

Chapter 11

AN784 — TRANSIENT POWER CAPABILITY OF ZENER DIODES

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INTRODUCTION

Because of the sensitivity of semiconductor components to voltage transients in excess of their ratings, circuits are often designed to inhibit voltage surges in order to protect equipment from catastrophic failure. External voltage transients are imposed on power lines as a result of lightning strikes, motors, solenoids, relays or SCR switching circuits, which share the same ac source with other equipment. Internal transients can be generated within a piece of equipment by rectifier reverse recovery transients, switching of loads or transformer primaries, fuse blowing, solenoids, etc. The basic relation, $v = L di/dt$, describes most equipment developed transients.

ZENER DIODE CHARACTERISTICS

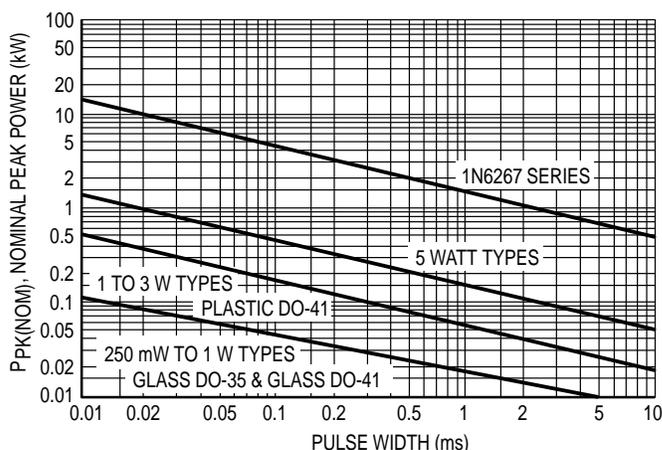
Zener diodes, being nearly ideal clippers (that is, they exhibit close to an infinite impedance below the clipping level and close to a short circuit above the clipping level), are often used to suppress transients. In this type of application, it is important to know the power capability of the zener for short pulse durations, since they are intolerant of excessive stress.

Some Motorola data sheets such as the ones for devices shown in Table 1 contain short pulse surge capability. However, there are many data sheets that do not contain this data and Figure 1 is presented here to supplement this information.

Table 1. Transient Suppressor Diodes			
Series Numbers	Steady State Power	Package	Description
1N4728	1 W	DO-41	Double Slug Glass
1N6267	5 W	Case 41A	Axial Lead Plastic
1N5333A	5 W	Case 17	Surmetic 40
1N746/957 A/4371	400 mW	DO-35	Double Slug Glass
1N5221A	500 mW	DO-35	Double Slug Glass

Some data sheets have surge information which differs slightly from the data shown in Figure 1. A variety of reasons exist for this:

1. The surge data may be presented in terms of actual surge power instead of nominal power.
2. Product improvements have occurred since the data sheet was published.



Power is defined as $V_Z(NOM) \times I_Z(PK)$ where $V_Z(NOM)$ is the nominal zener voltage measured at the low test current used for voltage classification.

Figure 1. Peak Power Ratings of Zener Diodes

3. Larger dice are used, or special tests are imposed on the product to guarantee higher ratings than those shown on Figure 1.

4. The specifications may be based on a JEDEC registration or part number of another manufacturer.

The data of Figure 1 applies for non-repetitive conditions and at a lead temperature of 25°C. If the duty cycle increases, the peak power must be reduced as indicated by the curves of Figure 2. Average power must be derated as the lead or ambient temperature rises above 25°C. The average power derating curve normally given on data sheets may be normalized and used for this purpose.

At first glance the derating curves of Figure 2 appear to be in error as the 10 ms pulse has a higher derating factor than the 10 μs pulse. However, when the derating factor for a given pulse of Figure 2 is multiplied by the peak power value of Figure 1 for the same pulse, the results follow the expected trend.

When it is necessary to use a zener close to surge ratings, and a standard part having guaranteed surge limits is not suitable, a special part number may be created having a surge limit as part of the specification. Contact your nearest Motorola OEM sales office for capability, price, delivery, and minimum order criteria.

