AN INVESTIGATION OF THE EFFECT OF FRINGING FIELDS ON MULTIPACTOR BREAKDOWN

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Abstract

In this paper the effect of fringing fields on the multipactor breakdown level in simple rectangular waveguide structures is investigated. Up to now multipactor analysis of these structures are based on the parallel plate case where the length of the structure is significantly longer than its height. There are strong indications that the multipactor breakdown level significantly increases for the non-parallel plate case, where the height of the structure exceeds its length. This effect, known as fringing field effect, occurs in structures like bandpass filter irises and corrugated lowpass filter elements.
Simulations and experimental research have been performed. A set of representative samples has been designed in X-Band for that purpose, using different height to length ratios without changing the electrical performance of the structure.

1. INTRODUCTION

Modern satellite payloads are operated with an increasing number of communication channels and a still increasing power level per channel. 16 channel multiplexers for DBS systems powered with levels of 270 W are currently state-of-the-art. TWTAs providing even higher power levels are under development.
With the number of carriers operated simultaneously the peak power in the multicarrier path, which comprises the output multiplexer, output lowpass filters, diplexers and antenna feed horns, is increasing dramatically. Operational equivalent peak power levels exceeding 50 kW are no exception for the new generation of high channel multiplexers. To avoid excessive test effort (time consuming and costly) margins of 6 dB on the equivalent peak power is required in the analysis. Based on the standard parallel plate approach this margin very often can not be demonstrated. During testing of hardware observations have been made, that for some waveguide structures the measured breakdown level exceeds the predicted level by far. Also in the literature some indications are described. The characteristic of these waveguide structures are that their height is significantly higher than their length.

In this paper, numerical simulations are presented which reproduce the results of the only model applied to these type of components [2] to the knowledge of the authors. The development of a typical test structure (test sample) will be described as well as the test bench. Finally, preliminary measured results are presented.

2. FRINGING FIELD EFFECT - GENERAL

The difference between the parallel-plate and the non-parallel plate case for typical waveguide structures like irises and corrugated elements is described in the following – see also Fig. 1. The parallel-plate approach is valid only for a certain range of gap height to gap length ratios (up to 1). For larger ratios, the voltage necessary to induce multipactor increases significantly. This can be explained as follows:
If the gap height to gap length ratio is increased, more electrons tend to accelerate along curved paths rather than along the straight-line path between the walls. The resonance condition within the gap is no longer valid. The longer effective path lengths shifts the operating location to larger values of the f x d product. Higher field gradients across the gap are thus necessary as the multipactor diagram shows. Furthermore, many of the electrons are accelerated in a direction completely away from the gap region and are no longer available for the breakdown.

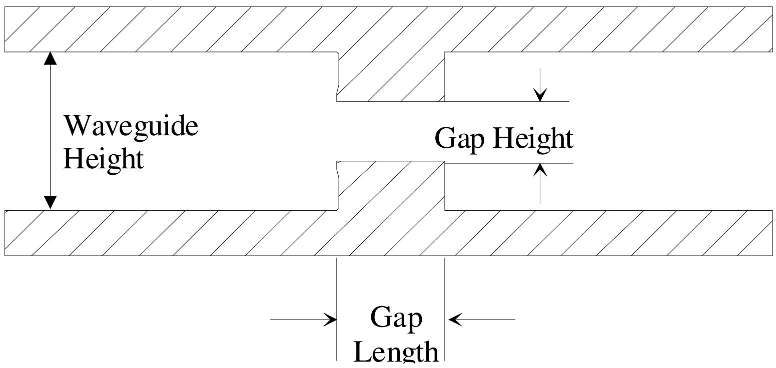

Fig. 1: Definition of height and length in a typical waveguide structure (iris).

The “fringing field effect” has been described and theoretically investigated for a gap height of 0.1 mm by Marrison [2]. In [1] test results are shown indicating a strong increase of the breakdown voltage. Such results are shown in Fig. 2.

