CAD of Multipactor-free Waveguide Components for Communication Satellites

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Abstract— **Power handling capabilities of satellite waveguide components are limited by multipactor discharge which, so far, has received scarce attention in terms of model for design purposes.**
We describe a procedure, based on the knowledge of field distribution inside the considered component, for calculating the minimum power above which the multipactor risk becomes significant. It is shown that the proposed technique allows to avoid over-restrictive specifications and is useful for quantitative evaluation of multipaction prevention techniques.
Experimental results and examples confirm the procedure validity.

I. Introduction

Although the multipactor effect has been known for many years, it still represents a considerable problem [1] and increased constraints from modern satellite systems in terms of transmit power, number of carriers and wider bandwidth, have even aggravated the situation. When multipactor is not properly addressed, the system performance degradation, or even the component distruction, becomes a possibility as a discharge may occur. Design and test margins definition has to take into account several different phenomena such as: component degradation during its lifetime [2]; effect of different carriers superposition [3], [4]; available accuracy when modeling the component discharge. In a multicarrier case, these margins can be defined with respect to the maximum instant power, as obtained by adding in phase the n carriers, $P_{test} = n^2 P_c$, where P_c the power of a single carrier.

Contributions regarding multipaction modeling tipically belong to three classes: works, mainly qualitative, concerning the design criteria [3], [5]; investigations devoted to specific case studies [6], methodological studies for analysis methods [7], [8], [9]. While the latter approaches represent a significant step forward, widely applicable CAD methods for multipaction prevention are still lacking.

The purpose of this work, and its novelty, is to provide a reliable and accurate CAD procedure for quantitative multipaction evaluation, as required for practical design purposes. Such a procedure, which is based on the rigourous full-wave field modeling and on the available physical description of the multipaction phenomenon, brings significant advantages:
- reduction of design margins;
- decreased need for testing;
- shortening of design time and consequent cost reduction.

II. The Multipaction CAD Procedure

We extend the approach of [10], which has been developed for the parallel-plate case, that is for a constant field. The validity of this method has been confirmed by [2] after an extensive experimental activity on waveguide samples. We introduce a new quantity, the Voltage Magnification Factor, VMF, which provides a measure of the maximum voltage occurring in the component for each spot frequency and is obtained from the field knowledge along the structure. With reference to a rectangular housing waveguide we assume, for sake of simplicity, that the field is directed along the vertical (y) direction. The VMF is obtained by computing the integral of E_y, as obtained by a full-wave analysis, at the i-th cross-section $z = z_i$, and by dividing this for the incident voltage $V_{in}(\omega)$:

$$VMF(z_i, \omega) = \frac{\max\limits_{x \in (0, w_i)} \int_0^{h_i} E_y(x, y, z = z_i; \omega) dy}{V_{in}(\omega)} \quad (1)$$

The procedure can be summarized as follows:
- from the field knowledge inside the component find the cross-section(s) where multipaction is expected to occur, i.e. the cross-section(s) where the equivalent voltage is maximum;
- for each of these cross-sections evaluate the $VMF(z_i, \omega)$, considering the entire operative bandwidth;

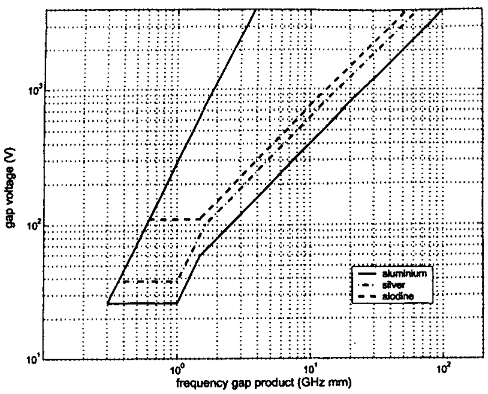

Fig. 1. Multipactor susceptibility zones for bare, silver treated and Alodine treated aluminium.

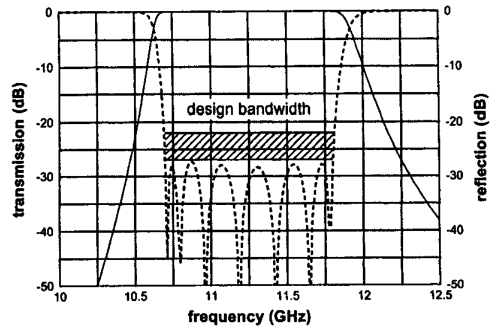

Fig. 2. Reflection and Transmission of the 7-poles transmit pass-band filter.

