

Designing real-time diagnostic circuits for automotive audio applications

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Designers of modern in-car audio systems are rapidly adopting diagnostic capabilities to monitor Class-D amplifier integrated circuits and attached speakers. Of key concern are the in-vehicle speakers connected to the telematics control unit (TCU) used during roadside emergency situations, such as a crash or breakdown (Figure 1). Detecting and notifying drivers to shorted or disconnected speakers enables them to schedule maintenance before a catastrophic event.

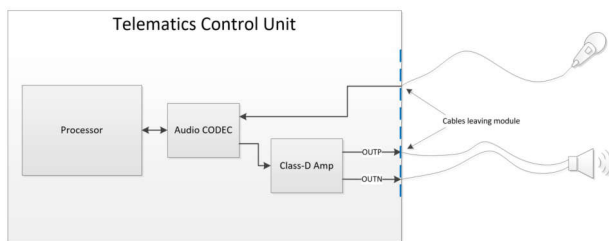


Figure 1. TCU with a Class-D audio amplifier showing the speaker connection

Real Time Diagnostics (RTD)

As an additional layer of safety, some vehicle manufacturers are requiring real-time diagnostics (RTD). Traditionally, Class-D speaker diagnostics check the speaker when the TCU module or Class-D amplifier turns on but will not monitor thereafter for all fault scenarios. RTD monitors the speaker at startup and continues to monitor it while the vehicle is in operation. This additional monitoring not only reduces the time between system failure and notification but also ensures prompt notification during events such as a lengthy hundred-mile drive.

Immediately alerting the driver minimizes the chance of an accident occurring while the emergency call speaker is in a faulty condition. Additionally, the system can also

alert emergency service operators during an emergency phone call if a speaker fault issue is detected. If the speaker experiences a fault after a car accident (such as severed wires between the TCU module and the speaker), the system can send a message to the emergency operator that the driver will not be able to hear their commands. As a final requirement, diagnostics should never introduce errant audio in the cabin.

The Class-D amplifier must be able to diagnose four main speaker fault conditions, as shown in the following figures.

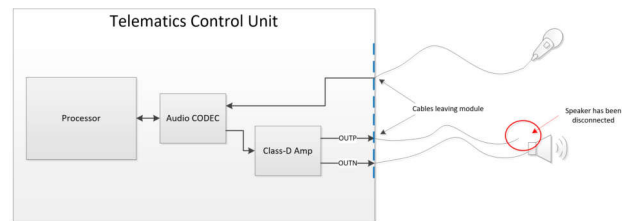
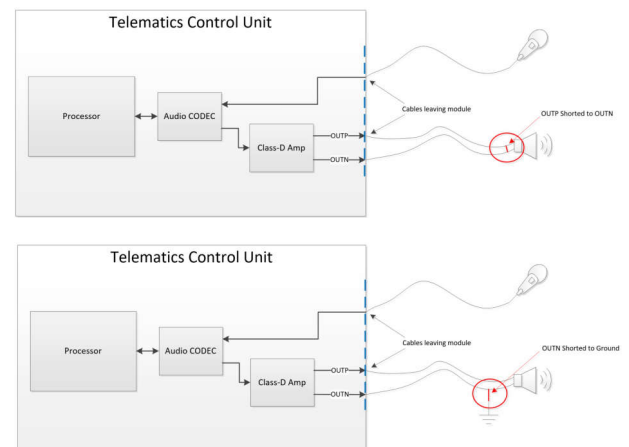
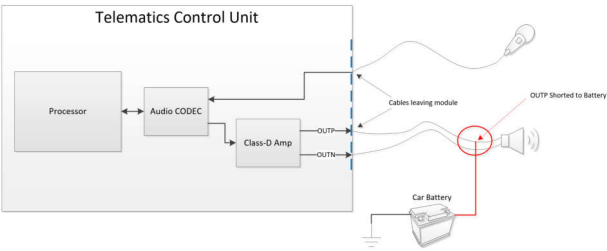


Figure 2. The four speaker fault conditions: open speaker or load (a); positive output shorted to a negative output (b); positive output or negative output shorted to ground (c); positive output or negative output shorted to the vehicle battery (d).





