Simulations of a Coaxial Multipactor Testbed

Rajani Budha
Department of Electrical Engineering
The University of New Mexico
Albuquerque, NM 87131, USA
rbudha@unm.edu

Salvador Portillo
Department of Electrical Engineering
The University of New Mexico
Albuquerque, NM 87131, USA
sportil@unm.edu

Edl Schamiloglu
Department of Electrical Engineering
The University of New Mexico
Albuquerque, NM 87131, USA
edls@unm.edu

Abstract: *A well-documented effect of cosmic and solar radiation on TWTs used in satellites is the production of secondary electrons from the bombardment of incident particles and the resultant cascade and growth of these secondaries, which in turn leads to tube failure. Our work focuses on numerical simulation of gap closure in coaxial geometry due to the multipactor effect. The secondary electron yield (SEY) is dependent not just on material properties, but also on the geometric properties of the surface and of the tube, as well as the size of the interaction space and the operating frequency. We then focus on particle-in-cell simulations of a coaxial testbed that will generate data to develop advanced models that incorporate patterned surfaces, new source geometries, and new materials developed to suppress SEY. This paper presents preliminary results from our coaxial PIC simulations utilizing the CST Design Studio and Spark3D codes.*

Keywords: multipactor, coaxial multipactor testbed, electron avalanche, secondary electron yield, particle-in-cell simulations, RF breakdown

INTRODUCTION

Traveling wave tubes (TWTs) operating from C, L, Q, and V bands are used for signal amplification in communication satellites. The harsh radiation environment in orbit leads to incident charged particles generating secondary electrons which can disrupt TWT operation [1]. These electrons may couple to the amplified signal which can be multi-tone and modulated and impinge on the walls of the TWT. Under the right conditions this bombardment can lead to the production of secondary electrons from the wall surface. The SEY from these surfaces is dependent on surface adsorbates, surface treatments, angle of incidence, base material, as well as a host of physical and geometrical parameters of the tube, such as signal frequency and interaction space gap, as well as distance to dielectric surfaces [2-4]. Some critical combination of conditions has been identified, independent of material, and curves for these, based on the product of the frequency (f) and gap spacing (d) - have produced guidelines for regions where the multipactor effect can be found for a given geometry [5,6]. This large parameter space presents opportunities for reducing the SEY contribution, via surface treatments, material changes, and novel source geometries. At the same time this large parameter space poses serious challenges for understanding and ultimately mitigating SEY production. To this end, researchers at the University of New Mexico (UNM) are developing particle-in-cell (PIC) models of a coaxial geometry testbed as a first step in developing complex models of TWTs with different emission properties as well as different modulated tonal inputs. Figure 1 shows a cartoon of an electron coupling to the incident amplified signal leading to a multipactor avalanche and eventual failure of tube components.

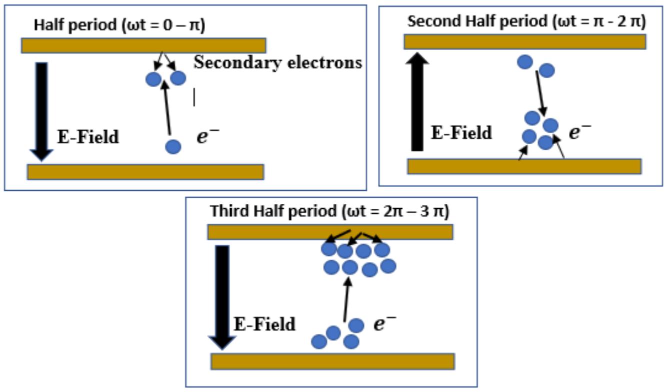

Figure 1. Cartoon describing the multipactor phenomenon (adapted from [5]).

Model Geometry

CST Design Studio was used to generate our preliminary multipactor models. The testbed geometry consists of a 2 cm inner radius cylinder and a 3 cm outer radius cylinder. The chosen base material was Cu, partly to tie into the Density Functional Theory (DFT) modeling being performed by UNM and other university colleagues and members of our multipactor group who had selected Cu is the basis for much of their initial work [see papers by Matanovic and by Polak in this conference].

The 1 cm gap lends itself to lower frequencies, in the range of 100-500 MHz for the multipactor effect to take place. The coaxial geometry is the starting point for more complex models that may include a full TWT tube geometry. Figure 2 shows a cross section of our geometry using an adaptive mesh approach. Electromagnetic fields and S-parameters were generated in Design Studio and then imported into Spark3D. In Spark3D electrons are launched into the interaction space and their

---

This work was supported by AFOSR MURI Grant FA9550-18-1-0062 administered through Michigan State University.

trajectories are self-consistently tracked; the resultant avalanche and growth of electron current due to a prespecified SEY emission were determined with the following assumptions: maximum SEY occurs at 165 eV with a value of 2.3 and with a first crossing point (W1) occurring at 35 eV.

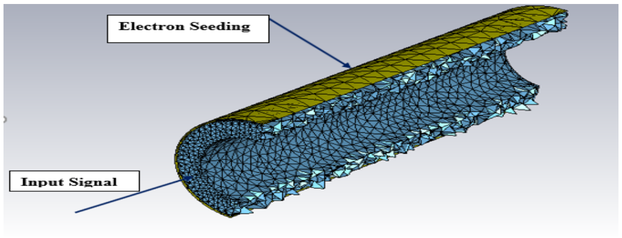

Figure 2. Cut-away view of the coaxial multipactor testbed showing the basic set-up for multipactor to occur.

