Helical Resonator Filters with Improved Power Handling Capabilities for Space Applications

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***Abstract*—The power-handling capabilities of helical resonator filters for space applications are discussed. Emerging difficulties due to the multipaction effects are highlighted. A method is proposed to increase the specified power handling without significantly sacrificing the size and quality factor. Experimental verification is attained by means of a fabricated prototype for which measured filter response and multipaction test results are obtained and presented.**

***Index Terms*—Helical resonator filters, Multipaction, space qualification, VHF/ UHF.**

I. Introduction

HELICAL resonator technology [1]-[4] has been proven to be a very reliable solution for demanding VHF/low UHF satellite filter applications [2]. It yields relatively high unloaded quality factor (Q) values as compared to the conventional lumped-element structures, and low volume and mass compared to coaxial resonator filters, offering valuable trade-off for space applications. On the other hand, due to the small dimensions compared to the wavelength, the power handling capabilities can be limited by multipaction [5]-[7]. In applications where, the desired high-power capability cannot be achieved by lumped element structures, coaxial filters are employed at the expense of high volume, mass and cost.

In this work we perform a study that highlights the difficulties emerging in the employment of helical resonator technology for high-power space applications in terms of multipaction-free performance, and propose a solution that increases the power handling without significantly affecting the quality factor, size or mass. Numerical results using Ansoft© High Frequency Structure Simulator (HFSS) are presented, as well as measurements of the fabricated prototype to verify the proposed approach.

II. Power Handling Capabilities

A 2nd order helical resonator filter operating in the UHF band is employed as an example to demonstrate the power handling limitations due to multipaction. Guidelines for the design of this type of filters are provided in [1]. The dimensions of the helices and the cavity of the filter employed in this example are given in Table I.

TABLE I
HELIX AND CAVITY DIMENSIONS

Helix Dimensions (mm)		Cavity Dimensions (mm)	
Diameter	20.47	Width	65.89
Pitch	7.67	Height	52.71
Wire radius	2.00	Length	67.89
Number of turns	4.74		

A review of the parallel-plate multipactor calculation techniques is given in [8]. Based on the critical region identification steps given in [7], we assume an input at the filter of a single carrier with time average power of 1 W. Employing HFSS a field analysis of the structure is performed. The electric field distribution inside the filter at the center frequency of 300 MHz is calculated and shown in Fig. 1. The field is stronger closer to the helix and gets weaker as it approaches the cavity wall. The critical region identification (see [7] section 5.3) involves consideration of the gap voltages and associated frequency-gap (fd) products in conjunction with the multipactor susceptibility zones. For this example the most critical region is marked in Fig. 1. The peak voltage calculated by the line integral of the electric field across the straight path of length 4.3mm depicted in Fig. 1 is found to be equal to 124 V at approximately 300 MHz.

According to the above, the frequency-gap product is 1.352 GHz·mm. Referring to the susceptibility zone boundaries for silver [7], the filter is therefore liable to potential onset of multipaction for voltages beyond the breakdown value of approximately 72.8 V [7]. The input power that produces this breakdown voltage is found to be 0.35 W. Space verification standards [7] require 8 dB margins from the theoretically calculated power level, so that this filter is qualified for 17.5 dBm. It is quite clear that since the operating frequency is very low (e.g., in the UHF) and the dimensions of the helical filter are very small compared to the wavelength, this filter configuration deals with significant difficulties as to how much input power it can handle. Additionally, it is impractical to apply the large-gap approach [5] since for helical resonator filters the cavity dimensions are typically close to the dimensions of the helices.

According to [5] section 20.6.5 prevention of multipaction is feasible by dielectric filling. By filling the empty spaces of the discharge region with solid dielectric, the mean free path of electrons is reduced shifting the multipactor threshold. However, this would result in a major decrease in the resonator unloaded Q, and is therefore considered as a great disadvantage [5]. In our

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example, this decrease is quantified for space qualified Rexolite1422 (dielectric permittivity $\varepsilon_r = 2.53$, and loss tangent $tan\delta = 3 \cdot 10^{-4}$), and given in Table II. For comparison purposes, Table II also gives the unloaded Q of the initial air-filled resonator. A significantly greater insertion loss would be the immediate consequence, particularly for filters of higher order, as well as greater total mass and cost.

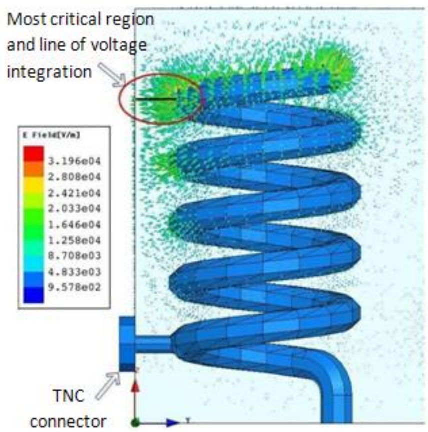

Fig. 1. Electric field distribution at the center frequency of the filter, and most critical region identification.

