MICROWAVE DEVICE COMBINING FILTERING AND RADIATING FUNCTIONS FOR TELECOMMUNICATION SATELLITES

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ABSTRACT

An original new design of microwave structure for integrating filter and antenna functions on a single device is presented. The structure is composed of a partially metallized dielectric plate enclosed in a parallelepipedic cavity. This topology allows a high integration in a planar environment type, and is suitable for high frequencies filtering and powers applications.

In order to validate the multilayer radiant filter concept, an opened two-pole filter using two superposed cavities coupled by a metallic iris is presented. Its filtering and radiating functions are optimized in the same time to present some required electrical performances. Moreover, to show the use variety of the antenna, two examples of use are described. The first one presents a coupled array of two radiant filters, and the second one an antenna with circular polarization radiation.

I. INTRODUCTION

In order to reduce in telecommunication satellites losses introduced by the transmission between radiant elements and filters, we propose in this article to conceive a n-pole radiant filter constituting the elementary design of an emission-reception antenna.

The resonant element, which constitutes the elementary cell of our radiant filter, acting around 20 GHz, has already been presented [1].

Many communication systems, such as satellite or mobile, require broadband circularly polarized (CP) antennas [2]. The resonant HEM_1 mode can be split into two near-degenerate orthogonal resonant modes of equal amplitudes and 90° phase difference, a CP radiation which enables.

The filtering function is presented in the first part. An opened Tchebyscheff two-pole tuning less filter at 20 GHz, with a 500 MHz 3 dB passband width, is designed applying a finite element software including perfectly matched layer (PML) conditions. The second part is devoted to the radiating function. We describe the radiation performances of the opened two-pole filter, of a coupled array of two radiant filters, and of the CP generation.

All the global electromagnetic (EM) analysis is performed applying the Finite Element Method (FEM).

II. FILTERING FUNCTION

The characteristics of the resonant structure, excited on its first hybrid mode, and its electrical performances have been described in a previous paper [1]. This resonant element constitutes the elementary cell of the radiant filter.

We aim at conceive an opened Tchebyscheff two-pole tuning less filter using two superposed cavities coupled by a metallic iris [3]. Filtering objectives of this filter are the following: center frequency at 20 GHz, 500 MHz 3 dB passband width, 15 dB return loss and 15 dB attenuation at fo $\mp$ 1 GHz.

In [1], we demonstrate the problem feasibility using two enclosed superposed cavities. The obtained reflection response constitutes the opened filter objective response. The main step of this study is to Characterize the opening surface effects on reflection response filter. Thus, we optimize the cavity-opened surface, taking into account several coupling parameters, to obtain the enclosed objective response. The case of a circular opening will be studied.

A. Coupling systems

The HEM_1 mode excitation is insured by coplanar line [4] drawn on one surface of the substrate (Fig. 1). Those excitations are easily manufactured and integrated on the resonator. The longer the line penetration X on the substrate, the more important the input/output coupling, related to the external Qe factor. If we use this solution, the external Qe factor can be controlled with high precision.

A classic rectangular metallic iris (Fig. 1) insures the inter-cavity coupling system. In this case, the coupling coefficient K between two dielectric resonators is defined as a function of rectangular iris dimensions.

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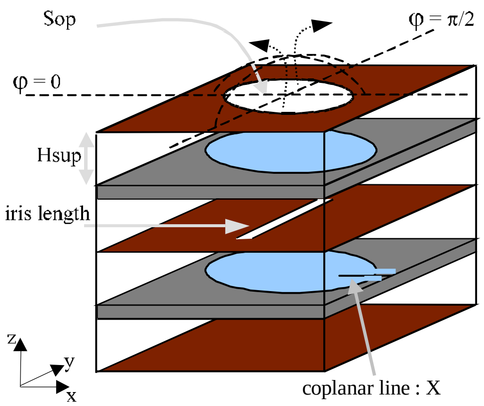

Figure 1: opened two-pole filter

B. Opened two-pole filter

The opened two-pole filter topology is described on Fig. 1. The filter is composed of two resonant elements superposed and coupled by a metallic iris. The upper cavity is constituted of a resonant element without excitation and of an opening surface. The lower cavity is constituted of a resonant element with one excitation line. The global EM demands to surround the opening surface applying PML conditions.

Four parameters are still used to optimize the filter reflection response: the penetration X of the excitation line on the lower substrate, the iris length, the Hsup dimension and the opening surface Sop. Each parameter is particularly studied on a one pole filter configuration to quantify its influence on the reflection response.

Two studies are combined to characterize the radiant element. The first one, applying the FEM to an opened one-pole filter, determinates the resonant frequency shift for each opening surface (Fig. 2). Indeed, the synthesis of the opened filter requires that the two cavities resonate at the same frequency. The second one, using an equivalent circuit of the one-pole filter, determinates the radiation resistance (Rr) for each opening surface (Fig. 3).

