# Modelling of Convection Cooling of High CW Power Waveguide

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## Introduction

Waveguide Structures are often used for transmission of high CW power. The inherent conductor losses in the waveguide material lead to an increase in its temperature. If appropriate thermal management is not undertaken, this high temperature may lower the breakdown threshold of the waveguide and hence its power handling capacity. Water cooling is commonly used when power levels of over 100 kW are encountered. The proposed work incorporates the thermal management of waveguide excited with high power RF waves. RF, Heat Transfer and CFD physics are coupled to arrive at the solution.

## Boundary Conditions and Computational Methods

A Waveguide (WR-284) is excited with 500 kW CW Power at 3.7 GHZ. Cooling pipes are laid out in the H plane of the waveguide at the centre where the E field is maximum to facilitate the flow of water. Figure 1 depicts the proposed structure.

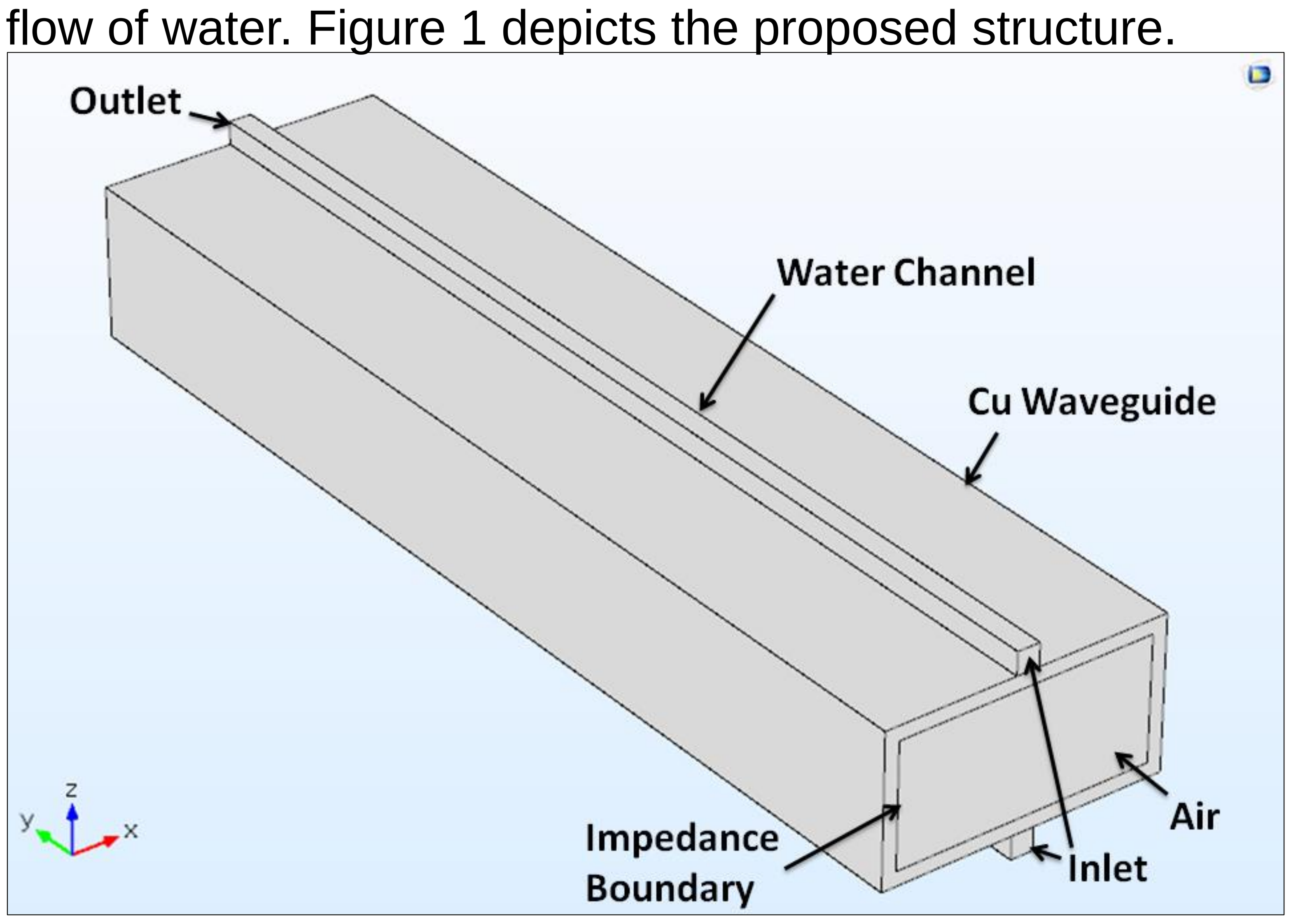


**Figure 1.** Waveguide Structure with cooling arrangement

Impedance boundary condition is used at the interior faces of the waveguide to account for skin depth. Heat flux condition is given to exterior faces to model for copper-air interface. Water is circulated at 8 lpm for cooling purposes. RF and Conjugate heat transfer physics are used. Frequency Stationary Solver has been used to obtain the steady state values.

