# Real Time Temperature Estimation of Heat Sources in Integrated Circuits with Remote Temperature Sensors

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**Abstract**

Temperature is an important factor affecting both electronic circuit operation and its life-time. Therefore, certain applications require continuous temperature monitoring during their operation so as to protect circuits from destruction. Such circuits should be equipped with temperature sensors placed directly where the heat is generated. However, quite often this is not allowed due to certain design constraints. Then, circuit temperature has to be monitored using sensors located away from the heat sources. The paper presents certain considerations on the possibilities and fundamental limitations of integrated circuit temperature estimation based on remote circuit measurements. The considerations presented in the paper are based on the simulations of a test structure with four heat sources of known location and size, which is similar to the real ones. In the simulations, for a given heat source sizes and position 25 sensor locations were considered as shown in the left figure. For this structure the heat equation was solved using the 3D Greens function method. First, given the position of heat sources, the optimal locations of sensors were found using the steady state solution. In the simulation different number of temperature sensors was considered and various cooling conditions

applied. Obviously all the best solutions always contained the sensors located in the heat sources. However, when the number of sensors was limited only to those located outside the sources, it turned out that the best remote sensor locations are always on the edges of the structure, as pictured for 8 sensors in the left figure with black circles. Next, the dynamic solutions were taken into consideration. The simulations proved that with poor cooling the temperature of a silicon chip is fairly uniform and remote sensor temperatures are lower only by a few degrees than the temperature of the heat source. Quite the opposite, in typical cooling conditions occurring in power applications, the sensor temperature might be lower by more than 50 K, even a few millimetres from the heat source. This suggests that the estimation of hot spot temperature from remote sensor measurements might be an extremely ill-posed problem. On the other hand, in good cooling conditions already after 100 ms the temperature rise in the heat source exceeds one third of its steady state value, which might cause serious problems in the detection of unexpected short circuits before the maximum allowed temperature is exceeded. Finally, the paper discusses the problem of real time heat source temperature estimation in the presence of noise corrupting sensor responses. The computer generated noisy input data was filtered using digital filters implementing the function specification algorithm derived from the Becks method. Exemplary results of such estimation are presented in the right figure, where the noisy estimate (light line) was filtered out (black lines) and compared with the original signal. As can be seen in the figure, owing to the application of the digital filter it was possible to improve significantly the quality of the obtained estimates.