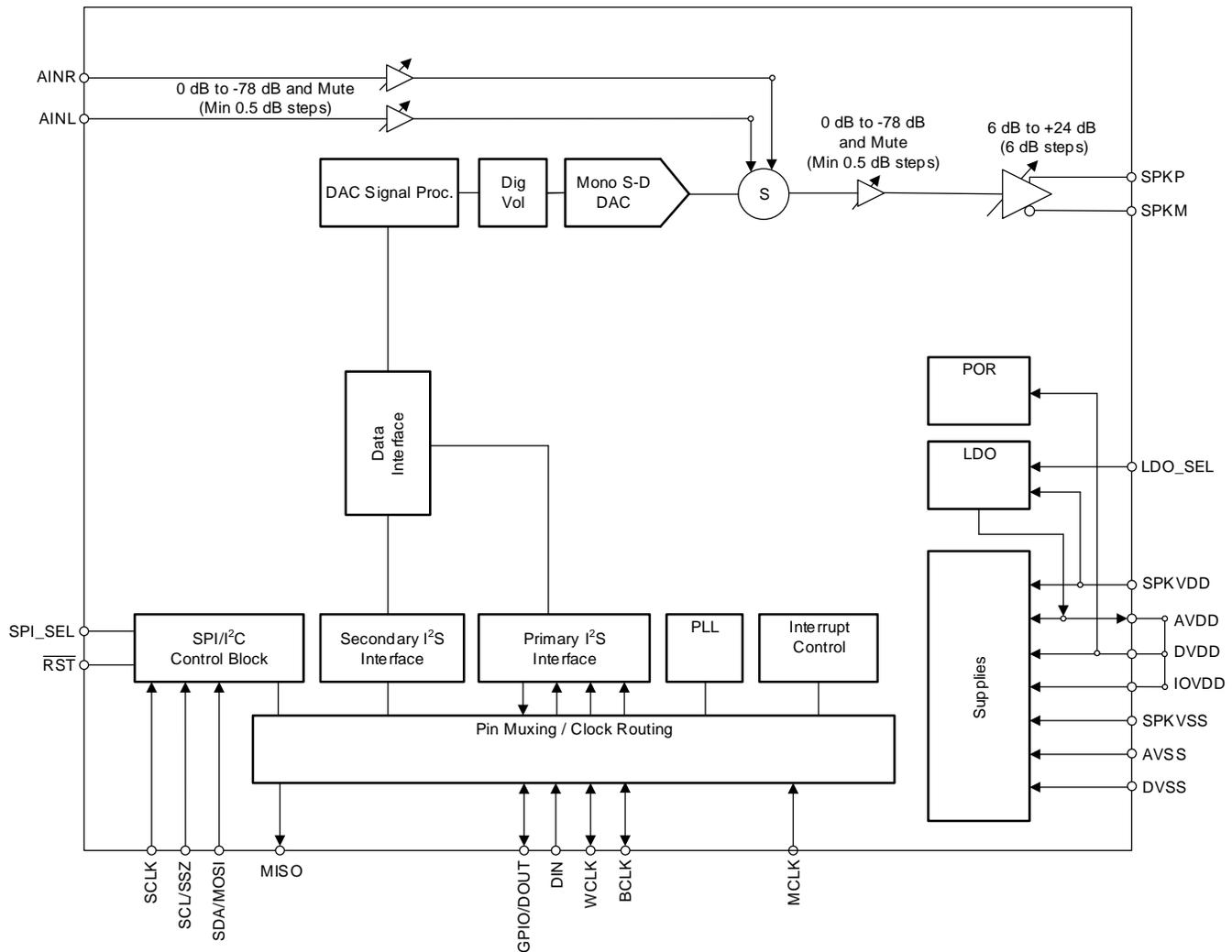


Figure 2. TAS2505-Q1 Functional Block Diagram

2.3.2 TCA9406

The TCA9406 is a 2-bit bidirectional I²C and SMBus voltage-level translator with an output enable (OE) input. The device is operational from 1.65 V to 3.6 V on the A-side, referenced to V_{CCA}, and from 2.3 V to 5.5 V on the B-side, referenced to V_{CCB}. This operation allows the device to interface between lower and higher logic signal levels at any of the typical 1.8-V, 2.5-V, 3.3-V, and 5-V supply rails.

The OE input pin is referenced to V_{CCA} but is also 5.5-V tolerant. The PE pin can also be controlled and set to a logic low to place all the SCL and SDA pins in a high-impedance state, which significantly reduces the quiescent current consumption.

Under normal I²C and SMBus operation or other open-drain configurations, the TCA9406 can support up to 2Mbps; therefore, the device is compatible with standard I²C speeds where the frequency of SCL is 100 kHz (standard mode), 400 kHz (fast-mode), or 1 MHz (fast-mode plus). The device can also be used as a general purpose level translator, and when the A- and B-side ports are both driven with push-pull devices, the TCA9406 can support up to 24 Mbps.

The TCA9406 features internal 10-kΩ pullup resistors on SCL_A, SDA_A, SCL_B, and SDA_B. Additional external pullup resistors can be added to the bus to reduce the total pullup resistance and speed up rising edges.

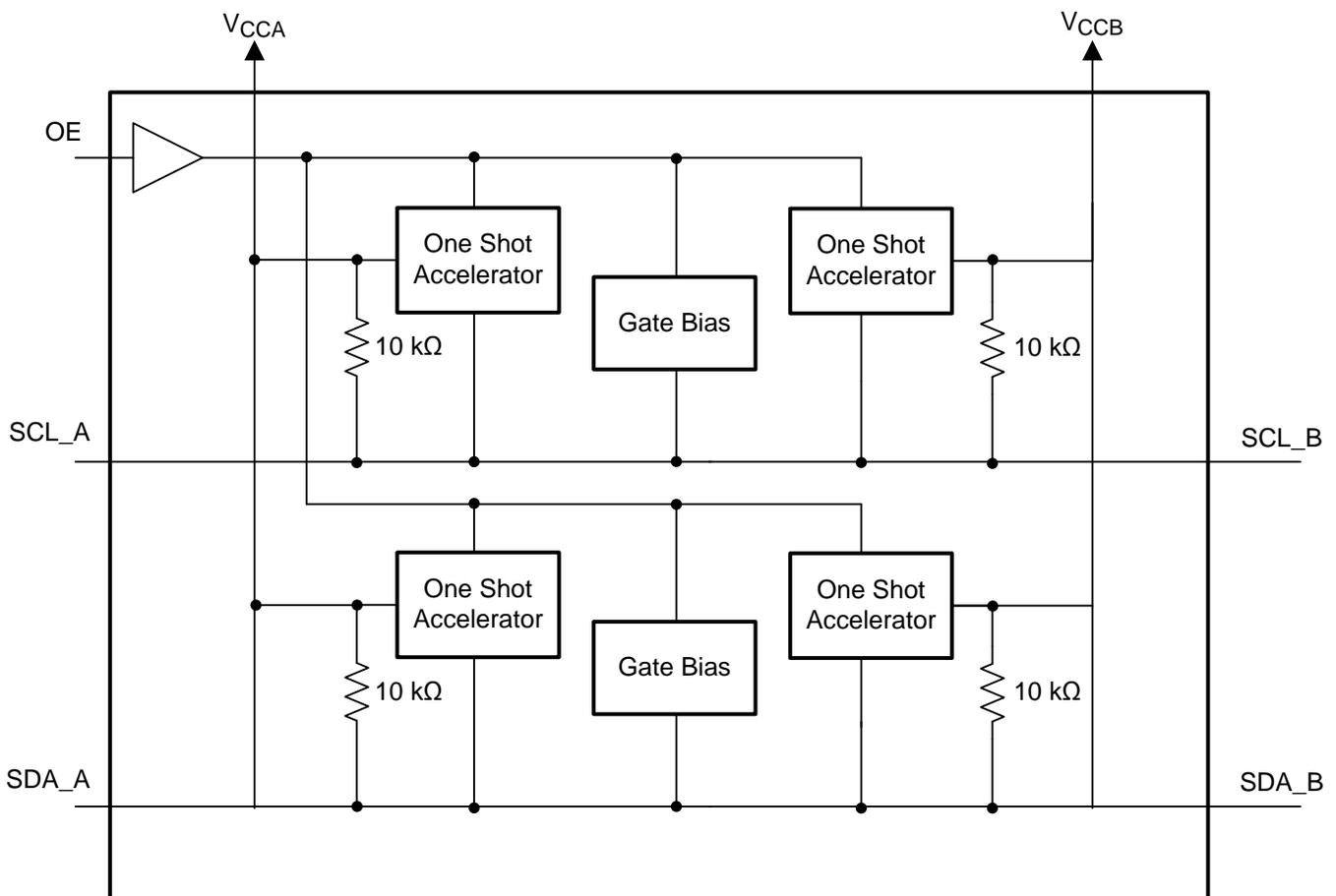


Figure 3. TCA9406 Block Diagram

2.3.3 SN74LVC1G126

This single buffer is designed for 1.65-V to 3.6-V V_{CC} operation. The LVC1G126 device is a single-line driver with tri-state output. The output is disabled when the output-enable input is low.

