Application Note

Zener Diodes Introduction

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ABSTRACT

In the expanding electronics industry, we see a growing need for discrete protection designs. Integrated circuit scaling to smaller geometries and rising system voltages that creep closer to absolute max ratings of pins create increased risks from transients and ESD strikes. In this case, discrete diodes allow hardware designers the freedom to place these transient suppressors close to the source of ESD or surge events and protect systems. To properly implement a protection scheme however, it is important to understand the various diodes and how each performs under a transient event. One of the most critical of these protection devices is the zener diode.

Zener diodes are the latest release of TI's growing protection devices portfolio. This article helps the reader understand the basic operation of a zener diode, how they can properly be used in circuit protection applications, and differentiate vs other protection designs. This document also explain why TI's zener diodes are making an impact in this market to solve key customer challenges.

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1 Introduction

One of the simplest ways to construct a diode is with a PN junction. The simple PN junction is a building block for various types of diodes, each for different applications of circuit protection. It is from this PN junction that the "avalanche" or zener diode is created. Other types of diodes that stem from this same building block include ESD & TVS diodes, switching diodes, rectifiers, and others. Each provides benefits over the other as the system requirements for protection vary. Each type of diode also varies in its fabrication and construction in order to optimize key performance parameters that are needed within the system for proper protection from unwanted transient events. For example, low capacitance is required for data line protection and therefore diodes in this scenario need to be constructed in a way to optimize junction capacitance of the diode as well as other parameters. Similarly, TVS diodes stem from the same construction as a zener diode, however die area and other factors can be optimized to enable the TVS to absorb higher amounts of transient energy for a use case. This paper focuses on the zener diode which is primarily used on power lines and hence optimization for long transients like that defined in IEC61000-4-5 as well as DC voltage regulation. In the subsequent sections, we will explain how a zener is constructed to enable such use cases as well as additional use cases supported by TI's unique zeners.

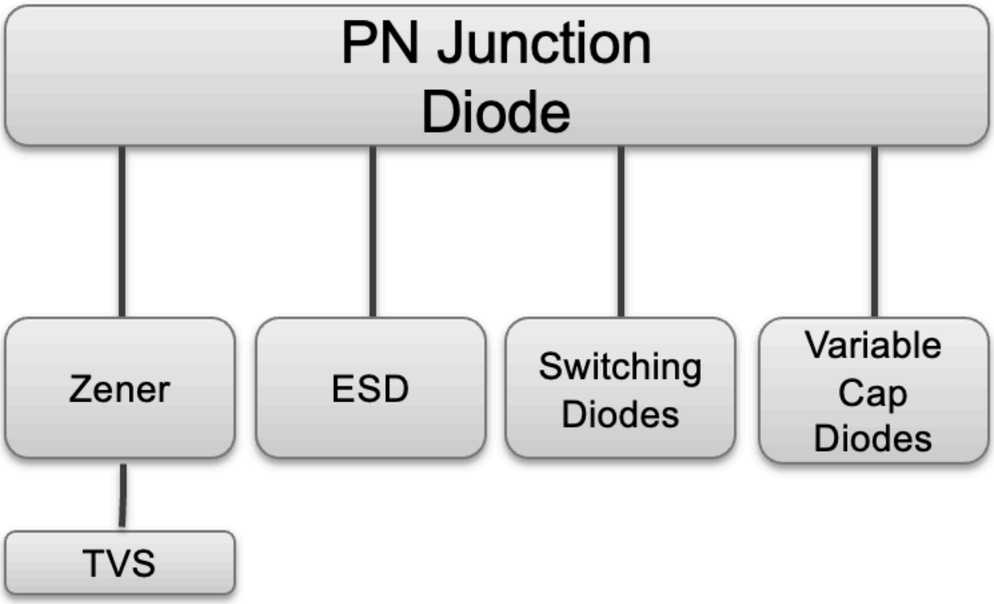


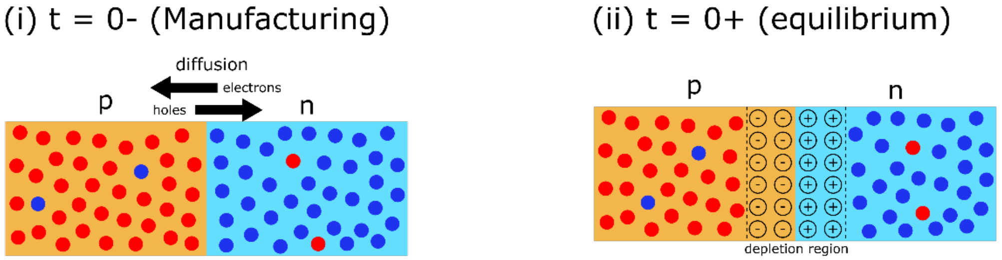
Figure 1-1. PN Junction Diode Types

2 Zener Operation and Key Parameters

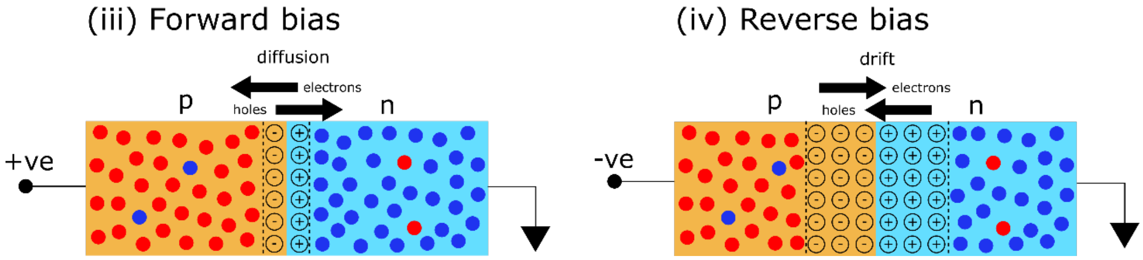
2.1 Operation

Under normal operation, a PN diode works like a directional switch. A PN diode allows current to flow in one direction (p to n) and blocks the current from flowing in the opposite direction (n to p). Figure 2-1(i) illustrates how a metallurgical junction formed during wafer fabrication steps has a large number of electrons (blue) in the n region and a large number of holes (red) in the p region. This concentration gradient triggers diffusion of electrons and holes from the high to low concentration areas as shown in the figure, resulting in a so-called 'depletion region' near the metallurgical junction (ii) under equilibrium condition (no external applied bias). Depletion region, as the name suggests, is depleted of majority carriers in both p- and n-regions and generates an electric field in the opposite direction of the diffusion current flow. This creates a 'barrier' in the current flow.

