Thermal simulation of an Antenna

Computational Heat Transfer, TMMV54

Bharath Kumar Kuna (bhaku277)

Kunal Muralidharan (kunmu664)

Yuvarajendra Anjaneya Reddy (yuvan983)

Linköping university
Division of Applied Thermodynamics and Fluid Mechanics
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1 Introduction

The prediction and management of heat transfer in an electrical equipment is an integral part in terms of the durability and the reliability. Particularly, in case of an antenna or an amplifier or a resistor where lots of heat is generated, the most common means of failure are due to the higher operational temperatures zones. This brings out the need for a research or a considerable study to be done in order to increase the efficiency and life of the electronic equipment.

The current trend of making everything compact has rubbed off in the antenna design sector as well and this leads to striking a fine balance between available space for squeezing in the components and an efficient cooling system. The geometry of the antenna considered here has amplifiers, made up of aluminium cores covered with thick copper covers. These amplifiers are then mounted on to a aluminium plates which is cooled by the circuit of copper tubes supplied with a steady water flow. The pictorial representation of the geometry is presented below in **Fig.1**

This project is aims to perform a study in order to investigate whether the current cooling system can keep the maximum operating temperature within 50 [degC] by considering the assumptions and geometrical simplifications of the model. Two simulations, steady state and transient state are performed here. The results from these simulations are presented so that the manufacturer of the antenna can have a better insight into the, temperature distribution, magnitudes of temperatures at important locations, time required to achieve thermal equilibrium and so on.

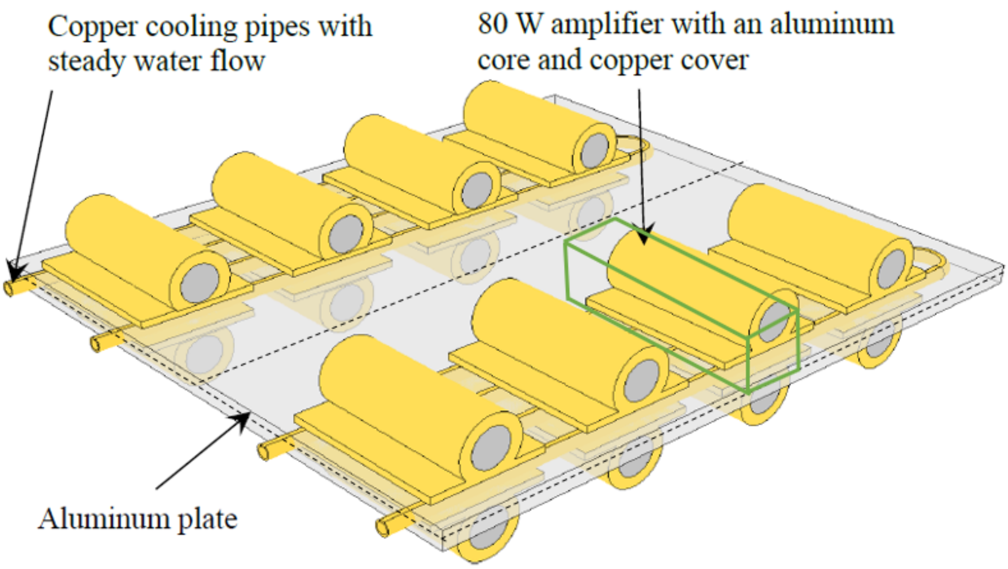


Figure 1: Schematic representation of the antenna [1]

2 Method

2.1 Geometry and simplifications

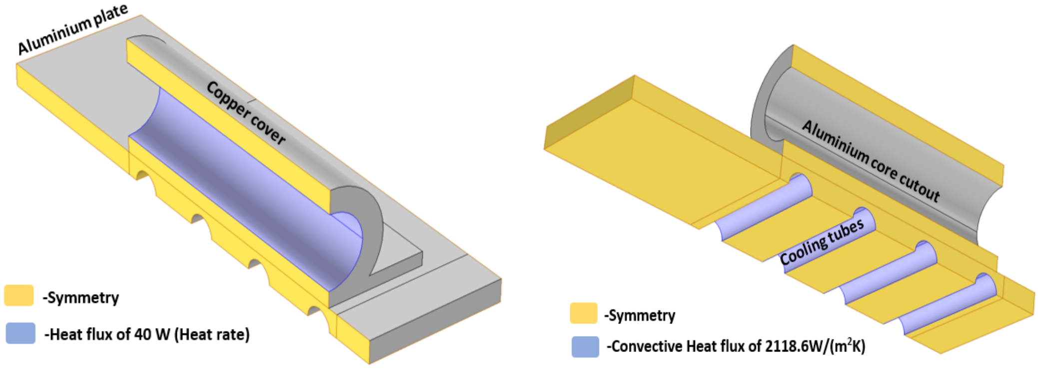
The geometry of the antenna is provided as the part of the assignment here. This geometry of the antenna consists of 8 similar parts with 16 amplifiers for each. These amplifiers here are the aluminium cores, which are covered by the thick copper covers as mentioned. The product of the aluminium cores and the copper covers are mounted on to the aluminium base plate that has copper tubes running through them where the water for cooling flows. All these components are placed in an airtight box indicating that the heat transfer through radiation is completely neglected. The air in this box is also assumed to be constant.