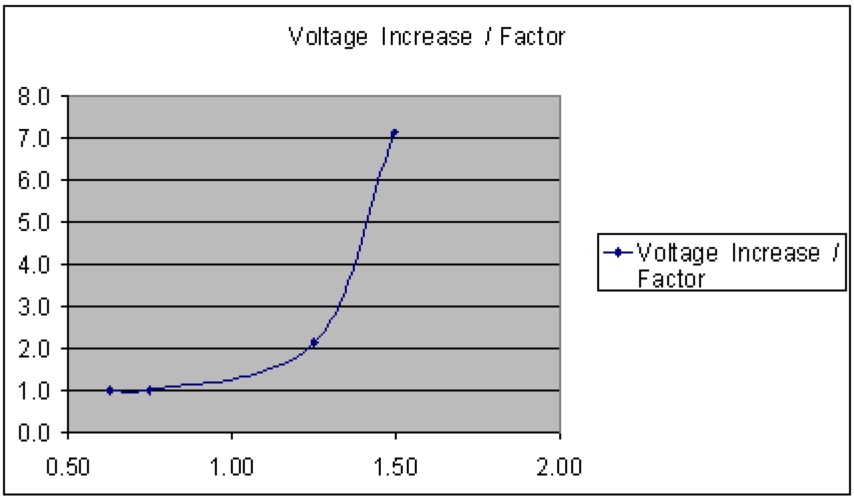

Fig. 2: Voltage Increase vs Gap Height / Length Ratio.

Typical values for the gap height to length ratios in real applications are between 1.2 and 6. According to the diagram of Fig. 2, there is an exponential function of the voltage increase factor and gap height to length ratio, leading to dramatic power increase factors between 4 and 49. For ratios > 1.5 no results exist.
Unfortunately the few data in the diagram are taken from tests using a configuration which is not typical for standard applications (two short-circuited waveguides coupled on the broad-wall by a slot orientated with an angle of 45 degrees). Indeed, in some cases the VSWR is extremely bad.
The intention of this paper is to verify the principal behaviour of this effect also for irises and corrugated structures.

3. SIMULATIONS

Simulations have been done using FEST3D. In principle, the objective is to reproduce the only available data regarding the fringing effect in the literature (Marrison [2]). The structure analysed is the one shown in Fig. 1, where the inner gap height is 0.1 mm. The outer ports are standard WR90 waveguides. Analogously to [2], the simulations where performed at 10.95 GHz. The results are shown in Table 1:

Table 1: Comparison between the results in this work and the literature (Marrison).

Length / mm	***Break. Marrison / V***	***Break. FEST3D***	***Marrison V/V(1mm)***	***V/V(1mm) FEST3D***
1	55	433 W / 50.6 V	1	1
0.5	56	165 W / 51.1V	1.02	1.01
0.2	58	67 W / 52.5 V	1.05	1.04
0.1	62	52 W / 56.2V	1.13	1.11
0.05	> 100	72 W / 69.3V	> 1.82	1.37

In order to know if the increase of the breakdown voltage is caused by the fact that the longitudinal field is modifying the electron trajectories or if it is due to the loss of electrons from the iris to the large regions where disappear, another structure has been used. In this case, it is just a 0.1 mm height WR-90 waveguide. It is assumed that if the electrons move away from the imaginary length of the gap, they are lost. Doing this, all the increase in the breakdown voltage is caused by the lost of electrons since no longitudinal component of the electric field exists. Results are shown in table 2, comparing the results from the literature and from FEST3D shown in the previous table.

Table 2: Comparison between the results in this work and the literature.

Length / mm	***Marrison V/V(1mm)***	***V/V(1mm) FEST3D (Table 1)***	***V/V(1mm) FEST3D (w/o discontinuity)***
1	1	1	1
0.5	1.02	1.01	1.01
0.2	1.05	1.04	1.04
0.1	1.13	1.11	1.13
0.05	>1.82	1.37	1.55

It is found that the results obtained with FEST3D in both cases are very similar. Indeed, in the case of not considering an iris between full-height waveguides, the increase of the multipactor threshold is more important. This is therefore indicating that the main reason for the increase of the breakdown voltage is the lost of electrons that flow out of the gap

region and not the change of the electron trajectories due to the existence of a longitudinal component of the electric field. However, more simulations are needed for different fxd products in order to confirm such results.
Apart from that, the flow of electrons out of the critic region slows down the discharge process. In fact, it is possible that effects not considered in the simulations are playing an important role, for instance, the interaction of the electron cloud electric field with the applied RF electric field.

