# A Two Zero Fourth Order Microwave Waveguide Filter Using A Simple Rectangular Quadruple-Mode Cavity

Nicolas Boutheiller*, Pierre Jarry*, *Member, IEEE*, Eric Kerhervé*, *Member, IEEE*,

Jean-Marie Pham*, and Serge Vigneron**

*IXL Laboratory, University Bordeaux I, 351 cours de la Libération, 33405 Talence cedex, France

**Alcatel Space, 26 avenue J. F. Champollion, BP 1187, 31037 Toulouse cedex 1, France

*Abstract* — **In order to reduce the size of microwave waveguide filters, triple and quadruple mode filters in circular waveguide have been investigated intensively. However, the research for such filters in rectangular waveguide is still poor and the rare trials have led to complicated sensible structures with loaded cavities. This paper describes a fourth order filter with two transmission zeroes obtained with only one basic rectangular cavity and two irises. Neither coupling nor tuning screws are needed. The analysis at the discontinuities is performed by the moment method. The synthesis lies on an optimization method based on the genetic algorithm.**

## I. Introduction

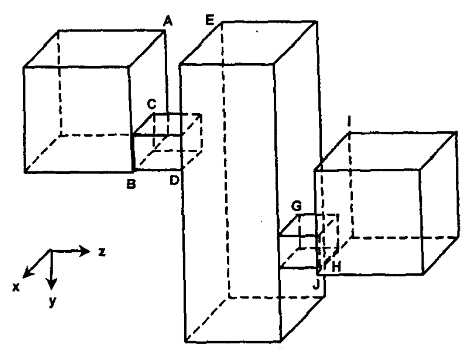
Design of triple and upper mode filters in circular cylindrical waveguides appeared many years ago. However, such designs in rectangular waveguide have progressed slowly. A hexa-mode filter was realized [1], but the couplings were fundamentally achieved by six coupling screws. This principle thus requires important time consumption during tuning phase and the intensive use of screws has contributed to the great sensibility reputation of multimode filters.

More recently, a triple-mode cavity in rectangular waveguide was introduced [2]. The couplings involved do not need screws but they are achieved by two small orthogonal steps placed at each extremity inside the cavity. The input and output modes are different and orthogonally polarized. Unfortunately, this basic building block implemented as a single cavity third order filter does not exhibit transmission zeroes.

The configuration used in this paper is even simpler. A basic rectangular cavity and two rectangular aperture thick irises permit to realize a 2-zero 4-pole filtering function.

## II. Structure Analysis

Fig. 1 shows the structure concerned. It is composed of five rectangular parallelepipeds dug into a metallic block. The axis are chosen so that x and z are horizontal and respectively transverse and longitudinal. The y axis is vertical and downward. For each parallelepiped, the coordinates of two vertices are given. The dimensions of the parallelepipeds located at the extremities are identical. They correspond to the normalized size of the SMA to waveguide converter.( WR 75 for the frequencies involved). The input and output electromagnetic modes are thus the TE10.




| Coordinates in mm ( x, y, z ) | |
|---|---|
| A ( 0.00, 0.00, 0.00 ) | F ( 18.63, 25.25, 13.4 ) |
| B ( 19.05, 9.525, 0.00 ) | G ( 7.95, 15.63, 13.4 ) |
| C ( 7.59, 6.28, 0.00 ) | H ( 18.56, 18.61, 17.09 ) |
| D ( 18.21, 9.52, 4.48 ) | I ( 0.88, 9.32, 17.09 ) |
| E ( -4.64, -0.06, 4.48 ) | J ( 19.93, 18.845, 17.09 ) |

Fig. 1. Structure description with dimensions given by specific point locations in the (x, y, z) coordinate system.



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To design a quadruple mode filter, four modes at least need to be propagative in the main cavity. In practice, the height, width and length of this cavity are chosen so that the resonance frequencies of the selected modes are located close to the expected frequency bandwidth. The size and the position of the irises are then sought in order to bring the resonance frequencies inside the desired bandwidth.

The analysis is performed by the composition of multimode scattering matrices. For the constant cross section parts, these matrices are easily filled in. In order to obtain them for the discontinuities, we made use of the moment method applied to a classically derived electrical field integral equation.

To establish this latter, the tangential electric and magnetic field continuity equations are expressed at the discontinuities as an expansion of incident and reflected eigenmodes of both sides separately. Making use of the mode orthogonality, the reflection magnitudes can be expressed versus the incident ones and the unknown tangential electric field. They are then reported in the equation stating for the tangential magnetic field continuity, leading to the desired integral equation.

