COOL Smartphones

Keeping a smartphone from overheating is becoming more challenging as increasing numbers of transistors and devices are made to fit into a small, sleek design. Qualcomm engineers have developed a way to use simulation to create a smaller model of the power sources in a smartphone. This model can be solved in a fraction of the time of a full thermal analysis, so that they can look at more operating scenarios. The goal is to create a dynamic power management strategy to selectively direct power where it is needed and keep temperatures down.

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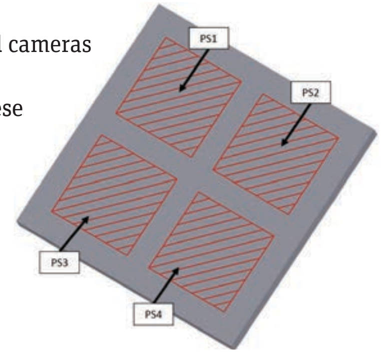
As smartphones continue to add features (high-end cameras and antennas) and multitasking capabilities, the additional processing power needed to control these features generates more heat. High temperatures can reduce battery life and accelerate the degradation of interconnects and devices. In addition, a feedback loop can occur in which high processor temperatures lead to high power consumption, which in turn leads to additional temperature increases, in an endless cycle. So smartphone manufacturers must find ways to keep their phones cool.

One solution is to develop a dynamic power management (DPM) strategy that selectively turns off or reduces the power



Layout of power sources in main processor

"Qualcomm *engineers* used a simple state-space model in a *simulation* to obtain nearly the same results as a full CFD simulation but 2,400 times *faster*."

to certain processors until they cool below a specified temperature. DPM strategy requires distributed temperature sensors around the device, especially at critical locations like processors, cameras and antennas. Optimizing a DPM strategy to prevent overheating while maximizing the functionality of the smartphone requires simulation.

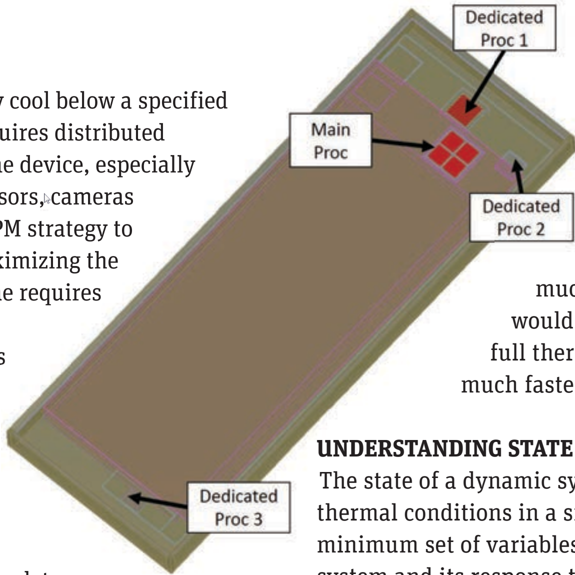
Traditionally, Qualcomm has used a full CFD analysis to investigate the transient thermal flow in a smartphone design and investigate possible DPM strategies. But because a full CFD simulation continuously solves for the complete temperature and flow field throughout the smartphone, investigating a single DPM strategy using this method is time-consuming. So Qualcomm engineers began exploring a reduced-order model (ROM) based on linear and time-invariant (LTI) systems and a state-space model that could be solved by simulation in a fraction of the time.

The result was a process that uses ANSYS Icepak to perform an initial thermal analysis of the smartphone. The data generated by Icepak was used by the integrated multi-domain systems modeling tool, Simplorer, to create a state-space model — a form of ROM. Simplorer then solved this simplified model in a fraction of the time required for a full CFD method.

LINEAR AND TIME-INVARIANT SYSTEMS

Linearity means that the relationship between the input and the output of the system is a linear map. Time invariance means that whether an input is applied to the system now or sometime in the future, the output will be identical. Most importantly, if two LTI systems have the same step response to a given input, the two systems behave identically. In this case, the two LTI systems are said to be equivalent.