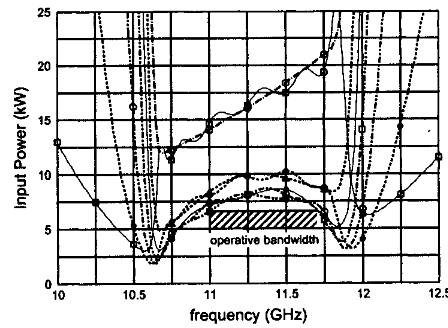

Fig. 3. Bandwidth enlargement for the filter presented in Fig. 2. The power limiting values for the seven cavities are reported. Siver surface finish has been considered.

- starting from ESA curves (Fig. 1) [2] compute, for each frequency and gap heigth h_i, the susceptibility limit V_{disc} corresponding to the selected surface material and treatment;
- for each cross-section determine a power limiting value by using the equation:

$$P_i(\omega) = \frac{V_{disc}^2(h_i, \omega)}{2Z_0(\omega) VMF^2(z_i, \omega)}. \qquad (2)$$

where $Z_0(\omega)$ is the impedance of the input waveguide;
- determine the overall susceptibility power (i.e. the input power above which the component is susceptibile to a multipactor discharge) by calculating over the operative bandwidth (ω_l, ω_u):

$$P_{min} = \min_{\omega \in (\omega_l, \omega_u)} \{ \min_{i} P_i(\omega) \} \qquad (3)$$

- apply the required design margin in order to obtain the power handling capability.

The above procedure accuracy has been ascertained by testing the computed discharge values against discharge values measured at ESTEC [11]. To this end, samples with a low discharge threshold have been selected for allowing multipactor discharge to take place.

III. Design for Multipaction Prevention

In the design of waveguide components for space applications several techniques are applicable for avoiding the multipactor effect; in the following we discuss these approaches and quantitatively illustrate their effectiveness. As a reference example we consider a transmit filter inside a diplexer, specifically the 7-poles Chebychev band-pass filter whose response is shown in Fig. 2. The input waveguide is a WR75, while the cavities are manufactured in a waveguide of dimensions w=21.05mm and h=9.52mm.

A. Bandwidth enlargement

It is advantageous to introduce the distinction between operative bandwidth (OB) and design bandwidth (DB). In some components tipically present in a satellite transmit chain (e.g. diplexer or OMT), due to the design specifications and constrains, these two bands may assume different values, with the OB being contained in the DB.

It is also expedient to note that, in a typical filter, multipactor discharge is likely to occur in proximity of filter band limits, where the VMF is higher due to resonant effects, as shown in [11]. Therefore, by considering a DB larger than the OB it is feasible to

Surface Treatment	Max Power (kW) (calculated)	Insertion Loss (dB) (measured)
Silver	6.6	-0.07
Alodine	9.6	-0.25

TABLE I

TRADE OFF BETWEEN INSERTION LOSS AND POWER HANDLING REQUIREMENTS FOR A 7-POLE CHEBYSHEV FILTER FOR A KU-BAND DIPLEXER.

Case study	Cavity height (mm)	Cavity width (mm)	Max Power(kW) (Silver)	Max Power(kW) (Alodine)
A	9.52	21.05	6.6	9.6
B	9.52	26	7.12	10.43
C	16	30	13.02	19.09

TABLE II

MULTIPACTOR SUSCEPTIBILITY POWER FOR FILTERS WITH DIFFERENT HOUSING WAVEGUIDES (INPUT IS ALWAYS WR75).

enhance the filter power handling capabilities.

This bandwidth enlargement is also beneficial to minimising the filter insertion loss; on the other hand, when considering e.g. a diplexer structure, it causes a reduction of the guardband between the two channels. With reference to Fig. 3 it is apparent that, by designing the filter on wider bandwidth DB and by operating it on the OB, a significant increase in power handling capabilities is obtained. Note also the asymmetrical behavior (with respect to centre band) of the power curves (Fig. 3); this suggests to position also the OB asymmetrically. In this particular case DB is 10.7-11.8 GHz, while OB is 11-11.7 GHz; the susceptibility power resulting from (3) when considering silver surface finish is 6.6 kW.

