Diode

Absolute Maximum Rating and Electrical Characteristics of Diodes

Data sheets for diodes provide specifications corresponding to the diode types. This application note explains the parameters listed for the absolute maximum rating and the electrical characteristics of the diodes.

Definition of absolute maximum rating

Absolute maximum rating is defined as “a synonym of maximum rating” in the JEDEC standard (JESD77D section 2.1, JESD88F) created by the JEDEC Solid State Technology Association. Subsequently, the “maximum rating” is defined as follows.

- Maximum rating (JESD77D section 2.1, JESD88F, JESD99C section 2.2.1):

  A rating that establishes either a limiting capability or a limiting condition beyond which damage to the device may occur. (Ref. IEC 747-1.)

  NOTE 1: A limiting condition may be either a maximum or a minimum.

  NOTE 2: IEC 747-1 refers to such a limiting condition as a “rating (limiting value)”.

- Maximum rating (JESD 282B.02 section 4.4):

  Maximum thermal and electrical ratings assigned to the device are to be given in this clause. Maximum ratings are those which, if exceeded, may cause permanent damage, or introduce latent failure mechanisms within the device.

Furthermore, it is referred to as a “rating (limiting value)” and defined as follows by the International Electrotechnical Commission (IEC).

- Rating (limiting value) (IEC60747-1 section 5.2.1):

  Semiconductor ratings are the limiting conditions of use that all conforming devices will withstand but beyond which damage to the device may occur.

  NOTE 1: Limiting conditions may be either maxima or minima and are known as maximum ratings and minimum ratings, respectively.

The absolute maximum rating is the value that must not be exceeded under any circumstance. Devices are not designed to operate with the value described for the absolute maximum rating. The concepts of tolerance and actual value are not applicable, either. In addition, devices may be damaged if this value is exceeded. However, it does not mean that the devices will necessarily be damaged if they are operated at this value.

Description of parameters

Since the parameters described depend on the diode types, they are classified into the following three groups for explanation in this application note.

Group 1: Schottky barrier diode, Fast recovery diode, Switching diode, Rectifier diode
Group 2: Zener diode, TVS (Transient Voltage Suppressor) diode
Group 3: PIN diode, Band switching diode, Detection schottky diode

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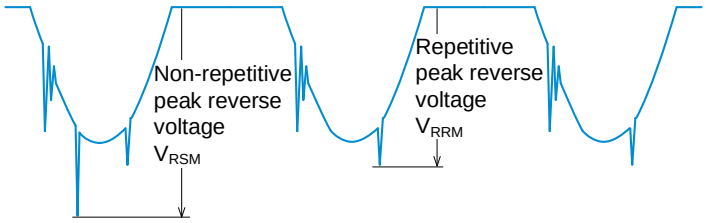
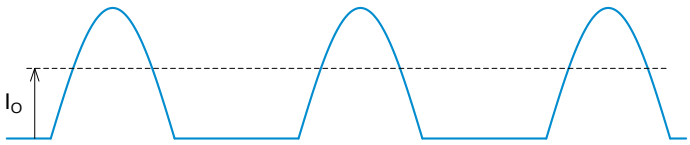
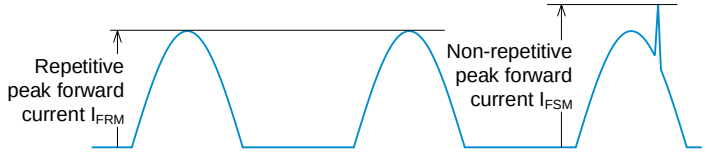
Group 1: Schottky barrier diode (SBD)
Fast recovery diode (FRD)
Switching diode (SW)
Rectifier diode (REC)