4. SAMPLE DESIGN

Several samples are needed to cover the height to length ratios in the range of interest between 0.5 and 1.5. The design of test samples has always to taken into account the actual formulation of the question. For the current application following aspects have to be considered:

- Test frequency f should be identical for all samples
- Gap height d should be identical for all samples
- Resulting f x d product is constant
- The samples should provide a good match over a wide frequency range
- No regions should exist, where breakdown level is below the breakdown level in the region of interest
- Surface treatment of all samples to be performed in one lot
- The samples should be constructed in a way that they are easy to inspect
- Gap height should be as close as possible to realistic application.

The selected basic sample type comprises a rectangular cavity in a full-height waveguide with two identical irises located at the input and output. The height of the iris is 1.2mm for all samples to provide a constant frequency-gap product The thickness of the iris will be different for all samples, varying between 0.7 and 2.4 mm. Interface is a WR 90 waveguide. All samples are silverplated. The typical electrical response of this sample type is shown in Fig. 4.
Based on these assumptions the predicted range of power levels lies between 300 W (parallel plate) and 30 kW (ratio 1.5)

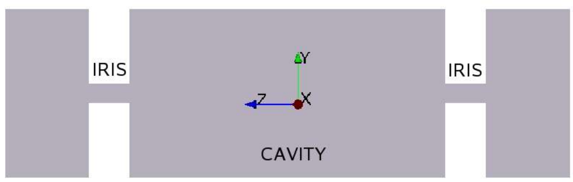

Fig. 3a: 2D Cross sectional view of the sample.

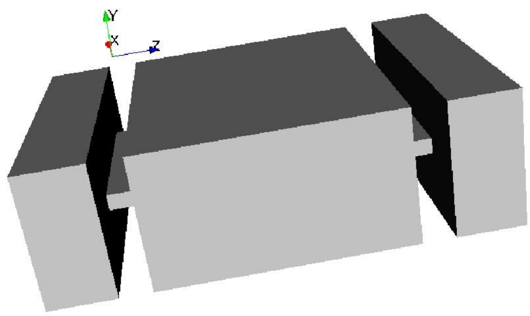

Fig. 3b: 3D view of the sample.

Fig. 3: Geometry of the samples.

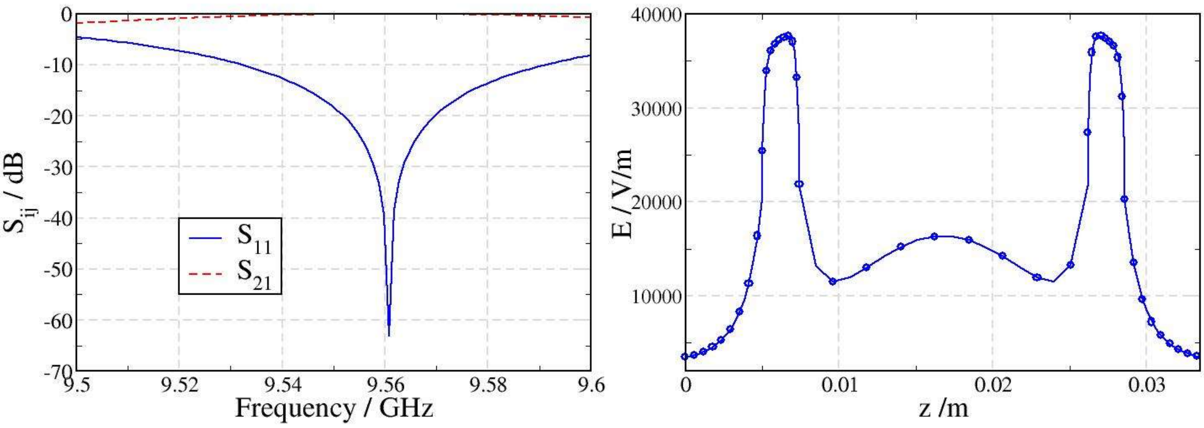

Fig. 4: Typical performance of the sample: in the left graph the scattering parameters and in the right side the electric field at the center axis along the propagation direction at the frequency of maximum transmission (9.561 GHz in this case).

A set of seven samples has been defined and manufactured. Dimensions and predicted breakdown levels, based on the parallel plate case and using FEST3D are collected in Table 3.

Table 3: Set of samples: geometry and multipactor breakdown onsets.

