Low-cost Dual-mode Asymmetric Filters in Rectangular Waveguide

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Abstract— **Dual-mode microwave filters are extensively used in modern communication equipment because they can implement sophisticated and selective filter transfer functions. Their most common implementation is based on circular-waveguide technology and generally requires a rather complex development procedure. In this paper we describe a new implementation of dual-mode filters in standard rectangular waveguide that can be used to produce asymmetric transfer functions. The proposed filter structure can be analyzed and optimized very efficiently using multimode equivalent network representations thus leading to a simple and rapid development procedure. In addition to theory, the measured performance of several filter structures are also presented thereby fully validating the proposed filter concept.**

I. Introduction

Dual mode filters in circular waveguide are commonly used in the input/output networks of communication equipment and their basic features are now well understood (see [1], [2] for instance). One of the reasons for their popularity is that they allow for the implementation of very selective filter with transmission zeros at finite frequencies. Using the current circular waveguide technology, transmission zeros can, in fact, be introduced both above or below the filter pass band so that symmetric or asymmetric transfer functions can be obtained. Generally speaking, however, dual mode filter in circular waveguide require a rather complex and expensive development and manufacturing procedure.

A family of filters that is significantly simpler to design, and also to manufacture, is the one based on inductively coupled resonators in rectangular waveguide [3]. Filters of this type have been studied by many researchers and are currently used for many telecom applications where large number of filters (or diplexers) are required [4]. In this context, one subject of investigation that has received much attention over the years, is the possibility of implementing asymmetric transmission zeros with rectangular waveguide filters in order to obtain more selective structures ([5] to [10].

The objective of this paper is to extend the state of the art of waveguide filters by introducing a new type of dual-mode filter in rectangular waveguide that can be used to implement very selective asymmetric transfer functions. The dual mode filter proposed in this paper is based on simple rectangular waveguide cavities coupled by inductive windows. The resulting filter structure is shown to be simple and of "low cost" optimization and manufacture. In the remainder of this paper, we first describe the basic dual mode resonator, we then discuss a filter design procedure, and, finally, we present comparisons between measured and simulated performances that fully validates the proposed filter concept.

II. Dual-mode filters in rectangular waveguide

The new family of dual-mode filters proposed in this paper is based on the use of a pair of resonant modes of a *single family* of modes of a rectangular resonator (patent pending). The use of higher order modes in rectangular waveguide filters is not new in itself and many contributions can be found in the technical literature exploiting the various possible modal interactions (see for instance [5] to [10]). All of the above contributions, however, basically describe single mode filters structures in which each resonator provides one transmission pole, and where the higher order mode interactions are used to implement transmission zeros to increase the filter selectivity. The novelty introduced in this paper is in that each cavity of the structures proposed produces two transmission poles and one transmission zero thereby allowing the implementation of simple "planar" dual-mode filter structures.

Following the concept described in this paper, many choices are indeed possible. To find the modal combinations which are possible in a rectangular resonator of sides a, b and l (Fig. 1), we first impose that the eigenvalue relative to the dimension b is equal to zero. Next, we impose the condition that both modes resonate at the same frequency, namely

$$(\frac{m\pi}{a})^2 + (\frac{n\pi}{l})^2 = (\frac{p\pi}{a})^2 + (\frac{q\pi}{l})^2 \qquad (1)$$

where the subscripts m, n refer to the first mode, and p, q refer to the second. Equation (1) leads to the following expression for the initial choice of the ratio a/l in relation of the chosen mode pair:

$$\frac{a}{l} = \sqrt{\frac{m^2 - p^2}{q^2 - n^2}} \qquad (2)$$

The resonance wavenumber is instead given by:

$$k_o = \sqrt{(\frac{m\pi}{a})^2 + (\frac{n\pi}{l})^2} \qquad (3)$$

The only additional constraint that must be imposed in order to obtain a dual mode operation is that the modal indexes m and p, (and n and q) must be different. By imposing this last condition, one ensures in fact that on each side of the resonator the field distribution of the resonant modes chosen are orthogonal, thereby allowing for the dual-mode operation.