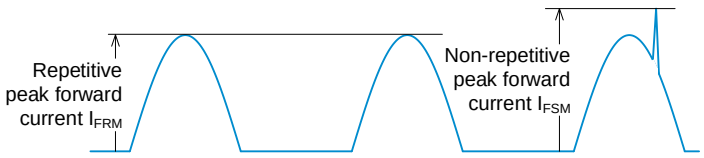
Absolute maximum rating

Parameter	Symbol	Type				Description
		SBD	FRD	SW	REC	
Repetitive peak reverse voltage	V_{RM}	✓	✓	✓	✓	The maximum reverse voltage value that can be applied repeatedly. Synonymous with “repetitive peak reverse voltage V_{RRM}” used by the JEDEC and the IEC. Indicates the maximum instantaneous value of reverse voltage among all repetitive transient voltages excluding all non-repetitive transient voltages. 
Reverse voltage	V_R	✓	✓	✓	✓	The maximum reverse voltage value that can be applied continuously. Synonymous with “reverse voltage V_R” used by the JEDEC and the IEC. Indicates the maximum value of DC voltage excluding the AC component applied to the diode in the reverse direction.
Average rectified forward current	I_O	✓	✓	✓	✓	The maximum average current that can be rectified at commercial frequencies under the specified conditions. Indicates the maximum value of average output current over the entire cycle from a rectifier with a sine wave input at 50 Hz or 60 Hz and a conduction angle at 180°. 
Forward current	I_{FM}	–	–	✓	–	The maximum forward current value that can be applied repeatedly. Synonymous with “repetitive peak forward current I_{FRM}” used by the JEDEC and the IEC. Indicates the maximum value of forward current among all repetitive transient currents excluding all non-repetitive transient currents. 

NOTE: The parameters may not be indicated depending on the product model names.

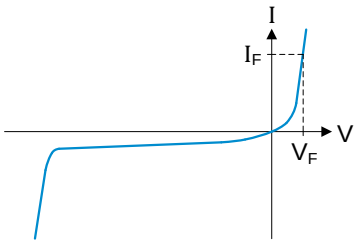
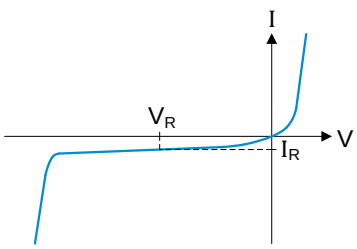
Group 1 (continued)

Absolute maximum rating (continued)

Parameter	Symbol	Type				Description
		SBD	FRD	SW	REC	
Peak forward surge current	I_{FSM}	✓	✓	✓	✓	The maximum value of non-repetitive forward current under the specified conditions. Indicates the maximum value of forward current among all non-repetitive transient currents excluding all repetitive transient currents. 
Junction temperature	T_J	✓	✓	✓	✓	Indicates the maximum value of the temperature at the semiconductor junction.
Storage temperature	T_{stg}	✓	✓	✓	✓	Indicates the temperature at which the device is stored without the power being supplied.

NOTE: The parameters may not be indicated depending on the product model names.

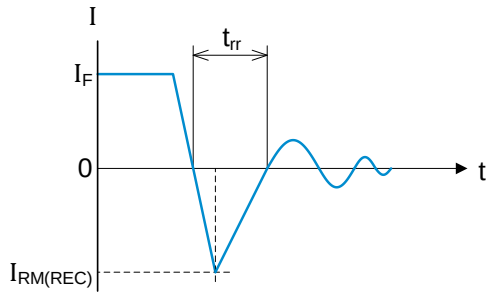
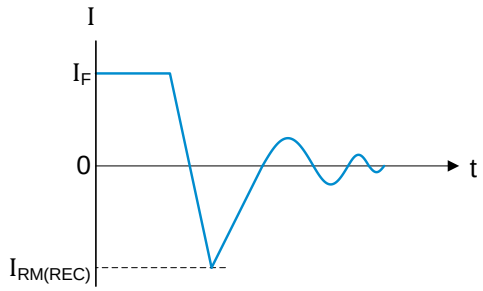
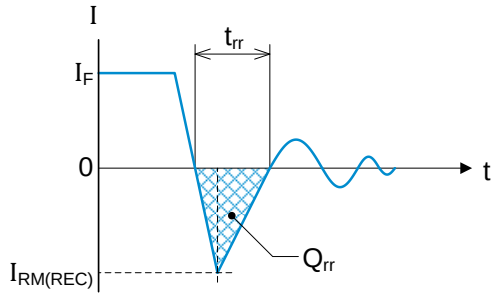
Electrical Characteristics

