Theoretical Analysis of Surface Mountable Triple-Mode Ceramic Cavity

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***Abstract*—A novel surface-mountable ceramic cavity has been considered. The high-permittivity ceramic filling of the basic triple-mode waveguide cavity makes the proposed structure physically small. Integrated microstrip to ceramic filled waveguide transitions provide effective coupling between ceramic cavity and planar circuit. A key point of the suggested theory consists of utilization of weighted Gegenbauer polynomials as the basis functions for the Galerkin's procedure. Such a choice of basis functions guarantees high accuracy and efficiency for the entire simulation algorithm. As an application example, a three-pole L-band filter with advanced high-quality factor is demonstrated.**

***Index Terms*—Ceramic filter, multiple-mode waveguide cavity.**

I. Introduction

WAVEGUIDE filters using degenerate cavity modes found important applications in a large variety of communication systems [1]–[5]. At the same time, with the breakthrough of ceramic technology, multiple-mode filters based on the dielectric loaded waveguide cavities have been expected to be competitive, even at relatively low microwave frequencies as compared with one very popular existing alternative—filters with quarter-wave dielectric filled coaxial *TEM* resonators. Generally, the cavities of the waveguide type possesses an advantage in quality factor, and the high-permittivity dielectric filling makes the cavity physically small.

A very simple triple-mode cavity structure in a conventional hollow rectangular waveguide was described by Lastoria *et al.* [6]. A method for realization of triple-mode coupling proposed in [6] completely replaces the traditional coupling screws and therefore can be used in the case of the full dielectric filling of the cavity, resulting in size reduction. Although the generic idea of filling the waveguide cavities is not new, the study of triple-mode filled cavity is not available yet.

A problematic concern is to create terminals suitable for surface mounting by a conventional manner. In this letter, we consider the possibility of implementing advantages of a triple-mode concept for the compact design of the surface mountable ceramic cavity. A key point of the proposed design is accretion of surface mountable terminals to the triple-mode ceramic cavity. As a result, all advantages of the waveguide multiple-mode concept hold true for surface-mountable cavity. The rigorously simulated L-band filter based on such a cavity validates the proposed concept.

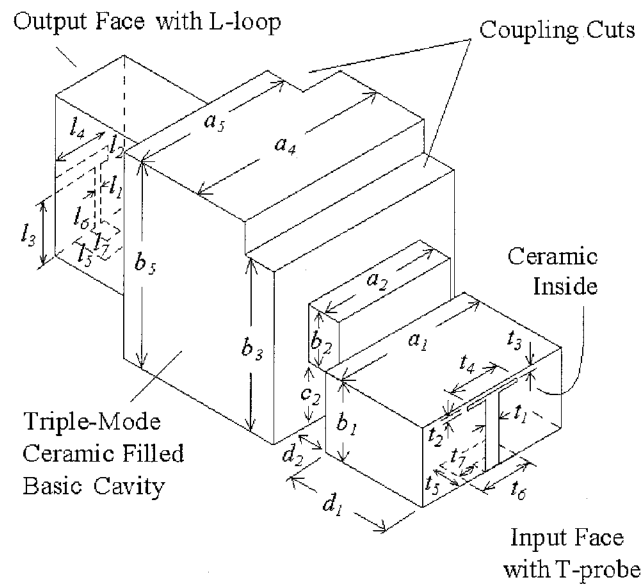

Fig. 1. Physical configuration of a surface-mountable triple-mode ceramic cavity.

II. Structure

The proposed structure is shown in Fig. 1. Almost all surfaces of the ceramic body are completely plated with metal except the face areas with partial metallization pattern and some isolation gaps around the input and output terminal islands. In the simplest terms of technology, the cavity can be easy fabricated in two steps. First, the monolithic body can be shaped by sintering or by another manner. Second, the metallization pattern can be plated upon the shaped ceramic body.

The cross section of basic cavity is square. The mode sequence $TE_{10}-TM_{11}-TE_{01}$ has been chosen in order to realizethree resonances. The intercavity mode-coupling configuration consists of two rectangular cuts on the corners of the basic cavity. It should be noted that bottom of the basic cavity, as well as the broad wall of the input and narrow wall of the output, are set upon the same plane of the surface mount board.