If Qualcomm engineers could show that the thermal model generated by full CFD simulation and the smaller state-space model were equivalent, solving the much simpler state-space model would be equivalent to solving the full thermal model using CFD, in a much faster time.



< Smartphone layout

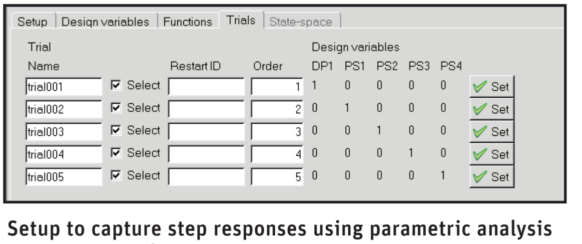
UNDERSTANDING STATE SPACE

The state of a dynamic system, such as the transient thermal conditions in a smartphone, refers to a minimum set of variables that fully describe the system and its response to any given set of inputs. These variables are called state variables, and together they define the state space of the system. In a state-space model, knowing the values of these variables at an initial time, along with any inputs to the system at later times, is enough to predict all future states of the system, including outputs. Because the number of state variables is orders of magnitude less than the number of cells in a full CFD analysis, a simulation run using a state-space model can be performed much faster.

For a smartphone, the power dissipated as heat within the processors as a function of time is the system input; the system output is the increase of the chip's junction temperature as a function of time. Under typical operating conditions, such a thermal system can be approximated as an LTI system.

CASE STUDY

Although a typical cellphone might have about 50 power sources, as a first proof-of-concept trial

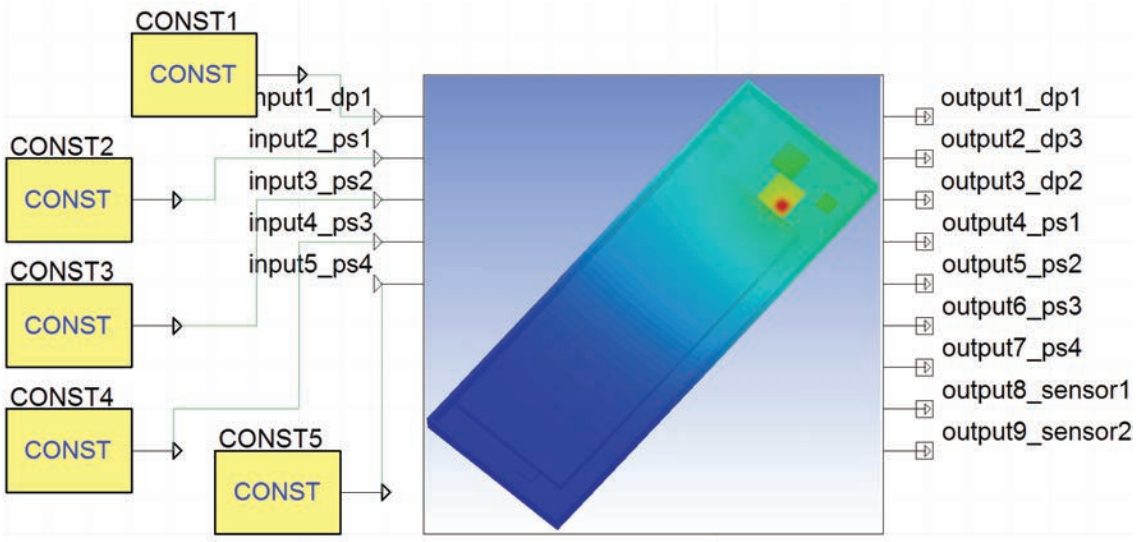


Setup | Design variables | Functions | Trials | State-space

Trial Name		Restart ID	Order	DP1	PS1	PS2	PS3	PS4	
trial001	Select		1	1	0	0	0	0	Set
trial002	Select		2	0	1	0	0	0	Set
trial003	Select		3	0	0	1	0	0	Set
trial004	Select		4	0	0	0	1	0	Set
trial005	Select		5	0	0	0	0	1	Set