Parameter	Symbol	Type				Description
		SBD	FRD	SW	REC	
Forward voltage	V_F	✓	✓	✓	✓	The forward voltage when the specified forward current is applied. Indicates the anode-cathode voltage generated by the flow of the specified forward current (I_F). This is a DC value excluding the AC component. 
Reverse current	I_R	✓	✓	✓	✓	The reverse current when the specified reverse voltage is applied. Indicates the current flowing from an external circuit to the cathode terminal at the specified reverse voltage (V_R) that is lower than the breakdown starting voltage. 

NOTE: The parameters may not be indicated depending on the product model names.

Group 1 (continued)

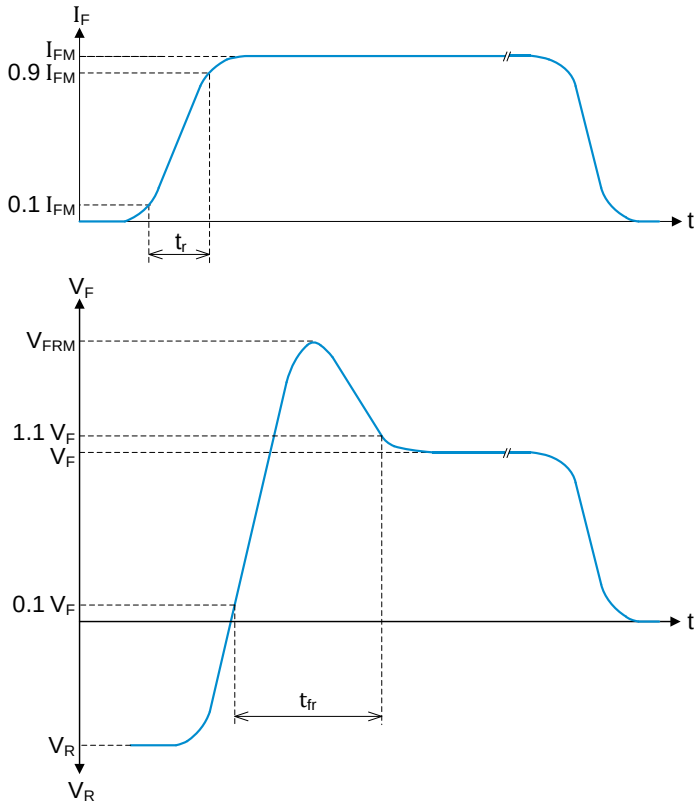
Electrical Characteristics (continued)

Parameter	Symbol	Type				Description
		SBD	FRD	SW	REC	
Reverse recovery time	t_{rr}	–	✓	✓	–	Indicates the time section from the moment the current crosses zero until the current returns to zero after the reverse current reaches the peak value ($I_{RM(REC)}$) when the current changes its direction from forward to reverse. 
Peak reverse recovery current	I_{Rp}	–	✓	–	–	Synonymous with “peak reverse recovery current $I_{RM(REC)}$” used by the JEDEC. Indicates the maximum instantaneous value of reverse current generated when the state switches from the forward current to the reverse voltage. 
Reverse recovery charges	Q_{rr}	–	✓	–	–	Indicates the charges calculated as a time integrated value of the reverse current flowing within reverse recovery time trr. 

NOTE: The parameters may not be indicated depending on the product model names.