Additionally, the Class-D amplifier should be able to operate normally even when a fault is removed without requiring host intervention. For example, it should be possible to detect an intermittent short on the speaker wires; however, the system still operates normally when the fault condition is removed.

Class-D amplifier selection

The Texas Instruments TAS5431-Q1 Class-D amplifier can deliver up to 8 W of power to a car speaker and protect itself and the TCU module from four fault conditions, as well as diagnose all four fault types at startup (also known as “deassertion of standby mode”). After startup, the amplifier can detect a positive or negative output shorted to ground, a positive or negative output shorted to the vehicle battery, and a positive output shorted to a negative output only while audio is playing. More details on how the TAS5431-Q1 diagnoses these fault conditions can be found in section 7.3.5 “Load Diagnostics” of the TAS5431-Q1 datasheet.

Although the TAS5431-Q1 is capable of diagnosing these fault conditions at startup, it cannot implement the full RTD suite on its own. A notable shortcoming is the inability to detect a positive output shorted to a negative output or an open speaker/load after deassertion of standby mode. Table 1 summarizes the standard capabilities of TAS5431-Q1 diagnostics.

	Deassertion of standby mode	Device in operation (no audio)	Device in operation (audio playing)
Positive or negative output shorted to ground	Yes	Yes	Yes
Positive or negative output shorted to battery	Yes	Yes	Yes
Positive output shorted to negative output	Yes	No	Yes
Open load	Yes	No	No

Table 1. TAS5431-Q1 RTD summary

Achieving RTD

To detect a positive output short to a negative output when no audio is present, the audio source (codec or processor) must mix in a baseline signal with the voice or audio signal (Figure 3). As an example, a baseline 5Hz 200mV peak-to-peak signal is well below the audio frequency range (20Hz to 20kHz) and has enough amplitude (200mV peak to peak) to produce the required excitation to detect a positive output short to a negative output.

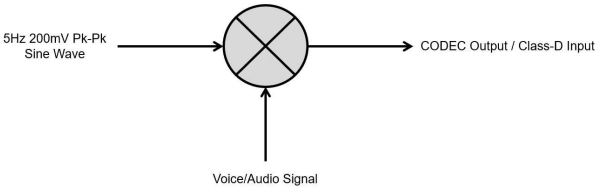


Figure 3. Mixing in an out-of-band baseline signal of 5Hz at 200mV peak to peak enables detection of output shorts when no audio is present

Applying a low-frequency baseline signal to the input of the TAS5431-Q1 ensures that the device will hit its overcurrent limit when a positive output shorts to a negative output. The diagnostic assessment mode integrated into the TAS5431-Q1 will then detect the positive and negative voltages and report the fault in the register map. Simply implementing this waveform changes the summary of diagnostics, as shown in Table 2.

	Deassertion of standby mode	Device in operation (no audio)	Device in operation (audio playing)
Positive or negative output shorted to ground	Yes	Yes	Yes
Positive or negative output shorted to battery	Yes	Yes	Yes
Positive output to a negative output	Yes	Yes	Yes
Open load	Yes	No	No

Table 2. Summary of TAS5431-Q1 RTD when adding a baseline 5Hz 200mV peak-to-peak sine wave to the Class-D amplifier input

Implementing a current-sense resistor, a current-sense amplifier, and a resistor-capacitor (RC) filter (**Figure 4**) in conjunction with the same 5Hz, 200mV peak-to-peak baseline signal enables the system to detect a speaker or open-load condition.

