MicroNote 010

How to Quickly Obtain Spice Parameters for Diodes

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Component SPICE modeling has become a frequently used analysis tool by design engineers to evaluate circuit performance. This MicroNote provides background information and methods useful for quickly obtaining many of the discrete diode SPICE parameters (such as BV, IBV, IS, EG, TBV1, etc.) from either specified datasheet parameters or other known information. Others may be approximated as described herein or obtained from the manufacturing source with other related physical design or characteristic background information. The SPICE parameters for diodes described in this MicroNote begin with the reverse diode characteristics and conclude with the forward parameter features. For quick reference, each of the SPICE parameter acronyms are underlined and are then described in further detail.

The first example of BV for reverse breakdown knee voltage simply approximates the avalanche breakdown voltage, or what has been identified in datasheets as V_{BR} for rectifiers and transient voltage suppressors (TVSs), or V_Z for zener diodes. If the V_{BR} parameter is not specified for rectifiers, it may be approximated as somewhat higher than the commonly rated reverse voltage (V_{RWM}) of a rectifier. A 10% to 20% higher value is typical for fast and ultrafast rectifiers, or Schottkys. For lower voltage standard rectifiers in a JEDEC registered series where reverse recovery time is not critical (e.g., 1N4000 series), the actual V_{BR} can be many times higher than rated $V_{RWM.}$ This occurs when rectifiers are downgraded from higher voltages in a series by a manufacturer where all other parameters (such as forward voltage) are identical in ratings.

The IBV that represents reverse breakdown knee current for onset of breakdown voltage can be approximated as ten times greater than the maximum specified leakage current (I_R). In other examples for a conservative or worst-case (highest) value, this may instead be specified as I_{ZK} for knee current on zeners or I_{BR} (sometimes listed a s I_T) for TVS. It may also simply be those values shown separately for the V_{BR} current on some signal/switching diode datasheets. Many of these latter examples often specify the V_{BR} at 100 µA that is applicable for IBV.

The saturation current ISR may be approximated as the process norm of the leakage current in large-scale signal dc modeling with SPICE. This may be further represented in datasheets as I_R for rectifiers or zeners, and I_D for TVSs. For glass passivated pn junction designs (as primarily offered by Microsemi), this may typically be 10% to 20% of maximum leakage current specified for diodes in many of the 1Nxxxx JEDEC registrations. For a worst-case (highest value) scenario, it can also be simply modeled as the maximum leakage current I_R (or I_D) value specified. This may be in the range of 10^{-8} A to 10^{-5} A depending on size of the diode. For low voltage zeners or TVSs that do not avalanche with a sharp knee region, the leakage current or saturation current approaches that of the rated maximum I_R of zeners or I_D of a TVS. This can sometimes approach 100 µA to 5000 µA (10^{-4} A to 5×10^{-3} A), again depending on size of the device.

If the IS value is needed for a linearized small-signal AC SPICE model, this would equate to smaller saturation current values when measured at 0.026 V (kT/q). This results in very low IS values in the 10^{-9} A to 10^{-15} A range (or nA to fA), depending on size of the diode.

The zero bias pn junction capacitance CJO is also often specified in various diode datasheets. This may simply be shown as C if also stated at 0 V. If not, it will require direct measurement or further information from the manufacturing source. Much like a parallel plate capacitor, the diode capacitance will be dictated by its pn junction area size and depletion layer spread (or plate separation). This results in higher capacitance for larger size rectifiers (or Schottkys) as well as zeners and TVSs. It is similarly dependent on the actual voltage V_Z or V_{BR} (or effective plate separation). The higher the actual voltage, the lower the capacitance. This is particularly evident when comparing the capacitance for an overall family series listing of zeners or TVSs where low-voltage devices are depicted with much higher capacitance than high-voltage types.

The pn grading coefficient M further characterizes sensitivity of capacitance and its decline with applied reverse voltage on a logarithmic scale. It is not directly shown on datasheets, but the effective M values generally lie between the value of 0.25 to 0.45 for most conventional pn junction diodes. Low-voltage zeners below 5 V using alloy-diffused pn junction technology may only have an M value of 0.25, whereas higher voltage zeners (50 V to 100 V) may be 0.35. Higher voltage rectifiers of many hundreds of volts may approach 0.45. An abrupt junction or Schottky diode has an M value of 0.5 if there is no graded pn junction guard ring present. Modern Schottky rectifiers have pn guard rings typically resulting in M values of approximately 0.4.

