Application Report

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Class-D Amplifier External Load Diagnostics

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ABSTRACT

This application report provides design information for an external load diagnostics circuit to detect and identify electrical faults between the output of an audio amplifier and a target speaker. While the TPA3111D1-Q1 class-D amplifier is used as an example in this application note, this design methodology is relevant for most class-D amplifiers to provide external fault diagnostics.

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1 Introduction

Embedded electronics are becoming ever more present in automotive applications, particularly as a means of limiting risk to drivers. With this increasing dependence on electronic systems comes an increasing need to monitor the functioning of these systems in order to detect potentially critical errors. The purpose of load-diagnostic circuitry is to diagnose potential faults which may occur in electrical circuitry throughout an automobile.

One example application of this circuitry is to support eCall system functionality. The emergency call (eCall) system represents an emerging application in which emergency responders are immediately alerted after an accident through the car phone. The responder is then able to speak with the victim through the audio systems embedded in the car. In the event of an accident, the audio systems of the car could sustain serious damage, preventing a victim from being able to hear instructions issued by emergency responders utilizing the eCall system.

After an accident, there are various faults which could cause the speaker system to fail. Damage from a serious accident could result in short circuits to battery or ground, short circuits across the speaker, or disconnection of the speaker from the audio amplifier. If a failure occurs, it is important that the emergency responders be notified that the victim is unable to hear them. In this instance, load diagnostics are needed to detect potential fault conditions in order to verify the level of functionality of the system.

Table 1. Fault Potential Detection

Fault Condition	Detectable Without External Diagnostics	Able to Identify Without External Diagnostics
Short to Ground	Yes	No
Short to Battery	Yes	No
Shorted Load	Yes	No
Open Circuit	No	No

While many audio amplifiers have internal diagnostic circuitry, amplifiers such as the TPA3111D1-Q1 have only a basic fault-detection system to detect short-circuit conditions. External circuitry is necessary for these amplifiers in order to determine the nature of the fault which has occurred. The object of the design presented within this application note is to provide a possible external fault diagnostic circuit topology as an alternative to chips possessing internal fault diagnostics.

The circuit and solution presented in this application note has not been tested to any industry standards. It is the responsibility of the reader to perform standard industry testing to assure safety when using the solution in part or in whole in any form. Texas Instruments does not provide any guarantees, written or implied, about the safety of the solution.

2 Overview

This application note covers the design of external fault-diagnostic circuitry intended to differentiate between various short-circuit conditions and to provide speaker detection. The system being tested consists of the TPA3111D1-Q1 class-D amplifier driving an output speaker, with load-diagnostic circuitry attached in shunt across the speaker lines. While the TPA3111D1-Q1 is used as an example throughout this application note, this design is equally relevant for almost any class-D amplifier which lacks integrated fault diagnostics.

3 Schematic and Design

The fault diagnostic circuitry presented within this application note is intended to address the four major types of faults which could occur on the speaker output lines. The circuitry provided is widely applicable and can be applied to virtually any amplifier circuit, provided the amplifier in question includes a manual shutdown control which drives the outputs of the amplifier to a high impedance state.