Sample Type	***Freq.***	***Height***	***Length***	***Ratio height/length***	***f x d product***	***Breakdown Voltage***	***Fieldstrength FEST3D***	***Break. Power Parallel plates***	***Break. Power (FEST3D)***
	GHz	mm	mm		GHz mm	V	V/cm	W	W
120-240	9.561	1.2	2.4	0.5	11.47	803	375	319	281
120-120	9.571	1.2	1.2	1	11.49	804	382	308	305
120-109	9.576	1.2	1.09	1.1	11.49	804	377	316	309
120-100	9.580	1.2	1	1.2	11.5	805	360	347	312.5
120-92	9.584	1.2	0.92	1.3	11.5	805	373	323	319
120-86	9.587	1.2	0.86	1.4	11.5	805	372	325	319
120-80	9.591	1.2	0.8	1.5	11.51	806	368	333	328

5. TEST SET-UP

The sample tests are performed using a X-Band ring resonator. Extremely high single carrier power level is necessary to investigate this effect up to realistic height to length ratios. The power source / ring resonator combination used at Tesat-Spacecom is capable to deliver output power levels exceeding 20 kW. The test setup is described in the following.

The X-Band ring resonator is operating between 9 and 10 GHz. Test frequency is about 9.57 GHz. The test signal is pulsed with a characteristic as given below:

Pulse Repetition Frequency	7 kHz
Max. Duty Cycle	5 %
Max. Pulse Length	30 µs
Available Peak Power	20 kW
Ring resonator Gain	about 10 dB

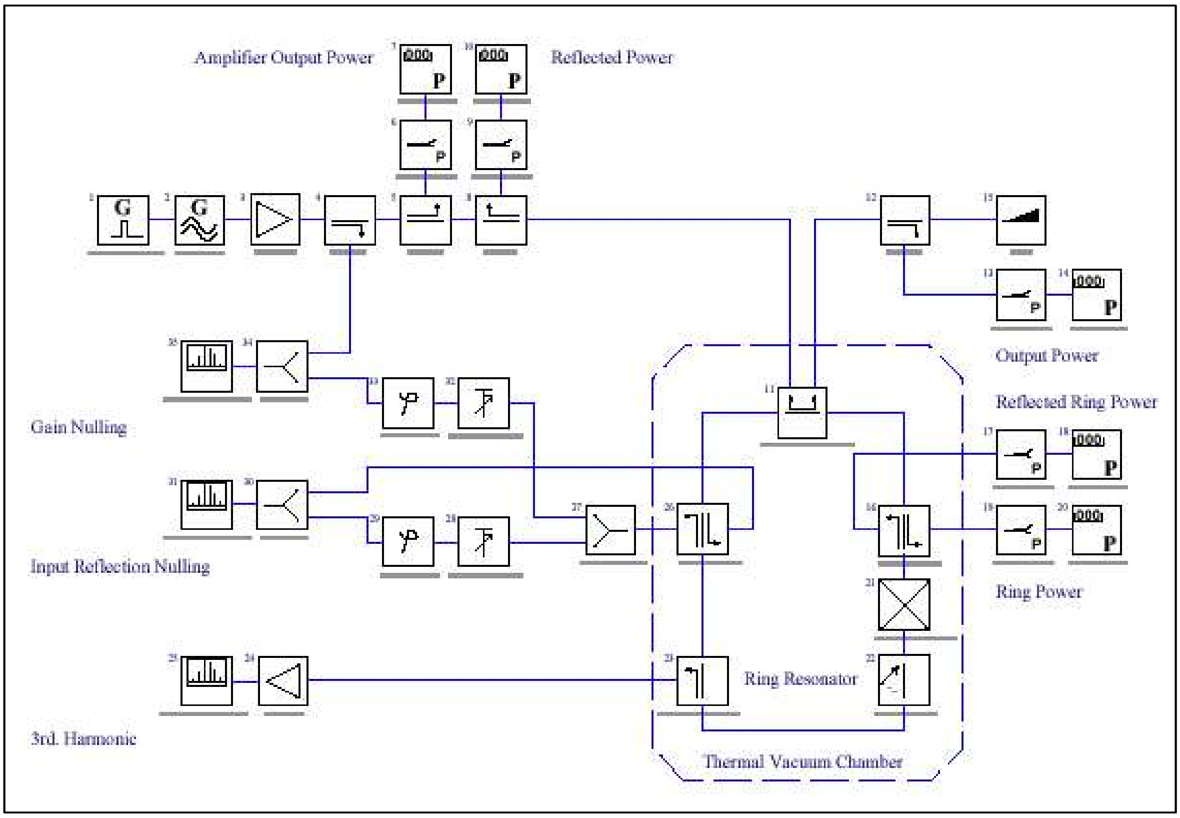

Fig. 5: 20 kW X-Band test bench with ring resonator.

