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RENESAS

User's Manual

Precautions Regarding Use of NNCD Series and RD Series

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1. INTRODUCTION

Electronic equipment has remarkably spread in use along with the rapid growth of the information society, and, within this context, NEC's RD Series of Zener diodes, which are used for voltage regulation applications such as reference voltage, voltage detection, and level shift, and the NNCD Series of noise clipping diodes for protection against electrostatic discharge (ESD) and surges occurring in circuits, are being widely used. This manual describes the characteristics of Zener diodes and noise clipping diodes and is designed as a reference for when these diodes are used.

2. DEFINITION OF ZENER DIODE AND NOISE CLIPPING DIODE

2.1 Zener Diode Definition

A Zener diode has the characteristic that when a voltage is applied in the reverse direction as shown in Figure 1, it changes to low impedance when the voltage reaches a certain value, at which point the current starts flowing rapidly.

The principle consists of exploiting the following breakdown phenomena that occur when the PN junction direction is reversed.

(1) Zener breakdown occurring through quantum mechanical tunnel effect
(2) Avalanche breakdown caused by electrons occurring in high electric field and avalanche-like increase in electron holes

These two breakdown phenomena are characterized by a threshold of 5 to 6 V. The Zener breakdown is dominant when the voltage is under 5 to 6 V, and the avalanche breakdown is dominant when the voltage is higher than 5 to 6 V. The γ_Z Zener voltage temperature coefficient is negative during Zener breakdown, and positive during avalanche breakdown. Figure 2 shows the relationship between the Zener voltage and the γ_Z Zener voltage temperature coefficient.

Figure 1. Zener Diode - Current Characteristics

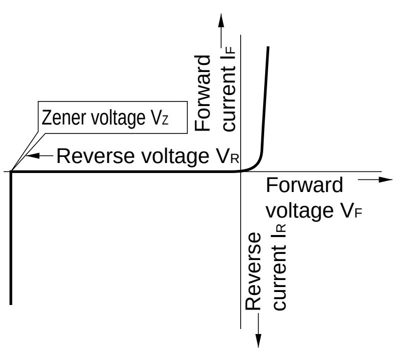
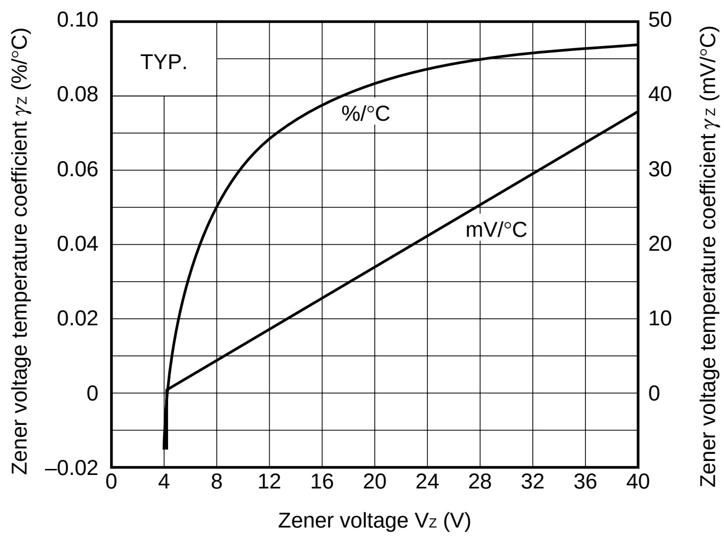


Figure 2. V_Z - γ_Z Characteristics Example



2.2 Noise Clipping Diode Definition

A noise clipping diode has the characteristic that when a voltage is applied in the reverse direction as shown in Figure 3, it changes to low impedance when the voltage reaches a certain value, at which point the current starts flowing rapidly.

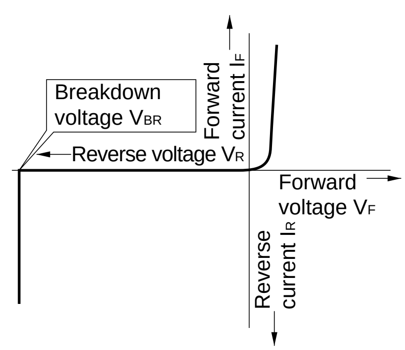
The principle consists of exploiting the following breakdown phenomena that occur when the PN junction direction is reversed.

(1) Zener breakdown occurring through quantum mechanical tunnel effect
(2) Avalanche breakdown caused by electrons occurring in high electric field and avalanche-like increase in electron holes

These two breakdown phenomena are characterized by a threshold of 5 to 6 V. The Zener breakdown is dominant when the voltage is under 5 to 6 V, and the avalanche breakdown is dominant when the voltage is higher than 5 to 6 V.

The noise clipping diode utilizes these characteristics to clip surge noise caused by static electricity, etc., at a set breakdown voltage.

Figure 3. Noise Clipping Diode - Current Characteristics



3. MAXIMUM RATINGS OF ZENER DIODE AND NOISE CLIPPING DIODE

It is extremely important to carefully check the maximum ratings when designing circuits that use Zener diodes and/or noise clipping diodes in order to use these diodes effectively and ensure high reliability.

The ratings applied for semiconductor products are absolute maximum ratings and threshold values that must not be exceeded in any usage conditions or test conditions. Exceeding these ratings will result in irreversible degradation of characteristics and possibly even destruction.

Maximum ratings for Zener diodes and noise clipping diodes apply to allowable dissipation, junction temperature, storage temperature, and surge reverse power. Since these items are interdependent, they cannot be addressed separately. They also differ depending on the circuit conditions and mounting conditions.

3.1 Temperature Rating

The storage temperature rating is for when no voltage, current, mechanical, or other stress other than temperature stress is applied to the device. It is specified as an upper and a lower limit that define a temperature range that enables storage over a long period of time without changes in ratings and characteristics. Normally, the upper value is specified as the maximum junction temperature, and the lower value is specified between −20°C and −65°C.

The junction temperature rating is normally specified as the maximum junction temperature. No minimum junction temperature is specified, but it can be considered to be the lower limit of the storage temperature.

The temperature rating is specified taking into consideration the following aspects.

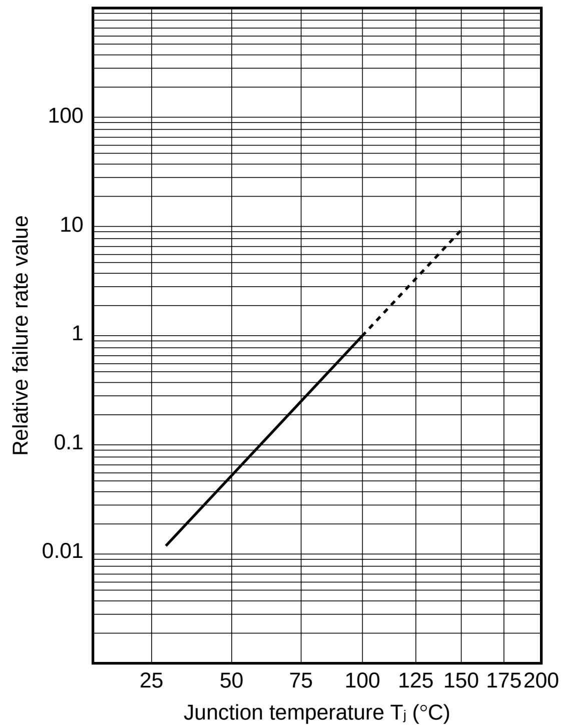
(1) Since the coefficient of thermal expansion differs for the various components of the device, mechanical stresses occur due to temperature fluctuations. The temperature range must be set to ensure the required reliability level without component damage.
(2) A range in which the materials that make up the device do not reach their fusion point and do not deteriorate through the passage of time.
(3) The temperature dependence of the device voltage, current, and other characteristics, so that the specific ratings and characteristics can be stably maintained.
(4) The reliability of the device, so that the characteristics can be guaranteed for a long period without deterioration caused by the lapse of time.

Generally, the deterioration of Zener diodes and noise clipping diodes accelerates as the junction temperature gets higher. The relationship between the average life L_m (time) and the junction temperature T_j (K) is indicated in the following formula, where A and B are fixed constants.

$$\log L_m \cong A + \frac{B}{T_j}$$

This relationship between the average life L_m (time) and the junction temperature T_j (K) is as shown in Figure 4.

Figure 4. Relationship Between Junction Temperature and Failure Rate



3.2 Power Rating

The power consumption of Zener diodes and noise clipping diodes is converted into thermal energy that causes the junction temperature to rise. Thus the maximum junction temperature value $T_{j(MAX.)}$ limits the maximum allowable consumption $P_{(MAX.)}$.

However, it is possible to minimize the rise of the junction temperature by efficiently radiating the generated thermal energy to the outside.

Heat radiation differs depending on the structure of the device and other factors. Thermal resistance R_{th} (°C/W) is used as the coefficient expressing the difficulty to conduct heat. This coefficient is related to the power consumption in the following way.

$T_j = R_{th} \cdot P + T_A$ …………… (3.1)

T_j: Junction temperature
R_{th}: Thermal resistance
P: Power consumption
T_A: Ambient temperature

Thus, allowable dissipation $P_{(MAX.)}$ is expressed by the following formula.

$$P_{(MAX.)} = \frac{T_{j\,(MAX.)} - T_A}{R_{th}} \quad \ldots\ldots\ldots\ldots\ldots \text{(3.2)}$$

As expressed in this formula, the allowable dissipation can be improved by reducing the thermal resistance.

(1) Thermal resistance

Thermal resistance R_{th} can be made smaller by the choice of mounting method. This thermal resistance R_{th} varies according to the surface size of the copper film on the printed wiring board and the lead length at the time of mounting. Figure 5 and Figure 6 show examples of characteristics for RD[ ]E and RD[ ]F.

