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Conjugate Heat Transfer for Wireless Power Amplifier

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Abstract: This study explores the ability of COMSOL multiphysics software to predict the performance of a forced-air thermal management system coupled with a commercially available wireless power amplifier in high-temperature environments. Particularly, the software was utilized to predict the maximum temperature on the heat sink affixed to that amplifier. Models utilized available information for the geometry and thermal properties of a commercially available heat sink affixed to a wireless power amplifier. Commonly available materials were used to create a forced-air cooling system. Multiple solutions were modeled. Experimental data will be gathered to compare with modeled results. Experiments will be conducted first at easily achieved ambient temperatures. Models with a close fit at moderate temperatures may be extended to air temperatures and velocities not easily achieved in a simple laboratory environment. Models that show close correlation to experimental data will lend confidence to modeling for design, where redundancies and factors of safety may be added.

Keywords: Conjugate Heat Transfer, Wireless Power Transfer

1. Introduction

Wireless power transfer is a technology quickly expanding in application. One such application is the use of wireless power technology on remote platforms. Advances in this area will allow electronic devices to be powered without human presence in difficult locations, including high-temperature environments.

This study explores the use of a forced-air system combined with a commercially available wireless power amplifier and heat sink. The design modeled was selected based on simplicity and availability of materials.

2. Methodology

This study modeled a heat sink which was already affixed to a wireless power amplifier, and available commercially. Other parts of the model were constructed to match the forced-air cooling system that was built from readily available and easy-to-use materials. One-eighth inch thick galvanized steel created a simple duct system through which electronic fans move air at varying ambient temperatures. A small cart was built for testing the wireless power amplifier and other similar systems. The cart is seen in Figures 1 and 2.

Additionally, the model utilizes a boundary heat source, inlet and exit conditions for flowing air, and ambient temperatures to predict the temperature profile and maximum temperatures of the heat sink during operation. Variables considered include ambient temperature, inlet air velocity and thermal conductivity of the heat sink. These variations will be compared to experimental data to determine the relative accuracy of each model. The maximum temperature predicted by the model will determine the velocity of forced-air required to maintain a stable working temperature for the wireless power amplifier, specifically in a hot environment. Solutions which limit the maximum temperature at the heat sink to 150 degrees F are sought. This limit will allow for stable operation of the amplifiers semiconductors.

2.1 Use of COMSOL Multiphysics

This study utilizes the Conjugate Heat Transfer physics, from the Heat Transfer Module, within COMSOL Multiphysics. Parts included in the model are representative of real parts used in the study and are geometrically accurate. Materials used include 6000-series aluminum, galvanized steel, and air. Material properties for aluminum and air are directly from the software's material library. Appropriate material properties for the galvanized steel duct-work were added from reference[2,3].

The variable ambient temperature of the model was used as an initial condition. At the interface of the wireless power amplifier and heat sink, a boundary heat source was applied as a boundary condition. A conservative assumption was made that the entire 200W rated output of the device would be applied at this boundary. Varying model types applied the output power over the entire surface of the heat sink or concentrated at specific amplifier-to-heat sink connections. Boundary conditions were applied at the inlet of the adjacent duct so that the air was being received at the ambient temperature, and with a known inlet velocity. Another boundary condition allowed for air to outlet at standard atmospheric pressure.

Three model combinations were utilized in this study. The first model assumes that heat from the amplifier is evenly distributed over the top surface of the heat sink, and that the heat sink has a constant thermal conductivity, k, equal to 217 (W/m*K). The second model maintains the distributed heat assumption, but utilizes a temperature-dependant function for the thermal conductivity of aluminum. This temperature dependant function was derived from a reference table[1]. For temperatures ranging from 300 to 600K, a function in the third order of temperature fit the reference values with an $R^2 = 0.9995$. The relationship of this temperature-dependant function to the referenced data is found in Figure 3. Model 3 concentrates the boundary heat to six specific locations to mimic the connections made between the actual amplifier and heat sink. Figures 4 and 5 give a visual representation of the temperature distribution for the differing model types. Temperatures range from the ambient temperature input to the predicted maximum surface temperature. Shown in the two figures are the very distinct differences between uniformly distributed and concentrated boundary heat sources.

Figure 6 compares the resulting maximum temperature predicted by each model with an ambient temperature of 130^{o}F over a range of inlet air velocities. This ambient temperature was selected to very high, but realistically achievable temperature. Figure 6 relates the maximum temperature achieved on the surface of the heat sink for all three models at varying inlet air velocities. The data shows little variation in the maximum temperature for constant and temperature-dependant thermal conductivity values, Models 1 and 2. The greatest variation is found when the boundary heat source condition is changed from being uniformly distributed to the six concentrated locations of Model 3.

Model 3 proved to be the most conservative of the three models tested at 130 degrees F. Further modeling was completed to show variations in performance of this model over a range of ambient temperatures. This data can be seen in Figure 7. Of particular interest here is where each predicted curve passes the 150 degree F threshold. With ambient temperatures up to 115 degrees F, cooling the heat sink requires relatively little airflow.

In addition to the thermal conduction of each material, the radiation of both metals was considered. The “radiate-to-ambient” boundary condition was applied to all exterior aluminum and galvanized steel boundaries. The ambient temperature to which the metals radiate is the same variable temperature at the air inlet.

3. Figures

Figure 1. Test cart including wireless power amplifier, heat sink, fans and ducts.