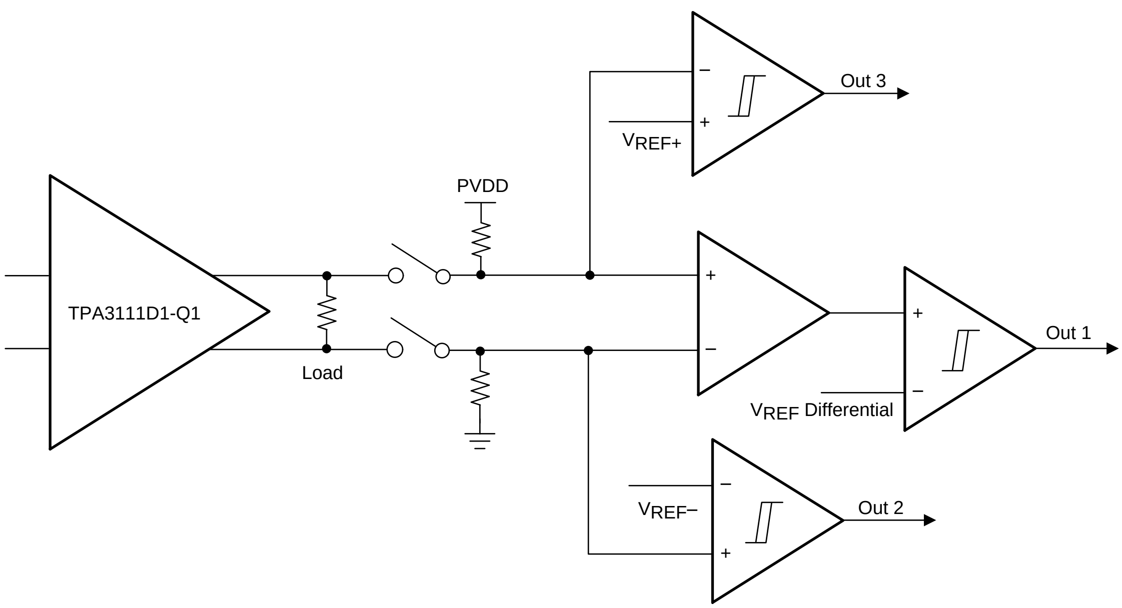

Figure 1. Full Diagnostic Circuit

Comparators are used to measure the voltages on either side of the load against voltage thresholds set by the resistor dividers. Additionally, a pair of operational amplifiers serves to measure the differential voltage across the load. The output lines of the comparators are pulled low when the voltages pass the thresholds, indicating the occurrence of a fault condition. By examining the outputs of the pins, it is possible to determine which type of fault has occurred. The following truth table gives the various fault conditions indicated by various output states.

The various fault detection mechanisms are similar in design. During operation of the diagnostic circuit, the outputs of the amplifier are placed into a high impedance state. In the event the output circuit is shorted to PVDD, the voltages throughout the circuit will rise to the level of PVDD, provided the amplifier outputs are high impedance to prevent current flow. Likewise, a short to GND will pull all voltages in the circuit to ground, provided that the amplifier outputs are high impedance. These cases pull the voltages in the diagnostic circuit up or down, respectively, past the referenced voltage thresholds set by the resistor divider networks; this causes the corresponding comparator outputs to be pulled to ground. In the event of an open circuit, the pullup and pulldown resistances within the diagnostic circuitry pull both voltages past their thresholds, pulling both the PVDD and GND detection pins low. By contrast, the short-circuit diagnostics rely on a differential amplifier to compare the differential voltage across the load to a threshold voltage; the output of the corresponding pin is pulled low when the amplified differential voltage falls beneath this threshold.

Additionally, dual PMOS switching circuits (see Figure 2) were implemented to isolate the diagnostics from the speaker circuit when the speaker is in use. This decreases power consumption and prevents the speaker pop caused by the biasing within the diagnostic circuitry. This also isolates the diagnostics when not in use, preventing them from contributing additional THD and noise to the audio signals.

