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INVESTIGATION OF MULTIPACTION RISK IN COAXIAL RESONATORS

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ABSTRACT

Multipaction risk in a resonator differs from transmission line risk, in that the former can store energy, both frequency-dependent electric and magnetic. Multipaction threshold powers likewise differ in coaxial resonators. In this paper, an investigation on multipactor risk in different coaxial resonators is presented for the first time. Peak voltage analysis and multipaction threshold measurements of four kinds of coaxial resonators indicate that multipaction threshold in the coaxial resonator is not simply proportional to minimize gap distant and that different inner cylinders structures in the same outside cavities resonating at L band have at least 1-dB difference. Experimental results agree with the predicted characteristics.

Keywords: *Multipaction Risk,Coaxial Resonator,Resonator Filters*,*Threshold Powers,High Power Handing*

1. INTRODUCTION

Multiplicator is a non-linear effect that may appear in microwave devices operating at high power and low pressure conditions, lower than 1.0×10^{-3} Torr. The process consists of a resonant electron avalanche between the inner metal surface of the component, which occurs when certain field conditions are met (amplitude, frequency, and phase), due to the Secondary Electron Emission (SEE) phenomenon [1]. The effects of the multipacting avalanche ranges from signal degradation to device destruction. For these reasons, multipactor is critical in the design of microwave devices for space applications [2], and remains an object of great interest for the scientific community [3], [4].

Multipactor susceptibility curves based on the parallel plate theory serve as standard for the multipactor design margins in the space industry [5]. To reduce the development time and cost of space hardware, assessing the multipaction risk in the devices is necessary before actual manufacturing and testing. The software 'ECSS Multipactor tool', which had finished in ESA/ESTEC, proposed the prediction software tool for multipaction threshold in several kinds of transmission lines, such as waveguide, coaxial, and micro-strip line, among others. The parallel plate approximation can be applied to real microwave components only when the gap size is relatively small compared with the rest of dimensions, and only the fundamental mode is propagating.

The multipaction breakdown effect in various kinds of transmission lines is proposed in [6-9]. The study of multipaction breakdown effect about passive waveguide filters is proposed in [10-13]. The main topics focus on various kind waveguides filters. In [14], an efficient method for performing electromagnetic analysis together with high power study for coaxial combline filters is presented. The Boundary Integral Resonant Mode Expansion (BI-RME) Method is employed to obtain the generalized admittance matrix of cavity resonators by using the Rao-Wilton-Glisson (RWG) basis functions to model both electric and magnetic current densities in the problem. The coaxial comb-line filters are examples for the method. These papers provide many simulation results for the investigations.

This paper deals with the multipaction risk in four kinds of coaxial resonators, as shown in Figure 1, which has same outsize and is usually used in L, S-band narrow band filter. To obtain the measured S-parameters and multipactor threshold, the 3-rd filters composed by four structures have been used. The full filter has been analyzed in HFSS to obtain the S-parameters and magnitude of the electric field. As the 3D full-wave simulation results, the peak voltage pre-W in different

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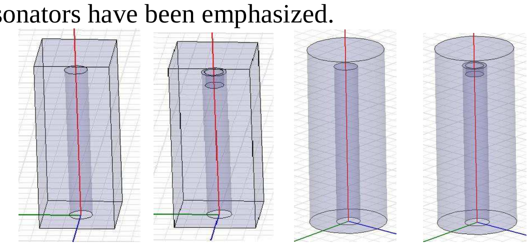
resonators have been calculated and the order of the multipaction threshold for the four kinds of coaxial resonators have been emphasized.



(a) (b) (c) (d)

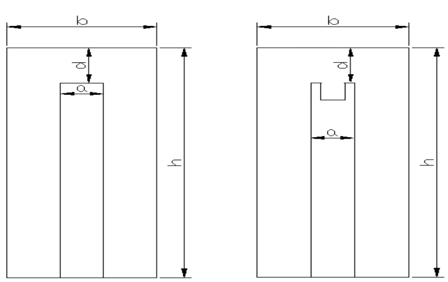
Figure 1:Structures of Four Kind Coaxial Resonators: (a) Flat Cylinder End In Square Cavity; (b) Concave End in Square Cavity; (c) Flat Cylinder End In Circular Cavity; (d) Concave Cylinder End In Circular Cavity

Table 1: Four Kinds of Coaxial Resonator Structure

Structure of outside cavity	Structure of cylinder end	Figure	Named in this paper
Square	Flat	Figure 1(a)	SF structure
	Concave	Figure 1(b)	SC structure
Circular	Flat	Figure 1(c)	CF structure
	Concave	Figure 1(d)	CC structure

The results were verified via the multipaction experiment measurements, which indicate at least 1-dB difference of multipactor threshold between two inner cylinder structures with the same size.