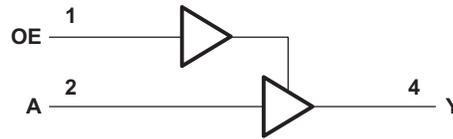


Figure 4. SN74LVC1G126 Functional Block Diagram

2.3.4 SN74AVC4T774

This 4-bit noninverting bus transceiver uses two separate configurable power-supply rails. The A port is designed to track V_{CCA} . V_{CCA} accepts any supply voltage from 1.2 V to 3.6 V. The B port is designed to track V_{CCB} . V_{CCB} accepts any supply voltage from 1.2 to 3.6 V. The SN74AVC4T774 is optimized to operate with V_{CCA}/V_{CCB} set at 1.4 V to 3.6 V. It is operational with V_{CCA}/V_{CCB} as low as 1.2 V. This allows for universal low-voltage bi-directional translation between any of the 1.2-V, 1.5-V, 1.8-V, 2.5-V, and 3.3-V voltage nodes. The SN74AVC4T774 is designed for asynchronous communication between data buses.

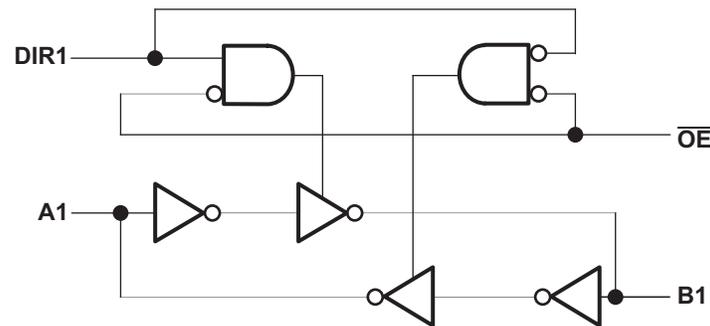


Figure 5. SN74AVC4T774 Functional Block Diagram

2.3.5 TPS736

The TPS736xx family of LDO linear voltage regulators uses a new topology—an NMOS pass element in a voltage-follower configuration. This topology is stable using output capacitors with low ESR and even allows operation without a capacitor. The device also provides high reverse blockage (low reverse current) and ground pin current that is nearly constant over all values of output current.

The TPS736xx uses an advanced BiCMOS process to yield high precision while delivering very low dropout voltages and low ground pin current. Current consumption, when not enabled, is under 1 μA and ideal for portable applications. The extremely low noise ($30 \mu\text{V}_{\text{RMS}}$ with $0.1\text{-}\mu\text{F } C_{\text{NR}}$) is ideal for powering VCOs. These devices are protected by thermal shutdown and foldback current limit.

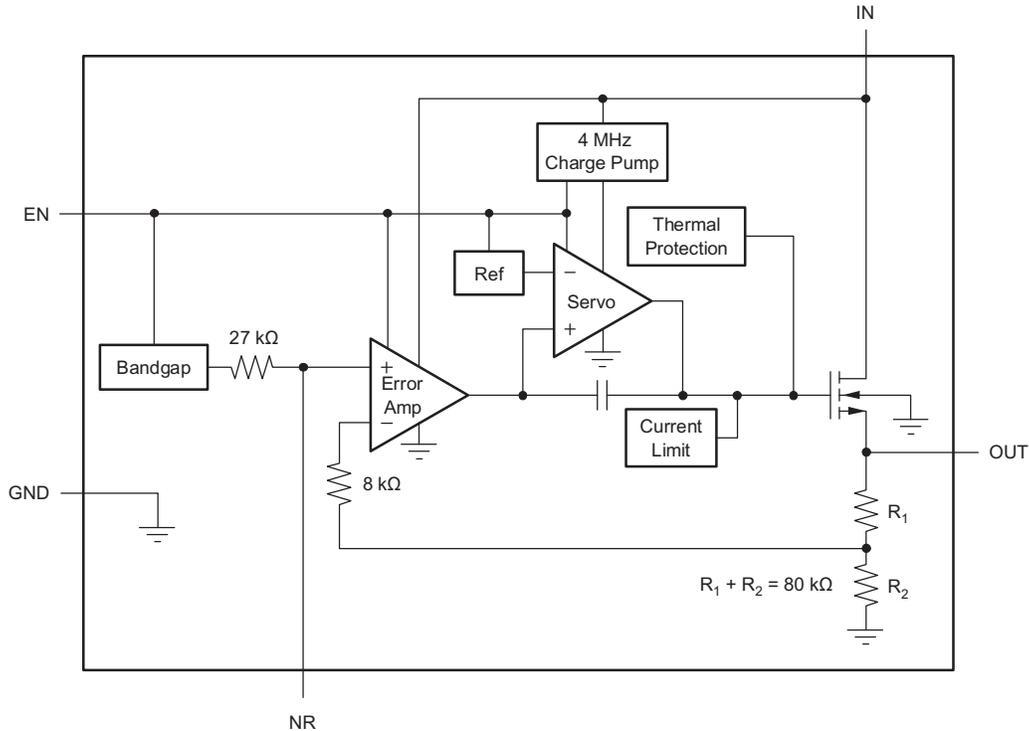


Figure 6. TPS736xx Functional Block Diagram

2.3.6 LM2903-Q1

The LM2903-Q1 device is an automotive catalog dual differential comparator. This device consists of two independent voltage comparators that are designed to operate from a single power supply over a wide range of voltages. Operation from dual supplies is possible as long as the difference between the two supplies is 2 V to 36 V, and VCC is at least 1.5 V more positive than the input common-mode voltage. Current drain is independent of the supply voltage. The outputs can be connected to other open-collector outputs to achieve wired-AND relationships.

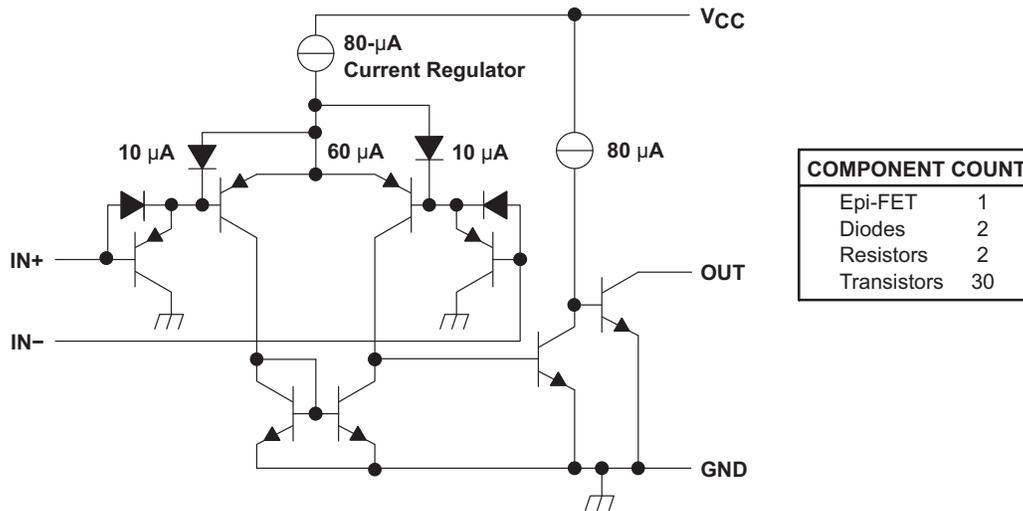


Figure 7. LM2903-Q1 Block Diagram

2.4 System Design Theory

2.4.1 Hardware Overview

The TIDA-01529 reference design allows a user to evaluate the TAS2505-Q1 class D speaker amplifier and the device's fault diagnostic capabilities. The board contains a 5-V to 3.3-V LDO to power the internal communication devices, such as the TAS1020 for the USB peripheral interface, the TCA9406 for the I²C voltage-level translator, and the SN74LVC1G126 and SN74AVC4T774 for the digital logic buffers. The TAS2505-Q1 can be configured to run with or without the 3.3-V LDO by using the device's internal LDO, which is discussed in the next section. The two diagnostic circuits can be selected with jumpers J23, J24, and J27 or removed entirely by removing the jumpers.