Making use of the symmetric properties of the geometry reduces then computational cost significantly. Workplanes are created in the COMSOL Multiphysics 5.5 app under geometry section to cut the geometry along the symmetric planes. In **Fig.1**, the black dotted lines represent the symmetric planes, and the green rectangular cuboid represents the final processed, simplified geometry for carrying out the simulations. Since the geometry is not a perfect symmetry, the results include some minute errors. It is also assumed that the around 99% of the heat generated by the amplifiers is taken up or absorbed by the water flowing through the cooling tubes. From the previously run simulations, the results have shown that the average heat transfer coefficient of these cooling pipes are close to *2118.6 [W/m^2 K]* at an estimated mean temperature of *18.5 [degC]*.[1]

2.2 Boundary and initial conditions

The boundary conditions used for this case are the symmetry, heat flux in terms of convective heat flux (Specified heat transfer coefficient) and heat rate of transfer. Thermal insulation is applied to the parts where the heat transfer through all three modes of heat transfer is considered to be zero. The copper pipes are also removed from the processed geometry along with the aluminium cores as these materials have high thermal conductivities, where the surface heat flux is applied as the boundary conditions. Higher thermal conductivities lead to greater rates of heat transfer, hence there is less temperature gradients which can be neglected between the copper tubes/aluminium cores and the other materials. The symmetry boundary condition is applied where the geometry is sliced for simplification purpose. **Fig.2** shows the boundary conditions specified in the simulations.

Initial conditions are specified and necessary only at the beginning of the simulation unlike the boundary conditions that are used throughout the simulations to bound the problem. These have utmost important case in the transient cases, where the solution is time dependent, but these initial conditions serve their purpose in the steady state cases too. An initial temperature of 20.15 [degC] or 293.15 [K] is set for the whole domain.



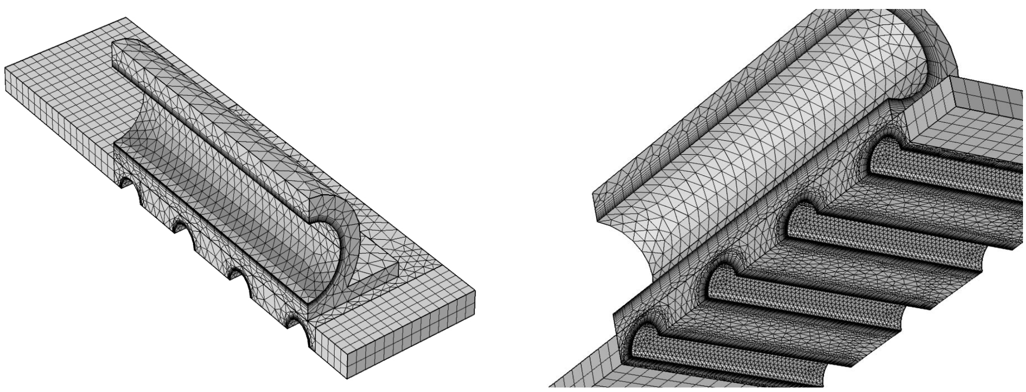
(a) (b)

Figure 2: Boundary conditions considered for he Antenna simulation

2.3 Meshing and Mesh Independence

Meshing process involves discretisation of the domain into numerous small elements where the equations are solved.The domain is sub divided into smaller parts for the ease and effective meshing. Both structured and unstructured meshes are generated as shown in the **Fig.3**. Free tetrahedral and swept mesh elements are majorly used here with the prism layers or the boundary layers in along the inner diameters of the copper tubes and the aluminium plates where the copper water tubes run. The tetrahedral mesh elements are used where the geometry has complexities, so that the elements are oriented and placed effectively to capture the physics along the direction of the temperature gradient.Using swept meshes (hexahedral elements) for the suitable geometry instead of the free tetrahedral meshes generates less elements which are comparably high quality to the tetrahedral elements.