The moment method is then used to obtain the tangential electric field as a linear combination of the incident magnitudes. The dependence of the reflection magnitudes on the incident ones can then be established, leading to the multimode scattering matrix characterizing the cross section discontinuity.

The analysis of the structure has been performed considering 30 modes along the whole structure and taking into account the energy distribution on 300 modes on each side of the discontinuities. The program implemented in C++ language spent 1.35s for each point on a 1.2 GHz AMD Athlon processor PC with 256 MB RAM under windows2000.

## III. THE SYNTHESIS PROCESS

The structure can be thought as a succession of parallelepipeds. Each one can be completely defined by six parameters : the width, the height, the length and the coordinates of one of its vertex. However, the width and height of the parallelepipeds at the extremities are such that they correspond to the size of the transition ( WR75 in this example) and their lengths only have to make the non fundamental modes sufficiently attenuated in respect to the transition multimode characteristic. Moreover, the different sections are joined so their positions along the z axis are imposed relatively to the first one once the lengths have been chosen. Thus, the size of the access guides and all the z coordinates must not be considered in the number of parameters. The x-y-z position of the input guide being fixed as reference, there are fifteen parameters left for the structure studied.

Their initial values are chosen according to the remark made at the beginning of the previous section. The synthesis process then relies on the accurate analysis. Indeed, the structure response is calculated and the parameters are modified in consequence. These two steps are repeated until a satisfying response is obtained.

The performances of such a synthesis scheme are strongly dependent on the simulation time, the objective function and the strategy employed to modify the parameters.

A genetic algorithm based optimization method has been employed. The different parameters are first coded in order to take into account the manufacturing tolerance. A simple method consists in coding them as integers corresponding to the rounded dividend of their division by the tolerance. In this algorithm terminology, each coded parameter is called "gene" and the set of them is named "chromosome". In the stationary genetic algorithm, a "population" is a fixed number n of chromosomes.

A number referred to as "fitness value" is associated with each chromosome. It expresses the performance level the parameters it represents lead to. This value is given by a user defined function. The inverse of a least mean square error function between the obtained and desired responses was used for this example.

The problem is now equivalent to the search of the chromosome with the highest fitness value. Two operators are defined to act on the chromosome. The first one is called "mutation" and consists in slightly modifying the value of one or more genes of a chromosome. The second one, the crossover, acts simultaneously on two chromosomes called "parents" by interchanging some of their genes in order to obtain two "children". Once a population of n chromosomes has been built from performing various mutations on the chromosome stemming from the initial parameter values, the main loop of the algorithm is entered. For each iteration, named "generation", a new population is obtained by selecting parents and performing crossover and mutation on them with a given probability. The strategy used for the selection strongly affects the algorithm performances. The loop ceases when a chromosome in the current population has reached a fitness value considered as satisfying.

More details on the implementation of the genetic algorithm can be found in [3]-[4].

## IV. Results

For technical reasons, the brass was employed for the manufacture of the filter. The tolerance was about ±20µm. The measured and expected transmission coefficient magnitudes are confronted in Fig. 2 whereas the reflection ones appear in Fig. 3. Neither coupling nor tuning screws have been used.

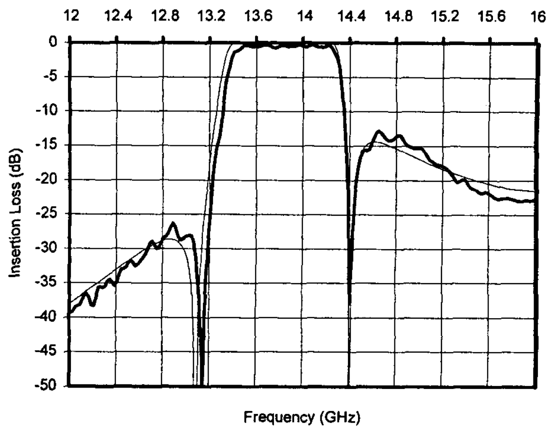


Fig. 2. Simulated (thin) and measured transmission response of the filter.

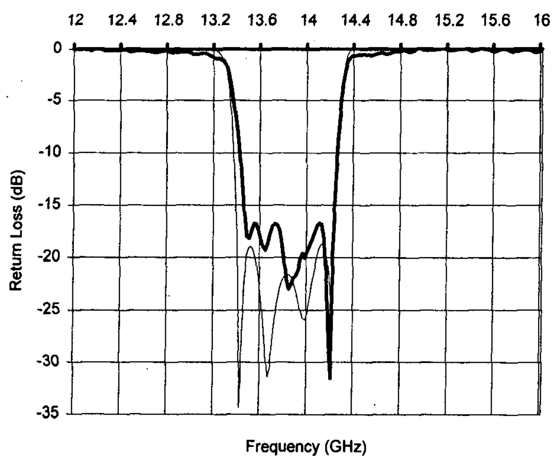


Fig. 3. Simulated (thin) and measured reflection response of the filter.