Group 1 (continued)

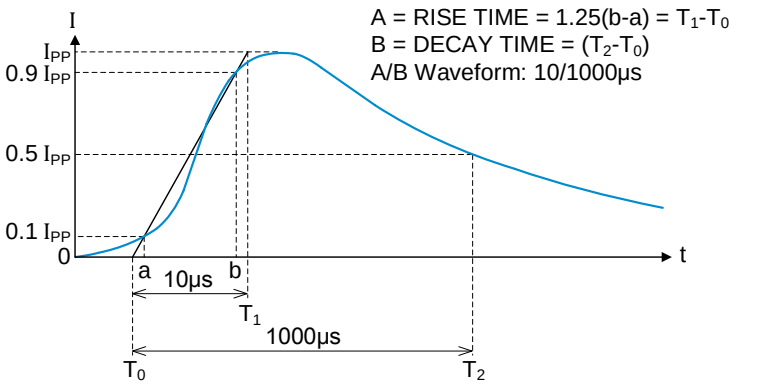
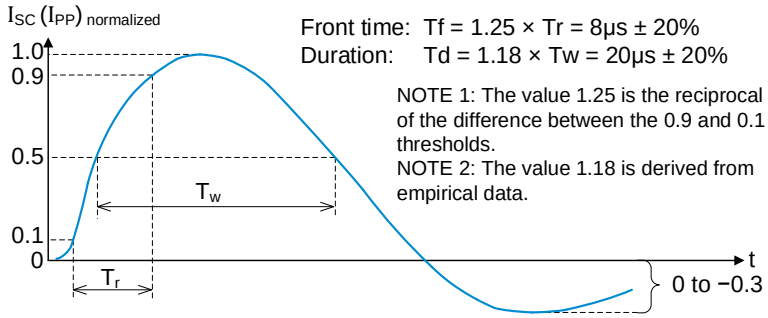
Electrical Characteristics (continued)

Parameter	Symbol	Type				Description
		SBD	FRD	SW	REC	
Forward recovery time	t_{fr}	–	✓	–	–	The time for the transient forward voltage to return to the steady forward voltage. Indicates the time section measured from the moment the forward voltage is increased to 10% of the final stable value with an application of the specified forward step current from zero or the specified reverse voltage state until the moment the forward voltage falls from its peak value to 110% of the final stable value. 
Forward recovery voltage	V_{FR}	–	✓	–	–	Synonymous with “peak forward recovery voltage V_{FRM}” used by the JEDEC and the IEC. Indicates the maximum value under a condition specified with the forward recovery time. See the figure above.
Capacitance between terminals	C_t	–	–	✓	–	Indicates the capacitance across the diode at the specified bias voltage and frequency.

NOTE: The parameters may not be indicated depending on the product model names.

Group 2: Zener diode (ZD)
TVS diode (TVS)

Absolute maximum rating

Parameter	Symbol	Type		Description
		ZD	TVS	
Peak pulse power	P_{PP}	–	✓	Represents the maximum surge power that the device can withstand without being damaged. The test waveform used is the Telcordia GR-1089-CORE 10/1000μs impulse waveform, which is used as the industry standard test condition, or an impulse waveform specified in IEC 61000-4-5. The maximum rating value is a product of the peak impulse current (I_{PP}) and the maximum clamping voltage (V_C).  GR-1089-CORE Double-Exponential Impulse Waveform  IEC 61000-4-5 Waveform of short-circuit current (8/20 μs) at the output of the generator with no CDN connected.
Peak pulse current	I_{PP}	–	✓	Represents the maximum surge current that the device can withstand without being damaged. See the figure above for the test waveform.
Power dissipation	P_D	✓	✓	Synonymous with “maximum steady-state power dissipation P_D” used by the JEDEC. Represents the maximum rating value of continuous DC power loss.
Junction temperature	T_J	✓	✓	See Group 1.
Storage temperature	T_{stg}	✓	✓	See Group 1.

NOTE: The parameters may not be indicated depending on the product model names.

