Application Brief
Low-Noise Zeners

Sebastian Muriel

Introduction

Zeners are one of the most versatile members of the diode family as Zeners can be used as low-cost voltage regulators and can also provide clamping protection from overvoltage events. Zeners used as voltage regulators and overvoltage clamps span many different applications such as battery management circuits in power tools or vehicles. Zeners are also widely used in power supply designs for applications such as wearables, chargers, and more. Battery powered applications can require very low current operation in the uA range, while most Zener diodes are characterized at test currents in the mA range. At test currents in the 50-500uA range the Vz can drift significantly, which possibly is not acceptable in applications requiring tight voltage regulation. This Vz behavior at low test currents is referred to as the Zener noise phenomenon. TI's Zener diodes, with a Vz of 8.2V and below, exhibit low Vz drift at these low-test currents, making them a good design for applications operating at low currents. These diodes are offered in tiny multi-source packages which can save board space compared to regulator IC's as well as savings in BOM cost.

Zener Noise Phenomenon

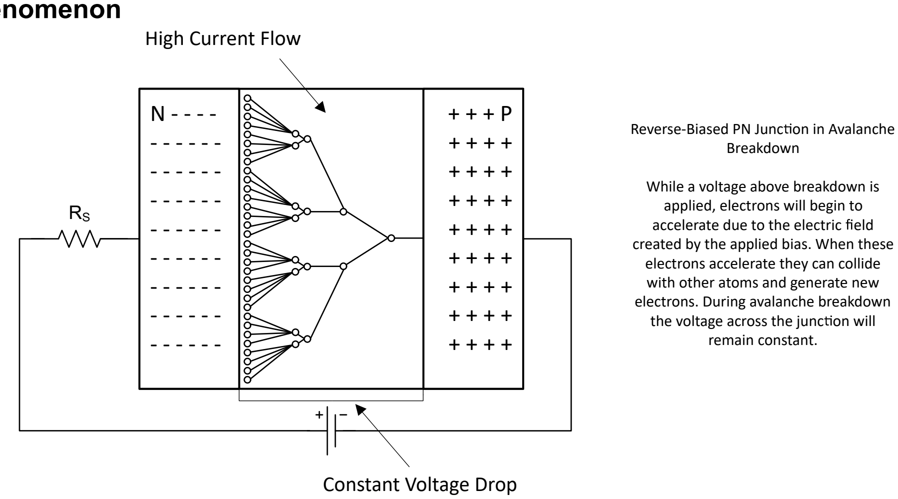

Figure 1. Reverse-Bias PN Junction in Avalanche Breakdown

For Zener diodes to provide a stable Vz, this must enter avalanche mode which requires two conditions:

- Field strength (or Reverse voltage) applied is sufficiently high for the diode to enter breakdown
- A certain minimum leakage current must flow

At currents below 1mA, the diode can exit avalanche breakdown momentarily. In this condition, the diode can behave like a capacitor. The time constant of the rising voltage signal is determined by the resistance of the current drive and the diode capacitance (Cd).

Once the diode is charged up to a high enough voltage, another avalanche breakdown can occur. The entering or exiting cycle of avalanche breakdown in these conditions can cause the voltage across the Zener to rise – this phenomenon is referred to as Zener noise.

Figure 2 shows the noise phenomenon of a 39V Zener diode at a reverse current of 50uA. Between each rising slope, the diode briefly exits avalanche mode, blocking the flow of electrons across the p-n junction. Once enough charge is built up to push a bound electron off, a collision with other electrons can occur, which can ionize more electrons until another avalanche breakdown is triggered. At low reverse currents in the 50uA range, the voltage drops until this reaches a voltage below breakdown, where the diode exits avalanche mode again. The constant switching in and out of avalanche breakdown is what causes the Zener noise. At higher reverse currents around 1mA or above, the diode can remain in avalanche breakdown as long as a sufficient reverse voltage is applied. This is why most Zener diodes are characterized at reverse currents in the mA range where a more stable Vz can be observed.

