Surface Mount Small Signal Diode Precautions for use

Outline:

This document provides an overview of the surface-mount small-signal diodes, the diode ratings, letter symbols, graphical symbols, and electrical characteristics, the power dissipation, transient thermal resistance, and application circuit examples.

Small signal diodes mainly refer to diodes in small packages with a power dissipation of 1W or less. A wide variety of products are available, including PN-junction diode, Schottky barrier diodes.

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Description

1. Diode rating

1.1. Definition of maximum rating

For semiconductor devices, applied voltage, current, temperature, power loss, and other factors are major factors limiting the operation function.

The maximum rating is the maximum allowable value that must not be exceeded in order to operate the semiconductor element effectively and ensure sufficient reliability, and is specified as the absolute maximum rating.

The absolute maximum rating (hereinafter referred to as the maximum rating) is defined as "the limit value that must not be exceeded either instantaneously or simultaneously, and that must not be reached for any two items at the same time." Operation exceeding the maximum rating may cause breakage, damage or deterioration, and may cause explosion or burn-in hazards.

1.2. Maximum rating of the diode

Table 1.1 Voltage ratings

Item	Symbol	Content of the maximum rating
Peak Reverse Voltage	V_{RM}	Peak value of the alternating current voltage that can be applied in the opposite direction within the range where the mean voltage does not exceed V_R given in the following paragraph
DC Reverse Voltage	V_R	Maximum value of the DC voltage that can be applied in the reverse direction

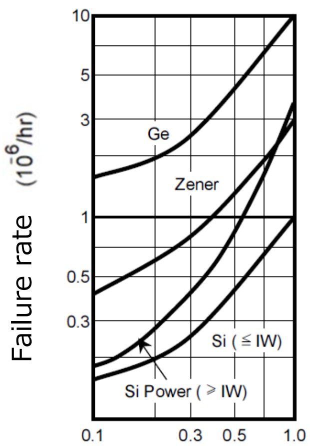
Table 1.2 Current ratings

Item	Symbol	Content of the maximum rating
Peak Forward Current	I_{FM}	The peak of an alternating forward current that can flow within I_O of the following term
Average Rectification Current	I_O	Maximum value of the average rectified current or direct current that can flow in the forward direction
Surge Current	I_{FSM}	Maximum surge current that can flow only once with a specified pulse width

Table 1.3 Power Dissipation Ratings

Item	Symbol	Content of the maximum rating
Power Dissipation	P	Continuously acceptable power loss under certain ambient and cooling conditions, determined by junction temperature (Tj), ambient temperature (Ta), and thermal resistance from the junction of the device to the atmosphere (Rth (j-a)). $P = \frac{T_j - Ta}{Rth_{(j-a)}}$
Peak Reverse Power Dissipation	P_{RM}, P_{ZM}	Maximum allowable power loss when intermittent power is applied to a constant voltage diode
Reverse Surge Power Dissipation	P_{RSM}, P_{ZSM}	Maximum surge power that can be applied only once to a constant voltage diode with a specified pulse width

Table 1.4 Temperature ratings

Item	Symbol	Content of the maximum rating
Junction Temperature	T_j	The maximum junction temperature T_{jmax} must not only operate as defined by the material and reliability of the element, but also be considered to be reliable in terms of degradation, life, etc. Generally, the degradation of the element is accelerated as the junction temperature rises, and the following relation is recognized between the average life Lm (hours) and junction temperature T_j (K) with A and B as element-specific constants. $\log \mathrm{Lm} = \mathrm{A} + \frac{\mathrm{B}}{\mathrm{T_j}}$ Therefore, the maximum junction temperature of the element that requires long life guarantee is determined. In addition, the temperature dependence of the reverse current (off-current) is expressed by the following equation. $\mathrm{I_R} \propto \mathrm{A} \cdot \exp\left(-\frac{\mathrm{qV}}{\mathrm{KT_j}}\right)$ A: Constant with element, q: Electron charge, K: Boltzmann constant, T_j: Junction temperature (absolute temperature), V: Applied voltage As can be seen in the above equation, the reverse current at high temperatures is large, and the power loss of the reverse current at high temperatures is also large. This power loss can cause thermal runaway due to repetition of increasing junction temperature and increasing reverse current. In order to suppress this thermal runaway, the junction temperature and heat dissipation conditions, etc., must be sufficiently considered.
Storage Temperature Range	T_{stg}	The storage temperature T_{stg} is defined by the nature and reliability of the materials that make up the components other than the silicon chip, and is defined by the ambient temperature at which the components can be stored without operating the device. When storing, be careful about oxidation of the terminals and take the conservation method into consideration. Figure 1 shows an example of the relationship between diode life and storage temperature.  $T_n = \frac{T_{stg} - Ta}{T_j max - Ta}$ **(Ta: normally 25℃)** **Figure 1.1 Diode Failure Rate (MIL-HDBK-217A)**