It is important to note that in all of the above equations, the wavenumber relative to the b dimension has been set equal to zero. As a consequence, one obtains very simple filter structures containing only *inductive* discontinuities which are at the same time easy to analyze and easy to fabricate with high mechanical accuracy.

III. Filter design

The numerical efficiency of the EM analysis of all of the structures described in this paper has a very important consequence: The design and optimization of the filters can be simply carried out by using an efficient full-wave simulator. For the application example discussed in this paper, the design procedure has been as follows. The first step is to use equations (2) and (3) to obtain the ideal dimensions of a resonant cavity at the frequency of interest. The next step is to analyze a single cavity structure with an efficient EM simulator. In this paper we used the package WIND developed at ESTEC. This software package is based on the multimode impedance network representation of an inductive step in a rectangular waveguide environment ([11], Page 213), however, any other simulation tool can be used as well.

The optimization of a single cavity filter requires only the adjustment of three parameters, namely the input/output apertures, the length and the width of the resonator. To start, the offset can be chosen to be zero. Using, for example, the TE_{102} and the TE_{201} resonances at 11 GHz, we obtain a resonator size of about 30 mm. Using a coupling aperture 10 mm wide and 2 mm thick, with zero offset, we obtain the result shown in Fig. 2 (Input/output waveguide WR75). The basic dual mode behavior is clearly evident. One important feature of the results obtained is the presence of a transmission zero on the right hand side of the passband. This zero is due to the fact that the input output aperture couples to both the TE_{102} and the TE_{201} modes [?]. However, since the TE_{102} resonance changes sign to the field going from the input to the output, a destructive interference is produced thus creating a transmission zero. The position of the transmission zero can be easily moved to the left of the bandpass by simply changing the ratio of cavity length to cavity width. Changing the width of the resonator to 31 mm, we obtain, for instance, the result shown in Fig. 3.

These two basic structures can then be used as starting points for the optimization of more complex filters composed of cascaded resonators using directly as a target function the final desired electrical behavior [12]. The position of the transmission zeros can be adjusted by changing the value of the offset in the input and output aperture of each resonator.

IV. Application example

As an application example we now present the results obtained by applying the design procedure described above to the case of a three-pole filter with one transmission zero to the left of the passband. The center frequency is 12 GHz and the bandwidth is about 500 MHz. The structure of the filter is shown in fig. 4, while the measured and simulated responses are shown in fig. 5. As we can see, there is good agreement between measurement and simulation. For this application example, only one dual mode cavity has been used. The resonating modes are the TE_{102} and TE_{301}. No tuning screws have been used.

As a second, more complex example, we now discuss a six pole filter with three transmission zeros. The center frequency is about 39 GHz, and the bandwidth is 350 MHz. The filter structure is shown in fig. 6. The modes used in this application are the $TE_{(102)}$ and the $TE_{(201)}$. The filter structure is composed of three cavities and is symmetrical with respect to the center of the filter. With this arrangement, the input and output cavities will each produce two transmission poles, and two transmission zeros. The two transmission zeros, however, will be located at the same frequency. The central cavity will produce the remaining two transmission poles, and the third transmission zero.

Figure 7 show the comparison between the theoretical and the measured response of the filter. As we can see, the agreement is very good. The only details that remains to be discussed is the presence of the tuning screws in the actual filter structure in fig. 6. The filter design and optimization has been carried out without tuning screws. The cavity dimensions obtained have then been reduced by 20 microns both in length and in width, in order to allow for the tuning action. Tuning screws are necessary in this case because, even though the design procedure indeed produces very accurate dimensions, the electrical specifications of the filter are such that the mechanical accuracy required for a tuning less implementation would increase significantly the manufacturing cost. Tuning screws are therefore necessary to tune the resonant cavities to the desired center frequency. The coupling apertures, on the other hand, have not been tuned.

