# Using Temperature Parameters and Equations

## Temperature Parameters

The following temperature parameters apply to all MOSFET model levels and the associated bulk-to-drain and bulk-to-source MOSFET diode within the MOSFET model. The temperature equations used for the calculation of temperature effects on the model parameters are selected by the TLEV and TLEVC parameters.

**Temperature Effects Parameters**

| Name (Alias) | Units | Default | Description |
|---|---|---|---|
| BEX | | -1.5 | Low field mobility, UO, temperature exponent |
| CTA | 1/ ° K | 0.0 | Junction capacitance CJ temperature coefficient. Set TLEVC to 1 to enable CTA to override default Star-Hspice temperature compensation. |
| CTP | 1/ ° K | 0.0 | Junction sidewall capacitance CJSW temperature coefficient. Set TLEVC to 1 to enable CTP to override default Star-Hspice temperature compensation. |
| EG | eV | | Energy gap for pn junction diode. Set default=1.11, for TLEV=0 or 1 and default=1.16, for TLEV=2.<br><br>1.17 - silicon<br>0.69 - Schottky barrier diode<br>0.67 - germanium<br>1.52 - gallium arsenide |
| F1EX | | 0 | Bulk junction bottom grading coefficient |
| GAP1 | eV/ ° K | 7.02e-4 | First bandgap correction factor (from Sze, alpha term)<br><br>7.02e-4 - silicon<br>4.73e-4 - silicon<br>4.56e-4 - germanium |

| | | | |
|---|---|---|---|
| | | | 5.41e-4 - gallium arsenide |
| GAP2 | ° K | 1108 | Second bandgap correction factor (from Sze, beta term)<br><br>1108 - silicon<br>636 - silicon<br>210 - germanium<br>204 - gallium arsenide |
| LAMEX | 1/ ° K | 0 | LAMBDA temperature coefficient |
| N | | 1.0 | Emission coefficient |
| MJ | | 0.5 | Bulk junction bottom grading coefficient |
| MJSW | | 0.33 | Bulk junction sidewall grading coefficient |
| PTA | V/ ° K | 0.0 | Junction potential PB temperature coefficient. Set TLEVC to 1 or 2 to enable PTA to override default Star-Hspice temperature compensation. |
| PTC | V/ ° K | 0.0 | Fermi potential PHI temperature coefficient. Set TLEVC to 1 or 2 to enable PTC to override default Star-Hspice temperature compensation. |
| PTP | V/ ° K | 0.0 | Junction potential PHP temperature coefficient. Set TLEVC to 1 or 2 to enable PTP to override default Star-Hspice temperature compensation. |
| TCV | V/ ° K | 0.0 | Threshold voltage temperature coefficient. Typical values are +1mV for n-channel and -1mV for p-channel. |
| TLEV | | 0.0 | Temperature equation level selector. Set TLEV=1 for ASPEC style - default is SPICE style.<br>When option ASPEC is invoked, the program sets TLEV for ASPEC. |
| TLEVC | | 0.0 | Temperature equation level selector for junction capacitances and potentials, interacts with TLEV. Set TLEVC=1 for ASPEC style. Default is SPICE style.<br>When option ASPEC is invoked, the program sets TLEVC for ASPEC. |

| | | | |
|---|---|---|---|
| TRD | 1/ ° K | 0.0 | Temperature coefficient for drain resistor |
| TRS | 1/ ° K | 0.0 | Temperature coefficient for source resistor |
| XTI | | 0.0 | Saturation current temperature exponent. Use XTI=3 for silicon diffused junction. Set XTI=2 for Schottky barrier diode. |

**Using MOS Temperature Coefficient Sensitivity Parameters**

Model levels 13 (BSIM1), 39 (BSIM2), and 28 (METAMOS) have length and width sensitivity parameters associated with them as shown in the following table. These parameters are used in conjunction with the Automatic Model Selector capability and enable more accurate modeling for various device sizes. The default value of each sensitivity parameter is zero to ensure backward compatibility.

| Parameter | Description | Sensitivity Parameters | | |
|---|---|---|---|---|
| | | **Length** | **Width** | **Product** |
| BEX | Low field mobility, UO, temperature exponent | LBEX | WBEX | PBEX |
| FEX | Velocity saturation temperature exponent | LFEX | WFEX | PFEX |
| TCV | Threshold voltage temperature coefficient | LTCV | WTCV | PTCV |
| TRS | Temperature coefficient for source resistor | LTRS | WTRS | PTRS |
| TRD | Temperature coefficient for drain resistor | LTRD | WTRD | PTRD |

## Using Temperature Equations

This section describes how to use temperature equations.

