Investigation of Multipactor Effect on Return Loss Degradation

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Abstract— **Multipactor effect on a dual-mode second-order waveguide filter response is presented. First, a dual-mode second-order waveguide filter using elliptical waveguide irises as input and output coupling is designed and simulated. Then multipactor current density is calculated with respect to the multipactor RF breakdown threshold in the elliptical waveguide irises. The magnetic filed corresponding to the multipactor current is then calculated and its equivalent surface impedance is applied to the solution space. Afterwards, the electromagnetic field distribution inside the filter is simulated using a finite-element simulator. The simulation results clearly show the effect of multipactor on the frequency response of the filter.**

I. INTRODUCTION

Multipactor is a RF breakdown that may occurs in the high power microwave devices working under the vacuum condition. Free electrons emitted from the surface of the microwave device resonance under the applied electromagnetic fields so that the electron population grows rapidly. A cloud of electron is created within the waveguide and causes undesirable effect on the system performance. It increases noise power and the temperature of waveguide walls, which leads to increased loss and degrades system response. Microwave components such as filters [1], [2] and antennas [3] that work under vacuum conditions are at risk of the multipactor occurrence.

The multipactor has been analyzed by Hatch and Willams in the parallel-plate waveguide [4] and its characteristics on the various geometries of waveguide structures has been studied and simulated in recent years [1-3], [5-8]. Usually the multipactor is simulated by using the effective electron method [5] for waveguide structures such as circular waveguide [6] or elliptical waveguide [1]. In these works, the electron trajectory has been determined under their fundamental mode and the multipactor breakdown threshold for various dimensions has been obtained. The steady-state computation that has been presented in [7] investigates the multipactor induced current on a cavity model in the presence of steady-state multipactor. Also some studies on the multipactor detection method have been presented in [8].

In this paper, we present the effect of the multipactor RF breakdown on a filter response. First, we consider a second-order dual-mode waveguide filter including two input and output elliptical waveguide irises. When multipactor begins a multipactor current duo to electrons motion within the waveguide is produced in the waveguide irises. The value of the multipactor current is obtained through effective electron tracking. The multipactor current varies as a function of time. The magnetic field generated by the multipactor current is calculated at three different times. To model the generated magnetic field, the equivalent surface impedance is calculated and applied to the boundaries of the solution space. Finally, the simulation results, including original response of the filter and multipactor effect on the filter response at different times are presented.

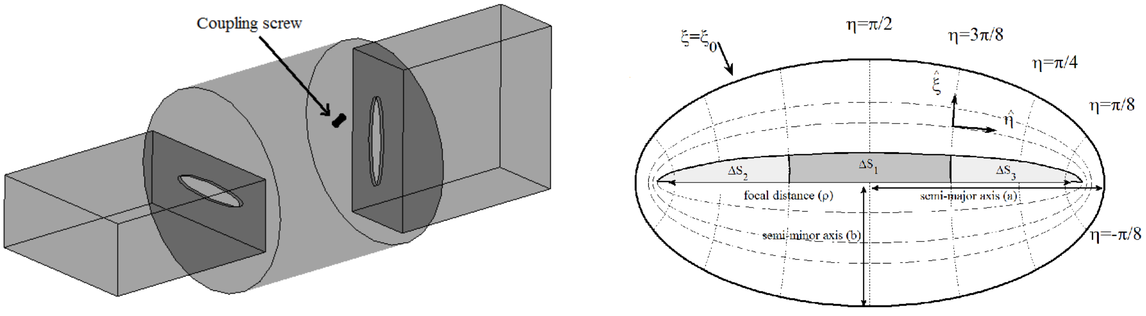
II. DESIGN AND MODEL DESCRIPTON

Consider a dual-mode second-order waveguide filter including a cavity along with input and output elliptical waveguide irises and a coupling screw as shown in Fig. 1 (a). The filter is designed based on the TE_{111} mode of the circular cavity. The orthogonal mode is excited by a 45^0 coupling screw. Two elliptical waveguide irises are employed in the proposed filter to provide input and output coupling.