Two configurations of the microstrip to ceramic filled waveguide transition have been implemented. First, one is suitable in the case when the broad wall of the ceramic rectangular waveguide is set upon the surface of the dielectric substrate of the microstrip circuit. This configuration consists of a printed

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TABLE I
DIMENSIONS OF THE CAVITY. ALL UNITS ARE IN MILLIMETERS

n	a_n	b_n	c_n	d_n	t_n	l_n
1	10.00	5.00	0.00	11.00	0.90	0.30
2	8.00	3.60	4.02	2.22	0.25	0.70
3	12.90	10.85	0.00	2.15	0.30	4.20
4	12.90	12.90	0.00	6.05	3.60	3.90
5	10.30	12.90	0.00	2.65	2.00	3.10
6	2.50	8.00	2.45	1.93	3.50	4.80
7	5.00	10.00	0.00	11.00	1.30	1.95

T-shaped probe placed on the ceramic face and connected with the terminal island at the perpendicular plane. The second transition consists of a printed L-shaped loop connected with the terminal metallized island. This configuration is suitable in the case when the narrow wall of the waveguide is set upon the surface mount board.

III. SIMULATION APPROACH

The frequency selective behavior of the proposed structure mostly depends on the topology of the basic triple-mode cavity. Therefore, the device is first designed with matched waveguide terminals and then is fitted with transitions. An electromagnetic CAD procedure using a three-dimensional (3-D) commercial simulator requires significant computer resources, in general. Even in the simplified case of basic cavity with conventional waveguide terminals, it usually takes long hours to calculate a sufficiently accurate response perone set of topological parameters. Therefore, there is still a need for an accurate simulator which is faster and, hence, more suitable for CAD.

In terms of electromagnetic simulation, the basic structure consists of uniform ceramic waveguide segments and cascaded step junction discontinuities. This is an important feature of the implemented triple-mode structure because it can be effectively decomposed. Accordingly, the generalized scattering matrix technique in conjunction with the singular integral equation method has been applied conveniently. A notably important fact is that the electromagnetic model is physically adequate for the proposed structure.

Following the singular integral equation technique, integral equations for the electric field at the discontinuities are derived and then solved by the Galerkin method. A key point of the suggested theory is the special choice of the basis functions for the Galerkin's procedure. Namely, these vector basis functions are weighted Gegenbauer polynomials [7]. The convergence of the algorithm has been investigated within a wide range of frequencies and structural parameters. It is found that, for practical calculations, it is sufficient to take into account just three or a maximum of four basis functions per coordinate for each step junction discontinuity. The rapid convergence is achieved exclusively by a special choice of the basis functions. Such a choice of edge-conditioned basis functions adequately describes field behavior, not only very near the structure's metal edges, but also within middle distances. In essence, the utilization of *a priori* explicit information about field behavior near the discontinuities guarantees rapid convergence, high accuracy, and, consequently, also high efficiency for the entire simulation algorithm [8].

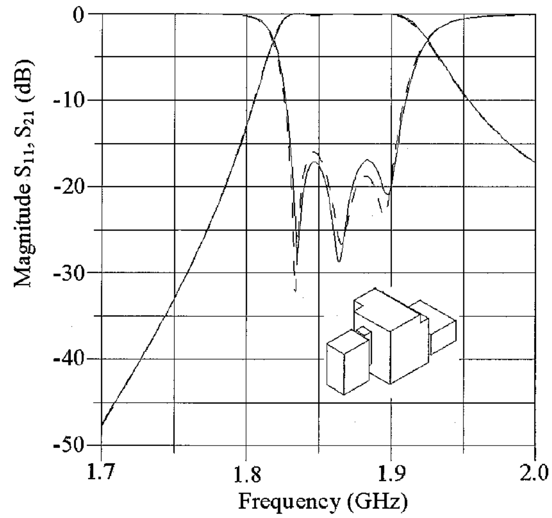

Fig. 2. Response of the cavity structure with matched ceramic waveguide terminals. Simulation by commercial HFSS (dashed) and proposed approach (solid).

We have amplified this very effective theoretical approach toward the 3-D structure at issue with dielectric of essentially high permittivity. Preparatory, microstrip to ceramic-filled waveguide transitions have been simulated separately by a commercial field simulator HFSS [9]. The connection of the overall structure of surface mount cavity into the microstrip circuit has also been simulated by HFSS.

IV. RESULTS

The dimensions of the cavity are given in Table I, and the corresponding denotations are shown in Fig. 1. Eventually, such a structure operates as a three-pole filter based on triple-mode rectangular cavity.

The validity of the numerical results has been evaluated first. Fig. 2 shows calculated data for the cavity with the waveguide terminals, where solid lines correspond to the proposed algorithm and dashed lines correspond to the simulation by HFSS. The agreement is very good. The computations by HFSS required 3 h for fast frequency sweep (maximum 20 points), while the original code requires 320 s for 100 frequency sample points.