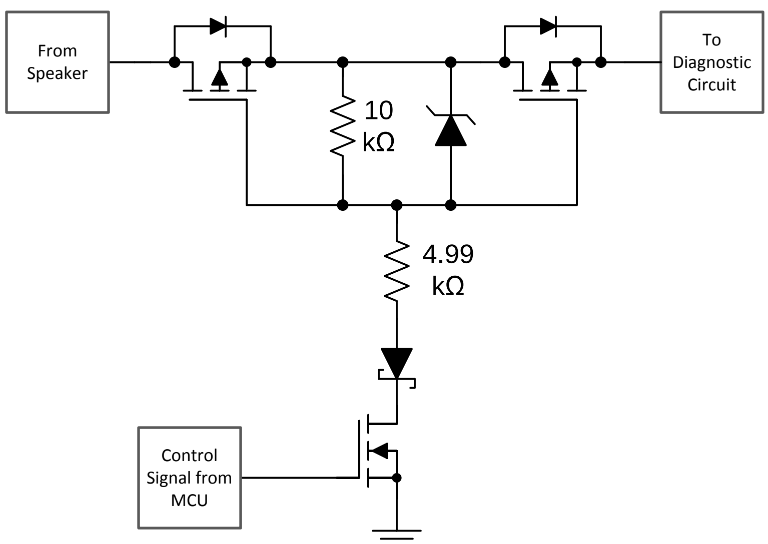

Figure 2. Diagnostic Circuit Isolation

3.1 Partial Diagnostic Circuits

The diagnostic circuitry can be broken into two main parts. The open load, short to GND, and short to PVDD conditions all rely on the circuitry shown in Figure 3. Note that the outputs of the comparators will need to go through level translation in the form of a resistor divider, depending on the logic levels of the MCU.

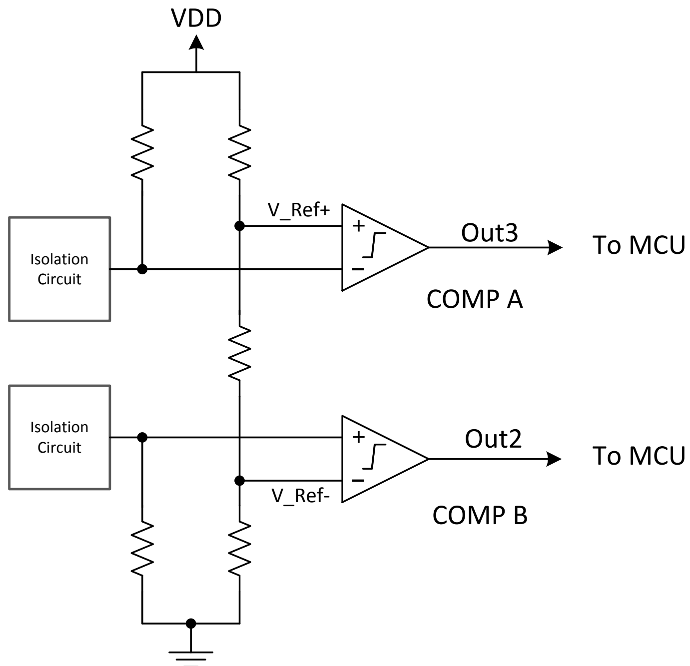

Figure 3. Partial Diagnostics Circuit Covering Short to GND, Battery, and Open Load

By contrast, the shorted load circuit detection is handled by measuring the voltage differential across the load. This functionality depends on a different diagnostic circuit, illustrated in Figure 4.