Boundary layers are used where the gradients of the desired parameters, here the temperature gradients are relatively high. This technique helps in resolving the mesh at the sensitive areas by adding more elements to those areas. 15 boundary layers are used here for the shown areas, with the first layer cell height being automatically adjusted by the software.



(a) (b)

Figure 3: Generated mesh for the geometry

Mesh independence provides an insight into the influence of mesh on the results. As we decrease the mesh element size, the mesh density increases, which is one of the factor for increasing the accuracy of the solution. But just increasing the number of mesh elements does not necessarily increase the accuracy of the solution. The parameters or the results stop varying at a certain size of mesh, where increasing the mesh elements had no effect on the results. Henceforth, a mesh independence study is much necessary to find out the optimum size of the mesh where we get reliable results for the smallest possible mesh. Here the mesh independence study was performed by measuring the temperature at the probes located on the boundaries as shown in **Fig.4** (Probe 2 and 3), also the domain probe (Probe 1) for average temperature over the copper cover.

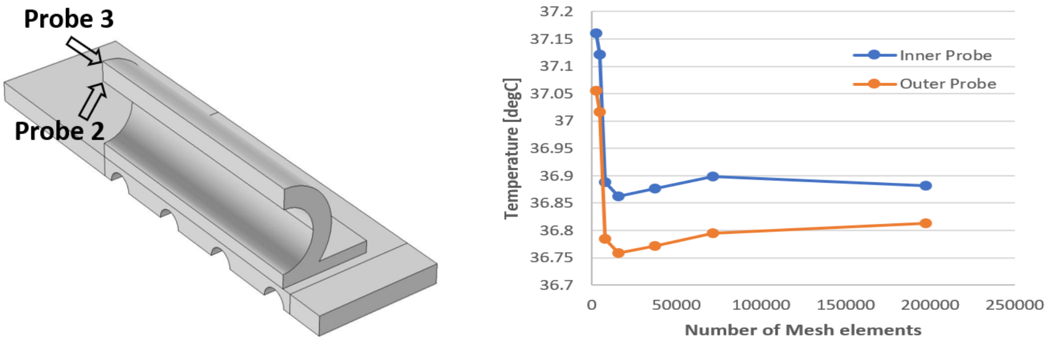
Table 1: Mesh independency study statistics

Mesh Independence study results						
	Elements number	Element quality	Probe 1 [degC]	%Error Probe 1	Probe 2 [degC]	Probe 3 [degC]
Coarser Mesh	2544	0.54	35.07	-	37.16	37.05
Coarse Mesh	4681	0.61	35.03	0.111%	37.12	37.01
Normal Mesh	7775	0.64	34.79	0.683%	36.88	36.78
Fine Mesh	15806	0.70	34.78	0.044%	36.86	36.75
Finer Mesh	37417	0.72	34.76	0.054%	36.87	36.77
Extremely fine	71545	0.73	34.76	-0.008%	36.89	36.79
Super fine	197739	0.72	34.76	0.002%	36.882	36.81

From **Table.1** it can be seen that as the number of mesh elements increase by two-fold, the temperature values starts to decrease by smaller quantities. The % Error column indicates the cumulative error between the two successive mesh sizes. It can be seen in **Fig.4** that the error percentage decreases significantly between the three probe temperatures, but the difference between the extremely fine mesh and the super fine mesh is considerably very small. Considering the results, the fine mesh with 71K elements was chosen as the optimum size for the simulations, as the error is really low compared to the normal and coarse meshes. Employing finer and extremely fine meshes are not necessary as the the results vary by third or fourth decimal.

2.4 Solver and study settings

The simulation is set up in steady state and the transient case for the detailed analysis of the heat transfer. Copper and Aluminium are used from the built in library of the COMSOL Multiphysics 5.5 software. This is a finite element method (FEM) solver. In this simulation setup only heat transfer through the solids is considered thereby neglecting the other physics. A default relative tolerance of 0.001 is set for the steady solver and 0.01 for the transient case. However, changing the tolerance limits (reducing), had negligible changes in the results.