The risk of the multipactor breakdown exists in the small irises of the waveguide filters. In these irises, the value of f×d (mm-GHz) product is less than twenty in which the lower-order multipactor with low-voltage RF breakdown threshold occur. Multipactor happens when the magnitude of the applied electromagnetic field is higher than the multipactor breakdown threshold.

As mentioned, the multipactor is a result of the electron resonance within a waveguide. These electrons are emitted from the surface. Thus, the multipactor induces a spurious current into the waveguide walls duo to electron emission from the waveguide surface [7]. In fact, a surface charge density of σ is created through electron motion within the waveguide and acts as impedance.

At this moment, a fixed value of time harmonic current or current duo to charge density is created within the iris according to the magnitude of the applied electromagnetic field and varies in time. First, we obtain the multipactor RF breakdown threshold for the elliptical waveguide irises in the proposed filter. For an elliptical waveguide iris, the RF breakdown thresholds have been obtained as a function of *f*×*d*



(a) (b)

Fig. 1 (a) Proposed waveguide filter (b) elliptical coordinates system and selected areas

Fig. 2. Surface impedance sheet used in simulation

(GHz-mm) product [1] where *d*=2*b* and *b* is the length of the semi-minor axis as shown in Fig. 1 (b). In [1], the value of the RF breakdown thresholds is given for different value of eccentricity, *e*. The eccentricity of the ellipse is

$$e = \sqrt{a^2 - b^2} \; / \; a \tag{1}$$

where *a*, *b*, and *ρ* are the lengths of the semi-major, semi-minor and focal distance, respectively.

To find the RF breakdown threshold the effective electron approach is employed. The electron motion equation in the elliptical coordinates system is formulated and is solved numerically by using the velocity-Verlet algorithm. The enhanced counter function is applied to detect multipactor. Detailed steps of the algorithm are described in [1]. By using this value of breakdown threshold, the electron trajectory by using the effective electron method is calculated. To obtain the produced impedance due to multipactor, we use

$$\vec{J} = ne\vec{v} \tag{2}$$

where $\vec{J}$ is the current within iris, $\vec{v}$ is the electron velocity and *e* is its the charge. Also $n = N / \Delta V$ in which *N* is the number of electrons (effective electron weight) within the volume ΔV. The cross section of ΔV which is Δs can be seen in Fig. 1 (b).

Each effective electron after t_i second produces a current within iris which leads to a magnetic field. The weight of each effective electron is the number of electrons at time t_i for the relative phase [1]. So the total number of electrons is the sum of the effective electrons weight and 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:

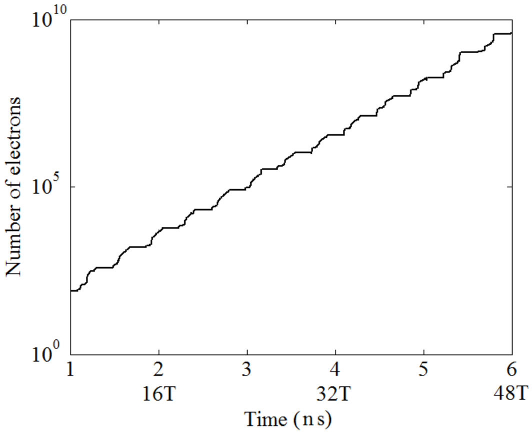


Fig. 3. Electron population as a function of time in the first area

$$\hat{n} \times \vec{H} = \frac{(\sum_{j=1}^{m} N_j \vec{V}_j)}{\Delta s} e \tag{3}$$

where *m* is the total number of electrons, $\vec{H}$ is total magnetic field, $\hat{n}$ is the normal vector to the surface and $\vec{V}_j$ is the velocity vector of j^{th} effective electron at time t_i.

Then the impedance of the radiated filed at different times is calculated and is used in the filter simulation. Here, we have considered three areas in the iris as shown in Fig. 2. The second and third sections have same properties due to symmetry whereas the first section is located at the center of the iris.