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2. Character symbol

2.1. General rectification, detection and switching diodes

Table 2.1 Symbols for Diode Characteristics

Symbol	Item	Definition or description
V_F	Forward Voltage	DC value of the voltage drop caused by the forward current flowing through the element (I_F specification)
V_R	Reverse Voltage	Voltage applied in the reverse direction of the element
$V_{(BR)R}$	Breakdown Voltage	Voltage (I_R specification) at the specified reverse current value in the breakdown region
I_F	Forward Current	DC current value (V_F specification) flowing in the forward direction of the element under specified voltage conditions
I_R	Reverse Current	DC current value (V_R specification) flowing in the reverse direction of the element according to the specified voltage condition
C_T	Terminal Capacitance	Capacitance value between pins under specified voltage conditions (V_R specification)
t_{rr}	Reverse Recovery Time	When the PN junction is conducted in the forward direction, even if a reverse voltage is applied to the PN junction to cut it off, the reverse current flows in the reverse direction with low impedance while the minority carriers accumulated in the junction remain. Time required to recover to 10% of reverse current I_R from this shut-off (I_F, I_R operation circuit specified)
η	Rectifying Efficiency	AC voltage Vi (rms) is applied to the element, and is expressed by the following equation according to the DC voltage V_O value after rectification $\eta = \frac{V_{O}(DC)}{\sqrt{2} \times V_{i(rms)}}$ (Vi, operation circuit specification)

2.2. Schottky barrier diode

Table 2.2 Characteristic Symbols for Shot Chibaria Diodes

Symbol	Item	Definition or description
NF	Noise Figure	It mainly represents the noise level of the Schottky barrier diode in the high frequency band.
BO	Reverse Burning	Energy tolerance when energy is applied in the opposite direction of the Schottky junction
ΔV_F	Forward Voltage Difference	When used for DBM, V_F is ranked and this V_F variation width
ΔC_T	Terminal Capacitance Difference	C_T difference within the same ΔV_F rank

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2.3. Other

Table 2.3 Other Symbols

Symbol	Item	Definition or description
Ta	Ambient Temperature	The temperature of air measured in a sufficiently uniform environment that is cooled by natural convection of air alone and is not substantially affected by reflection and radiation
R_{th}	Thermal Resistance	A value representing how many times the junction temperature rises per unit power over an external specified point when the heat flow due to junction power consumption is in equilibrium
$R_{th(j-a)}$	Thermal Resistance (between junction and ambient atmosphere)	Thermal Resistance Generally Without Heat Dissipator
$R_{th(j-c)}$	Thermal Resistance (between junction and case)	Thermal resistance from junction to package surface
r_{th}	Transient Thermal Resistance	A value representing how many times the junction temperature rises per unit power over an external specified point when the case temperature or ambient temperature is constant and the junction power loss is pulsed

3. Graphical symbol

The letters and numbers in the graphic symbols are for illustrative purposes only and are not part of the symbols. These characters are shown below.

A: Anode

C: Cathode

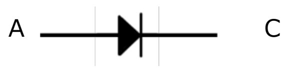
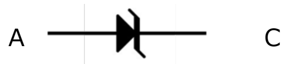
Type	Graphical symbol
Diode	
Zener diode	

Figure 3.1 Schematic Symbols

4. Electrical Characteristics

4.1. General-Purpose Rectifiers, Detectors and switching Diodes

(1)PN junction

Consider the contact between a P-type semiconductor and an N-type semiconductor. In this case, we assume that the P-shaped region and the N-shaped region exist adjacent to each other in a single crystal. Such a structure is called a PN junction, and the band structure is shown in Figure 4.1.

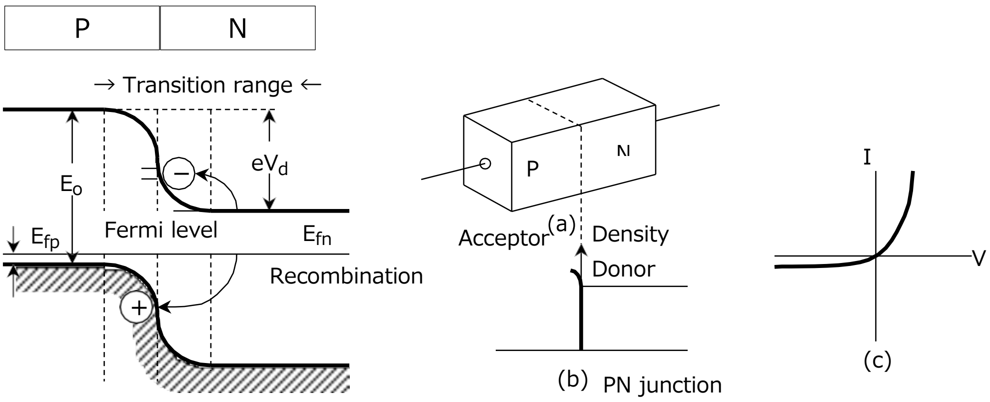


Figure 4.1 Energy Level Diagram of PN Junctions

The P-type and the N-type part originally differ in the height of the Fermi level. The Fermi levels are located near the upper edge of the filling band in the P-type region and near the lower edge of the conduction band in the N-type region. If they are in contact with each other, electrons in the N-type region near the contact move to the P-shaped region, where they recombine with free holes. This electron transfer lowers the level of the conduction band in the N-type region and reaches a new equilibrium state where the Fermi level matches both the N-type and P-type regions. At this time, the reduction of the conduction band level is equal to the work-function difference in both regions, and a diffusive potential called V_d appears between the two regions.