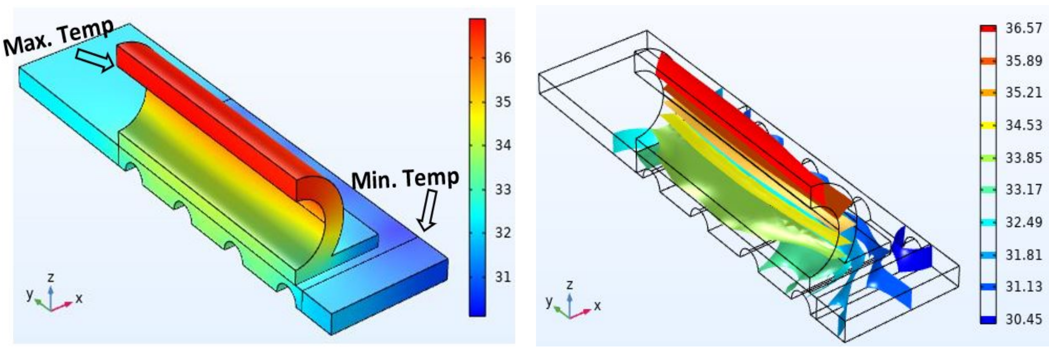


(a) (b)

Figure 4: Probe locations and Mesh independency graphs for Probe 2 and Probe 3

3 Results

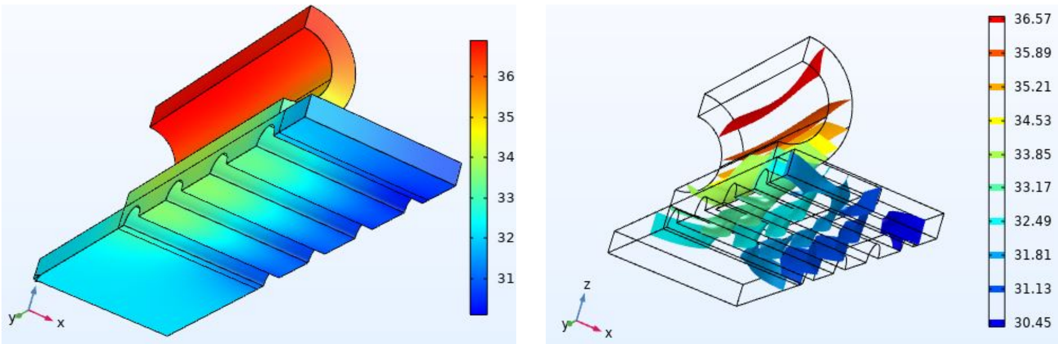
Fig.5 shows the temperature variation along the geometry of the simplified antenna. This contour plot is a result of the steady state simulation which took 16 seconds to complete. The maximum temperature of the overall domain attained to be was 36.913 [degC]. The average temperature of the domain, 34.769[degC] was obtained by setting up a domain probe that would compute the average temperature in the domain. Probe 2 and Probe 3 as indicated in **Fig.4** was 36.882[degC] and 36.779[degC] respectively. **Fig.6** shows the bottom iso view of the contours and the iso surfaces,i.e, the temperature variation in the aluminum plate. This indicates that the heat from the antenna is convected away into the cooling water in the copper tubes effectively.



(a) (b)

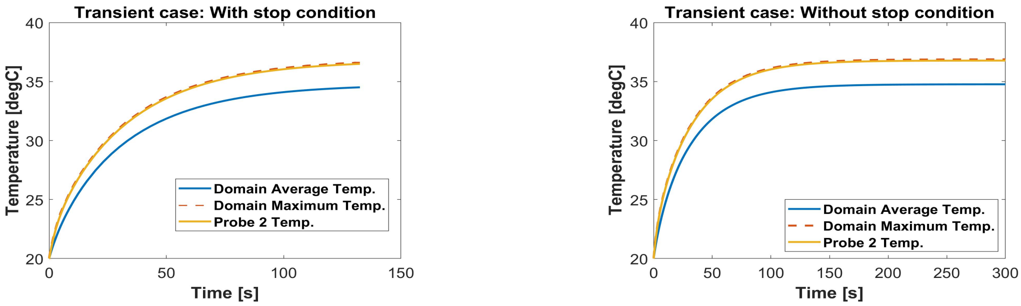
Figure 5: Temperature contours variation and Iso-surfaces for constant temperatures of the steady state case of the antenna

Fig.7, shows the temperature variations as there is advancement in time. There was a stop condition specified for the left graph and the right graph was run till 300 seconds with variable time steps. The stop condition specified in the solver setting for transient case is, **36.913[degC]-comp1.MaxTemp**, where MaxTemp is the maximum temperature of the overall domain. When the stop condition was specified, the simulation ended at 132.49 seconds.



