AN5370

Using Avalanche Diodes Without Sharing Capacitors

Application Note

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1. INTRODUCTION

The important property of the avalanche diode is its ability to safely handle, without damage, relatively large reverse powers levels. Normally diodes are limited to a reverse current of the order of mA at room temperature and mA at elevated temperatures but with avalanche diodes reverse currents of greater than 1 A are possible.

The reverse characteristic of an avalanche diode is compared in figure 1 with the characteristic of a normal diode. The avalanche diode has low leakage current up to the avalanche voltage and does not show the same increase in leakage current as the normal diode. The silicon of avalanche diodes is regular across the cross section therefore the majority of the reverse current is conducted within the bulk of the silicon. In a normal diode the majority of the reverse current is conducted close to the edge of the silicon where the electric field strength is highest. As a consequence of this, the reverse power handling capability of the avalanche diode is expressed in kW for rectangular shaped pulses of defined width. Normal diodes may conduct the reverse current in a very small localised area so the reverse current has to be limited.

The avalanche rating curve is shown in fig 2 for the MZ0409W, a 2A, 1400V Vrrm (repetitive rating) and 1500V V(AB)R (avalanche voltage) diode. The curve is valid for a case temperature of 25ºC and 150ºC. The permissible avalanche power is 9kW for a rectangular pulse of 10us and 0.9kW at 1 millisecond width.

Provided the diode is operated within the limits specified on the data sheet, the excursion into the avalanche region is non destructive.

2. DESIGN VOLTAGE

Avalanche diodes are used in series to make high voltage strings. Due to their avalanche capability they can be used without static sharing resistors or dynamic sharing capacitors.

For these strings, it is customary to allow a voltage safety margin of 2.4 to 3 between the rated repetitive voltage of the string and