In the vicinity of the boundary layer, free electrons in the N- type region recombine with free holes in the P- type region, and free carriers are depleted, and later distributed donor ions (positive) and acceptor ions (negative) exist, and this distributed space charge exists, even at the diffusion potential. This distributed space-charge layer generates an electric field from the N-type to the P-type, which acts to move electrons to the N-type and holes to the P-type, respectively.

When electrodes are attached to each region of such a structure, current flows well when a voltage is applied in a direction where the P type is positive and the N type is negative. When a voltage is applied in the opposite direction, the current hardly flows and strong rectification appears.

(2)Characteristics of the diode

Figure 4.2 shows the static characteristics of the diode. Rectifier detection and switching diodes utilize forward characteristics, where the forward current I_F is expressed by the following equation.

$$I_F = I_S(\exp\frac{qV_F}{KT} - 1) \quad \text{..........................} \ (1)$$

I_S : Reverse saturation current
T : Absolute temperature
V_F : Forward voltage
K : Boltzmann constant
q : Total charge of electrons

The above equation is for the small current region. In the large current region, a voltage drop occurs due to the internal resistance, and the value of V_F is changed, so it cannot be applied.

The forward characteristics of the diode depend on the semiconductor material and structure used. A typical example is the difference between Ge and Si materials.

Ge diodes have rising voltages of 0.1 to 0.2 V and Si diodes of 0.6 to 0.7 V, which are essential to the difference in energy gap between the two type.

The forward characteristics vary with temperature. In the small current region, both Si and Ge vary with dV/dT =-2.3 mV/°C.

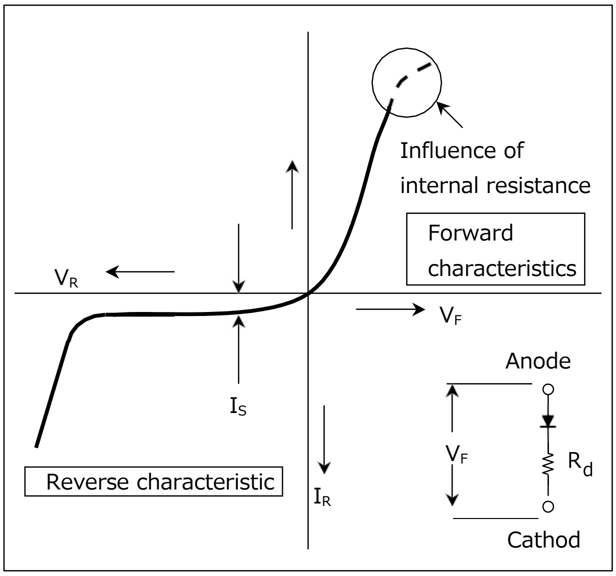


Figure 4.2 Static Characteristics of Diodes

However, in the large current range, the temperature coefficient of the voltage drop due to the internal resistance becomes positive, so the temperature coefficient of dV/dT becomes small.

Figure 4.3 shows the I_F-V_F temperature characteristics of a Si diode.

When a voltage is applied in the reverse direction of the diode, the current flowing is called the reverse current I_R or saturation current I_S.

Generally, Ge-Diodes are several μA (10^{-6} A) and SiDiodes are several nA (10^{-9} A). Figure 4.4 shows the I_R-V_R temperature characteristics of a Si diode. The IR changes approximately twice as much as the temperature change of 8 to 10°C. Therefore, the inverse current I_R is approximated.

$$I_R = I_{RO}(\exp \quad k(T - To)) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

I_{RO} : Reverse current at standard temperature To

k : Constant determined by the semiconductor material

It can be expressed as about 0.1/℃ for Si and about 0.08/℃ for Ge.