Another aspect that deserves to be discussed, is the location and number of tuning screws used for each cavity. Due to the resonant modes chosen, each resonance will exhibit a line in the resonator along which the field is equal to zero (the dotted line in fig. 6). Along the same line, however, the other resonant mode will exhibit two resonance maxima of opposite sign. Placing two tuning screws along each of these lines will therefore result in four screws for each resonator, as shown in fig. 6, and will ensure the independent tunability of the two degenerate modes of each cavity.

V. Conclusion

In this paper we have introduced a new family of dual mode filters based on the use of TE_{m0n} mode family in a rectangular resonator environment. The major features of this new family of filters are three. The first is that they are extremely easy to simulate and optimize since they only employ inductive discontinuities. The second is that they are amenable to a very low-cost high precision manufacturing process. The third is that they are ideally suited for low-loss, diplexer applications where asymmetric response is highly desirable. The performance of typical filter structures is demonstrated, including also measured results, thereby fully validating the new filter concept.

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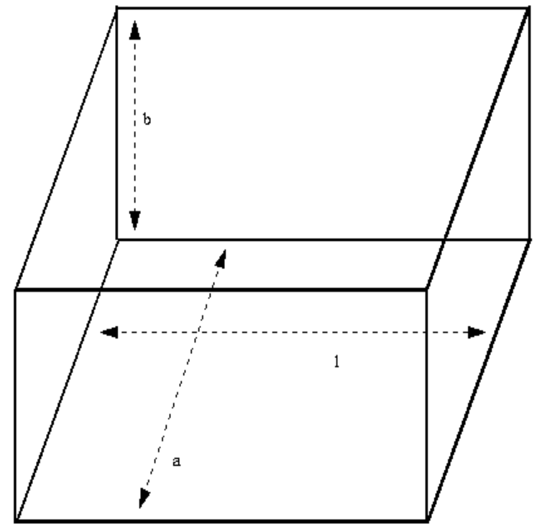

Fig. 1. Basic rectangular resonator.

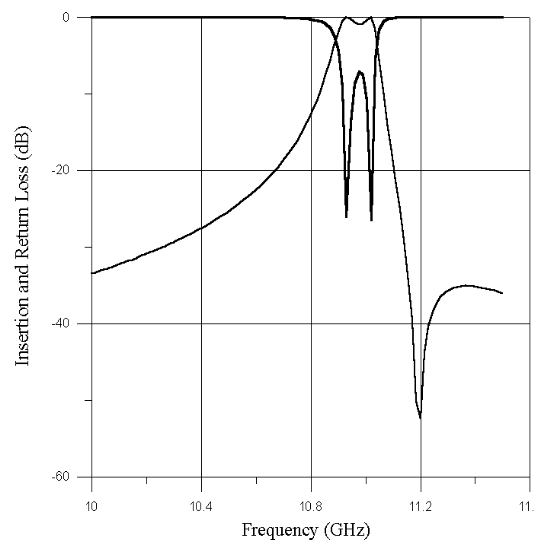

Fig. 2. Basic response of a dual mode resonator with one transmission zero to the right of the pass-band.

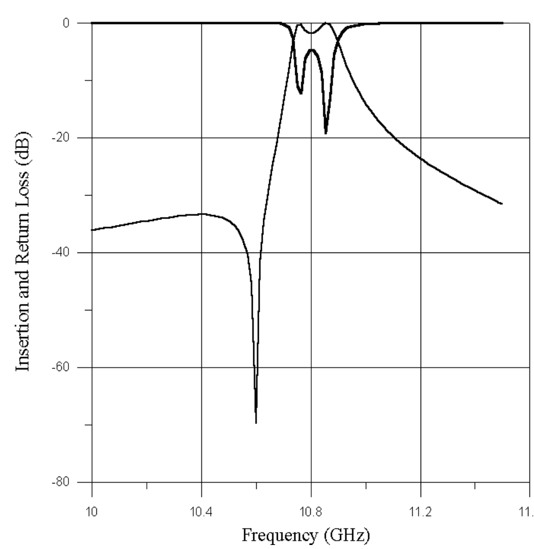

Fig. 3. Basic response of a dual mode resonator with one transmission zero to the left of the pass-band.

