An Efficient Finite Element Analysis on an RF Structure Used to Evaluate the Effect of Microwave Radiation on Uveal Melanoma Cells

Andrei Dulipovici*[1], Dacian Roman[2], Ion Stiharu[2], Vahé Nerguizian[1], and Nicolas Constantin[1]
[1]École de technologie supérieure, [2]Concordia University
* Corresponding author: 1100 Notre Dame West, Montreal, Quebec, Canada, H3C-1K3, Andrei.dulipovici.1@ens.etsmtl.ca

Abstract: The use of Microwave/RF energy on cancer cells is explored for tumor ablation using medium power level ranging between a few Watts to about 50 Watts. Very little research uses low power Microwave/RF energy to explore the effect of this type of energy on malignant cells. In this research, low power levels, less than 100 mWatt, are used to evaluate the effect of this energy on Uveal melanoma cells by proliferation tests. The set-up, consisting of parallel plate type transmission lines used to inject this energy to these cancer cells was adapted and accommodated to the proliferation test. This paper investigates the electromagnetic distribution of the RF set-up structure using Finite Element Analysis (FEA). The outcome of the FEA analysis validates the statistical proliferation test results on several malignant cells.

Keywords: Finite Element Analysis (FEA), Microwave/RF Radiation, Low Power Energy, Uveal Melanoma Cells, Proliferation.

1. Introduction

For several decades many researchers [1]-[3] are investigating the effect of electromagnetic radiation on human normal and cancer cells. In most cases the frequencies range in the RF region at around 860 MHz and 2.4 GHz and in the millimeter wave range at around 40 and 60 GHz [4]. In these investigations, the power levels were basically at medium level, ranging from a few Watts to 50 Watts. In recent works [5],[6], a new set-up was designed in order to examine and investigate the low power Radio Frequency (RF) radiation effect on the human Uveal Melanoma cell lines 92.1 and normal fibroblast cells. The input frequency ranged from 1 to 3 GHz, and the input power levels were less than 100 mWatt. For the radiation effect assessment, a method and set-up was adapted to the existing viable proliferation experiment using 96 well plates. The proliferation test would indicate if the cells are growing or dying. In order to adapt to proliferation testing and have statistically consistent results, a simple RF system was designed and produced with standard transmission line techniques on the cover of the 96 well plate.

The RF system shown in Figures 1 and 2 accepts, in the form of a drawer, the 96 well plates. Some columns of the plate were filled with Uveal melanoma cells and others with fibroblast cells. Each well contained about 5000 cells. Consecutively, the three transmission lines were subjected to RF energy at frequencies of 1 to 1.6 GHz (range 1), 1.7 to 2.3 GHz (range 2), and 2.4 to 3 GHz (range 3) with input power levels of 18 dBm.

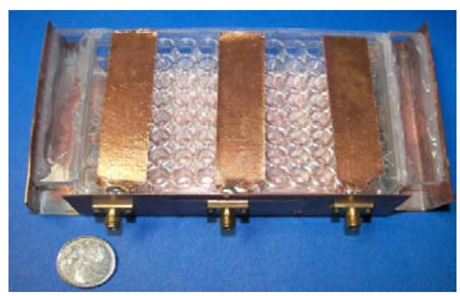

Figure 1. RF radiation system that receives the 96 well plates - Top view.

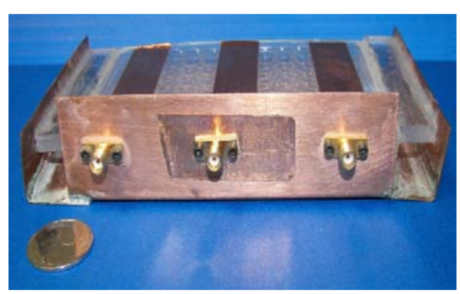

Figure 2. RF radiation system that receives the 96 well plates - Side view.

The energy injected from the SMA connector to the open ended transmission lines is not uniformly distributed over the cells within the wells due to the nature of the structure. The complex theoretical evaluation of the energy distribution through the transmission lines could be overcome by using a finite element method (FEM) that would be appropriate for this structure.