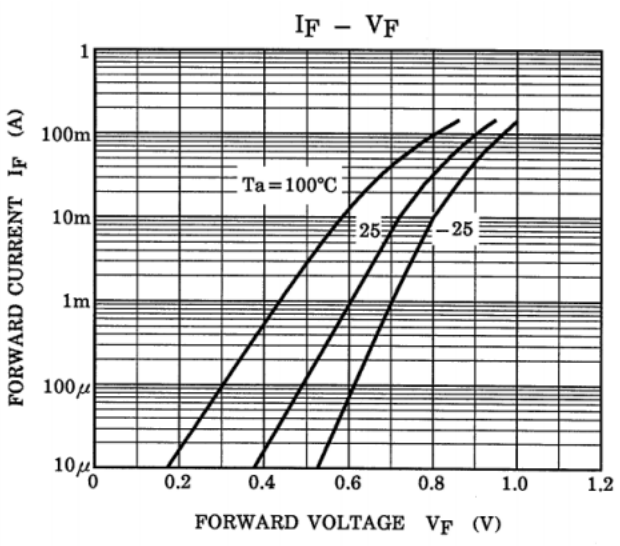


Figure 4.3 I_F-V_F Temperature Characteristics

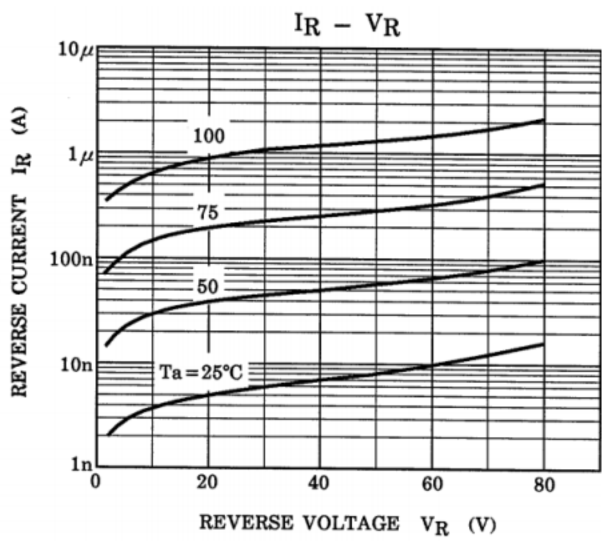


Figure 4.4 I_R-V_R Temperature Characteristics

Figure 4.5 shows the operating principle of the diode detection circuit.

The characteristics required for these detection and switching diodes are as follows.

For detection diodes, a higher detection efficiency η is required first.

This requires a small V_F, a small I_R, and a small junction capacitance C_j.

In the case of switching diodes, a fast switching time is required.

For this purpose, the reverse recovery time t_{rr} must be small and C_j must be small.

Naturally, it is also important that the I_R is small.

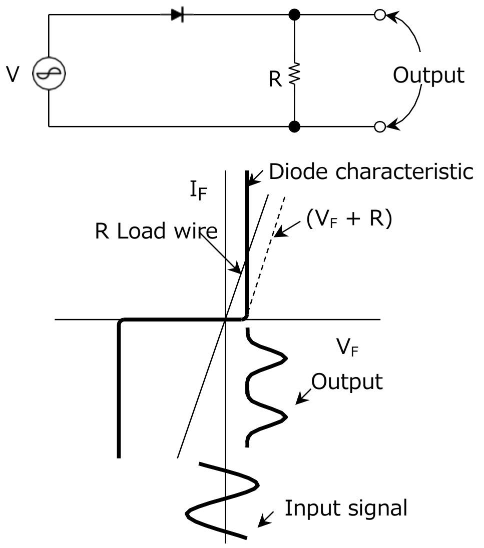
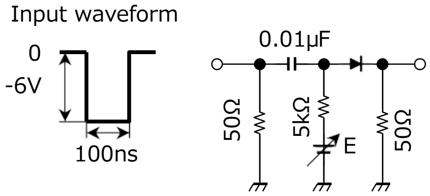


Figure 4.5 Diode Detection Operation

When forward current I_F is applied to the diode, even if the reverse voltage V_R is applied to the diode to cut it off, the reverse direction also becomes low-impedance while the minority carriers accumulated in the P junction remain, and a large reverse current I_R flows. The time from the cutoff to the recovery of 10% of the reverse current I_R is called the reverse recovery time t_{rr}, which



represents the switching time of the diodes. The measurement circuit is shown in Figure 4.6.

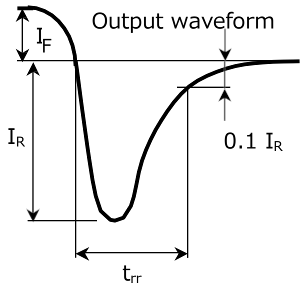


Figure 4.6 Reverse Recovery Time trr Measuring Circuit

t_{rr} is expressed by the following equation.

$$t_{rr} = \tau \ln\left(1 + \frac{I_F}{I_R}\right) \quad \text{..} \ (3)$$

τ: Minority carrier lifetime

Therefore, the shorter the minority carrier lifetime, the smaller the I_F, and the larger the I_R, the shorter the t_{rr}.

4.2. Schottky barrier diode

Because this diode utilizes the rectifying property of metal-semiconductor contacts, which was proposed by Schottky, This is called a Schottky barrier diode.

It is characterized by creating a shotky barrier between the deposited metal and the N-shaped epitaxial layer.

Typical metals that create a Schottky barrier are molybdenum (Mo), titanium (Ti), and so on. The Schottky barrier diode has a small rising voltage, similar to a Ge diode, and has no complicated factors such as needle pressure, such as a point contact diode, making it easy to handle in manufacturing.

This diode is mainly used for mixed circuits and detection circuits above the UHF band, and has the reliability advantage of a noise figure of 2 dB or more lower than that of the point contact type, and also strong mechanically and electrically. Figure 4.7 shows the structure of the Schottky barrier diode.

