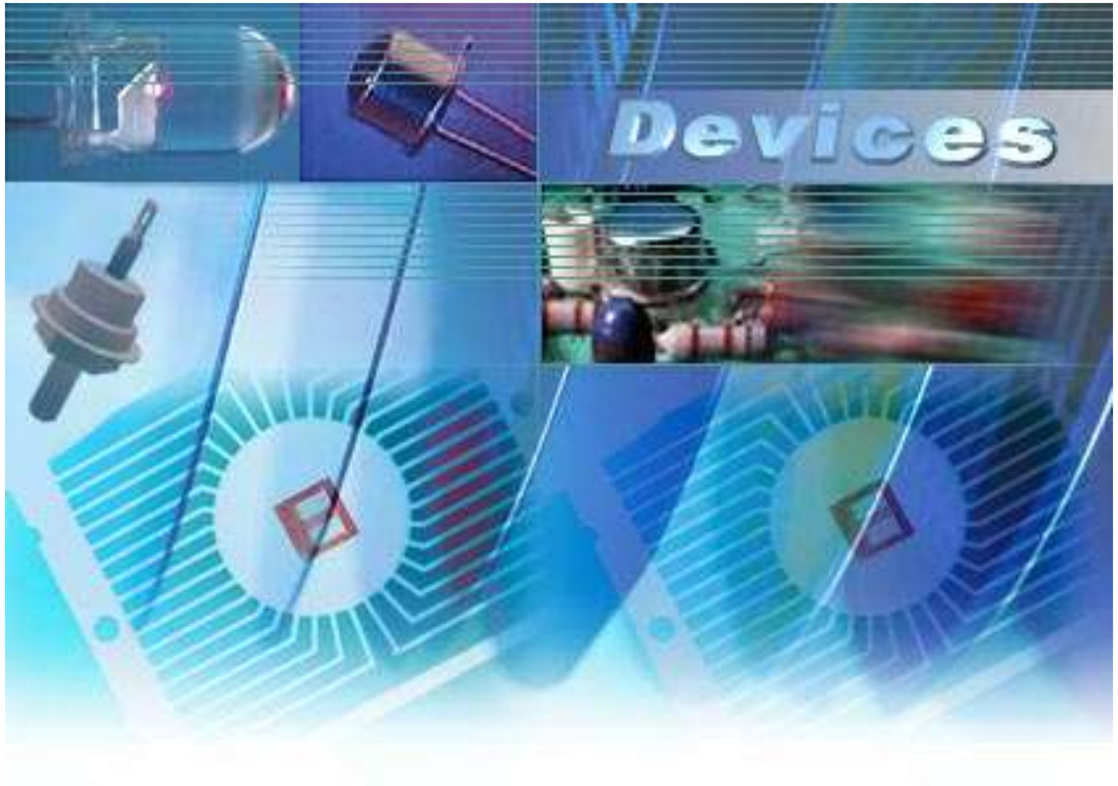
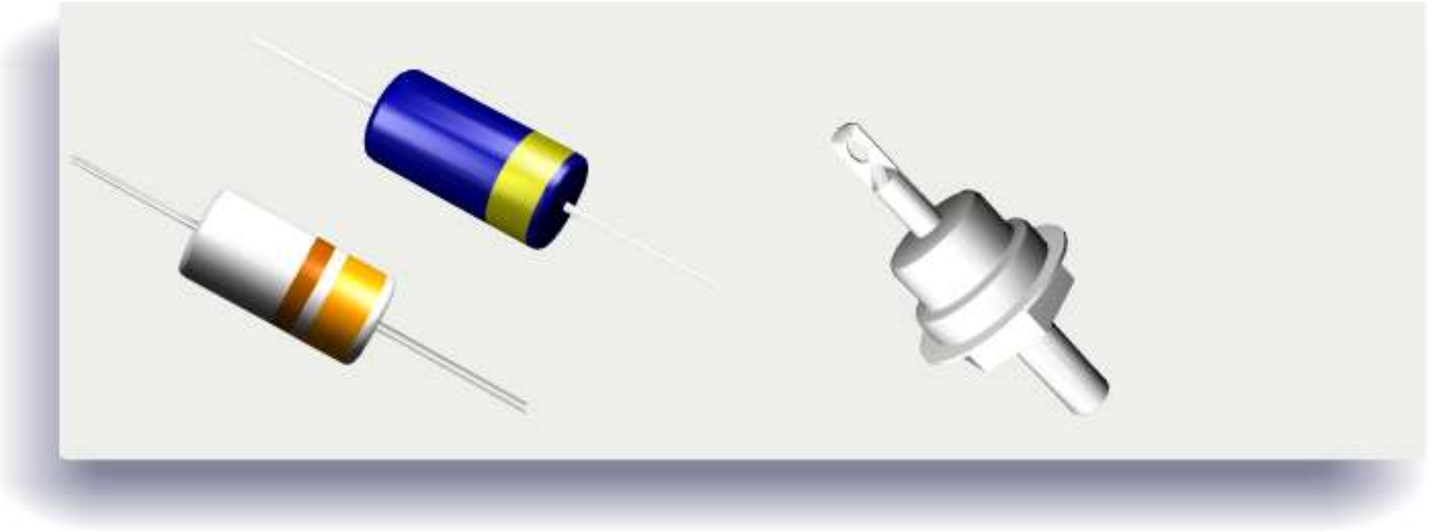
Zener Diode