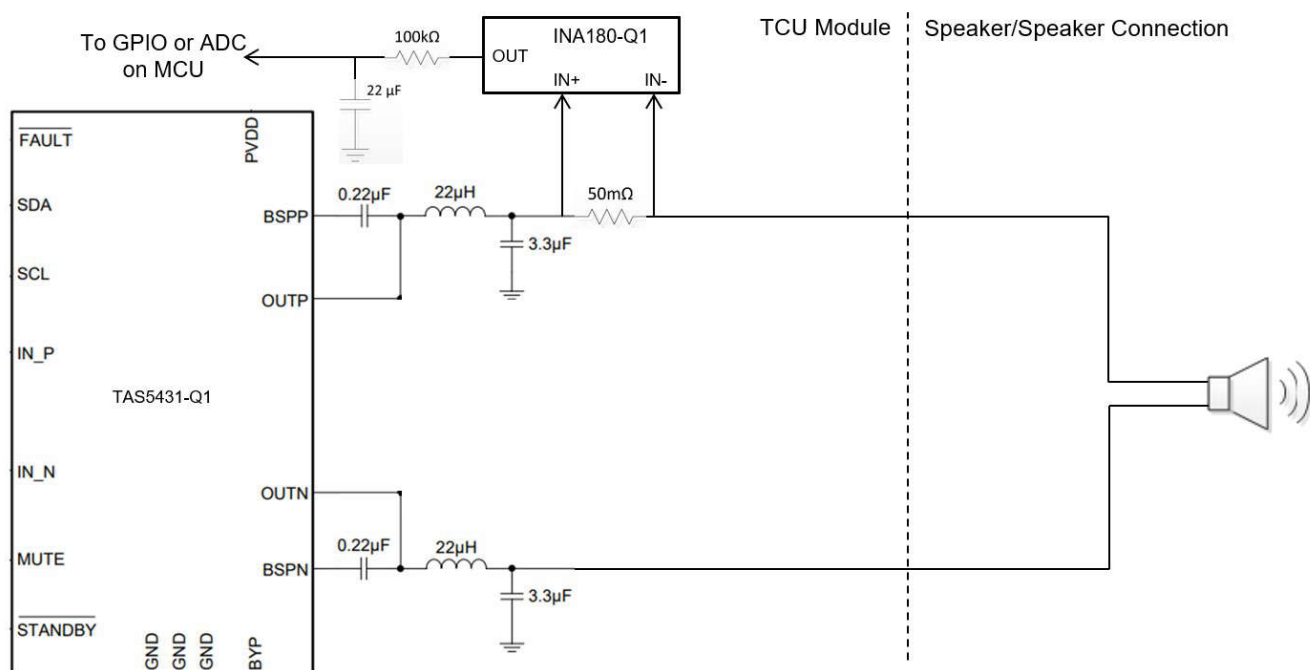


Figure 4. Implementing a simple current-sense amplifier circuit with the TAS5431-Q1 enables the detection of open circuits

The baseline signal generates current through the 50mΩ current-sense resistor, regardless of whether audio is present, which the **INA180-Q1** converts to a proportional voltage. Although the baseline signal is bipolar (goes both positive and negative), the unidirectional nature of the **INA180-Q1** automatically half-wave-rectifies the output voltage and vastly reduces the post-filtering requirements to a simple RC filter. The resulting DC output from the RC filter is driven into a

microcontroller general-purpose input/output or analog-to-digital converter (ADC) for analysis (**Figure 5**). During an open-load failure, current will cease to flow through the current-sense resistor, forcing the output of the **INA180-Q1** to 0 V. The **INA180-Q1** output crossing a pre-determined threshold triggers an alert to disconnect the speaker (**Figure 6**).

