Thermal Analysis of an ADAS Camera in FloTHERM XT

By Vladimir Kirichenko, Student Intern, Mentor, a Siemens Business

As the world continues to evolve, autonomous vehicles suddenly have stopped being seen as something from the future. In fact, both world leading companies and new start-ups are getting involved in the automotive world with the aim of not only providing simple driving assist features, but enabling full control of the vehicle to drive its passengers to their destination of choice. While humans mainly rely on their eyes to navigate, autonomous vehicles have to depend on cameras and other sensors to analyze the outside world to familiarize themselves with their surroundings.

Inaccurate data from these devices could have catastrophic consequences and cost lives of passengers and pedestrians. One of the factors that affect image quality is the thermal performance of the optical cameras, resulting in a challenging task of keeping the temperatures at sensible levels.

Challenges

As can be seen from Figure 1, the temperature of the image sensor chip plays a large role in image quality, as higher temperatures dramatically raise noise levels in the Complementary Metal–Oxide–Semiconductor (CMOS) circuitry. Consequently machine vision algorithms may struggle to distinguish objects from the background. To make autonomous vehicles safer and more trustworthy, the camera complexity has increased, and may also incorporate radar, lidar or ultrasonic sensors. Combining such power-intensive devices in one package leads to problems with heat dissipation, therefore serious consideration should be given to virtual thermal analysis during iteration of the design of the cameras used for autonomous driving to develop a final product that will give satisfactory and reliable operation.

Modeling

To analyze thermal dissipation of the automotive cameras in the current market, Mentor kindly provided to me one of the top of the range ADAS cameras available on the market today to disassemble and examine. Based on the research and the physical device, I created a model, using Siemens NX 10.0, as that was the CAD software I had the most experience with, allowing me to spring into action as soon as possible. It was also a great opportunity to do my primary job role, which was to test FloTHERM XT 3.2 using different import formats to ensure every feature worked correctly. An exploded view of the model I built is shown in Figure 2.

The camera is housed in a plastic shell, apparently for purely aesthetic reasons with cut-outs to provide airflow. The casing of the camera was modeled in a way that the bottom of the casing acts like a heatsink, dissipating most of the heat from major image-processing components in a convective manner. To encourage airflow inside the metal casing, multiple cut-outs have been made to the bottom and top of the casing. This design allowed for the air to circulate inside of the casing, removing the heat from the rest of the components. Any cables and connectors that could restrict the airflow were modeled for increased accuracy of the simulation.

Simulation

Once complete, the model was easily transferred to FloTHERM XT, which meant there was only one part missing before I could perform a thermal analysis on the camera - the main PCB. It was created using FloEDA Bridge, which allowed for a

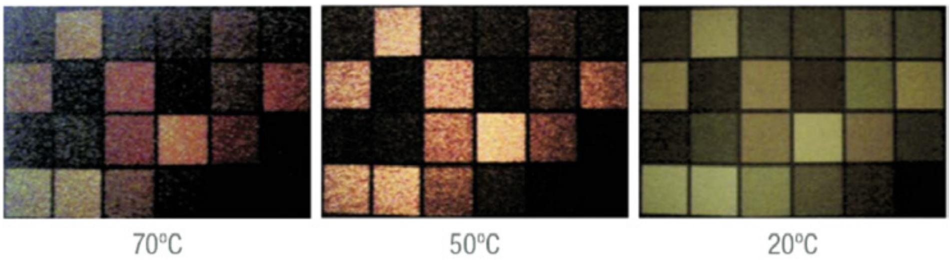

Figure 1. High dynamic range camera image sensor noise under low light for different ambient temperatures (Ref. 1)