Semiconductor Elements

Last update 14.04.2020

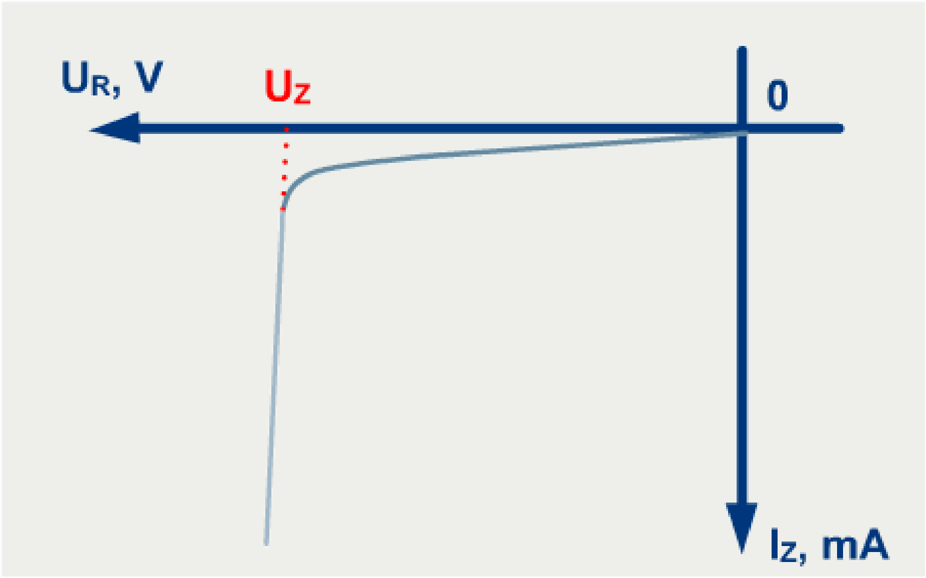
Zener Diode Cases



Plastic and glass packages

Metal case for large power

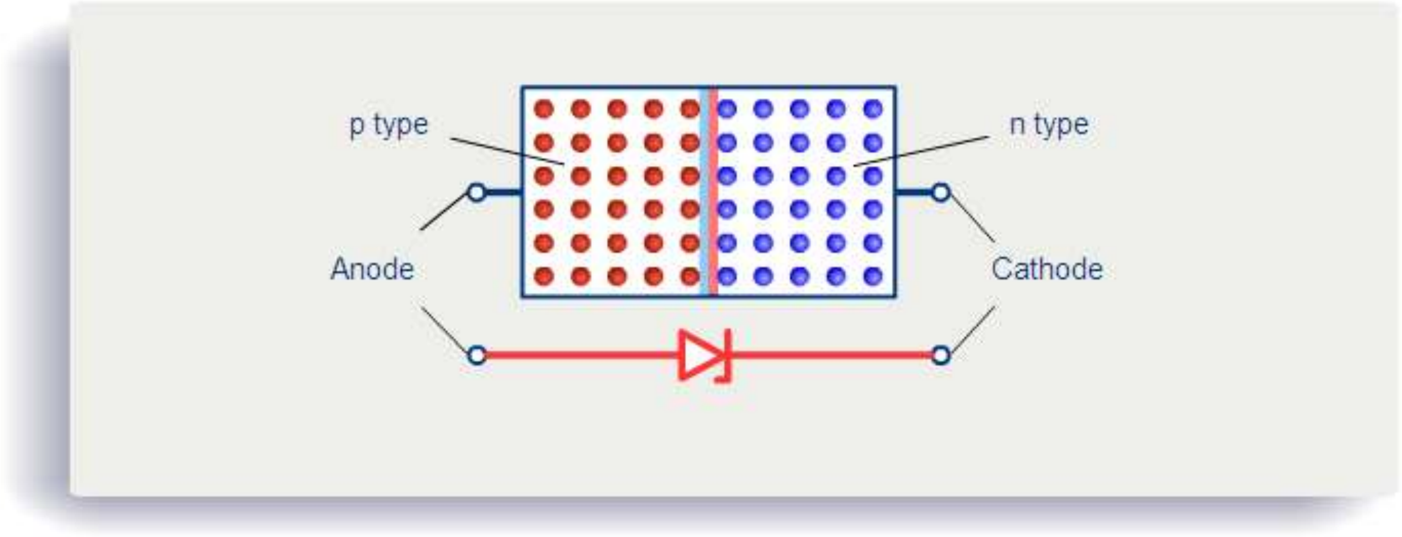
Basic Zener Diode Feature



A **Zener diode** is a special-purpose silicon diode optimized for operation in the **breakdown region**.

Once a breakdown occurs the voltage U_Z across the zener diode becomes almost constant and independent of the current through the diode. By utilizing a constant voltage zener diodes often operate as **voltage regulators**.

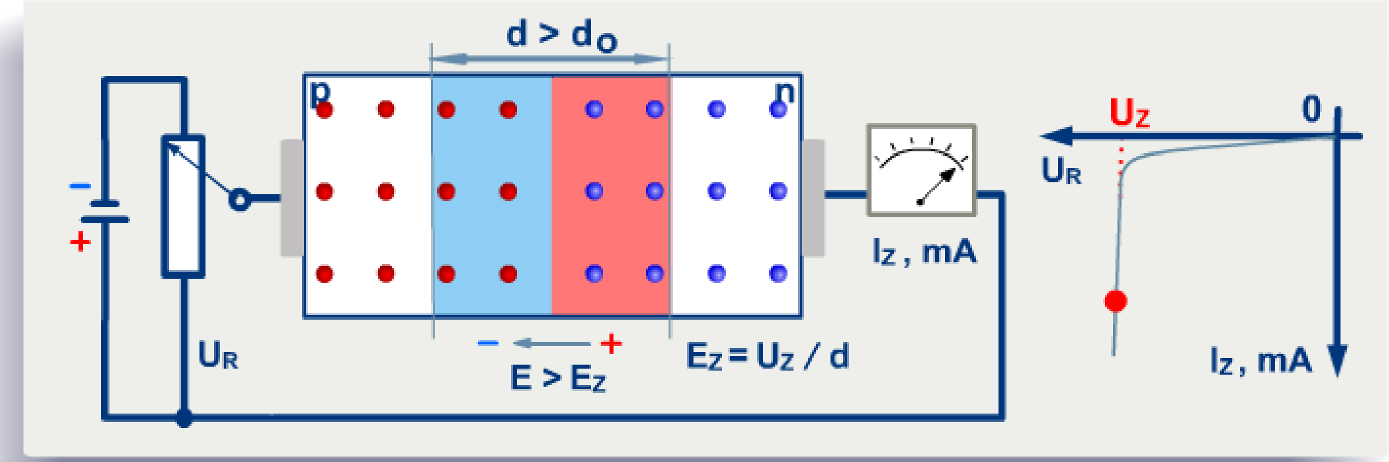
Zener Diode Schematic Symbol



The zener diode has two electrodes. The *p*-side is called anode, and the *n*-side - cathode.

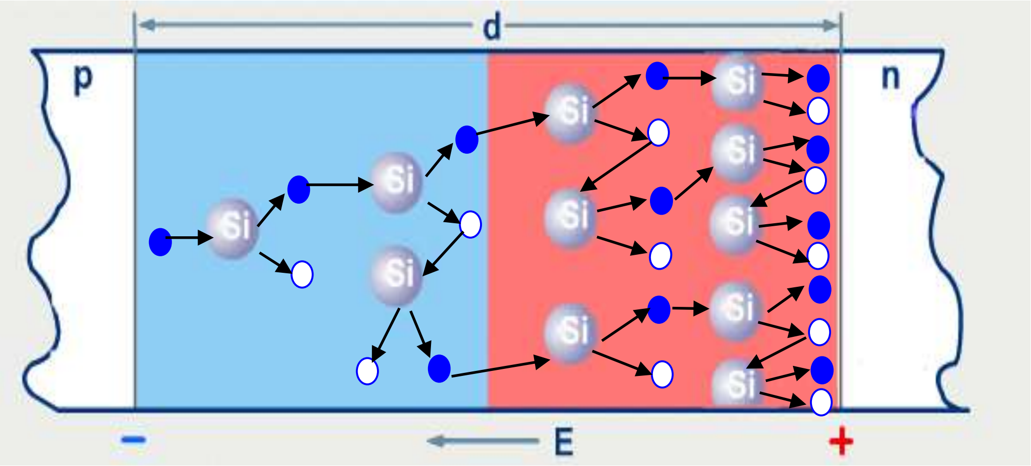
When zener diode operates in breakdown mode, the cathode must be positive in respect to the anode.