Group 2 (continued)

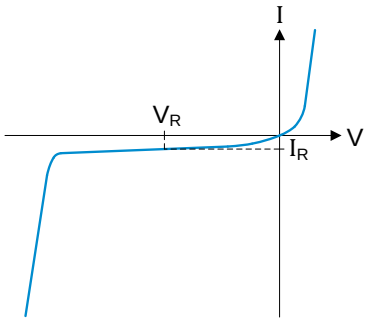
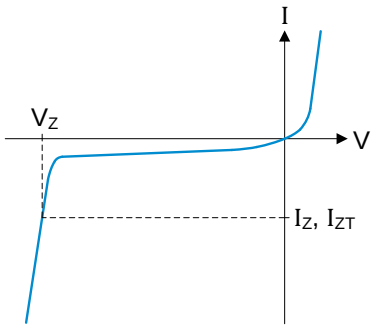
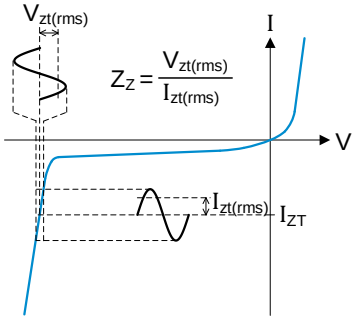
Absolute maximum rating (continued)

Parameter	Symbol	Type		Description
		ZD	TVS	
ESD capability	V_{ESD}	−	✓	The value of the electrostatic discharge rating under the specified conditions. The IEC 61000-4-2 standard describes tests simulating a situation in which an electrically charged human body holds a piece of metal in one hand and discharges to electronic equipment. The following two types are defined. - Air discharge: Represents the electrostatic discharge when a discharge occurs with an air layer existing between the equipment under test and the discharge terminal. - Direct contact discharge: Represents the electrostatic discharge when a discharge occurs with a direct contact between the equipment under test and the discharge terminal. The human body model (HBM) describes tests simulating a situation in which the electrically charged human body contacts a device and a discharge occurs. (MIL-STD 883E method 3015.7, JEDEC JS-001) The machine model (MM) describes tests simulating a situation in which an electrically charged piece of metal contacts a device and a discharge occurs. The JEDEC specifies that MM should not be used as a certification requirement for ESD of integrated circuits (see JEDEC JEP172). The charged device model (CDM) describes tests simulating a situation in which the device itself is electrically charged and static electricity is discharged. (JEDEC JS-002)

NOTE: The parameters may not be indicated depending on the product model names.

Group 2 (continued)

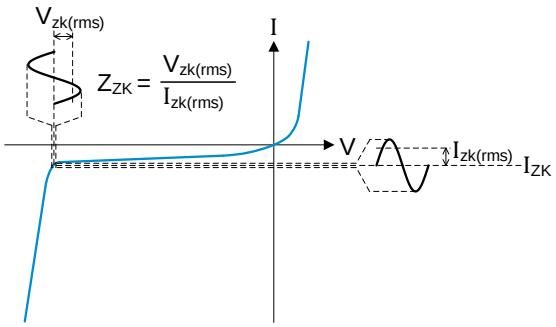
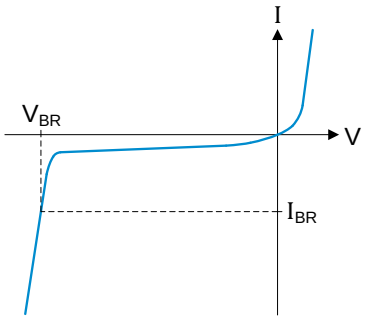
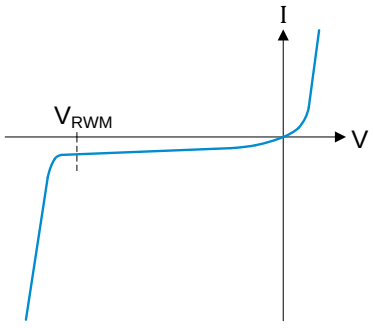
Electrical Characteristics

