A CIRCULAR CAVITY STRUCTURE FOR THE EFFICIENT CAD OF DUAL MODE FILTERS

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I. ABSTRACT

A novel type of circular cavity enabling two orthogonally polarised resonances to be coupled and tuned without using screws is presented. In order to achieve an accurate and efficient electromagnetic modeling, the coupling mechanism is realized by inserting in the middle of the circular cavity a short section of rectangular waveguide at an appropriate inclination angle.
The proposed cavity allows to realize dual-mode filters entirely by using junctions of waveguides with rectangular and circular cross-sections, thus enabling a very efficient CAD of such filters. Numerical analyses of this structure have been performed showing a noticeable agreement with measured data. It has also been confirmed, both theoretically and experimentally, the ability to achieve close control of resonant frequencies and coupling values without using screws.

II. INTRODUCTION

The usefulness and advantages of dual mode cavity filters for satellite applications are widely known [1], [2]. In recent years, a considerable interest has arisen toward the development of electromagnetic models for such cavity filters. The aim of these CAD tools is twofold. On one hand it is important to reduce the risk of passive intermodulation (PIM) generation, thus enhancing the power handling capability by eliminating contact surfaces between the screws and the cavity body. On the other hand, accurate computer predictions are an effective way to decrease development and production costs of flight hardware.

Several published results on dual mode cavity filters make use either of a modification of the cavity transverse cross-section, so as to obtain the desired coupling effect [3], or of the direct modellisation of screws, seen as short posts protruding out of the cavity wall [4]. Unfortunately, the very high degree of accuracy required, owing to the stringent specifications imposed on channel filters for satellite bands, poses considerable difficulties to the cited methods. These difficulties are due to the necessity of numerically computing a very large number of modes, when dealing with modal approaches using nonseparable waveguides cross-sections, or to unlikely time and memory requirements for purely numerical methods.

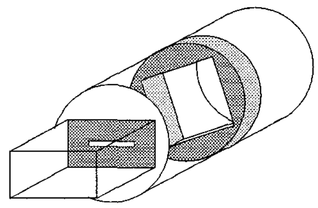

Fig. 1. Circular cavity with new tuning and coupling section.

It seems apparent that, in order to develop an efficient CAD of such structures, it would be highly desirable to use only waveguide cross-sections with analytically known modal spectra, i.e. cross-sections geometries which allows solution of the transverse Helmholtz equation by separation of variables. This is actually the case for the structure recently appeared in [5], which describes an implementation of a dual mode filter by tilted rectangular waveguides. Though being an advance over previous solutions, the latter structure requires an external phase equalisation, thus making difficult the realisation of multicavity filters. Moreover, it still seems subject to improvements from the manufacturing viewpoint.

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In order to overcome all the previously mentioned difficulties, while retaining the efficiency of modal analysis, a novel type of circular cavity structure is proposed. The cavity is composed by two circular end cross-sections having a length of inclined rectangular waveguide in between[1], as shown in Fig. 1. Coupling and tuning actions are obtained by suitably modifying the following geometrical parameters:

1. the sides of the rectangular sections, a and b;
2. the inclination angle, θ;
3. the cavity length, L.

Note that, by using this structure, no external adjustment is necessary, thus making feasible the realisation of multicavity filters. Modal analysis is performed by using the generalised scattering matrix approach and

[1] patent pending

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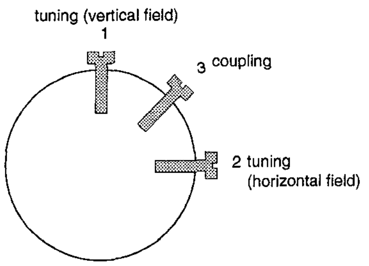

Fig. 2. Tuning and coupling screws in a conventional circular cavity.

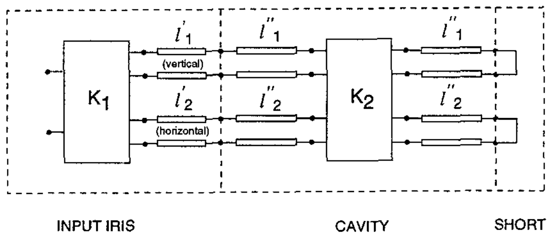

Fig. 3. Equivalent circuit of the cavity structure.

the mode spectra of guides, being analytically known, are straightforward to evaluate up to any number of modes. This last feature is a key factor in obtaining fast and accurate results, as confirmed by experimental verification.