Figure 5. Example of S - R_{th} Characteristics (RD2.0E to 120E)

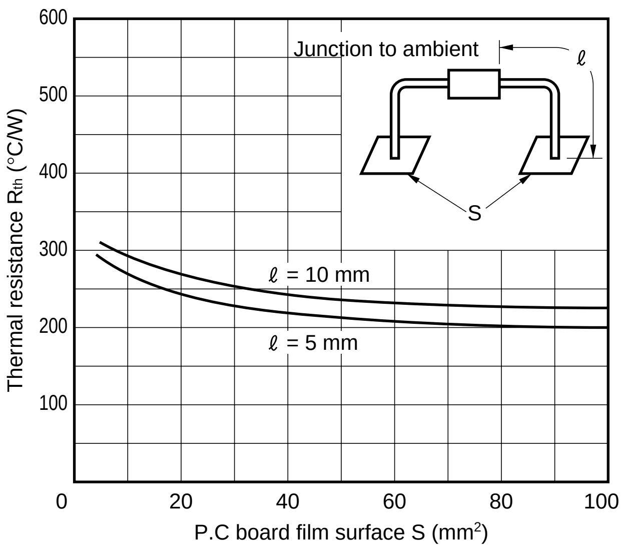
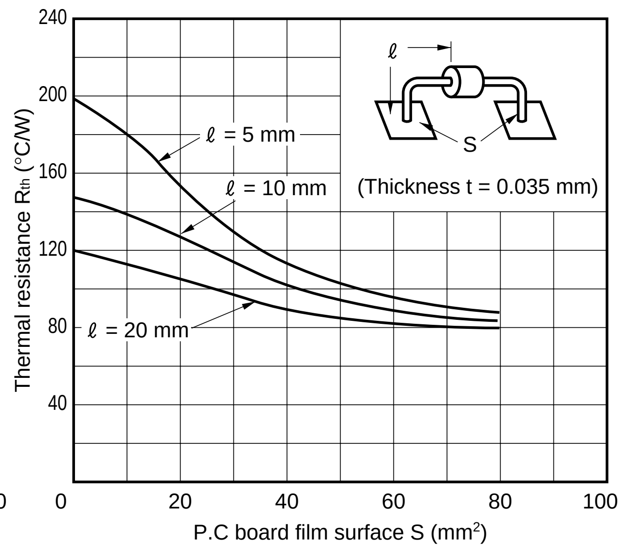


Figure 6. Example of S - R_{th} Characteristics (RD[ ]F)



The heat radiation can be improved by increasing the surface size of the copper film on the printed wiring board. Attention must also be paid to the fact that the lead wire diameters for RD[ ]E and RD[ ]F are different, being respectively 0.5 mm and 0.8 mm. Their heat radiation efficiency also differs; The lead length should be shorter for RD[ ]E, and longer for RD[ ]F to make heat radiation more efficient. Thus the P - T_A rating can be improved as shown in Figure 7 and Figure 8.

Figure 9 shows an example of the S-R_{th} characteristics for NNCD[ ]B, and Figure 10 shows the P - T_A rating.

Figure 7. P - TA Rating (RD2.0E to 120E)

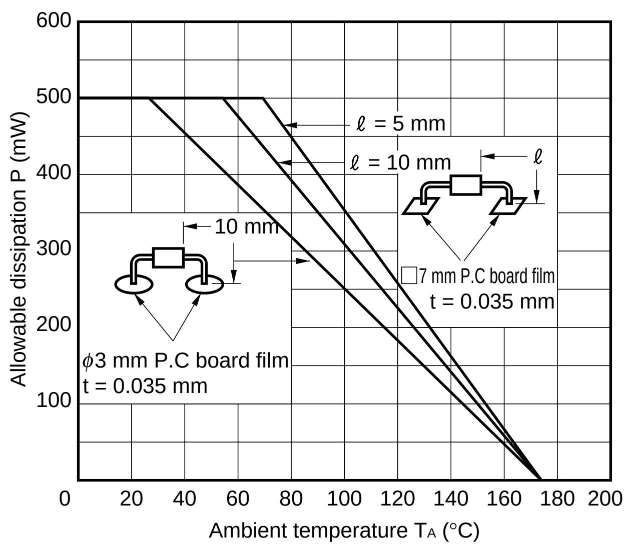


Figure 8. P - TA Rating (RD[ ]F)

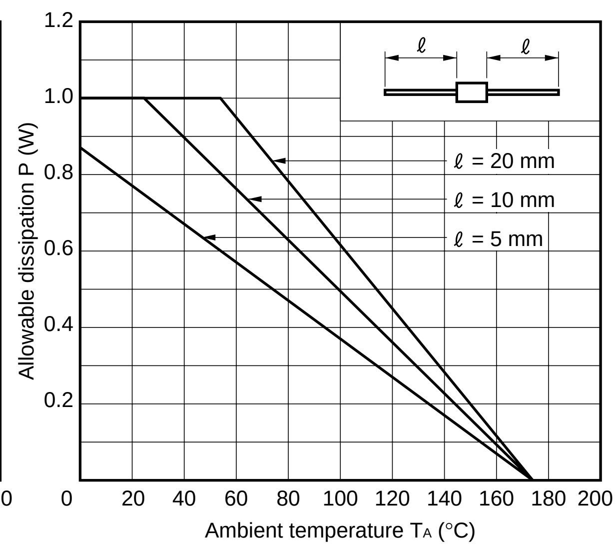


Figure 9. S - Rth Characteristic Example (NNCD[ ]B)

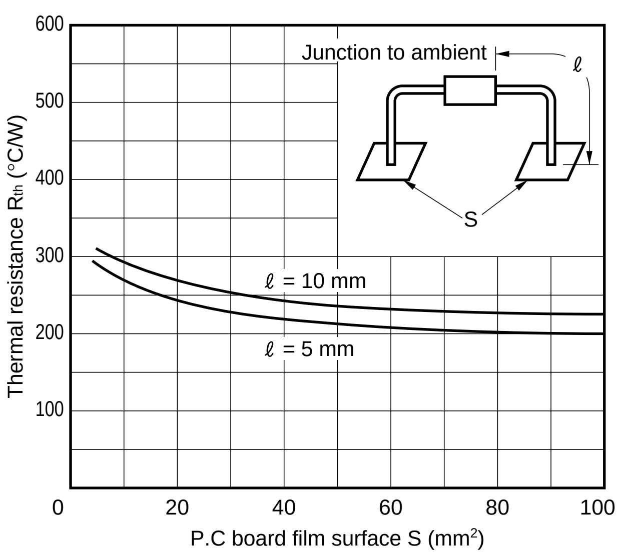
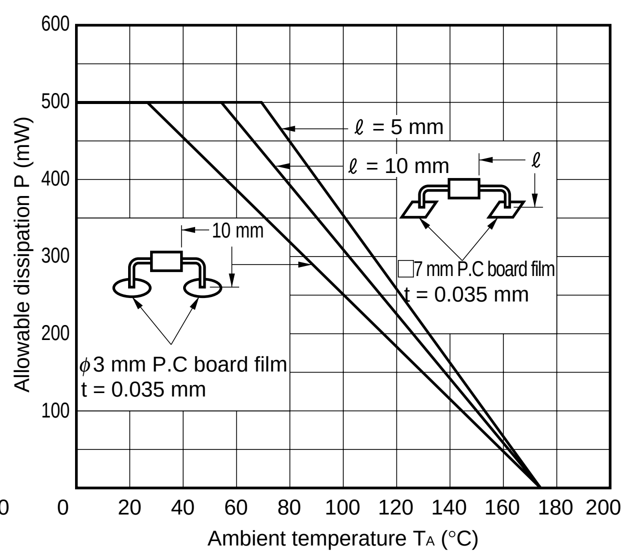


Figure 10. P - TA Rating (NNCD[ ]B)



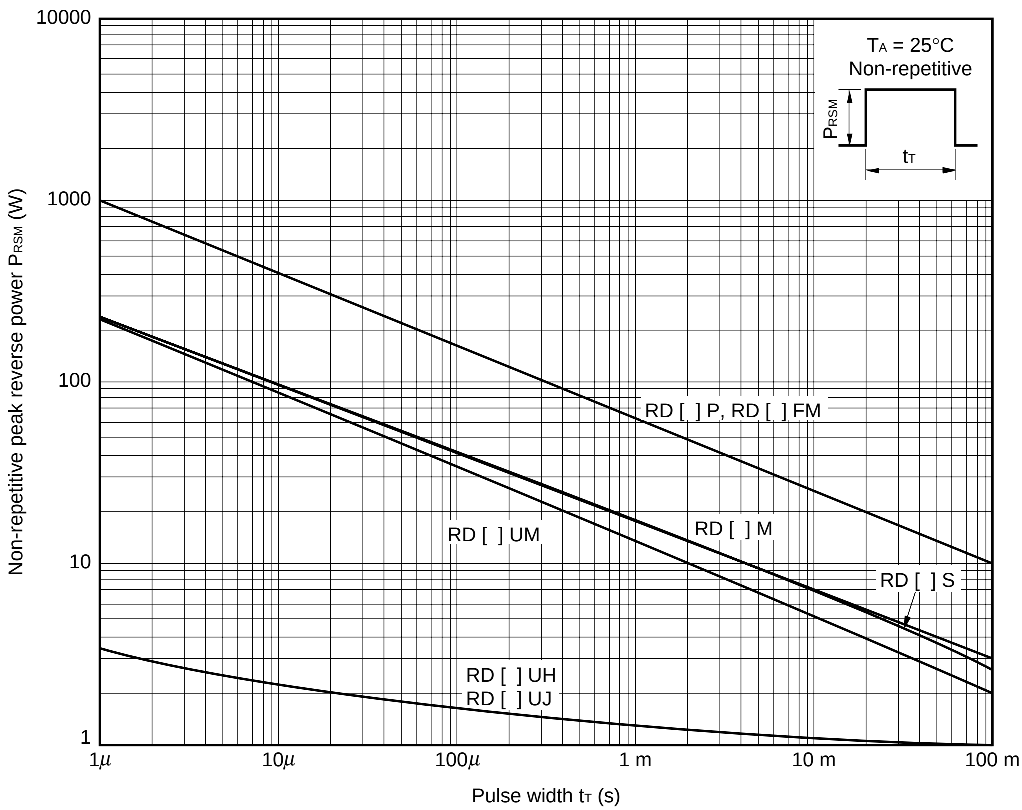
3.3 Surge Reverse Power Rating

The surge reverse power rating is a rating that is determined for surge voltage and surge current that are accidentally generated or invade the circuit. It is normal for the junction temperature to exceed the maximum junction temperature $T_{j(MAX.)}$ for this rating, and under no circumstances is it permissible for this surge reverse power rating to be exceeded, even momentarily.