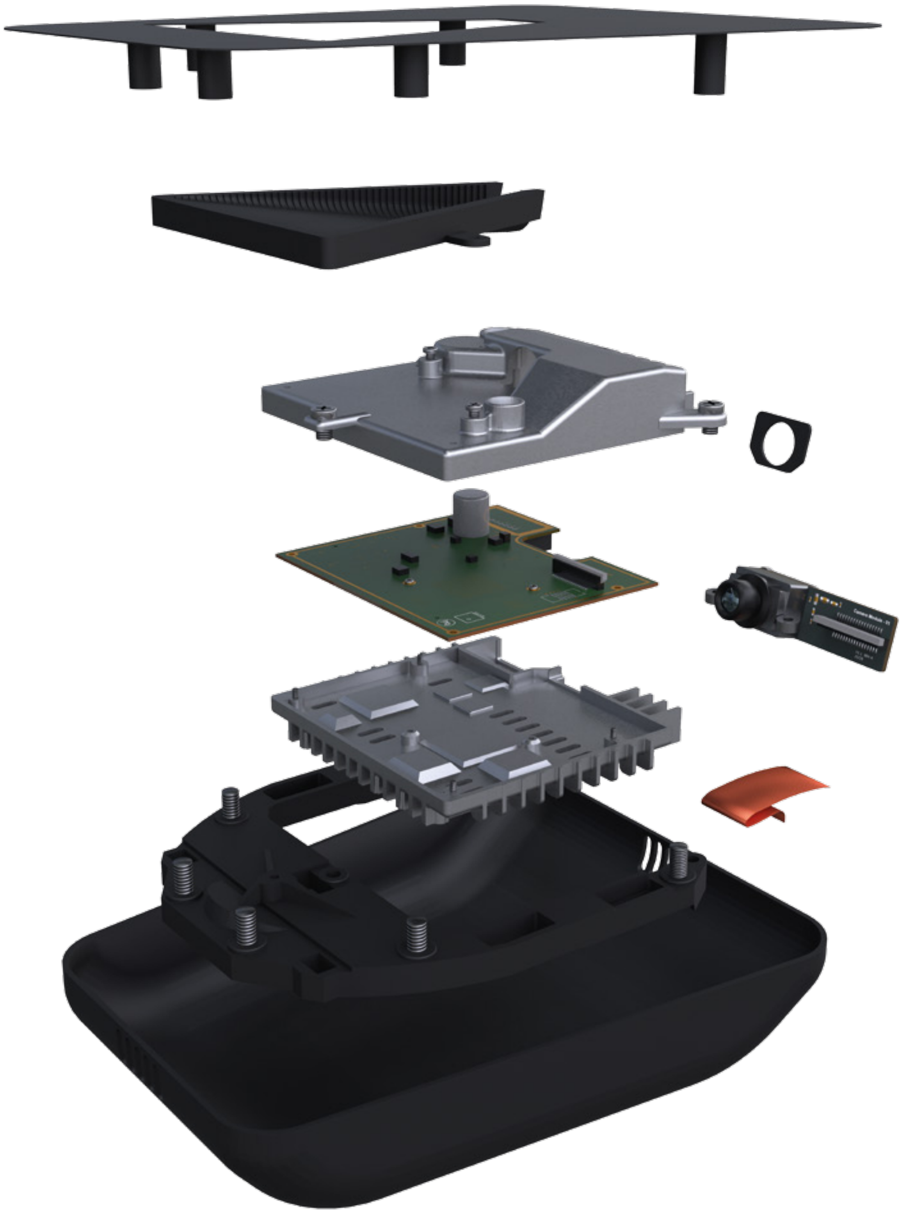

Figure 2. Exploded view of ADAS camera model

complex shape of the board and detailed manipulation of necessary parameters. However, if I had the EDA file, it could have been easily imported. Overall, the camera was modeled with eight thermally-significant components assumed to have a total heat dissipation of 6W. The main SoC was dissipating 2.5W of power at the maximum load and has been modeled in detail. All of the power values were assumed based on the research of vision computing SoCs available on the market and engineering judgement. To speed up the simulation, the remaining components were modeled as simple cuboids with an appropriate material attached. For the same reason, compact modeling level of the PCB was chosen instead of detailed or explicit.