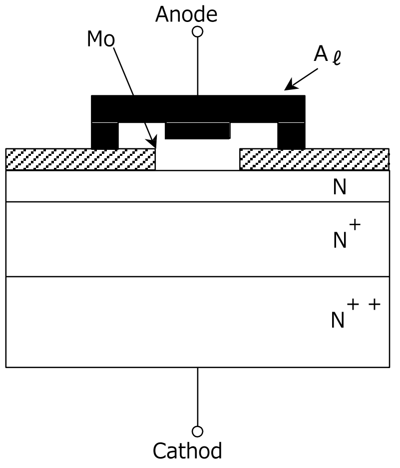


Figure 4.7 Structural Diagram of Shotky Barrier Diode

Reliability Test Example (Switching Diode)

The following shows a test example of the Super Mini Type (S-Mini) switching diode.

Table 4.1 Switching Diode Reliability Test Example

1. Thermal tests

Test Item	Test Condition	Failure Size / Sample Size
Heat resistance (Reflow)	Peak : 260 deg.C(a moment) Reflow zone : 230 deg.C 30 to 50 s Preheat : 180 to 190 deg.C , 60 to 120 s 4 times	0 / 32
Heat resistance (Flow)	Peak : 260 deg.C Immersion time : 10 s Once	0 / 32
Heat resistance (Iron)	Temperature of the iron tip : 400 deg.C Time : 3 s Once	0 / 32
Temperature cycling	- 55 deg.C(30 min) to 125 deg.C(30 min) ,100 cycles	0 / 50

2. Mechanical tests

Test Item	Test Condition	Failure Size / Sample Size
Solderability	Solder bath : Sn-Ag-Cu 245 deg.C , 5 s ,once (using Flux) Solder bath : Sn-Pb 230 deg.C , 5 s ,once (using Flux)	0 / 11

3. Life tests

Test Item	Test Condition	Failure Size / Sample Size
Steady state operation	Ta = 25 deg.C, IO = 100mA , 1000 h	0 / 30
High temp. reverse bias	Ta = 125 deg.C, VR = 80V , 1000 h	0 / 30
High temp. storage	Ta = 125 deg.C , 1000 h	0 / 30
High temp. high humidity storage	Ta = 85 deg.C, RH = 85% , 1000 h	0 / 30
High temp. high humidity bias	Ta = 85 deg.C, RH = 85%, VR = 80V , 1000 h	0 / 30
Pressure cooker test	Ta = 121 deg.C(203kPa)(Unsaturated) , 96 h	0 / 20

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5. Power Dissipation

Note that the power dissipation varies greatly depending on the mounting method of the element and the ambient temperature. The following shows examples of power dissipation changes by package.

