CAD of Triple-Mode Cavities in Rectangular Waveguide

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***Abstract*— In this paper describe a very simple cavity structure which can be used as the basic building block for the computer-aided design (CAD) of triple-mode filters in rectangular waveguide. The input output ports are standard rectangular waveguides with a common longitudinal axis. The proposed configuration is geometrically simple and exhibits the very important feature of being amenable to a rigorous electromagnetic simulation. As an application example, a three-pole filter is demonstrated thereby fully validating the configuration proposed.**

***Index Terms*—Computer-aided design, microwave filters, multimode cavity.**

I. Introduction

SINGLE-CAVITY multiple-mode filters were first introduced by Lin in 1951 [1]. The basic concept was then extended to dual-, triple-, and later to quadruple-mode multicavity filters [2]–[4]. Since then, multiple-mode coupled cavity filters have made their way in a large variety of microwave systems, both for ground and space applications. The traditional procedure for the design and manufacture of this type of filters was practically based on measurement techniques and manual tuning (see, for instance, [5] and [6]). The current requirements on this type of hardware call for significantly reduced development time and effort. Large global reductions, however, can only be achieved developing, *at the same time*, advanced configurations and more performing CAD tools (see [7]–[13], for instance).

In this context, a very simple triple-mode cavity structure in rectangular waveguide is presented in this letter. The modes used to implement the three resonances are the $TE_{1,0}$ $TM_{1,1}$, and $TE_{0,1}$ modes, in that order, respectively. The possibility of exciting three degenerate modes in a cubic cavity is not new, however the novelty introduced in this letter is in that the particular choice of modal sequence makes the structure easily amenable to a rigorous electromagnetic analysis. In fact, using the proposed configuration, the input and output ports of the resonator have the same longitudinal axis so that the structure can be viewed as a series of cascaded uniform waveguides. The cascaded waveguide structure can then be easily analyzed using an accurate and efficient full-wave approach [14]. As an application example, a three-pole filter performance is demonstrated thereby fully validating the concept proposed.

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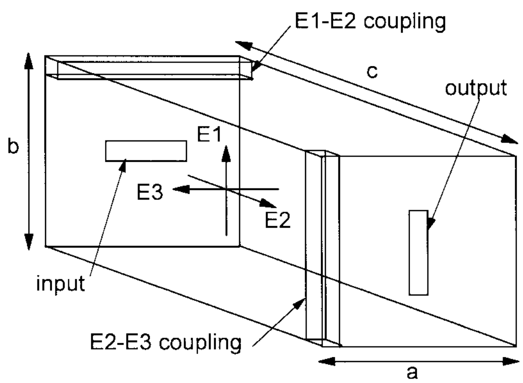
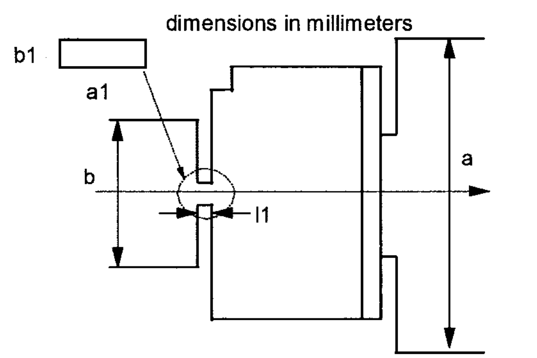


Fig. 1. Triple-mode cavity structure.



a1=12.2	b1= 5.0	l1= 5.3	a= 19.05
a2=19.6	b2=15.6	l2= 4.0	b= 9.525
a3=19.6	b3=19.6	l3= 8.6	
a4=15.6	b4=19.6	l4= 4.0	
a5= 5.0	b5=12.2	l5= 5.3	

Fig. 2. Longitudinal section of a three-pole triple-mode filter.

II. The Triple-Mode Cavity

The structure of the triple-mode cavity under examination is shown in Fig. 1. The basic resonator is a cube with sides equal to a, b, and c, respectively. The first resonant mode has a uniform electric field in the E1 direction of Fig. 1 and is coupled to the input waveguide with a standard rectangular aperture. The *E1-E2 coupling step* in Fig. 1 is then used to couple E1 into the second resonant mode E2 [8]. This second mode has a uniform electric field in the longitudinal E2 direction and is coupled to the third resonant mode E3 by the *E2-E3 coupling step*. The third mode can now be coupled to the output waveguide (or to another resonator) with a standard rectangular aperture.

The traditional modal sequence used in triple-mode cavities is, using our notation, E2-E1-E3. With this sequence, however,

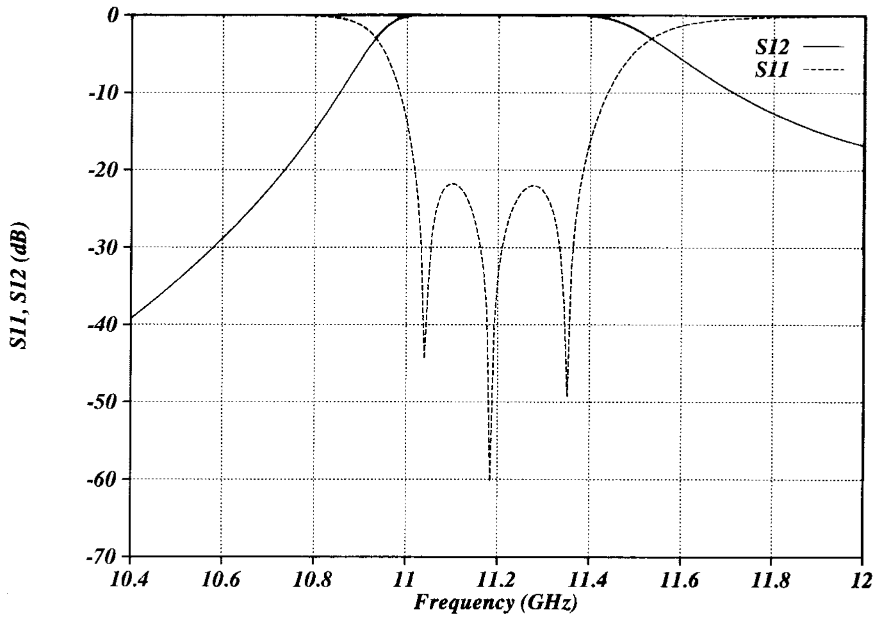


Fig. 3. Response of the triple-mode filter structure in Fig. 2 obtained using the multimode impedance matrix approach.