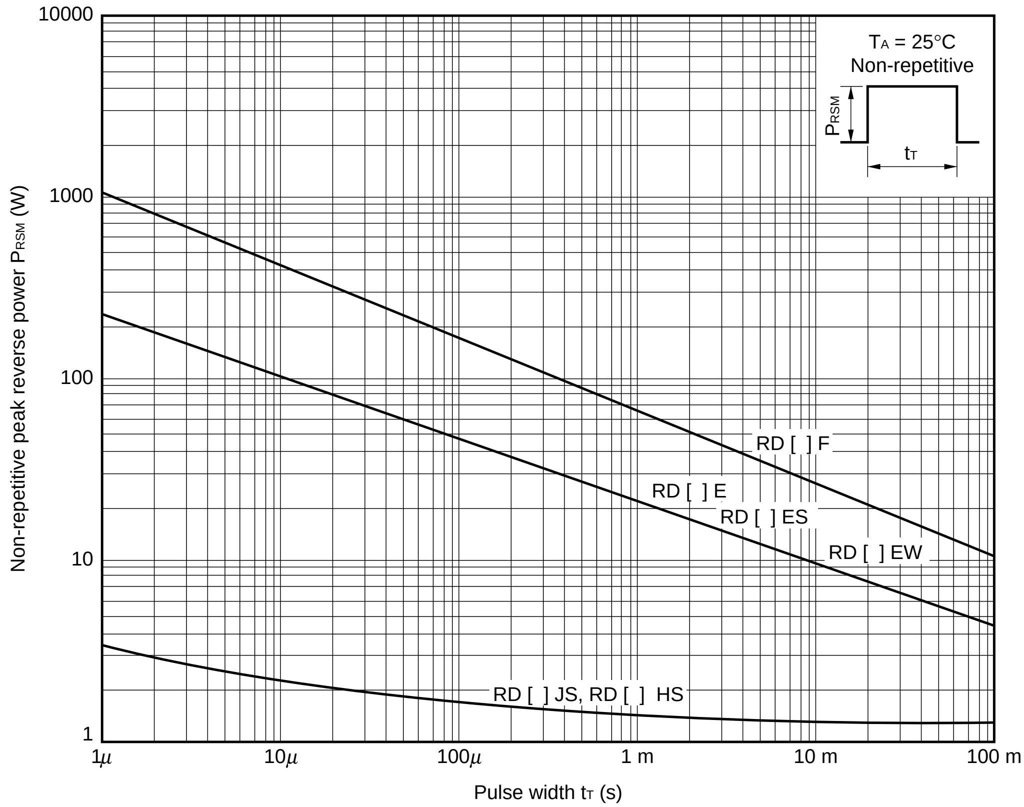
Thus if surge reverse power is applied some tens to some hundreds of times over the life of the device, the value of this surge reverse power must be reduced to between 1/2 to 1/3 of this rating.

Figure 11. Surge Reverse Power Rating

(a)

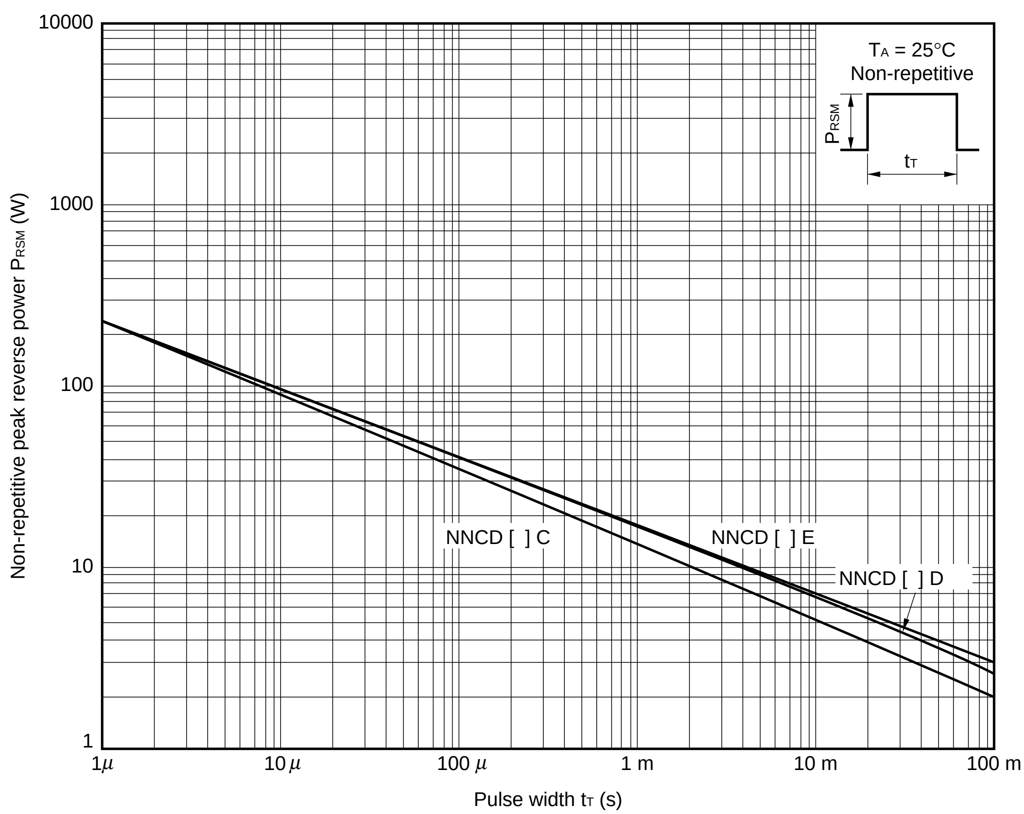


(b)



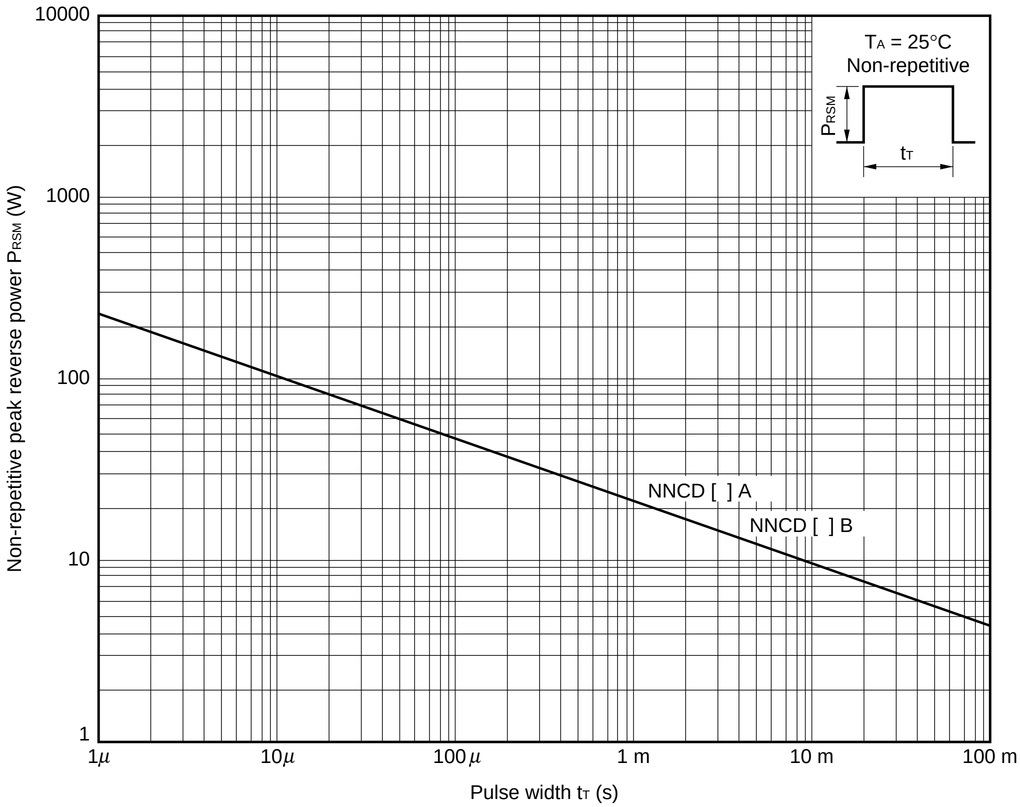
TA = 25°C
Non-repetitive
PRSM
tT
10000
1000
100
10
1
1μ
10μ
100μ
1 m
10 m
100 m
Non-repetitive peak reverse power PRSM (W)
Pulse width tT (s)
RD [ ] F
RD [ ] E
RD [ ] ES
RD [ ] EW
RD [ ] JS, RD [ ] HS

(c)



TA = 25°C
Non-repetitive
PRSM
tT
10000
1000
100
10
1
1μ
10 μ
100 μ
1 m
10 m
100 m
Non-repetitive peak reverse power PRSM (W)
Pulse width tT (s)
NNCD [ ] C
NNCD [ ] E
NNCD [ ] D

(d)


10000
1000
100
10
1
Non-repetitive peak reverse power PRSM (W)
1μ
10μ
100μ
1 m
10 m
100 m
Pulse width tT (s)
TA = 25°C
Non-repetitive
PRSM
tT
NNCD [ ] A
NNCD [ ] B

4. ZENER DIODE CHARACTERISTICS

Figure 12 shows the V_Z-I_Z characteristics of a Zener diode.