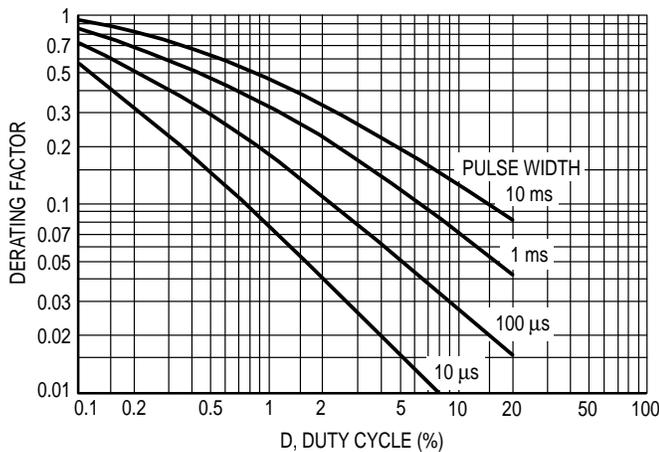


Figure 2. Typical Derating Factor for Duty Cycle

MATHEMATICAL MODEL

Since the power shown on the curves is not the actual transient power measured, but is the product of the peak current measured and the nominal zener voltage measured at the current used for voltage classification, the peak current can be calculated from:

$$I_Z(PK) = \frac{P(PK)}{V_Z(NOM)} \quad (1)$$

The peak voltage at peak current can be calculated from:

$$V_Z(PK) = F_C \times V_Z(NOM) \quad (2)$$

where F_C is the clamping factor. The clamping factor is approximately 1.20 for all zener diodes when operated at their pulse power limits. For example, a 5 watt, 20 volt zener can be expected to show a peak voltage of 24 volts regardless of whether it is handling 450 watts for 0.1 ms or 50 watts for 10 ms. This occurs because the voltage is a function of junction temperature and IR drop. Heating of the junction is more severe at the longer pulse width, causing a higher voltage component due to temperature which is roughly offset by the smaller IR voltage component.

For modeling purposes, an approximation of the zener resistance is needed. It is obtained from:

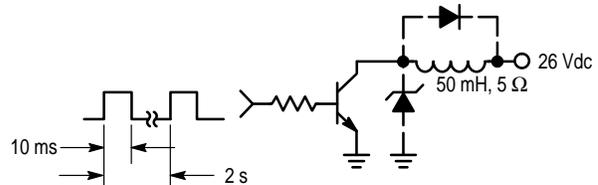
$$R_Z(NOM) = \frac{V_Z(NOM)(F_C - 1)}{P_{PK}(NOM)/V_Z(NOM)} \quad (3)$$

The value is approximate because both the clamping factor and the actual resistance are a function of temperature.

CIRCUIT CONSIDERATIONS

It is important that as much impedance as circuit constraints allow be placed in series with the zener diode and the components to be protected. The result will be a lower clipping voltage and less zener stress. A capacitor in parallel with the zener is also effective in reducing the stress imposed by very short duration transients.

To illustrate use of the data, a common application will be analyzed. The transistor in Figure 3 drives a 50 mH solenoid which requires 5 amperes of current. Without some means of clamping the voltage from the inductor when the transistor turns off, it could be destroyed.



Used to select a zener diode having the proper voltage and power capability to protect the transistor.

Figure 3. Circuit Example

The means most often used to solve the problem is to connect an ordinary rectifier diode across the coil; however, this technique may keep the current circulating through the coil for too long a time. Faster switching is achieved by allowing the voltage to rise to a level above the supply before being clamped. The voltage rating of the transistor is 60 V, indicating that approximately a 50 volt zener will be required.

The peak current will equal the on-state transistor current (5 amperes) and will decay exponentially as determined by the coil L/R time constant (neglecting the zener impedance). A rectangular pulse of width L/R (0.01 sec) and amplitude of I_{PK} (5 A) contains the same energy and may be used to select a zener diode. The nominal zener power rating therefore must exceed $(5 A \times 50) = 250$ watts at 10 ms and a duty cycle of $0.01/2 = 0.5\%$. From Figure 2, the duty cycle factor is 0.62 making the single pulse power rating required equal to $250/0.62 = 403$ watts. From Figure 1, one of the 1N6267 series zeners has the required capability. The 1N6287 is specified nominally at 47 volts and should prove satisfactory.

Although this series has specified maximum voltage limits, equation 3 will be used to determine the maximum zener voltage in order to demonstrate its use.

$$R_Z = \frac{47(1.20 - 1)}{500/47} = \frac{9.4}{10.64} = 0.9\Omega$$

At 5 amperes, the peak voltage will be 4.5 volts above nominal or 51.5 volts total which is safely below the 60 volt transistor rating.