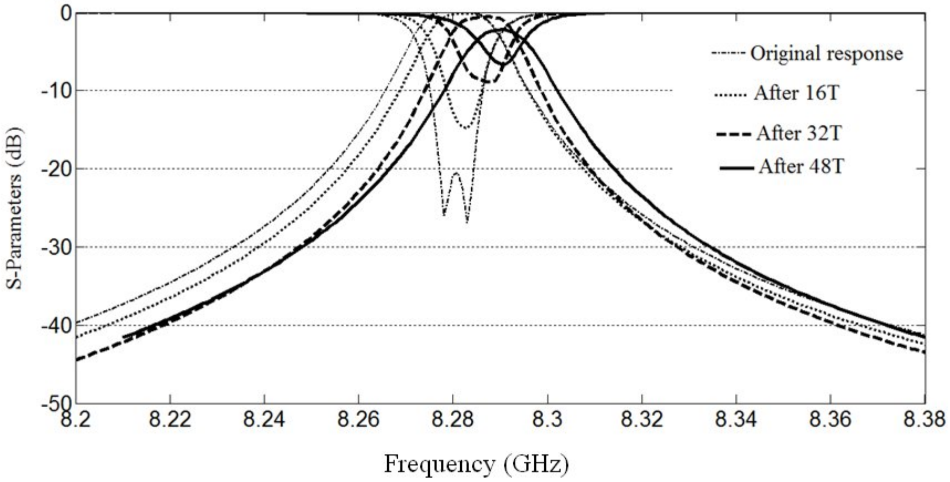


Fig. 4. Multipactor effect on the filter response

III. SIMULATION RESULTS

The proposed filter is shown in Fig. 1(a). In this filter, the input and output waveguides are WR-90 rectangular waveguides. Two elliptical waveguide irises are used in the filter to provide input and output coupling. These irises have the eccentricity of 0.95. The second mode excited by 45^0 coupling screw. Because the second mode is orthogonal to the first mode, the output iris and output rectangular waveguide is rotated 90^0 as can be seen in Fig. 1(a). The resonant mode in the circular cavity is TE_{111}. The length and diameter of the circular cavity are 28.2mm and 27.79mm, respectively. The length of the coupling crew is tuned to give the best frequency response. The diameter and length of the screw is 1mm and 2.15mm, respectively. This filter provides 10 MHz bandwidth with the center frequency of 8.28 GHz and a quality factor of Q=804.

To observe the effect of the multipactor on the filter response, we need to calculate the multipactor breakdown threshold in the elliptical waveguide irises. The RF breakdown threshold has been obtained for the elliptical waveguide iris [1]. Running a simulation for our case with the $f \times d$ product of 10.3 yields a RF breakdown of about 2320 V. In this case, we have considered silver for waveguide walls. In the simulation, the number of effective electrons and their weight at different time has recorded in the specified areas. The selected area dimensions are:

$$\Delta s_1 = (0 < \xi < 0.05, 0.3\pi < \eta < 0.7\pi)$$
$$\Delta s_2 = (0 < \xi < 0.05, 0.7\pi < \eta < \pi)$$

The third area is considered to be the same as the second one because of the symmetry. The electron population is obtained as a function of time in the first and second areas. Fig. 3 shows how the number of electrons grows in the first area.

The algorithm described in the previous section is employed to obtain the surface impedance created by multipactor. A number of 360 effective electrons are launched and tracked. At time steps corresponding to 16 Rf period (T), 32T and 48T, 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 surface current density the values of the impedance in the mentioned areas have been computed. It is found out that the impedance in the first and the second areas are 22.5 $M\Omega$ and 55.8 $M\Omega$ after $16T$, 212.3 $K\Omega$ and 2.3 $M\Omega$ after $32T$, and 62.7 $K\Omega$ and 375.9 $K\Omega$ after 48 T. These impedances are applied in the simulation as surface impedance sheet with three sections as shown in Fig. 2.

The original responses of the proposed filter along with the response affected by multipactor are shown in Fig. 4. As can be seen the filter response is degrading with time because the number of electron within the waveguide is increasing. The response of the filter is substantially degraded after 48RF period.

IV. CONCLUSIONS

The response of a dual-mode waveguide filter has been investigated in the presence of the multipactor. First a dual-mode waveguide filter using elliptical irises has been designed. Then multipactor breakdown threshold of the elliptical irises has been applied to the filter irises in the simulations as surface impedance sheet. 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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