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# Your 15 V Zener and TVS diodes are avalanche diodes

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A04 Fast Recovery Diodes

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## Abstract

“Zener diodes” are very common components provided from 1.8V up to 200V by suppliers. Avalanche diodes are specific diodes between 200V and 1000V characterized in avalanche clamping voltage mode. The connection in series of avalanche diodes allows designing high voltage diodes. For most components avalanche is often understood as a catastrophic phenomenon of failure of the component. The goal of this presentation is to explain the Zener effect and the avalanche effect, the area of voltage where Zener clamping voltage may occur and the impact on the  $i(V)$  curves. In fact, most “Zener diode” or Transient Voltage Suppressor (TVS) work in avalanche mode.

## Synopsis

CEA carries out researches and realizations on components in avalanche mode for years [1]. But even now, avalanche in components is presented as a dangerous phenomenon as avalanche of snow. At the opposite, power electronic engineers considers Zener diode and TVS as very safe components to clamp the voltage. The reality is that most “Zener diodes” don't use Zener effect but voltage clamping with avalanche effect.

The goal of this presentation is to clarify the very common misunderstanding about Zener effect and avalanche effect in diodes, with highlights on some parameters we can find in some datasheets and some tests on the components.

For low clamping voltages, a Zener diode has a sharp and highly doped p-n junction. Because of the thickness of the junction, quantum effects occur and the conduction is due to tunneling effect of electrons. Due to the quantum effect, the conduction of some electrons may occur at lower voltage than the voltage gap.

For higher voltages, the junction of the “Zener” diode is a classical junction one and voltage clamping is made by avalanche. The conduction is due to the acceleration of the minority carriers by the high electric field, which is sufficient to create ionization. Depending of the design, the conduction by ionization can be localized in hot spot and failure may occur, or the reverse conducting current may be spread on the entire surface without concentration of losses, without local thermal collapse.

The two phenomena co-exist for Zener diode around 5 to 6 V. It is the reason why the global temperature coefficient of the component is minimized for this level of voltage, because Zener effect has a negative one and avalanche clamping a positive one.

Only some datasheets of some suppliers offer the details to study the two phenomenon.

The figure 1 presents the leakage current of “Zener diode” as a function of the clamping voltage.

The figure 2 presents the voltage of a “Zener diode” for  $V_z$  up to 12V (MMSZ4xxxT1G Series ON Semi)

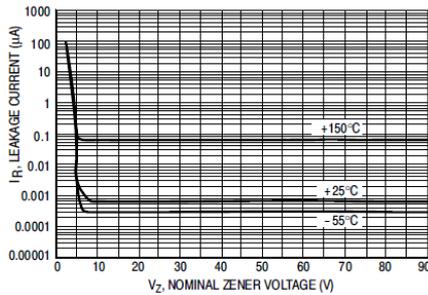


Figure 1: Leakage current versus nominal voltage

Diodes with nominal voltage lower than 6V works by Zener effect, with high leakage current and a high internal impedance.

For higher voltages, the clamping uses avalanche effect with very low leakage current, low impedance, and a straightforward corner.

Table 1 presents voltage for different levels of current for three BZX85C Zener diodes with a nominal voltage of 3.3V, 5.1V, 12V, and 15V and for an 1N4148 diode in direct mode, at ambient temperature. Table 2 presents the voltage variation between the different levels of current.

Voltage \ Current (mA)	0,1	1	10	20
3,3 V	2,04	2,70	3,54	3,80
5,1 V	3,40	4,20	4,87	5,00
12 V	11,88	11,90	12,22	12,59
15 V	15,04	15,08	15,64	16,20
1N4148	0,499	0,608	0,722	0,761

Table 1: Voltage at different level of current for three Zener diodes and a diode in direct mode

Voltage \ % Current variation	0,1 => 1 mA	1 => 10 mA	10 => 20 mA
3,3 V	27,8	26,9	7,1
5,1 V	21,1	14,8	2,6
12 V	0,2	2,7	3,0
15 V	0,3	3,6	3,5
1N4148	19,7	17,1	5,3

Table 2: Voltage variation between the different level of current for three Zener diodes and a diode in direct mode

Avalanche mode provide a very good clamping. The regulation voltage is near constant for some orders of magnitude of current. A characterization at lower current should be interesting.