Figure 2-1(iii) shows how depletion region shrinks (or the barrier reduces) under forward bias (p-region is at a positive bias compared to n-region) which allows larger diffusion current to flow with increasing bias. Due to underlying physical mechanism, the current increases exponentially with applied forward bias and the diode is in 'on' condition. In reverse bias, the depletion width widens resulting in suppressed diffusion current, but increased drift current due to minority carriers as shown in Figure 2-1(iv). However, this current is very small compared to forward current for the bias lower than the breakdown voltage, and the diode is in 'off' condition.


(i) t = 0- (Manufacturing)

(ii) t = 0+ (equilibrium)


(iii) Forward bias

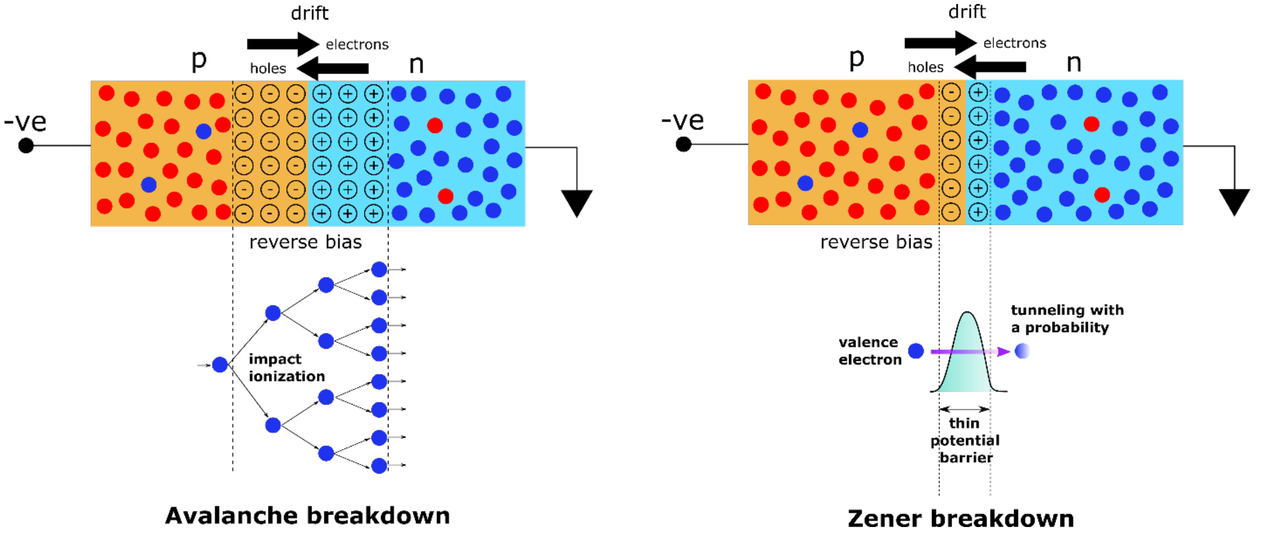
(iv) Reverse bias

Figure 2-1. Carrier Dynamics in a PN Junction Diode Under Equilibrium and Under Forward or Reverse Bias Operation

2.1.1 Device Operation Under Breakdown

When a PN diode is subjected to a reverse bias higher than the breakdown voltage (V_Z), the diode can conduct a large amount of current. Alternatively, the PN diode can hold the voltage to V_Z when a fixed current is forced through the diode in reverse bias condition. This behavior of the PN diode can provide a fixed voltage clamp for a wide range of currents and can be used as a crude voltage reference or voltage clamp for circuit protection. There are two major physical phenomena that lead to PN diode breakdown, namely, avalanche breakdown and zener breakdown as shown in Figure 2-2. Irrespective of the breakdown mechanisms at play, the commercially available diodes are colloquially called 'Zener' diodes.

Avalanche breakdown results from impact ionization by high-energy electrons in the depletion region. Every electron that enters the depletion region can multiply and generate exponentially more electron-hole pairs that result in a sudden increase in the current when bias is V_Z or higher in the reverse bias. Zener breakdown results from tunneling of valence electrons from p-region to n-region through silicon bandgap under extremely high junction electric fields. Zener breakdown typically occurs for the PN diodes that are heavily doped in both p- and n-type regions. Avalanche breakdown typically occurs for larger voltages (>6V) whereas zener breakdown primarily occurs at lower bias (approximately 2-5V). Both breakdown phenomena are reversible as long as the PN diode does not undergo a thermal breakdown due to excessive current.



Avalanche breakdown **Zener breakdown**

Figure 2-2. Two Major Breakdown Phenomena in PN Diode Under Reverse Bias

2.2 Key Parameters

The zener diode operation described in detail above now creates a set of characteristics which can be defined into parameters of interest. These typically include the zener voltage V_Z, zener impedance Z_Z, reverse leakage I_R, temperature coefficient S_Z, Power dissipation P_D, as well as capacitance C_D.

The zener voltage as discussed in the previous section is one of the most critical specifications when choosing a zener as this defines the effective breakdown voltage where the zener begins to conduct and regulate the protected line. For this reason, V_Z is specified at a given *zener current* or I_Z for which the V_Z is stable. More on this and stability at lower currents will be discussed later in description of TI zener diodes. It is a common misconception that zener diodes always clamp the protected line at V_Z. This is likely the case if the diode were an ideal zener diode, however every diode has a non-zero dynamic impedance, Z_Z, in the breakdown region which increases the regulated voltage level that can be calculated as using Equation 1.

$$\Delta V = \Delta I \times Z_Z \tag{1}$$

Like V_Z, the zener impedance of Z_Z is specified at the same zener current. The zener impedance represents the ratio of the change in V_Z to to the change in I_Z within the breakdown region as shown in Figure 2-3. A low zener impendence can translate to more robust line regulation as this means large changes in line current that result in relatively small shifts in voltage. This is most critical in cases where the zener is used for DC voltage regulation.

