MicroNote 202

Zener Voltage Regulation with Operating Current Changes

By Kent Walters

Zener diodes primarily serve as voltage regulators to minimize voltage changes with possible operating current changes when placed in parallel across a load to be regulated. Selected Zener voltage (V_Z) nominals in numerous data sheets are available from as low as 1.6 V up to 200 V or higher with voltage tolerances of ±5% or less at a specified test current (I_{ZT}) when operated at 25 °C. At other I_Z operating currents, slight changes will be observed in Zener voltage from regulator impedance (Z_Z) effects or what has also been identified as dynamic impedance. The maximum Z_{ZT} is provided in Zener data sheets at their specified test current (I_{ZT}) to help calculate small voltage changes (ΔV_Z) from the initial V_Z at I_{ZT} when operating current is changed by some small value (ΔI_Z). This simply involves Ohm's Law whereby:

$$\Delta V_Z = \Delta I_Z \times Z_{ZT}$$

These considerations are important to understand good voltage regulation or when using lower voltage Zeners below 5 V where Z_{ZT} is comparatively high.

For I_Z values that significantly deviate from I_{ZT}, this calculation becomes less accurate for determining ΔV_Z since Z_Z changes with current. In those applications, the following is further provided since Z_Z typically decreases with increasing Zener current on a log-log scale as shown in Figure 1.

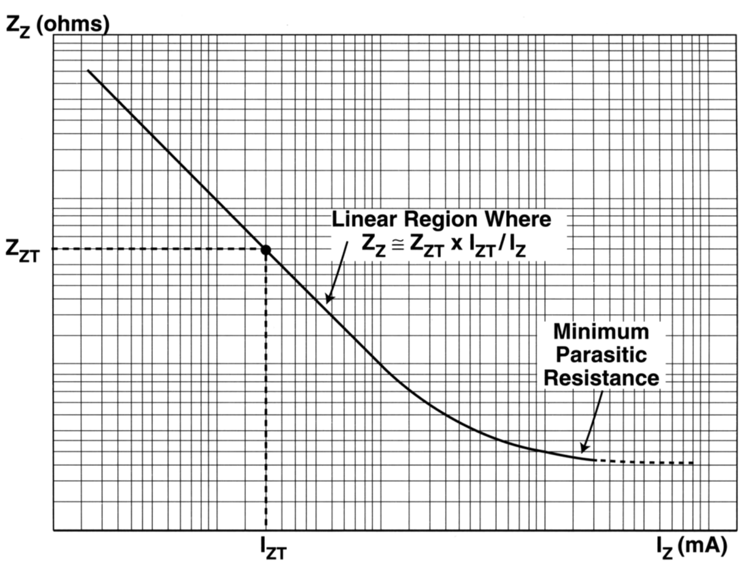

Figure 1 • Typical Dynamic Impedance (Z_Z) vs. Zener Current (I_Z) Characteristics

For Zeners operating in the linear declining slope region of the log-log plot in Figure 1, it may be demonstrated that:

$$Z_Z \approx Z_{ZT} \times I_{ZT}/I_Z$$

As a result, a good approximation for the greater changes in Zener voltage (ΔV_Z) when current is changed from I_{ZT} to another value I_Z is as follows:

$$\Delta V_Z = 2(I_{ZT} \times Z_{ZT})(I_Z - I_{ZT})/(I_Z + I_{ZT})$$

In this calculation, ΔV_Z is in volts, I_Z and I_{ZT} are in Amps, and Z_{ZT} is in Ohms.

This is applicable only for operating currents in the linear operating regions of Figure 1 where "dynamic impedance" values of the Zener p-n junction are still above the illustrated minimal parasitic region and also well within maximum rated continuous operating currents. During brief high-surge currents that are also within the rating of the device, Zeners or TVSs in avalanche breakdown may be driven into this "minimum parasitic resistance" region for good voltage clamping features.

Voltage changes with operating current will typically be greater for low-voltage Zeners (below 5 V) where their regulator impedance is much higher with field emission or tunneling effects compared to the "sharp knee" avalanche breakdown characteristics of higher voltage Zeners (well above 5 V). These differences are illustrated in Figure 2 where the described calculations for ΔV_Z above are still applicable with the higher specified values of Z_{ZT} in datasheets.

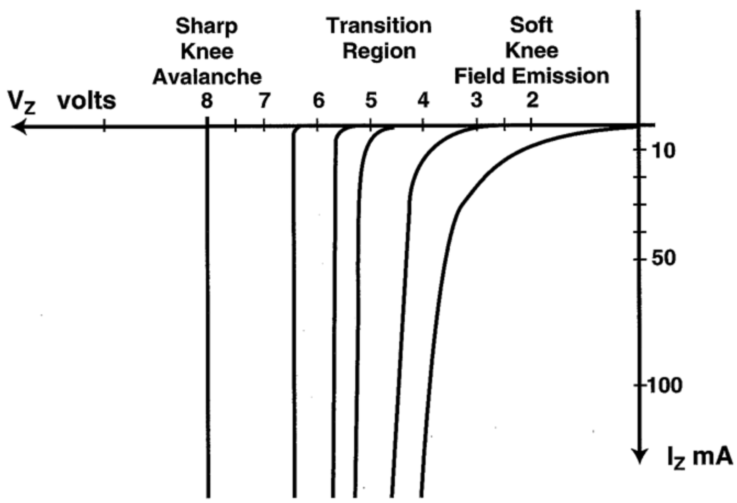

Figure 2 • Typical Zener (I-V) Characteristics

The above equations for V_Z voltage changes do no include additional effects from ambient temperature changes or thermal self-heating effects with applied Zener power ($P = V_Z \times I_Z$) as well as thermal resistance junction to ambient. These added effects can further influence V_Z by the Zener voltage temperature coefficient (α_{VZ}) and thermal resistance ($R_{\theta JA}$) characteristics with Zeners and mounting features, particularly when power is significant relative to full rating or when heat sinking is marginal. Ambient temperature and power heating effects on Zener voltage regulators are further detailed in MicroNotes 203 and 204. Zero Temperature Coefficient or "Zero-TC" reference diodes are also described in MicroNote 205. MicroNote 070 is also now available on "Thermal Management For Discrete Semiconductors" for overall added reference.

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