**Calculating Energy Gap Temperature Equations**

To determine energy gap for temperature compensation use the equations:

**TLEV = 0 or 1:**

$$egnom = 1.16 - 7.02e{-}4 \cdot \frac{tnom^2}{tnom + 1108.0}$$

$$eg(t) = 1.16 - 7.02e{-}4 \cdot \frac{t^2}{t + 1108.0}$$

**TLEV = 2:**

$$egnom = EG - GAP1 \cdot \frac{tnom^2}{tnom + GAP2}$$

$$eg(t) = EG - GAP1 \cdot \frac{t^2}{t + GAP2}$$

### Calculating Saturation Current Temperature Equations

$$isbd(t) = isbd(tnom) \cdot e^{facln/N}$$

$$isbs(t) = isbs(tnom) \cdot e^{facln/N}$$

where

$$facln = \frac{egnom}{vt(tnom)} - \frac{eg(t)}{vt(t)} + XTI \cdot \ln\left(\frac{t}{tnom}\right)$$

These isbd and isbs are defined in Using a MOSFET Diode Model.

### Calculating MOS Diode Capacitance Temperature Equations

TLEVC selects the temperature equation level for MOS diode capacitance.

**TLEVC=0:**

$$PB(t) = PB \cdot \left(\frac{t}{tnom}\right) - vt(t) \cdot \left[3 \cdot \ln\left(\frac{t}{tnom}\right) + \frac{egnom}{vt(tnom)} - \frac{eg(t)}{vt(t)}\right]$$

$$PHP(t) = PHP \cdot \left(\frac{t}{tnom}\right) - vt(t) \cdot \left[3 \cdot \ln\left(\frac{t}{tnom}\right) + \frac{egnom}{vt(tnom)} - \frac{eg(t)}{vt(t)}\right]$$

$$CBD(t) = CBD \cdot \left[1 + MJ \cdot \left(400u \cdot \Delta t - \frac{PB(t)}{PB} + 1\right)\right]$$

$$CBS(t) = CBS \cdot \left[1 + MJ \cdot \left(400u \cdot \Delta t - \frac{PB(t)}{PB} + 1\right)\right]$$

$$CJ(t) = CJ \cdot \left[1 + MJ \cdot \left(400u \cdot \Delta t - \frac{PB(t)}{PB} + 1\right)\right]$$

$$CJSW(t) = CJSW \cdot \left[1 + MJSW \cdot \left(400u \cdot \Delta t - \frac{PHP(t)}{PHP} + 1\right)\right]$$

**TLEVC=1:**

$$PB(t) = PB - PTA \cdot \Delta t$$

$$PHP(t) = PHP - PTP \cdot \Delta t$$

$$CBD(t) = CBD \cdot (1 + CTA \cdot \Delta t)$$

$$CBS(t) = CBS \cdot (1 + CTA \cdot \Delta t)$$

$$CJ = CJ \cdot (1 + CTA \cdot \Delta t)$$

$$CJSW = CJSW \cdot (1 + CTP \cdot \Delta t)$$

**TLEVC=2:**

$$PB(t) = PB - PTA \cdot \Delta t$$

$$PHP(t) = PHP - PTP \cdot \Delta t$$

$$CBD(t) = CBD \cdot \left(\frac{PB}{PB(t)}\right)^{MJ}$$

$$CBS(t) = CBS \cdot \left(\frac{PB}{PB(t)}\right)^{MJ}$$

$$CJ(t) = CJ \cdot \left(\frac{PB}{PB(t)}\right)^{MJ}$$

$$CJSW(t) = CJSW \cdot \left(\frac{PHP}{PHP(t)}\right)^{MJSW}$$

**TLEVC=3:**

$$PB(t) = PB + dpbdt \cdot \Delta t$$

$$PHP(t) = PHP + dphpdt \cdot \Delta t$$

$$CBD(t) = CBD \cdot \left(1 - 0.5 \cdot dpbdt \cdot \frac{\Delta t}{PB}\right)$$

$$CBS(t) = CBS \cdot \left(1 - 0.5 \cdot dpbdt \cdot \frac{\Delta t}{PB}\right)$$

$$CJ(t) = CJ \cdot \left(1 - 0.5 \cdot dpbdt \cdot \frac{\Delta t}{PB}\right)$$

$$CJSW(t) = CJSW \cdot \left(1 - 0.5 \cdot dphpdt \cdot \frac{\Delta t}{PHP}\right)$$