Sop (mm^2)		Frequency shift (MHz)
16	→	250
18,9	→	425
19,8	→	470
22,5	→	650
25	→	800

Figure 2: resonant frequency shift

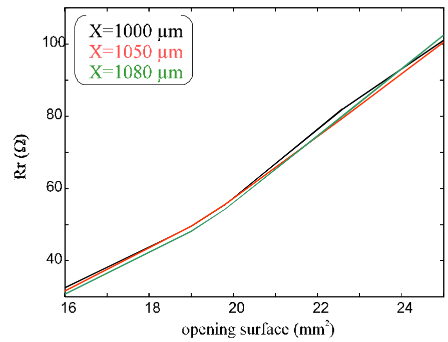

Figure 3: radiation resistance variations

Hsup parameter is used to compensate the frequency shift of the resonant frequency due to the opening.

The synthesis based on Tchebyscheff filter theory, of the opened two-pole filter using an equivalent circuit gives the different theoretical couplings: external quality factor Qe=57, inter-cavities coupling coefficient K=17.5 10^{-3} and radiation resistance Rr=80 Ω. All the previous studies allow to define the filter dimensions which satisfy the objective couplings:

Qe=57 → X=1080 µm
K=17.5 10^{-3} → iris length=5.4 mm
Rr=80 Ω → Sop=22.5 mm^2
=> Scircular=π x $(2.68)^2$ (mm^2)

Fig. 4 compares the simulation and the experimentation reflection responses for the circular opening with the enclosed one, which represents the objective response.

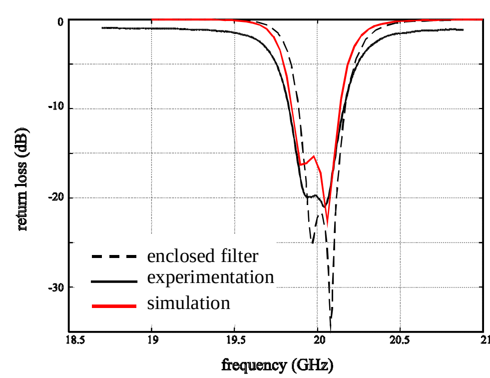

Figure 4: reflection responses of the radiant filter

The filtering objectives are respected. We can see a good agreement between simulation and measurements. The radiant filter presents a reflection coefficient lower than –18 dB in the bandpass, which insures the antenna matching.

The filtering function is validated.

So an opened two-pole filter presenting a really good reflection response has been dimensionned. Our next purpose is to study the radiation properties.

III. RADIATING FUNCTION

A. Opened two-pole filter

Defining a Huyghens surface surrounding the opening surface, we extract the tangential electromagnetic field on it. And then the radiation integrals allow to extract the radiation properties : d(θ,φ) [5]. For a given direction (θ,φ), those radiation properties are defined as (1):

$$d(\theta,\varphi) = \frac{P(\theta,\varphi)}{P_{iso}} \qquad (1)$$

where P(θ,φ) is the radiated power density and P_{iso} the radiated power density of an isotropic antenna.

Fig. 5 shows the Ex modulus component of the radiated electrical field on the Huyghens surface above the circular opening.

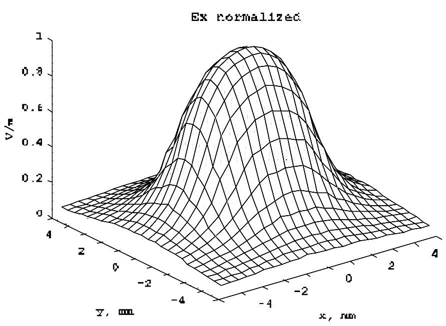

Figure 5: Ex modulus component of the electrical field

Concerning a limited ground plane, the comparaison in φ planes, defined in Fig. 1, between theory and simulation is given on Fig. 6. The radiation performances are in good agreement with required ones for such applications.

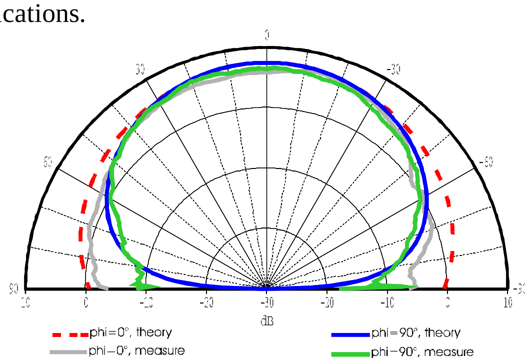

Figure 6: calculated and measured radiation properties

We can see a good agreement between theory and measurement. The antenna gain is 7,7 dB. These experimental and theoretical results enable to validate the multilayer radiant filter concept proposed in this paper.

B. Array construction

Our purpose is to present the use of the radiant filter in an antenna array. The geometry of a 2x1 coupled array of two identical filters is presented on Fig. 7. This array has a simple structure and it is easy to combine it further to form a larger array.