B. Surface treatment

Silver plating, frequently employed in satellite applications to reduce ohmic losses, guarantees higher breakdown voltages with respect to bare aluminium. Alodine 1200 treatment provides a still higher susceptibility level, but causes a non negligible increase of ohmic losses. The choice of the surface treatment comes from a trade-off between insertion loss and power handling requirements as illustrated in Table I, which refers to the 7-poles Chebychev band-pass filter example. The table reports the computed susceptibility power, according to the outlined procedure, and its insertion loss as measured on the diplexer prototype.

C. Geometry control

The enlargement of the waveguide width allows improvement of power handling capabilities, as the field is spread over a larger cross-section. A more significant improvement in power handling can be achieved by varying the height of the most critical sections of the component under analysis. This leads to a larger frequency-gap product and, consequently, to higher values of breakdown voltages. Drawbacks of this solution are size and weight increase.

As an example, in Table II we consider the Ku-band filter previously introduced (case A); its power handling capability can be improved (mantaining the 7-poles response and the operative bandwidth) by choosing a larger waveguide for the cavities (case B) or by enlarging both width and height (case C). Silver and alodine surface treatments are also compared.

IV. EXPERIMENTAL RESULTS

Some results of experimental activities are reported in order to show the effectiveness of the proposed prevention techniques.

The test bed included a Ku-band TWTA source, able to provide up to about 7 kW at the component input.

The first experimental example proposed is a proptotype TX/RX diplexer for Ku-band satellite applications designed and breadboarded in TILAB; this device is composed by two H-plane Chebychev band-pass filters and a stepped E-plane bifurcation. The TX filter of this diplexer is basically the same described in the preceeding section apart for its final optimization for operating inside the diplexer. Bandwidth enlargement has been introduced in order to reduce the VMF at band edges and the adopted surface treatment has been silver plating.

The test has been performed at 11.7 GHz, which is the frequency where minimum power handling takes place; relative test results are summarized in Table III. A susceptibility power of 6.48 kW has been calculated by using the procedure summarized in section II and by considering the entire diplexer assembly. The input power has been increased up to 6.8 kW, i.e. to the maximum available. The margin with respect to the required $n^2 P_c$ has been found to be about 4.2 dB.

A second test campaign has been performed on a

Measurement Frequency	11.7 GHz
Surface Finish	silver plating
Required Power (n^2P_c)	2.57 kW
Measurement results	No discharge up to 6.8 kW
Calculated Susceptibility Power	6.48 kW

TABLE III
SUMMARY OF MULTIPACTION TEST PARAMETERS FOR THE 7-POLE BAND-PASS FILTER.

Measurement Frequency	11.3 GHz
Required Power (n^2P_c)	1.88 kW
Aluminium sample Calculated Susceptibility Power Measurement results	3.33 kW no discharge up to 6.7kW
alodine 1200 sample Calculated Susceptibility Power Measurement results	11.71 kW no discharge up to 6.4kW

TABLE IV
SUMMARY OF MULTIPACTION TEST PARAMETERS FOR THE KU BAND LOW-PASS FILTER.

corrugated low pass filter designed for a Ku band satellite diplexer using as input waveguide a WR62. Geometry control and bandwidth enlargement techniques have been employed in order to enhance the filter power handling capability.

Multipactor tests have been performed at ESTEC before and after Alodine 1200 treatment: relative results are reported in Table IV. No discharge has been observed up to the maximum available power in both cases. The margin with respect to n^2P_c has been found to be about 5.3 dB. We remark that the calculated susceptibility power represents the lower bound above which the component may present a risk of multipaction. This explains the difference between measured and calculated values reported in Table IV.

V. CONCLUSIONS

We have described a procedure for quantitative evaluation of the multipactor discharge in waveguide components for satellite communication systems. To this end we have introduced a new quantity, the Voltage Magnification Factor, which provides a measure of the maximum voltage occurring in the component and is obtained from the field knowledge along the structure. Several methods for preventing multipaction, such as bandwidth enlargement, surface treatment and geometry control have been investigated in a quantitatively accurate manner. Experimental results and design examples have confirmed the procedure validity.

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