III. Proposed Approach

The behavior of dielectrics in the single-surface multipactor has been investigated in [9]. An investigation of multipactor discharges in a parallel plate waveguide structure where a layer of dielectric covers one of the metallic plates has been recently presented in [10-11]. In [10], it was demonstrated that the inclusion of dielectric extends the multipaction-free region for low values in the fd product axis of the susceptibility chart. Furthermore, in [11] it was shown that the use of the dielectric layer extinguishes the multipaction discharge with time due to the build-up of a static field produced by the charging of the dielectric layer. Following this approach, herewith we propose to cover all the metallic parts of the resonating helices by a dielectric layer. In this way, both the mass and the insertion loss of the filter can be maintained at the levels of the air-filled filter adding further mechanical stability. As it can be seen in Table II, the unloaded Q of the dielectric loaded resonator is only slightly decreased from 1340 to 1273 when a layer of 2.6 mm of Rexolite 1422 is used to cover the resonators, demonstrating that the effect on the insertion loss is minimized. For arbitrary geometries like a helical filter and mixed material cavities, the lack of tools to predict the breakdown onset, limits the theoretical power handling estimation, which is therefore tested experimentally according to the verification routes described in [7], section 4.

A prototype has been fabricated and measured. A photograph of the fabricated prototype is shown in Fig. 2. The helices were made in aluminum and were then silver-plated in order to lower the insertion loss and improve the multipaction-free filter operation [5]. A layer of 2.6 mm of Rexolite 1422 was used to cover the helices. We note that due to fabrication limitations, the lower end of the helix (lower than the TNC connector in Fig. 1) was not covered by the dielectric. The simulated and measured reflection and transmission of the filter are superimposed in Fig. 3 for comparison. The in-band insertion loss is shown in the inset of Fig. 3. Good agreement between the simulated and measured results is observed. From the measured insertion loss in the passband, the unloaded Q of the resonator is found to be 1238, in good agreement with the simulated one which is 1273.

Table II
Unloaded Quality Factor For Helical Resonator Filters

Case	Q_U (simulated)	Q_U (measured)
No dielectric	1340 (298 MHz)	
Fully covered cavity	780 (188 MHz)	
Dielectric cover	1273 (245 MHz)	1238

A multipaction measurement has been performed in David Florida Laboratory of the Canadian Space Agency[1]. The measurement is based on a combination of three different global detection methods, namely the forward/backward nulling, the 3rd harmonic response, and the noise close to carrier, as described in [7] section 7. The methods rely on the effect that multipaction has on the return loss, the 3rd harmonic response and the sideband noise, respectively. Monitoring all three signals simultaneously minimizes the possibility of false detection. The onset of multipaction is manifested as a simultaneous disturbance on at least two of these signals [7].

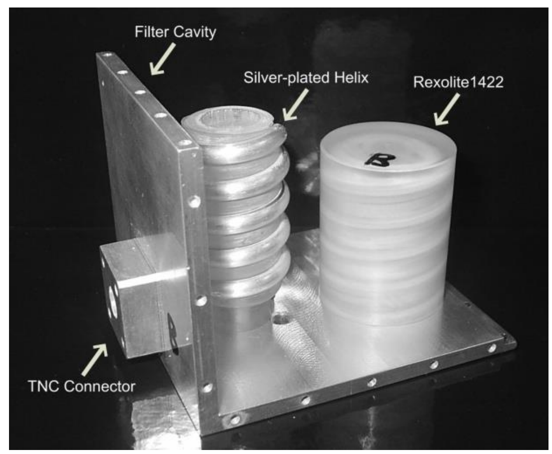

Fig. 2. Fabricated prototype of the second-order helical resonator filter.

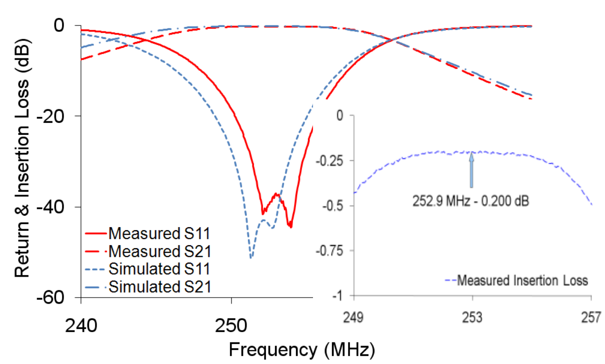

Fig. 3. Simulated and measured filter performance (2nd order filter with Rexolite1422 cover).