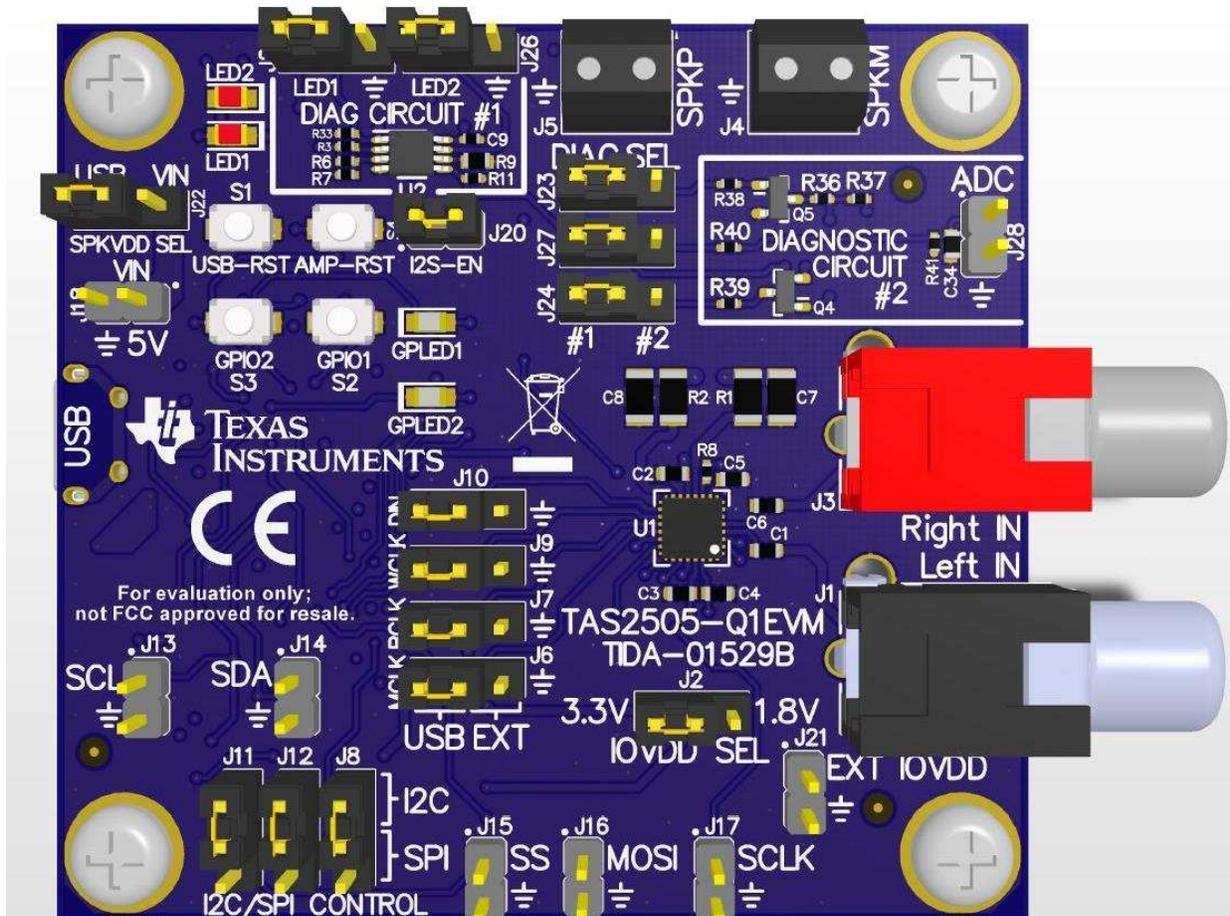


Figure 8. Board Image (Front)

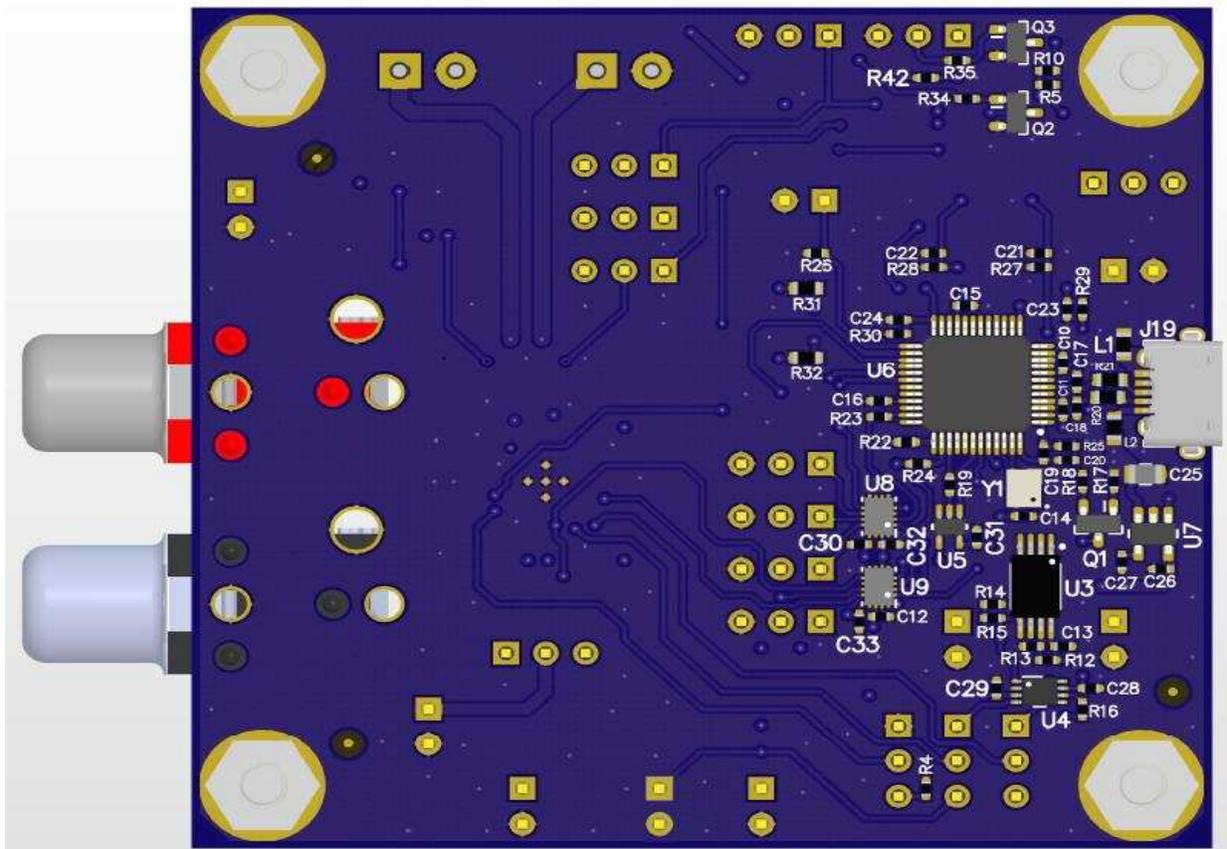


Figure 9. Board Image (Back)

2.4.1.1 Power

The board receives 5 V from the micro-USB input, or from J18 with an external power source. As stated in [Section 2.2](#), there are two possible setups with for this design. The first uses the micro-USB for communication and power, so a PC can send digital audio and the user can manually adjust the amplifier settings using the GUI provided by the Codec Control software. The TAS2505-Q1 has a built-in LDO that can generate the analog supply (AVDD) and also the digital supply (DVDD) at 1.8 V from an input voltage range of 2.7 V to 5.5 V. In order to use the LDO output voltage for the analog supply (AVDD) and digital supply (DVDD), the analog and digital supply pins are connected externally and the LDO select pin is wired to speaker power supply (SPKVDD). While AVDD and DVDD function at 1.8 V, the IO power supply (IOVDD) can function at either 1.8 V or 3.3 V depending on the user's desired configuration. In the first configuration, IOVDD functions at 3.3 V by using an external 5-V to 3.3-V LDO—TPS73633DBVR.

The second setup, single-rail configuration, demonstrates TAS2505-Q1's ability to run on a minimalist design. In this setup, the amplifier can be powered externally through J18 (provided the user adjusts J22 for external power input) or through a micro-USB connection. Control and audio signals can either be provided to the board by the user externally using a row of connection pins or through Codec Control software using the USB interface. The logic levels of these signals can be either 3.3 V or 1.8 V. If using an external input, providing the signals at 1.8 V allows TAS2505-Q1's IOVDD pin to function at 1.8 V and use the internal LDO of the amplifier. However, if 3.3-V logic levels are used, IOVDD must use the external 3.3-V LDO. Jumper J2 (IOVDD SEL) allows the user to select the voltage level of IOVDD.

2.4.1.2 TAS2505-Q1

The TAS2505-Q1 has an integrated class-D mono speaker driver (SPKP/SPKM) capable of driving an 8- Ω or 4- Ω differential load. The speaker driver can be powered directly from the battery supply (2.7 V to 5.5 V) on the SPKVDD pins; however, the voltage (including spike voltage) must be limited below the absolute maximum voltage of 6 V.

The speaker driver is capable of supplying 800 mW per channel with a 3.6-V power supply. Through the use of digital mixing, the device can connect one or both digital audio playback data channels to either speaker driver; this also allows digital channel swapping if necessary. The class-D speaker driver can be powered on by writing to page one, register 45, bit D1. The class-D output-driver gain can be controlled by writing to page one, register 48, bits D6–D4, and it can be muted by writing to page 1, register 48, bit D6–D4 = 000.

The TAS2505-Q1 has a short-circuit protection feature for the speaker drivers that is always enabled to provide protection. If the output is shorted, the output stage shuts down on the overcurrent condition. Current limiting is not an available option for the higher-current speaker driver output stage. In case of a short circuit, the output is disabled and a status flag is provided as a read-only bit on page 0, register 46, bit D7.

If shutdown occurs due to an overcurrent condition, the device requires a reset to re-enable the output stage. Resetting can be done in two ways. First, the device master reset can be used, which requires either toggling the RST pin or using the software reset. If master reset is used, it resets all of the registers. Second, a dedicated speaker power-stage reset can be used that keeps all of the other device settings. The speaker power-stage reset is done by setting page one, register 45, bit D1 for SPKP and SPKM. If the fault condition has been removed, the device returns to normal operation. If the fault is still present, another shutdown occurs. Repeated resetting (more than three times) is not recommended as this could lead to overheating.

To minimize battery current leakage, the SPKVDD voltage level must not be less than the AVDD voltage level. The TAS2505-Q1 has a thermal protection (OTP) feature for the speaker driver which is always enabled to provide protection. If the device is overheated, the output stops switching. When the device cools down, the output resumes switching. An overtemperature status flag is provided as a read-only bit on page 0, register 45, bit D7. The OTP feature is for self-protection of the device. If die temperature can be controlled at the system or board level, then overtemperature does not occur.

2.4.1.3 Diagnostic Circuit #1

Diagnostics to detect an open load can be done externally with minimal impact to size and cost of the design. Figure 10 shows the first external load diagnostic circuit.

