Investigation of Multipactor Effect on Return Loss Degradation on Dielectric Resonator Filters

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Abstract — **The objective of this letter is to study the effect of multipactor on the dielectric resonator filter response. First, a dual-mode cylindrical dielectric resonator waveguide filter is designed and Multipactor breakdown threshold of this filter has been obtained by using effective electrons approach in Monte Carlo method. Then multipactor current density in the radial space between the internal dielectric and the external metallic cavities is calculated. The magnetic field generated by the multipactor current is calculated and its equivalent volume impedance is applied to the solution boundaries and is used in the filter simulation. The simulated results are obtained using the Ansoft simulation software high-frequency structure simulator and clearly show the effect of multipactor on the frequency response of the filter.**

Keywords-component; ***multipactor, monte carlo, Effective electron, dielectric resonator***

I. INTRODUCTION

The multipactor effect is an electron-avalanche discharge in resonance with a radiofrequency electromagnetic field, which feeds on the exposed surfaces by secondary electron emission caused by impacting electrons accelerated by the field [1]. This phenomenon can cause many adverse effects in the microwave components such as electric noise, power reflection, detuning of resonat structures, and production of heat [2]. One of the other effects of this phenomenon is alteration of resonator's parameters in filters. In this case, the amount of signal reflects increases significantly. Multipactor breakdown have been studied for various geometries of waveguide structures and simulated in recent years such as coaxial line [3], circular waveguide [4], and elliptical waveguide [5].

Usually, Dual mode filters simulated with hybrid mode and these are routinely made of a cylindrical waveguide that axially loaded with a concentric dielectric cylinder. These filters are key elements in satellite's pilot [6]. These communication systems operate in vacuum environment and under the high power microwaves, in these conditions, the probability of occurring multipactor exists. In this paper, we present the effect of the multipactor RF breakdown on a filter response.

In Section II describes the physical model used in our simulations. In this section, algorithm of multipactor is also describes. In Section III, the simulation results, including original response of the filter and multipactor effect on the filter response at two different times (after 16T and 32T) are presented. A few conclusions are made in Section IV.

II. THEORY AND DESIGN

A. Physical Model

The proposed filter is shown in Fig. 1. In this filter, the input and output waveguides are WR-90 rectangular waveguides. Two rectangular waveguide irises are used in the filter to provide input and output coupling. The tuning screw can be used for the coupling which is oriented at 45° to the input iris. The filter is designed based on the HE_{111} mode of the cylindrical dielectric resonator cavity. The risk of the multipactor breakdown exists in the radial space between the internal dielectric and the external walls of the waveguide filters.