Cases

In order to perform a thorough thermal analysis, three different simulations were run. One of the places where autonomous driving technology becomes very useful is the highway, as most of the time the trip becomes monotonous and some drivers can lose concentration. Therefore, to simulate the worst case conditions and analyze a case where, if the limit of 85°C was exceeded when the vehicle is in fully autonomous mode and the camera is functioning at full power, a steady state simulation was created. The vehicle was assumed to be driven at 50 mph on a warm sunny day, consequently, 1000 W/m2 of solar radiation was applied at a right angle to the windscreen. To make the simulation more realistic, 20% of the radiation has been absorbed by the windscreen by using a thermal planar source, 60% was applied as a simulated solar radiation and the remaining 20% of the solar radiation was assumed to be reflected and therefore ignored. Further to this, the heat from the camera has been removed solely by natural convection without the presence of forced airflow inside of the cabin. The absolute maximum temperature on the main SoC reached 82°C, while the air inside of the vehicle was simulated at 22°C and the outside temperature levelled at 35°C. From these results, it becomes apparent that although these are absolute extreme conditions and can be considered as a torture test, the camera components are close to their limits.

Problems

Having tested the thermal limits of camera components, two transient simulations were performed to simulate a more realistic scenario. The main problem with the current model was the excess level of detail. Therefore, to improve simulation times, I have made several adjustments. The main SoC was simplified to a simple cuboid with the same thermal properties and a heatsink for the camera module was replaced by a Heatsink Smart Part available in FloTHERM XT 3.2. This led to a dramatic decrease in the number of cells, allowing for significantly reduced simulation times. Even though the mesh number has decreased significantly, I

