COOLIT thermal analysis of cooling solutions with heat pipes and TEC devices

Dr. Song Lin, John Broadbent
CE Technologies Ltd, E-mail: songlin@cetechnologies.co.uk, Web: www.cetechnologies.co.uk

Abstract

COOLIT is an advanced CFD package for thermal management, especially in electronics industry. Due to its innovative approaches in model construction, meshing and solving, it becomes the world's easiest-to-use and most cost-effective computational fluid dynamics (CFD) software for design engineers and CFD specialists. In this case, COOLIT provides the most efficient way to simulate cooling solutions using heat pipes and TEC devices.

In electronic systems, thermoelectric (TEC) devices associated with heat pipes (HP) can be used to maintain key component temperatures below the ambient temperature. Utilisation of heat pipes in thermoelectric systems may lead to a significant enhancement of the system thermal performance. However, the design of thermoelectric system with heat pipes still meets number of challenges, especially in the calculation stage. This paper presents the thermal design analysis for such a system by using COOLIT. In COOLIT, the simulation of thermoelectric device with embedded heat pipes can be carried out easily and produce good results. The study suggests that the COOLIT model is able to predict thermal performance of the thermoelectric devices with heat pipes and thus can be used in system designs.

Key words

Thermal design analysis, CFD simulation, COOLIT, heat pipe technology, embedded heat pipes, TEC, thermoelectric conversion, thermoelectric modules, high performance thermal solutions

Introduction

Thermoelectric (TEC) devices integrated with heat pipe technology have found their increasing applications for thermal management in microelectronics, telecommunications and power electronics. In such integrated systems, heat pipes are two-phase heat transfer devices with extremely high effective thermal conductivity. They can be cylindrical or planar in structure to fit with TEC devices. Due to the high heat transport capacity, cooling systems with heat pipes will become much smaller than traditional extruded fins in handling high heat fluxes. With the working fluid in a heat pipe, heat can be absorbed on the evaporator region and transported to the condenser region where the vapour condenses releasing the heat to the cooling media.

TEC device, also called "Peltier device," is a solid-state approach to transport heat through dissimilar semiconductor materials. In a thermoelectric refrigeration system, the three main working parts are a cold junction, a heat sink and a DC power source. The cold junction becomes cold through absorption of energy by the electrons as they pass from one semiconductor to another. The DC power source pumps the electrons between the two semiconductors. A heat sink discharges the accumulated heat energy from the system.

Good thermoelectric semiconductor materials, such as bismuth telluride, greatly impede conventional heat conduction from hot to cold junction, and provide an easy flow for the carriers. In addition, these materials have carriers with a capacity for transferring more heat. Thermoelectric materials are also of interest for applications as heat pumps and power generators. The performance of the heat sink is a very important aspect of good thermoelectric systems. Thus heat pipes as highly thermal conductive element can play an important role in such systems.

To design and make an effective TEC cooling system integrated heat pipes, thermal analysis of such a system is essential. The task can be frustrating to engineers, due to performance prediction of TEC modules associated with heat pipes. The right combination of TEC modules and heat pipe assemblies can mean the difference between leap-forward competition and lagging behind.

In order to optimize a thermal design of TEC heat pipe systems, engineers typically set up a TEC model with initial guess data to calculate the temperature difference across the hot side and cold side of the TEC module through manual iteration with CFD modelling. This process can be incredibly time-consuming.

To eliminate the guess-work and manual calculations for TEC systems, COOLIT[1] has integrated a TEC module within the components panel. This allows engineers to set up a model with TEC device and run the simulations easily and quickly. Users only define the TEC module parameters, then click "Start" to run the simulation. The COOLIT solver takes care of the rest. This function transforms thermal analysis for TEC systems into a faster and more effective, and guarantees that engineers will examine all possibilities for optimising the system.