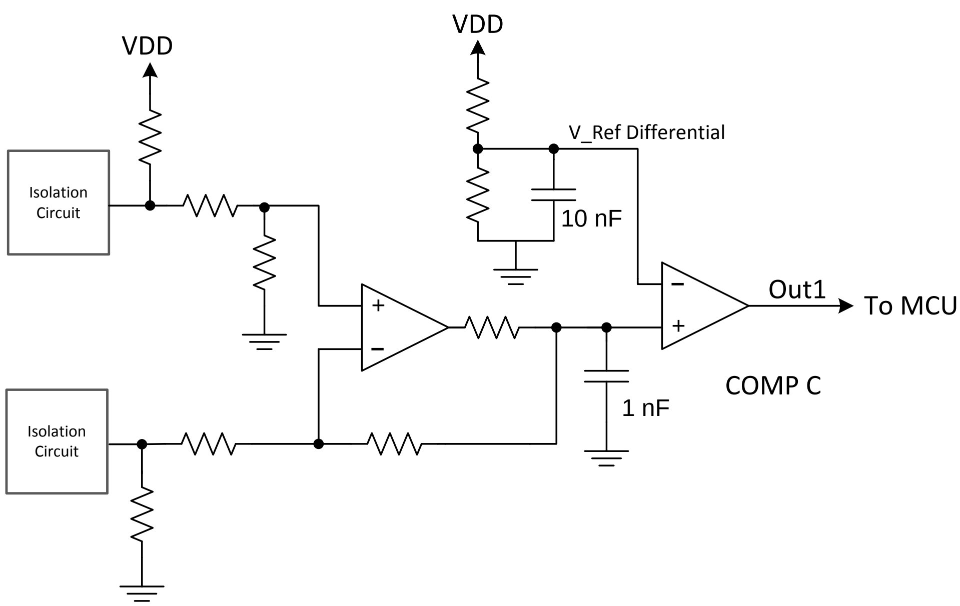

Figure 4. Partial Diagnostics Circuit Covering Shorted Load

In the event that the amplifier contains internal fault detection, it is possible to implement a simpler circuit design by removing the redundant portions of the external diagnostics. For example, the TPA3111D1-Q1 has internal short-circuit detection. Therefore, the circuitry for detecting the shorted load condition can be omitted, leaving the circuitry for detecting the open circuit and the diagnostic capabilities for short to GND and short to PVDD conditions, and allowing the Fault pin to serve as the indicator for shorted load.

3.2 Tuning the Circuit

Choosing the correct resistances for a given design may require tuning of the diagnostic circuit. Many amplifiers have pulldown and possibly pullup resistances on the outputs as shown in Figure 5. This impacts the behavior of the amplifier when outputs are put into a high-Z state. As a result, TI recommends prototyping this circuit in order to verify that the correct resistance values are chosen for a particular application.