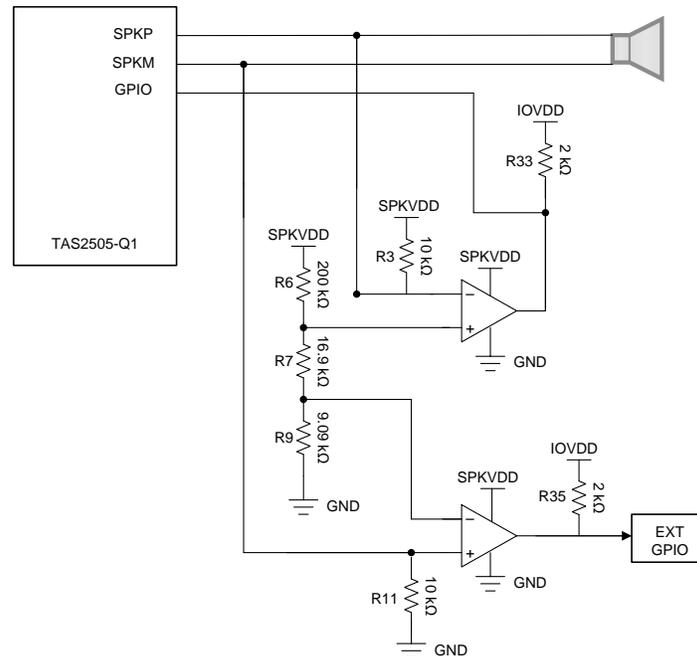


Figure 10. Diagnostic Circuit #1 Schematic

The speaker must be connected to the SPKP and SPKM output points on J5 and J4 for this circuit to function properly. The circuit detects load faults by monitoring the noninverting speaker line (SPKP) and the inverting speaker line (SPKM) of each channel. Abnormal voltages on each output line are identified by comparing reference voltages created by the resistor network of R6, R7, and R8 to the voltages on the output lines with a LM2903-Q1 dual comparator. If the voltage on one of the output lines is too high or too low, then the output of the comparator will pull the GPIO to ground. The output of the comparator is normally pulled high to IOVDD, and is pulled low when a fault occurs. The GPIO pin on the TAS2505-Q1 can be programmed as an input and then used to detect this change. On the reference design, LEDs are controlled by the output of the comparators via transistors to give the user visual indication of the state of the output of the comparators. In the normal state the comparator is high and the LED is on. If the comparator goes low, then the LED turns off, indicating a fault. Section 3.2 discusses the specific fault conditions. These LEDs are labeled LED1 and LED2 on the board, and their functionality is determined by J25 and J26. With the jumpers the LEDs can be connected to the output of the comparators, tied to ground and ignored, or the jumper can be removed so the user can measure the output of the comparator directly. The LEDs are not included in Figure 10 because they are for visual indication only.

The output of the first comparator is connected to the TAS2505-Q1 as a GPIO input. Since the TAS2505-Q1 only has one GPIO input, the output of the second comparator can be connected to an external MCU's GPIO input or ignored. Only one comparator is necessary for open load detection, but using two allows the user to differentiate between the potential faults: short to power, short to ground, short between the speaker terminals, and open load. Table 7 shows the fault conditions and the corresponding state of the comparators and registers.

To limit power draw during operation and minimize effects on audio performance, R3, R6, R7, R9, and R11 are high-impedance resistors. The value of R7 determines the reference voltages that the speaker terminals (SPKP and SPKM) are compared to for fault detection. This reference window is crucial for open load detection and therefore resistances with 1% or less tolerance should be used. The comparator goes low if the negative input is greater than the positive input.

Refer to Section 3.2 for more information regarding programming the device to recognize faults, or see the application report *Automotive Diagnostic solutions for TAS2505-Q1 Application Report* .

2.4.1.4 Diagnostic Circuit #2

Figure 11 shows the second diagnostic circuit, which consists of only two transistors and a few resistors. The first step is to mute the amplifier via software. The GPIO is set to an output, and pulling the GPIO high will enable the circuit by biasing the BJT which turns on the P-channel MOSFET and allows current to flow from SPKVDD, across the speaker, and through the voltage divider created by R40 and R41. If the speaker is disconnected and there is an open circuit, then the voltage at the voltage divider will be zero, but if there is a speaker connected and there is no fault, then the voltage at the voltage divider will be approximately 1.2 V. This voltage can be read from an external ADC such as an analog input pin from a MCU to determine if there is an open circuit fault or not. The circuit should be disabled by pulling the GPIO low before unmuting the amplifier and resuming normal operation.

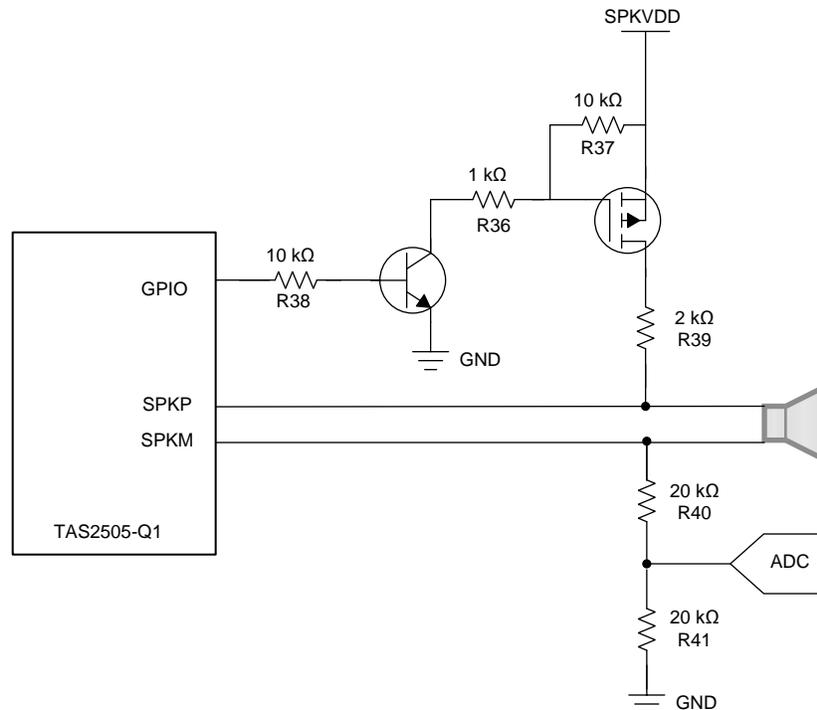


Figure 11. Diagnostic Circuit #2 Schematic

2.4.1.5 Diagnostic Circuit #3

Figure 12 shows the third diagnostic circuit, which is similar to diagnostic circuit #2 but the BJT transistor used to control the MOSFET is removed. The control logic is the inverse of circuit #2, so the GPIO must be HIGH to disable the diagnostic circuit and set the device into *Normal Operation*; setting GPIO to LOW enables the circuit and open load test can be performed.

There is a tradeoff on removing the BJT, which is an increase in current consumption. For example, when TAS2505-Q1 is off, there would still be current drawn if SPKVDD is on.

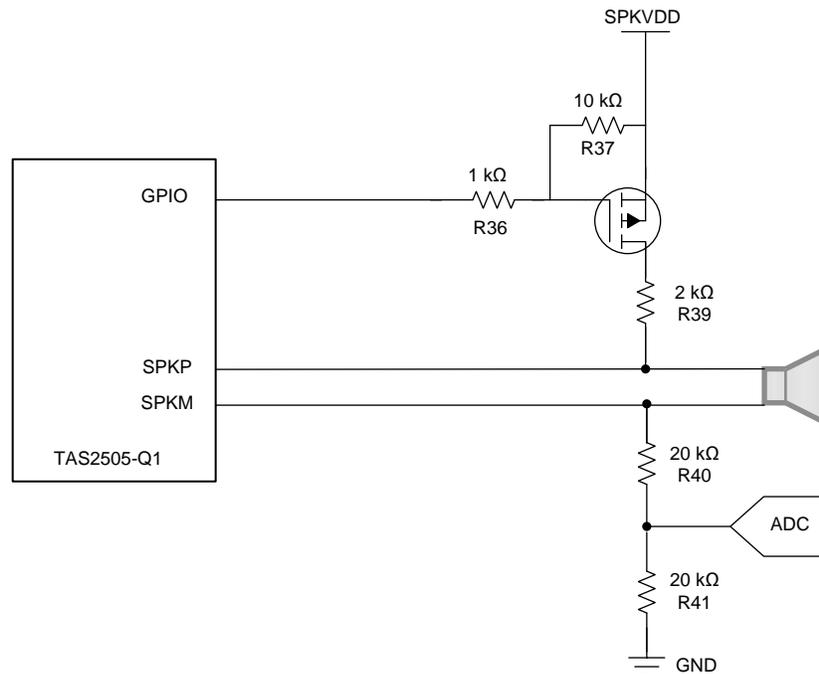


Figure 12. Diagnostic Circuit #3 Schematic

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware and Software

Although not required, TAS2521 or TAS2505 Codec Control software is available online for use with this device. The software allows the user to easily read and write to device registers through the use of a GUI. The amplifier can also be controlled directly using I²C or SPI commands. Refer to *TAS2505, TAS2521 Codec Control EVM User's Guide* for more information on this software. The guide includes instructions on installation, sample device configurations, and how to use the GUI. To download the software, go to the [TAS2505EVM](#) page and download *TAS25xx Codec Control EVM GUI* under the Software section. After downloading, run the executable file *CodecControl.exe*.