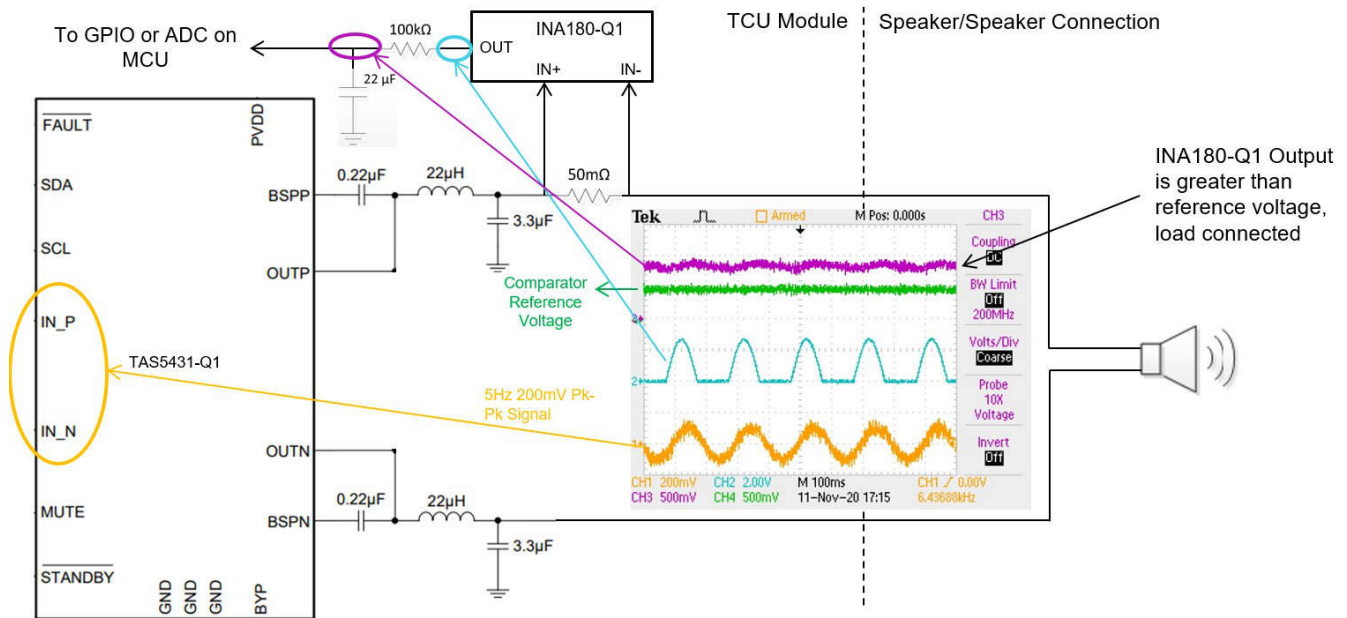


Figure 5. During normal operation, the INA180-Q1 rectifies the baseline signal to a measurable DC voltage