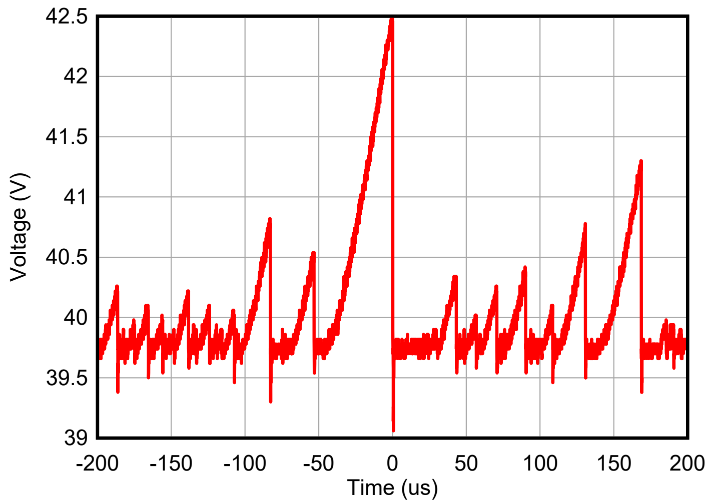

Figure 2. 39V Vz at 50uA

Figure 3 depicts the Vz drift of TI's BZX84C8V2 and a competitor 8.2V Zener diode at a test current of 50uA.The peak to peak voltage of the TI diode is much lower and settles towards the Vz quicker with minimal ringing. The noise phenomenon is more prevalent at these lower test currents, with TI's design having the lower peak to peak noise of the group of diodes tested.

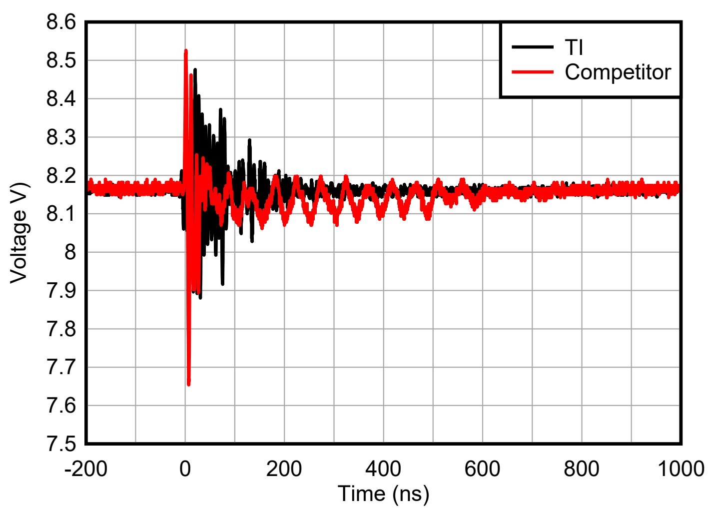

Figure 3. 8.2V Vz at 50uA

Theoretically as the test current increases, lower peak to peak noise shall be observed since the increased current can sustain the avalanche breakdown when a voltage at or above Vz is supplied. The required current to sustain avalanche breakdown can vary from supplier to supplier due to differences in process technology. TI's Zener diodes steadily exhibit less noise as the test current increases, while some competitor Zener's tested exhibited higher noise at 500uA.