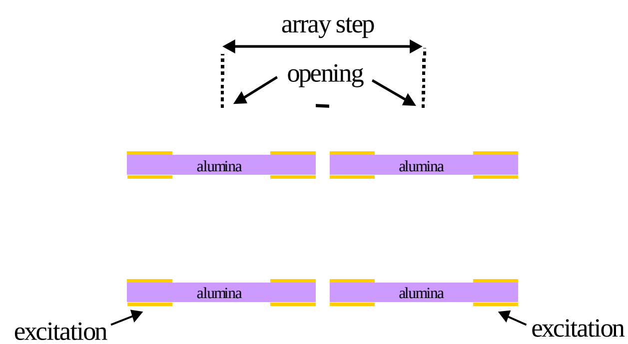

Figure 7: array representation

To compensate for a coupling between the two radiant filters, we optimize the circular opening surface, the Hsup parameter and of course the array step.

With Scircular=π x $(2.56)^2$ mm^2, Hsup=2.35 mm and array step=11.9 mm (#0.8λ_o), the EM responses and the radiation properties are presented on Fig. 8.

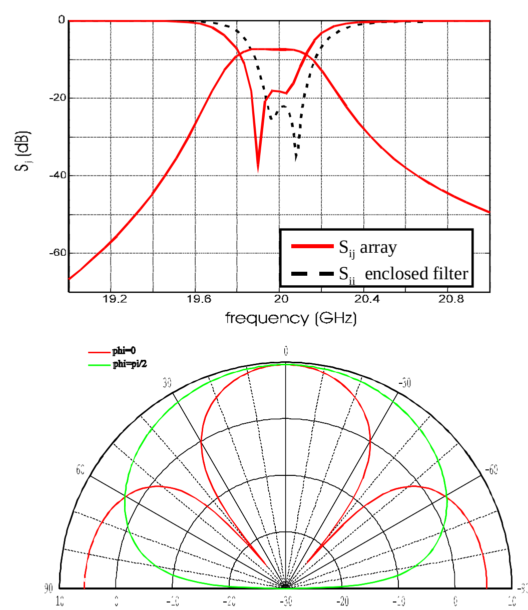

Figure 8 array performances

The array presents a reflection coefficient lower than –18 dB, and a 9,6 dB gain in the main radiation direction. Some primary nulls at ± 40° in the pattern appear.

C. Circular polarization

With the increase of wireless communications, multifrequency antennas become desirable, if possible with polarization diversity. In this way, using a brief study, our propose is to show the feasibility of CP on our radiant filter.

The resonant mode HEM_1 is a dual mode, so it presents two orthogonal polarizations at the same frequency. It splits into two close degenerate orthogonal modes of equal amplitudes and a 90° phase difference enable a CP radiation (Fig. 9).

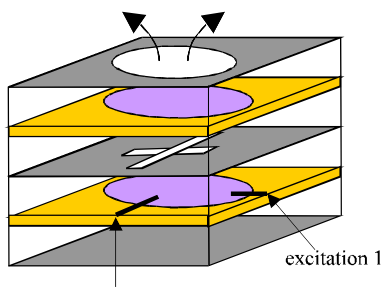

Figure9: circular polarization

A direct coupling between excitations disturbs the two reflection responses. Figure10 shows the EM response when X=950 µm, iris length=5,4 mm, Hsup=2,3 mm and Scircular=π x $(2,62)^2$ mm^2.

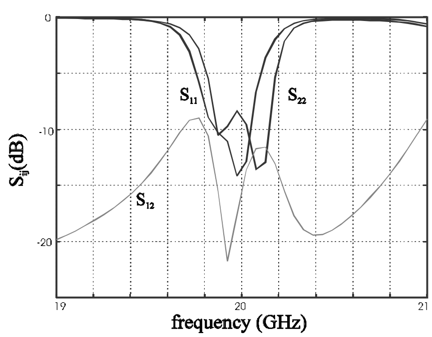

Figure 10: EM responses in CP configuration

The radiant filter presents reflection coefficient in each access lower than –8 dB in the bandpass. The calculated radiation properties is in cure, and will be presented at the conference The feasibility is showed.

IV. Conclusion

An original technology of multilayer radiant filter has been presented and validated in this paper.

A Tchebyscheff radiant two-pole filter at 20 GHz with 2.5 % of –3 dB pass bandwidth has been computed. A specific study of the radiant element has allowed to determinate the radiation resistance and the resonant frequency shift due to each opening surface. This study combined with a filter synthesis has allowed to define a circular opening which gives a satisfying reflection response. We have computed the radiation properties by extraction of the electromagnetic field on a Huyghens surface.

Simulation results have been validated by experimentation. The constituted antenna presents an matching lower than –18 dB in the bandpass and 7,7 dB gain.

The array and CP uses have been presented to prove the high interest of these microwave devices combining filtering and radiating fucntions,. A brief study indicates the possibility to generate easily some CP.

Acknowledgement

The authors wish to acknowledge the assistance of the IDRIS for the FEM computations.

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