The equivalent circuit can be represented as shown in Figure 13.

Here, V_Z is the same power supply as the voltage value at which the breakdown phenomena start, and Z_Z is the operating resistance.

Figure 12. Example of V_Z - I_Z Characteristics

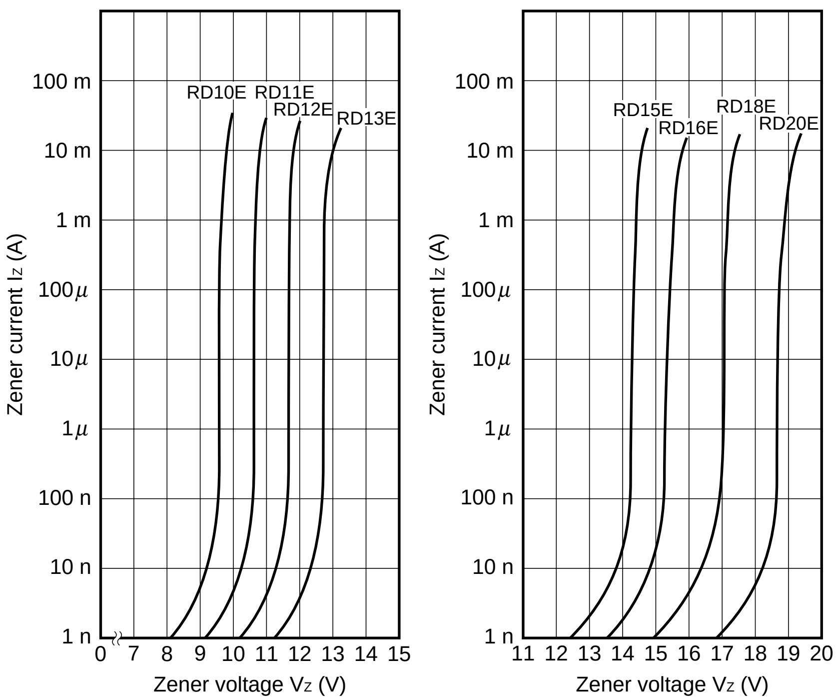
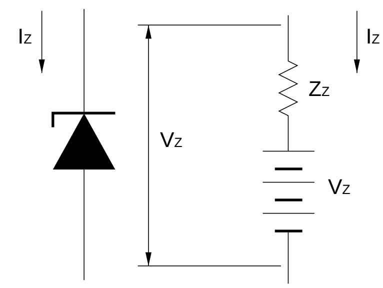


Figure 13. Zener Diode Equivalent Circuit



4.1 Zener Voltage V_Z and Zener Current I_Z

As shown in Figure 12, Zener voltage V_Z increases at the same time as Zener current I_Z. Thus, the following caution must be observed during use.

Caution

The Zener voltage V_Z rating is determined as a Zener voltage V_Z for a given Zener current I_Z. Thus the Zener voltage may differ from the expected value depending on the Zener current I_Z at the time of use. A V_Z-I_Z correlation table for the RD Series of Zener diodes (Information Document No. DEI-602[Note]) that indicates the Zener voltage upper and lower limits taking into consideration variations in the typical Zener current I_Z for the fine classifications of Zener voltages specified in the data sheet is provided. Use it to determine part numbers and ratings.

Note Japanese version only

Table 1. V_Z - I_Z Correlation Table (Excerpt from Information Document DEI-602)

Part No.	Voltage Classification	Zener Voltage V_Z (V) Pulse 40 ms ▭ Reference value							
		I_Z = 1 mA		I_Z = 5 mA		I_Z = 10 mA		I_Z = 20 mA	
		MIN.	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.
RD2.0E	B1	1.24	1.38	1.55	1.73	1.69	1.89	1.88	2.10
	B2	1.32	1.45	1.66	1.82	1.80	1.98	2.02	2.20
RE2.2E	B1	1.38	1.51	1.73	1.89	1.89	2.08	2.12	2.30
	B2	1.45	1.59	1.83	2.00	2.00	2.18	2.22	2.41
RD2.4E	B1	1.52	1.64	1.91	2.08	2.10	2.28	2.33	2.52
	B2	1.59	1.72	1.99	2.17	2.18	2.38	2.43	2.63
RD2.7E	B1	1.65	1.83	2.08	2.27	2.28	2.50	2.54	2.75
	B2	1.76	1.94	2.21	2.42	2.43	2.65	2.69	2.91
RD3.0E	B1	1.87	2.08	2.34	2.57	2.58	2.80	2.85	3.07
	B2	2.00	2.18	2.49	2.70	2.72	2.94	3.01	3.22
RD3.3E	B1	2.12	2.31	2.67	2.84	2.87	3.09	3.16	3.38
	B2	2.26	2.42	2.78	2.98	3.03	3.24	3.32	3.53
RD3.6E	B1	2.35	2.54	2.90	3.13	3.17	3.40	3.47	3.68
	B2	2.47	2.69	3.05	3.28	3.32	3.55	3.62	3.83
RD3.9E	B1	2.64	2.86	3.22	3.46	3.48	3.72	3.77	3.98
	B2	2.75	3.01	3.36	3.62	3.63	3.88	3.92	4.14
RD4.3E	B1	2.91	3.15	3.52	3.77	3.78	4.03	4.05	4.26
	B2	3.07	3.34	3.68	3.95	3.95	4.19	4.20	4.40
	B3	3.27	3.54	3.87	4.13	4.11	4.35	4.34	4.53
RD4.7E	B1	3.38	3.69	4.03	4.27	4.26	4.48	4.47	4.65
	B2	3.51	3.84	4.15	4.40	4.38	4.60	4.59	4.77
	B3	3.65	4.14	4.29	4.65	4.56	4.84	4.71	4.91
RD5.1E	B1	3.85	4.31	4.49	4.81	4.70	4.94	4.85	5.03
	B2	4.16	4.74	4.69	5.10	4.85	5.15	4.97	5.18
	B3	4.43	4.96	4.90	5.32	5.02	5.34	5.12	5.35
RD5.6E	B1	4.77	5.16	5.15	5.43	5.23	5.49	5.29	5.52
	B2	5.19	5.60	5.38	5.65	5.42	5.69	5.46	5.70
	B3	5.43	5.77	5.58	5.85	5.61	5.88	5.64	5.88
RD6.2E	B1	5.70	6.00	5.75	6.04	5.77	6.05	5.81	6.06
	B2	5.90	6.22	5.94	6.33	5.96	6.24	5.99	6.24
	B3	6.06	6.37	6.09	6.38	6.12	6.39	6.16	6.40
RD6.8E	B1	6.20	6.53	6.20	6.55	6.28	6.57	6.32	6.59
	B2	6.39	6.72	6.43	6.75	6.47	6.77	6.52	6.79
	B3	6.56	6.90	6.63	6.91	6.65	6.95	6.70	6.97
RD7.5E	B1	6.76	6.11	6.80	7.14	6.84	7.16	6.88	7.19
	B2	6.99	7.33	7.03	7.35	7.07	7.38	7.11	7.41
	B3	7.21	7.56	7.25	7.59	7.29	7.61	7.33	7.64
RD8.2E	B1	7.40	7.79	7.45	7.82	7.50	7.85	7.56	7.90
	B2	7.66	8.04	7.70	8.07	7.76	8.10	7.82	8.15
	B3	7.91	8.30	7.96	8.33	8.01	8.36	8.07	8.41
RD9.1E	B1	8.24	8.64	8.27	8.67	8.30	8.67	8.33	8.70
	B2	8.51	8.95	8.53	8.96	8.56	8.96	8.61	8.99
	B3	8.79	9.25	8.82	9.26	8.85	9.26	8.89	9.29

4.2 Zener Voltage V_Z and Zener Voltage Temperature Coefficient γ_Z

Zener voltage V_Z changes according to the chip junction temperature. This is caused by the two breakdown phenomena described in section 1, and the rate of change, i.e. Zener voltage temperature coefficient γ_Z, is expressed by the following formula.

$$\gamma_Z = \Delta V_Z / \Delta T_j \quad \text{............} \ (4.1)$$

ΔV_Z: Zener voltage change amount
ΔT_j: Junction temperature change amount

The actual Zener voltage temperature coefficient γ_Z (ambient temperature T_1 to T_2) is generally expressed by the following formula.

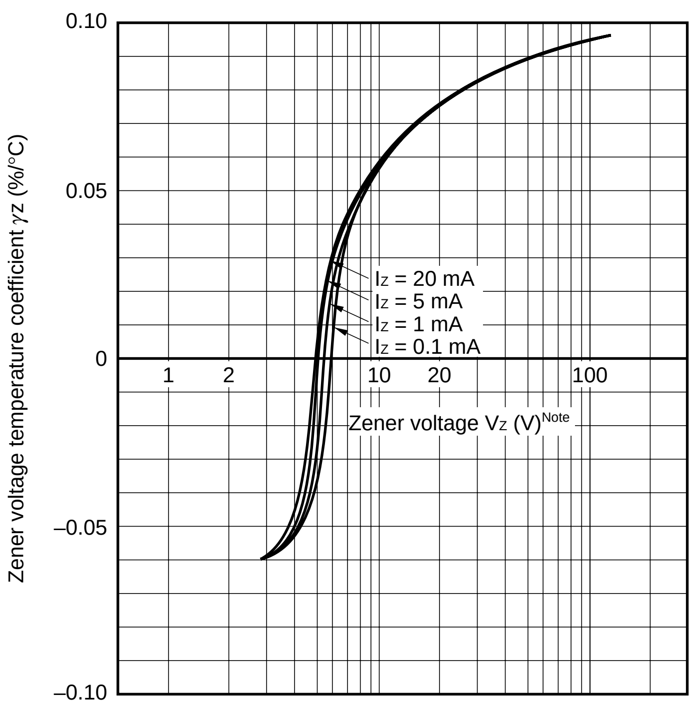
$$\gamma_Z = \frac{V_Z(T_2) - V_Z(T_1)}{V_Z(25°C)\,|T_2 - T_1|} \times 100 \qquad (\%/°C) \ \text{............} \ (4.2)$$

Since this temperature coefficient exists, consideration of the rise in junction temperature is required when considering Zener voltage V_Z. The calculation method for the junction temperature is described in detail in the following section, but consideration of the ambient temperature, mounting method, and operating time is required.