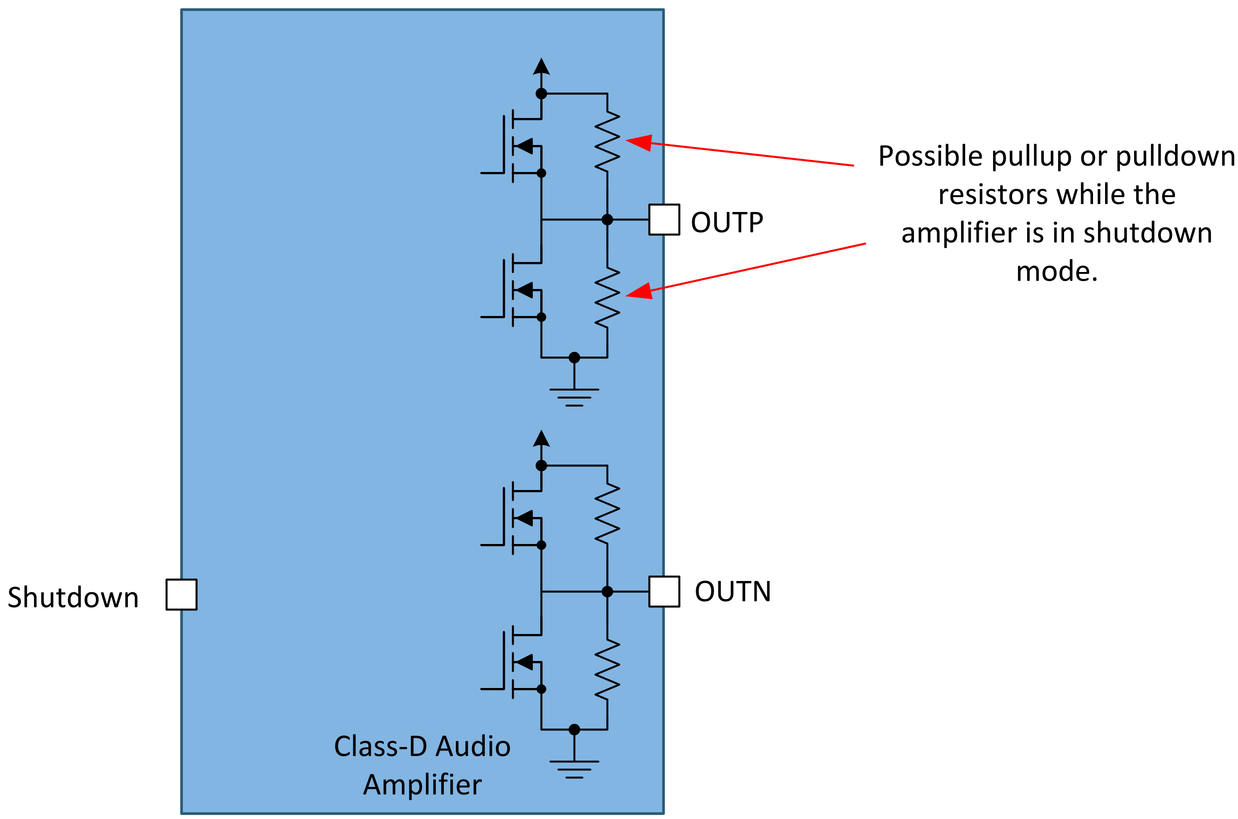

Figure 5. Class-D Amplifier Impedance While in Shutdown Mode

The resistances shown in the example schematic, see Figure 6, were chosen based on the design parameters required by this particular implementation. The resistances within the dual PMOS switches control the current necessary to turn on the circuit, while the resistors used in the voltage dividers set the threshold voltages for the comparators. The resistors used in conjunction with the operational amplifier set the desired amplification of the differential signal. This diagnostic circuit design is widely flexible and must be tuned based on the specifications of the application. The procedure for tuning is as follows:

1. Connect the diagnostic circuit across the output of the audio amplifier in parallel with the load.
2. Switch the diagnostic circuit on by pulling the NMOS gate high.
3. Measure the diagnostic line voltages for each of the four possible fault conditions.
4. Adjust the resistor divider values to set voltage thresholds for the various fault conditions.
5. Verify the functionality of the settings used.

The tuning process allows the designer to specify the sensitivity and margin of error to be used when detecting a given fault. For example, a short-circuit fault can be set to trigger when the resistance across the amplifier outputs drops below 2 Ω, or it can trigger at a threshold of 4 Ω instead. This also allows adjustment for speakers of various impedances; the relevant thresholds in a circuit used to drive an 8-Ω speaker might differ drastically from the same thresholds used to drive a 4-Ω circuit. The resistor divider circuitry can be adjusted to adjust for particular voltage thresholds, while the pullup and pulldown resistor values associated with the diagnostic circuitry can be modified as needed. Additionally, the resistors associated with the differential operational amplifier can be adjusted to raise or lower the sensitivity of the short-circuit detection circuit by varying the differential amplifier gain.

Once again, the passive component values chosen are highly dependent on the amplifier model utilized, the topology of the output circuit, and the way in which various faults are defined. Table 2 gives the specific fault definitions which were used in this particular design for the TPA3111D1-Q1.

Table 2. Fault Definitions

Fault	Description
Short circuit to PVDD	Resistance to PVDD < 16 kΩ
Short circuit to GND	Resistance to GND < 1.8 kΩ
Short circuit across the load	Resistance across load < 0.5 Ω
Open circuit (load disconnected)	Resistance between outputs > 16 kΩ

3.3 Circuit Parameters

Table 3 shows the supply voltage used in data collection, as well as the threshold voltages measured for each of the comparators.

Table 3. Data Collection Supply Voltages

Parameter	Value (V)
Supply Voltage	12.033
V_Ref +	6.86
V_Ref -	5.157
V _Ref Differential	2.76

Using the parameters from Table 3, the following bias voltages were measured when the diagnostics were activated in the presence of each of the various faults. The bias point voltages are also given for a situation in which the diagnostics are activated when no fault is present.

Table 4. Diagnostic Circuit Bias Points

Fault	Speaker Terminal + (V)	Speaker Terminal – (V)	Comparator Output (V)	Outputs
Short to GND	2.43	0.017	10.79	101
Shorted Load	5.95	5.94	0.5	110
Short to PVDD	12.03	11.73	10.85	011
Open Load	11.8	0.159	10.79	001
No Fault	5.88	5.85	5.33	111

It is important to note that the value of the comparator measuring the differential voltage across the speaker terminals is 1 V during its low state, as opposed to 0 V for the other two comparators. This is due to the fact that this comparator is actually the second operational amplifier in the LM2904 package, which is configured as a comparator to avoid the need for additional components.