In this study, the objective is to evaluate the energy distribution over the entire transmission line using a finite element analysis (FEA). This distribution affects the cells in the wells. The outcome of the analysis confirms the statistical validity of the proliferation results. Moreover, with this confirmation, apoptosis tests could be performed to understand the proliferation results. The apoptosis test will indicate the cell death information.

2. Use of COMSOL Multiphysics

Several FEA tools can be used to simulate the structure of the RF system. For research purposes, fortunately several universities in Canada have access to these different tools, namely COMSOL, ANSYS, COVENTOR and many others via the Canadian Microelectronic Corporation (CMC). In general, the user of the FEA tool looks for the following characteristics:

- User friendly environment
- Ease of structure design
- Compatibility with other CAD tools for import purposes
- Fast analysis time
- Reliable and valid results.

For graduate students, COMSOL software is a very efficient and adaptable tool offering a steep learning curve and allowing students master the software in a very reasonable time. Moreover, the link between COMSOL and MATLAB™ is a powerful tool for students using already MATLAB in their daily activities.

3. Microwave/RF Structure

The Microwave/RF set-up was built with practical and ease of manufacturing considerations, using simple stripes of copper tapes on the existing 96 well plates cover. These stripes and a rigid copper ground plane form parallel transmission lines as shown in Figures 1 and 2. The presence of the 3 stripes on the wells was necessary to ensure the simultaneous radiation of Uveal melanoma and fibroblast cells at 3 different frequency ranges. During the assays only 6 wells were filled with cells for radiation. The separation distance between the parallel lines was dictated by the thickness of the 96 well plate, and is about 1.25 cm.

For easy cell manipulation and contamination free operations, the transmission lines were left open at their ends.

4. FEA Design and Simulation Results

To simplify the meshing and to improve the simulation time and analysis efficiency, only 1 transmission stripe and 3 wells are drawn for simulation. The bloc diagram of Figure 3 shows all major steps at top level for creating the structure, analyzing and solving the system with COMSOL software.

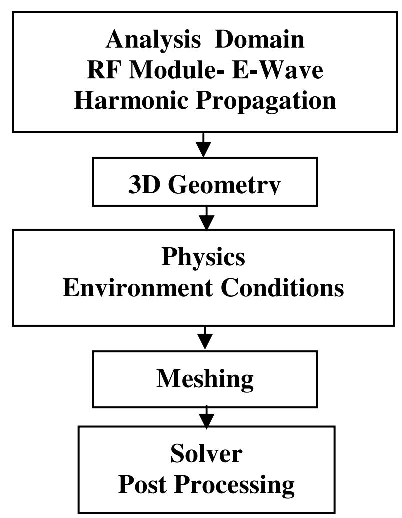

Figure 3. FEA major design steps.

The complete RF structure is designed using COMSOL with the appropriate environment and meshing definitions. The conductivity of the stripe material and the effective permittivity proper to the parallel transmission lines are input to the simulation.

A 3D drawing of the complete structure is shown in Figure 4. Figure 5 shows the complete RF structure with a spherical wave translated in a scattering boundary condition. Perfect match layer (PML) boundary condition could also have been used, with almost similar results.

The RF module electromagnetic wave and the harmonic propagation mode are used for the analysis domain in the simulation. The geometry is created in 3D, and the system generates different boundary limits: one for the cylindrical structure representing the wells, and another two for the transmission lines and the spherical environment.

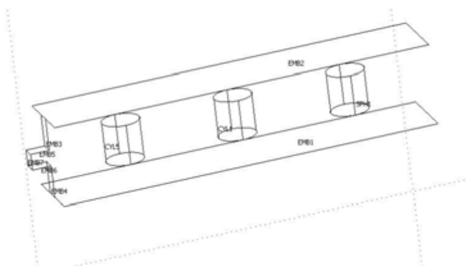

Figure 4. 3D Geometry of the complete RF structure.