**where for TLEV=0 or 1:**

$$dpbdt = -\frac{\left[egnom + 3 \cdot vt(tnom) + (1.16 - egnom) \cdot \left(2 - \frac{tnom}{tnom + 1108}\right) - PB\right]}{tnom}$$

$$dphpdt = -\frac{\left[egnom + 3 \cdot vt(tnom) + (1.16 - egnom) \cdot \left(2 - \frac{tnom}{tnom + 1108}\right) - PHP\right]}{tnom}$$

**TLEV=2:**

$$dpbdt = -\frac{\left[egnom + 3 \cdot vt(tnom) + (EG - egnom) \cdot \left(2 - \frac{tnom}{tnom + GAP2}\right) - PB\right]}{tnom}$$

$$dphpdt = -\frac{\left[egnom + 3 \cdot vt(tnom) + (EG - egnom) \cdot \left(2 - \frac{tnom}{tnom + GAP2}\right) - PHP\right]}{tnom}$$

## Calculating Surface Potential Temperature Equations

**TLEVC=0:**

$$PHI(t) = PHI \cdot \left(\frac{t}{tnom}\right) - vt(t) \cdot \left[3 \cdot \ln\left(\frac{t}{tnom}\right) + \frac{egnom}{vt(tnom)} - \frac{eg(t)}{vt(t)}\right]$$

**TLEVC=1:**

$$PHI(t) = PHI - PTC \cdot \Delta t$$

If the PHI parameter is not specified, it is calculated as:

$$PHI(t) = 2 \cdot vt(t) \cdot \ln\left(\frac{NSUB}{ni}\right)$$

The intrinsic carrier concentration, ni, must be temperature updated, and it is calculated from the silicon bandgap at room temperature.

$$ni = 145e16 \cdot \left(\frac{t}{tnom}\right)^{3/2} \cdot \exp\left[EG \cdot \left(\frac{t}{tnom} - 1\right) \cdot \left(\frac{1}{2 \cdot vt(t)}\right)\right]$$

**TLEVC=2:**

$$PHI(t) = PHI - PTC \cdot \Delta t$$

**TLEVC=3:**

$$PHI(t) = PHI + dphidt \cdot \Delta t$$

**where TLEV=0 or 1:**

$$dphidt = -\frac{\left[egnom + 3 \cdot vt(tnom) + (116 - egnom) \cdot \left(2 - \frac{tnom}{tnom + 1108}\right) - PHI\right]}{tnom}$$

**TLEV=2:**

$$dphidt = -\frac{\left[egnom + 3 \cdot vt(tnom) + (EG - egnom) \cdot \left(2 - \frac{tnom}{tnom + GAP2}\right) - PHI\right]}{tnom}$$

## Calculating Threshold Voltage Temperature Equations

The threshold temperature equations are:

**TLEV=0:**

$$vbi(t) = vbi(tnom) + \frac{PHI(t) - PHI}{2} + \frac{egnom - eg(t)}{2}$$

$$VTO(t) = vbi(t) + GAMMA \cdot (PHI(t))^{1/2}$$

**TLEV=1:**

$$VTO(t) = VTO - TCV \cdot \Delta t$$

$$vbi(t) = VTO(t) - GAMMA \cdot (PHI(t))^{1/2}$$

**TLEV=2:**

$$VTO(t) = VTO + \left(1 + \frac{GAMMA}{2 \cdot PHI^{1/2}}\right) \cdot dphidt \cdot \Delta t$$

$$vbi(t) = VTO(t) - GAMMA \cdot (PHI(t))^{1/2}$$

## Calculating Mobility Temperature Equations

The MOS mobility temperature equations are:

$$UO(t) = UO \cdot \left(\frac{t}{tnom}\right)^{BEX}$$

$$KP(t) = KP \cdot \left(\frac{t}{tnom}\right)^{BEX}$$

$$F1(t) = F1 \cdot \left(\frac{t}{tnom}\right)^{F1EX}$$

## Calculating Channel Length Modulation Temperature Equation

The LAMBDA is modified with temperature if model parameter LAMEX is specified.

$$LAMBDA(t) = LAMBDA \cdot (1 + LAMEX \cdot \Delta t)$$

## Calculating Diode Resistance Temperature Equations

The following equation is an example of effective drain and source resistance:

$$RD(t) = RS \cdot (1 + TRD \cdot \Delta t)$$

$$RS(t) = RS \cdot (1 + TRS \cdot \Delta t)$$