The power consumption of the circuit was also quantified in terms of the amount of current drawn. The measured current draw of the circuit is shown in Table 5.

Table 5. Measured Current Draw

Diagnostic Circuit State	Typical Current (mA)
Active-No Faults	40
Active-Faults	36-56
Inactive	15

Note that the values reflect the current drawn for this particular circuit and may not reflect other implementations with resistor values differing from those used in this sample design.

3.4 Operation

In order to run the fault diagnostics, it is necessary to drive the $\overline{SD}$ pin of the device low to initiate shutdown conditions; this ensures that the amplifier outputs reach a high-Z state. Next, the gate of the N-channel MOSFET must be driven high to activate the diagnostics. The values of the three outputs may then be read to detect any existing fault condition and to diagnose the nature of the fault.

Table 6. Logic Table of Fault State Outputs

Condition	Out3	Out2	Out1
Short to GND	High	Low	High
Shorted Load	High	High	Low
Short to PVDD	Low	High	High
Open Load	Low	Low	High
No Fault	High	High	High

4 Schematic and Bill of Materials

Figure 6 illustrates the schematic.

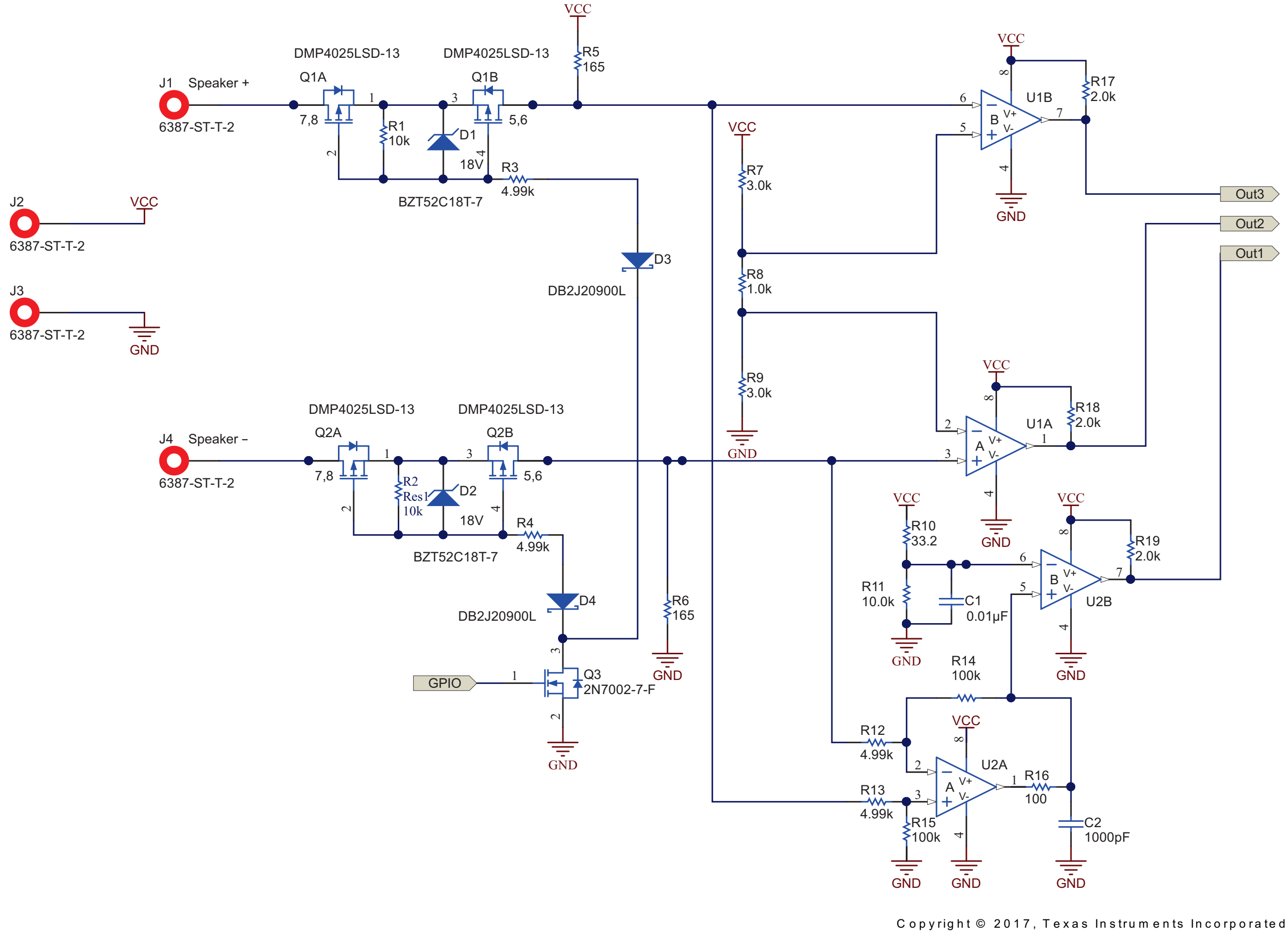

Figure 6. Schematic

Table 7 lists the bill of materials.

Table 7. Bill of Materials

Designator	Part Number	Description	Quantity
C1	06031C103JAT2A	CAP, CERM, 0.01 µF, 100 V, +/- 5%, X7R, 0603	1
C2	06035A102KAT2A	CAP, CERM, 1000 pF, 50 V, +/- 10%, C0G/NP0, 0603	1