B. Multipactor Algorithm

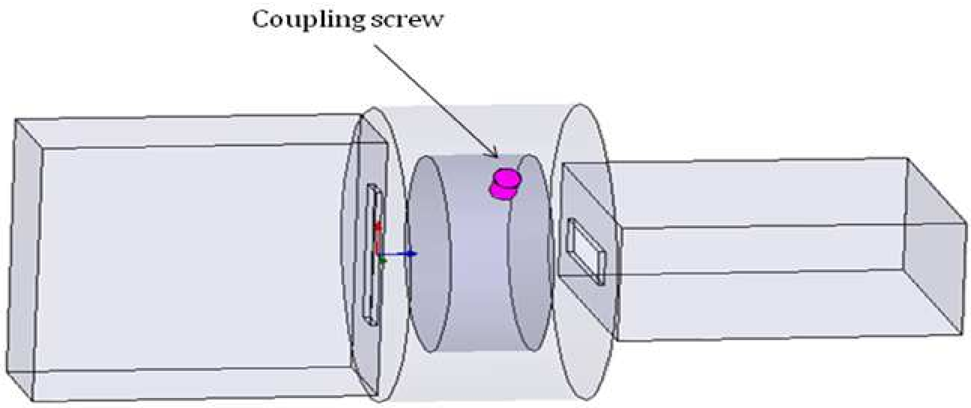

Fig. 1 Proposed waveguide filter

In this paper, a modified approach to study multipactor phenomenon in dielectric resonator waveguide using effective electron model combined with Monte Carlo method. An electron inside the radial gap space between the internal dielectric and the external metallic walls is accelerated by the RF electric field. The movement may eventually lead the electron to impact with any surface. Each collision can result in the emission or absorption of secondary electrons. The number of electrons emitted or absorbed after each impact is determined by the value of the secondary electron yield (SEY) parameter. The trajectory of the electron is tracked by solving its equations of motion by means of the Velocity-Verlet algorithm [7]. A sample of effective electron trajectory is presented in Fig. 2, for 30 numbers of impacts where *a*, and *b*, are the dielectric radius, and the radius of metallic cylindrical cavity, respectively

The value of the multipactor current duo to electrons motion is obtained through effective electron tracking. The electron trajectory has been determined under electromagnetic fields of hybrid mode of dual-mode dielectric resonator waveguide filter. The multipactor current varies as a function of time. The magnetic field generated by the multipactor current is calculated at two different times. To model the generated magnetic field, the equivalent volume impedance is calculated and applied to the boundaries of the solution space. Therefore, at first, the intensity of multipactor breakdown field must be obtained in empty radial space between the internal dielectric and the external wall of the filter. To predict the occurrence of multipactor, the enhanced counter function is used [5]. This function calculates the weighted sum of the effective electrons and divides it by the initial total number of effective electrons.

The RF breakdown thresholds have been obtained as a function of $f \times d$ (GHz-mm) product where d is the distance between the metallic and dielectric walls ($d = b - a$) .To obtain the produced impedance due to multipactor, we use:

$$\vec{J} = ne\vec{v} \tag{1}$$

where $\vec{J}$ is the current duo to electrons motion within outer and inner radius, $\vec{v}$ is the electron velocity and e is the electron charge. Also $n = N / \Delta V$ in which N is the number of electrons (effective electron weight) within the volume ΔV .

Each effective electron after t_i second produces a current within outer and inner radius which leads to a magnetic field. The total number of electrons N at a given time t is calculated by means of the effective electrons weight and is defined as:

$$N(t) = \sum_{i=1}^{m} N_i(t) \tag{2}$$

where m is the total number of electrons and $N_i(t)$ is the population of electrons of the ith effective electron at time t. The total magnetic field is the sum of the magnetic field produced by each effective electron at time t_i. The effective electron velocity and weight are recorded and the magnetic field is obtained as follows:

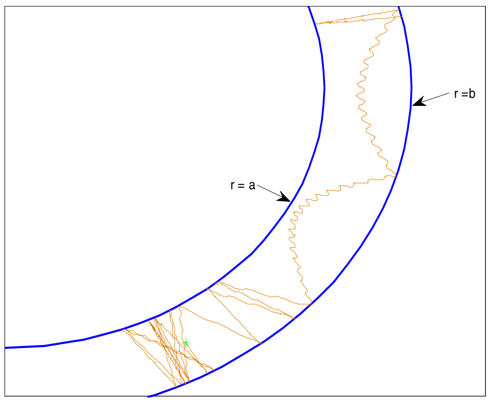

Fig. 2. Electron trajectory for first 30 impacts

$$\nabla \times \vec{H} = (e\sum_{j=1}^{m} N_j \vec{V}_j) + j\omega\varepsilon_r \vec{E} \tag{3}$$