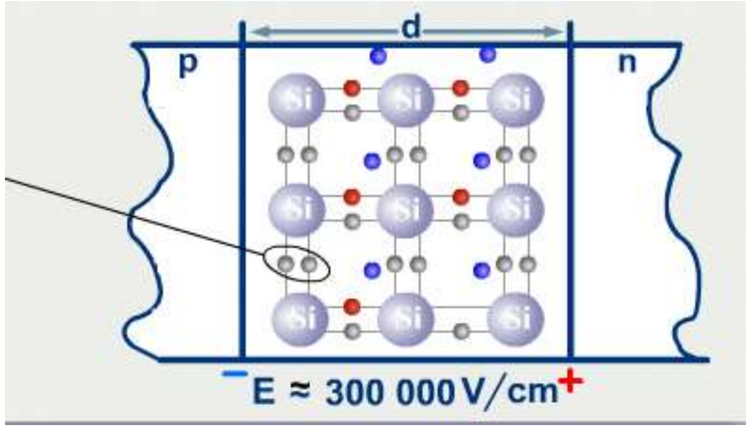
Zener Diode Mode of Operation



Once the breakdown voltage is reached, a large number of minority carriers suddenly appears in the depletion layer and the diode starts to conduct heavily. This results from two mechanisms known as **avalanche** and **zener breakdown.**

Avalanche and Zener Breakdown

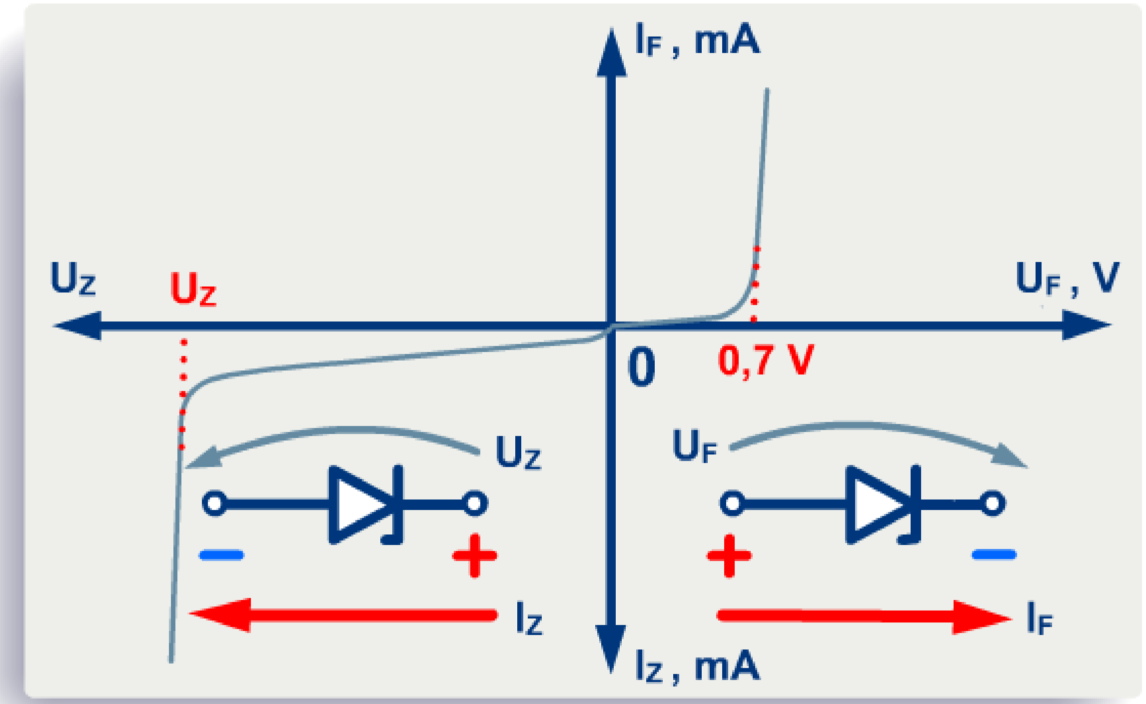




Avalanche breakdown occurs in wide depletion layers with a reverse bias **higher than 7V**.

Zener breakdown occurs in very narrow depletion layers with a reverse bias **less than 5V**.

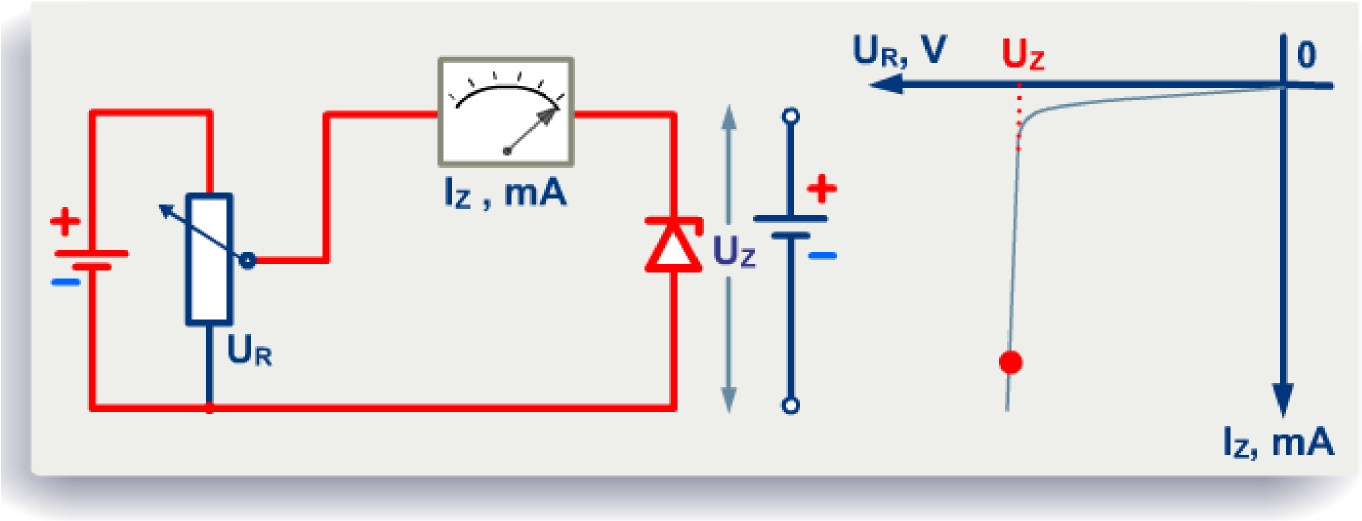
Zener Diode VA Characteristic



A zener diode can operate in any of the three regions: **forward, reverse and breakdown**.

In the forward region it starts conducting around 0.7 V, just an ordinary Si diode. The reverse current before breakdown is very small. In the breakdown region there is an almost vertical rise in current, where the voltage is almost constant.