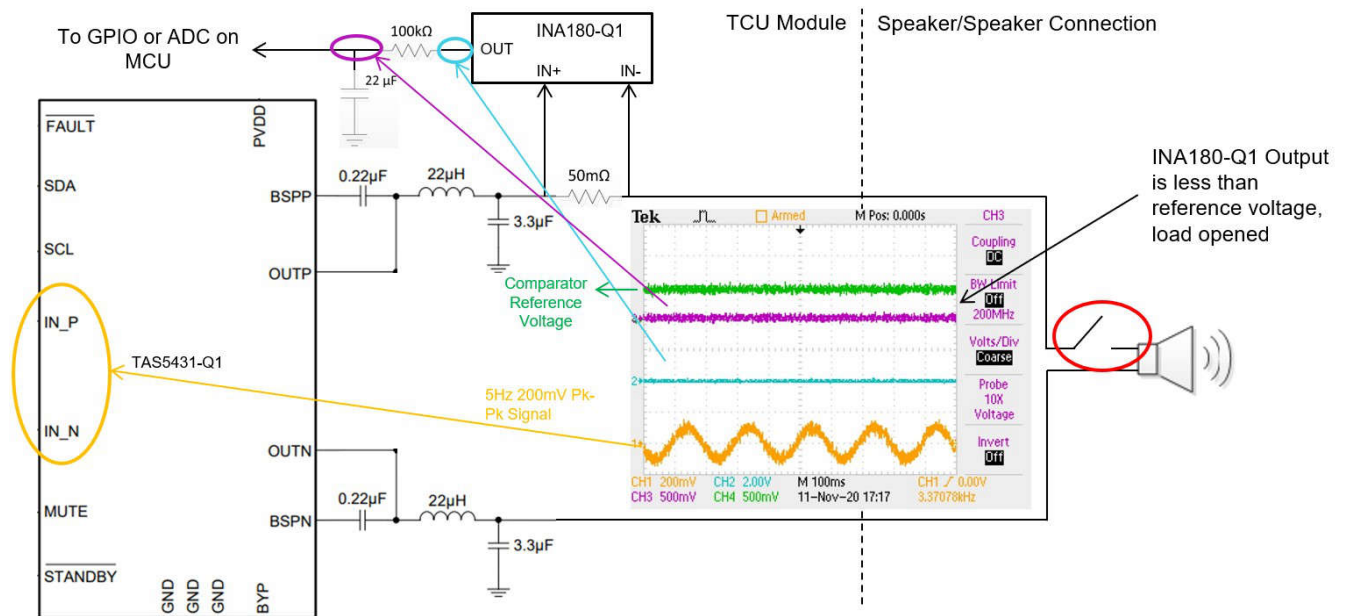


Figure 6. During an open-fault condition, the INA180-Q1 measures zero current, which is easily detectable by an attached comparator or ADC

Final verification of the circuit (Figure 7) with audio superimposed on the baseline signal yields the intended results during normal operation. The INA180-Q1 converts load current traveling through a 50mΩ resistor to a half-wave-rectified voltage. The post-filtered result is a DC voltage of 1V, which is greater than the pre-selected

threshold. All designs must be tuned to the intended load characteristics and the INA180-Q1 is available in several additional gain options. The INA180-Q1 also features a large common-mode input voltage range (26 V), ensuring that no damage will occur during a shorted battery fault, which typically induces up to 16 V on the lines.

