Compact E-Plane and Ridge Waveguide Filters/Diplexers With Pseudo-Elliptic Response

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***Abstract* — A new class of low-cost and mass-producible filters based on cross-coupled resonators or highly dispersive stubs are introduced. The filters exhibit pseudo-elliptic transfer functions with steep attenuation slopes. They are based on E-plane and ridged waveguide technology and are well suited for millimeter-wave application. Metallic inserts are used not only to determine the filter response but also to separate the folded filter sections and to control the coupling coefficient of the cross-coupled resonators. Designed filters and diplexers are highly compact and much shorter than traditional E-plane filters. At the same time the ease of manufacturing known from typical E-plane filters is preserved.**

I. INTRODUCTION

Filters and diplexers are key components when it comes to lower the cost of customer premises equipments (CPE's). Their electrical performance determines the overall system concept and thus low-insertion loss filters with high slope selectivity are essential. There are many filter structures that satisfy the above criteria but only few are really suitable for low-cost, mass fabrication. Most prominent among them are E-plane filters. While these filters are well known for over two decades, only their direct coupled type has been utilized so far in the frequency range from a few GHz to 150GHz (i.e. [1],.[2]). The performance of E-plane filters is essentially determined by the metallization pattern of the metal insert, which ranges in thickness from 30-100μm and can be fabricated by photolithographic or electroforming processes with high accuracy and repeatability. Furthermore, the filter housing can be mass-produced by plastic injection molding techniques with subsequent surface metallization. This technique has already been applied very successfully to iris-coupled diplexers with dispersive stubs [3] and is currently under development for E-plane filters to lower their cost even further.

A commonly known disadvantage of E-plane filters is that, for a given number of resonators, they do not provide steep attenuation slopes. Exactly this feature, however, is required in many broadband front-ends to avoid cross-talk. If, for cost reasons, E-plane filters are the preferred choice for the diplexer, the number of resonators must be increased accordingly. Although this approach has been successful in practice it is not very satisfactory: First, the size of the diplexers increases significantly and, second, the passband losses deteriorates. A technique to overcome these disadvantages is to introduce cross-coupling between resonators to generate an elliptical function response. Although this technique is known from iris-coupled filters [4] it has only recently been introduced to E-plane filters [5] resulting in significantly improved slope selectivity and a more compact design.

In this paper, the advantages of cross-coupled E-plane filters (i.e. simple design, mass-producible) are further investigated and are applied to ridged cross-coupled E-plane filters and E-plane filters with highly dispersive stubs. Very compact diplexer structures for millimeter-wave applications are presented.

II. FILTER AND DIPLEXER CONFIGURATIONS

In the following the same principles as in [5] are, for the first time, applied to ridge waveguide filters. This is illustrated in Fig.1. Ridge waveguide filters have several advantages compared with full-height E-plane filters [1]: shorter resonator lengths, larger spurious-free frequency range, ease of integration with quasi-planar structures. To make this type of filters even more compact, the structure can be folded about the middle resonator or any other resonator. Another compact configuration in which the filter is folded at the middle coupling section has been introduced in [6] where only Chebychev filters were implemented. In this paper, we push the state-of-the-art

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further and design compact pseudo-elliptic filters by adding cross-coupling and exploiting shifting techniques to place the transmission zero on either side of the passband [5]. Cross-coupling is realized by an opening in the separating wall between both waveguide sections. The opening height can be equal to the waveguide height or smaller. For fabrication simplicity the metal inserts and the separating wall have the same thickness t. A possible difficulty with this configuration is the fact that a 90^0 waveguide bend is necessary at the input and output. This bend must be included in the filter/diplexer design.

An alternative structure with which one can avoid the above mentioned waveguide bends is shown in Fig.2. Although this structure may not offer the kind of compactness as in the configuration of Fig.1, it is still very attractive in view of its pseudo-elliptic response and ease of manufacturing. In this solution the two filter halves are laterally offset and coupled through an opening in the common waveguide wall. The example of Fig.2 has four direct-coupled cavities whereby the coupling is achieved between the second and the third resonator. The third cavity is longer than all of the other cavities and acts as a strongly dispersive stub which introduces one transmission zero [7].

