Physical Explanation

General Terminology

Semiconductor diodes are used as rectifiers, switchers, Varicaps and voltage stabilizers (see chapter 'Voltage Regulator and Z-diodes').

Semiconductor diodes are two-terminal solid-state devices having asymmetrical voltage-current characteristics. Unless otherwise stated, this means a device has single pn-junction corresponding to the characteristics shown in figure 1.

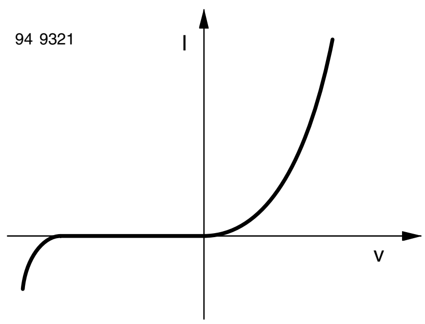

Figure 1.

An application of the voltage current curve is given by

$$I = I_S\left(\exp\frac{V}{V_T} - 1\right)$$

where

I_S = saturation current

$$V_T = \frac{k \times T}{q} = \text{temperature potential}$$

If the diode is forward-biased (anode positive with respect to cathode), its forward current ($I = I_F$) increases rapidly with increasing voltage. That is, its resistance becomes very low.

If the diode is reverse-biased (anode negative with respect to cathode), its reverse current ($-I = I_R$) is extremely low. This is only valid until the breakdown voltage $V_{(BR)}$ has been reached. When the reverse voltage is slightly higher than the breakdown voltage, a sharp rise in reverse current results.

Bulk resistance

Resistance of the bulk material between junction and the diode terminals.

Parallel resistance, r_P

Diode resistance resulting from HF rectification which acts as a damping resistance to the pre-tuned demodulation circuit.

Diode capacitance, C_D

Total capacitance between the diode terminals due to case, junction and parasitic capacitances.

Breakdown voltage, $V_{(BR)}$

Reverse voltage at which a small increase in voltage results in a sharp rise of reverse current. It is given in the technical data sheet for a specified current.

Forward voltage, V_F

The voltage across the diode terminals which results from the flow of current in the forward direction.

Forward current, I_F

The current flowing through the diode in the direction of lower resistance.

Forward resistance, r_F

The quotient of dc forward voltage across the diode and the corresponding dc forward current.

Forward resistance, differential r_f

The differential resistance measured between the terminals of a diode under specified conditions of measurement, i.e., for small-signal ac voltages or currents at a point of forward direction V-I characteristic.

Case capacitance, C_{case}

Capacitance of a case without a semiconductor crystal.

Integration time, t_{av}

With certain limitations, absolute maximum ratings given in technical data sheets may be exceeded for a short time. The mean value of current or voltage is decisive over a specified time interval termed integration time. These mean values over time interval, t_{av}, should not exceed the absolute maximum ratings.

Average rectified output current, I_{FAV}

The average value of the forward current when using the diode as a rectifier. The maximum allowable average rectified output current depends on the peak value of the applied reverse voltage during the time interval at which no current is flowing. In the absolute maximum ratings, one or both of the following are given:

Document Number 84053
Rev. 1.2, 20-Jan-04

- The maximum permissible average rectified output current for zero diode voltage (reverse)
- The maximum permissible average rectified output current for the maximum value of U_{RRM} during the time interval at which no current is flowing.

Note:

I_{FAV} decreases with an increasing value of the reverse voltage during the interval of no current flow.

Rectification efficiency, η_r

The ratio of the dc load voltage to the peak input voltage of an RF rectifier.

Reverse recovery time, t_{rr}

The time required for the current to reach a specified reverse current, i_R, after instantaneous switching from a specified forward condition (I_F) to a specified reverse bias condition (I_R).

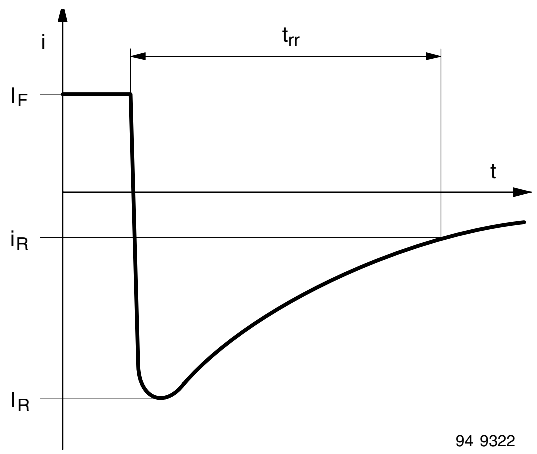

Figure 2.

Series resistance, r_s

The total value of resistance representing the bulk, contact and lead resistance of a diode given in the equivalent circuit diagram of variable Varicaps.

Junction capacitance, C_j

Capacitance due to a pn junction of a diode which decreases with increasing reverse voltage.

Reverse voltage, V_R

The voltage drop which results from the flow of reverse current (through the semiconductor diode).