5.1. ESC

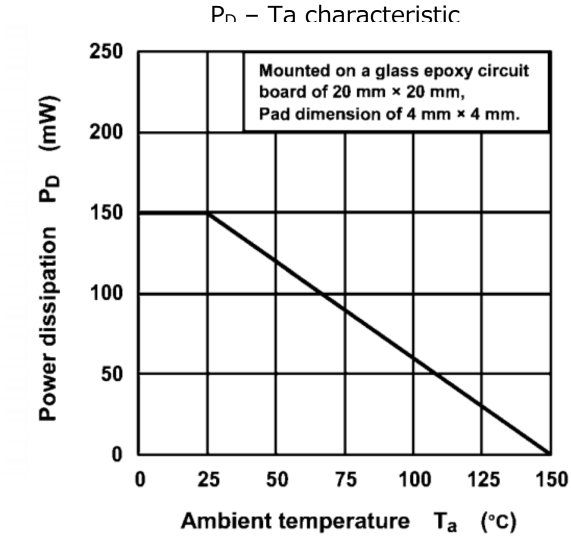

Figure 5.1 ESC Power Dissipation P_D – Ta characteristic example

5.2. SSM

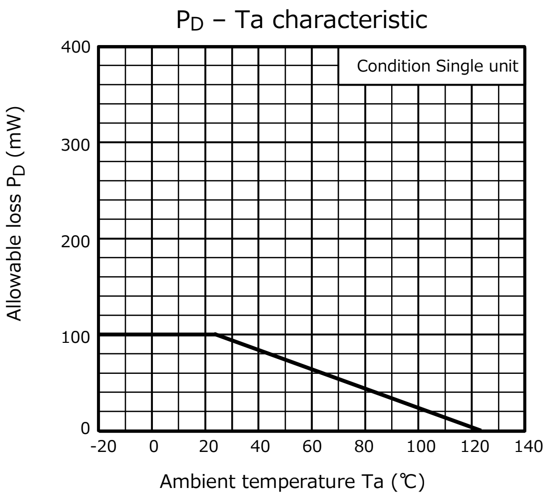

Figure 5.2 SSM Power Dissipation P_D – Ta characteristic example

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5.3. USC

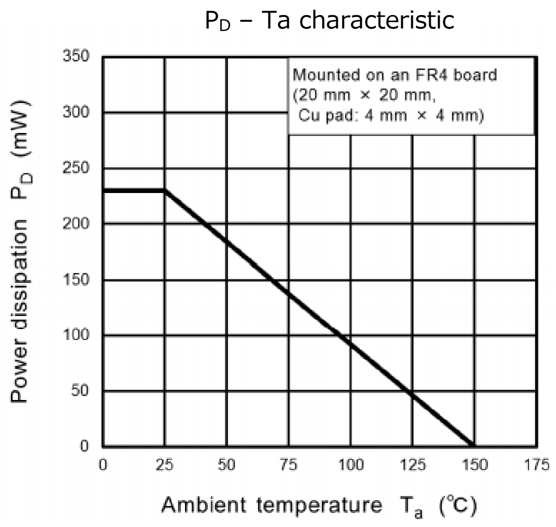


Figure 5.3 USC Power Dissipation P_D – Ta characteristic example

5.4. USM

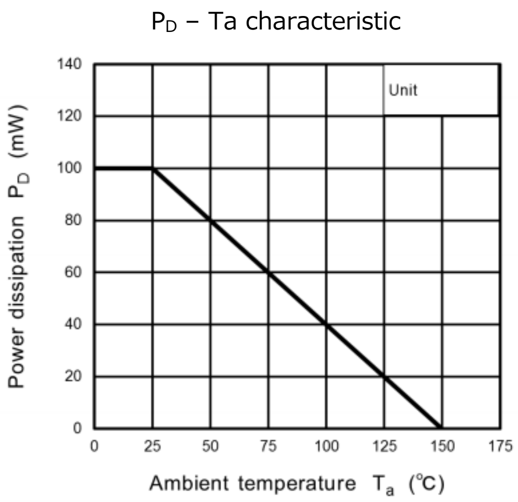


Figure 5.4 USM Power Dissipation P_D – Ta characteristic example

5.5. S-Mini

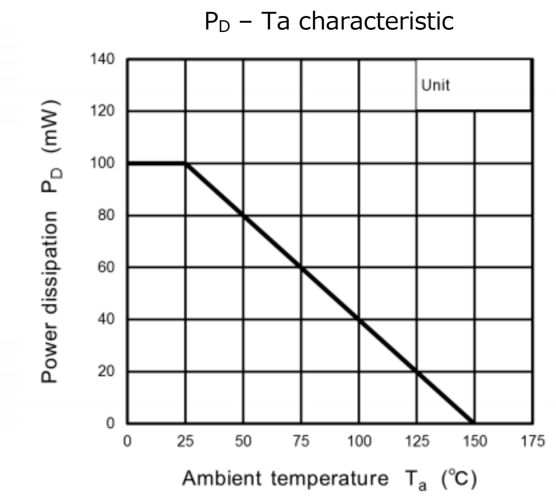
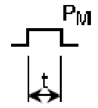
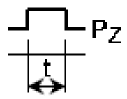
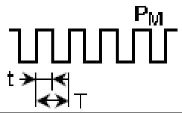


Figure 5.5 S-Mini Power Dissipation P_D – Ta characteristic example-

6. Transient Thermal Resistance (r_{th})

The power dissipation when pulsed rather than continuous power is applied to the diode is determined by the transient thermal resistance r_{th} and the following table. Fig. 6.1 shows the transient thermal resistance r_{th}-t.

Table 6.1 Allowable Power Calculation Formula for Pulsed Power Applications

Type of load	Power waveform	Permissible power (crest value)
Single pulse loading		$P_M = \frac{T_j - Ta}{r_{th}}$
Load where a single pulse load is superimposed on a continuous DC load		$P_M = \frac{T_j - Ta - P_Z \cdot R_{th}}{r_{th}} + P_Z$
Continuous repetitive pulse loading		$P_M = \frac{T_j - Ta}{\frac{t}{T}R_{th} + \left(1-\frac{t}{T}\right) r_{(t+T)h} - r_{Th} + r_{th}}$

Note: R_{th} : Thermal resistance when steady
r_{th} : Transient thermal resistance at t
r_{Th} : Transient thermal resistance at T
$r_{(t+T)h}$: Transient thermal resistance at t + T