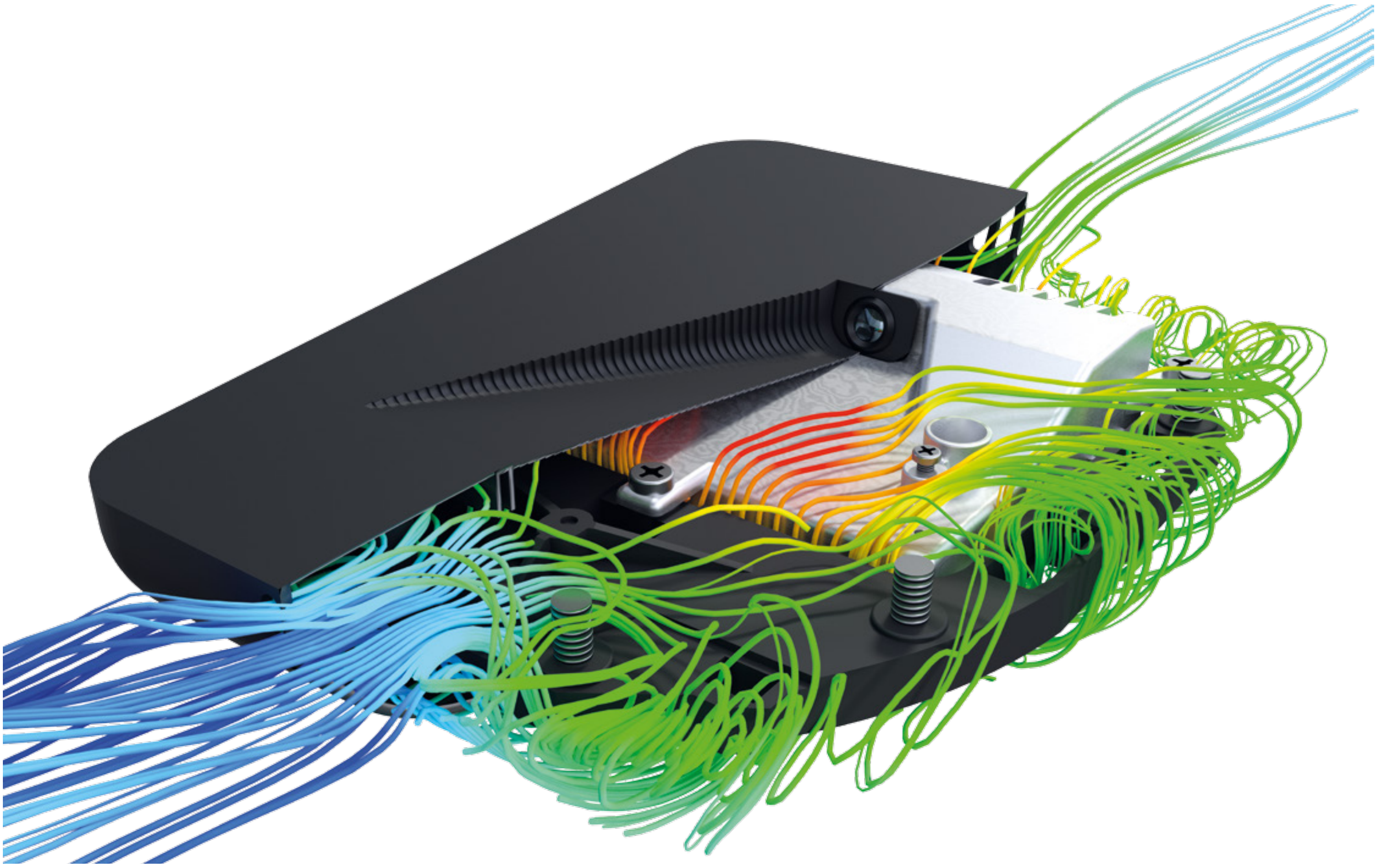

Figure 3. Predicted airflow inside the camera housing

was still unsatisfied with the amount of time it was going to take to perform the thermal analysis. To further optimize the simulation, manually-variable time steps were used.

To further limit the time needed for the simulations, the overall calculation domain was restricted to a box 180x190x135 mm, which worked perfectly for the simulations in still air. However, after an introduction of wind the problems started to appear. As the moving air created turbulence, this solution domain size was not large enough to resolve the flow. Therefore I increased the domain size by approximately 2.5 times.

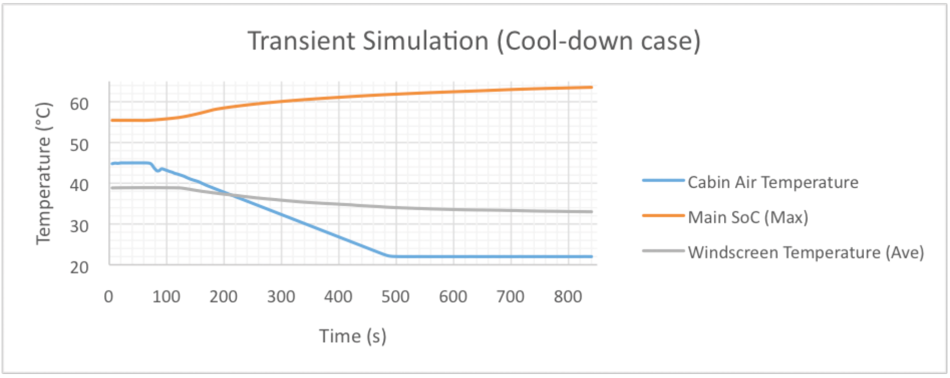

Figure 4. Key temperatures during transient cool-down simulation

Transient results

Continuing with the theme of testing the thermal limits of the camera, one of the transient simulations was performed as a cool-down case. I assumed the vehicle was parked under the sun at 30°C with a solar radiation of 750 W/m^2, 50% of which was applied as radiation, 10% being absorbed by the windscreen and another 40% was reflected, and after that it is driven at 30 mph in a city area.

To ensure the correct starting point of the transient simulation, I have performed a steady state simulation with static air first. This allowed the interior of the vehicle to warm up due to solar radiation and stabilize temperatures of the camera components. These results determined the starting point for the cool-down transient case. The temperatures inside of the cabin stabilized at 45.0°C and the temperature of the main SoC in the camera stabilized at 55.4°C.

The overall time of the transient simulation was 14 minutes, from the first to the eighth minute the AC was turned on to cool the cabin air down to 22°C and keep it at this temperature until the end of the simulation. From the second minute the vehicle accelerated from 0 to 30 mph in 10 seconds and then continued at this speed. The camera itself was powered at 25% while the vehicle was stationary and the AC was on. As soon as the vehicle started moving, the power was increased to 75%, which was assumed to be sufficient to provide advanced driver-assistance systems. From Figure 4 it is apparent that the maximum temperature of the main SoC of the camera stabilizes at 64°C, which is an acceptable result, as in reality the solar radiation would tend to vary due to the surroundings and the power consumption of the camera unit would be altered by traffic conditions.