Parameter	Symbol	Type		Description
		ZD	TVS	
Reverse current	I_R	✓	✓	The current flowing from an external circuit to the cathode terminal at the specified reverse voltage (V_R) that is lower than the breakdown starting voltage. 
Zener voltage	V_Z	✓	–	The voltage across the diode at a current (I_{ZT}) specified with the breakdown region. 
Dynamic impedance	Z_Z	✓	–	Represents the slope of the Zener voltage when a breakdown occurs. Synonymous with “regulator (Zener) impedance z_{zt}” used by the JEDEC. The small signal impedance of the diode that is biased with I_{ZT} so that it can operate in the breakdown region. The impedance is measured by superimposing effective value current I_{zt} (I_{zt} is 10% or less of I_{ZT}). The parameter can be determined from a variation in the Zener voltage against a small change in the reverse current. 

NOTE: The parameters may not be indicated depending on the product model names.

Group 2 (continued)

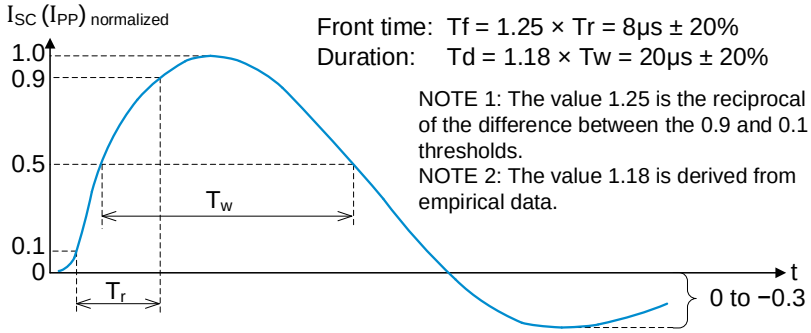
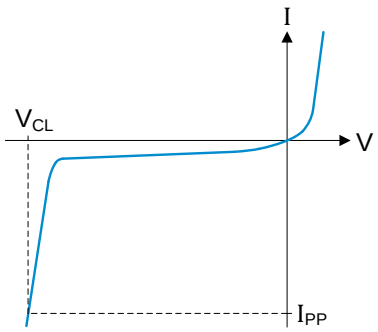
Electrical Characteristics (continued)

Parameter	Symbol	Type		Description
		ZD	TVS	
Zener Impedance	Z_{ZK}	✓	–	Represents the slope of the Zener voltage in the knee characteristic part entering a breakdown. Synonymous with “regulator (Zener) knee impedance z_{zk}” used by the JEDEC. The small signal impedance of the diode that is biased with I_{ZK} so that it can operate on the knee entering the breakdown region. The impedance is measured by superimposing effective value current I_{zk} (I_{zk} is 10% or less of I_{ZK}). The parameter can be determined from a variation in the Zener voltage against a small change in the reverse current. 
Breakdown voltage	V_{BR}	–	✓	The voltage measured with the specified current in the breakdown region. It has the same implication as that of the Zener voltage of Zener diodes, and is measured with a very small current such as a few mA. 
Stand-off voltage	V_{RWM}	–	✓	The maximum voltage immediately before the TVS enters the breakdown state. This parameter is important for protective elements because the TVS will not operate below this voltage when an application circuit is in the normal state. 

NOTE: The parameters may not be indicated depending on the product model names.

Group 2 (continued)

Electrical Characteristics (continued)

Parameter	Symbol	Type		Description
		ZD	TVS	
Clamping voltage	V_{CL}	−	✓	The peak voltage across the TVS when an impulse current (I_{PP}) is applied as specified in IEC61000-4-5. Since breakdown voltage V_{BR} is measured with a very small current such as a few mA, it is different from the avalanche voltage under actual application conditions. Therefore, the maximum breakdown voltage when a large current is applied is indicated as clamping voltage V_{CL}.  IEC 61000-4-5 Waveform of short-circuit current (8/20 μs) at the output of the generator with no CDN connected. 
Capacitance between terminals	C_t	−	✓	The capacitance across the diode at the specified bias voltage and frequency. For usage in communication lines, it is necessary to select a TVS with a capacitance between terminals so that data waveforms will not be blunted.