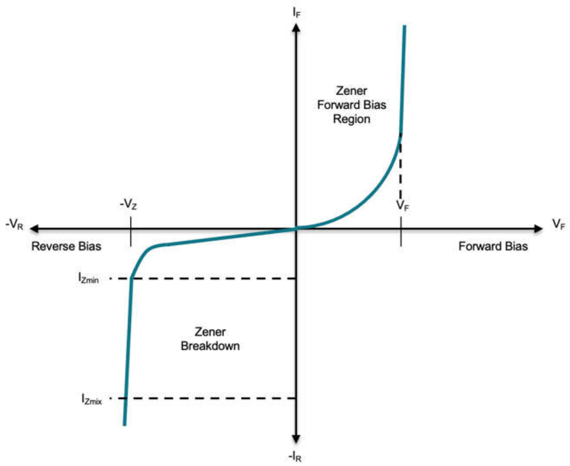


Figure 2-3. Zener I-V Curve

As many zeners are used for powerline protection, specifying the leakage current, referred to as the reverse leakage I_R, is critical. This leakage current is verified at a voltage condition for which the zener is off (in a non-conducting state), called the reverse voltage or V_R. This leakage ranges from the nA to µA range depending on the V_Z of the selected zener.

Another critical parameter is the temperature coefficient, S_Z. This is referred to in terms of mV per degree, mV/C or mV/K. This is another parameter to understand the stability of your zener voltage but over the specified operating temperature range. Automotive applications where electronic components are introduced to wide range of temperatures within the car (near the engine block) or external weather conditions are examples of where the temperature coefficient can play a part if the zener is used for DC voltage regulation.

Many of the use cases discussed thus far involve DC voltage regulation and in these scenarios, the zener needs to conduct seemingly indefinitely. For this reason, understanding what the maximum power the diode can dissipate as the diode regulates is critical, and this is referred to the total power dissipation P_D. This is largely controlled by the package the zener is placed in and thus P_D varies as zeners are scaled from small packages such as DFN1006 to larger packages such as SMA-F, shown in Figure 2-4.

Figure 2-4. Comparison of a Small 0402 Package and Large SMA-F Package

The last specification to highlight is capacitance. In many power line applications the zener diode capacitance C_D is not critical and this is why zener diodes with capacitances up to hundreds of picoFarads are acceptable. However, since zeners can also be used for dataline protection, the selected device C_D is important to note and how that relates to the overall capacitive budget for the system and impact to signal integrity.

3 Zener Diode Manufacturing Process

Now that we have covered much off how the zener operates, we will discuss the typical manufacturing process to enable this unique operation. In this section, we will describe typical fabrication steps for a PN diode and its working under normal operation as well as under breakdown.

3.1 Manufacturing

3.1.1 Wafer Fabrication

A PN diode can be manufactured in a wafer by diffusing p-type dopants into an n-type substrate or vice versa. Figure 3-1 illustrates a simple wafer fabrication flow starting with an n-type substrate (i). Next, an optional n-type layer can be deposited to control resistivity of the n-layer different to that of the substrate (ii). A p-type layer is created using either direct diffusion of dopants or through ion implantation as shown in (iii). Typically, a photomask is used to selectively define the p-type region through photolithography. Lastly, metal contacts are deposited on p- and n-type regions to complete the wafer fabrication. Keeping the contacts on top and bottom of the wafer as shown in (iv) gives a vertical PN diode, whereas contacting the n-type layer on top of the wafer through an n+ region can result in a lateral PN diode. Generally, vertical diodes are used in discrete diode products for better cost and active area utilization while lateral diodes are suitable for integrated circuits for ease of routing and interconnectivity with the CMOS or analog integrated designs. The process parameters for p- and n-type regions, mask layout and device geometry are carefully engineered to achieve stable breakdown voltage, lower leakage and lower capacitance.

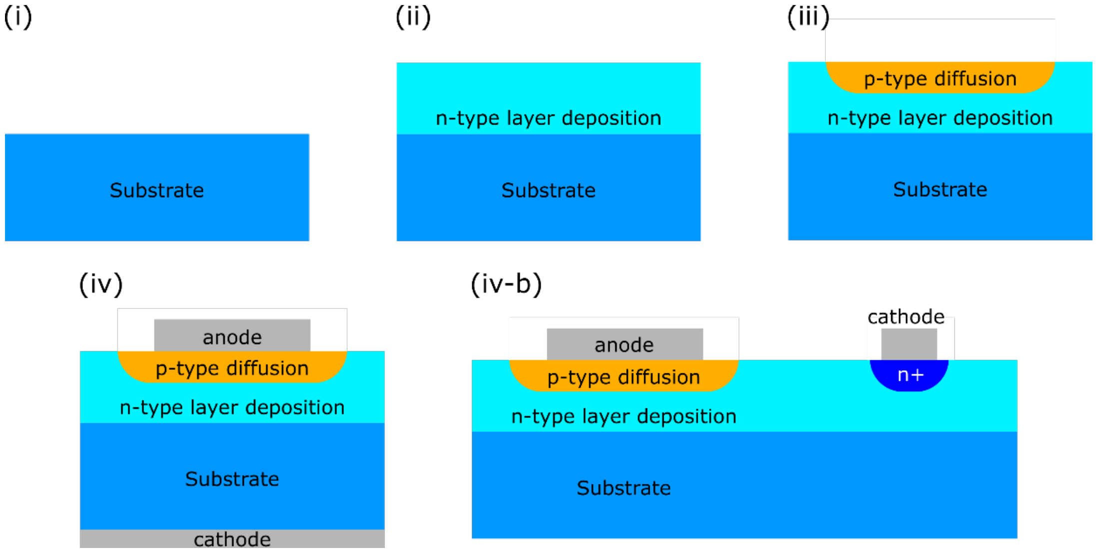


Figure 3-1. Simple p-n Diode Fabrication Flow

3.1.2 Complete Manufacturing Flow

The flowchart in Figure 3-2 shows end-to-end product manufacturing. After wafer fabrication, the die goes through a series of steps during packaging. Die dimensions and choice of material for die mount and package mold can affect device performance. Afterwards, each unit goes through x-ray inspection and functional electrical test and screened to adhere to the datasheet specifications and TI quality standards. After the test, devices are packed in a reel and shipped out. There may be a series of reliability stress tests usually during initial device release and subsequent changes to ensure that the product can reliably operate throughout the projected lifetime. The nature and severity of reliability is tied to the class of product and intended market, for example, automotive grade 0, commercial, or industrial equipment.