Diode in direct mode has a dependence between voltage and current.

For an ideal diode, the relations are:

$$I = I_s \cdot \left( e^{\frac{U}{U_t}} - 1 \right) = I_s \cdot \left( e^{\frac{qU}{kT}} - 1 \right) \quad \text{so} \quad U = U_t \cdot \ln \left( \frac{I}{I_s} + 1 \right)$$

For the 1N4148, the voltage increase of 100 mV for each decade.

According to the table 2, a silicon diode in direct mode is a better clamping component than a 3.3V Zener diode. The dependence of the 3.3V Zener diode to the current is higher than the 1N4148 in direct mode.

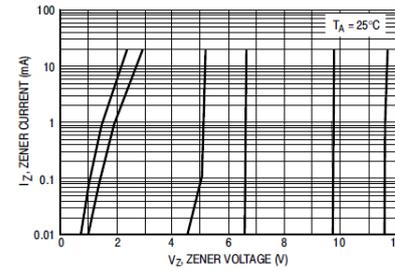


Figure 2: Zener voltage versus Zener currents

This behavior could be detected in some datasheets (MMSZ4xxxT1G Series ON Semi). With avalanche effect, the impedance decrease when the clamping voltage decrease. When Zener effect occurs, the impedance increase of around an order of magnitude.

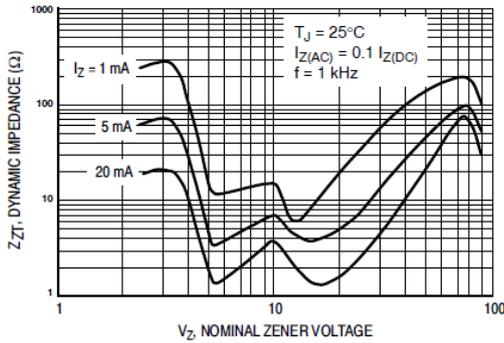


Figure 3: Effect of Zener voltage on internal impedance

A Transient Voltage Suppressor diode (TVS) as Transil® from ST is a clamping diode optimized for a good spreading of the avalanche current on the entire surface of the die and a mounting between two copper nails. The die is soldered between the heads of the two nails to increase the thermal capacitance and so to maximize the single pulse energy of the component.

Order code	$I_{RM}$ @ $V_{RM}$		$V_{BR}$ @ $I_R^{(1)}$				$V_{CL}$ @ $I_{PP}$ 10/1000 $\mu s$		$V_{CL}$ @ $I_{PP}$ 8/20 $\mu s$		$\alpha T^{(2)}$	$C^{(3)}$
	max.		max.	nom.	min.	max.	max.	max.	max.	max.	typ.	
	$\mu A$	V	V	V	V	mA	V	A	V	A	10-4/ °C	pF
1.5KE6V8A/CA	1000	5.8	6.45	6.8	7.14	10	10.5	143	13.4	746	5.7	9500
1.5KE7V5A/CA	500	6.4	7.13	7.5	7.88	10	11.3	132	14.5	690	6.1	8500
1.5KE10A/CA	10	8.55	9.5	10	10.5	1	14.5	100	18.6	538	7.3	7000
1.5KE12A/CA	5	10.2	11.4	12	12.6	1	16.7	90	21.7	461	7.8	6000
1.5KE15A/CA	1	12.8	14.3	15	15.8	1	21.2	71	27.2	368	8.4	5000

Table 3: Specification of 1.5KE Transil® diodes from 6.8V to 15V

In the table 3, the transition between Zener effect and avalanche one is very clear. For 15V TVS, the voltage decrease of only 15%, when the current decrease of three order of magnitude, from 1 mA to 1  $\mu A$ . For the 6.8V TVS, the voltage decrease of 17% for only one order of magnitude, from 10 mA to 1 mA. For this family of components, 6.8V is the lowest voltage.

**Conclusion:**

The final presentation will be completed by some others characterization of diodes for several order of magnitude of current to have convenient tables to use, a schematic of current generator with the use of “Zener diode” with very low polarization current allowed by the avalanche effect, and the illustration of the internal design of Transil® diode.

**References:**

[1] Chatroux, D., Lausenaz, Y. Small standard components strategy, twenty years later, PCIM Europe 2020 Conference Proceedings 1, pp. 776-780