Lattice Semiconductor Corporation

Temperature Sensing Diode in LatticeSC Devices

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Introduction

Diodes make excellent temperature sensors. A temperature-sensing diode that is embedded into every LatticeSC™ device as an internal thermometer provides a way to monitor the die temperature. This document describes the temperature diode and provides application-specific details for its use.

Diode Description

PTEMP is a dedicated pin attached to the substrate/die. It is a passive device and always available. There are no special design requirements necessary to use it. If the temperature-sensing feature is not used, then PTEMP pin can be left unconnected.

Every device has different amounts of leakage and process deviations. Since each device is unique, the readings are often never identical. One of the parameters used in the equation to determine the device temperature is the Diode Ideality Factor, which describes the behavior of the diode relative to a theoretically perfect diode.

LatticeSC PTEMP Diode Ideality Factor	1.008

Another variable that influences the temperature accuracy is the series resistance, which is a measure of the resistance in the traces leading up to and away from the thermal diode including package and board connections. The temperature distribution across the die may result in significant temperature differences due to the physical location of the on-die temperature diode. This temperature variability across the die is highly dependent on the application in use. As a result, the temperature sensing diode can deviate approximately +/-4% of the actual on-die temperature.

Diode Usage

The most common approach to measuring temperature with the temperature sensor diode is to force two different currents through the diode via the PTEMP pin, typically with a current ratio of about 10:1. This is accomplished by steering bias current through the diode and measuring forward voltage. The actual sensing comes from a simple measurement of the junction's base-emitter voltage (VBE). The PTEMP pin is connected internally to the collector-base and the emitter connection is connected to VSS. VSS_PROBE, a dedicated pin, serves as the ideal point of VSS for this type of measurement, as it assures the absolute point for VSS inside the device.

In general, thermal diode temperature measurements are based on the change of forward bias voltage of the diode when operated at two different currents. The ∆VBE is proportional to an absolute temperature based on the following formula. This difference in V_{BE} of the diode at two different forward currents varies with temperature and can provide a base for the on-die temperature only while the diode is operating within its linear region. A base-emitter PN junction has an inherent temperature dependency described in two different ways:

- $V_{BE} = kT_J/q * \ln (Ic/Is)$
- $T_J = m * V_{BE} + T_0$

Details of these equations are explained in later sections of this document. Both of these relationships are linear and V_{BE} changes approximately -2.3mV / °C.

Figure 1. Diode Measurement Method (Slope Intercept)

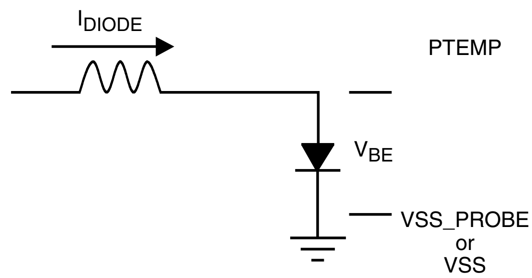
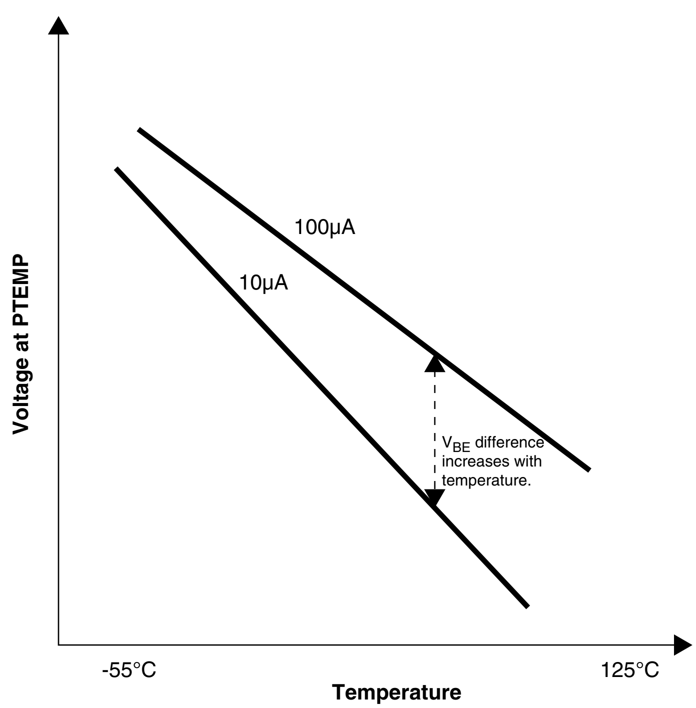