Multipaction test results are presented in Fig. 5 and Fig. 6. The test frequencies were chosen at the center frequency of the filter, and at the lower band edge [7], [12]. The measurement procedure includes an initial measurement with starting input power of 10 W and subsequent tests increasing the power at a step of 10 W. The measured design has shown that multipaction

[1] http://www.asc-csa.gc.ca/eng/dfl/radio.asp#7

is affecting the filter's performance at a power level of 90 W at 250.8 MHz. The forward/reverse nulling power level jumps from a value of less than -120 dBm to a value of almost -60 dBm after about 10 seconds of pulsed operation as shown in Fig. 4. This indicates an imbalance in the null at this power level, which was not observed in any previous steps. Similar phenomena occur at a power level of 100 W at 252.9 MHz as shown in Fig. 5. At an input power of 300 W a complete breakdown occurs in the measurement and all power is reflected. We note that visual observation of the filter following the test showed no signs of damage anywhere within the filter.

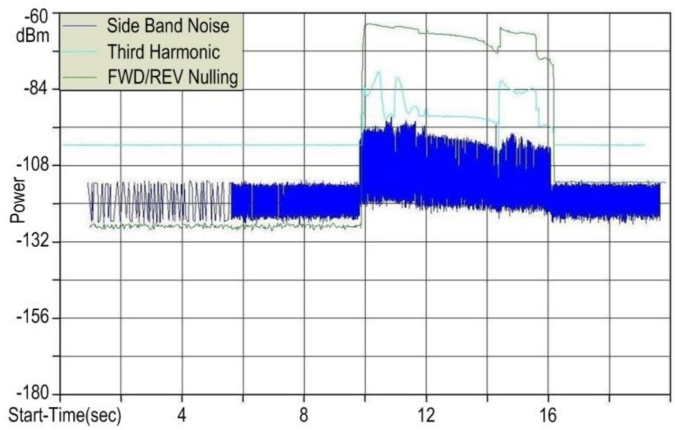

Fig. 4. Multipaction results at 250.8 MHz with a peak power of 90 W on a 30% duty cycle.

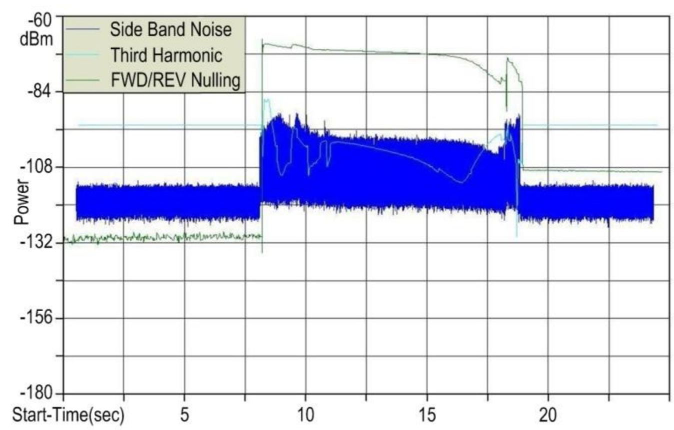

Fig. 5. Multipaction results at 252.9 MHz with a peak power of 100 W on a 30% duty cycle.

IV. Discussion and Conclusions

Accurate tools to model multipaction for this class of structures have yet to appear in the literature and are beyond the scope of this letter. However the conducted study provides some evidence that by virtue of the dielectric coating, multipaction was not detected in the most critical region identified for the uncoated filter. This can be attributed either due to the discharge switching off with time before the effects can be experimentally detected [11] or due to shifting of the multipaction risk zone to higher fd values, extending the risk-free zone to include the region under consideration [10]. Further numerical analysis predicted an input power threshold of about 51dBm in the uncoated region between the lower uncovered part of the helix and the cavity wall of the fabricated prototype. This calculated value is comparable to the experimentally obtained value of about 50dBm and is an indication that multipaction may have been initiated in that part of the filter.

Additionally, we note that a possible alternative to this design approach would be the use of a thin dielectric covering to the metallic walls of the filter cavity instead of the metallic parts of the helices. This solution however is associated with increased mechanical instability.

In conclusion, a multipaction analysis for helical resonator filters is presented and shows that the power handling capabilities are severely limited. A 2nd order UHF filter was used as an example, and it was shown that according to verification standards it qualifies for power input up to 17.8 dBm. In order to improve the power handling capability, it was proposed to introduce dielectric covers of the resonators. A prototype has been fabricated employing space qualified dielectric and experimentally tested. The measurement results showed initiation of multipaction at input power of 90 W. Space verification standards (see [7] section 4.6.2) require 4 dB margins from the measured multipaction onset power, so that the power handling capability of the coated filter after the verification margins is 45.5 dBm. This corresponds to more than 27 dB improvement compared to the uncoated case with reduction in the unloaded Q-factor limited to about 5%.

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