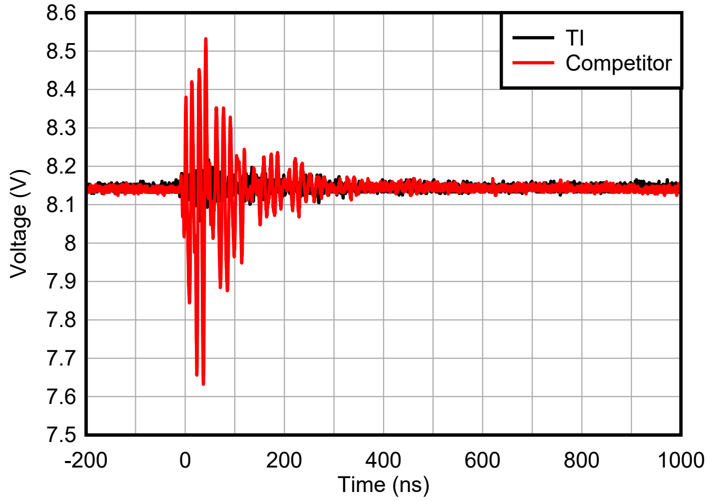

Figure 4. 8.2V Vz at 500uA

Example Applications

Zener's are often implemented in battery pack designs that have monitoring features for situations such as cell overvoltage/undervoltage, overtemperature, charge and discharge overcurrent modes and more. Zener's characterized at low current are fit well in applications where the battery management unit operates in low power modes where only a few uA can be consumed. The wide use of Zener's in battery pack designs is not only for voltage regulation but also clamping protection of sensitive circuitry like an MCU GPIO or battery monitor IC temperature sensor pin that can often only withstand a few volts. If a transient pulse is seen by the Zener, and little to no bias current is applied, the overshoot can be worse. Zener's that can exhibit a more stable Vz at low currents can have a more stable clamping voltage in these scenarios.

In the simplified circuit below of a battery pack reference design, the voltage at cell 1 can fluctuate the moment switch (SW) is triggered. If this voltage is not clamped to a level below the abs max voltage rating, the temperature sensing pin of the battery monitor IC can be damaged. After wake-up, voltage monitoring returns to normal but the D1 Zener is necessary to regulate any DC voltage and/or clamp transients.

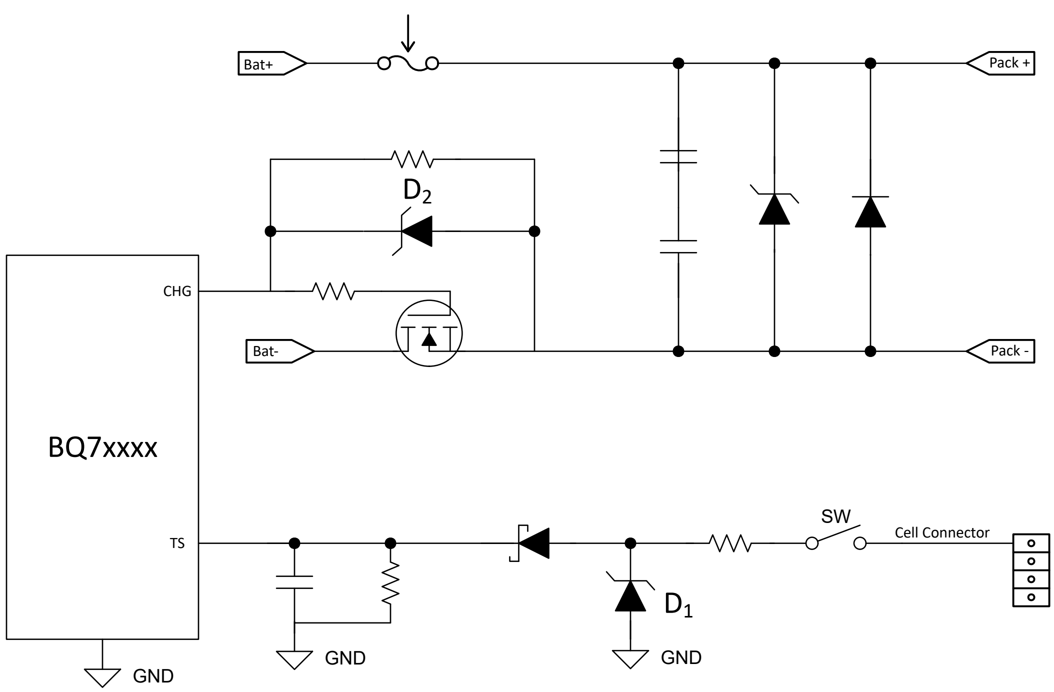

Figure 5. Simplified Battery Monitor Protection Circuit

The D2 Zener diode is also required to clamp transients that can damage the V_{GS} of external charge/discharge control FETs wired to the pack +/- connections. On the battery side, transient clamping protection is also required for the cell balancing FETs.