(a) (b)

Figure 6: Bottom Iso view of the above presented contours



(a) (b)

Figure 7: Temperature versus time variation for the transient case, with and without stop conditions specified respectively

4 Discussion

Considering the symmetry of the geometry is one of the important simplifications made here in this study. The entire antenna is reduced to a small geometry as shown in the **Fig.2(a)**. This simplification leads to reduced computational time and memory allocation, less number of mesh elements generated. The entire geometry of the antenna has many complexities in it, like the rounded surfaces and sharp edges, which can pose potential errors during meshing. Employing symmetry has reduced these complexities, making meshing process comparatively easier. Here the model is not purely symmetrical along the planes where the symmetry is considered. This leads the reader or the company to not completely rely on the results presented here. It is assumed that the water through the cooling copper tubes takes off almost 99% of the heat from the aluminium base plate which is not practically possible. However, considering all these would require addition of extra physics that would again increase the computational expense.

The heat transfer coefficient in the real world is never a constant value. It keeps changing as the temperature varies for every instance. However, to reduce the complexities in the calculation, the heat transfer coefficient is estimated (as a constant value) from a previously performed studies. This induces some error in the results.

Meshing techniques has a major role in the accuracy of the solution. The three dimensional, Free tetrahedral mesh elements are the most widely used type of mesh elements as these elements are the most suitable for the irregular geometries where the hexahedral elements are not an optimal choice. As mentioned earlier, the copper coverings in the domain has curved and irregular shapes where the hexahedral elements cannot be placed efficiently. The swept meshes that are swept from the source face to the destination face are used for the simplified shapes of geometry where the hexahedral elements are generated with low skewness factor.[2] Prism layers serve their purpose of capturing the physics in the near wall region or the areas where the gradients of desired parameter, here temperature is high.

The boundary conditions specified here in this simulation are of the Drichlet type as they are the constant values unlike the Nuemann type, where the values are specified as the gradients to the normal.[3]. Neglecting Copper water supply tubes and the aluminium cores has significantly impacted the total number of mesh elements and accuracy of the results, which on the other hand would have spiked up the computational cost and time. The heat generated by the amplifier is taken to be half the value of total heat generated (0.5*80W = 40W) due to the symmetry, which is specified on the inner walls of the copper tube in the computation. The convergence criteria is set as 1e-6, where the results converge after 8-10 iterations. However, the convergence independence studies were not performed in this case due to time constraints and the value 1e-6 was obtained from the literature studies. There can be possible error due to this convergence, which is neglected here.

From the steady state results, the temperature contours it can be observed that the location of the Probe 2, the inner walls of the thick copper tube has the highest temperature as this region receives the heat first from the aluminium core and the cooling pipes are sufficiently far from this location. Henceforth, the placement of the Probe 2 is justified. The location of the minimum temperature as shown in **Fig.5** is because this location is away from the heat generating aluminium core, that is the source but has greater influence of the cooling tubes on it. The main motive of this transient study is to check if the maximum operating range of the Antenna is within 50[degC]. From the results it can be seen that the temp of 36.923 [degC] which is well within the limit.

The transient case simulations were performed in order to have an insight of the time required by the system to attain the state of thermal equilibrium. This helps in determining the effectiveness of the cooling system or methods employed to take out the heat. An initial temperature of 20.15 [degC] or 293.15 [K] was used. Default settings were used for the solver configuration. A stop condition as mentioned above was specified in order to terminate the computation once the required conditions are satisfied. One more simulation was carried out without any stop condition to check the behaviour if the temperature pattern. Once the maximum saturation temperature is obtained at the probes and the overall maximum temperature of the domain the graph lines had no change, where they were parallel to the x-axis as shown in **7**. The value 39.913 [degC] as mentioned in the stop condition is the maximum temperature of the domain obtained from the steady state analysis which took 16 seconds for the results to converge. Therefore, using the results of the steady state simulation as the input to the transient case makes the computations faster.

5 Conclusion

Going through the data and the results presented it can be concluded that the current cooling system for the antenna that uses water at constant mass flow rate of 22.15 [l/min] at 15 [degC] is sufficient enough to keep the maximum temperature below 50 [degC]. The maximum temperature of 39.913[degC] and the minimum temperature of 30.107 [degC] locations are shown in the **Fig.5**. The cooling water from the copper tubes take away the heat, resulting in location of the maximum temperature point at a distance far away from the cooling tubes. However, the results include some errors due to the simplifications and assumptions mentioned above.

The transient case simulations that were run to find out the time required by the whole system to reach the state of thermal equilibrium was 132.49 seconds.Therefore, if the present antenna is set at an initial temperature of 20 [degC] then it takes 132.49 seconds for the water from the cooling copper tubes running through the aluminum base plates to bring it to thermal equilibrium state.

References

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