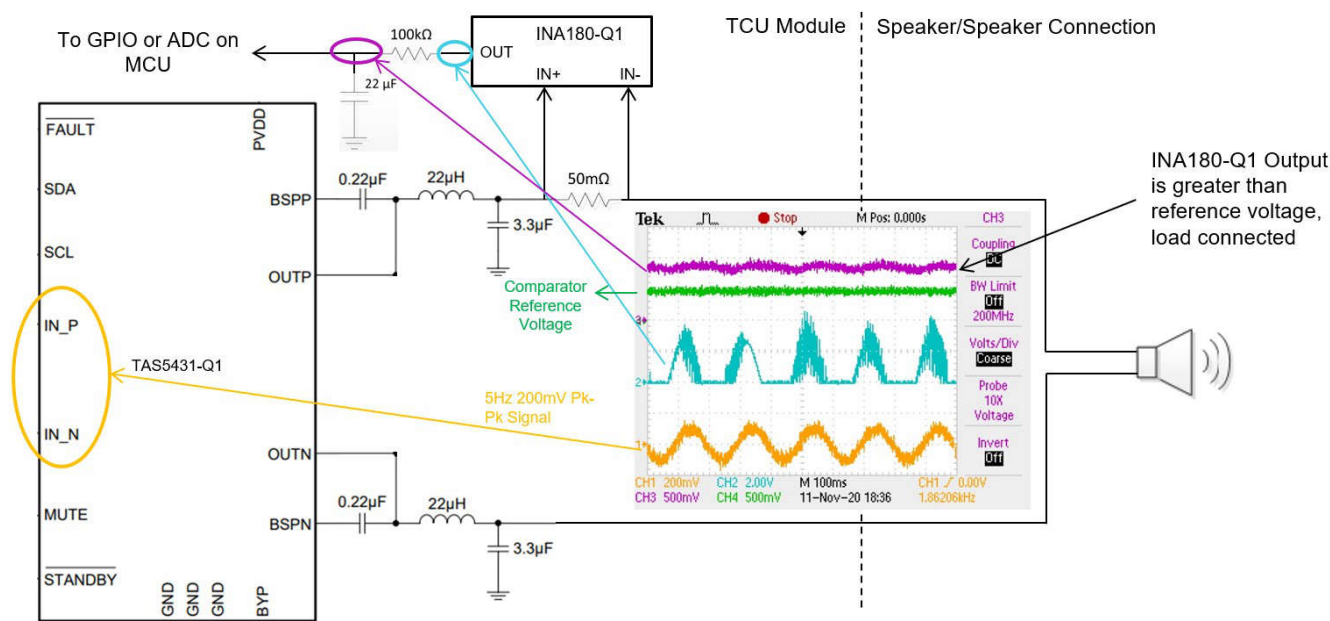


Figure 7. Open-load diagnostics, no fault condition, audio mixed into input

With the additional circuitry, the TAS5431-Q1 is finally able to achieve full RTD, as shown in Table 3.

	Deassertion of standby mode	Device in operation (no audio)	Device in operation (audio playing)
Positive or negative output shorted to ground	Yes	Yes	Yes
Positive or negative output shorted to battery	Yes	Yes	Yes
Positive output to a negative output	Yes	Yes	Yes
Open load	Yes	Yes	Yes

Table 3. Summary of TAS5431-Q1 RTD when adding a baseline 5Hz 200mV peak-to-peak sine wave and additional circuitry to the Class-D input

Additional considerations

Having achieved RTD with the TAS5431-Q1, there are two additional design considerations to review. The first is fault recovery. When a fault scenario is active, the Class-D amplifier should protect itself and any connected circuitry from damage, while also diagnosing the fault. Once the fault is removed, the device is expected to

immediately detect that the fault has been removed and continue to play audio (if audio is being applied to the input). The TAS5431-Q1 achieves fault recovery by continuously running its 229ms diagnostic cycle on repeat indefinitely. When a fault is removed, the diagnostic cycle determines that there is no longer a fault and allows the output stage to operate as normal. More details on this can be found in Section 7.3.5.1, “Load Diagnostics Sequence,” of the TAS5431-Q1 datasheet. The additional circuitry required to achieve RTD does not impact the device’s ability to recover from a fault and immediately play audio.

The second consideration is that, depending upon the total impedance of the load, the Class-D amplifier may have difficulty detecting the positive and negative output shorted condition. Each Class-D amplifier has an impedance threshold at which it will detect the positive output and negative output shorted together (a shorted speaker). In a given design, there may be a significant amount of impedance between the positive and negative outputs, especially when a short occurs close to a speaker, which can exceed the detection threshold of the Class-D amplifier. In vehicle systems, the cabling from

the TCU module to the speaker (and back to the TCU module) can be as long as 10 to 12 meters. Figure 8 shows all the different impedances to consider.