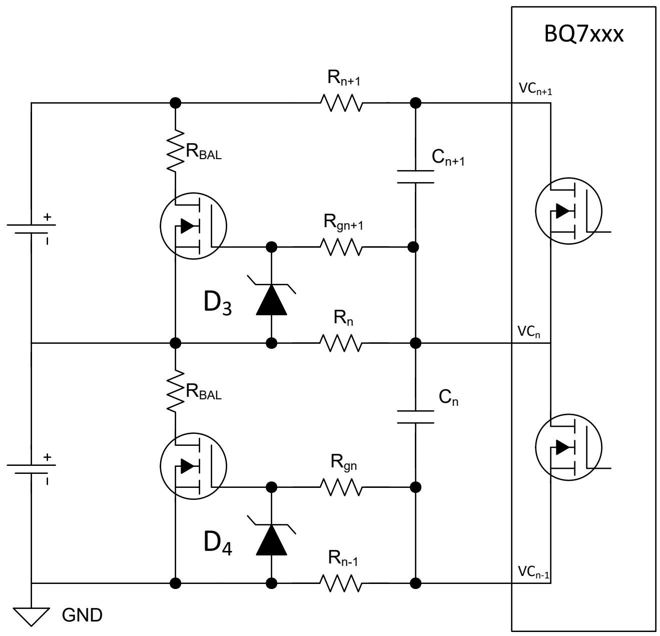

Figure 6. Simplified Battery Cell Protection Circuit

There is also a CAN transceiver in this battery pack reference design that uses a 5.6V Zener to clamp any voltage spikes of the 5V supply.

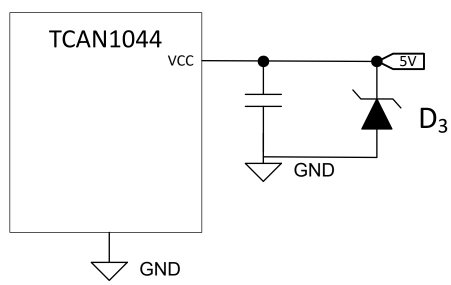

Figure 7. Supply Pin Protection or Regulation Circuit

Power supplies in battery powered applications such as a backup battery unit often require low current operation to maximize battery life. The D1 and D2 Zener diodes in the figure below are used to keep the BOOT to SW node voltage of a buck boost controller below abs max ratings. These switch nodes can ring causing the BOOT to SW voltages to spike. TI's Zener diodes also have low capacitance compared to industry standard Zener's. This is crucial in switch node power supplies to help avoid excessive switching losses due to additional parasitic capacitance.

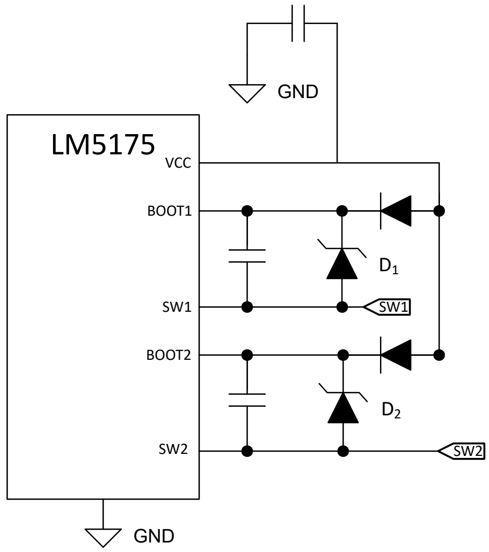

Figure 8. Buck-Boost Controller SW Node Protection

Conclusion

Zener diodes are essential components in power electronics, offering cheap but reliable voltage regulation and clamping protection in a broad variety of markets. However, Zener performance at low currents need to be characterized to provide stable voltage regulation due to the Zener noise phenomenon. TI's low-noise Zener diodes address this limitation by providing stable breakdown voltage at currents as low as a few uA. Learn more and browse our Zener diode selection here: Zener diodes.

Trademarks

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