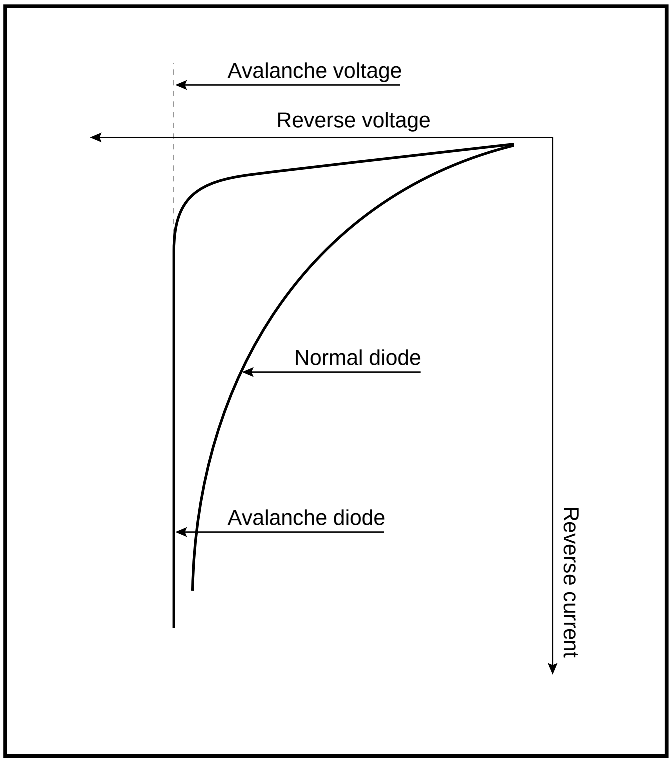

Fig.1 Reverse characteristics

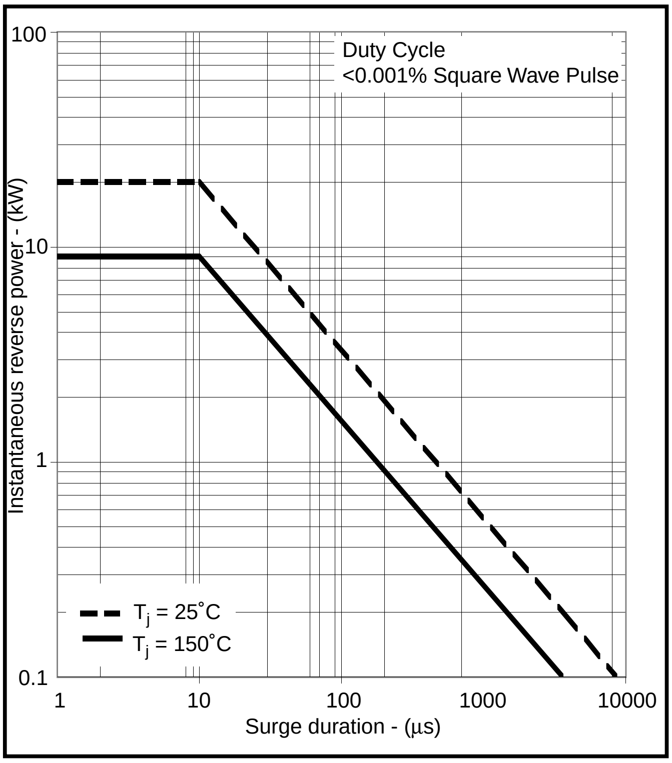

Fig.2 Non-repetitive peak reverse power

the peak reverse applied voltage (PIV) . If N is the number of series diodes and VRRM is the reverse repetitive voltage of the diode then

$N \times V_{RRM} = 2.4 \times PIV$ (2.4 safety margin)....................(1)

In the case of bridge rectifiers

PIV = K x 1.57 x UDC (single phase).........................(2)

PIV = K x 1.05 x UDC (Three phase)..........................(3)

Where UDC is the DC voltage and K is the mains overvoltage factor typically 5%.

Using the above formula with K equal to 1.05 the number in series is

$N = 3.96 \times \frac{U_{DC}}{V_{RRM}}$ (Single phase)..........................(4)

$N = 2.56 \times \frac{U_{DC}}{V_{RRM}}$ (Three phase)...........................(5)

3. VOLTAGE SHARING

a) Static

A series string of avalanche diodes will contain diodes with different reverse leakage and differing avalanche voltage levels. This is inevitable given that any production contains diodes having a spread of characteristics and that diodes do not normally have to be selected. The only criteria for avalanche diodes used in a string is that they should have the same repetitive voltage rating. This means that the leakage current at the repetitive voltage will be less than the value given in the data sheet.

When the diodes are connected in series without sharing components there is a unique leakage current such that the sum of the voltages across the individual diodes will be equal to the applied voltage. According to the design rules given above the design voltage per diode, assuming they share equally could be

$V_{diode} = \frac{V_{RRM}}{2.4}$ ………………......................................(6)

That is 416V for a 1000V diode and 583V for a 1400V diode.

The distribution of voltage between the diodes will depend upon the applied voltage, the number of diodes and the leakage characteristics (these are temperature dependent)

The design voltage is considerably less than the avalanche voltage however, it is conceivable that diodes of such extreme characteristics could be in series causing one or more diodes to avalanche during the reverse blocking of normal operation. This is not serious because the current level will be of the order of milliamps. If the equipment has been designed according to the