NOTE: The parameters may not be indicated depending on the product model names.

Group 3: PIN diode (PIN)
Band switching diode (BSD)
Detection schottky diode (DET)

Absolute maximum rating

Parameter	Symbol	Type			Description
		PIN	BSD	DET	
Repetitive peak reverse voltage	V_{RM}	–	–	✓	See Group 1.
Reverse voltage	V_R	✓	✓	✓	See Group 1.
Forward current	I_F	✓	✓	✓	The maximum forward current value that can be applied continuously. This is a DC value excluding the AC component of a current flowing through the diode in the forward direction.
Junction temperature	T_J	✓	✓	✓	See Group 1.
Storage temperature	T_{stg}	✓	✓	✓	See Group 1.

NOTE: The parameters may not be indicated depending on the product model names.

Electrical Characteristics

Parameter	Symbol	Type			Description
		PIN	BSD	DET	
Forward voltage	V_F	✓	✓	✓	See Group 1.
Reverse current	I_R	✓	✓	✓	See Group 1.
Capacitance between terminals	C_t	✓	✓	✓	See Group 1.
High frequency forward resistance	r_F	✓	✓	–	The equivalent series resistance when the specified forward current is applied at the specified frequency. The parameter is measured with an impedance analyzer.

NOTE: The parameters may not be indicated depending on the product model names.

References

[1] JESD77: AUGUST 2012, Terms, Definitions, and Letter Symbols for Discrete Semiconductor and Optoelectronic Devices
[2] JESD88F: FEBRUARY 2018, JEDEC Dictionary of Terms for Solid State Technology – 7th Edition
[3] JESD99C: AUGUST 2012, Terms, Definitions, and Letter Symbols for Microelectronic Devices
[4] JESD210A: MARCH 2017, Avalanche Breakdown Diode (ABD) Transient Voltage Suppressors
[5] JESD211.01: NOVEMBER 2012, Zener and Voltage Regulator Diode Rating Verification and Characterization Testing
[6] JESD282B.02: JANUARY 2023, Silicon Rectifier Diodes
[7] JS-001-2023: MAY 2023, Human Body Model (HBM) Device Level
[8] JS-002-2022: JULY 2022, Charged Device Model (CDM) Device Level
[9] JEP172A: JULY 2014, Discontinuing Use of the Machine Model for Device ESD Qualification
[10] IEC 60050-521 Edition 2.0 2002-05, International Electrotechnical Vocabulary Part 521: Semiconductor devices and integrated circuits
[11] IEC 60747-1 Edition 2.1 2010-08, Semiconductor devices - Discrete device Part 1: General
[12] IEC 60747-2 Edition 3.0 2016-04, Semiconductor devices - Discrete device Part 2: Rectifier diodes
[13] IEC 60747-3 Edition 2.0 2013-07, Semiconductor devices - Discrete device Part 3: Signal, switching and regulator diodes
[14] IEC 60747-4 Edition 2.1 2017-01, Semiconductor devices - Discrete device Part 4: Microwave diodes and transistors
[15] IEC 61000-4-5 Edition 3.0 2014-05, Electromagnetic compatibility (EMC) -Part 4-5: Testing and measurement techniques - Surge immunity test
[16] MIL-STD 883E method 3015.7, 31 DECEMBER 1996, DEPARTMENT OF DEFENSE TEST METHOD STANDARD MICROCIRCUITS
[17] Telcordia Technologies Generic Requirements GR-1089-CORE, Electromagnetic Compatibility and Electrical Safety - Generic Criteria for Network Telecommunications Equipment

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