The designed L-band filter is contemplated for connection into a 50-Ω microstrip line circuit. Accordingly, the transitions of T-probe kind and L-loop kind have been designed with a 50-Ω microstrip connection on the 0.635 mm thin alumina ($\epsilon_r = 9.8$) substrate. In both cases, the level of return loss better than -25 dB has been achieved.

Fig. 3 shows the data corresponding to overall microstrip-connected filter. For this computation, HFSS went through 11 aggressive mesh refinement steps (248 K of unknowns) and spent more than 20 h. The probable variation of the permittivity of the ceramic has been also evaluated. The normal value of the permittivity is ϵ_r =83, and the corresponding return and insertion losses are shown in Fig. 3 by solid lines. The effect of ± 1 deviation of ϵ_r is demonstrated in Fig. 3 for comparison. Dashed and chain lines correspond to the value of ϵ_r =82 and 84, respectively. It is observed that the designed filter is quite stable with respect to typical deviations of the ceramic permittivity.

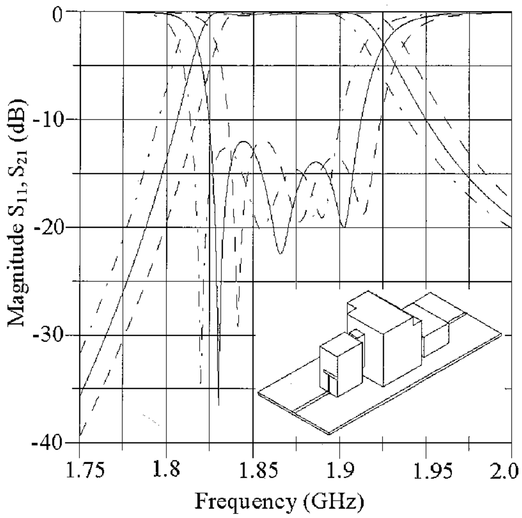

Fig. 3. Response of the overall microstrip-connected filter. $\epsilon_r = 83$ (solid lines), $\epsilon_r = 82$ (dashed), and $\epsilon_r = 84$ (chain).

V. CONCLUSION

A possibility of successful implementation of a triple-mode waveguide concept for the design of a surface mountable ceramic cavity has been demonstrated. The proposed configuration has the potential for inexpensive mass production. The outlined effective CAD-oriented simulation algorithm for the basic cavity guarantees veracity of the numerical results. A sensitivity study was undertaken. It was found that the cavity is stable with respect to typical variations of the high permittivity of the ceramic-filling. Proposed configuration can be implemented in a bandpass filter design for various wireless systems.

REFERENCES

[1] A. E. Atia and A. E. Williams, "Narrow bandpass waveguide filters," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-20, pp. 258–265, Apr. 1972.
[2] S. J. Fiedziuszko, "Dual-mode dielectric resonator loaded cavity filters," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, pp. 1311–1316, Sept. 1982.
[3] X.-P. Liang, K. A. Zaki, and A. E. Atia, "Dual mode coupling by square corner cut in resonators and filters," *IEEE Trans. Microwave Theory Tech.*, vol. 40, pp. 2294–2302, Dec. 1992.
[4] R. Ihmels and F. Arndt, "Field theory CAD of L-shaped iris coupled mode launchers and dual-mode filters," in *1993 IEEE MTT-S Int. Microwave Symp. Dig.*, June 1993, pp. 765–768.
[5] M. Mattes, J. Mosig, and M. Guglielmi, "Six-pole triple mode filters in rectangular waveguide," in *2000 IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 3, June 2000, pp. 1775–1778.
[6] G. Lastoria, G. Gerini, M. Guglielmi, and F. Emma, "CAD of triple-mode cavities in rectangular waveguide," *IEEE Microwave Guided Wave Lett.*, vol. 8, pp. 339–341, Oct. 1998.
[7] Y. I. Tikhov, "Electrodynamic modeling of multi-sectionstructures containing double-plane offsets and junctions of therectangular waveguides," *J. Commun. Technol. Electron.*, vol. 40, pp. 44–50, Sept. 1995.
[8] Y. Tikhov, J. H. Ho, and Y. K. Cho, "Field theory based design and comparison of two kinds of quasiplanar bandpass filters," *Proc. IEE Microwaves Antennas Propagat.*, vol. 145, pp. 441–448, June 1998.
[9] "High frequency structure simulator (HFSS)," Agilent Technologies, Palo Alto, CA, 1999.