III. Cavity operating principles

Conventional dual mode cavities use a typical three-screw arrangement (see Fig. 2) in order to achieve the desired tuning and coupling actions. In particular screws 1 and 2, placed othogonally and aligned with the polarisation plane of resonant modes, are used, almost independently, for tuning purposes. The third screw, placed in the symmetry plane with respect to resonance polarisations, performs the coupling action, also showing a tuning effect on both resonant modes. All these screws may be doubled, for reasons of symmetry, by placing an additional screw on the same axis but on the opposite cavity wall.

In this paper we propose to replace this screw-based tuning and coupling section with a short length of rectangular waveguide having an inclination angle with respect to resonant modes in the circular cavity. It is shown that the proposed configuration provides complete tuning and coupling capabilities, being in addition particularly suited to efficient electromagnetic modeling.

The fundamental modes of the cavity shown in Fig. 1 are described by an equivalent circuit as reported in Fig. 3. The input iris and the central section are represented as ideal impedance inverters plus equivalent line lengths in order to account for their finite thickness. We may notice that for the vertical (input) mode the physical length ℓ of the cavity is increased by equivalent lengths ℓ_1' and ℓ_1'' due to the input iris and central section, respectively; the increase in length for the horizontal (coupled) polarisation is ℓ_2'' only, while the contribution ℓ_2' of the input iris is virtually zero, since the iris is a thin horizontal slot (see Fig. 1). This is a typical situation in every dual mode cavity: the modes show a frequency imbalance Δf due to their different reactive loadings (or, equivalently, to their different trasmission line lengths). The purpose of the coupling and tuning section is precisely to adjust such a situation, thus producing two synchronously tuned resonant modes displaying a specified coupling value.

In order to achieve a better understanding of the coupling mechanism, let us consider some particular positions of the rectangular waveguide. When the inclination angle, θ, is $\theta = 0$ or $\theta = \pi/2$ (see Fig. 4 (a) and (b)) no coupling takes place and a vertically polarised input mode does not generate any horizontally polarised field. When the inclination angle lies in between (as in Fig. 4(c)), coupling is originated and, owing to symmetry, it is maximum at $\theta = \pi/4$. This maximum is a function of the aspect ratio a/b; the higher the aspect ratio, the strongest the coupling, as shown in Fig. 5. If the rectangular section degenerates into a square (unity aspect ratio), no coupling is generated, whatever is the angle. By applying a similar reasoning to tuning (frequency shift) properties and by observing that for $\theta = 0$ and $\theta = \pi/2$ angles tuning is maximum and at $\theta = \pi/4$ it is zero, the behaviour reported in Fig. 6 is obtained.

For a specified coupling value k_1 (see Fig. 5) we have a set of acceptable $(a/b, \theta)$ pairs. If this curve $k_1(a/b, \theta)$ is represented on the $(\Delta f, \theta)$ plane reported in Fig. 6, we will get the required $(a/b, \theta)$ point at the intersection with the Δf of our cavity. By properly adjusting the inclination angle θ, the aspect ratio a/b of the rectangular section and the cavity length L, it is then possible to tune the two modes so as to obtain the desired coupling value.

IV. Electromagnetic modeling

Let us consider now the rigorous full-wave modeling of the cavity structure and also of the entire filter. It is noted that only two junction types need to be studied, namely:

1. rectangular-to-circular;
2. rectangular-to-rectangular.

The case of the inclined rectangular-to-circular junction (Fig. 4(c)) is readily decomposed in the cascade of a standard rectangular-to-circular junction (Fig.4(a)) plus a rotation of coordinate axes in circular waveguide. This second junction takes a simple form and requires no computations of coupling integrals. A detailed analysis of the rectangular-to-circular discontinu-

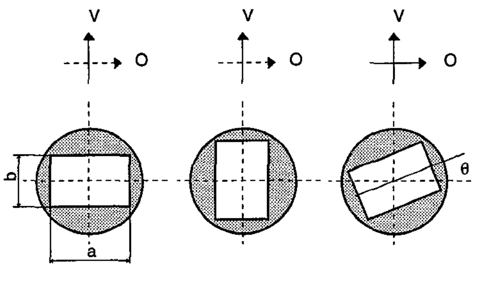

Fig. 4. Electric fields inside the proposed cavity.