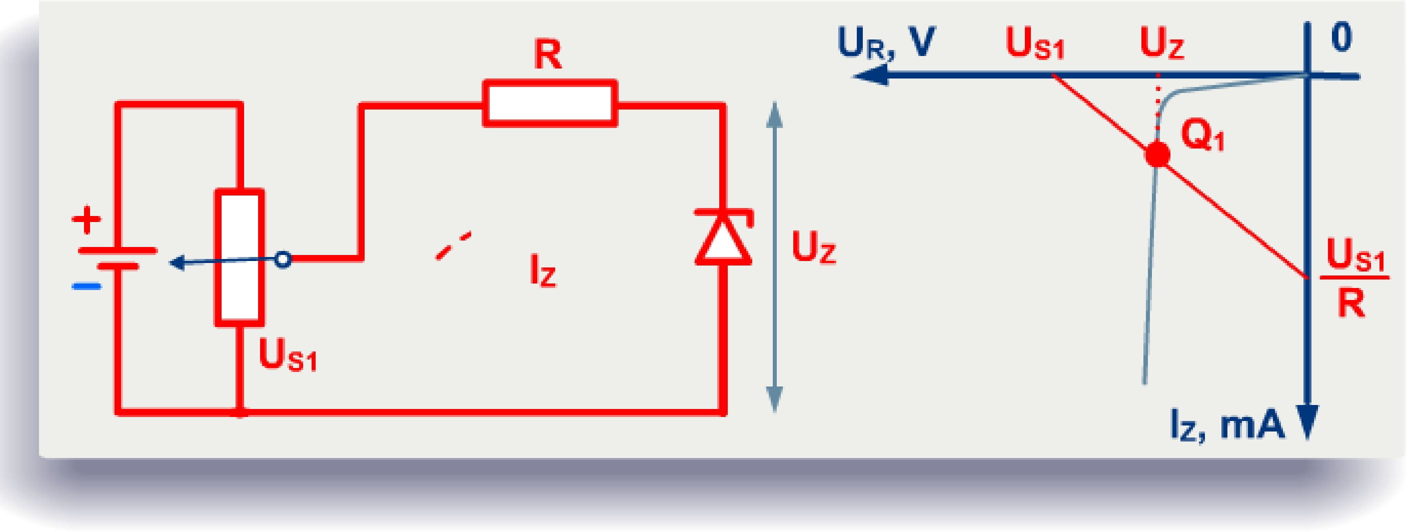
Breakdown Region



A Zener diode maintains a constant output voltage even though the current changes through it.

In the *breakdown region* a *zener diode* ideally *acts like a battery* and can be replaced by a voltage source of U_Z.

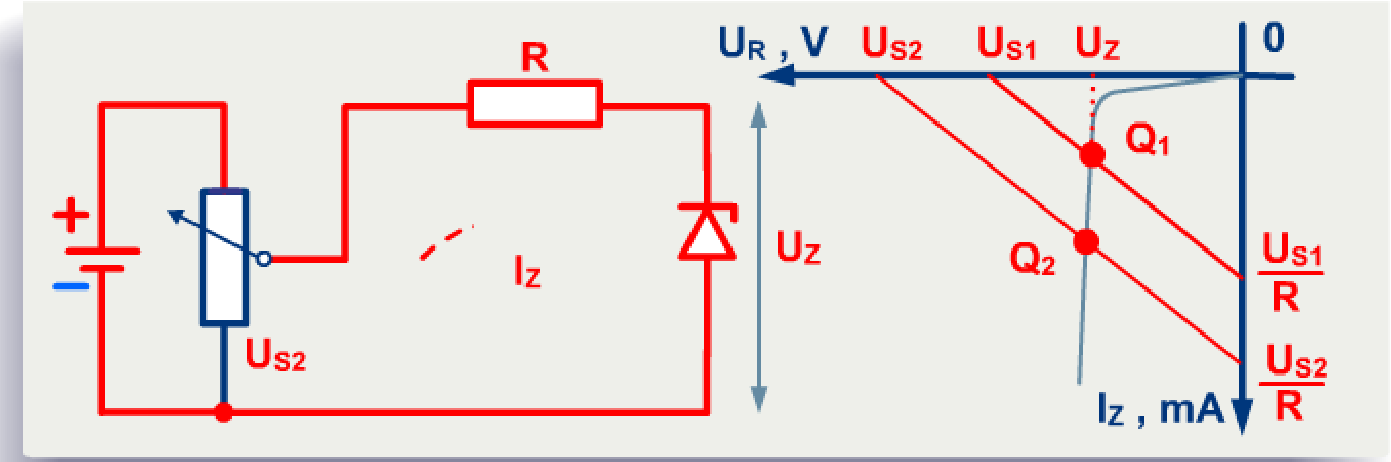
Load Line



The load line can be plotted with its intercepts on the horizontal and vertical axes.

The interception point of a load line with the zener diode VA characteristic gives **operational point** of Q_1.

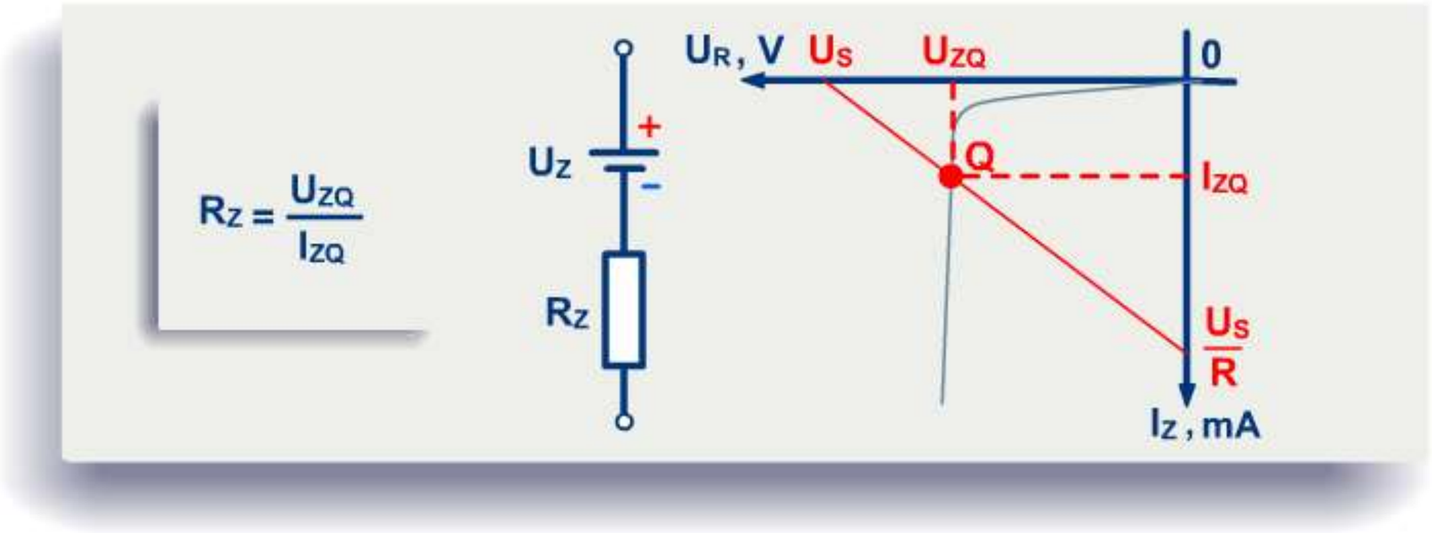
Load Line Shifting



If the source voltage changes the zener current will also change. With *R* fixed the load line slope is unchanged but the *U* intercept shifts.

This is the basic idea of **voltage regulation** - the output voltage remained almost constant even though the input voltage changed by a large amount.