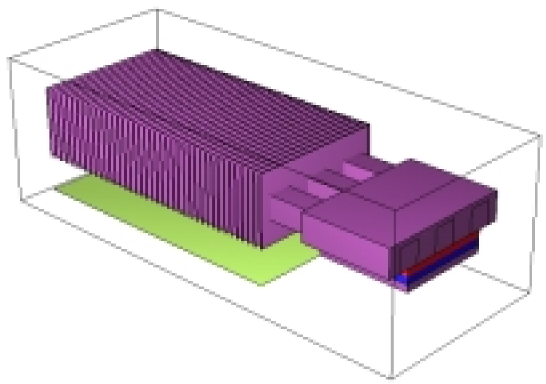
The powerful function of TEC module in COOLIT is demonstrated in the case study. The cooling system is required to maintain the key component below the ambient temperature and there is a remote air flow source available to dissipate the heat into the ambient. At CE Technologies Ltd, we proposed a conceptual design with TEC and heat pipe fin stack and finalised the system parameters to meet the specifications.

Model construction and simulation

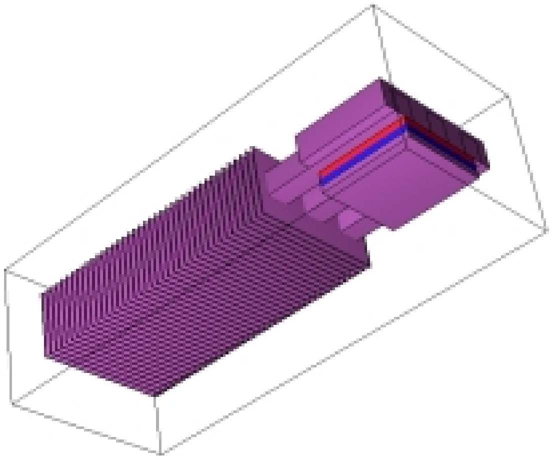
The key component is 40 mm by 40 mm with a heat dissipating power 10 W and will operate in a 20°C ambient. The component temperature should be below 15ºC at this ambient.

Based on previous design cases, the initial design consisted of a 40mm×40 mm TEC module and the heat pipe fin assembly. The TEC characteristics are available from the supplier. The voltage of the power supply is 24 V. The heat pipe fin assembly included 3 off ½ inch water/copper heat pipes, fin stack and copper spreader. The length was 180 mm which was determined by the location of the air flow. The envelope of the fin stack was 30mm×60mm×120mm. The fin parameters such as fin gap, fin thickness and fin size can be optimised within COOLIT to achieve the lowest temperature on the component. The available air flow for the fin stack was 150 CFM.

COOLIT has provided the easies way to construct such models with TEC devices. There are standard fin, cuboid and TEC module in the tool bar. By selecting and dropping in the 3D drawing window, the system model has been constructed within less than an hour. By specifying parameters, such as volt, current, number of TEC couples, and characteristic curve, the TEC model is ready to go. Here the heat pipes were modelled as cuboids with very high thermal conductivity. The copper spreader is also modelled as a cuboid. The model of the system is shown in Figure 1. The air flow rate was defined across a flow area and blow towards the fin stack region. To optimize the fin design we could use COOLIT OptimizeIt module. We could specify several fin number and fin thickness values for optimising simulations.



a) View 1



b) View 2

Figure 1 Coolit model of TEC & heat pipe cooling system

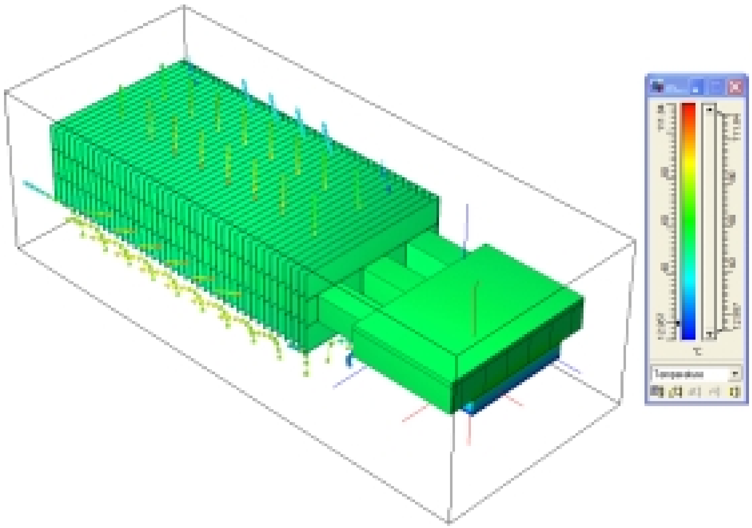
The mesh for the simulation domain has been automatically generated by Coolit with the embedded mesh technology which has dramatically reduced cell counts and made it possible to model complex systems to details required. Coolit has provided a compact model and detail model for heat sinks. This analysis has used the detail model to the fin stack for more accurate results. Three cells were selected between two neighbouring fins and one cell for fin thickness.