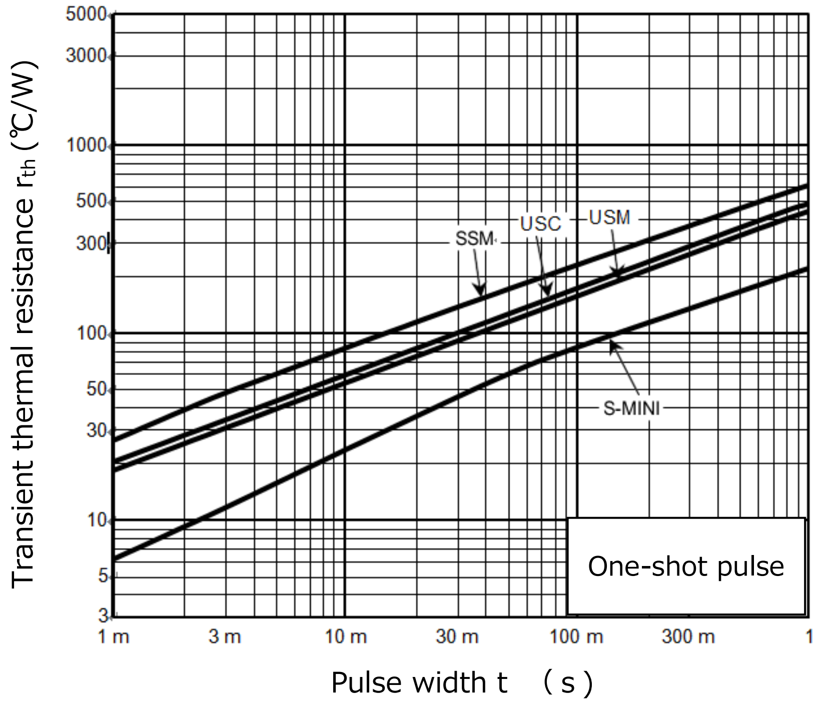


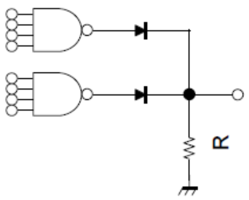
Figure 6.1 r_{th} by Diode Package-t

Typical Circuit Diagram

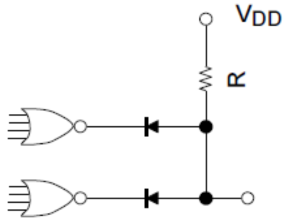
7. Typical Circuit Diagram

7.1. Switching diode

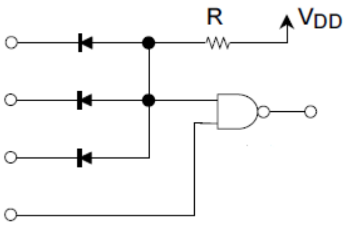
(a)8 Inputs NAND gate



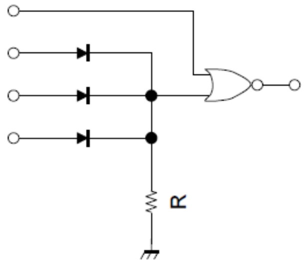
(b) 6 Inputs NOR gate



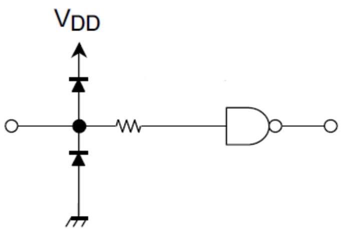
(c) 4 Inputs NAND gate



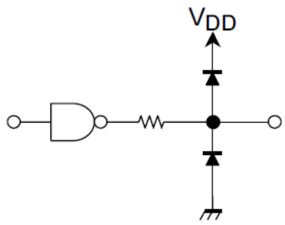
(d) 4 Inputs NOR gate



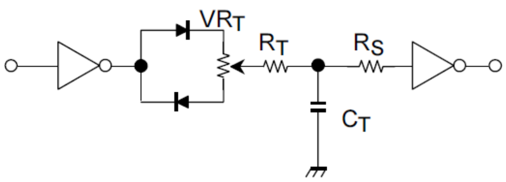
(e) Input protection circuit



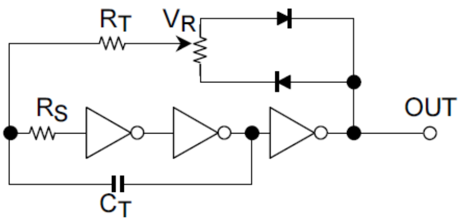
(f) Output protection circuit



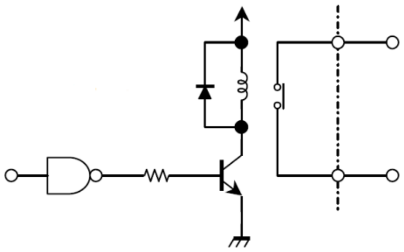
(g) Delay time control circuit



(h) Square wave generator

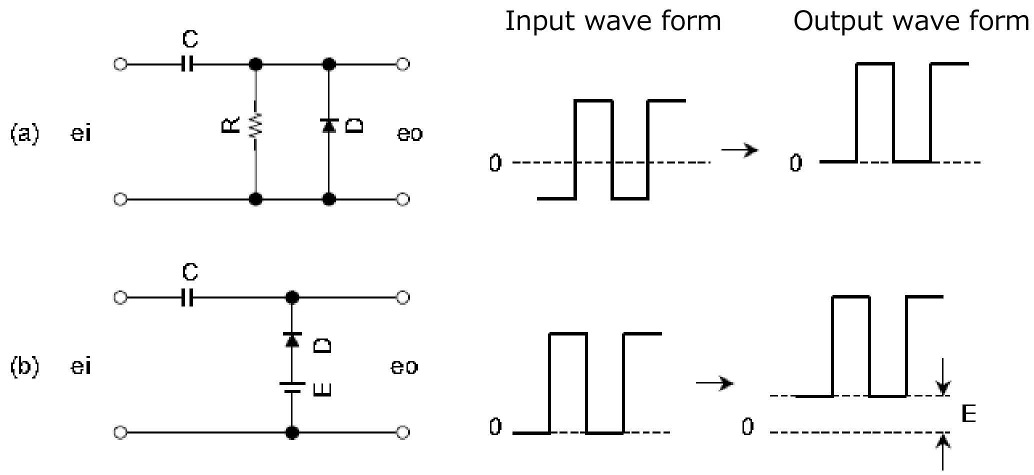