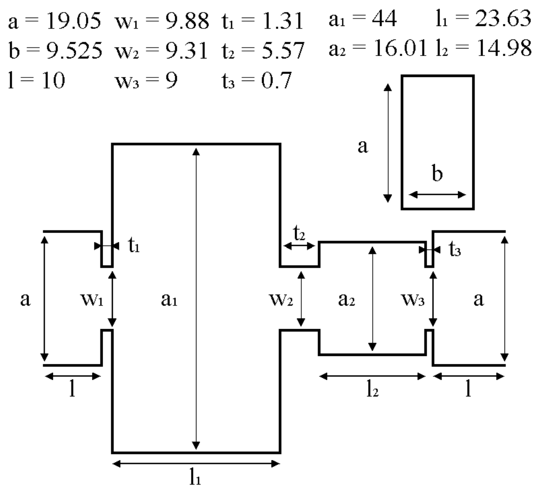

Fig. 4. Geometry of asymmetric three-pole filter (dimensions in millimeters).

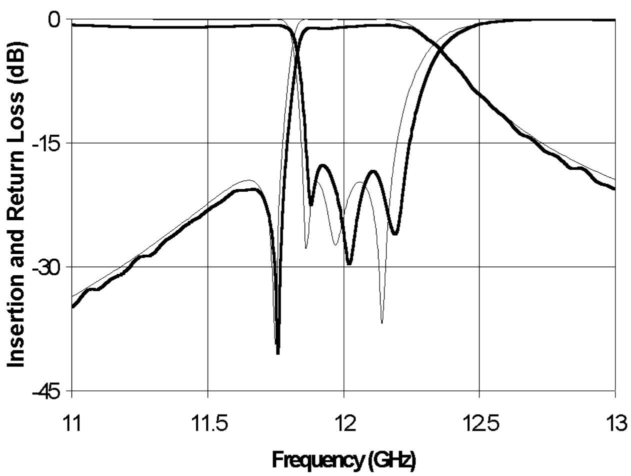

Fig. 5. Measured and simulated performance of the filter in fig. 4.

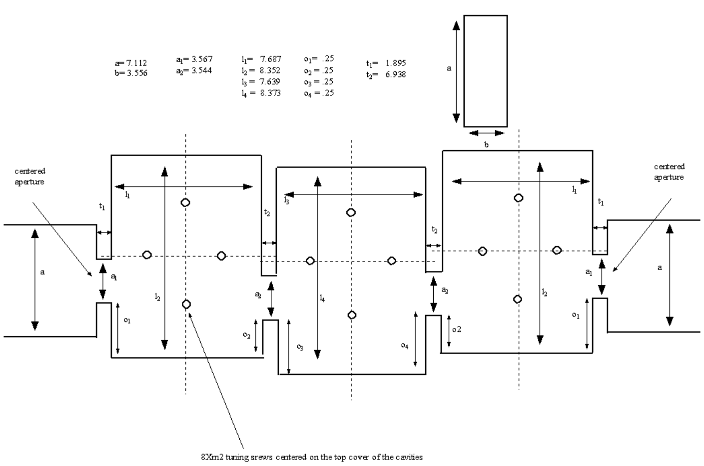

Fig. 6. Geometry of asymmetric six-pole filter (dimensions in millimeters).

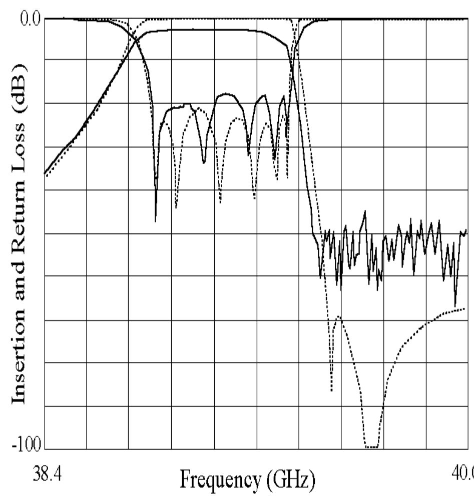

Fig. 7. Measured (thick) and simulated response of the single dual mode cavity in Fig. 6.