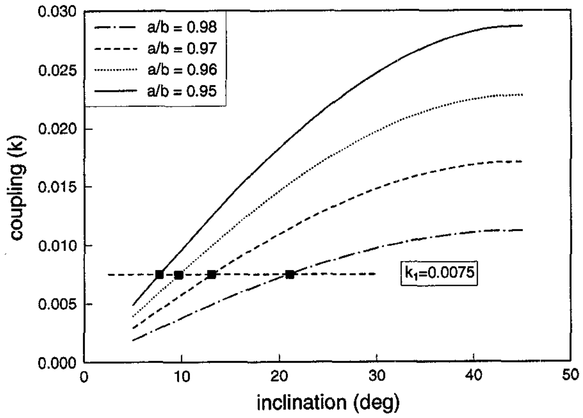

Fig. 5. Coupling properties of the proposed cavity.

ity has been recently presented [6] and is not repeated here for the sake of conciseness. The rectangular-to-rectangular transition is also considered as a well-assessed problem [7]. In all cases, the modal spectra of the guides are analytically known and it is straightforward to account for a large number of modes in the spectral expansions.

V. Theoretical and Experimental Results

In order to validate the above concepts, a prototype test cavity has been fabricated and measured. The sample cavity has been selected so as to possess a coupling value for a typical narrowband channel filter at *Ku*-Band. Noticeable care has been applied in order to maintain mechanical accuracy within +/- 10 μm, as it is well known that the correct validation of a cavity model to be used in narrowband applications at frequencies above 10 GHz requires carefully measured comparisons. Moreover, in order to provide a reliable proof of the cavity behaviour, the prototype has been designed with alignment pins allowing different mounting positions, with a fixed angular difference between each other of 30 degrees.

Representative measurements of input reflection at two different angular positions are provided in Figs. 7 and 8. The input iris has been designed so as to realize

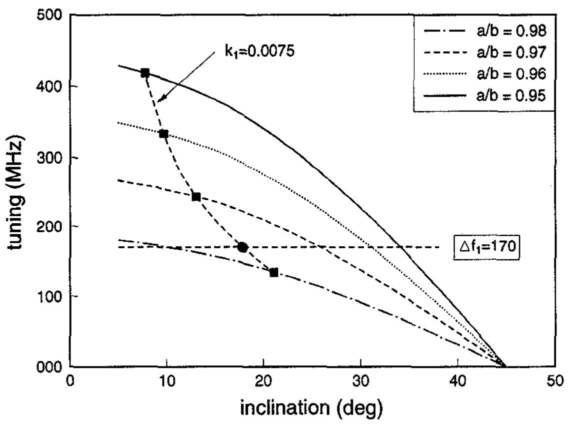

Fig. 6. Tuning properties of the proposed cavity.

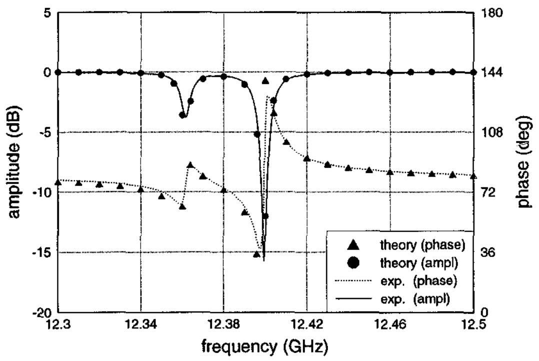

Fig. 7. Theoretical and experimental input reflection of the experimental cavity (inclination angle = 13.5 deg).

a moderately strong coupling in order to provide significant data both for amplitude and phase. The usual response of such a configuration shows two amplitude peaks, the depth of which is related to the tuning of each mode. The peaks frequency distance is a direct function of the coupling value. The angular positions of 13.5 and 43.5 degrees offer a significantly different behaviour: the former causes the coupling to be quite low and the first resonant mode tuned at a lower frequency than the second; the latter displays a much stronger coupling value and a reversed tuning condition. Total length of the cavity is 15.6 *mm*, the rectangular (inclined) guide has a thickness of 1 *mm* and a cross section of 15.03 x 15.18 *mm*. Computed results are obtained from a program running on an HP 735 machine. All discontinuities are analysed using a TE/TM expansion; the number of TE modes is 10 for the input iris and 70 for the central tuning section. The correspondent number of modes in the larger waveguide is 200 for the input rectangular guide, 350 in the circular cavity when interfacing the input iris and 110 when interfacing the central section. The number of TM modes is computed according to the spectral criterion [6]. A typical analysis of the dual mode structure requires about 150*s* of computing time for each frequency point. As