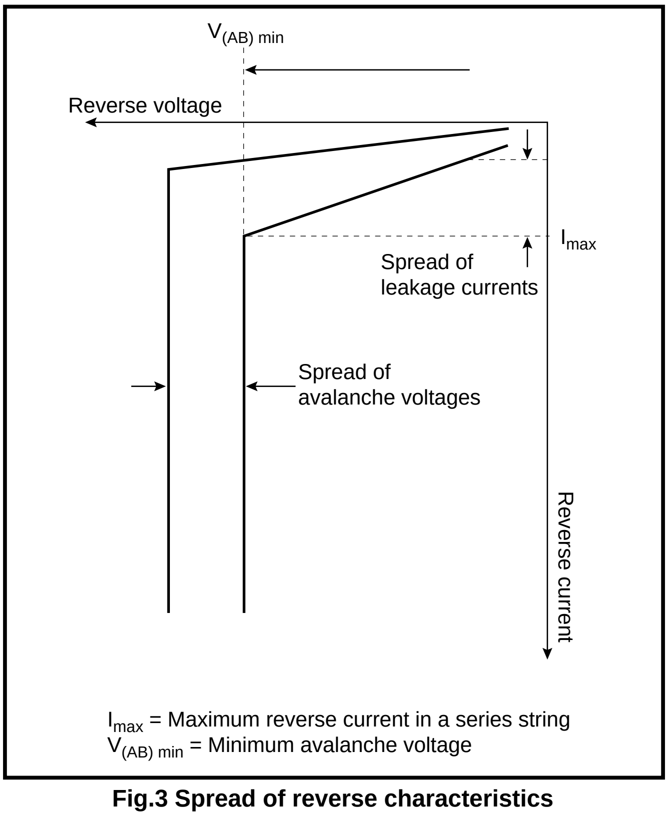

Fig.3 Spread of reverse characteristics

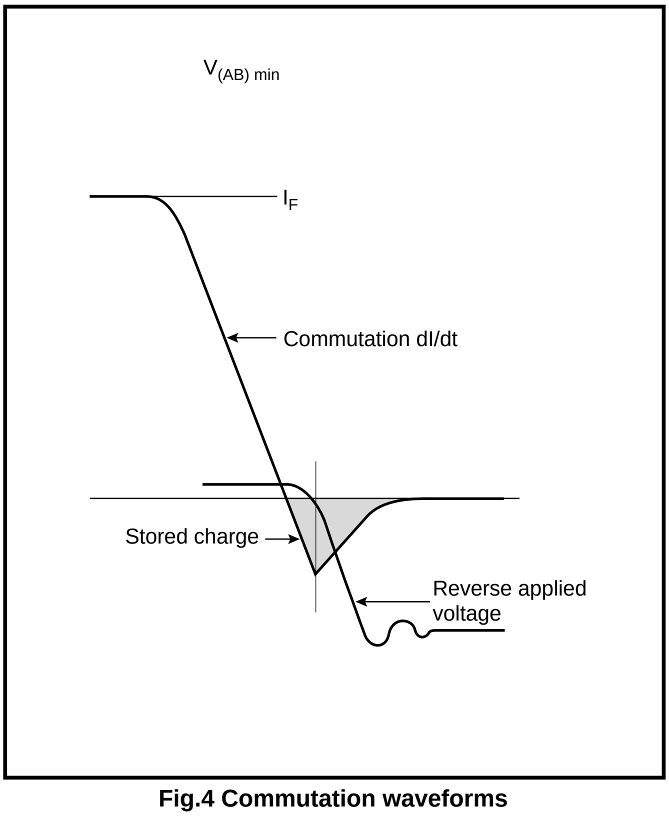

Fig.4 Commutation waveforms

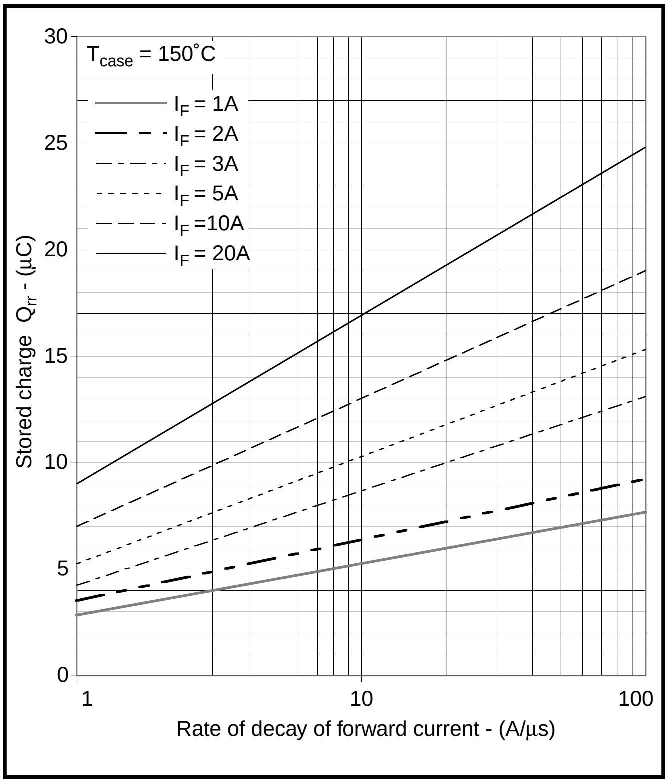

Fig.5 Stored charge (max)