Texas Instruments has in-house end-to-end manufacturing capability including wafer manufacturing, assembly and packaging, physical and electrical screening, and reliability testing. With customer requirements as a central driving force, TI also provides geopolitical multi-sourcing for our products. Additionally, TI strives to periodically improve its manufacturing operations for performance improvement and cost reduction towards perpetual benefits for its customers.

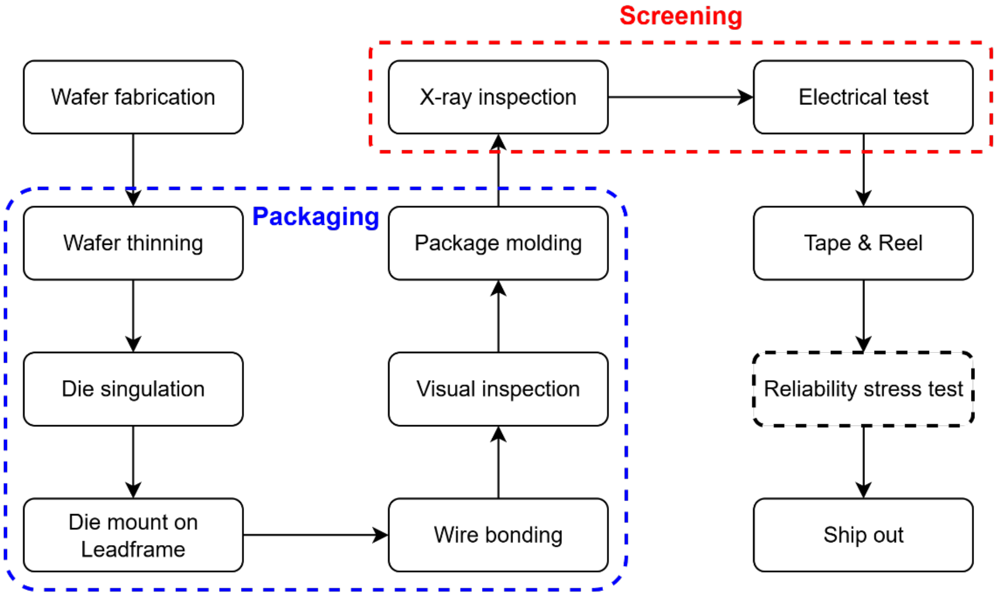


Figure 3-2. Complete Manufacturing Flow from Wafer Processing to Material Ship Out to Customers

3.1.3 Process Control and Capability

Process control in large volume manufacturing is a crucial aspect to adhere to high quality of parts as well as reliably meeting electrical specifications without fail. Statistical process control (SPC) is employed to track centering and distribution of in-line physical and electrical parameters to monitor any undesired excursion due to any error or tool malfunction during production. A simple device such as the PN diode can have more than 20 in-line and end-of-line tests to monitor wafer process control and verify that the final product meets high quality standards. Each wafer passes through all the tests before being released for further production steps.

Similarly, there are several process control and monitoring steps employed during assembly and test as well to verify the final product meets all the specifications. In-depth process control and capability analysis is carried out during a new product qualification to verify that Cpk, or capability index, is high for each physical and electrical control parameter to verify >99% yield in production. A detailed quality report is available on ti.com for each orderable part for customers.

4 Why Choose TI Zener Diodes?

While zener diodes have limited characteristics, each can have effects on the system. As you've learned of each of these parameters, the following section focuses on three parameters and there importance as an example of how TI's zeners have stood out in this zener market.

DC voltage regulation is a very typical use case for zener diodes and as mentioned earlier, the total power dissipation, P_D, varies as you select from the various packages available. Optimizing the zener P_D allows a much higher zener current to flow through the diode while still accurately regulating the zener voltage on the protected line. Several factors can impact the diodes maximum power dissipation such as the size of pad layout which can be a heat sink for the zener. Internal to the diode however, the importance of a properly designed leadframe is critical for similar reasons of thermal performance which directly relates to P_D. Beyond the design, the material make-up of the leadframe can also help bolster the power dissipation performance. TI's zeners in the popular SOT-23 package optimize both of these variables to provide industry-leading power dissipation in the BZX84Cx series zeners. As shown in Table 4-1 below, TI's SOT-23 zener provides a power level that leads the industry in similar packages, and also, achieves P_D levels seen in larger packages such as SOD123. See Why Use TI zener Diodes for High Power Applications to learn more and how customer systems are improved in various applications.

Table 4-1. Competitor Analysis of Zener PD

	TI	Competitor A	Competitor B	Competitor C
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

Zener stability of V_Z is ultimately the most critical performance metric across all applications and use cases for the zener diode. We learned earlier in this app note that V_Z is defined at a given zener current I_Z and for most general purpose zener diodes the current required to achieve stable V_Z is in the mA range. For most end equipments that are wall powered, this amount of current is easily achievable, however for battery-powered electronics, I_Z in the μA range is desirable. General purpose zeners under these low zener current conditions can become unstable and cause high fluctuations in the zener voltage. What the user observes in these conditions is what's called the 'Zener noise' phenomenon where the diode is entering and exiting avalanche breakdown and thus causing an unstable voltage regulation. An example of this instability is depicted in Figure 4-1 where a competitor zener diode exhibits high ringing under this lower current load condition. TI's zener diodes however have been designed and fabricated to minimize this instability even at I_Z currents as low as 50μA which make them preferred for many battery-powered applications and voltage regulation in general. This is described in more detail in the Low-Noise Zeners application note.

