Application Brief

Why Use TI Zener Diodes for High Power Applications

TEXAS INSTRUMENTS

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Introduction

Zener diodes are widely used in many DC voltage regulation applications. In these cases, the power capabilities of the device can become extremely crucial since inefficient power capacity can lead to excessive heat generation, ultimately damaging the diode and other nearby components. TI has solved this challenge by creating a high power Zener diode in the most widely used package on the market, SOT-23. The SOT-23 is a 3-pin package that is roughly 2.9mm x 2.4mm with leads. Due to the material makeup of the device and the unique lead frame, the thermal performance is almost 50% better. Having a better thermal performance leads to having an overall higher power dissipation. The following sections detail the steps in how TI created a high power SOT-23 Zener, the competitive analysis that was conducted during the process, and a walk through of an application example.

Competitive Analysis

The SOT-23 package has been dominant in the Zener market for decades. This package offers flexibility to house many different types of diodes and multichannel variants. The challenge with the package, however, is the limitation in power output which is why the market is primarily capped at 300mW for SOT-23 Zeners. The main contributor to power dissipation is the device's thermal performance, specifically the $R_{\theta JA}$. $R_{\theta JA}$ is the junction to ambient thermal resistance which measures the thermal performance of a package mounted on a specific test coupon, typically a FR-4 printed circuit board with single sided copper. The test coupon allows for easy comparability between companies.

A lower $R_{\theta JA}$ indicates the package can transfer heat more easily between junction and ambient temperatures, meaning the package is more thermally efficient. This prevents device overheating and can potentially extend the lifespan of the device. As shown in Table 1, there is a noticeable difference between TI's $R_{\theta JA}$ and a few competitors on the market today. Competitor C uses a different package that is the next highest in terms of power dissipation. This is included to show that TI's SOT-23 can compete in the SOD-123 Zener space as well even with the SOT-23 having a 20% smaller body size.

Table 1. Competitive Analysis for Zener Diodes

	TI	Competitor A	Competitor B	Competitor C
$R_{\theta JA}$	285.5°C/W	417°C/W	500°C/W	338°C/W
P_D	430mW	300mW	250mW	370mW
Package	SOT-23	SOT-23	SOT-23	SOD123
Body Area	3.8mm^2	3.8mm^2	3.8mm^2	4.8mm^2

In Table 1, power dissipation (P_D) is also shown. To calculate the overall power dissipation of the device, the following equation is used, with T_J being junction temperature and T_A as ambient temperature. Using a max junction temperature limit of 150°C and ambient temperature of 25°C with the $R_{\theta JA}$ listed above, the power dissipation can be calculated. This holds true for all values listed in Table 1.

$$T_J = T_A + \left(P_D \times R_{\theta JA}\right) \quad (1)$$

Material Composition

To overcome the challenge of power dissipation, especially in small packages, the material composition becomes crucial. This involves lead frame material, mount compound, mold compound, and so forth. In terms of the competitive landscape, Iron-Nickel alloy lead frames have been adopted, however, this has a low thermal conductivity. Iron-Nickel alloy is a material that has been used for decades and is known to have delamination and solder joint issues due to the material and construction. As an alternative, copper alloy lead frame materials present much higher thermal conductivity. Because of this material difference, TI's SOT-23 Zener diodes perform better at longer durations, this can be seen in Figure 1. The figure compares the $R_{\theta JA}$ over time between the TI SOT-23 package and a competitor SOT-23 package. When conducting the thermal analysis, a few parameters such as die thickness, die attach, lead frame material, and lead frame design were kept as actual construction. Die size and PCB were constants to have an accurate comparison between the two devices.