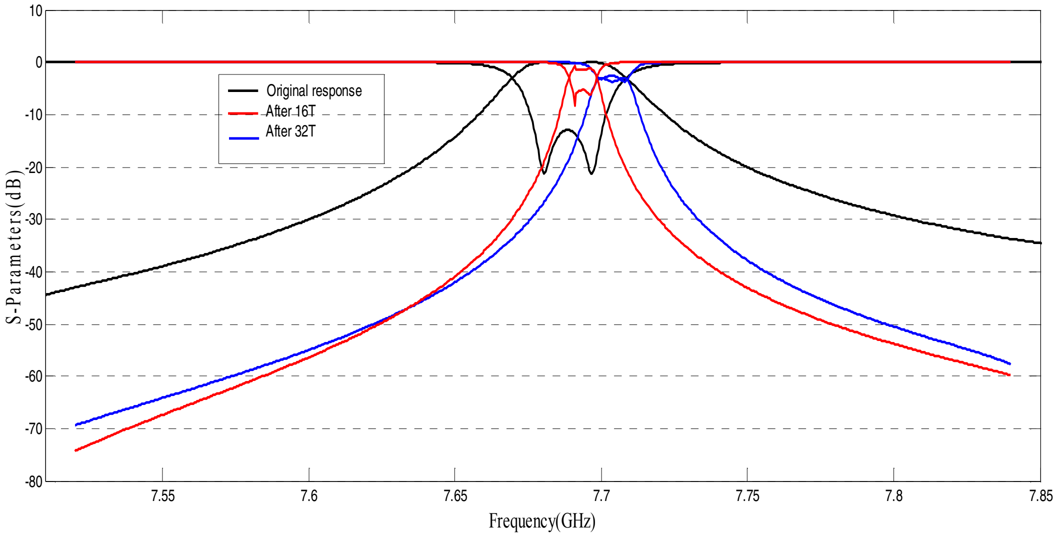

Fig. 3. Multipactor effect on the filter response

where $\vec{H}$ is total magnetic field, and $\vec{V}_j$ is the velocity vector of j[th] effective electron at time t_i and ε_r is its dielectric permittivity, and $\vec{E}$ is the electric field component for a dual-mode cylindrical dielectric resonator waveguide filter have been written in analytical form as reported in [8]. Then the impedance of the radiated filed at different times is calculated and is used in the filter simulation.

III. Simulation Results

The proposed filter is shown in Fig. 1. In this filter, the dielectric radius, *a*, is 10 mm and the waveguide radius, *b*, is 12.7 mm. The dielectric resonator permittivity is considered to be ε_r =37.6. The parameters of secondary emission yield (SEY) model for dielectric ($diel_{silver}$), and for metallic walls (silver) are given in Table I that are extracted from [9]. $Diel_{silver}$ is a fictitious dielectric material, which shares with silver the same SEY properties to have that value (37.6) for its dielectric permittivity.

The resonant mode in this filter is HE_{111}. The length of the cylindrical cavity is 15.24 mm and the length of the dielectric cylindrical is 7.62mm. The penetration depth of the screw determines the coupling strength and the length of the coupling screw is tuned to give the best frequency response. The diameter and length of the screw is 1mm and 3mm, respectively. This filter provides 30 MHz bandwidth with the center frequency of 7.68 GHz.

The algorithm described in the previous section is employed to obtain the volume impedance created by multipactor. At time steps corresponding to 16 Rf period (T), 32T , the weight and velocity of each effective electron has been recorded and the current vector is obtained. Finally, by calculating the magnetic wave due to multipactor current density the values of the impedance in the mentioned areas have been computed. It is found out that the impedance is $2439\,M\,\Omega$ after $16T$, and 576 GΩ after $32T$. These impedances are applied in the simulation as volume impedance within the radial space between the internal dielectric and the external metallic walls.

The original responses of the proposed filter along with the response affected by multipactor are shown in Fig. 3. As can be seen the filter response is degrading with time because the number of electron within the gap space is increasing.

TABLE I. Secondary electron emission properties for the materials

Material	E_{max} *(ev)*	δ_{max}	E_1*(ev)*
Silver	165	2.22	30
$diel_{silver}$	165	2.22	30

IV. Conclusions

In this paper the effect of multipactor breakdown thresholds on a dual-mode dielectric resonator waveguide filter response is presented. First a dual-mode waveguide filter using cylindrical dielectric resonator cavity has been designed and multipactor breakdown threshold of this filter has been obtained. Then volume impedance generated by the magnetic field is calculated and applied to the filter in our simulations. The results of multipactor effect have been presented at various time steps after multipactor breakdown. It has been shown qualitatively how the multipactor degrades system response.

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