Figure 1 shows an approach to calibrate the temperature diode where a fixed resistance is placed in series with the PTEMP pin. With no power applied to the device, a constant current of 100µA is applied to the test circuit and the voltage value across the PTEMP pin and VSS or PTEMP and VSS_PROBE is monitored. The forward voltage measurement at two temperature values is directly correlated to the internal temperature of the device. This method is used to determine the slope and intercept using the equation and procedure below.

Figure 2. Diode vs. Temperature Relationship



T_J is determined by the following equation:

$$T_J = m * V_{BE} + T_0$$

The following method is used to determine m (slope) and T_0 (intercept):

- Apply a known current (I_{DIODE}) to the Temp pin via a resistor at a known temperature
- No power to the device
- Measure V_{BE} between PTEMP to VSS_PROBE (or VSS)
- Maintain constant I_{DIODE} of 100µA

- $m = (T_{J2}-T_{J1}) / (V_{BE2}-V_{BE1})$
- $T_0 = T_{J1} - m * V_{BE1}$

T_J is determined during operation by measuring the VBE and using the following equation:

$$T_J = m * VBE + T_0$$

System Application

The temperature-sensing diode can be used in conjunction with a Temperature Sensor Interface Chip. This subsystem will improve the accuracy of the measurements. A temperature sensor device typically connects to the LatticeSC device by means of the PTEMP and VSS pins.

On most temperature sensing devices, corresponding pins connect to DXP and DXN. These ICs have many variations for how they are used in systems. Some have upper and lower limits that can be used to create interrupts or alarms. Other follow-on devices have analog to digital converters and serial interface buses.

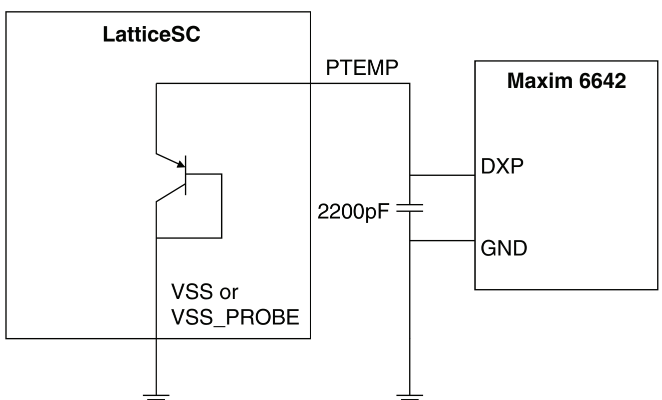
Using the formula $T_J = (V_{BE2} - V_{BE1}) / ((k/q) * LN(I2/I1))$ the temperature at the internal diode is calculated using the data gathered by the temperature sensing IC.

where:

- k = Boltzman's Constant
- q = Charge of electron
- N = Ideality factor

Using these subsystems increases the accuracy of the temperature measurement since it does not depend on the diode and the voltage vs. temperature curve is the physical nature of the diode. The accuracy relies upon the temperature sensor device, which translates the IV vs. temperature curves into a temperature reading. They also increase the accuracy since the required bias is only asserted for a limited amount of time. This reduces the influence of the temperature sensing diode caused by self-heating. The data sheets of the temperature sensors listed in the next section contain the accuracy specifications

Figure 3. LatticeSC to Maxim6642 Temperature Sensing IC



Technical Support Assistance

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Revision History

Date	Version	Change Summary
October 2006	01.0	Initial release.
June 2007	01.1	Updated LatticeSC to Maxim6642 Temperature Sensing IC diagram.
September 2007	01.2	Updated LatticeSC to Maxim6642 Temperature Sensing IC diagram.
December 2010	01.3	Removed reference to examples of Temperature Sensor ICs.