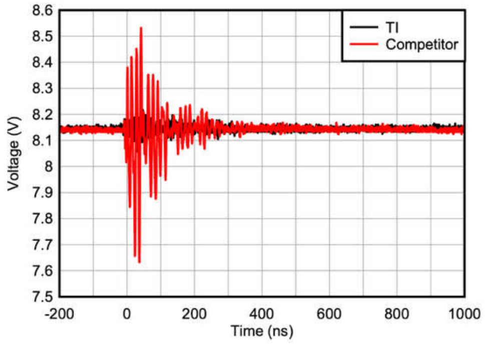


Figure 4-1. TI's BZX84C8V2 vs Competitor at 500μA I_Z

A parameter for designers to also be mindful of is the reverse leakage, I_R. As discussed earlier in this paper, this defines the quiescent current of the diode and a higher I_R translates into unwanted power loss. TI zener diodes are, in many cases, half the I_R as competitor zeners and thus directly proportional to half the power loss for a given line voltage. This comparison is shown in Table 2 below. In battery powered applications, minimizing leakage is always critical to extend battery lifetime. Additionally, if these batteries are left in warehouses for extended periods of time and temperature, the power loss is increased and is even more important to choose TI's low leakage diodes.

Table 4-2. Competitor Analysis of Zener I_R

Parameter	TI	Competitor A	Competitor B	Competitor C
V_Z	15V	15V	15V	15V
Package	SOT-23	SOT-23	SOT-23	SOT-23
I_R Leakage	30nA	50nA	50nA	100nA

5 Selecting the Correct Protection Diode

As mentioned in past sections, there are various types of diodes that include Junction, Schottky, Zener and others. For the purposes of this application note, this document focuses on the following protection diode categories designed to protect against excessive voltage and current – zener diode, electrostatic discharge (ESD) diode, and transient voltage suppression (TVS) diode, how to properly select the right diode for an application.

5.1 Zener Diode

A zener diode has similar properties to a junction diode when forward biased, but are uniquely designed to operate in the breakdown region with reverse current flow. When reverse biased at a voltage equal to or greater than the zener voltage, a zener diode can maintain its zener voltage continuously without damage provided the package power dissipation rating is not exceeded.

5.2 ESD Diode

ESD is the sudden release of electricity from one charged object to another when the two objects come into contact or close proximity. ESD diodes are electrostatic suppressor diodes designed to protect integrated circuits (IC). ESD diodes are used to protect various data interfaces such as ethernet, USB, and so on, and are connected in reverse direction. Under normal operation with forward voltage applied, they are inactive and conduct zero current. As the ESD diode experiences reverse voltage it consumes some minimal (leakage) current. In the event of an ESD strike where the voltage exceeds its rated reverse breakdown voltage, the ESD diode creates a low impedance path diverting current flow to ground. The ESD diode limits the peak voltage and current, thereby protecting the downstream IC. For additional description of ESD events, system design considerations, and parameter terminology please refer to TI's System-Level ESD Protection Guide.

Typically, a diode is referred to as ESD type if it includes protections for system-level IEC61000-4-2 testing methods such as contact discharge or air-gap discharge. In the contact-discharge method, the test-simulator electrode is held in contact with the device under test (DUT). In air-gap discharge, the charged electrode of the simulator approaches the DUT, and a spark to the DUT actuates the discharge. For more information on IEC test procedures please refer to Design considerations for system-level ESD circuit protection.

These are not to be confused with device-level testing methods like human body model (HBM), charge device model (CDM), and machine model (MM). Device-level HBM, CDM, and MM tests are intended to verify only that integrated circuits survive the manufacturing process, while system-level tests specified by IEC 61000-4-2 are intended to simulate end-user ESD events in the real world.

In high-speed data transmission applications, ESD diodes have low capacitance to maintain signal integrity and minimize signal distortion. The target ESD capacitance varies by interface type (USB, Ethernet, CAN FD / XL, etc.). More information can be found in the following engineer to engineer (e2e) forum post on recommended max capacitance for various interfaces: (2) [FAQ] What TI ESD/TVS diode should I use to protect Interfaces in my system? - Interface forum - Interface - TI E2E support forums

5.3 TVS Diode

TVS diodes are transient suppressor diodes designed to protect integrated circuits from voltage spikes. They include specifications for voltage clamping performance. System-level test method IEC61000-4-5 lightning (surge) specifications are generally provided for TVS diode, surge events are usually produced by the power system switching activities or lightning events.

TVS diodes may also include system-level test method IEC61000-4-4 electrical fast transient (EFT), or burst. EFT events from the environment, surrounding power cables or data cables may interrupt data communications through inductive or capacitive couplings. Since TVS diodes are often the first active component in a signal path to encounter transients, many semiconductor vendors test burst immunity using a standard test.

In some TVS diodes IEC61643-321 surge test is also included. IEC61000-4-5 surge immunity test is conducted using a pulse with 8us rise time and 20us half length. In contrast, IEC61643-321 surge standard tests integrated circuit immunity to a much longer pulse with 10us rise time and 1000us half length. More information on IEC61000-4-x tests can be found in IEC 61000-4-x Tests for TI's Protection Devices.

TI ESD and TVS diodes are robustly designed to meet electrostatic discharge and transient voltage standards across various industrial and automotive end equipment. Applications frequently require protection diodes to pass multiple ESD, burst and surge specifications. Therefore, many TI protection diodes test to several IEC61000-4-x standards. TI branded 'ESD' diodes may also include transient voltage suppression protection, and TI branded 'TVS' diodes may also include ESD protection. Please refer to the device datasheet for precise voltage and current ratings.

6 Typical Applications

Protection diodes are required in many industrial and automotive applications for a wide variety of interfaces, such as CAN bus and USB. They can be used to protect other active components such as MOSFETs and transistors, or to discretely regulate voltage. When deciding between zener, ESD, and TVS diodes to protect a circuit, consider the following questions. How fast is the interface and what line capacitance is required? Does the circuit require overvoltage protection and what clamping voltage level is desired? How much power could the diode have to dissipate? What IEC ESD and surge levels are needed? The following section provides common circuit examples for zener, ESD, and TVS protection diodes.

6.1 Zener Diode

There are a variety of zener diode applications including voltage stabilizer (regulator), AC voltage signal clipping, overvoltage protection, and many others. Below we will cover voltage regulation, MOSFET gate overvoltage clamping, and CAN bus overvoltage protection.