MULTIPACTOR SIMULATION USING SPARK3D

Three different frequencies were used in our simulations: 100, 300, and 500 MHz. For each of these frequencies power was increased from 50 to 4000 W, which in turn yielded breakdown occurring at 91.4 W for the 100 MHz, 2324.9 W for the 200 MHz input, and 3424.9 W for the 500 MHz signal. The 100 MHz input yielded a first order multipactor mode, the 300 MHz input yielded a 3rd order multipactor mode, and the 500 MHz input produced multipactor in the 3rd and 5th order modes. These breakdown values fall within the multipactor susceptibility curves [2,3]. As the f-d product increases, the multipactor mode also gets higher with a narrower susceptibility zone [4]. Figure 3 shows electron growth as a function of time for various powers for a 100 MHz input signal. Figures 4 and 5 show electron growth for 300 and 500 MHz input signals, respectively.

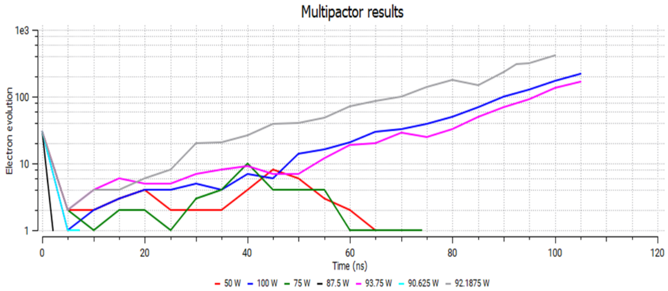

Figure 3. Electron evolution as a function of time for a 100 MHz input signal with an initial number of 30 electrons.

Figure 6 presents a snapshot of electrons in the coaxial multipactor testbed at different stages of evolution for a 500 MHz input signal.

CONCLUSION

Our preliminary PIC model of a coaxial multipactor testbed serves as a foundation for more advanced material, surface and geometry models. This paper presents multipactor results for a coaxial geometry at 3 different frequencies and for powers up to 4000 Watts. These results will serve as the foundation for future experiments.

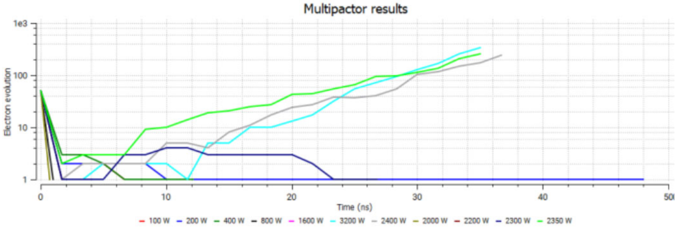

Figure 4. Electron evolution as a function of time for a 300 MHz input signal with an initial number of 50 seed electrons.

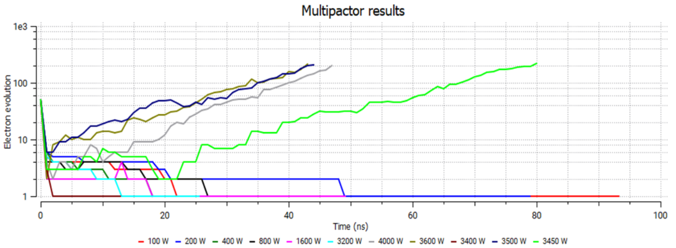

Figure 5. Electron evolution as a function of time for a 500 MHz input signal with an initial number of 50 seed electrons.

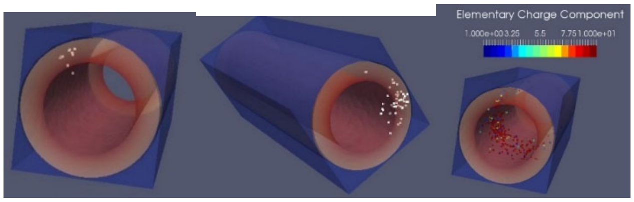

Figure 6. Snapshots at different stages of electron growth in the coaxial testbed for a 500 MHz input signal; the times range from 0 to 120 ns.

REFERENCES

1. D.M. Goebel, “Pulse shortening causes in high power BWO and TWT microwave sources,” *IEEE Trans. Plasma Sci.*, vol. 26, pp. 263-274, June 1998.
2. R. Woo, “Final report on RF voltage breakdown in coaxial transmission lines,” NASA Jet Propulsion Lab, California Institute of Technology, Technical Report 32-1500, 1970.
3. R. Udiljak, D. Anderson, M. Lisak, V.E. Semenov, and J. Puech, “Multipactor in low pressure gas,” Phys. Plasmas, vol. 10, pp. 4105-4111, October 2003.
4. T.P. Graves, “Experimental investigation of electron multipactor discharges at very high frequencies,” Ph.D. Dissertation, Massachusetts Institute of Technology, Cambridge, MA, June 2006.
5. B.G. Martínez, “Multipactor and long-pulse phenomena,” International Workshop on Breakdown Science and High Gradient Technology HG2017 (Valencia, Spain, June 13-16, 2017).
6. Hughes Aircraft Company, “The Study of Multipactor Breakdown in Space Electronic Systems,” NASA Technical Report NASA-CR-71999, P65-49, April 1965.