3.1.1 Hardware

As stated in [Section 2.2](#), there are multiple setups for this design, as described in [Table 2](#). The input/output voltage (IOVDD) of the TAS2505-Q1 establishes the logic level of the control and audio signals. It can operate at either 3.3 V or 1.8 V, determined by J2. Providing these signals at 1.8 V allows the TAS2505-Q1 to use the internal LDO of the amplifier. If 3.3-V logic levels are used, however, IOVDD will need to either use the 3.3 V LDO (external to the TAS2505-Q1) or have 3.3V externally provided via J21. If using the 3.3 V LDO, the power supply voltage must be at least 5 V, provided either externally or through USB. If providing IOVDD externally through J21, remove the jumper on J2.

Table 2. Possible Configurations for Power, Control, and Audio

FUNCTION	INPUT	PARAMETER	JUMPERS	EXTERNAL INPUT
Power	USB	5 V	J22 - USB	—
	External	2.7 V to 5.5 V	J22 - VIN	J18
Control	USB	I2C	J8, J11, J12	—
	External	I2C	J8, J11, J12	J13, J14
		SPI	J8, J11, J12	J15, J16, J17
Audio input	USB	I2S	J6, J7, J9, J10, J20	J6, J7, J9, J10, J3, J1
	External	I2S or analog		

Table 3. Configurations for Diagnostics

DIAGNOSTIC CIRCUIT	JUMPER	OUTPUT	JUMPER
#1	J23, J24, and J27 inserted to #1	LED1	J25 - LED1
		LED2	J26 - LED2
#2	J23, J24, and J27 inserted to #2	ADC	J28
No external diagnostics	Remove J23, J24, and J27	LED1	J25 - GND
		LED2	J26 - GND

For normal operation, a 4- or 8-Ω speaker should be connected differentially by inserting one speaker terminal to SPKP on J5 and the other speaker terminal to SPKM on J4. For singled ended operation, simply use one terminal - either J4 or J5.

The simplest configuration uses the micro-USB for communication and power, so a PC can send digital audio and the user can adjust the amplifier settings through the GUI provided by the Codec Control software. For this setup, connect the jumpers as described in [Table 4](#). This is the default configuration referred to as GUI configuration.

Table 4. Jumper Configuration for GUI Mode (Default)

JUMPER	CONFIGURATION
J2	3.3 V
J6, J7, J9, J10	USB
J8, J11, J12	I2C
J20	Connected

Single-rail configuration demonstrates TAS2505-Q1's ability to run on a minimalist design without the assistance of the external 5-V to 3.3-V LDO. In this setup IOVDD must operate at 1.8 V. There are variations of this implementation: power could be supplied externally or through USB, and the host PC could be used to send control and audio signals. The [Section 3.1.3](#) will outline how to implement this single-rail supply using a micro-USB connection but only to provide the 5-V rail. Control and audio signals are externally provided to the board by the user through a row of connection pins.

3.1.2 Software

The Codec Control software displays most features of a supported TI audio codec EVM through an intuitive graphical user interface (GUI). The software includes a script interpreter, a block-diagram based GUI, a register inspector and supplemental features depending on codec capabilities.

NOTE: Before the PC running Microsoft® Windows® can use the TI audio converter EVM as a sound card, the EVM must be configured (sampling rate, audio routing, internal amplifier settings, and so forth) with the Codec Control software. This happens automatically, once an EVM is detected by the Codec Control software.

The following sections will describe the various methods of controlling the device—with and without the GUI.

3.1.3 Commands and Audio Using Host PC and GUI

1. Connect a 4-Ω speaker to the TAS2505-Q1 board (SPKP on J5 and SPKM on J4).
2. Open the *CodecControl.exe* executable file downloaded with the software.
3. Ensure the jumpers are in the correct positions as described in [Table 4](#).
4. Connect the board to a host Windows (XP, Vista, 7 or 10) device with a micro-USB connection.
5. Ensure the PC has successfully recognized the board by opening the sound dialog from the control panel. The amplifier enumerated as *USB-AudioEVM* and be the default playback device. Additionally, the main console of the software now displays interactive block objects.
6. Verify that the sampling rate matches the Windows setting by highlighting the device and then opening *Properties*→*Advanced*. The firmware supports a 48-kHz sampling rate by default. This setting must match the board's format of two channel, 16 bit, 48000 Hz (DVD quality).
7. Finally, program TAS2505-Q1 to play audio using the speaker outputs. To do so, click on *View*→*Example Configurations...*→*Configurations*→*Playback Class-D Speaker*.
8. The board should now work as the sound card for any audio files played by the PC.

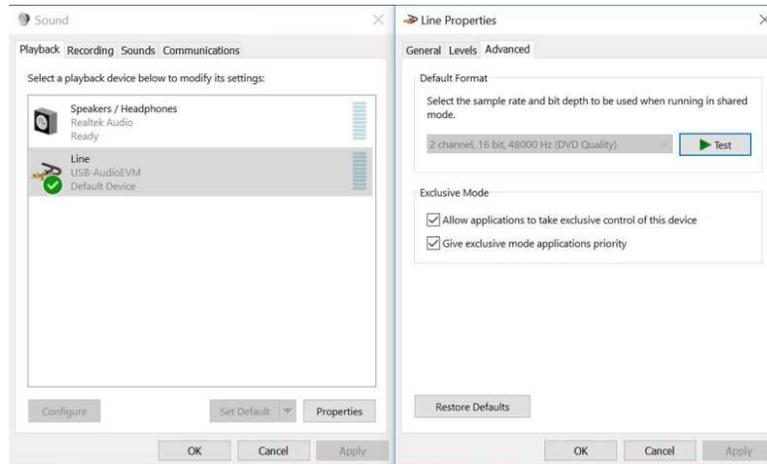


Figure 13. Desired Microsoft® Windows® Sound Card Settings for Reference Design Board

9. (Optional - Analog input) The above instructions set up the TAS2505-Q1 for digital playback using USB. Analog playback is also possible and can even be played simultaneously with digital files.
10. (Optional - Analog input) To do so, follow the above instructions and then connect an analog source to J3 and J1.

11. (Optional - Analog input) Program TAS2505-Q1 for analog playback using one of the two methods:
 - a. On the GUI, close the switches circled in red in [Figure 14](#) by clicking on them.
 - b. Click on *View* → *Register Inspector...* This will make the *Register Inspector* appear. Now make the following changes:
 - i. Navigate to page one, register 9.
 - ii. Change the value of this register to 0x03 or 0000 0011. This can be done by writing into the second *data* column or by clicking on individual bit values.
 - iii. Navigate to page one, register 12.
 - iv. Change the value of this register to 0x90 or 1001 0000. This can be done in the same manner as before.

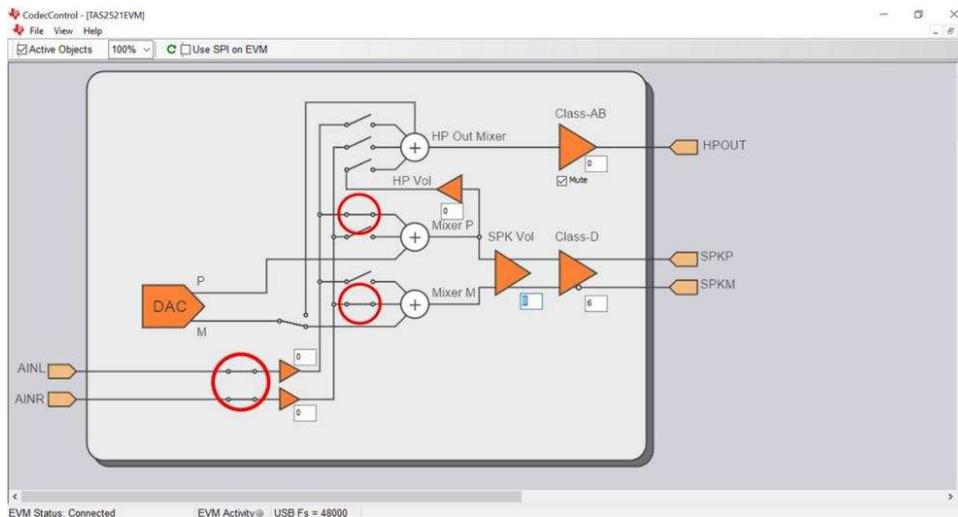


Figure 14. Settings for Analog Inputs

3.1.4 Single Rail With Direct Digital Interface Connections and I²C Control Signals

1. Connect a speaker to the TAS2505-Q1 board (SPKP on J5 and SPKM on J4).
2. Ensure jumpers are connected as [Table 5](#).

Table 5. Jumper Configuration for Single Rail Supply With I²C

JUMPER	CONFIGURATION
J2	1.8 V
J6, J7, J9, J10	EXT
J8, J12, J11	I2C
J20	Connected

3. Connect the board's I²C and I²S pins to signal sources from the host. See [Section 4.1](#) for a complete list of signals required. The *TAS2505 Application Reference Guide* [1] and *TAS2505-Q1 2.6-W Digital/Analog Input Automotive Class-D Speaker Amplifier With Audio Processing Data Sheet* [2] can provide detailed information on these signal types.
4. Connect the board to a host device with a micro-USB connection (J19) to provide a 5-V supply.