Turning to a warm-up case, it was assumed that the vehicle was parked outside at -10°C and there is no solar radiation. Similarly to the cool-down case, a steady state simulation was performed first and the vehicle was assumed to be driven at 30 mph. As the changes were not as dramatic as with warm-up case, the simulation had to be run for much longer for the temperature of the main SoC to stabilize.

Eventually, main SoC temperature levelled out at 19.5°C, which puts the camera assembly at a very comfortable level in terms of working temperatures. In this case the temperature of the cabin air had to be raised to a comfortable temperature for the driver and passengers.

Conclusion

With a rapid growth of the automotive industry, there will be increasingly higher demand for cameras and radars that are required to work for longer periods of time without failures in varying weather conditions. As this article has shown, thermal analysis is extremely important to ensure that the design of the Advanced Driver Assistance Systems (ADAS) camera is effective at removing excessive heat from the internal components.

To improve the design of the device, it will be worth considering several materials before production, as well as, simulating the whole camera assembly with the casing and inside of the vehicle's interior. This would help to identify critical locations for the cut outs in the casing to optimize the airflow. It is important to mention, that while regular processors in a PC or a laptop can be thermal-throttled to reduce the temperatures, this approach is highly undesirable as this would slowdown the processor frequency and reduce the performance, which consequently reduces the speed of image-processing and may affect how efficiently and safely an autonomous vehicle reacts to the road conditions.

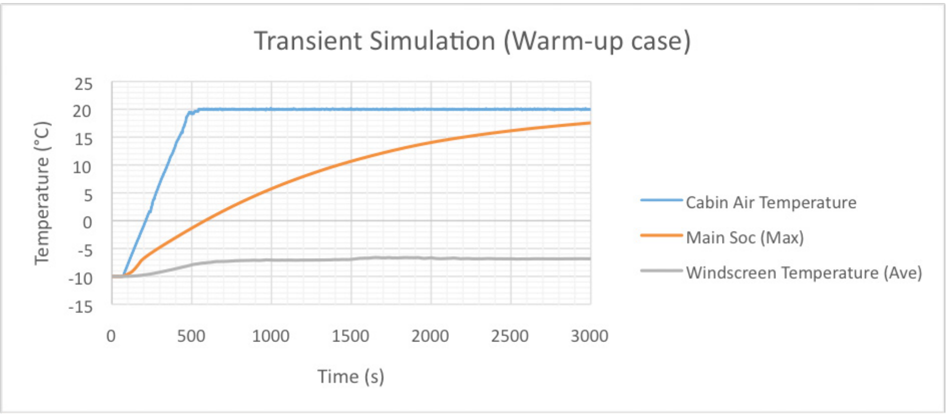

Figure 5. Key Temperatures During Transient Warm-Up Simulation

Power	"Climate Control" temperature	speed
0-1 mins: 0 %	0-1 mins: not set	0-2 mins: 0
1-2 mins: 0-25%	1-8 mins: from cabin ambient to 22 degC	2-2:10 mins: 0-30 mph
2-3 mins: 25-75 %		
3-13:50 mins: 75%	8-13:50 mins: 22 degC	2:10-13:50 mins: 30 mph

Power	"Climate Control" temperature	speed
0-2 mins: 0 %	0-1 mins: not set	0-4 mins: 0
1-2 mins: 0-25%	3-8 mins: from cabin ambient to 22 degC	4-4:10 mins: 0-30 mph
2-3 mins: 25-75 %		
3-50 mins: 75%	8-50 mins: 22 degC	4:10-50 mins: 30 mph

Reference:

[1] "Comparing Ethernet and SerDes in ADAS Applications", Dave Lewis, Texas Instruments. http://artsdocbox.com/Television/66316313-Comparing-ethernet-and-serdes-in-adas-applications.html (downloaded 07 March 2018)