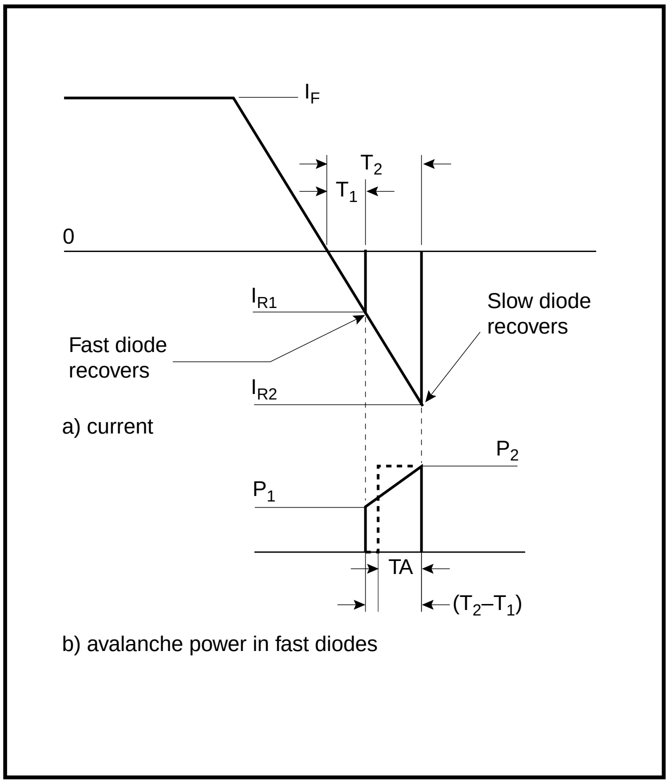

Fig.6 Series diodes

criteria above it is not possible for all diodes to avalanche, therefore the current in the series string will always be less than the current at which the diode with the highest leakage current enters the avalanche region. (see fig. 3)

The fact that avalanche diodes in a series string can be allowed to operate with voltage sharing determined by the diodes, makes it unnecessary to use static sharing resistors.

b) Dynamic

The dynamic sharing is concerned with the reverse voltage appearing across the series string when the current in the diodes is being commutated. The diodes conduct a small current in the reverse direction (fig. 4) at the end of the commutation and when the current snaps off a voltage is induced in the commutating circuit imposing a reverse voltage across the diodes.

The integral of the reverse current is called the stored charge and is expresses in micro-coulombs. The limit case curve for the MZ04xxW diode is shown in figure 5. The stored charge is dependent upon the commutating current, the rate of commutation and the diode junction temperature. Diodes taken from production will show a spread of stored charge, the fast diode having a low stored charge and the slow diode having a high stored charge. The reverse currents of the fast and slow diodes could be as shown in fig.6. In order to simplify the analysis, a triangular current with an instantaneous snap-off at the peak reverse current is assumed. A possible condition exists where the applied voltage is sufficiently high for the fast diodes to be subjected to the avalanche voltage at snap-off (time T1). The fast diode starts the avalanche regime at time T1 with a current IR1 and finishes the regime at time T2 with a current IR2. The instantaneous avalanche power at IR1 and IR2 is P1 and P2 respectively.

$P1 = I_{R1} \times V_{(AB)R} + \Delta 1)$ ....(7)

$P2 = I_{R2} \times (V_{(AB)R} + \Delta 2)$ ....(8)

The Δ values represent the increase in voltage in the avalanche region. From the analysis given in the appendix it follows that the avalanche rating of the diodes in a series string, if no dynamic sharing capacitors are used, must be :

Avalanche Power = $I_{R2} \times (V_{(AB)R} + \Delta 2)$, Watts ....(9)

for a time

TA = $\sqrt{}(1/(2.di/dt) \times (\sqrt{}Qmax - Qmin / \sqrt{}Qmax)$, µsec. .....(10)

Where Qmax & Qmin are the maximum and minimum diode stored charge in µC and di/dt is the rate of change of commutation current in Amps/µs.