Results and discussions

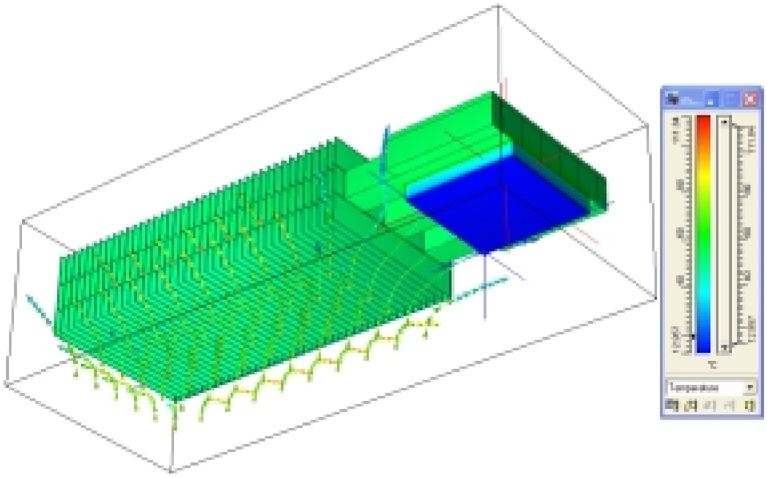
The thermal performance of the cooling system for the basic conceptual design is shown in Figure 2. The air flow within the fin stack region is also shown in Figure 2. In Coolplot, the flow vector and surface temperature profile in the model are generated automatically. The post processor is integrated in the package for easy use.

The temperature profiles of the system via the cutting planes are illustrated in Figure 3. Since the heat pipe cuboids were defined as super-conductor, the temperature difference along the heat pipe cuboids should be very small. The profiles illustrate that the temperature variation along the heat pipes is within 1.5ºC. The temperature distribution along the heat pipe cuboids reflect the actual situation of heat transferred via heat pipes.

The results show that with this cooling system, the maximum temperature of the key component is 13.5°C, which is 1.5°C below the required component temperature, 15°C. The temperature profiles on the cutting planes show the hot end of the TEC device. Due to the low thermal conductivity of the TEC case, the temperature of the hot side section is much higher than the ambient temperature. Figure 3a) shows the temperature profile at the central cutting plan and the point with the maximum temperature in the system. From the temperature profiles on the cutting planes, it can be derived that the hot spot will be within the central part of the hot side of the TEC chips and the heat needs to be transferred into the ambient to maintain the temperature difference between the hot side and cold side. The cold side of the TEC chip is the point with the lowest temperature in the system. The Coolit simulation results just illustrate this feature of TEC device.