6.1.1 Voltage Regulation

In this example, a preferred zener diode to generate a 15V system rail from a 24V input source is selected. Figure 6-1 displays an example of using a zener diode for voltage regulation. The calculations below outline considerations for selecting the zener diode (D), sizing the series input resistor (R1), and verifying the zener diode ratings are not exceeded. The series resistor is used to limit zener current Iz to the device.

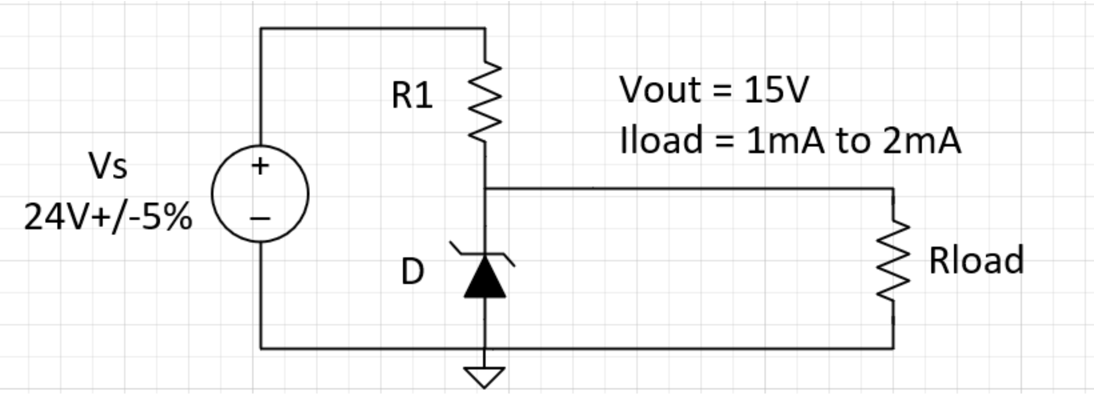


Figure 6-1. Voltage Regulation Zener Application Example

In this example, the required load conditions are a 15V rail with 1mA minimum and 2mA maximum current consumption. The circuit is used in an ambient, environmental temperature up to 55C. Consider TI 15V zener diode BZX84WC15V, analyzing its suitability for this circuit. BZX84WC15V has a 15V nominal zener voltage with ±5% tolerance, 360mW max power dissipation, 80pF max IO capacitance, and 0.03μA max leakage current in the SC70-3 package.

As evidenced in Figure 6-2, this zener has relatively flat zener voltage vs. zener current characteristics. Designing for a nominal zener current of 5mA is within the zener current safe operating range. We can estimate the nominal zener voltage at 5mA to be approximately 15V.

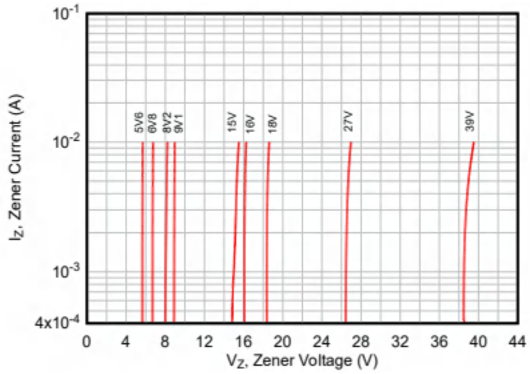


Figure 6-2. BZX84WC15V Zener Current vs. Zener Voltage at T_a = 25C

Calculate the nominal series resistor value R1:

$$\mathrm{R1} = \frac{(V_{in,max} - V_{Z,max@25C})}{(I_{Z,typ} + I_{load,max})} = \frac{(22.8V - 15.75V)}{(5mA + 2mA)} \approx 1k\Omega \tag{2}$$

To calculate the maximum power dissipated in the zener, we must first calculate the maximum expected zener current Iz,max in our circuit using Equation 3.

$$I_{Z,max} = \left(\frac{V_{in,max} - V_{Z,min}}{R1}\right) - I_{load,min} = \left(\frac{25.2V - 14.25V}{1k\Omega}\right) - 1mA \approx 10mA \tag{3}$$

The maximum zener voltage also varies over temperature. The nominal zener voltage +/-5% rating only applies to a 25C room temperature condition. In the case of BZX84WC15V, the device exhibits a temperature coefficient (S_Z) of +13mV/C. $V_{Z,max@25C}$ is 15.75V. Eq. 4 and 5 below is used to calculate the estimated max zener voltage at 55C.

$$V_{Z,max@T_A} = V_{Z,max@25C} + (S_Z \times (T_A - 25C)) \tag{4}$$

$$V_{Z,max@55C} = 15.75V + (13mV/C \times (55C - 25C)) \approx 16.14V \tag{5}$$

Zener diode maximum power dissipation Pz,max@55C can then be calculated by multiplying Vzmax@55C by Iz,max as shown in Eq. 6 below.

$$P_{Z,max@55C} = V_{Z,max@55C} \times I_{Z,max} = 16.14V \times 10mA \approx 162mW \tag{6}$$

Next, we will check that the max zener power dissipation in our circuit does not exceed the BZX84WC15V power dissipation rating at 55C ambient temperature using Figure 6-3. At 55C ambient temperature, the nominal 360mW SC70 package power dissipation derates by approximately 75%. This equates to a power rating of 270mW at 55C ambient, which is sufficiently above our 162mW requirement.

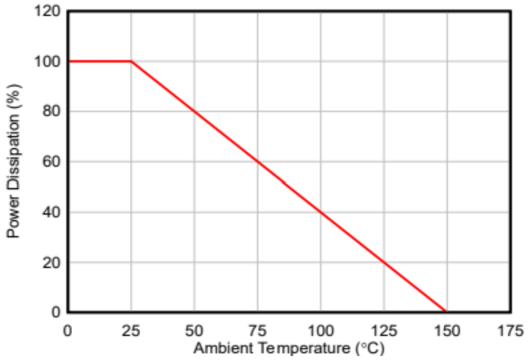


Figure 6-3. BZX84WC15V Power Dissipation Derating Over Temperature

The final design values are depicted in Figure 6-4. BZX84WC15V is acceptable for this application.