(i) MOS IC output protection circuit

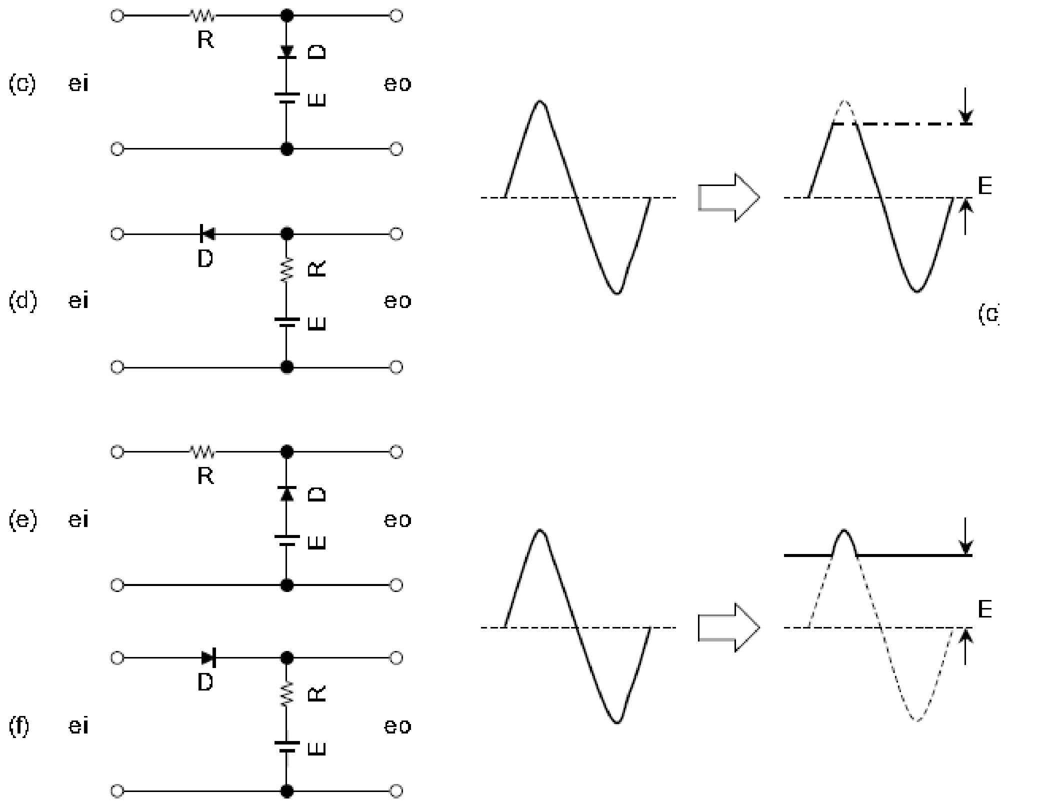


7.2. Switching circuit diagram

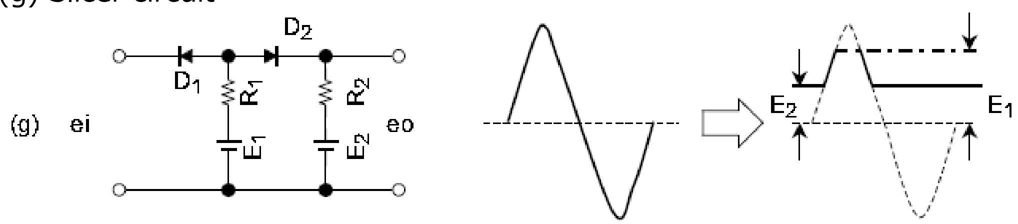
(a) (b) Level shift circuit



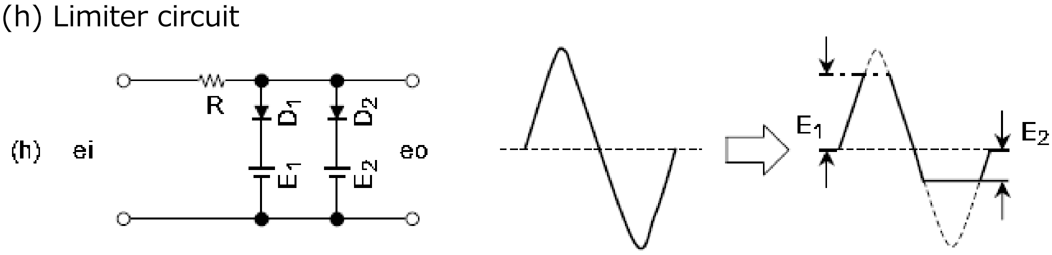
(c) (d) (e) (f) Clipping circuit



(g) Slicer circuit



(h) Limiter circuit



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- ■TVS diode (parametric search) Click
- ■Schottky barrier diode (parametric search) Click
- ■Switching diode (parametric search) Click
- ■Zener diode (parametric search) Click
- ■High Frequency Diode (Details) Click
- ■Online distributor purchase, inventory search Buy Online
- ■FAQ of small-signal diodes Click
- ■FAQ of the TVS diode Click
- ■Application notes Click
- ■Reference Design Center Click

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