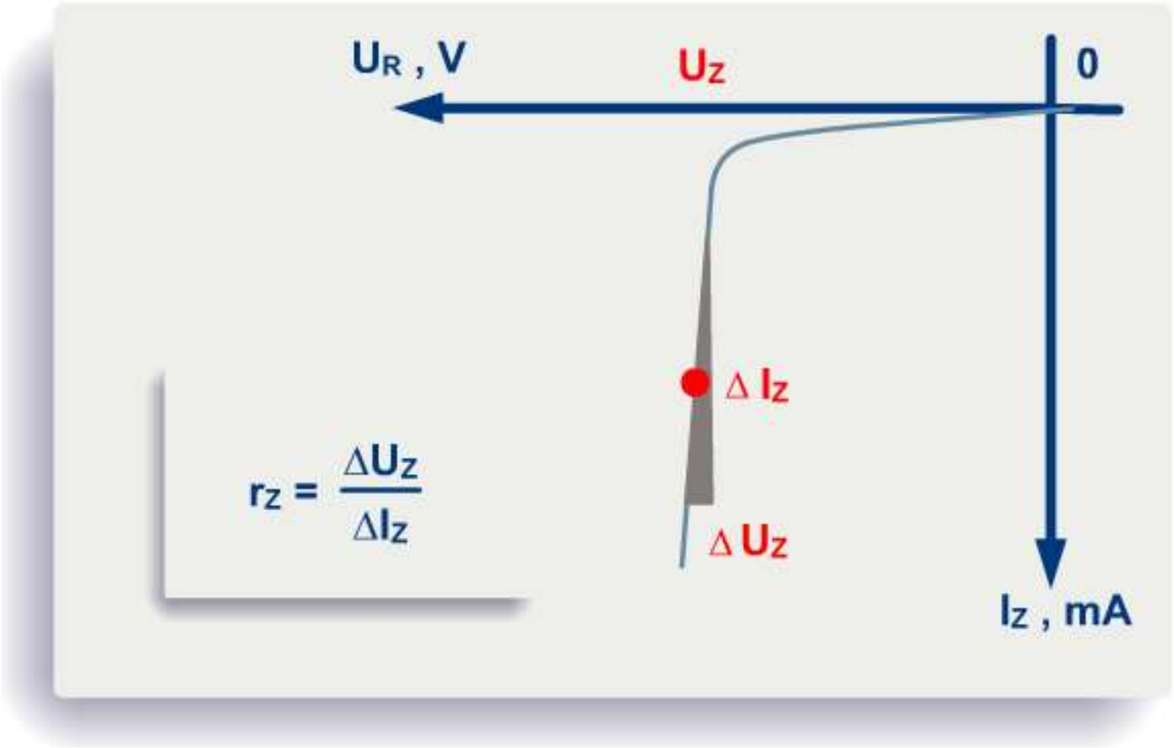
Parameters – Zener Static Resistance



Zener static (or dc) **resistance** R_Z is the ratio of total zener diode voltage to total diode current measured at given operating point.

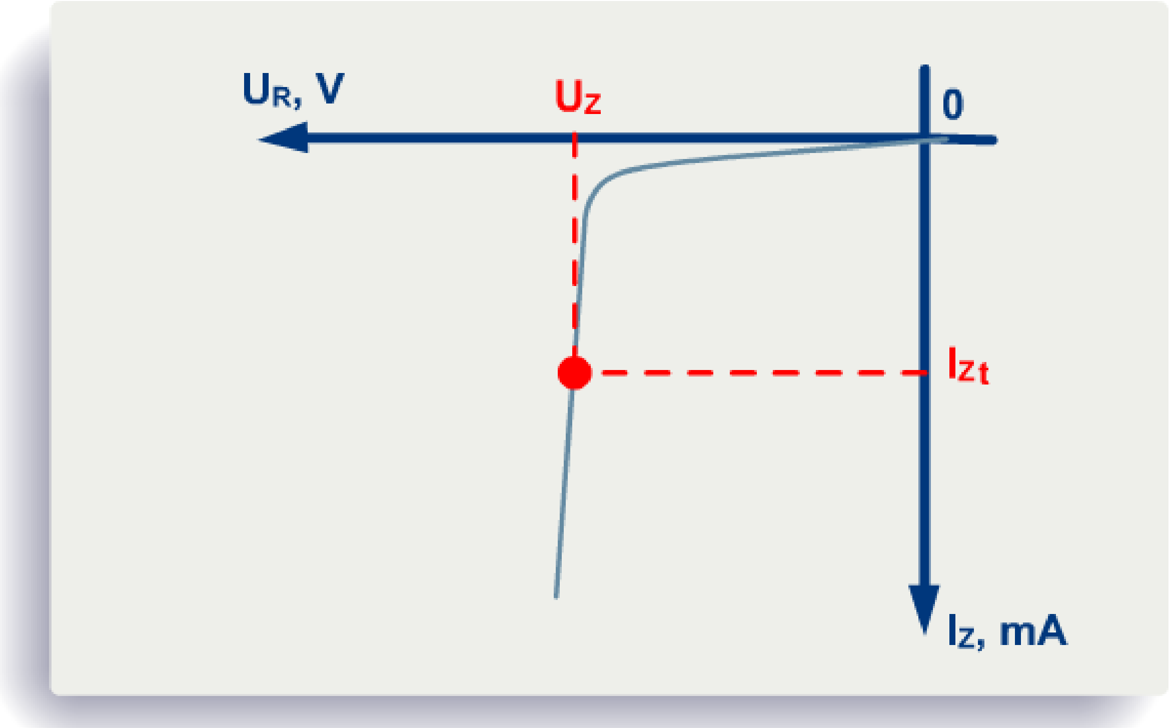
For more precise calculation a zener diode can be replaced by an ideal battery in series with a small zener resistance R_Z.

Zener Dynamic Resistance



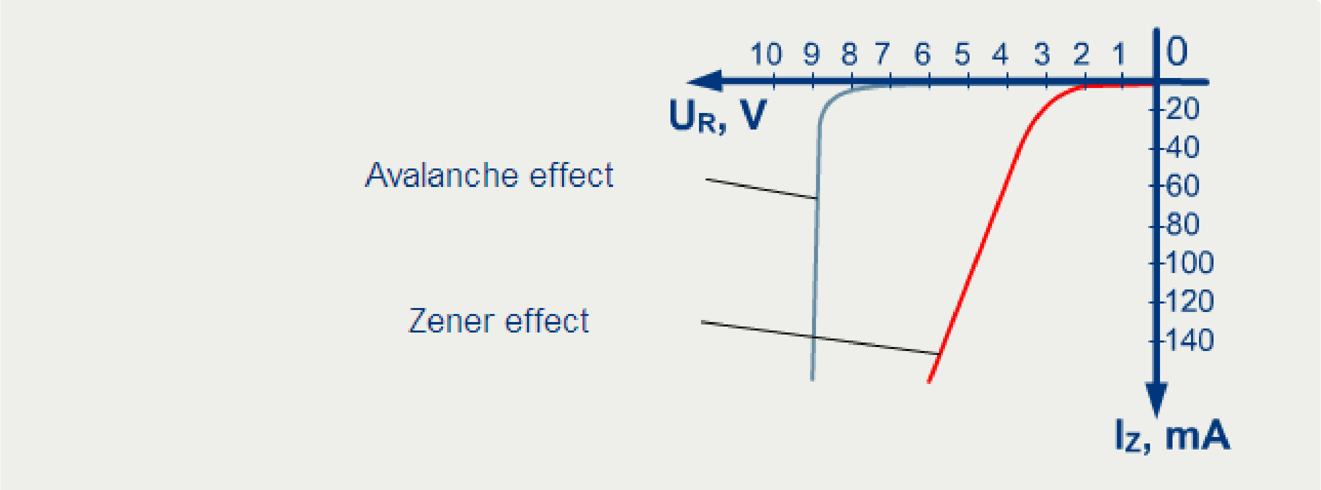
The **dynamic** (or ac) **zener resistance** R_Z is defined as voltage difference divided by current difference at given operating point. The less the dynamic resistance the better the zener diode as a voltage regulator.