D1, D2	BZT52C18T-7	Diode, Zener, 18 V, 300 mW, SOD-523	2
D3, D4	DB2J20900L	Diode, Schottky, 20 V, 0.5 A, SOD-323F	2
J1, J2, J3, J4	6387-ST-T-2	Banana Jack For Sheathed Banana Plugs, 4mm, TH	4
Q1, Q2	DMP4025LSD-13	MOSFET, P-CH, -40 V, -6.9 A, SOIC-8	2
Q3	2N7002-7-F	MOSFET, N-CH, 60 V, 0.17 A, SOT-23	1
R1	CRCW060310K0JNEA	RES, 10 k, 5%, 0.1 W, 0603	1
R2	RC0603FR-0710KL	RES, 10.0 k, 1%, 0.1 W, 0603	1
R3, R4, R12, R13	CRCW06034K99FKEA	RES, 4.99 k, 1%, 0.1 W, 0603	4
R5, R6	CRCW0603165RFKEA	RES, 165, 1%, 0.1 W, 0603	2
R7, R9	CRCW06033K00JNEA	RES, 3.0 k, 5%, 0.1 W, 0603	2
R8	CRCW06031K00JNEA	RES, 1.0 k, 5%, 0.1 W, 0603	1
R10	CRCW060333R2FKEA	RES, 33.2, 1%, 0.1 W, 0603	1
R11	RCG060310K0FKEA	RES, 10.0 k, 1%, 0.1 W, 0603	1
R14, R15	CRCW0603100KJNEA	RES, 100 k, 5%, 0.1 W, 0603	2
R16	CRCW0603100RJNEA	RES, 100, 5%, 0.1 W, 0603	1
R17, R18, R19	CRCW06032K00JNEA	RES, 2.0 k, 5%, 0.1 W, 0603	3
U1	LM2903AVQPWRQ1	Automotive Dual Comparator, PW0008A	1
U2	LM2904AVQPWRQ1	Automotive Dual Low Power Op Amp, PW0008A	1

5 Summary

When properly tuned for the application, the provided circuit should correctly identify specified fault conditions. While additions and modifications may improve the robustness of the circuit, the design shown utilizes a minimal number of parts while remaining clear and concise for analysis. Ultimately, the solution shown demonstrates applicability in fault diagnostic capabilities within audio amplification designs.

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