5. Run the following I²C script or commands to program the output speaker for digital inputs.

```
# Page switch to Page 0 W 30 00 00 # Assert Software reset W 30 01 01 # Page Switch to Page 1
W 30 00 01 # LDO output programmed as 1.8V and Level shifters powered up. W 30 02 00 # Page
switch to Page 0 W 30 00 00 # Dac Instruction programming PRB #1 W 30 3c 01 #
CODEC_CLKIN=MCLK.MCLK should be 12.288MHz W 30 04 00 # Codec Interface control Word length =
16bits.BCLK&WCLK inputs.I2S mode. W 30 1b 00 # Data slot offset 00 W 30 1c 00 # DAC NDAC
Powered up, NDAC=1 W 30 0b 81 # DAC MDAC Powered up, MDAC=2 W 30 0c 82 # DAC OSR(9:0)-
> DOSR=128 W 30 0d 00 # DAC OSR(9:0)-
> DOSR=128 W 30 0e 80 # Only LDAC powered up. DAC path setup LDAC data Mono of LDAC and RDAC.
RDAC # data disabled. Soft step 1 per Fs. W 30 3f B0 # DAC volume for Left channel not muted.
Right DAC muted. W 30 40 04 # LDAC digital gain 0dB W 30 41 00 # Page Switch to Page 1 W 30 00
01 # Master Reference Powered on W 30 01 10 # Output common mode for DAC set to 0.9V (default)
W 30 0a 00 # LDAC AFIR is 6th order FIR filter and Powered up. W 30 03 00 # SPKL attn. Gain
=0dB W 30 2E 00 # SPKL driver PGA Gain=6.0dB W 30 30 10 # SPK OSCP enabled , OCP Deglitch=4,
OTP enabled , OTP Deglitch=5 W 30 52 00 # SPK powered up W 30 2D 02
```

6. Provide audio input through I²S to play sounds as desired. If using SPI, make sure jumpers J11, J12, and J8 are configured for SPI.

7. (Optional) As with the first setup, analog inputs can also be provided and played.

8. (Optional) To do so, first connect an analog source at J1 and J3.

9. (Optional) Next, run the following I²C commands:

```
# Page switch to Page 1 W 30 00 01 # Enable AINL and AINR W 30 09 03 # Enable Mixer P and Mixer M
W 30 0C 90
```

3.2 Using Diagnostics

Fault conditions can be monitored digitally through I²C commands or the GUI for a fast reading of fault conditions. The GUI will write and decipher the I²C messages for the user, but the user is not forced to use the GUI and can take care of the I²C communication without it. If this method is chosen and fault diagnosis is being performed by a host, the external machine must do this through polling. If using the first diagnostic circuit, fault conditions can also be observed visually by looking at the LEDs when the amplifier is muted or off.

3.2.1 Diagnostic Circuit #1

Figure 15 shows the process for determining a fault with diagnostic circuit #1. This assumes normal operation of the amplifier and that the amplifier has not been muted manually by using page 1, register 0x2D.

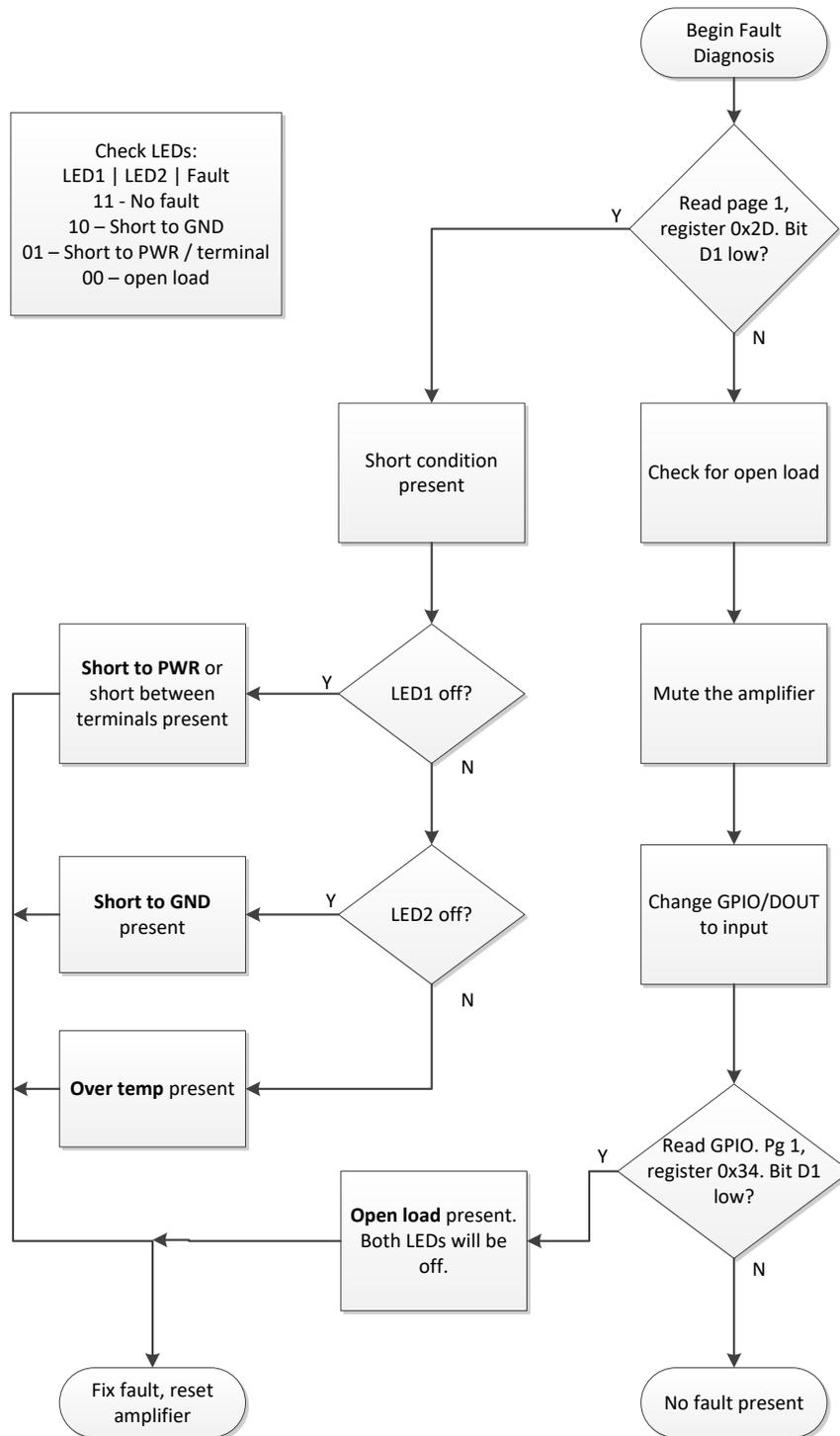


Figure 15. Process for Fault Diagnosis with Diagnostic Circuit #1

Information regarding short and open load fault conditions for the TAS2505-Q1 amplifier's speakers can be accessed through two integrated registers using I²C. External host can poll the two registers (register 0x2D and 0x34) to see if an error occurred. See [Table 6](#) to interpret the error. There is no requirement on how often to poll these registers as the device self protects on the event of an error.

To determine whether or not a short has occurred, the host reads register 0x2D of page one. If bit D1 of this register is low, a short condition exists in the amplifier and has caused it to shut down. The fault condition must be fixed, and the device must be reset before it will operate again. If this bit is high, no short circuit condition has been detected.

The other primary type of output fault condition, open load, can also be read through I²C. To do this, the first output of the LM2903 dual comparator is routed back to the GPIO/DOUT pin. Additionally, the user must first mute the amplifier to stop switching at the outputs by setting bit D1 of register 0x2D from page one to 0. The user should then write 00001000 or 0x08 to register 0x34 of page 0. This sets the GPIO/DOUT control register to its general input setting. The first output of the comparator is then automatically written to this register and stored in bit D1 as a high or low bit. The user can then read back register 0x34 of page 0 at any time and, comparing its D1 bit with the D1 bit of register 0x2D on page 1, determine if an open load fault has occurred. Once diagnostic reading is complete, make sure to reset D1 of register 0x2D, page one back to 1 to re-enable the amplifier. If a fault was detected, it needs to be corrected and the amplifier reset before sound can be played again. [Table 6](#) demonstrates the register information that corresponds to each primary state of amplifier operation.

The TAS2505-Q1 has an overtemperature protection (OTP) feature for the speaker driver, which is always enabled to provide protection. If the device is overheated, the output stops switching. When the device cools down, the output resumes switching. An overtemperature status flag is provided as a read-only bit on page 0, register 0x2D, bit D7. The OTP feature is for self-protection of the device. If die temperature can be controlled at the system or board level, overtemperature does not occur. The OTP feature triggers above 140°C.

Table 6. Primary Operation States and Fault Detection: I²C

AMPLIFIER STATE	PAGE 0, REGISTER 0x34, BIT D1	PAGE 1, REGISTER 0x2D, BIT D1
No fault	1	1
Short circuit	X	0
Open load	0	1

In addition, LEDs are added on the board to reflect if an error happened. The state of the two LEDs can also reveal the output of the comparator and thus the state of the amplifier's fault condition. This is used only for indication.

Table 7. Complete Operation States and Fault Detection: I²C and LEDs

AMPLIFIER STATE	COMPARATOR OUT 1	LED 1	COMPARATOR OUT 2	LED 2	PAGE 1, REG 0x2D, BIT 1
No fault	1	ON	1	ON	1
Short to GND	1	ON	0	OFF	0
Short to power	0	OFF	1	ON	0
Shorted load	1	ON	1	ON	0
Open load	0	OFF	0	OFF	1

3.2.2 Digital Fault Diagnostics—GUI

1. Make sure the speakers have been programmed as instructed in [Section 3.1.3](#).
2. Click on *View*→ *Register Inspector...* This will bring up the *Register Inspector* as shown in [Figure 16](#).