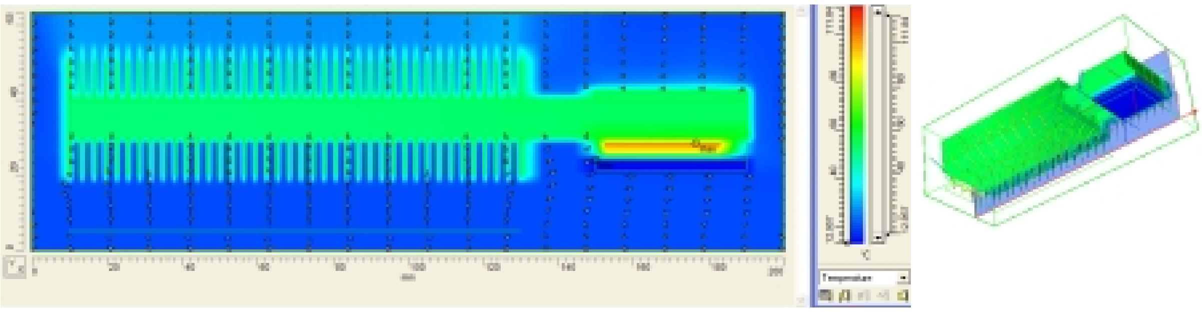
a) View 1



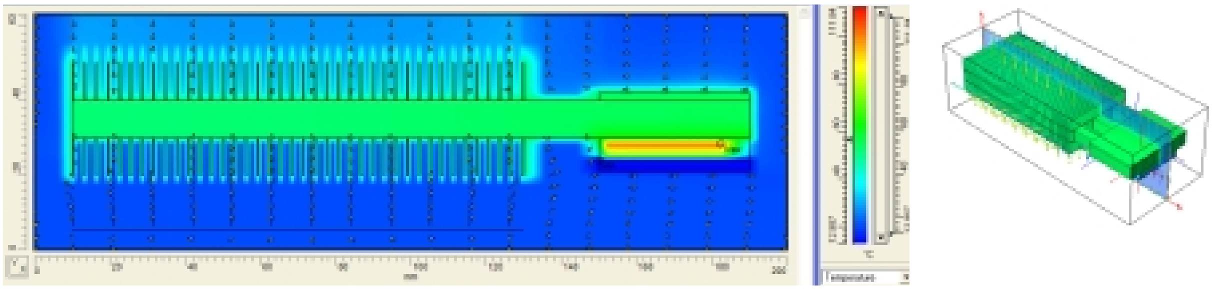
b) View 2
Figure 2 Temperature distribution and flow pattern around fin stack

OptimizeIt in Coolit is a powerful function for set of cases with similar basic parameters, which has been used to analyse the effect of number of fins on the component temperature with other parameters unchanged. Figure 4 shows the cases established and key output parameter, the maximum temperature of the key component. It is known that with increasing number of fins, the heat transfer area within the fin stack will be increased and thus the thermal resistance from the surface of the hot side of the TEC device to the ambient via the cooling solution can be reduced. Furthermore, the component temperature can be reduced consequently.

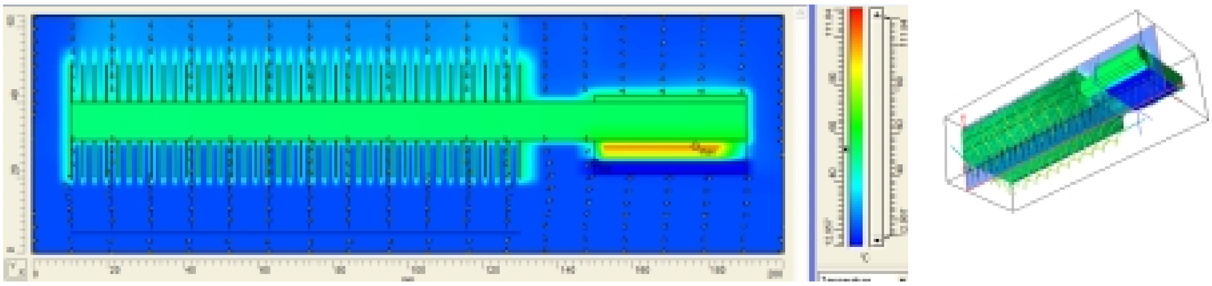
With 4 cases in the case map, the results show that the component temperature will drop by only 2.3°C with 12 more fin added. Using more fins will lead to higher unit cost for such cooling solution. Since the initial design of the cooling solution has met the specifications for cooling the temperature of the component, for this case, we recommend that 40 fins with 0.5mm thickness should be used and ensure the system to cost-effective. With consideration of manufacturing cost, standard 0.5mm fins are easy and cheap to be formed.



a) Temperature profile on Z-plane 01



b) Temperature profile on Z-plane 02



c) Temperature profile on Z-plane 03

Figure 3 Temperature profiles via cutting planes

OptimizeIt

Study Type | Parameterization | Objective Function | Constraints | Case Map

Status/File	Runs	heat sink Pins/Fins Number, Widthwise	comp Max Temperature(°C)
OK Case-1	Locally	40	1.3560999e+001
OK Case-2	Locally	44	1.2521997e+001
OK Case-3	Locally	48	1.1747003e+001
OK Case-4	Locally	52	1.1232996e+001

Figure 4 Simulation of set of cases with parameter variation using OptimizeIt

Conclusions

With Coolit TEC module, the simulation of systems using TEC device, becomes a simple process. The predicted results show that Coolit predictions are reasonably good. The customer, impressed by how well the Coolit predictions matched their test results, thought that the Coolit predictions of TEC systems are rather reliable.

Reference:

1 DAAT, Inc; www.daat.com; June 2005