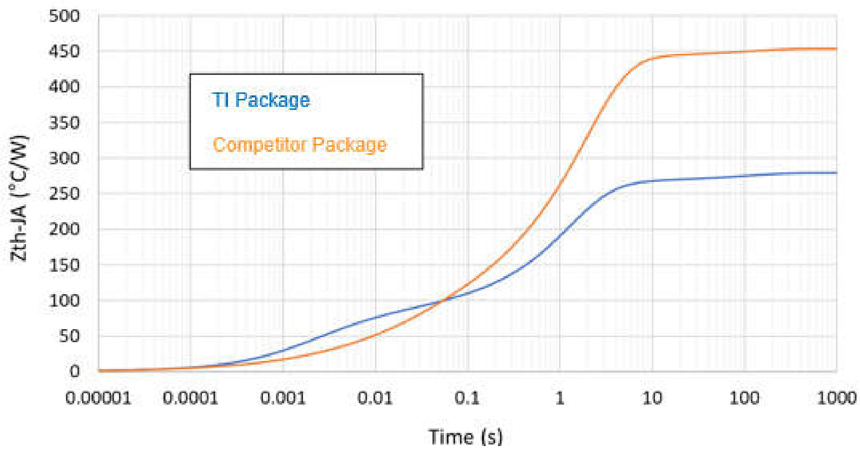

Figure 1. SOT-23 Package Thermal Comparison

Based on Figure 1, the competitor device does perform a little better at short durations. This is because of the die attach material. Die attach being the material used to connect the die to the lead frame. The competitor device is using pure silver and backside plating which allows for better thermal conductivity at short durations but can be a more costly route. The image below shows the material composition of the die attach for the competitor device, with majority of the makeup being silver (Ag). An alternative to a pure silver die attach is using silver epoxy instead. Silver epoxy does not offer the same level of thermal conductivity, but the epoxy does allow for faster manufacturing times and improved reliability. There are always tradeoffs when designing a device, but for our case, the route taken led to a huge advantage in power dissipation.

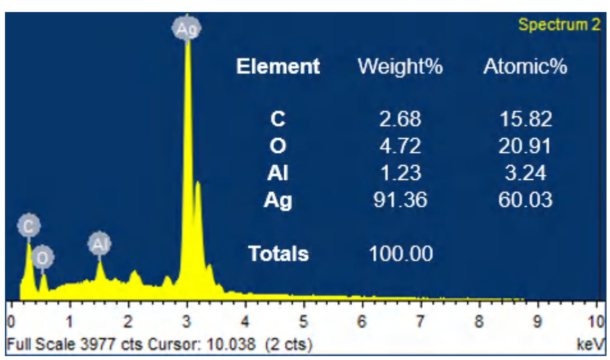

Figure 2. Die Attach Composition

Lead Frame Design

Another contributor to thermal performance is the design of the lead frame. The two common lead frame designs for SOT-23 are shown below in the figures. The designs are commonly referred to as either a standard lead frame or a split lead frame. A standard lead frame has a large middle paddle that the die sits on and is bonded to the outer paddles. To place a die on the outer paddles with the standard lead frame design is not possible due to size constraints. A split lead frame is when the lead frame is not a continuous structure but rather split or divided. For a split SOT-23 lead frame, the die can either sit on the middle paddle or the outer paddles depending on device configuration. Comparing the two lead frame styles, the standard lead frame clearly has a larger middle paddle. This larger paddle allows for better heat dissipation resulting in overall better thermal performance.

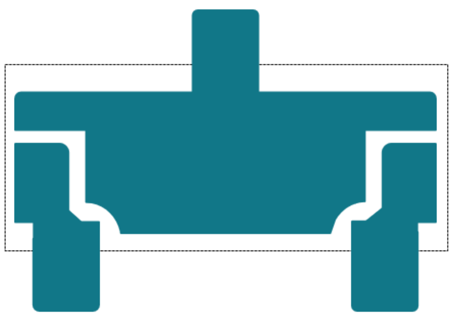

Figure 3. SOT-23 Standard Lead Frame

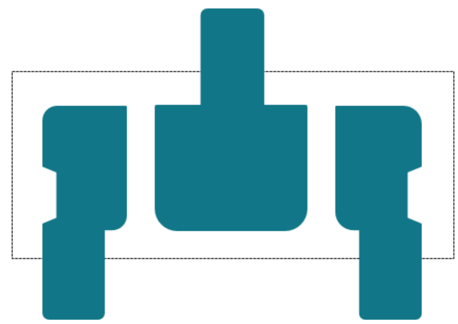

Figure 4. SOT-23 Split Lead Frame

Applications

Higher power Zener diodes can be useful in many applications, such as medical equipment, power tools, smart meters, and advanced driver assistance systems (ADAS). Specific to ADAS systems, higher power Zener diodes, between 350mW and 500mW are commonly used for reverse battery protection. In these designs, a SOD123 Zener diode is typically used due to the higher power capabilities, but TI can reach those same power capabilities in a SOT-23 package. Both SOT-23 and SOD123 take up a similar amount of space on a PCB but SOT-23 has a lower profile, smaller body size area, and is more cost-efficient.

