# Temperature Effects On Silicon Semiconductor Devices

Many applications require reliable circuit operation over a wide temperature range. Automotive environments for example may experience a range of -40°C to +125°C, while a more usual industrial range may be -10°C to 85°C. To ensure that electronic components and systems behave satisfactorily, the design process must include consideration of device parameter variation with temperature, in particular those parameters which affect leakage currents, drive conditions, on-state losses, and switching performance.

This design note provides a general indication of the effects of temperature on silicon devices, and lists typical temperature coefficients for the main parameters. This information is based on known physical effects, and measurements conducted previously. The latter applies when either the device textbooks do not consider the device/parameter of interest, or a product specific measurement is required. Obviously for such a general guide, these values must be considered as approximate, but will probably be adequate in many cases.

## BIPOLAR (except Darlingtons)

| Parameter | Temp. Coefficient | Comment |
|---|---|---|
| $h_{FE}$ | +0.3 to 0.6%/°C | In active region at low to medium currents |
| | Negative | At high currents. Cross over point falls as $I_C$ and Breakdown Voltage Increases |
| | -0.25%/°C | In saturation region |
| $V_{BE(sat)}$ | -0.15%/°C | |
| $V_{BE(on)}$ | -1.9 to 2.2 mV/°C | PNP tend to be higher than NPN |
| $V_{CE(sat)}$ | +0.23 to 0.4%/°C | Small signal devices (eg ZTX300) |
| | 0.12 to 0.15%/°C | Medium power devices (eg ZTX650) |
| $V_{CBO}$($V_{CES}$) | +0.07 to 0.09%/°C | |
| $V_{CEO}$ | + or - about zero | (Eg. can be small, but very device dependent) |
| $V_{EBO}$ | +0.04%/°C | |
| $I_{CBO}$. | x2 per 11°C | |
| $I_{CEO}$ | Approx x4 per11°C rise | Very dependent on $h_{FE}$ |
| $I_{CER}$(10k) | Approx x3 per 11°C rise | |
| $t_d$ and $t_r$ | Independent | |
| $t_s$ | +1.4 to 1.6%/°C | |
| $t_f$ | +1.0 to 2.5%/°C | |

## DARLINGTONS

| Parameter | Temperature Coefficient | Comment |
|---|---|---|
| $h_{FE}$ | +0.5 to 1.6%/°C | In active region at low to medium currents |
| | + or - about zero (small) (due to inability to saturate fully) | In saturation region |
| $V_{CE(sat)}$ | + or - about zero (small) | |
| $V_{BE(on)}$ | -0.2%/°C | |
| $V_{CBO}$ | +0.08%/°C | |
| $V_{EBO}$ | +0.04%/°C | |
| $I_{CEO}$ | Approx x2 per 8-10 °C rise. | Dependent on voltage as well as temperature |

## MOSFETS

| Parameter | Temperature Coefficient | Comment |
|---|---|---|
| $V_{DSS}$ | +0.04 to 0.1%/°C | Increases with resistivity ($BV_{DSS}$) |
| $R_{DS(ON)}$ | +0.7 to 1.0%/°C | |
| $V_{GS(TH)}$ | -0.1 to 0.2%/°C | |
| $I_{DSS}$ | Approx x2 per 11°C rise | |
| $g_{fs}$ | Small ( say -0.2% / °C) | |
| $V_f$ (of body diode) | -2 to 2.5mV/°C | |
| dV/dT capability falls as temperature increases. Switching speed does not alter significantly. | | |

## DIODES

| Parameter | Temperature Coefficient | Comment |
|---|---|---|
| $V_{SS}$ | -1.9 to 2.2mV/°C | |
| $B_{SS}$ | +0.7 to 0.09%/°C | |

## VARICAP/VARACTOR DIODES

| Parameter | Temperature Coefficient | Comment |
|---|---|---|
| Capacitance | Abrupt:280 ppm @ 4V; 100 ppm @ 20V | Very dependent on bias voltage |
| | Hyperabrupt:350 ppm @ 3V; 80 ppm @ 20V | |

## VOLTAGE REFERENCE DIODES

| Parameter | Temperature Coefficient | Comment |
|---|---|---|
| $V_Z$ | -0.06%/°C<br>Nominally zero<br>+0.075%/°C<br>0.2%/°C | 3.3V(Field effect)<br>5.0V<br>12.0V (Avalanche effect)<br>24.0V (Avalanche effect) |

## SCHOTTKY DIODES

| Parameter | Temperature Coefficient | Comment |
|---|---|---|
| $V_F$ | -1.2mV/°C | |