Caution

Zener voltage temperature coefficient γ_Z changes according to Zener current I_Z as shown in Figure 14. Thus evaluation using the actual Zener current used is required.

Figure 14. Zener Voltage Temperature Coefficient



Note Indicates V_Z value calculated with I_Z condition listed in data sheet.

4.3 Zener Voltage V_Z and Ambient Temperature

The Zener voltage when ambient temperature $T_A = T$ is expressed by the following formula.

$$V_{Z\,(T_A = T)} = V_{Z\,(T_A = 25°C)} + \frac{V_{Z\,(T_A = 25°C)} \times \gamma_Z \times (T - 25)}{100} \quad \text{………… (4.3)}$$

Caution

In the case of devices for which high precision is required, such as measuring instruments, full consideration must be given to the ambient temperature. If Zener diodes are used as reference power supplies in such devices, use of a reference diode instead of a general Zener diode is recommended.

Reference

Reference diode

This type of diode is a Zener diode especially designed to reduce Zener voltage temperature coefficient γ_Z for devices that require high precision, based on the principle of canceling positive Zener voltage temperature coefficient γ_Z using the forward voltage VF (γ_Z is negative) of a general diode. The following three product groups are available.

Package		DO-35		DO-35	
V_Z (V) TYP.		6.2		6.4	
γ_Z (%/°C)[Note]	0.01		1SZ50		1SZ45A
	0.005		1SZ51		1SZ46A
	0.002		1SZ52	1SZ47	1SZ47A
	0.001	1SZ53		1SZ48	1SZ48A
T_A (°C)		0 to 75	–25 to +75	–10 to +60	–40 to +100

Note Zener voltage temperature coefficient γ_Z calculation method

- 1SZ45A Series, 1SZ53

$$\gamma_Z = \frac{\Delta V_Z}{T_A\,(\text{MAX.}) - T_A\,(\text{MIN.})} \times \frac{100}{V_Z}$$

Note that ΔV_Z is the difference between the maximum value and minimum values of V_Z at T_A (MIN.), 25°C, T_A (MAX.).

- 1SZ50 to 1SZ52

Either γ_{ZL} or γ_{ZH} is used as γ_Z, with the one with the larger absolute value being selected.

$$\gamma_{ZL} = \frac{\Delta V_{ZL}}{T_{A2} - T_{A1}} \times \frac{100}{V_{Z2}} \qquad \gamma_{ZH} = \frac{\Delta V_{ZH}}{T_{A3} - T_{A2}} \times \frac{100}{V_{Z2}}$$

$T_{A1} = -25°C \quad T_{A2} = 25°C \quad T_{A3} = 75°C$

ΔV_{ZL}: Difference between maximum value and minimum value for T_{A1}, T_{A2}.

ΔV_{ZH}: Difference between maximum value and minimum value for T_{A2} and T_{A3}.

4.4 Zener Voltage V_Z and Operating Time

Zener voltage V_Z changes because junction temperature T_j rises due to dissipation P when power is applied. The calculation method for this junction temperature is explained in detail in section 6, but if the operating time is short, the Zener voltage drift is expressed by the following formula.

$$V'_Z = V_Z + \underbrace{I_Z \cdot V_Z \cdot Z_{th\,(t-t')} \cdot \gamma_Z}_{\text{(Junction temperate rise amount)}} \text{ .... } (4.4)$$

(Junction temperate rise amount)

V_Z: Zener voltage after initial period t (V)
V'_Z: Zener voltage after t' time (V)
I_Z: Zener current (A)
$Z_{th\,(t-t')}$: Difference in transient thermal impedance between t' and t (°C/W)
γ_Z: Zener voltage temperature coefficient (V/°C)

Caution

A considerable margin is required due to variations in thermal resistance R_{th} and Zener voltage temperature coefficient γ_Z in order to guarantee correlations through pulse measurement of the steady-state value of the Zener voltage. Thus it is difficult to guarantee a steady-state value of ±2%. Therefore, the pulse method (the method that uses V_Z as the measurement value after the power application time t_P (ms) has elapsed) is used for the Zener voltage rating, and a pulse width value of t_P = 40 ms is commonly employed. Thus it is necessary to calculate the Zener voltage during operation using the above formula according to actual use.

4.5 Zener Voltage V_Z and Mounting Method

If the operating time is long, Zener voltage V_Z reaches a thermal equilibrium and becomes a steady-state value. This steady-state value is expressed by the following formula using thermal resistance R_{th} described in 2.3.

$$V'_Z = V_Z + I_Z \cdot V_Z \cdot (R_{th} - Z_{th}\,(t)) \cdot \gamma_Z \text{ .... } (4.5)$$

(Junction temperature rise amount)

V_Z: Zener voltage after initial period t (V)
V'_Z: Steady-state value
R_{th}: Thermal resistance
$Z_{th\,(t)}$: Transient thermal resistance at time t
γ_Z: Zener voltage temperature coefficient

As described in section 3.2, the thermal resistance value changes according to the mounting method. Therefore, it is possible to minimize changes in Zener voltage V_Z caused by the consumption resulting from the thermal resistance by selecting a mounting method that minimizes thermal resistance.

As indicated in Figure 5 and Figure 6, the thermal resistance can be reduced by using a large printed board copper film surface, or making the lead length shorter for RE[ ]E and making it longer for RD[ ]F. (See section 2.)

5. ESD TOLERANCE OF NOISE CLIPPING DIODE

Noise clipping diodes comply with the electrostatic discharge test (IEC61000-4-2), which requires that electronic devices have a noise elimination capability (immunity), which is currently an international trend, and guarantee the following contact discharges:

High ESD tolerance type: 30 kV
Low-capacitance type: 8 kV

Figure 15 shows the electrostatic discharge test circuit as per IEC61000-4-2, and Table 2 shows the ratings.

Figure 15.

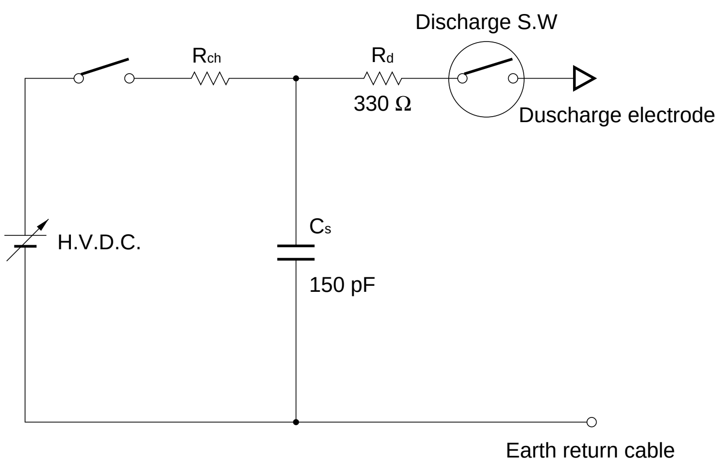


Table 2. Ratings

Level	Test Voltage Contact Discharge
1	2 kV
2	4 kV
3	6 kV
4	8 kV
X	Special

Level	Test Voltage Aerial Discharge
1	2 kV
2	4 kV
3	8 kV
4	15 kV
X	Special

6. JUNCTION TEMPERATURE CALCULATION METHOD

The junction temperature is generally calculated using the following formula. (See section 3. (3.1).)

$T_j = R_{th} \cdot P + T_A$ …………… (6.1)

R_{th}: Thermal resistance
P: Power consumption
T_A: Ambient temperature

6.1 Junction Temperature Calculation Method in Case of Pulsed Power Consumption

If power consumption is in pulses, a reliable junction temperature cannot be obtained without newly using transient thermal impedance. Here, since the Zener diode can be used in applications in which the application current is subject to variations such as surge absorption and level shifts, the junction temperature calculation method in the case of pulsed power consumption is described.

(1) Transient thermal impedance

Transient thermal impedance refers to the inverse of the conductance for pulsed power consumption. The travel path of the heat generated at the chip junction due to power consumption, which varies slightly depending on the structure (glass sealing, plastic sealing), is largely as follows:

Junction → Chip (silicon) → Case → (heat sink) → Ambient air

Generally, a steady state takes 1 to 10 seconds to occur between the junction and case, and several minutes between the case and ambient. Thus in the case of a short-pulse power consumption, the temperature rise is limited to the vicinity of the junction, and does not lead to heat radiation.

Generally transient thermal impedance for a short pulse width is approximated using the following formula.

$Z_{th} \propto \sqrt{t}$

Z_{th}: Overheat impedance
t: Pulse width

(2) Junction temperature calculation method in case of pulsed power consumption

Basically power consumption is approximated to a square wave, and the junction temperature is calculated using the following formula and the principle of superposition.