Zener Voltage



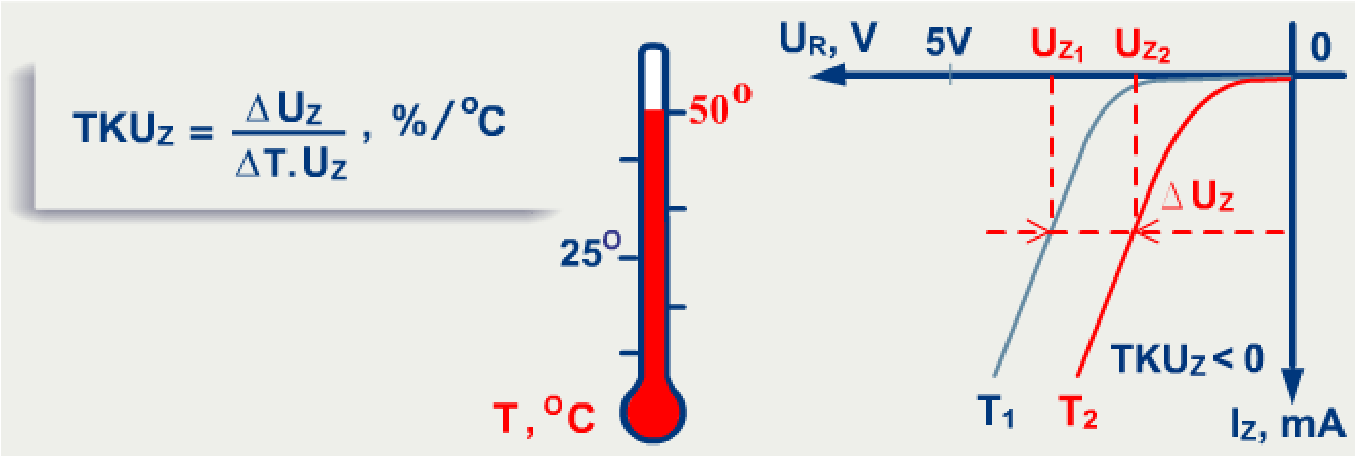
Zener diodes are available with the **zener breakdown voltage** U_Z in the range from several volts to several hundred volts. Data sheets usually specify the value U_Z at a particular current I_Z.

Zener Voltage & Breakdown Effect



The **zener effect** occurs for **reverse voltages less than 5V**. **Avalanche effect** requires reverse **voltages above 6V**.

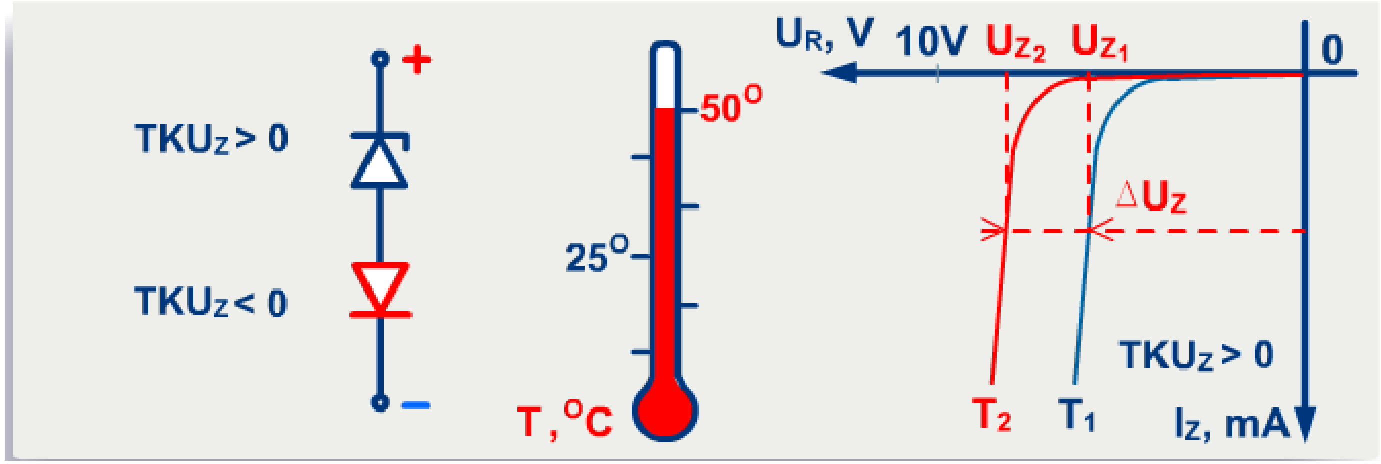
Temperature Coefficient



On data sheets, the effect of temperature is listed under the **temperature coefficient**, which is the percentage change per degree change.

For zener diode with **breakdown voltages of less than 5V, the temperature coefficient is negative**.

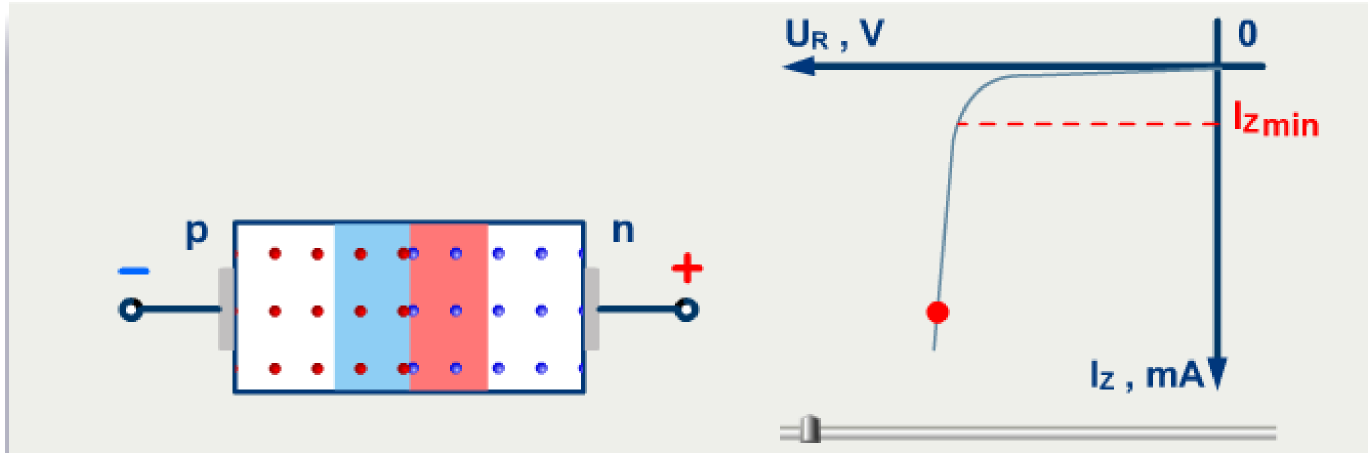
Termo Compensation



For zener diode with U_Z > 6V, the **temperature coefficient is positive**.