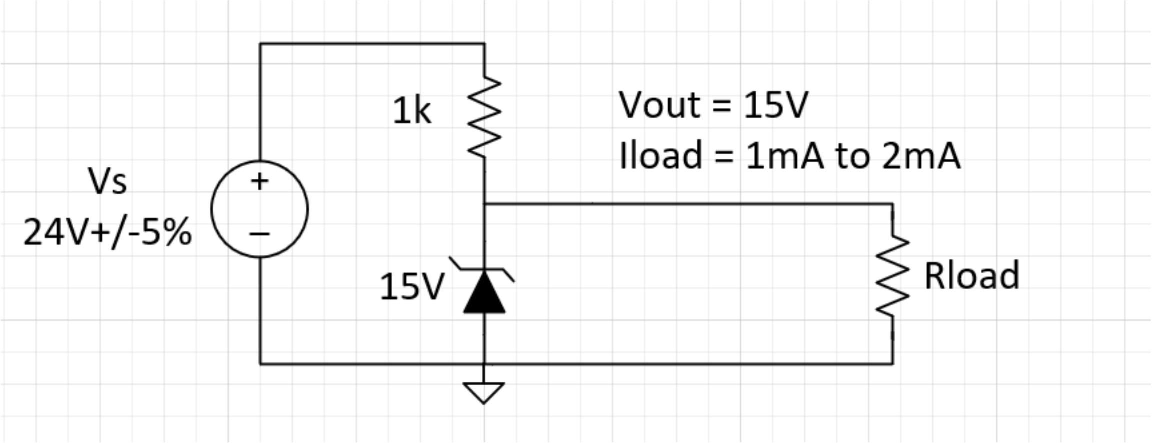


Figure 6-4. Voltage Regulation Circuit Design Values

6.1.2 MOSFET Gate Overvoltage Clamping

In this example we select a zener diode to prevent an enhancement mode N-channel MOSFET's gate-to-source maximum voltage rating from being exceeded. The input voltage is 12V with a 1A maximum load current condition. The chosen MOSFET Q1 is CSD16401Q5. From the MOSFET datasheet, it specifies a 1.5V typical threshold voltage (Vgs,th) for turn-on. The absolute maximum rated gate-to-source voltage (Vgs) is specified as 16V, therefore we must limit the gate voltage to less than 16V. In order to provide sufficient design margin an 8.2V nominal zener voltage is selected. The chosen D1 zener diode is BZX84WC8V2, as shown in Figure 6-5. Similar to the voltage regulation application example above, maximum power dissipation should be calculated to ensure the package rating is not exceeded.

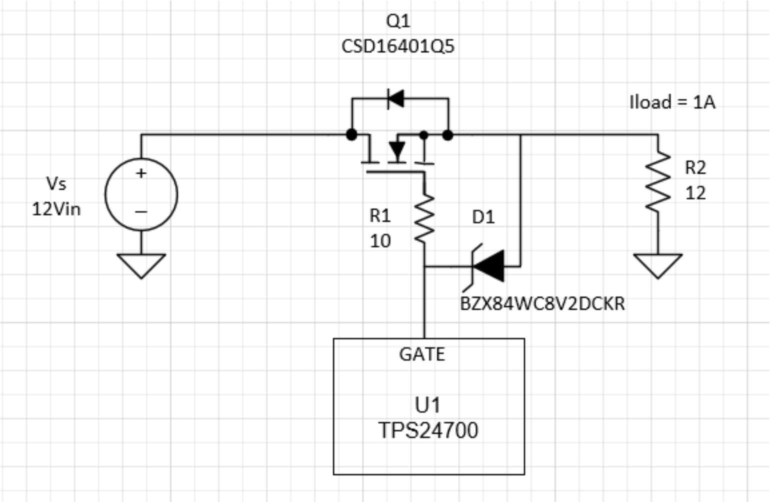


Figure 6-5. MOSFET Gate Overvoltage Clamping Final Circuit

6.1.3 CAN Bus Overvoltage Protection

Zener diodes can also be used to protect data lines from overvoltage events. A controller area network (CAN) bus has two data lines – CANH and CANL. In the recessive state both lines are biased to approximately 2.5V. In the dominant state CANH is increased by 1V to approximately 3.5V while CANL is reduced by 1V to approximately 1.5V, therefore creating a approximately 2V differential signal between the two data lines. ISO 11898 standard specifies CAN data lines bus voltages between -2V to 7V, but CAN transceivers are typically rated for much wider common mode voltage. For instance, TI CAN signal improvement capability (SIC) transceiver TCAN1462-Q1 is rated for 8Mbps maximum data rate, with CANH and CANL pins rated for +/- 58V absolute maximum voltage. In this example we will look for a zener diode to verify the voltage stays below 58V. For CAN-SIC the suggested maximum bus capacitance is <6pF.

The selected zener diode is MMBZ30VCL-Q1 that has a 30V working voltage, 34.8V maximum breakdown voltage, 30kV contact ESD in a SOT23 package. MMBZ30VCL-Q1 has 4.5pF typical capacitance across both internal diodes. Each line has 4.5pF / 2 = 2.25pF rated capacitance when connected in a bi-directional configuration. Figure 6-6 shows the typical circuit implementation.