Setup to capture step responses using parametric analysis in ANSYS Icepak

Beat the Heat with ANSYS Icepak
ansys.com/beat-heat

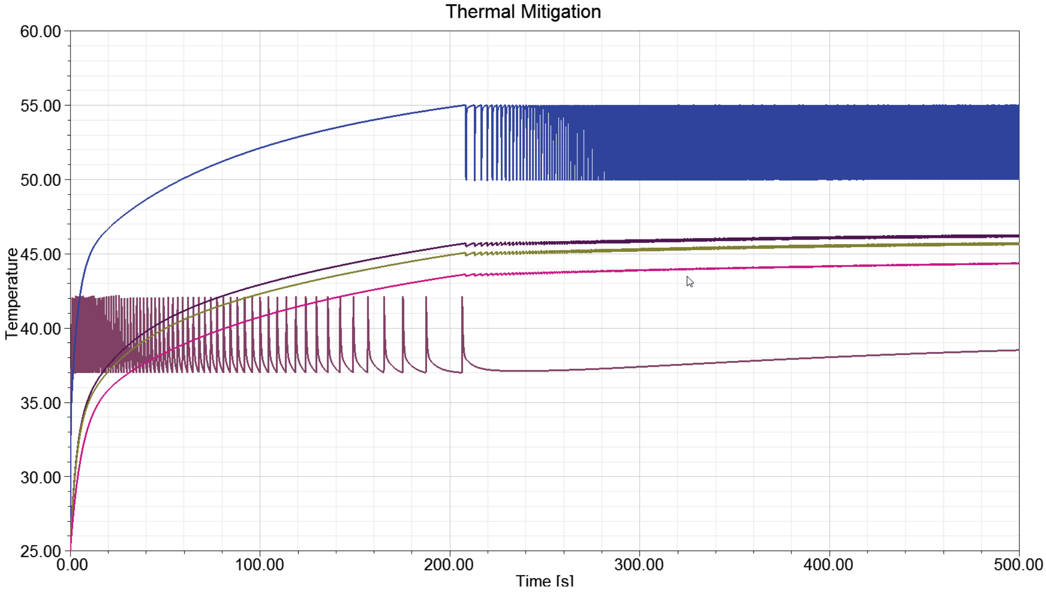


ANSYS Simplorer model validation

Qualcomm engineers simplified the model to five power sources: four in the main processor and one in a dedicated processor (such as the one that controls the camera, for instance). These five power source inputs require five Icepak simulation runs, using its parametric capabilities. Using the step response generated from these Icepak simulations, Qualcomm engineers then performed some mathematical calculations to prepare for creating the state-space model, including:

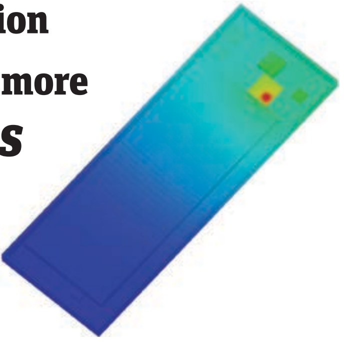
1) Calculating the impulse response from the time derivative of the step response.
2) Sampling the impulse response curve.
3) Performing a fast Fourier transform (FFT) of the sampled impulse response.
4) Using the low-frequency portion of the FFT and scaling it in both coordinates to get the sampled Fourier transform of the impulse response.
5) Performing vector fitting to obtain the poles and residuals of the transfer function of the state-space model.
6) Extracting the state-space model from the transfer function using Simplorer.