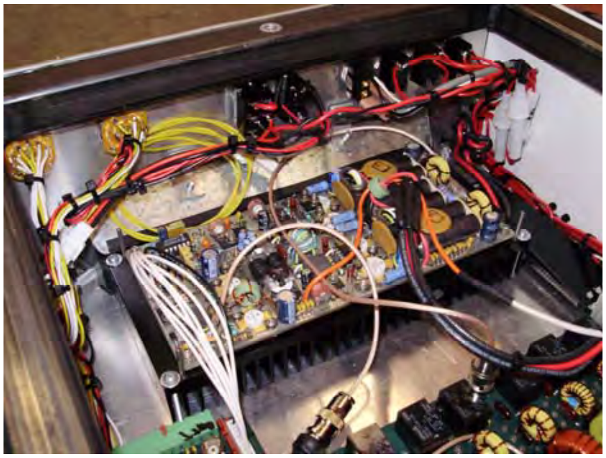

Figure 2. Amplifier and heat sink inside cart, near duct.

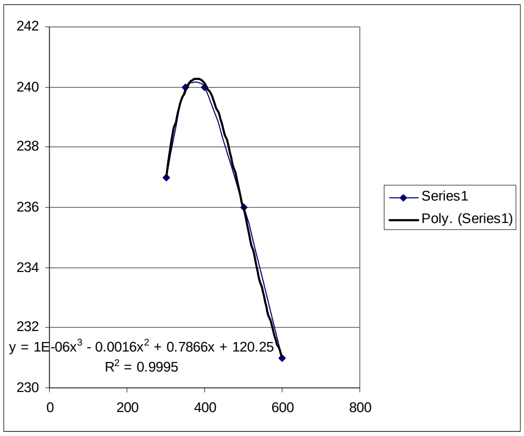

Figure 3. Temperature-dependant function of thermal conductivity of aluminum.

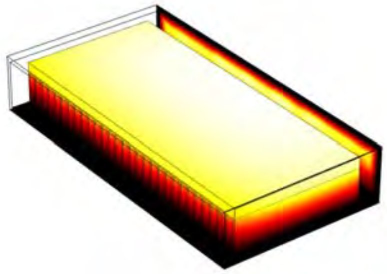

Figure 4. Temperature distribution for uniformly distributed heat source.

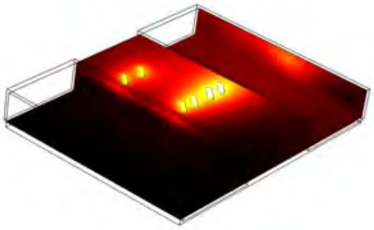

Figure 5. Temperature distribution for concentrated heat source.

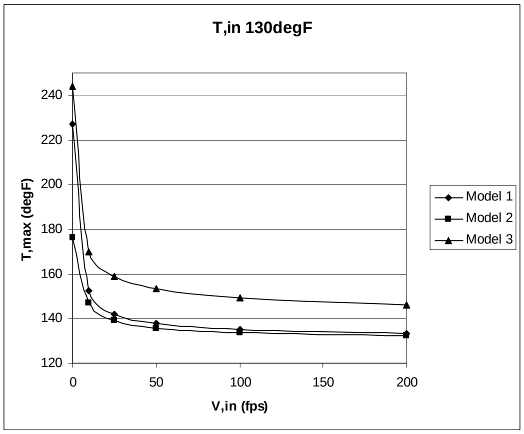

Figure 6. Maximum heat sink temperature vs. inlet velocity for three model assumptions with ambient temperature of 130 degrees F.

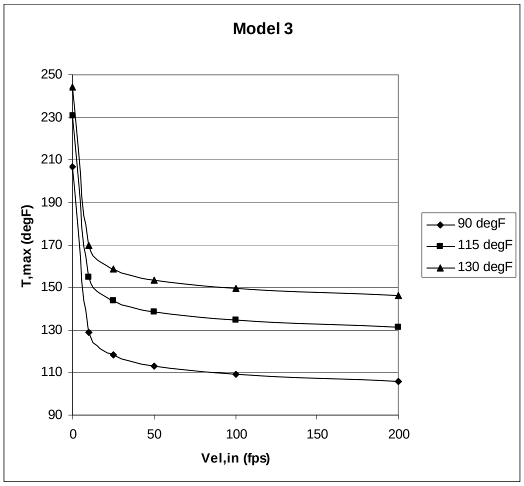

Figure 7. Maximum heat sink temperature vs. inlet velocity for three ambient temperatures.

4. Conclusions

This study was undertaken to better understand the thermal management performance of a commercially available wireless power amplifier and heat sink system. Using COMSOL multiphysics software to model a real, forced-air solution, several conclusions can be made.

First, for operation at high temperature, some cooling system is required. When airflow across the heat sink approached zero, maximum temperatures on the heat sink were significantly greater than those at which the amplifier would be stable. This was found true for all model types.

The inlet velocity needed to maintain a stable environment varied with ambient temperature and model assumptions. Model 3, with concentrated boundary heat sources, was consistently the most conservative. In order to maintain heat sink temperatures at or below 150 degrees F in a 130 degree F ambient environment, Model 3 required an inlet air velocity of 100 feet per second. Lower ambient temperatures, and less conservative models all required significantly less air flow.

Future considerations include collecting experimental data for the modeled system. This data will be used to confirm the accuracy of the modeled system. Additionally, more novel cooling systems will be considered. Goals will include reducing the weight and power needs of the entire thermal management system.

In addition to this 200W wireless amplifier, a 2kW wireless power amplifier solution has been considered for similar applications. The modeling done for this study may be extended to account for much greater outlet energy, as well.

8. References

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