2. FULL-WAVE ANALYSIS OF FOUR KINDS OF COAXIAL



(a) (b)

Figure 2:Structures of Cylinder End In Coaxial Resonator: (a) Flat Cylinder End; (b) Concave Cylinder End. In This Paper, The Sizes of All Coaxial Resonators Are: a=8 mm, b=26 mm, h=55 mm, And The Gaps (d) Differ

Two kinds of coaxial resonator structures, with inner cylinder in the square or circular outside cavities, were primarily used in space passive devices. The end of the inner cylinder is commonly flat, as shown in Figure 2(a). The end of the metal cylinder is concave to allow for convenient frequency tuning, as shown in Figure 2(b). In order to improve generality of study, four kinds of coaxial resonator structures have been analyzed, as seen in Table 1.

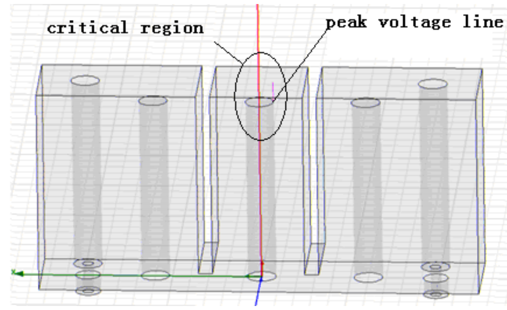


Figure 3:Structure of The 3-pole Filter And Its Critical Region

2.1 Confirmation of Analysis Schemes

The coaxial resonator is the basic unit of the coaxial filter. In order to obtain the multipactor threshold of coaxial resonator, several schemes have been regarded.

The multipactor experiment cannot direct analyze the multipactor parameter of an ideal coaxial resonator in HFSS software with the eigenmode method.

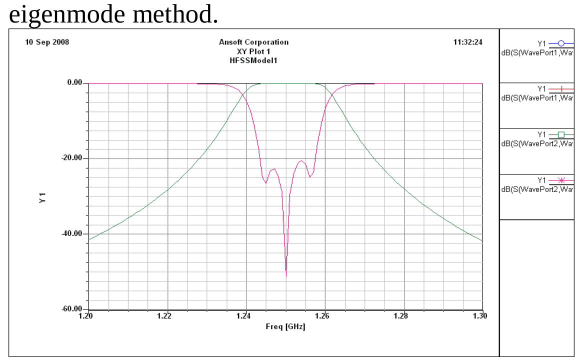


Figure 4: Simulation Result of The 3-rd Filter

3-rd order filters were used to obtain the multipactor threshold of the ideal coaxial. The structure of the second resonator in 3-rd order filter, as shown in Figure 3, was similar to the ideal model of coaxial resonator. Most of the energy in the 3-rd order filter is stored in the second resonator according to electric circuit analysis. The greater stored energy requires larger field intensity levels inside the resonators, therefore, leading to higher risk of multipaction.As a whole 3-rd order coaxial filter, the S-parameter and multipactor threshold can be directly measured.

2.2 Electrical Design

The design begins with the generation of a suitable prototype filter. The coupling matrix of the 3-rd order chebyshev prototype with a response of 0.01 dB ripple is M01=M34=1.13755, M12=M23=1.10102.

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Table 2: Peak Voltage of Simulation

Structure	f*d(GHz*mm)	Peak voltage/W(V)
CF	7.536	148.69
CC	5.884	109.57
SF	4.371	88.01
SC	4.325	81.37

The filters were designed in four kinds of coaxial resonators in columnar and square cavities. The M-matrix elements were realized as physical dimensions by using 3D full-wave simulator. By using four kinds of coaxial resonators with the same outsizes, as shown in Figure 2, the same outsize of four kinds of filters was designed.

Finally, the physical dimensions of the whole filter were checked. The return loss is higher than 20 dB with insertion loss lower than 0.4 dB.

2.3 High Power Handling Capability

Passive intermodulation (PIM) and multipaction analysis is necessary to predict high power handling capability. PIM is RF distortion that occurs whenever signals at two or more frequencies are simultaneously conducted in a passive device. The nonlinear behavior generates unwanted products with frequencies that are linear combinations of the original signals. The physics behind the PIM problem remains unclear. Normally, the reason for PIM generation at waveguide contacts is the poor metal contact in combination with native oxidation of the waveguide metals and the lack of precision in the fabrication process [9].

Therefore, the filter should be manufactured by using proper materials with the minimum number of contact junctions and no tuning screws. The filters of this paper were machined from aluminum alloy, and then silver-plated. The filters did not have any frequency tuning screw. Although the filters in this paper were not tested for PIM, these steps are necessary for undertaking high power working conditions.

Multipaction is an RF breakdown phenomenon, the generation of which depends on four constraints: vacuum condition, applied RF voltage, frequency of operation in conjunction with geometry of RF components (f*d product), and surface condition. One, for multipaction to occur, the mean free path of electrons must be long enough to permit the acceleration of electrons between the emitting surfaces with a low probability of collision with the ambient atoms or molecules. Consequently, we can safely assume that multipaction can occur under pressures of 1.0×10^{-3} Torr or less. Two, the electrons are accelerated by the electric field created by the applied RF voltage to produce more than one secondary electron. Three, the gap size should be a multiple of the half-cycle of the applied RF voltage to ensure the condition of electron resonance. Four, the secondary emission coefficient δ is very sensitive to the relative purity of materials. Most contaminants increase the value of δ and enhance the possible occurrence of multipaction.