| Physics | Equations |
|---|---|
| Heat Transfer (ht) | $\rho C_p \bar{u}.\nabla T + \nabla.\bar{q} = Q$ <br> $\bar{q} = -k\nabla T$ |
| Turbulent Flow, k-ε (spf) | $\rho(\bar{u}.\nabla)\bar{u} = \nabla.\left[-pI + (\mu+\mu_T)\left(\nabla\bar{u} + (\nabla\bar{u})^T\right)\right] + \bar{F}$ <br> $\rho\nabla.\bar{u} = 0$ <br> $\rho(\bar{u}.\nabla)k = \nabla.\left[\left(\mu + \frac{\mu_T}{\sigma_k}\right)\nabla k\right] + P_k - \rho\varepsilon$ <br> $\rho(\bar{u}.\nabla)\varepsilon = \nabla.\left[\left(\mu + \frac{\mu_T}{\sigma_e}\right)\nabla\varepsilon\right] + C_{\varepsilon 1}\frac{\varepsilon}{k}P_k - C_{\varepsilon 2}\rho\frac{\varepsilon^2}{k}, \varepsilon = ep$ <br> $\mu_T = \rho C_\mu \frac{k^2}{\varepsilon}$ <br> $P_k = \mu_T\left[\nabla\bar{u} : \left(\nabla\bar{u} + (\nabla\bar{u})^T\right)\right]$ |
| Electromagnetic Waves, Frequency Domain | $\nabla\times\mu_r^{-1}(\nabla\times\bar{E}) - k_0^2\left(\varepsilon_r - \frac{j\sigma}{\omega\varepsilon_0}\right)\bar{E} = 0$ |

## Results

Figure 2 depicts the E field in the waveguide while Figure 3 shows the surface losses in the structure. Figure 4 depicts the temperature profiles of the structure. The temperature rise in the cooling channels is $2^0$ Celsius.