A radioactive source and an electron gun are used to provide a sufficient amount of seeding electrons. Three different techniques are used to detect the occurrence of multipacting.

1. nulling of the 3rd harmonic
2. input reflection nulling
3. Ring gain nulling.

6. TEST RESULTS

In a first test campaign three samples have been tested. The w/l ratios of these samples are 0.5, 1.0 and 1.5. In Table 2 the predicted and the applied power levels are collected. Fig. 5 presents the results in a diagram. In this diagram the measured breakdown power is shown as a function of the iris height to length ratio.

The 0.5 ratio sample (120-240) shows a multipactor breakdown level close to the predicted. A clear increase of breakdown power occurs for the ratio 1.0 sample (120-120). The ratio 1.5 sample (120-80) exhibits an extreme

increase of breakdown power. Up to 12.8 kW no multipactor has been detected. At that power level the test has to be interrupted in the first test campaign.
The corresponding voltage increase factors have been entered into the diagram of Fig. 6. Table 4 shows the measured data together with the numerical results.

Table 4: Predicted vs. measured multipactor breakdown level

Sample	Multipactor Breakdown	
Type	Predicted	Measured
	[W]	[W]
120-240	281	400
120-120	305	2190
120-80	328	>12700

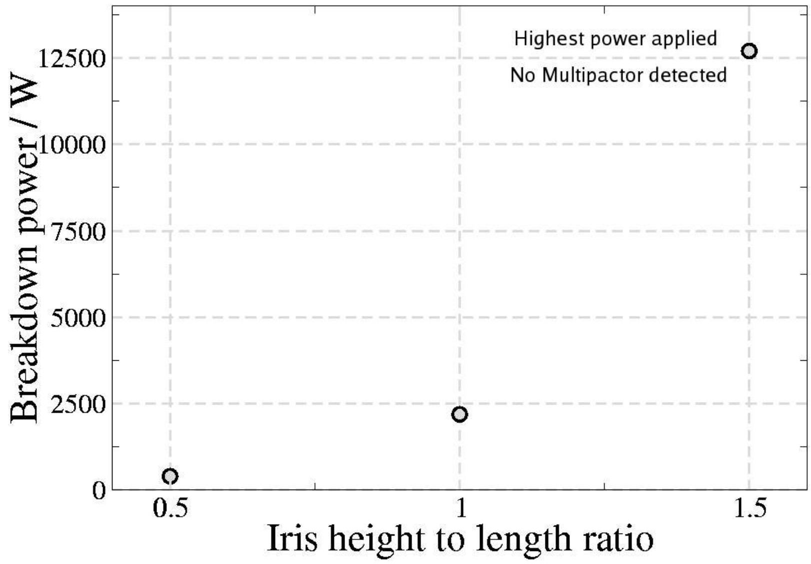

Fig. 6: Measured multipactor breakdown level versus iris height to length ratio.

7. CONCLUSIONS

First test results strongly indicate that the fringing field effect described in [1] is applicable also for iris structures. A second test campaign is currently running with a larger number of samples. Generally, the consideration of the fringing field effect in a multipactor analysis would lead to significantly higher power margins, which may help to make equipment tests unnecessary and / or to extend the operational power levels of satellite high power components. The simulations performed agree with previous numerical results published in the literature. However, there is a large disagreement between experimental data and the numerical results. Further theoretical investigations have to be done in this field.

8. REFERENCES

[1] "The study of Multipactor Breakdown in Space Electronic Systems", NASA Report CR-448.

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[3] C.Vicente, M.Mattes, D.Wolk, H.L.Hartnagel, J.R.Mosig, D.Raboso, "FEST3D – A simulation tool for Multipactor Prediction," in press for MULCOPIM Workshop 2005