According to the above constraints, when the different structures of test pieces, which undergo the same surface treatment at almost same time, have been tested in the same vacuum tank with pressures of 1.0×10^{-3} Torr or less, the vacuum and surface conditions of these test pieces are assumed to be the same. An odd number N (N$>$1) of filters were manufactured for each kind of structure, and all test pieces were tested to exclude special cases.

Obtaining precise values of applied RF voltage means that the multipaction threshold was accurately predicted. Generally, express multipaction threshold power can detect multipaction. In the simple transmission line system, such as parallel-plate, multipaction threshold power from the detection can be easily translated into applied RF voltage. However, in complex geometric structures, such as coaxial resonator, the translation from the detection power to applied voltage is very difficult, causing difficulties in obtaining the equivalent characteristic impedance of minimized gap in coaxial resonator.

The parallel-plate geometry determines breakdown as a function of an frequency and gap width product (f$\times$d). Each odd multiple of the gap width has a multipaction curve, which corresponds to the half-cycle of the RF voltage. Generally, the larger the minimized gap is, the higher is the breakdown of the RF voltage the gap when f is given. The higher breakdown RF voltage the gap has, the higher the threshold power when the characteristic impedance of the gap is constant. Different kinds of structures have different minimized gaps and equivalent characteristic impedance, which can be calculated by simulating the applied RF peak voltage pre W at the maximum E field using HFSS. The equivalent characteristic impedance of the minimized gap is the square of the applied RF peak voltage pre W.

In TEM mode resonator, maximum E field occurs at the end of resonator cylinder. This also appears at the smallest gap between the end of resonators and the cavity wall. The end of the second resonator is critical area for the multipactor where the electric field is at maximum in the filter,

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as shown in Figure 4. The peak voltages in the second resonators of four kinds of filters were calculated by 3D-EM analysis tool and the sort order is summarized in Table 2. The SC structure has the least peak voltage.

Table 3: Responses of Filters

Parameters	Designed	Measured
Center Freq.	1255 MHz	1255 MHz
Operational Band	10 MHz	10.3 MHz
Insertion Loss	⩽0.4 dB	0.36 dB
Loss variation	⩽0.2 dB	0.18 dB
Group delay	⩽30 ns(f0) ⩽36 ns(f0±5MHz)	⩽28.34 ns(f0) ⩽5.9 ns
RX/TX VSWR	⩽1.2	⩽1.19
RX/TX Connector	TNC	TNC

Table 4: Measured Multipactor Threshold Power

Structure	Peak voltage/W(V)	Threshold (W)
CF	148.69	70
CC	109.57	90
SF	88.01	100
SC	81.37	150

3. EXPERIMENTAL RESULTS

All the four kinds of filters with TNC connectors have the same outer size, which is 146 mm × 34 mm × 71 mm. The resonators in all filters was almost 75Ω coaxial line geometry, and the minimized gap in the resonator was the open end of the inner cylinder to the outer cavity.

Table 3 presents the measured responses of the typical filter, achieving excellent agreement.

Table 4 presents the measured multipactor thresholds of four kinds of coaxial resonators, which include the sort order of the multipactor threshold.

Table 4 likewise indicates a 1.06 dB different between two structure cylinders in the circular outside cavity, and 1.76 dB different between two structure cylinders in the square outside cavity. The SC structure has the least multipactor risk among the four kinds of coaxial resonators.

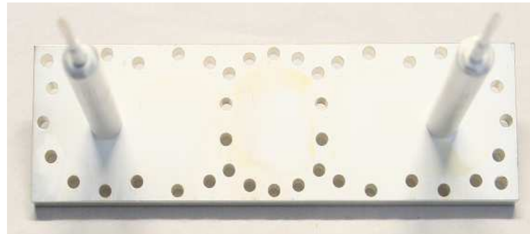

Figure 5: Photo of Multipaction Trails

When the diameter of the park chamber is equal to the side of the square cavity, the power capacity of the park chamber is smaller than the square cavity. In Table 4, the measurement result indicates the same as the multipaction threshold.

In the TEM mode resonator, different parts have different characteristic impedances, especially at the end of the inner cylinder of the resonator. Reducing the characteristic impedance of the minimum gap in the resonator by changing the structure will improve the multipactor threshold power.

According to the analysis, the multipaction critical areas in the 3-rd order filter are the inner open end of the second resonator. Figure 5 depicts the visible SEE trail in the second resonator of the 3-pole filter.

4. CONCLUSIONS

This paper presents a full-wave analysis of peak voltage and experimental measurements in four kinds of coaxial resonators. As the 3D EM analysis result, the multipactor susceptibility region in the coaxial resonator as well as the peak voltage of the four kinds of coaxial resonators in 3-rd order filters have been emphasized. Experimental results indicate a good agreement with predicted characteristics. The measurement indicates at least 1-dB difference of multipactor threshold between two resonator structures with the same size.

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