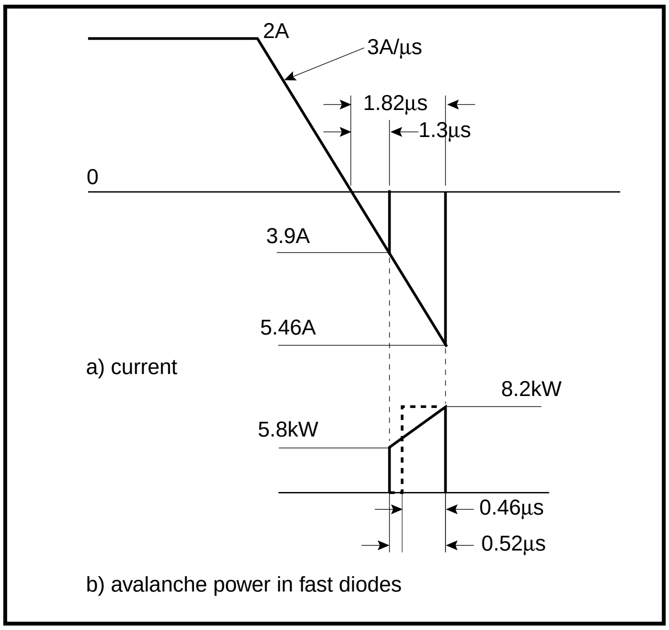

Fig.7 Series diodes

APPENDIX 1

Avalanche Power during reverse recovery

The analysis considers the waveform discussed in fig. 6 and assumes that the voltage drop in the avalanche region is negligible compared with the avalanche voltage.

From the stored charge waveform we have :

$t_1 = \sqrt{(2.Qmin/(di/dt))}$ ....(11)

$t_2 = \sqrt{(2.Qmax/(di/dt))}$ ....(12)

$I_{R1} = (di/dt) \times t1$ ....(13)

$I_{R2} = (di/dt) \times t2$ ....(14)

$P1 = I_{R1} \times V_{(AB)R}$ ....(15)

$P2 = I_{R2} \times V_{(AB)R}$ ....(16)

The avalanche rating in the data sheets is normally for a rectangular current pulse so it is convenient to convert the avalanche power waveform into a rectangular shape. This can be done by considering a rectangular pulse of power P2 and width TA. The width TA is calculated so that the junction temperature after time TA is the same as that occurring during the actual pulse.

If it is assumed that the avalanche power varies linearly between P1 and P2 then the temperature at time T2 is,

$$TJ(T2) = \int_0^{T} \{P1 + ((P2-P1)/T)t\}.(dZ(T-t)/dt).dt \quad ....(17)$$

where Z is the transient thermal impedance and T = T2 – T1

The junction temperature calculated for the rectangular pulse is,

$$TJ(TA) = \int_0^{TA} P2.(dZ(TA-t)/dt).dt \quad ....(18)$$

The transient thermal resistance for the short times encountered (i.e. microseconds) in this analysis can be assumed to have a derivative equal to a constant b.

The two equations give :

$$TJ(T2) = b(T2-T1).\frac{(P1 + P2)}{2} \quad ....(19)$$

$$TJ(TA) = bTAP2 \quad ....(20)$$

Equating equations 18 and 19 to solve for TA and using equations 11 to 16 gives,

$$TA = \sqrt{(I.(di/dt))}.[(\sqrt{(Qmax)} - (Qmin / \sqrt{Qmax})] \quad ....(21)$$

APPENDIX 2

Worked Example

The example considers the diode MZ0414W whose avalanche power rating and stored charge are given in figs 2 and 5 respectively. The avalanche power and pulse width TA, which are required if no sharing capacitors are to be used, will be calculated using the equations of Appendix 1.

It will be assumed that the commutation current is 2A and the rate of the commutation is 3A/µs. Fig 5 shows a maximum stored charge of 5µC. A general rule for stored charge distribution is that Qmax = 2 x Qmin. so that in this case we can assume that Qmin = 2.5µC.

Using equations 11 to 16 we have

$t_1 = \sqrt{(2 \times 2.5/ 3)} = 1.73\mu s$

$t2 = \sqrt{(2 \times 5/3)} = 1.82\mu s$

$I_{R1} = 3.87A$

$I_{R2} = 5.46A$

P1 = 3.87A x 1500V = 5.8kW

P2 = 5.46A x 1500V = 8.2kW

$TA = (\sqrt{1/(3 \times 2)}) \times (\sqrt{5} - 2.5 / \sqrt{5}) = 0.46\mu s$

The current and power waveforms are shown in figure 7. Therefore, no capacitors are required if the avalanche power of 8.2kW for 0.52µs is within the diode rating. Reference to figure 2 indicates that the diode has a power rating of 9kW at 1µs and a T_j of 150 °C and therefore will be capable of handling 8.2kW for 0.5µs.

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