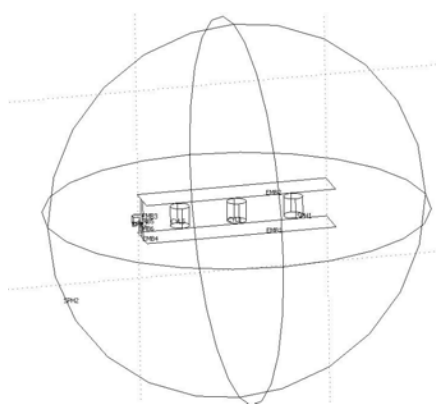

Figure 5. 3D Geometry of the complete RF structure with its boundary environment.

The total electromagnetic field distribution is given at Figure 6 where field strength variations along the transmission line and the 3 wells are clearly seen.

Sliced planes (Figure 7) are created to evaluate the electromagnetic field distribution in the wells. Figure 8 shows the field distribution in the central well.

The post processing permitted the evaluation of the return loss (S11) at the input port of the structure from 0.5 to 5 GHz. Figure 9 shows the return loss at the input port of the structure.

Finally, the power distribution on the transmission line in the 0x axis is given in Figure 10.

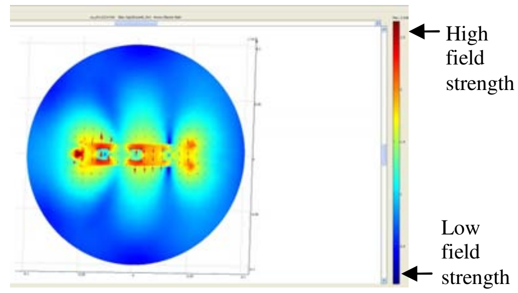

Figure 6. Electromagnetic field distribution over the entire RF structure.

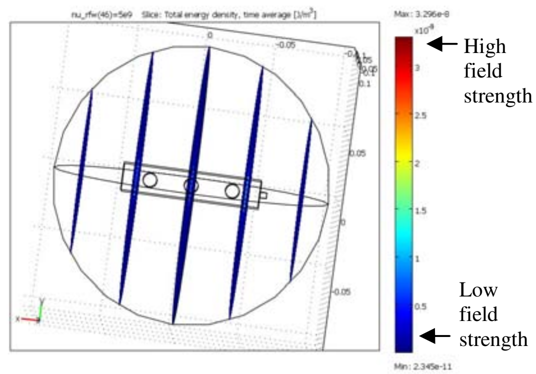

Figure 7. Structure sliced planes for electromagnetic field distribution in the wells.

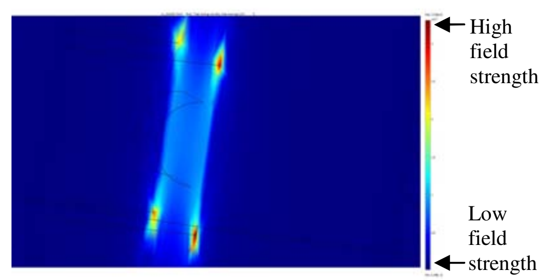

Figure 8. Electromagnetic field distribution for the central well between the transmission line plates.

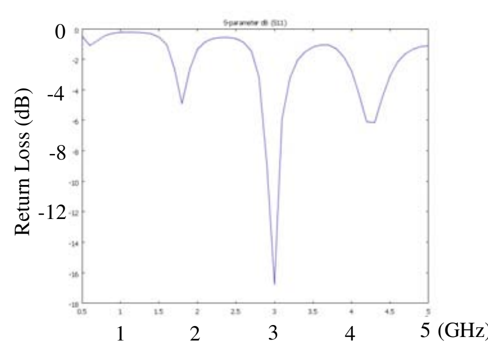

Figure 9. Return Loss of the input port of the structure versus the frequency.