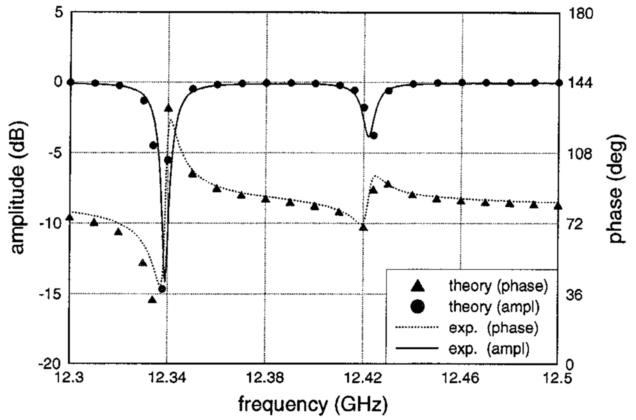

Fig. 8. Theoretical and experimental input reflection of the experimental cavity (inclination angle = 43.5 deg).

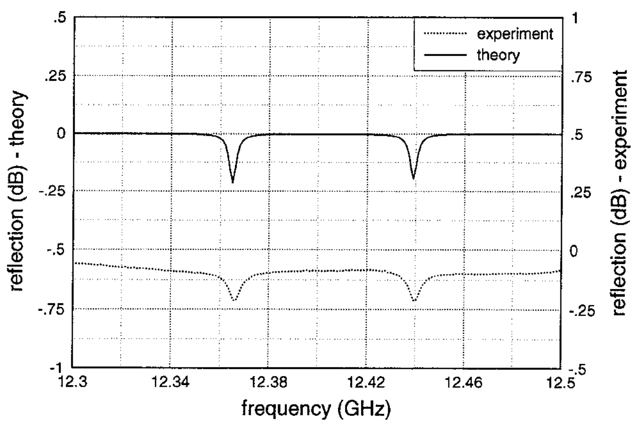

Fig. 9. Theoretical and experimental input reflection with a small input iris.

can be noticed from Figs. 7 and 8, the agreement between computed and measured results is very good at both angular positions and all tuning and coupling parameters are correclty simulated.

A second measurement with a small input iris (strongly undercoupled condition) is reported in Fig. 9. Also in this case, where the number of modes in the input discontinuity is largely unbalanced, the modal analysis performs satisfactorily well. The agreement of predicted resonant frequencies with respect to measurement is within 2 MHz for both the lower and the upper peak. Finally, in order to provide a better appreciation of the capabilities shown by the proposed structure, the full-wave analysis of a complete 4-pole elliptic filter assembly is reported in Fig. 10.

VI. Conclusions

A novel type of dual mode circular cavity that can be tuned and coupled at design level without addition of external screws has been presented. The electrical behavior of the cavity has been theoretically investigated

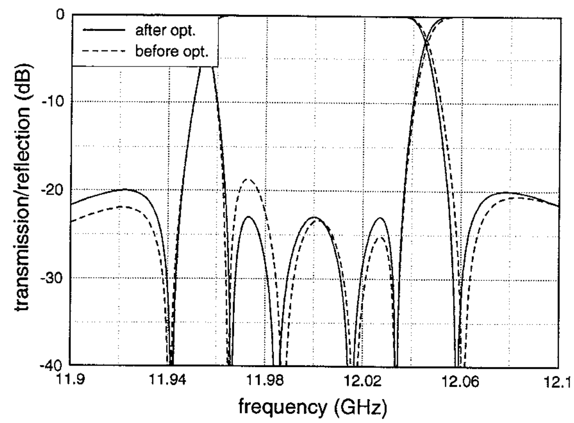

Fig. 10. Transmission and reflection response (full-wave) of a complete 4-pole elliptic filter.

and experimentally confirmed by several validations.

By using this cavity, a dual mode filter is realized by considering only junctions of waveguides with rectangular and circular cross-sections. As a result, the proposed dual mode circular cavity has proven to be successful for the efficient CAD of dual mode filters.

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