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Study of the multipactor phenomenon using a full-wave integral equation technique

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***Abstract*—Multipactor effect is a well-known phenomenon of RF breakdown in satellite payloads which degrades components, generates undesirable harmonics, contributes to power dissipation and increases noise in communications. Traditionally, multipactor has been investigated with the aim of obtaining the so-called multipactor threshold voltage, or to present different multipaction detection methods. However, very little attention has been focused on analysing this phenomenon using a multimodal approach. The main goal of this work is to analyse the interaction between a multipactor current and a realistic microwave cavity by means of a rigorous and accurate formulation. For the first time to the authors' knowledge, a full-wave method based on the 3-D Boundary Integral - Resonant Mode Expansion (BI-RME) technique is proposed to model the aforementioned undesired effect. In this work, the classical formulation used in the 3-D BI-RME method is exploited to achieve a full-wave representation of the multipactor effect in terms of an equivalent multimode network expressed in the form of a generalized admittance matrix.**

Keywords: multipactor effect, full-wave analysis, integral equation technique.

I. Introduction

Multipactor is a well-known and undesired effect affecting microwave devices used in space telecommunication systems. Typically, multipactor phenomenon occurs in microwave components operating under high-power conditions and immersed in a ultra-high vacuum environment, such as RF satellite components and particle accelerators devices. It consists of a generation of an electron avalanche that may result in a resonant discharge with harmful consequences for the satellite RF payloads. Among these consequences, it is worth mentioning the degradation of the component, the detuning of resonant cavities, power dissipation and a significant increase of noise in communications.

Multipactor has been usually investigated with the aim of predicting the so-called multipactor breakdown threshold voltage [1–4], to present different multipaction detection methods [5, 6], to study the radiated power by a multipactor discharge [7, 8], or to investigate the phenomenon in order to predict under which conditions it will result in an electron discharge [9, 10]. Little effort has been devoted, in contrast, to study the problem from a full-wave point of view, thus allowing for the analysis of more complex structures. Among such technical contributions, we can mention the study performed in [11], where a multimode network for multipactor discharges in rectangular waveguides is proposed to model the electromagnetic radiation of a multipactor event occurring within a waveguide transformer.

The objective of this paper is to present a novel approach, based on the 3-D Boundary Integral - Resonant Mode Expansion (BI-RME) method [12, 13], to study the multipactor phenomenon, with the aim of obtaining a full-wave characterization of such effect in terms of an equivalent multimode network expressed in the form of a generalized admittance matrix. 3-D BI-RME method is an integral equation technique for the full-wave analysis of passive waveguide devices with an arbitrary geometry. This method has been widely employed to characterize a great variety of passive microwave components [14, 15], and it yields an accurate full-wave representation of the analysed device, while making use of extremely low CPU resources (both computational time and memory).

For the first time to the authors' knowledge, the 3-D BI-RME technique has been exploited to cope with the full-wave characterization of the multipactor effect. In particular, in this work we describe a method for the rigorous modeling of a multipactor discharge within a canonical rectangular cavity. As a result, the authors have concluded that the generalized admittance matrix obtained in the classical 3-D BI-RME formulation needs to be loaded with an appropriate set of current sources to cope with a rigorous characterization of the multipactor effect. The proposed technique has been successfully validated by comparing our simulated results, for an E-plane transformer implemented in waveguide technology, with experimental data available in the technical literature.

II. Study of the multipactor effect by means of an integral equation technique

The 3-D BI-RME method is a very efficient technique for the full-wave analysis of arbitrarily shaped components, that relates the pole expansion of the generalized admittance matrix of the device to the resonant modes of the cavity obtained after short-circuiting all the access ports of the structure [12–15]. Therefore, the method finally provides a rigorous electromagnetic characterization of the investigated component in terms of an equivalent generalized admittance matrix, expressed as a pole expansion in the frequency domain. Essentially, the method is based on the obtention of a set of electric- and magnetic-field integral equations whose kernels turn out to be frequency independent, and on their subsequent transformation into an equivalent real-matrix linear eigenvalue problem through Galerkin's procedure [16].

Let us consider a resonant cavity with two waveguide access ports. The electric and magnetic fields in such a cavity originated by inner volumetric electric sources $\mathbf{J}$ (in this problem, this current represents the multipactor discharge), and magnetic current sheets $\mathbf{M}$ on the boundary, can be expressed in terms of the electric scalar and vector potentials