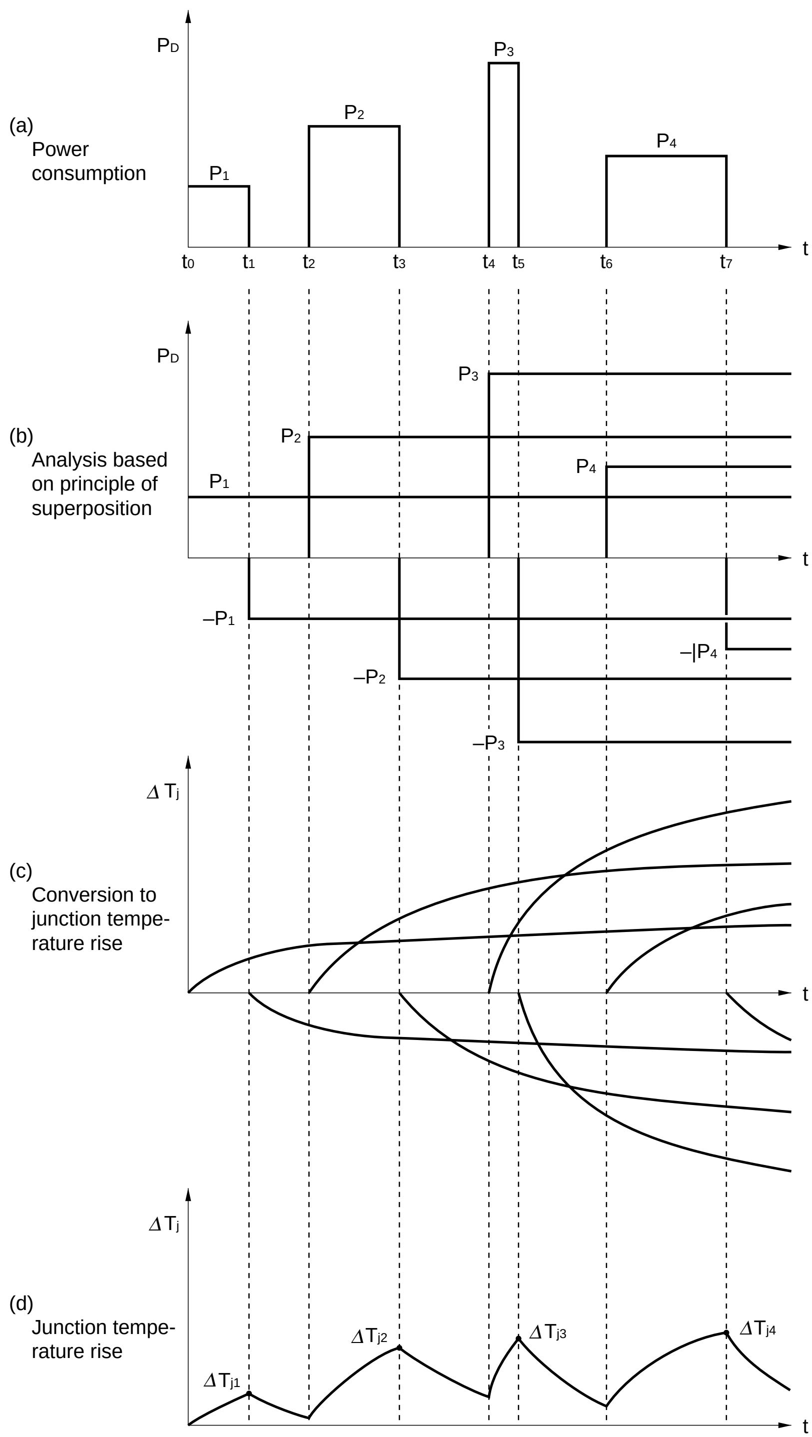
$\Delta T_j = Z_{th}(t) \cdot P$ …………… (6.2)

ΔT_j: Junction temperature rise amount
$Z_{th}(t)$: Transient thermal impedance for pulse width t
P: Power consumption

(i) Irregular repetitive square wave power consumption

Figure 16 shows how to calculate junction temperature rises for irregular square wave power consumption. The junction temperature rise for irregular square wave power consumption is obtained by using the principle of superposition, with an assumption that infinite positive power consumption P_1 is applied step-wise from $t = t_0$, and then an infinite negative power consumption is applied step-wise from $t = t_1$, which is applied to P_2, P_3, and P_4 below. The calculation result is as follows.

Figure 16. How to Obtain Junction Temperature Rise in Case of Irregular Repetitive Square Wave Power Consumption



$$\Delta T_{j1} = P_1 \cdot Z_{th} (t_1 - t_0)$$
$$\Delta T_{j2} = P_1 [Z_{th} (t_3 - t_0) - Z_{th} (t_3 - t_1)] + P_2 Z_{th} (t_3 - t_2)$$
$$\Delta T_{j3} = P_1 [Z_{th} (t_5 - t_0) - Z_{th} (t_5 - t_1)] + P_2 [Z_{th} (t_5 - t_2) - Z_{th} (t_5 - t_3)] + P_3 Z_{th} (t_5 - t_4)$$
$$\Delta T_{j4} = P_1 [Z_{th} (t_7 - t_0) - Z_{th} (t_7 - t_1)] + P_2 [Z_{th} (t_7 - t_2) - Z_{th} (t_7 - t_3)] + P_3 [Z_{th} (t_7 - t_4) - Z_{th} (t_7 - t_5)] + P_4 Z_{th} (t_7 - t_6)$$

This can be expressed as a general formula as follows.

$$\Delta T_{jn} = \sum_{i=1}^{n} P_i [Z_{th} (t_{2n-1} - t_{2i-2}) - Z_{th} (t_{2n-1} - t_{2i-1})] \quad \text{.............. (6.3)}$$

$P_1, P_2, \ldots, P_n$:	Power consumption
$\Delta T_{j1}, \Delta T_{j2}, \ldots, \Delta T_{jn}$:	Junction temperature rise at end of $P_1, P_2, \ldots, P_n$
$t_0, t_1, \ldots, t_n$:	Power consumption beginning and end times
$Z_{th} (tx - ty)$:	Transient thermal impedance for pulse width $(t_x - t_y)$

(ii) Repetitive square wave power consumption

Figure 17 shows how to obtain the junction temperature rise for irregular square wave power consumption.

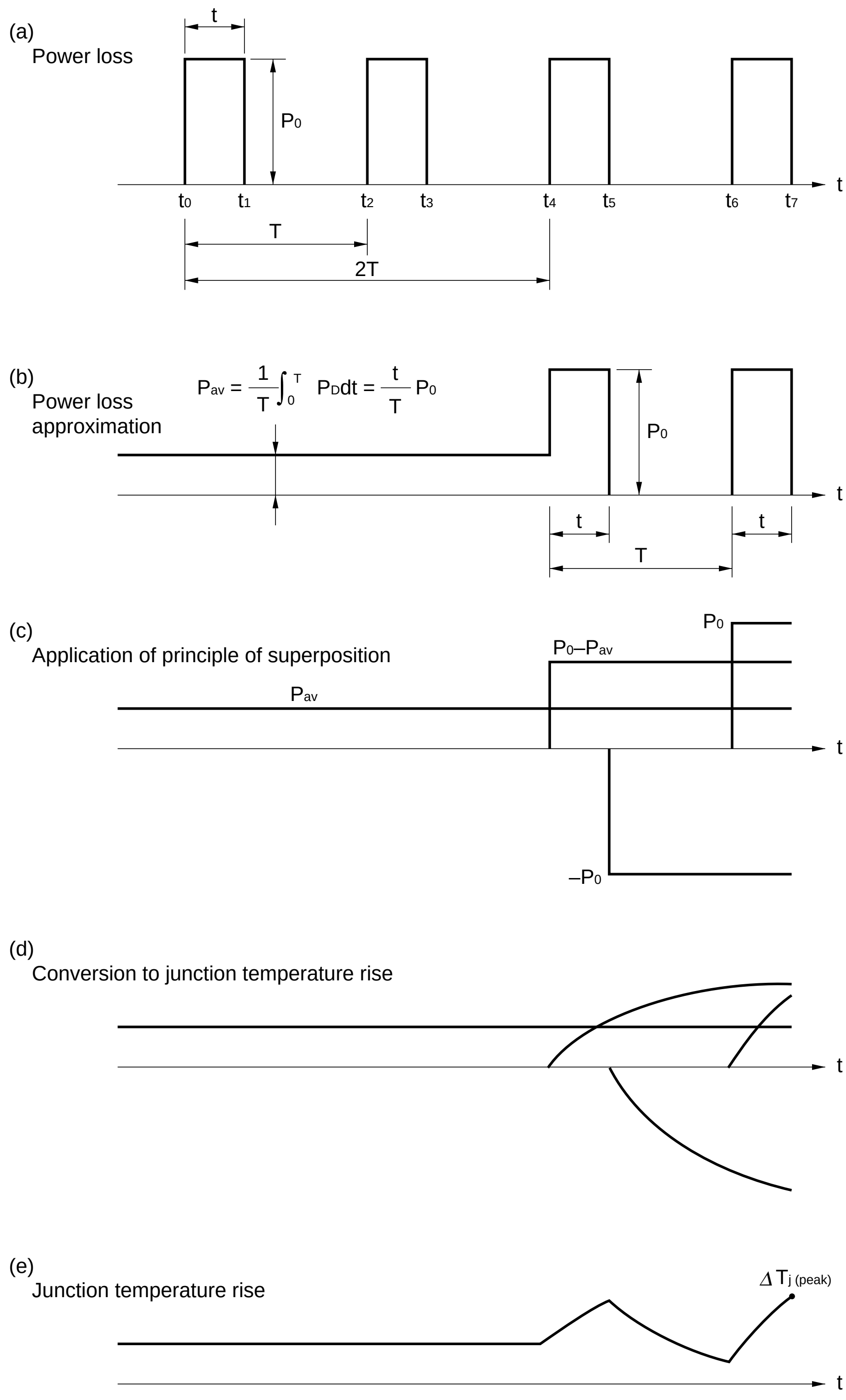
Calculating the junction temperature rise for irregular square wave power consumption by combining 2 or 3 waves that differ from the average over the total period for power consumption waveforms is the most simple and accurate method.