The BV temperature coefficient (linear) of TBV1 is equivalent to the specified zener voltage temperature coefficient α_{VZ} parameter, specified for most zeners as well as the breakdown voltage temperature coefficient $\alpha_{V(BR)}$ for TVSs on numerous datasheets. For rectifiers, it approximates the same value as high-voltage zeners or TVSs, or approximately 0.11%/°C. This positive temperature coefficient (where V_{BR} increases with temperature) is also the reason that V_{BR} for rectifiers must be at least 10% or higher than rated voltage V_{RWM} at 25 °C when operating temperatures are reduced. This will ensure an operating temperature range down to –55 ℃ where V_{BR} also declines but still remains above V_{RWM} with this initial 10% design margin at 25 °C.

The parasitic resistance RS is not a value directly given on datasheets. It is determined by the diode element contact resistance and bulk resistance R through the material of resistivity (ρ), of area (A), and length in current flow (L) on either side of the pn junction. The length of this current flow is primarily related to semiconductor element thickness. The resistivity ρ also varies over this thickness as dictated by device geometry and diffusion profile. The effective resistance R is then primarily determined by the classic relation of $R = \rho \times L/A$ that *may* be integrated over this thickness. It can also be measured with special test methods or acquired from the manufacturer.

One example of parasitic resistance effects on zeners or TVSs is described in MicroNote 202. Small configured devices have higher RS compared to large devices of the same voltage rating. Also, higher voltage devices will have higher RS than low voltage due to higher resistivity material or thickness required for generating higher voltage V_z or V_{BR} characteristics. These overall effects can result in large low-voltage zeners running as low as 0.001 Ω, whereas small geometry high-voltage rectifiers may run many Ω in RS value. Many diode types are typically in the range of 0.01 Ω to 0.1 Ω .

The RS temperature coefficient TRS1 is often given a default value of zero; however, it is better approximated as 0.76%/°C for silicon if needed for critical circuit analysis in PSPICE regarding slight variations of RS over a broad operating temperature range.

The transit time TT is often given a default value of zero when it is not considered a critical feature in circuit design. When needed, the TT value is a complex parameter to quantify for pn diodes since it is also dependent on the operating current and slew rate (di/dt) similar to that observed for reverse recovery time (trr). This may be further reviewed in MicroNote 302 describing trr. The TT value may be approximated by a value somewhat greater than specified for trr in fast or ultrafast rectifier datasheets. It can be somewhat less than 10 ns for small signal or switching diodes, or in the range of approximately 50 ns for ultrafast rectifiers, or 250 ns in fast rectifiers. For zeners or TVSs where trr is not specified or controlled, this value typically varies from 200 ns for low-voltage types less than 10 V to as much as 3 ms for high-voltage devices exceeding 100 V, including standard rectifiers. For Schottky rectifiers, the TT value is zero.

The bandgap voltage (barrier height) EG is 1.11 eV for silicon pn diodes and typically 0.7 eV for Schottky diodes. Germanium diodes have an EG of 0.67 eV. Most diode types are silicon.

In rectifiers where forward voltage characteristics can also be important in SPICE modeling for circuit designs, the pn potential VJ for most diodes is considered 0.8 V in default value and the forward bias depletion capacitance coefficient FC is 0.5. The emission coefficient N can be used to modify the slope of the low-level forward current versus voltage I-V characteristics curve. Its default value is 1.0 and typical value is 1.1. In the high-level injection forward current region the slope is primarily determined by the resistive effects of the diode as influenced by the previously described RS parasitic resistance. To help identify these two regions, the forward knee current Ikf models the intersecting asymptotes of low-to-high forward current injection versus forward voltage. When viewing typical forward current characteristics on a log scale versus linear forward voltage scale, this intersection or subtle inflection point for determining the value of Ikf is often in the same vicinity as the average forward current rating I_O for rectifiers.

Other SPICE parameters exist but these are the primary examples of interest for most applications. In summary, the descriptions provided herein may serve as a quick approximation method for many diode SPICE parameters and how they may vary based on specified parameters found in datasheets or as additionally provided by the manufacturing source.

Support

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