Reverse current, I_R (leakage current)

The current which flows when reverse bias is applied to a semiconductor junction.

Reverse resistance, R_R

The quotient of the dc reverse voltage across a diode and the corresponding dc reverse current.

Reverse resistance, differential, r_r

The differential resistance measured between the terminals of a diode under specified condition of measurement i.e., for small-signal (ac) voltage or currents at a point of reverse-voltage direction V-I characteristic.

Peak forward current, I_{FRM}

The maximum forward current with sine-wave operation, f ≥ 25 Hz, or pulse operation, f ≥ 25 Hz, having a duty cycle $t_P/T \leq 0.5$.

Peak reverse voltage, V_{RRM}

The maximum reverse voltage having an operating frequency f ≥ 25 Hz for sine-wave as well as pulse operation.

Peak surge forward current, I_{FSM}

The maximum permissible surge current in a forward direction having a specified waveform with a short specified time interval (10 ms) unless otherwise specified. It is not an operating value. During frequent repetitions, there is a possibility of change in the device's characteristic.

Peak surge reverse voltage, V_{RSM}

The maximum permissible surge voltage applied in a reverse direction. It is not an operating value. During frequent repetitions, there is a possibility of change in the device's characteristic.

Power dissipation, P_V

An electrical power converted into heat. Unless otherwise specified, this value is given in the data sheets under absolute maximum ratings, with T_{amb} = 25 °C at a specified distance from the case (both ends).

Forward recovery time, t_{fr}

The time required for the voltage to reach a specified value after instantaneous switching from zero or a specified reverse voltage to a specified forward biased condition.

This recovery time is especially noticeable when higher currents are to be switched within a short time. The reason is that the forward resistance during the turn-on time could be higher than the dc current (inductive behavior). This can result in the destruction of a diode because of high instantaneous power loss if constant current control is used.

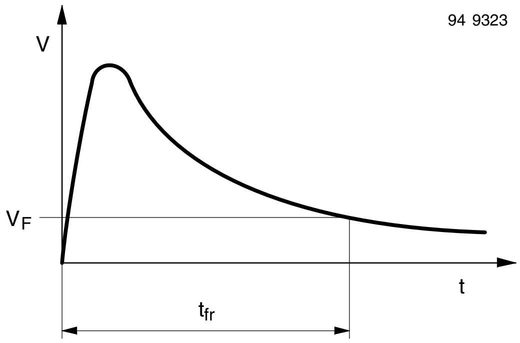

Figure 3.

Voltage Regulator Diodes and Z-diodes

A voltage regulator diode is a diode which develops an essentially constant voltage across its terminals throughout a specified current range.

Special reverse-biased diodes known as Z-diodes and certain forward-biased silicon diodes can be used as voltage regulator diodes.

Z-diodes are silicon diodes which result from a specified applied reverse voltage onward in a rapid increase of reverse current avalanche or Z-breakdown voltage. These diodes are operated permanently in this breakdown region.

Due to the sharp rise of the reverse current the corresponding breakdown voltage is nearly constant.

Z-diodes are used for voltages above 2.4 V. If lower operating voltages are needed, the above mentioned forward-biased silicon diodes can be used.

Operating or working voltage, in the breakdown region, V_Z

Voltage across the terminals of a Z-diode for a specified value of reverse current in the breakdown region.

Operating or working current in the breakdown region, I_Z

Reverse current flowing in an allowable area of the breakdown region of a Z-diode.

Differential resistance in the breakdown region, r_z

Differential quotient between operating voltage and operating current for a specified working current.

$$r_Z = \frac{dV_Z}{dI_Z}$$

This value is the sum of inherent (r_z) and thermal differential (r_{zj}) resistances.

$r_z = r_{zj} + r_{zth}$

Inherent differential resistance, r_{zj}, in the breakdown region

This value is a part of the total differential resistance of a Z-diode in the breakdown region. It is responsible for short-time load change and constant junction temperature.

$$r_{zj} = \left(\frac{\delta V_Z}{\delta I_Z}\right) T_j = \text{constant}$$

It is valid for the case where the frequency of load changes is so high that the junction temperature does not change.

Thermal differential resistance, r_{zth}, in the breakdown region

The thermal differential resistance is a result of the thermal characteristics of the diode. This should be considered together with inherent differential resistance, r_{zj}.

$$r_{zth} = \frac{dT_j}{dI_Z} \times \left(\frac{\delta V_Z}{\delta T_j}\right) I_Z = \text{constant}$$

$$= U_Z^2 \times R_{thJA} \times TK_{VZ}$$

Measuring current, I_Z

The value given in technical data serves as a measuring condition for the operating voltage, V_Z, inherent differential resistance, r_{zj}, and the temperature coefficient of the operating voltage, T_{KVZ}.