Concretely, the junction temperature rise amount is obtained by applying t/T P_0 for an infinite period from power consumption waveform approximation (b), then further applying (1 – t/T) P_0 for a period of (t + T), $-P_0$ for a period of T, and P_0 for a period of t. The calculation result is as follows.

$$\Delta T_{j\,(peak)} = \frac{t}{T} P_0 R_{th} + \left(1 - \frac{t}{T}\right) P_0 Z_{th} (T + t) - P_0 Z_{th} (T) + P_0 Z_{th} (t)$$
$$= P_0 \left[\frac{t}{T} R_{th} + \left(1 - \frac{t}{T}\right) Z_{th} (T + t) - Z_{th} (T) + Z_{th} (t) \right] \quad \text{.............. (6.4)}$$

$\Delta T_{j(peak)}$:	Maximum junction temperature rise value
P_0:	Power consumption
t:	Power consumption pulse width
T:	Cycle
R_{th}:	Thermal resistance
$Z_{th} (t)$:	Transient thermal impedance for pulse width t

Figure 17. How to Obtain Junction Temperature Rise in Case of Regular Repetitive Square Wave Power Consumption



(iii) Non-square wave power consumption square wave approximation

Since actual power consumption waveforms have a complex shape, the junction temperature is obtained using the methods described in (i) and (ii) following square wave approximation.

When the waveform closely approximates a square waveform as in Figure 18 (a), the same peak value is used and a pulse width resulting in the same area is used.

With regard to the sine wave and the triangular wave shown in Figure 18 (b), the peak value $0.7 \times P_P$ and the pulse widths $0.91 \times t$ and $0.71 \times t$ are used (which results in the same area).

In the case of a complex waveform such as the one shown in Figure 18 (c), the waveform is approximated as several square waves so as to obtain the same area.

A point that must be paid attention to when approximating these waveforms is that calculation results may greatly differ even for the same power consumption depending on the approximation method. This is because the rise in junction temperature for the same energy is greater when the peak value is large and the pulse width is short than when the peak value is small and the pulse width is large.

In Figure 19, fine gradations such as in (b) are more desirable for economic design as they approximate the actual rise in temperature more than in the case of (a).

In the approximation shown in Figure 18 (b), ΔT_j = 62°C, which is almost equivalent to the value in Figure 19 (b).

Figure 18. Power Consumption Square Wave Approximation

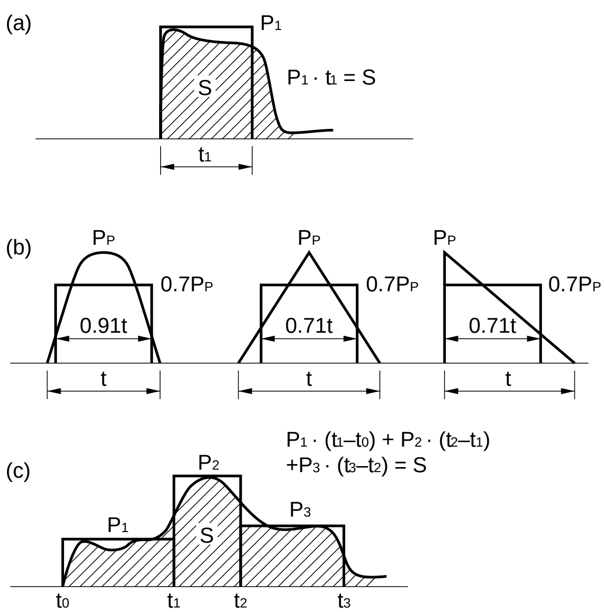
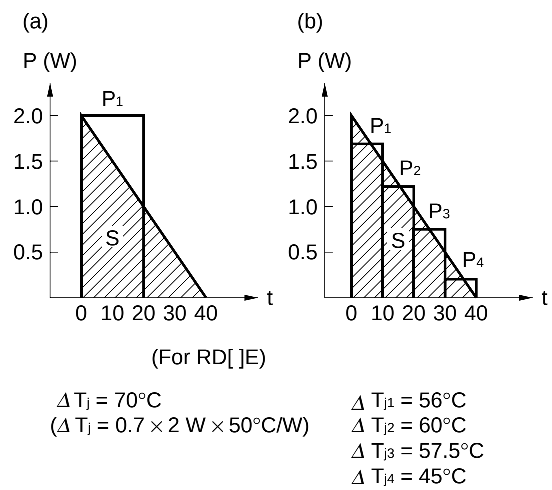


Figure 19. Junction Temperature Rise for Triangular Power Consumption



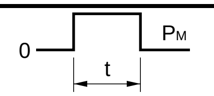
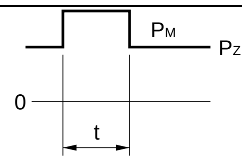
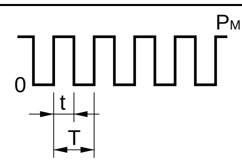
7. ALLOWABLE POWER FOR PULSED POWER

Applications for Zener diodes can be generally classified into constant voltage circuits, constant current circuit level shift, fixed bias level shift, clippers, limiters, slicers, and surge absorption, as shown in the basic circuit examples in Figure 24.

As can be seen from these circuit examples, Zener diodes are frequently used with pulsed power, which is divided into three major categories.

(1) Single pulse
(2) Single pulse power applied on top of continuous DC power
(3) Repetitive pulse power

These allowable powers are calculated as follows based on the junction temperature calculation methods introduced in section 6. (Also see section 6 for the power waveform approximation methods.)

Load Type	Power Waveform	Allowable Power (Peak Value)
Single pulse load		$P_M = \dfrac{T_j - T_A}{Z_{th}(t)}$ ……………… (1)
Load for which single pulse load is superimposed on continuous DC load		$P_M = \dfrac{T_j - T_A - P_Z \cdot R_{th}}{Z_{th}(t)} + P_Z$ ……… (2)
Continuous repetitive pulse load		$P_M = \dfrac{T_j - T_A}{\dfrac{t}{T} R_{th} + \left(1 - \dfrac{t}{T}\right) Z_{th}(t + T) - Z_{th}(T) + Z_{th}(t)}$ ………………… (3)

However,

- R_{th}: Thermal resistance during steady state
- Z_{th} (t): Transient thermal impedance at time t
- Z_{th} (T): Transient thermal impedance at time T
- Z_{th} (t+T): Transient thermal impedance at times t + T

T_j: Junction temperature rating

Figures 20 to 23 show the transient thermal impedance characteristics of NEC's Zener diodes.

Figure 20. Transient Thermal Impedance Characteristics

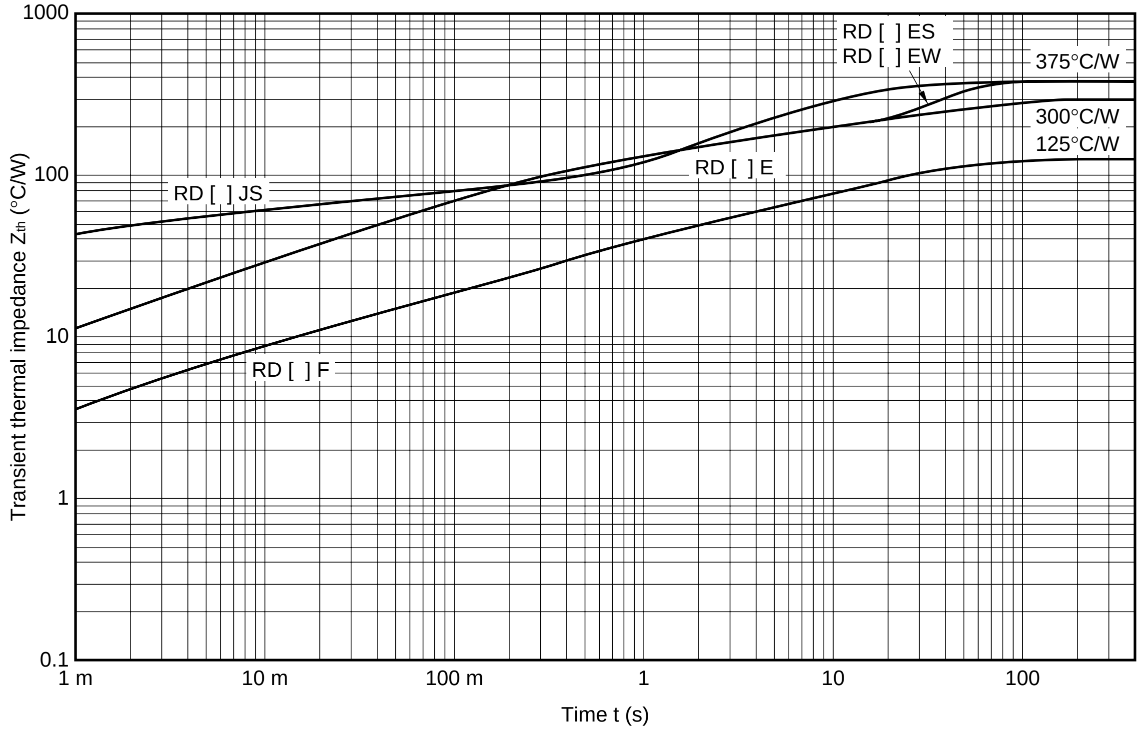
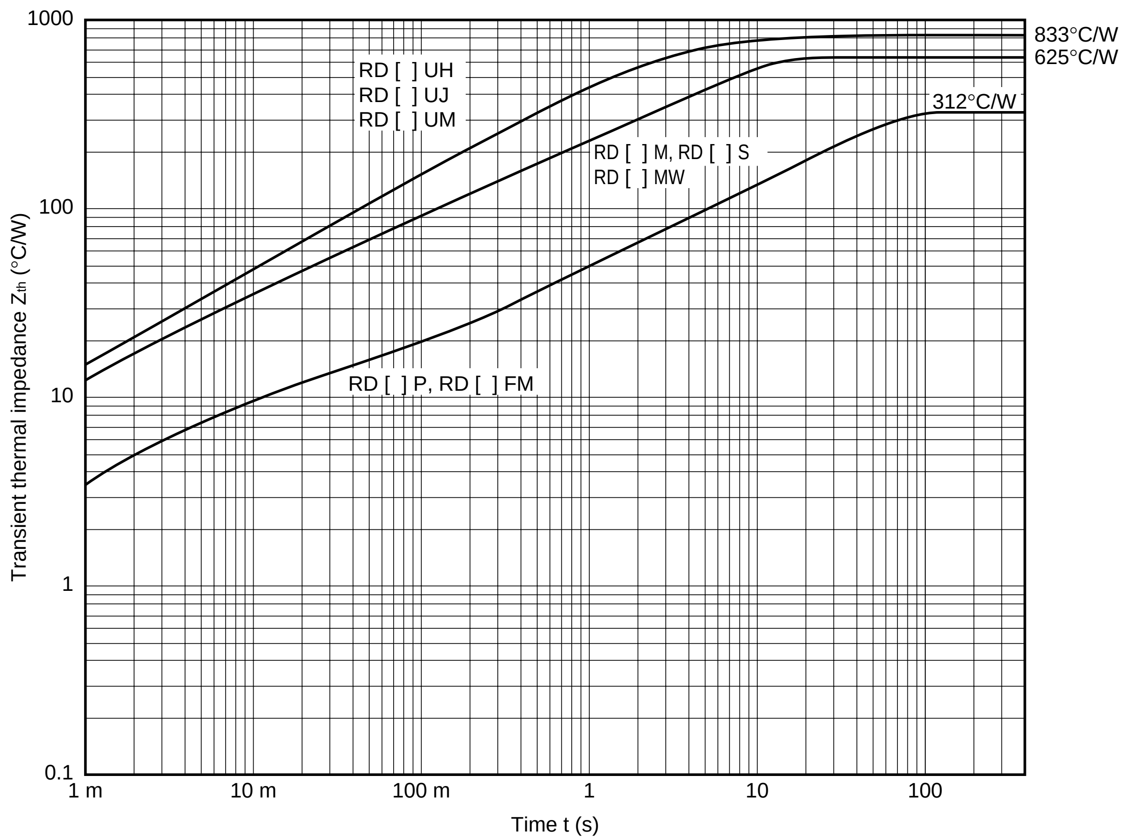