The filter bandwidth is about 6.1 % and the insertion losses obtained are lower than 0.8 dB. The low unloaded quality factor Q is due to the use of some modes at their cutoff frequency resonance. This type of structure is thus suitable for relatively modest bandwidths.

The frequency shift of the left transmission zero is explained by the technique employed for the manufacturing. Indeed, as it appears on Fig. 4, a vertical cut plane was used so as to be able to dig the cavity and the irises with a reamer. As a consequence of the diameter of this latter, the corners of the parallelepipeds seen along the x axis are no more rectangular. This default is known to lead to effective lengths shorter than the desired ones [5]. As the effective height of the cavity is decreased, the resonating electromagnetic modes which depend on it have their resonance frequencies and the transmission zero they produce moved to upper frequencies.

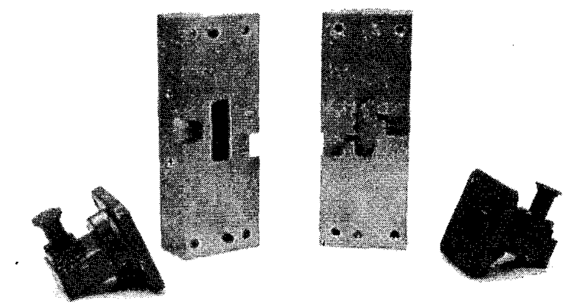

Fig. 4. Prototype filter opened showing the corner radii due to the manufacture process employed.

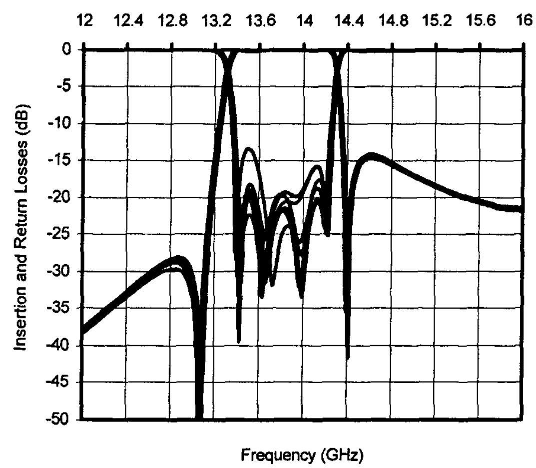


Fig. 5. Effect of variations of the dimensions on the transmission and reflection responses of the filter.

The bandwidth sensitivity to variations of the dimensions (due to the manufacture process or the temperature change) is depicted in fig. 5. The family of curves has been obtained by shifting six times all the corner positions of all the parallelepipeds (except the access guides) by a positive or negative displacement randomly chosen between 10 and 30 microns. As can be observed, even if the resonating modes are different, the effect on the response is light.

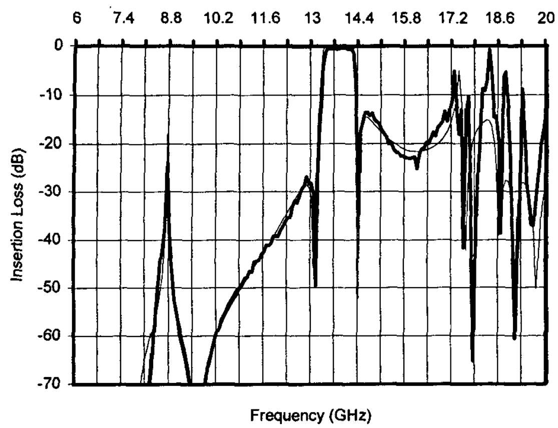


Fig. 6. Simulated (thin) and measured wide-band transmission response of the filter.

Fig. 6 shows the transmission magnitudes on a wider range of frequency. No spurious bandwidth is visible beneath 20 GHz. Only few isolated poles are present.

## V. CONCLUSION

This paper has demonstrated that using a single basic rectangular waveguide cavity and two irises, it is possible to realize a four pole filter with two transmission zeroes. Coupling screws are not required for the device. This feature is entirely accomplished by the irises.

With the manufacture process employed, it could be useful to take into account during the design the effect of the corner radii on the effective lengths.

A two cavity seven pole filter with two second order transmission zeroes is being manufactured to generalize the principle to filters made of multiple cavities.

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