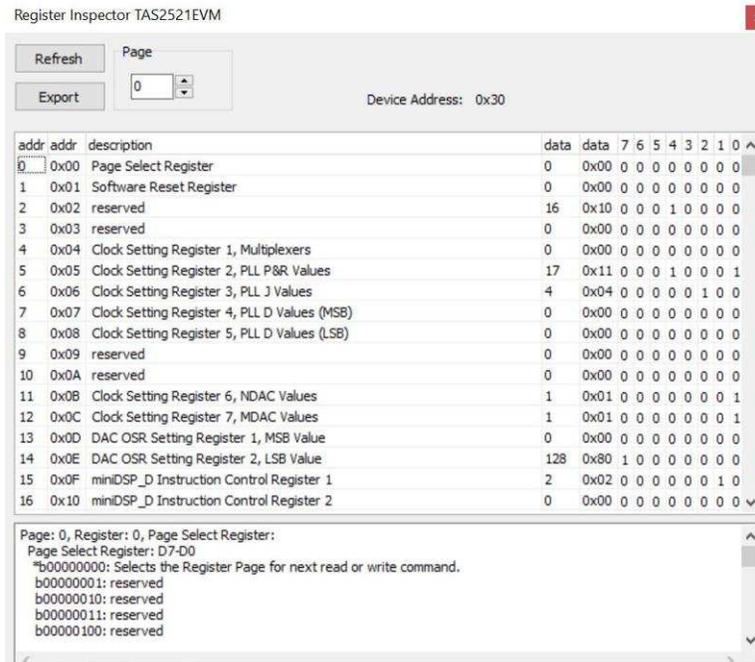


Figure 16. Register Inspector Box

3. Navigate to page one, register 0x2D. Click the *Refresh* button in the upper-left corner.
 - a. Clicking this button ensures the most up-to-date values are visible. Make sure to press *Refresh* before reading from a register or else the values read may no longer be accurate. After clicking *Refresh*, bit values that show as red instead of black are values that have switched since the last time the button was pressed.
4. Observe bit D1
 - a. If this bit is 1 then there is no short condition in the amplifier.
 - b. If this bit is 0 then the amplifier has been shut down due to a short circuit condition. A short circuit condition can be caused by the speaker outputs being shorted to ground or one or both of the speaker outputs being shorted to the supply rail.
5. If a short condition exists, it must be fixed and the amplifier reset before it will turn back on and produce sound again.
6. If a short condition does not exist, proceed to check for an open load fault. The amplifier must first be muted to do so.

NOTE: Muting the amplifier is not the same as simply cutting all audio streams to the device. Muting the amplifier is also different from shutting down the entire board. Muting the amplifier means turning off the amplification feature of the TAS2505-Q1 while keeping the board and chip powered up.

7. To mute the amplifier, change bit D1 of the same register from 1 to 0 by clicking on the bit.
8. Navigate to page 0, register 0x34.
9. In bits D5 through D2, write 0010. The GPIO pin is now set to general input mode.

10. Click the *Refresh* button and observe the value of bit D1.
 1. If there is no short circuit condition and bit D1 of this register is high, no open load condition exists either, and there is no fault.
 2. If there is no short circuit condition and bit D1 of this register is low, an open load condition exists. This situation must be fixed before sound is heard again.

3.2.3 Digital Fault Diagnostics—Direct I²C

1. Set up the speaker as described in [Section 3.1.3](#).
2. Ensure jumpers are in positions described in [Table 5](#).
3. Read page one, register 0x2D by running the following I²C commands:

```
# Page switch to page 1 W 30 00 01 # Read page 1, register 0x2D R 30 2D 01
```
4. The value is a two digit hexadecimal value or an 8-bit binary value.
5. Observe bit D1 or the second least significant bit.
 - If this bit is 1 then there is no short condition in the amplifier
 - If this bit is 0 then the amplifier has been shut down due to a short circuit condition. A short circuit condition can be caused by the speaker outputs being shorted together, one or both of the speaker outputs being shorted to ground, or one or both of the speaker outputs being shorted to the supply rail.
6. If a short condition exists, it must be fixed and the amplifier reset before it will turn back on and produce sound again.
7. If a short condition does not exist, then one can proceed to check for an open load fault. To do so, the amplifier must first be muted.

NOTE: Muting the amplifier is not the same as simply cutting all audio streams to the device. Muting the amplifier is also different from shutting down the entire board. Muting the amplifier means turning off the amplification feature of the TAS2505-Q1 while keeping the board and chip powered up.

8. To mute the amplifier, provide the following I²C commands:

```
# Mute output amplifier W 30 2D 00
```
9. Now to detect open load, the input provided at the GPIO/DOUT pin from the diagnostic circuit must be measured.
10. To set GPIO/DOUT to receive general purpose input, provide the following I²C commands:

```
# Page switch to page 0 W 30 00 00 # Set GPIO to accept general purpose input W 30 34 08
```
11. Now read the output of the diagnostic circuit through the GPIO pin with the following I²C commands:

```
# Read input into GPIO/DOUT pin R 30 34 01
```
12. Observe bit D1, or the second least significant bit.
 - If there is no short circuit condition and bit D1 of this register is high, no open load condition exists either and there is no fault.
 - If there is no short circuit condition and bit D1 of this register is low, an open load condition exists. This situation must be fixed before sound is heard again.

3.2.4 Observable Fault Diagnostics—GUI

The fault diagnostics can be performed visually. The TIDA-01529 board employs a pair of LEDs that light up according to the state of comparator outputs. If desired, J25 and J26 can be removed to measure the output of the comparator directly using those pins.

1. Make sure the amplifier has been programmed as instructed in [Section 3.1.3](#).
2. Click on *View*→ *Register Inspector...* This will bring up the *Register Inspector* as shown in [Figure 16](#).
3. Navigate to page one, register 0x2D. Click the *Refresh* button in the upper-left corner.
4. If bit D1 is 1, change it from 1 to 0 by clicking on the bit. This will mute the amplifier. If the bit is already 0, the amplifier has already been muted by the chip's internal protection features, which suggests a short condition is present. The fault LEDs will allow the user to determine what type of short has occurred.
5. Observe the output LEDs on the top of the board. Use [Table 7](#) to determine which fault is present.
6. If a fault condition exists, fix the fault condition before attempting to play audio.
7. To play audio again:
 1. If there was a short-type fault, TAS2505-Q1 must be reset. This reset can be done by reprogramming the speakers as described in [Section 3.1.3](#).
 2. If the fault was open load or there was no fault condition at all, the amplifier must be turned back on by writing 1 to page one, register 45, bit D1.

3.2.5 Observable Fault Diagnostics—Direct I²C

1. Make sure the speakers have been programmed as instructed in [Section 3.1.3](#).
2. The amplifier must first be muted for the external diagnostics to work properly. To mute the amplifier, provide the following I²C commands:

```
# Page switch to page 1 W 30 00 01 # Mute output amplifier W 30 2D 00
```

3. Observe the output LEDs on the top of the board. Use [Table 7](#) to determine how the LED states correspond to fault conditions.
4. If a fault condition exists, fix the fault condition before attempting to play audio.
5. To play audio again:
 - If there was a short-type fault, TAS2505-Q1 must be reset. This reset is done by reprogramming the speakers as described in [Section 3.1.3](#).
 - If the fault was an open load or there was no fault condition at all, the amplifier must be turned back on. To do so, provide the following I²C command:

```
# Turn amplifier back on W 30 2D 02
```

3.3 Diagnostic Circuit #2

Instead of using the GPIO as an input like the first diagnostic circuit, the second diagnostic circuit uses the GPIO as an output. This circuit determines whether or no the speaker is connected - open fault detection. Follow the steps to use diagnostic circuit #2:

1. Insert jumpers J23, J24, and J27 to #2 to connect the circuit to the speaker lines.
2. Program GPIO as an input by writing 00001100 or 0x0C to register 0x34 of page 0. This sets the GPIO/DOOUT control register to its general output setting.
3. Mute the amplifier by setting page 1, register 0x2D, bit D1 to 0.
4. Set the GPIO high by setting page 0, register 0x34, bit D0 to 1.
5. Determine the voltage across J28. If the voltage is zero, then the speaker is disconnected. If there is a positive voltage of 1.2 V, then the speaker is connected.
6. To disable the circuit, set the GPIO low by setting page 0, register 0x34, bit D0 to 0.

Note that during normal operation, there will be a voltage present on J28 because of the positive voltage from the outputs switching.

3.4 Testing and Results

3.4.1 Test Setup

3.4.1.1 Bench Test Setup

The primary test setup is used to characterize most of the operation parameters of the TIDA-01529 design, specifically THD+N ratio vs frequency, THD+N ratio vs output power, sound pressure level, and idle channel noise. An Audio Precision SYS-2722 is used to supply the audio signal input and to measure power output and THD+N. The SYS-2722 outputs are connected to the inputs for the channels to be tested and the SYS-2722 inputs are connected to the load resistors to measure the power output and THD for the channels of interest. A digital multimeter (DMM) is used to measure DC current and voltage at the power input. [Figure 17](#) shows a view of the board connected to a host PC through USB and also connected to a 8-Ω speaker. The TAS2505-Q1EVM is configured for external analog inputs using Codec Control as outlined in [Section 3.1.3](#). [Figure 17](#) shows the electrical connections in the TIDA-01529 design.