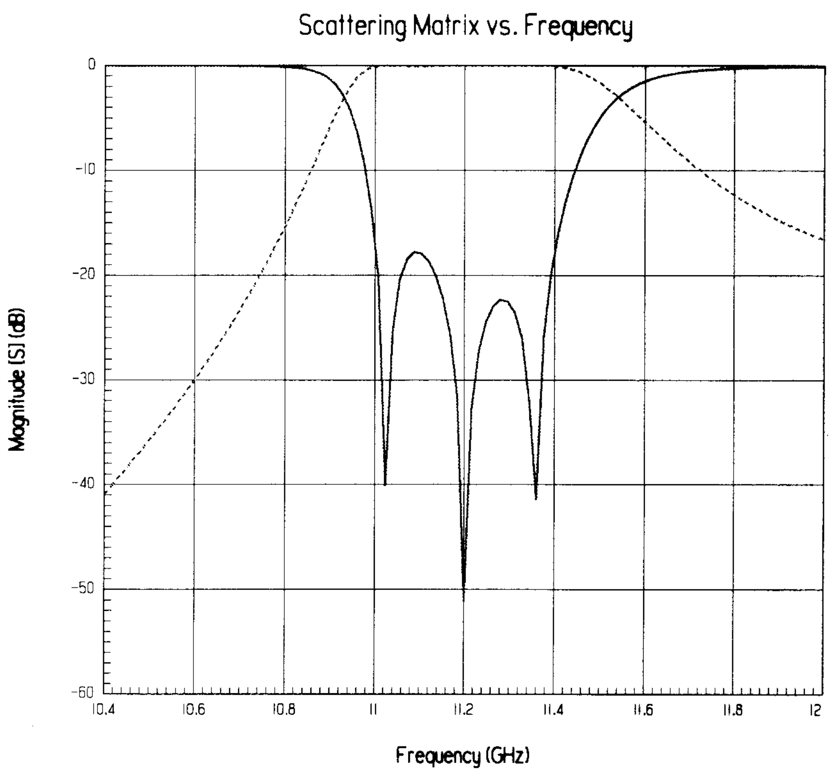


Fig. 4. Response of the triple-mode filter structure in Fig. 2 obtained using a commercial finite-elements package.

the input aperture must be placed on a lateral wall of the resonator thus making the CAD considerably more complex. Using the modal sequence proposed in this letter, on the other hand, the complete structure can be easily analyzed in terms of cascaded uniform waveguide sections.

One point that deserves further consideration is the possibility of controlling independently the three resonant frequencies in order to optimize the structure for specific applications. If we start by considering an ideal cube with sides equal to a, b, and c, we can write

$$(K_{1,0})^2 = \left(\frac{\pi}{a}\right)^2 + \left(\frac{\pi}{c}\right)^2 \tag{1}$$

$$(K_{1,1})^2 = \left(\frac{\pi}{a}\right)^2 + \left(\frac{\pi}{b}\right)^2 \tag{2}$$

$$(K_{0,1})^2 = \left(\frac{\pi}{b}\right)^2 + \left(\frac{\pi}{c}\right)^2 \tag{3}$$

where $K_{m,n}$ is the resonant wavenumber of the specific mode. These three equations can now be seen as a linear system of equations that relates the three resonances to the three cavity dimensions. The solution of the system can therefore be used, in an optimization loop, to determine the cavity dimensions which are required in order to change the value of one of the resonant frequencies while leaving the other two in their original position.

III. Three-Pole Filter

The longitudinal section of a single-cavity triple-mode filter is shown in Fig. 2. The analysis of the complete filter structure can now be easily performed with any available full-wave simulation software. In our case, it has been performed using the multimode impedance matrix representations [14]. Following this approach, the main computational effort which is required is the calculation of the modal structure or each waveguide section, and the coupling integrals between waveguides. Since all waveguides are rectangular in cross section, however, the required calculations can be carried out analytically with a very small computational effort.

Fig. 3 shows the results obtained after the structure has been optimized. As we can see, a three-pole filter bandpass response has been achieved. The computation of the results shown in Fig. 3 was performed using 400 modes to represent the fields at each discontinuity and 25 connected modes in each waveguide section. The time required was 2.5 min for the frequency independent calculations and 1.5 s per each frequency point. The platform used was an ALPHA 233.

As a further verification of the concept proposed, we show in Fig. 4 the response of the structure in Fig. 2 obtained this time with a commercial finite-element simulator. For this computation the structure was decomposed in 10000 tetrahedra in order to achieve a relative accuracy of 0.01% in the S parameters. The computations required 3 h for 100 points in frequency on a SPARK ULTRA 3000. As we can see, there is good agreement between Figs. 3 and 4, thereby fully validating the triple-mode cavity concept proposed in this letter.

IV. Conclusion

In this letter we describe a triple-mode cavity structure in rectangular waveguide which is amenable to a full-wave electromagnetic analysis. The basic triple-mode cavity is fully discussed and a three-pole filter performance is demonstrated.

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