Figure 21. Transient Thermal Impedance Characteristics[Note]



Note Measurement value for forward characteristic

Figure 22. Transient Thermal Impedance Characteristics

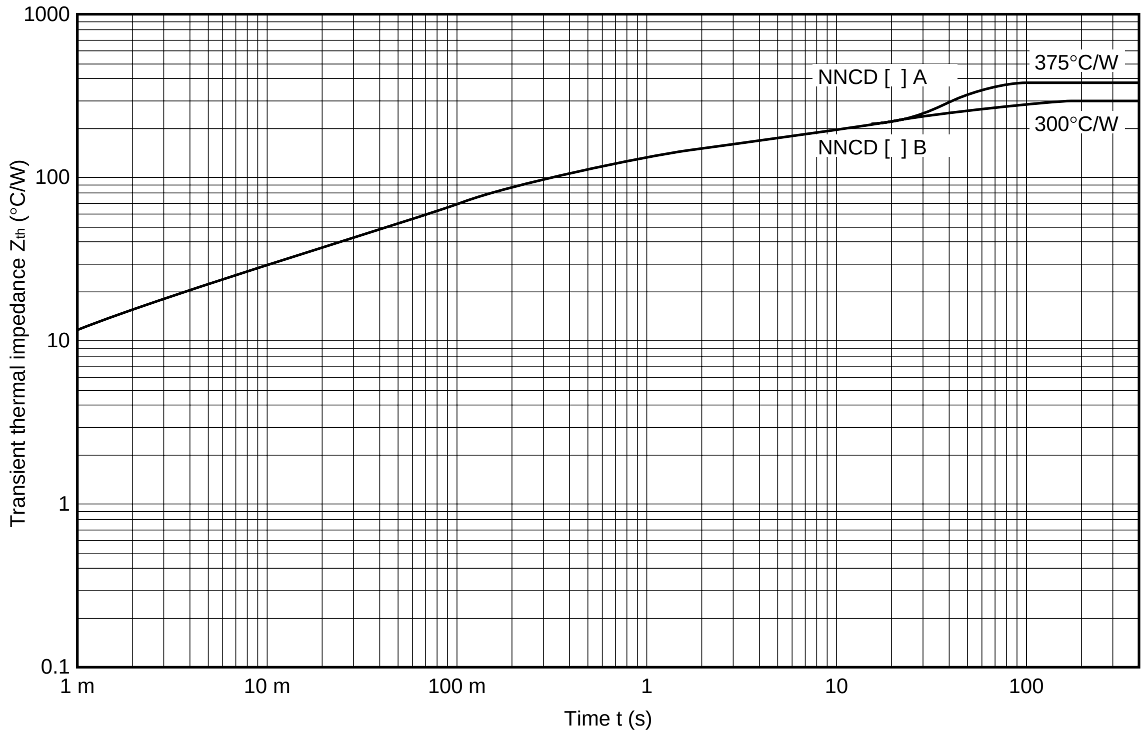
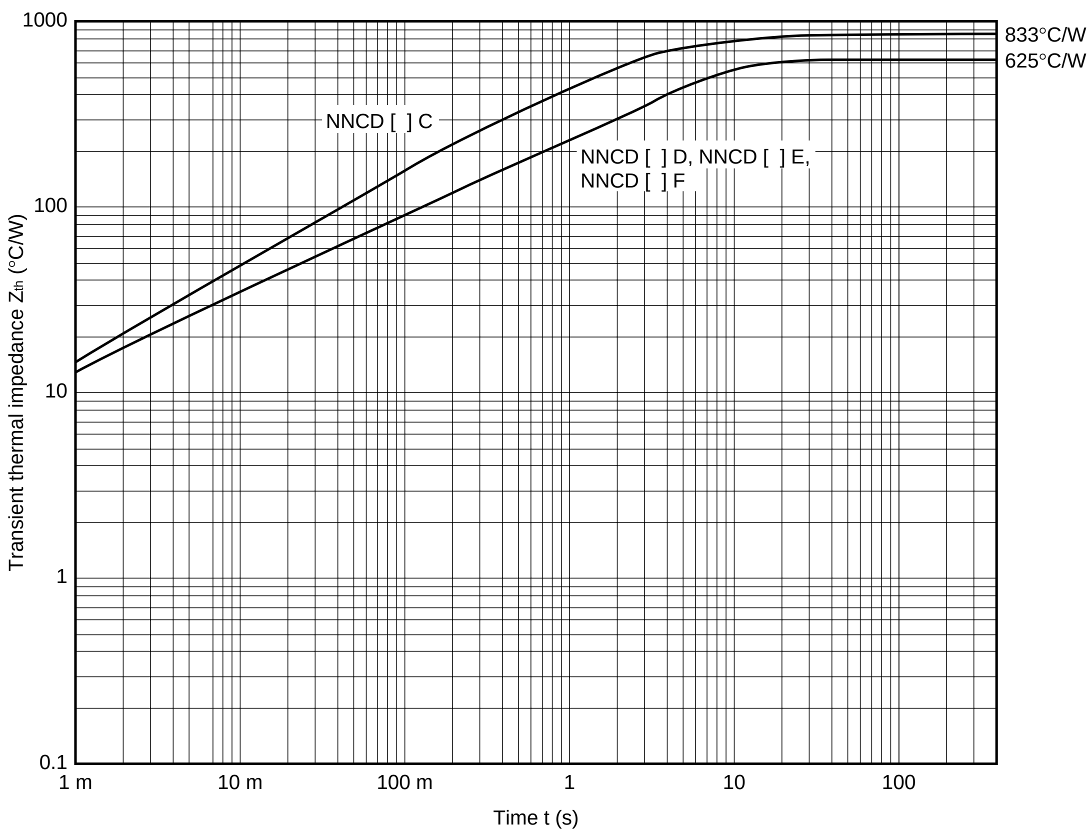
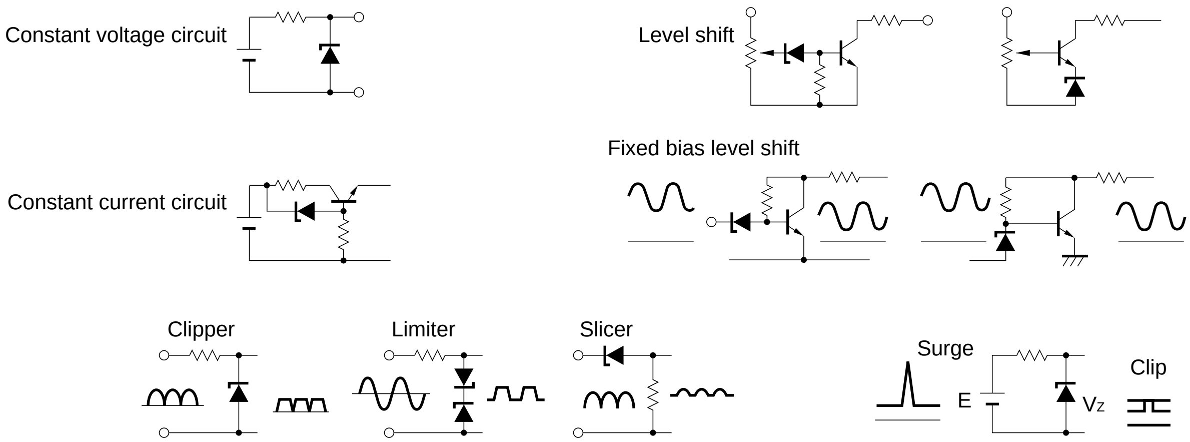


Figure 23. Transient Thermal Impedance Characteristics Note



Note Measurement value for forward characteristic

Figure 24. Basic Circuit Examples



8. CONCLUSION

When using Zener diodes, observe the points described in this manual, make efficient use of the data listed in data sheet, and consider the use of NEC's RD Series of Zener diodes.

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