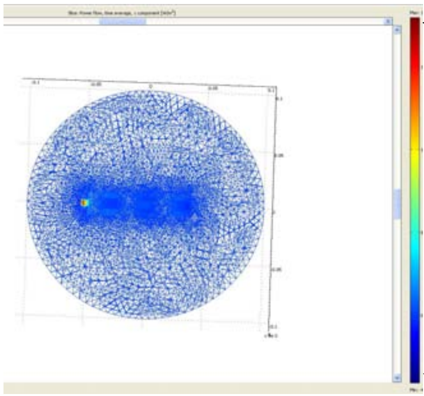

Figure 10. Power distribution in the 0x axis.

5. Results Assessment and Discussions

The effect of standing wave ratio is seen on the transmission line distribution field of Figure 6, as expected due to the open end of the transmission lines at the end of the copper stripes. Figure 8 shows the electromagnetic distribution in the central well, with uniform strength in the well. High field spots can be seen at the edge of the transmission line.

Within the assay frequency range (1 to 3 GHz) the simulation results in Figure 9 show return loss values of about -2dB, except in the vicinity of 1.8 and 3 GHz, where they reach values of -5dB and -16dB respectively. This indicates that more than half of the injected power is returned to the source in most of the frequency range. The matched condition around 1.8 and 3 GHz may be attributed to impedance matching between the structure and the environment, and to undesired resonance. Very similar return loss response was also observed experimentally on a network analyzer with 1 dB better return losses in the measured frequency range. Note that these return loss results imply some power variations with frequency. The proliferation results [5]-[6] showed a reduction more pronounced at frequency ranges 2 and 3 compared to what was observed at range 1. Therefore, we believe that the power variation with frequency due to input return loss points to a probable cause for the proliferation variation results.

For every frequency range, the proliferation tests results from all wells were averaged. The simulation results of Figure 10 indicates a near uniform power distribution over the wells. Therefore, the simulation validates the averaging process.

6. Conclusions and Future Works

The COMSOL simulation of the RF structure used to evaluate the radiation energy on Uveal and fibroblast cells has enabled the assessment of the non uniform energy distribution along the parallel plate transmission lines.

The power of COMSOL FEA software has reduced the analysis time by avoiding long analytical and theoretical evaluations of the field distribution on the RF/Microwave structure. It has also allowed identifying common trends between simulation and experimental proliferation results. This outcome allows orienting further research work on the effects of power distribution on proliferation.

As future works, we anticipate optimizing the RF structure for longer radiation exposure time, wider frequency ranges, and more uniform power distribution along the RF lines. For longer radiation exposure, the RF structure under test could be kept in the incubator during days rather than a few hours (since cells die within 2 hours outside the incubator). All the required RF structure design optimization could be completed with COMSOL FEA simulator.

7. References

1. Sienkiewicz, Z., Biological effects of electromagnetic fields and radiation. Journal of Radiological Protection, 18(3): p. 185-193, 1998.
2. Vander Vorst, A., et al., RF/microwave interaction with biological tissues. Medical Physics, 34: p. 786, 2007.
3. Barnes, F.S. and B. Greenebaum, Handbook of biological effects of electromagnetic fields. 2007: CRC Press.
4. Makar, V.R., et al., Effect of cyclophosphamide and 61.22 GHz millimeter waves on T-cell, B-cell, and macrophage functions. Bioelectromagnetics, 27(6), 2006.
5. V. Nerguizian, A. Dulipovici, D. Abourbih, S. Maloney, S. Bakalian, I. Stiharu, M.N. Burnier Jr., The Effect of Non Thermal Radio Frequency Radiation on Uveal Melanoma Cells. ARVO2009: E-Abstract 3375, Fort Lauderdale, Florida, 3-7 May 2009.

6. V. Nerguizian, S. Bakalian, I. Stiharu, M.N. Burnier Jr., The effect of Low Power Microwave Frequencies on Uveal Melanoma Cells, AAHPO-AMWC 2009, New York, NY, 1-4 July 2009.

8. Acknowledgements

The authors would like to acknowledge the contribution of Dr. Miguel N. Burnier Jr. and his team from Henry C. Witelson Ocular Pathology laboratory at McGill University, for the preparation of Uveal melanoma cells and the completion of proliferation tests.