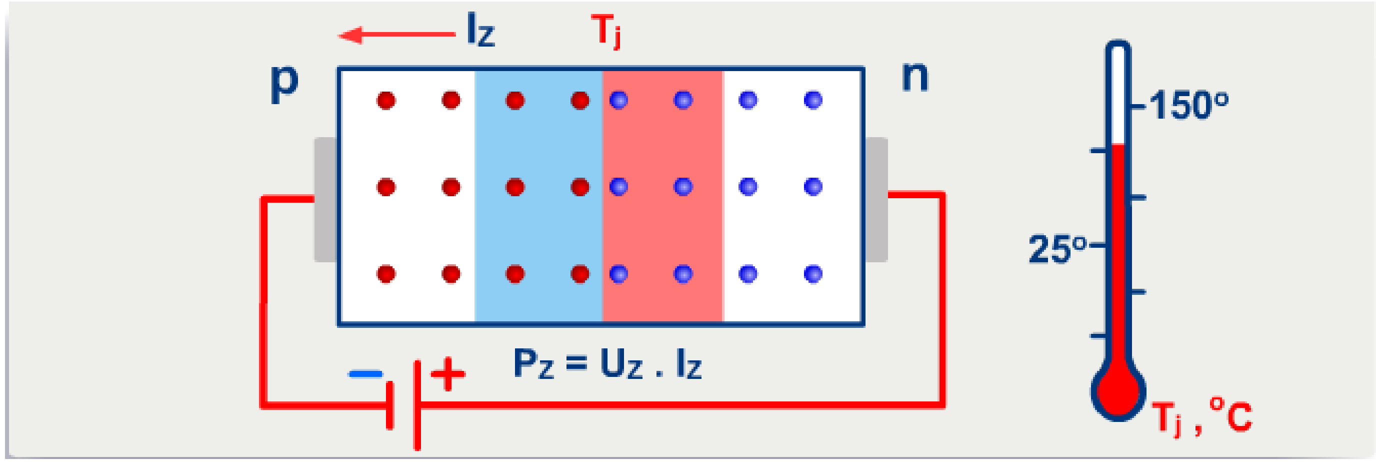
Positive temperature coefficient can be compensated by connecting a zener diode in series with forward based *pn* junction diode. A forward biased ***pn*** **diode has negative temperature coefficient** and its forward voltage decreases -2 mV/oC.

Zener Diode Ratings



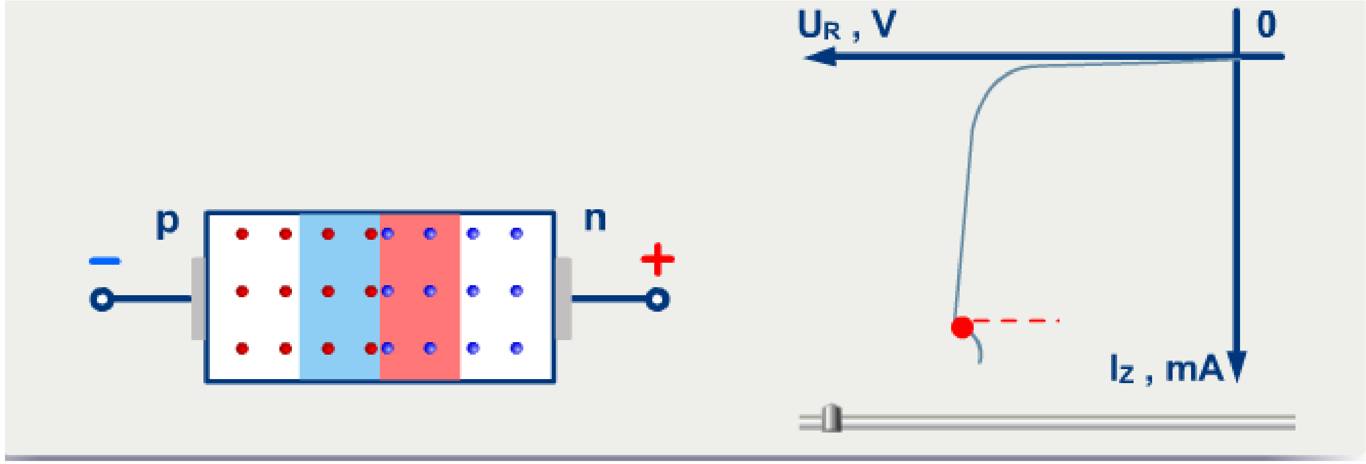
Minimum zener current I_{Zmin} is the minimum reverse current where the breakdown becomes stable. If a zener diode has to remain in the breakdown region the current through it has to be more than I_{Zmin}.

Maximum Power



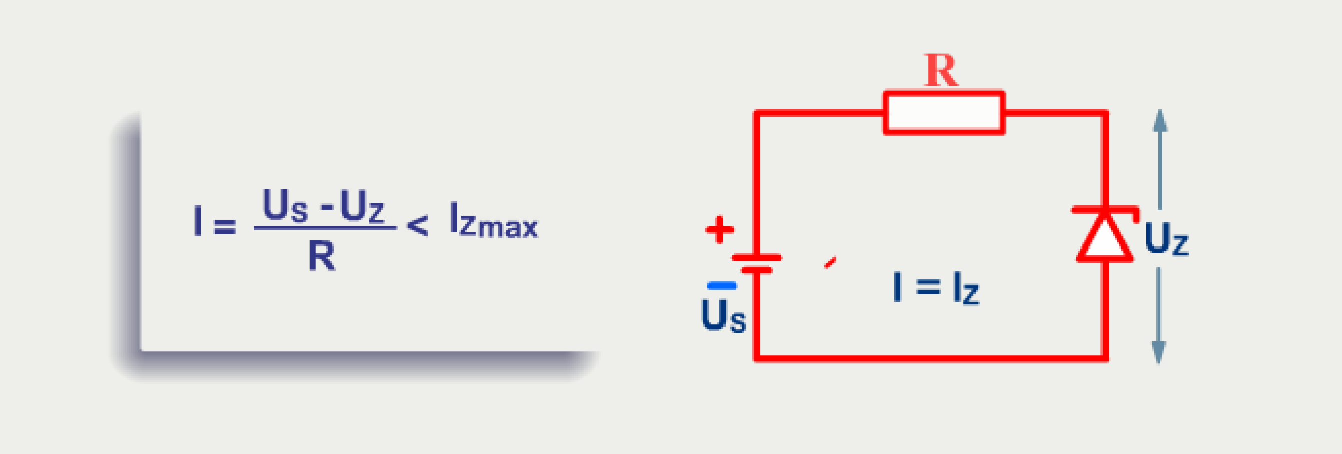
The power dissipation of a zener diode equals the product of its zener voltage and current $P_Z = U_z.I_z$. As long as P_Z is less than the **maximum power rating** P_{Zmax} the zener diode can operate in the breakdown region without being destroyed.

Maximum Current



The maximum current of a zener diode I_{Zmax} is related to the power rating P_{Zmax} as follows: $I_{Zmax} = P_{Zmax} / U_Z$, where U_Z is the zener voltage. This parameter gives the max current a zener diode can handle without exceeding its power rating.

Current-Limiting Resistor



In the figure, the series resistor *R* is referred to as a **current-limiting resistor**. It's purpouse is to keep the zener current less than its maximum current rating I_{Zmax}. The zener diode will otherwise be destroyed like any device exposed to power overload.