Temperature coefficient, T_{KVZ}

This characteristic gives the temperature dependence of the operating voltage for a specified operating current such as

$$TK_{VZ} = \frac{1}{V_Z} \times \frac{dV_Z}{dt}$$

The unit of measurement used is either %/ °C or 10^{-4}/ °C

Z-voltage, V_Z

See operating or working voltage

Z–current, I_Z

See operating or working current

Z-resistance, r_Z

See differential resistance

Varicap Diodes

Varicap diodes are used in different circuits, such as tuning, AFC, frequency multiplier, modulation, couple element in filters with controlled bandwidth, parametric amplification, switching in the VHF- and microwave regions, etc. In all these applications, the basic variation of junction capacitance with reverse voltage has been investigated.

A simplified equivalent circuit of an encapsulated Varicap diode is shown in figure 4.

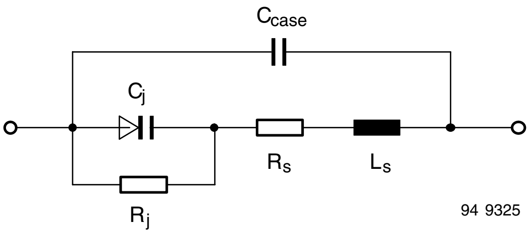

Figure 4.

C_{case} = Case capacitance
C_j = Junction capacitance
r_s = Series resistance
L_s = Series inductance
r_j = Junction resistance

In the case of silicon (Varicap) diodes, the junction resistance, r_j, is very high at zero or negative (reverse) bias. At high resonant frequency, C_{case} can be neglected and the equivalent circuit is the one shown in figure 5.

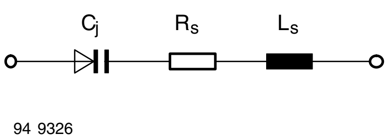

Figure 5.

Junction capacitance C_j can be calculated as follows:

$$C_j = \frac{C_{jo}}{\left(\frac{1 + V_R}{V_D}\right)^n}$$

C_{jo} = Junction capacitance at zero bias ($V_R = 0$)
V_D = Diffusion voltage, 0.7 V for silicon
n = The exponent n has different values according to the technology used, such as:
n = 0.33-diffused diode with linear technology
n = 0.5-abrupt pn junction, planar epitaxial technology
n ≥ 0.75-diode with retrograded junction

Retrograded junction diodes (n ≥ 0.75) are capable of very large capacitance deviation and are therefore suitable for tuning with large frequency range (i.e., BB205 for VHF). For these diodes, n is a function of reverse voltage, i.e., n = f(V_R). The quality, Q, of the Varicap is an important factor and can be calculated as follows:

$$Q = \frac{1}{2\pi \times f \times C_j \times r_S}$$

The series resistance, r_s, decreases with the increasing applied bias. It is also frequency dependent. The non-linearity of a capacitance characteristic results in a signal distortion or deformation due to the ratio of a signal amplitude to the applied bias.

In push-pull arrangements one can further minimize the distortion even with a larger range of signal.

Because the signal modulates the diode in counter phase, the capacitance changes. The diode is now almost compensated.

The temperature coefficient of the junction capacitance is approximately 3×10^{-4}/°C with V_R = 3 V. It is a result of a change of –2 mV/°C in diffusion voltage, V_D. The temperature coefficient of the junction capacitance decreases with increasing reverse voltage.

The junction resistance, r_j, decreases 6 % and the series resistance, r_s, decreases approximately 1 % with an increase in the junction temperature of 1°C.

PIN Diodes

PIN stands for p-intrinsic-n. In this type of diode, a heavily doped p region and a heavily doped n region are separated by a layer of high resistivity material which is nearly intrinsic (I), as shown in figure 6. Under reverse bias, the PIN diode has a very high impedance (at microwave frequencies), whereas at moderate forward current it has a very low impedance.

This permits the use of the PIN diode as a low-loss switch with small self capacitance.

The RF resistance of the diode can be varied continuously from large to small values by changing the diode bias. The PIN diode can therefore be used more advantageously as an HF attenuator in a π or T–circuit.

Typical examples are: VHF-band switch diode BA282, BA682 and attenuator diode BA479G and BA679.

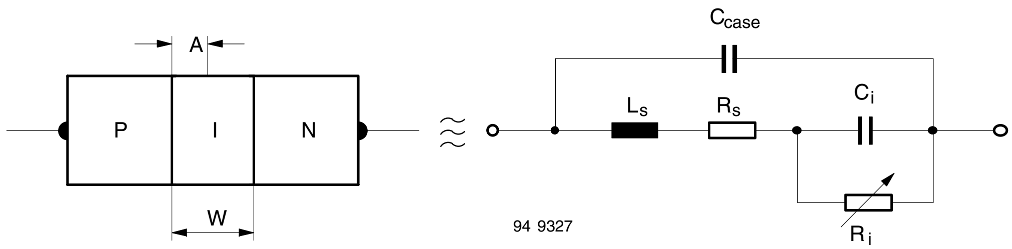

Figure 6.

W = Width of the I-Zone

A = Space charge carrier area

L_S = Total series inductance

r_s = Total resistance of the p and n layers and any resistance associated with the contacts of these

c_i = Layers r_i and represent the resistance and capacitance of the portion of the I-layer exclusive of the swept-out region.