After the state-space model was created, engineers applied a constant power of 1.5 watts to the four main processor power sources and 0.1 watts to the dedicated



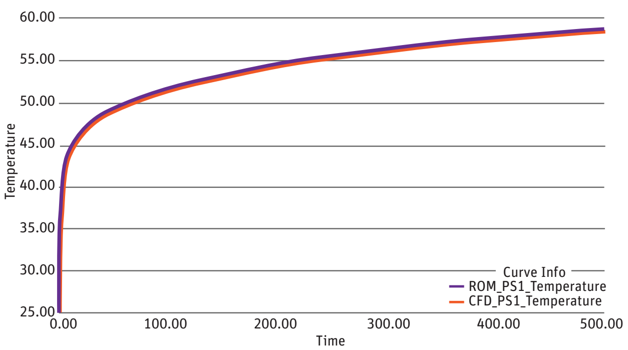
The state-space model results for model with dynamic power management

> **"By keeping *smartphones cooler*, simulation will extend their working lifetimes, even as more features and *multitasking capabilities* are added in the future."**



processor. A system-level thermal simulation produced nine outputs corresponding to the junction temperature of all the processors and sensors in the smartphone: one output each for the four main processors; three outputs for the dedicated processor; and two outputs for the two sensors on the chip.

A full CFD run on the complete smartphone model had 1 million computational cells and took two hours to run on eight compute cores. The results of the system-level thermal run on the state-space model with only five inputs and nine outputs took 20 seconds on one compute core. A plot of the two runs shows almost identical results, verifying that the reduced-order state-space model was the equivalent of the full CFD model — an important conclusion, as discussed above.



Comparison between ANSYS Icepak results and the state-space model results for PS1

ANALYZING DYNAMIC POWER MANAGEMENT OF A SMARTPHONE

Because the state-space model can be solved in 20 seconds, Qualcomm engineers were able to study different usage scenarios quickly, which enabled them to investigate more scenarios than before. For the published study, they used a two-point hysteresis element with two power inputs and two thermal outputs to study the DPM of one of the main processors. Setting up a lower temperature limit of 98 C for the output and an upper temperature limit of 100 C, they used Simplorer to simulate a DPM strategy, turning on the power at 1.5 W when the output temperature was 98 C, and shutting off the power input (0 watts) if the temperature reached the upper limit of 100 C. At the same time, the dedicated processor was simulated with a temperature window of 40 C to 45 C and a power input range of 0 watts to 0.1 watts.

The results of the simulation showed that the main processor never reached the upper temperature limit of 100 C in this scenario. The dedicated processor, however, did exceed 45 C. It was never turned back on because the heat from the main processor never allowed the temperature of the dedicated processor to go below 40 C. Ideally, once engineers have found the optimal power-on duration, they can optimize the chip only for that duration. Alternatively, if a temperature limit is exceeded on a critical power source on the chip, it can be set to a lower frequency and perform at a reduced workload without completely shutting down.

CONCLUSIONS

This investigation showed definitively that Qualcomm engineers can use a simple state-space model in a simulation to obtain nearly the same results as a full CFD simulation. The framework developed can predict the heat dissipation and the location of hotspots under a certain workload, sounding the alarm when temperature limits are exceeded. There is a one-time cost in making the reduced-order model, but once it is available it enables engineers to explore a lot more what-if conditions. Because the state-space simulation is a factor of 2,400 faster than a full CFD run, they can run many more simulations to fine-tune the DPM of all the power sources in a smartphone. Even though this test case used only five power sources, it will be possible to create a state-space model containing the more than 50 power sources in a working smartphone, and use the integrated system modeling features of Icepak to develop a DPM strategy that may reduce the power input to a specific source but never turn it off completely, so that the phone will retain full functionality, if perhaps not at full speed. By keeping smartphones cooler, simulation will extend their working lifetimes, even as more features and multitasking capabilities are added. Λ

The Role of Simulation in Innovative Electronic Design
ansys.com/role