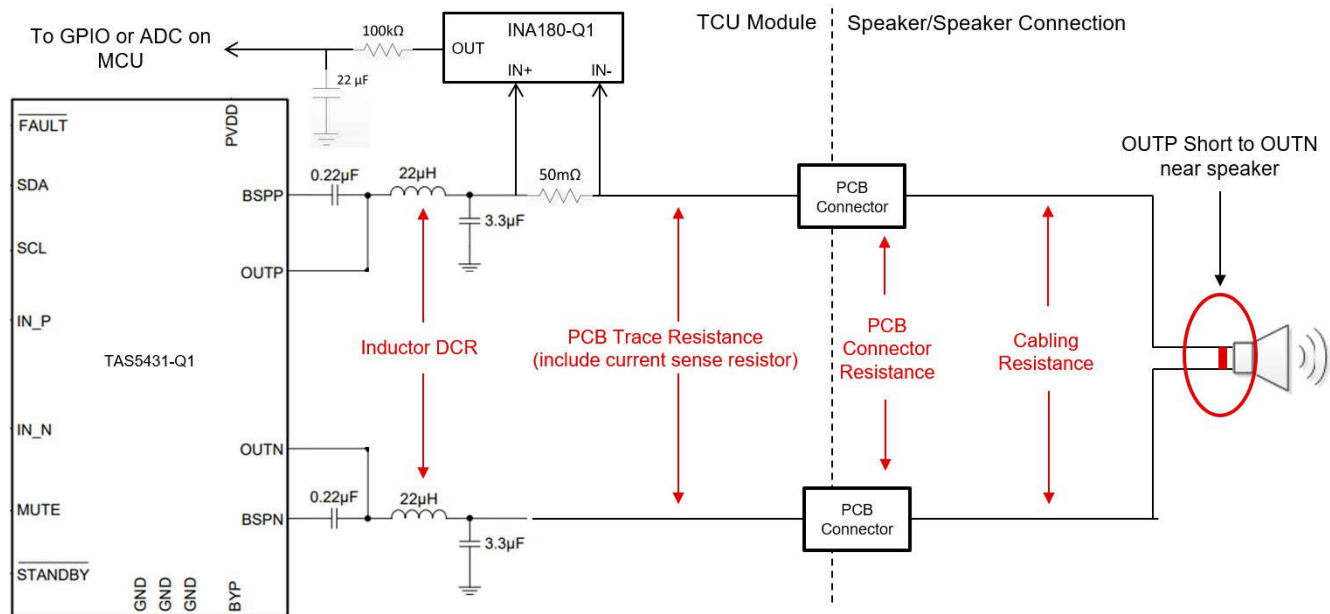


Figure 8. Accounting for impedances between the positive and negative outputs when a positive output short to the negative output occurs near the speaker

Next, we will review an example analysis of how to consider the various impedances in the system and compare them to the **TAS5431-Q1** detection threshold.

We can start by assuming 12 meters of 22AWG external cabling (0.053Ω/meter) totals 636mΩ of resistance, as shown in Equation 1:

$$12 \text{ meters} \times \frac{0.053 \Omega}{\text{meter}} = 636 \text{ m}\Omega \quad (1)$$

Standard automotive connectors such as the Molex 34826-8160 specify approximately 20mΩ per connector, totaling 40mΩ for the two connectors.

For the inductors, it is important to find an automotive-grade, low direct current resistance (DCR) inductor such as the VAMV1009AA-220MM2 from Cynotec. The 22 μ H inductor has a maximum of 56m Ω , multiplied by 2 for each coil, totaling 112m Ω .

Finally, adding the 50mΩ for the current-sense resistor totals approximately 838mΩ of resistance between the positive and negative outputs, not including trace resistance.

According to the **TAS5431-Q1** data sheet, the short-circuit detection threshold specification is 900 mΩ. Thus, to ensure the device identifies a short between the positive and negative outputs, the resistance between the two must be less than 900 mΩ. Based on the total calculated 838 mΩ of resistance, there is approximately 62 mΩ of trace impedance before the **TAS5431-Q1** may be susceptible to missing a short between the outputs.

Meeting the 900mΩ specification requires careful printed circuit board design and trace routing. You can also fine-tune other aspects of the design, such as using the “**LC Filter Design**” application report to select an alternative, lower-DCR inductor, or minimize the current-sense resistor value and select an **INA180-Q1** with a larger gain setting.

Conclusion

RTD has become a critical safety aspect for TCU systems. Through a series of clever circuit design techniques, vehicle manufacturers can overcome this challenge and start implementing RTD in TCU modules today. Additional diagnostics will lead to safer vehicles and safer vehicles will lead to a better experience for all drivers on the long road ahead.

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