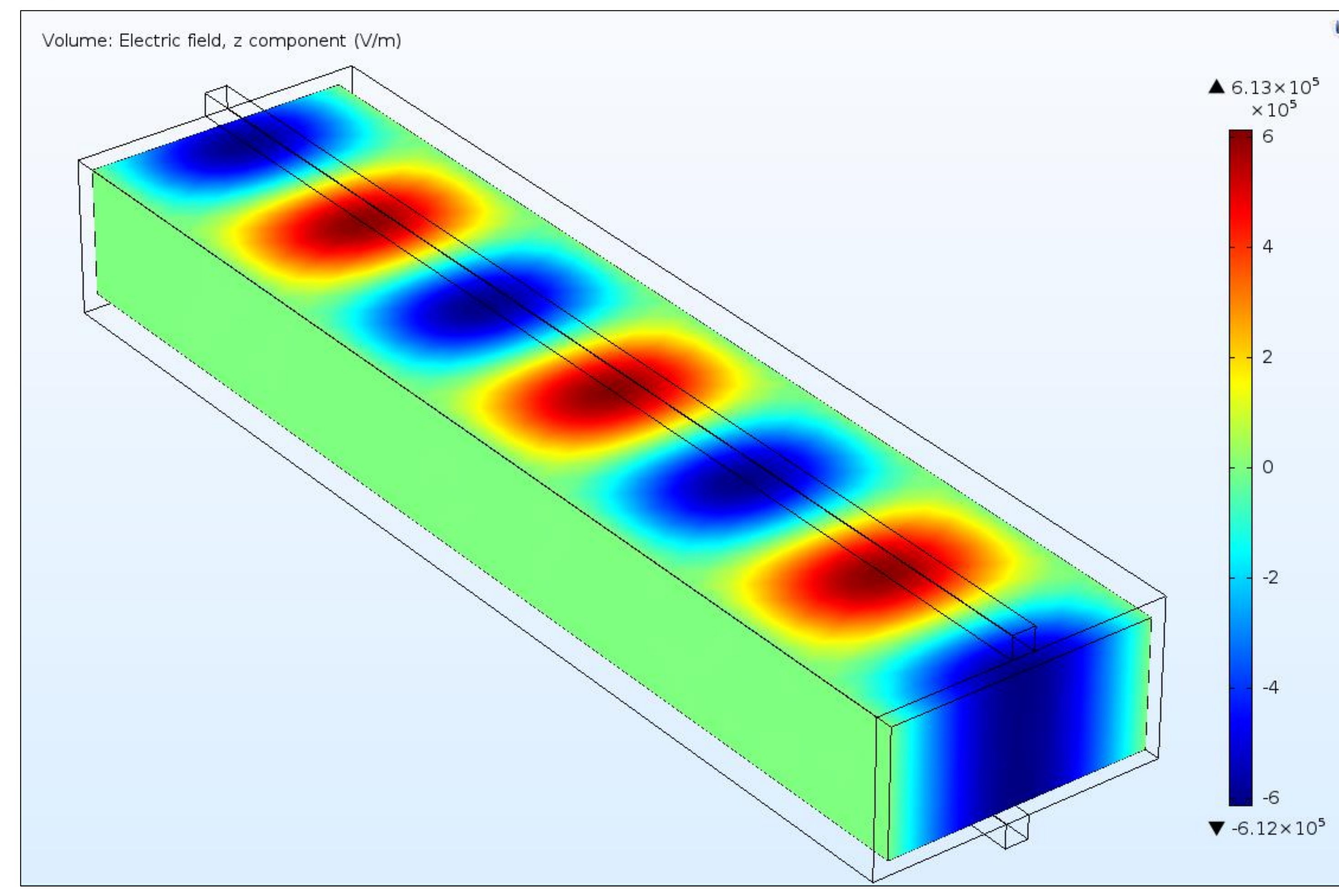


**Figure 2**. Electric Field in the waveguide structure

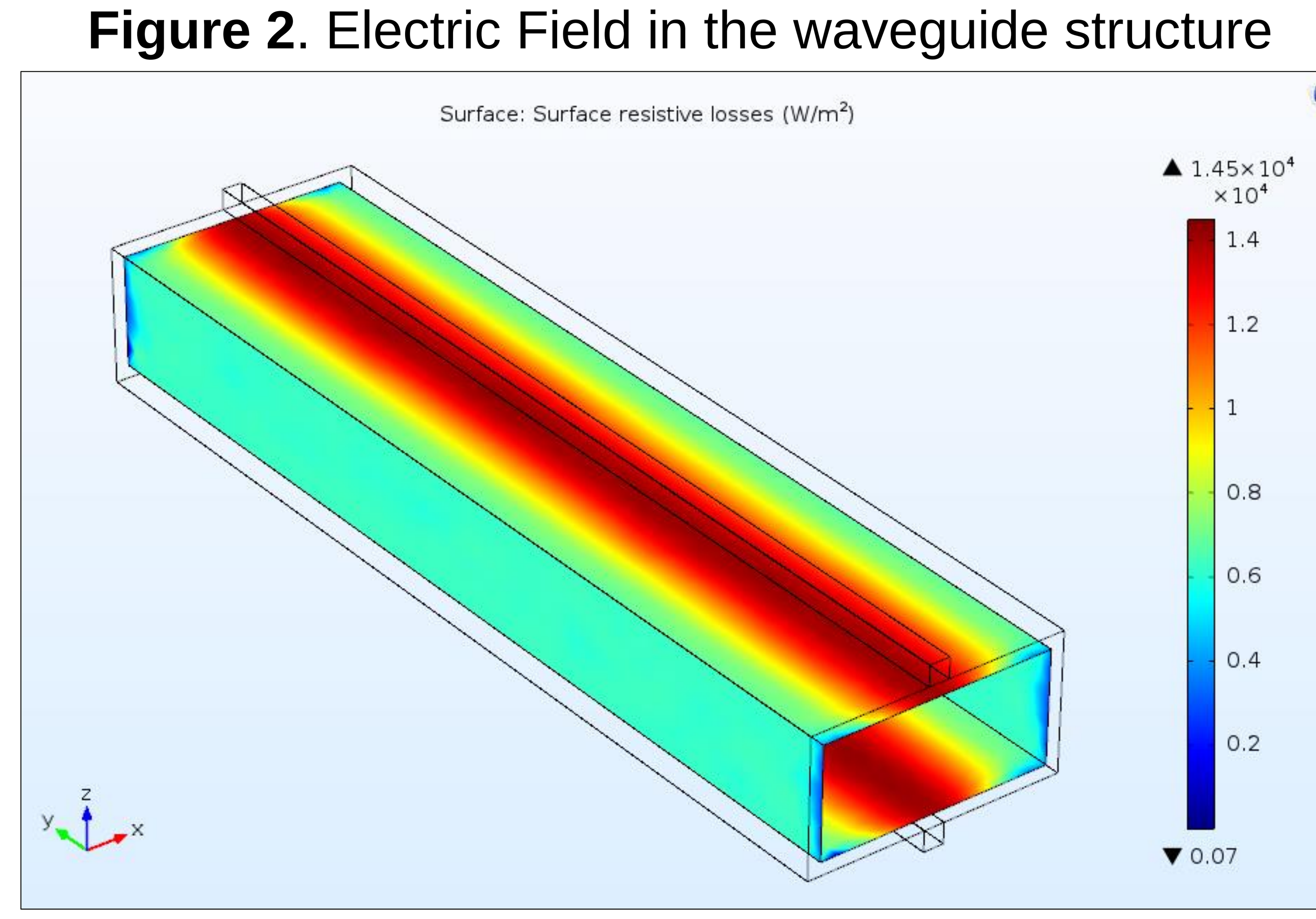


**Figure 3**. Surface Losses in the waveguide structure

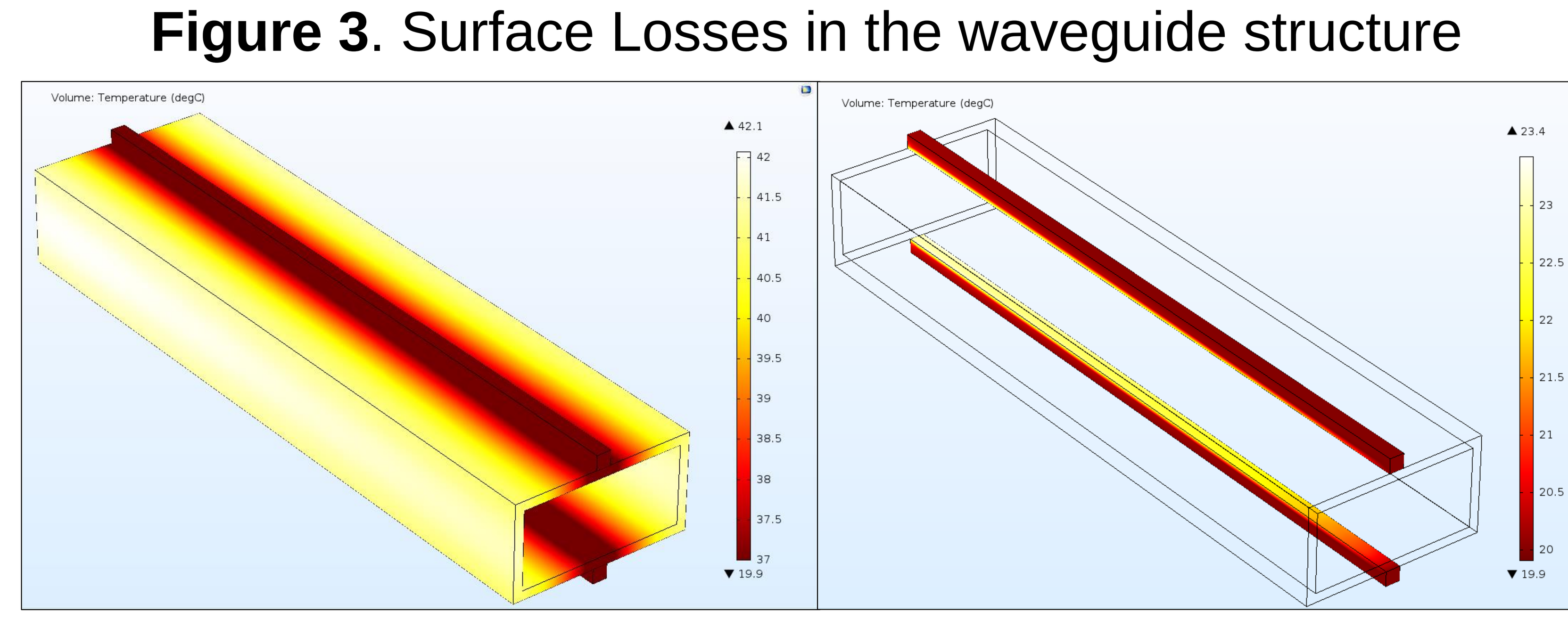

**Figure 4**. Temperature Profile of the waveguide and cooling channels

## Conclusion

A Coupled Analysis of RF, Heat Transfer and CFD is proposed to evaluate the thermal management of a high power waveguide structure. The obtained results verify with the analytical values.

## Results

1. King, H. E., 'Rectangular Waveguide Theoretical CW Average Power Rating,' *IEEE Transactions on Microwave Theory and Techniques*, Vol. 9, Issue 4, July 1961.
2. Persky, G., 'The Sinusoidal Variation of Dissipation Along Uniform Waveguides,' *IEEE Transactions on Microwave Theory and Techniques*, Vol. 10, Issue 6, November 1962.