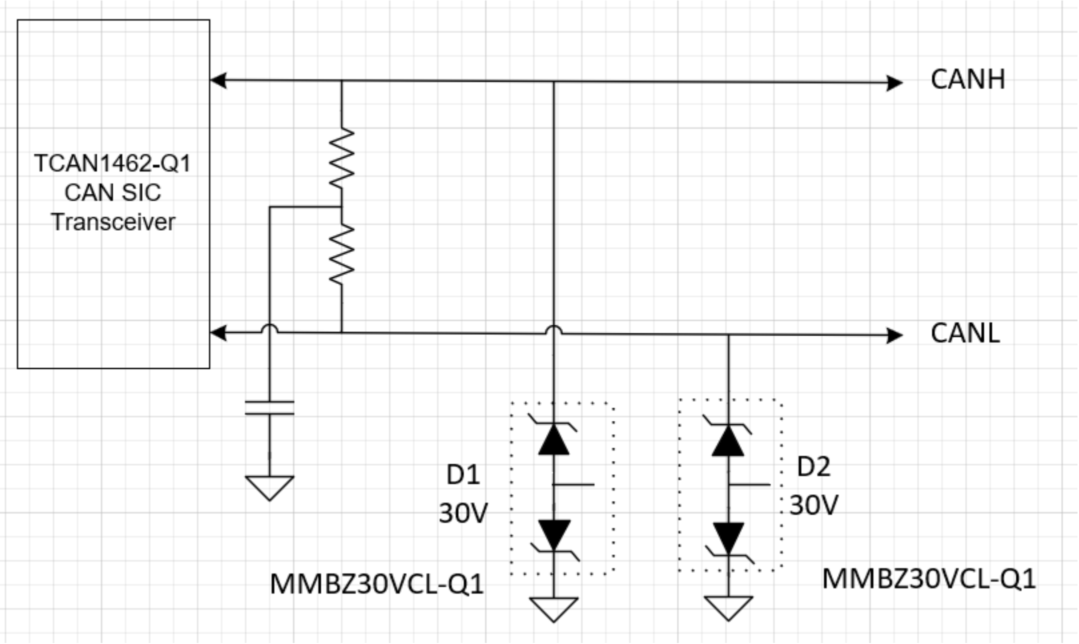


Figure 6-6. CAN SIC Typical Application Circuit

6.2 ESD Diode

ESD diodes are generally used for faster data interfaces that require low line capacitance to avoid corrupting data bits. For example, USB High Speed (USB 2.0) released in 2000 specifies 480Mbps maximum speed. The data lines (D+/D-) are bidirectional, and when pulled high operate at approximately 3.3V, therefore an ESD diode with 3.6V working voltage is recommended. To avoid signal integrity issues the ESD diode line capacitance should be kept less than 4pF maximum. ESD441 is a 1 channel unidirectional ESD diode with 1pF typical line capacitance. It has +/-30kV air gap discharge ESD, +/-30kV contact discharge ESD, and 6.2A surge rating. ESD441 is well suited for USB2.0 applications. Figure 6-7 shows the typical circuit implementation.

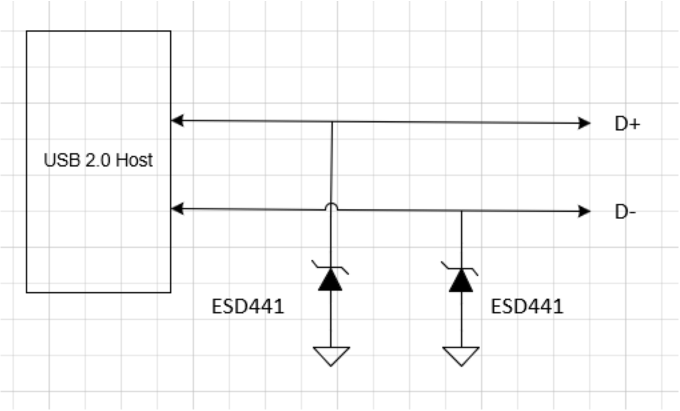


Figure 6-7. USB 2.0 Typical Application Circuit

6.3 TVS Diode

TVS diodes are commonly selected when both overvoltage clamping is needed and the system must be protected from higher power surge events. As a result, TVS diodes typically have a higher power rating than zener or ESD diodes. Recently, USB Power Delivery (USB PD) standard has advanced the power rating beyond 100W. USB Type-C connectors via the USB PD 3.1 specification can now provide up to 240W (48V, 5A), now called Extended Power Range (EPR). Previous USB PD specifications were limited to 20V bus voltage, while USB PD 3.1 EPR supports voltage levels up to 48V. This requires higher rated TVS diode, both in terms of voltage and power ratings. TVS5200 is a 1 channel TVS diode with 52V working voltage, 58.8V clamping voltage, 20A surge rating, along with +/-15kV air-gap discharge ESD rating in a small DFN package. TVS5200 is preferred for USB PD 3.1 EPR applications. Figure 6-8 shows the typical circuit implementation.

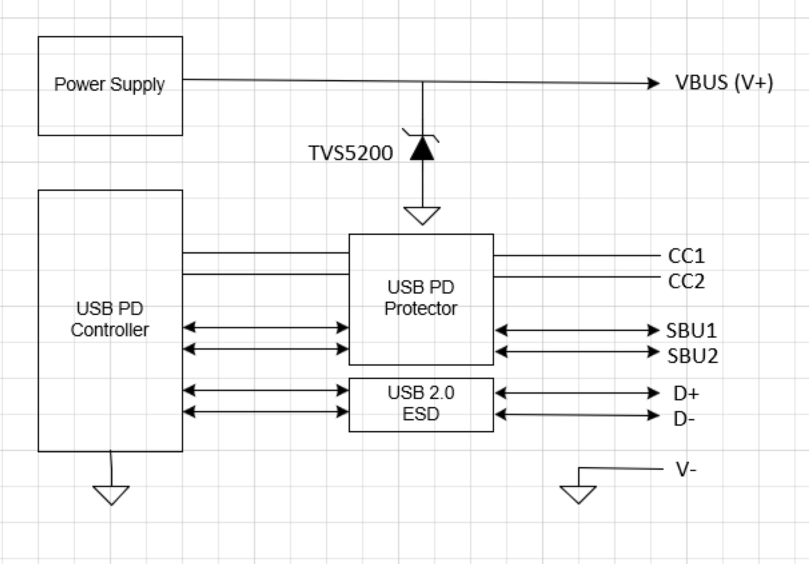


Figure 6-8. USB EPR Typical Application Circuit

7 Summary

Zener diodes are an important part of most system protection schemes and as this document has explored, the unique construction relative to other diode types makes them preferred for voltage regulation under constant current conditions. The zener diode Vz stability over different conditions such as load current and temperature are extremely critical. TI's zener portfolio has proven to stand out in these specifications and thus are very valuable to the wide range of applications needed in the electronics industry. Our zeners add to an already extensive ESD and TVS portfolio to offer customers a wide variety of protection options. To explore these designs, visit TI.com or consult with a Field Applications Engineer.

8 References

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