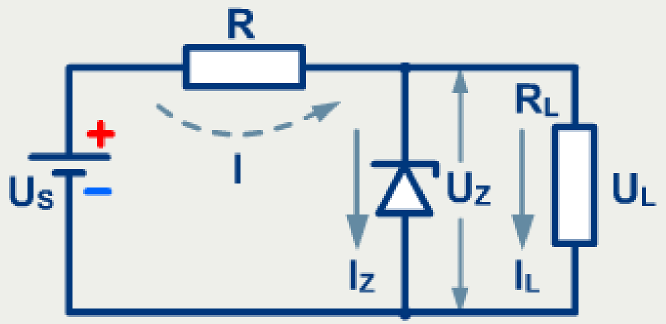
Loaded Voltage Regulator

$$I = \frac{U_S - U_Z}{R}$$

$$I_L = \frac{U_Z}{R}$$

$$I_Z = I - I_L$$

Currents in the circuit

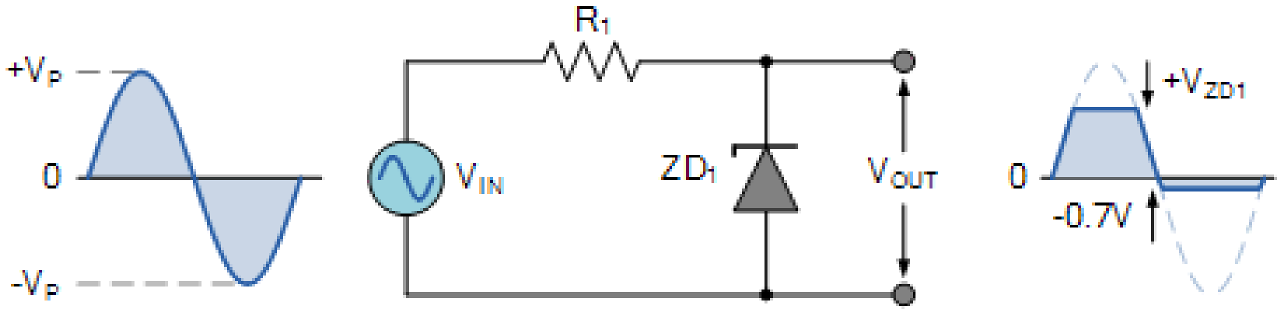


Loaded voltage regulator

The zener diode **holds the load voltage constant despite large changes in source voltage or in load resistance**.

Voltage Limiter

Half-wave Zener diode clipping

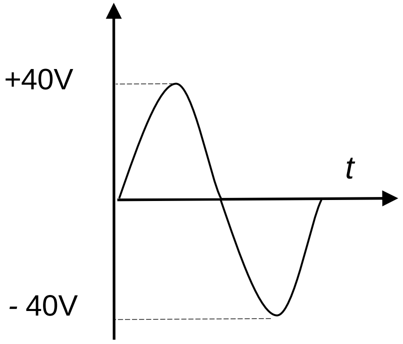


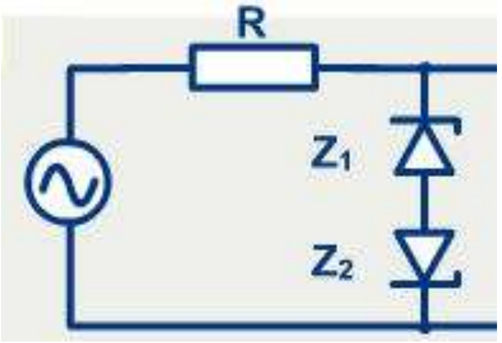
Voltage limiter removes signal voltages above or below a specified level. It is useful not only for signal shaping but also for protecting the circuits that receive the signal.

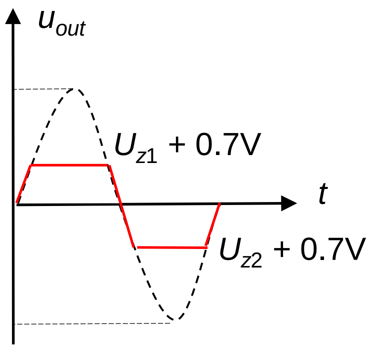
In this circuit during the positive half of the waveform the Zener diode is reverse biased so the waveform is clipped at the Zener voltage, V_{ZD1}. During the negative half cycle the Zener acts like a normal diode with its usual 0.7V junction value.

Voltage Limiter

Full-wave Zener diode clipping



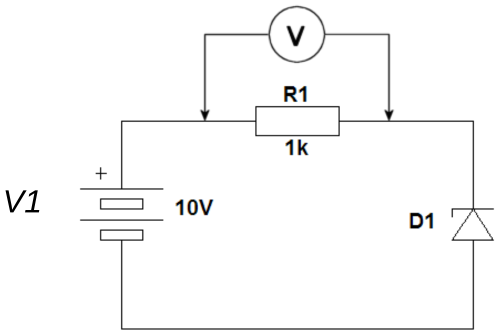


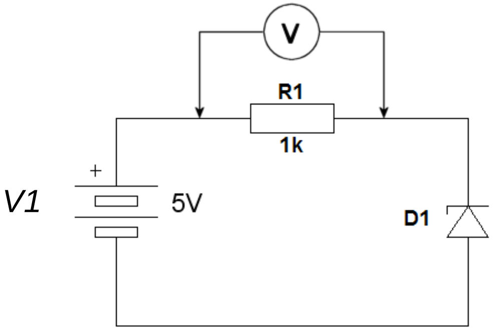


On the positive half cycle, the diode Z_1 breaks down and the diode Z_2 is forward biased. The output is then clipped. The clipping level equals the Zener voltage U_Z of Zener diode plus 0.7V of forward-biased diode.

Examples

Uz = 8.2V





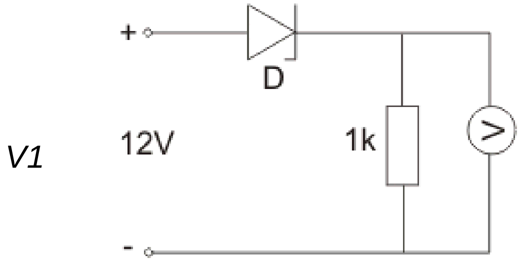
V1>Uz Diode is in the breakdown region with Uz=8.2V over it

Ur =V1-Ud = 10-8.2 = 1.8V according Kirchhoff law

V1<Uz Diode is in the reverse connection, I=0

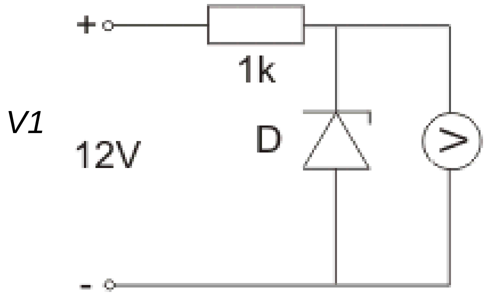
Ur=I.R = 0V, according Ohm's law

Ud=V1-Ur= V1= 5V, according Kirchhoff law



Uz=9V

V1 > Uz breakdown region



Ur =V1-Ud = 12 - 9 = 3V according Kirchhoff law

Vd = Uz = 9V