Looking at the schematic below from the TIDA-050008 Reference Design for ADAS, a 15V, 370mW SOD-123 Zener diode is being used to clamp the voltage of the comparator during over-voltage events. The main purpose of clamping the comparator supply voltage is to not exceed the max gate to source voltage ($V_{GS\ (MAX)}$) of the MOSFET. In this application, TI's BZX84C15V-Q1 (also have a commercial version) which is a 15V, 430mW SOT-23 Zener diode can easily replace the current Zener.

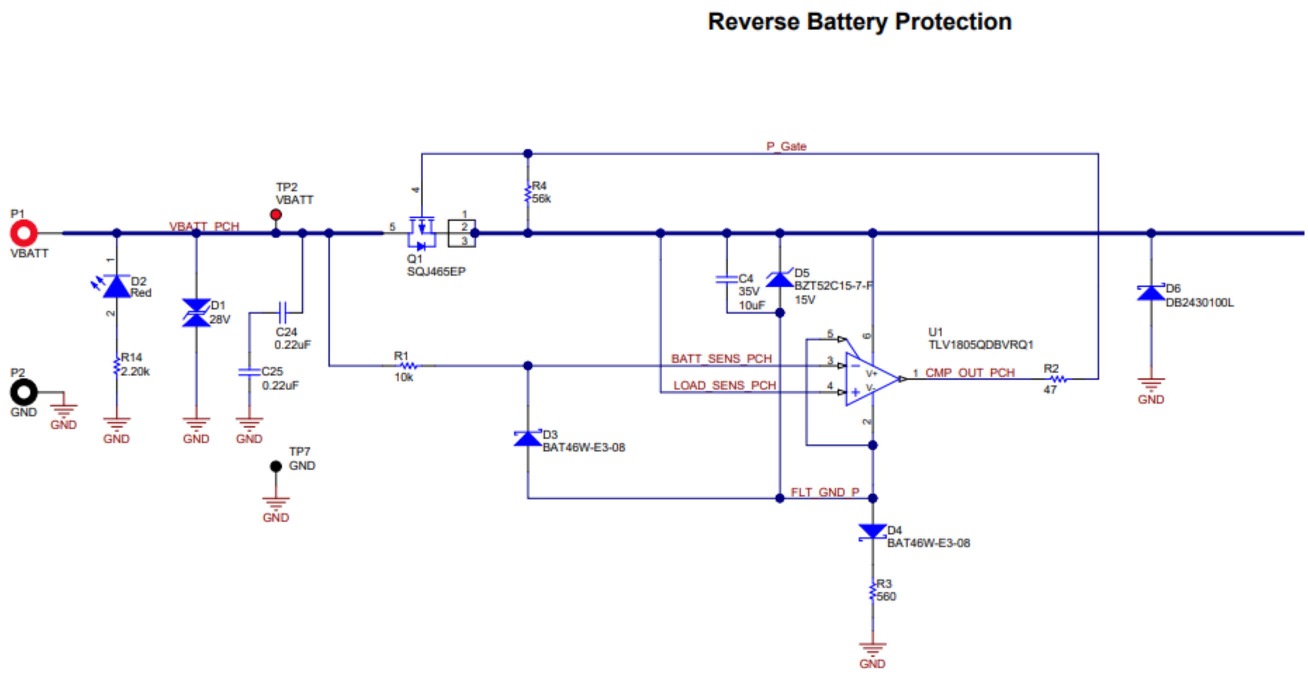

Figure 5. Reverse Battery Protection for ADAS

Summary

As PCB sizes become more space constraint, applications grow more power-hungry, and project bill of materials become more complex, the importance of optimizing power out of smaller and commonly used packages continues to grow. TI has achieved this with the introduction of a high power SOT-23 and helping to consolidate power needs from other packages like SOD123. By optimizing choices in materials to the design of the lead frame, our SOT-23 Zener diodes are better equipped to tackle many of our customers challenges. For more information on TI's Zeners, check out our page here.

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