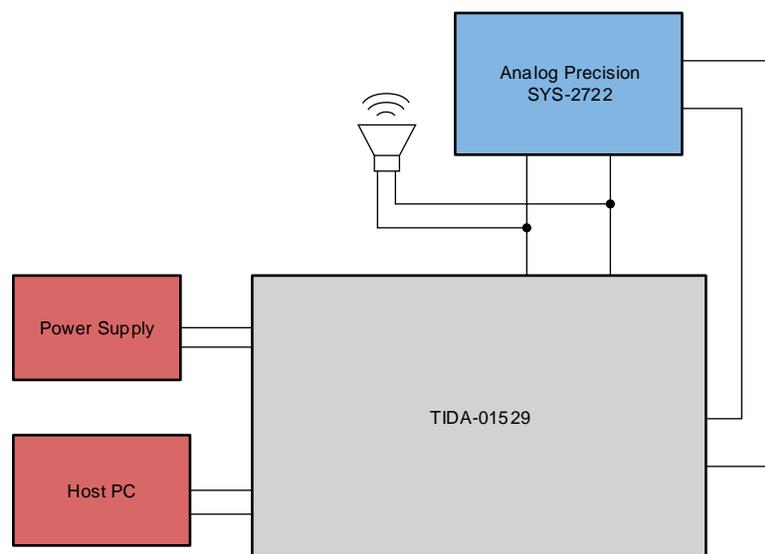


Figure 17. Test Setup Block Diagram for Power Output, THD, and ICN Tests

3.4.2 Test Results

3.4.2.1 Power Output, Total Harmonic Distortion, and Noise (THD + N)

Total Harmonic Distortion + Noise (THDN) 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 TAS2505-Q1EVM. The audio precision then measures the THDN of the analog signal across the 8- Ω load. Figure 18 shows the THDN versus output power across two different 8- Ω loads, the US4008J from Unique Sound and an 8- Ω resistor. The input voltage was set to 5.5 V with an external power supply.

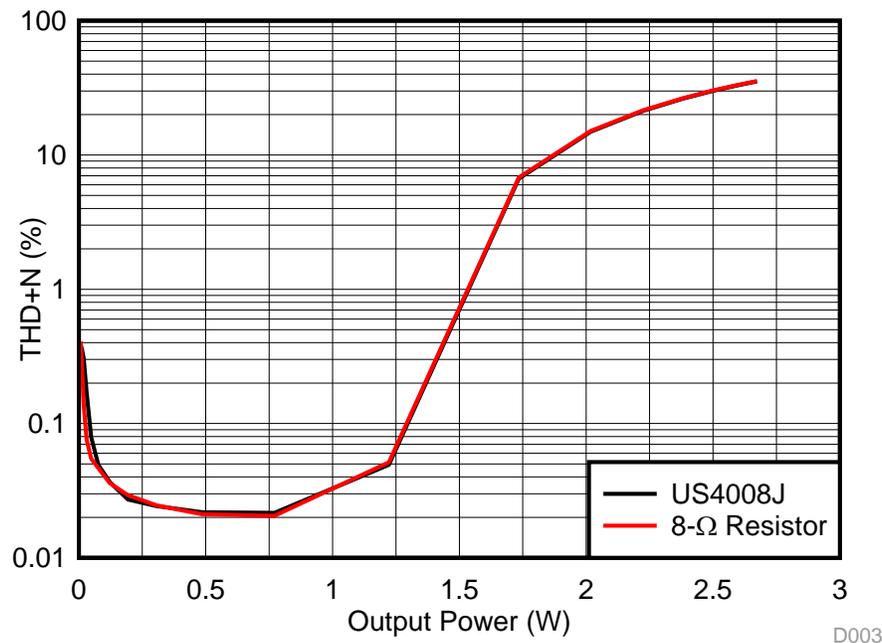


Figure 18. THDN vs Power

Figure 19 shows a plot of the frequency response of the system. The frequency response was tested with the output set to 1 W when the input frequency was 1 kHz. To achieve 1 W, the analog input was 379.0 mV_{RMS} and the digital input was -2.851 dBFS with the gain set to 12. Both the digital and analog inputs were generated by the audio precision equipment. An 8-Ω speaker, the US4008J, was used for the load.

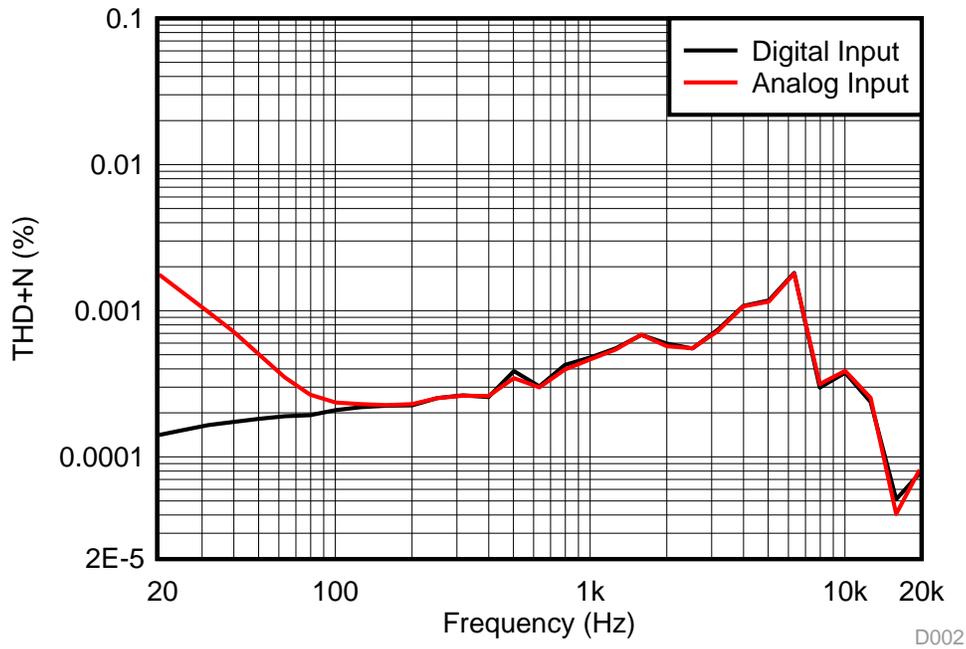


Figure 19. THDN vs Frequency

Idle channel noise (ICN) was found by measuring the amplitude of the output with the audio precision equipment when no sound was playing. ICN was 55.59 μV.

3.4.2.2 Sound Pressure Level

The TAS2505-Q1EVM was programmed to read audio from laptop through I²S. The device was placed 10 cm away from a Shure® X2u microphone and the speaker played a 1-kHz full scale sine wave. The gain and volume were adjusted to multiple levels in order to achieve the speaker's power rating, and two different 8-Ω speakers were used: the SM360508 from DB Unlimited and US4008J from Unique Sound.

8-Ω SPEAKER	SPEAKER RATING	OUTPUT POWER (W)	SPL (dB)	AMPLIFIER SETTINGS	
				SPK VOLUME (Pg1 0x2E)	CLASS D GAIN (Pg 1 0x30)
SAC-30B	86 dB at 0.2 W	0.212	86.22	-3.66	0
		0.48	89	0	6
		0.74	90.6	-4.88	12
US4008J	103 dB at 1.5 W	1.06	92.3	-3.05	12
		1.41	99.2	0	12
		1.48	101.7	-5.49	18

3.4.2.3 Current Consumption and Diagnostics

Table 8. Current Consumption With 5-V Input, 8-Ω Load

CONDITION		CURRENT (mA)
Amplifier muted		7.00
Amplifier on		16.42
Amplifier active, 6-dB gain	-12 dBFS	28.6
	-6 dBFS	54.9
	0 dBFS	105.0

Table 9. Diagnostics

FAULT	-40°C	0°C	105°C
Open load	Pass	Pass	Pass
Short to GND	Pass	Pass	Pass
Short to PWR	Pass	Pass	Pass
Short between terminals	Pass	Pass	Pass
Overtemperature	Pass	Pass	Pass—OT detected at 142.2°C

The TAS2505-Q1EVM's diagnostic capabilities were tested at -40°C, room temperature, and 105°C. *Pass* means the fault condition was detected properly. As such, the diagnostics function at the full range of operation for the TAS2505-Q1, and the overtemperature threshold was measured at 142.2°C. The OT fault temporarily mutes the speaker until it cools to an appropriate level.

4 Design Files

4.1 Schematics

To download the schematics, see the design files at [TIDA-01529](#).

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [TIDA-01529](#).

4.3 PCB Layout Recommendations

4.3.1 Layout Prints

To download the layer plots, see the design files at [TIDA-01529](#).

4.4 Altium Project

To download the Altium Designer® files, see the design files at [TIDA-01529](#).

4.5 Gerber Files

To download the Gerber files, see the design files at [TIDA-01529](#).

4.6 Assembly Drawings

To download the assembly drawings, see the design files at [TIDA-01529](#).

5 Software Files

To download the software files, see the design files at [TIDA-01529](#).

6 Related Documentation

1. Texas Instruments, [TAS2505 Application Reference Guide](#)
2. Texas Instruments, [TAS2505-Q1 2.6-W Digital/Analog Input Automotive Class-D Speaker Amplifier With Audio Processing Data Sheet](#)
3. Texas Instruments, [Automotive Diagnostic solutions for TAS2505-Q1 Application Report](#)
4. Texas Instruments, [TAS2505, TAS2521 Codec Control EVM User's Guide](#)

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Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (August 2018) to A Revision	Page
• Added Diagnostic Circuit #3 section.	14

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