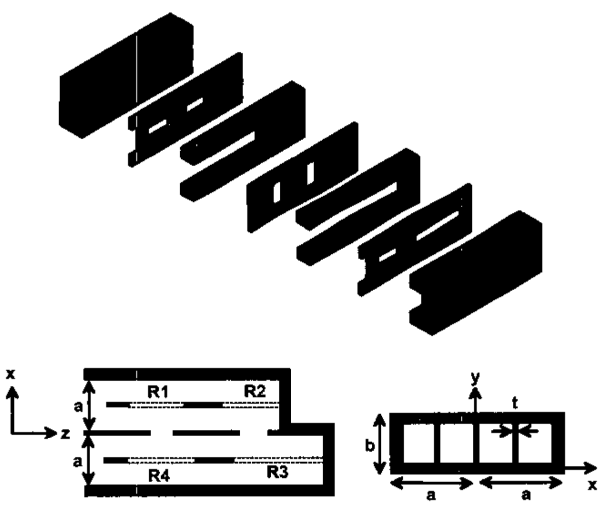

Fig. 1. Cross-coupled folded E-plane single metal-insert filter structure with ridged waveguide sections (dashed).

These filters are also well suited to form compact and high performance diplexers for millimeter wave application. One possible realization is illustrated in Fig.3. In this example two direct-coupled folded E-plane filters with dispersive stubs (Fig.2) are fed by a tapered broadband H-plane power divider.

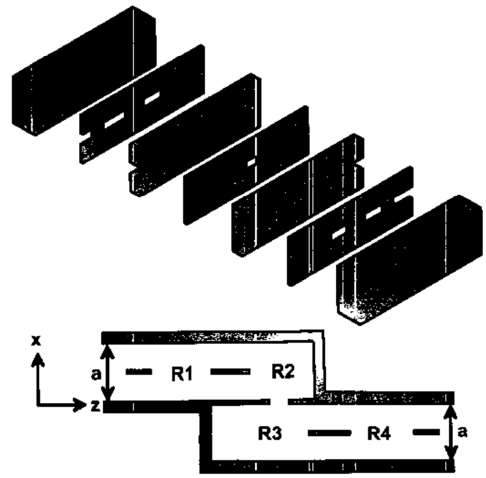

Fig. 2. Direct-coupled E-plane metal insert filter structure with strongly dispersive section (4 resonators).

The design and optimization of the H-plane transformer section is well known from [8]. Although the power divider and channel filters are first optimized as stand-alone components, the entire diplexer with the power divider and the filters in place must undergo a final fine tuning in order to account for the interaction effects at the various interfaces.

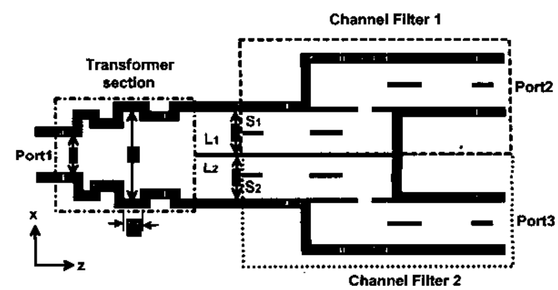

Fig. 3. Top view of the new diplexer structure consisting of direct-coupled E-plane metal-insert filters using strongly dispersive stubs.

III. Design And Results

An optimization-based design approach is followed in this work since synthesis techniques are not available. In the case of the cross-coupled ridged E-plane filter design, the optimization tool available in Ansoft's HFSS is utilized with an appropriate cost function. In the case of the direct-coupled E-plane filter with dispersive stub, the design is based on the Mode Matching Technique (MMT) in conjunction with optimization routines from the NAG library. In both cases, the independent variables are the lengths of the resonators and coupling sections. The cost function is the sum of the squares of the errors between ideal and computed response over 10 frequency points in HFSS simulations and 50-100 frequency points in MMT simulations. The smaller number of frequency samples in the HFSS simulation is due to the extremely long computation times. Different weights are used in the passband and in the vicinity of finite attenuation poles.

Initial design of cross-coupled ridged E-plane filter is performed by adjusting the dimensions of the original optimized cross-coupled E-plane filter. The lengths of each coupling septum in the ridged filter are adjusted to obtain the same 2-port scattering parameters as the corresponding septa in the original filter structure without ridged sections at the center frequency of the filter. The lengths of the ridged resonator sections are then calculated using the propagation constants of the fundamental mode in the ridge sections, i.e., making the electrical lengths of resonators in both filters equal.

Cross-Coupled Ridge Waveguide Filters

A Ka-band cross-coupled ridged E-plane filter is designed by optimizing the initial dimensions of the filter. The response of the filter is shown in Fig.4. In comparison to standard ridge waveguide filters, it is clearly seen that the presence of the two finite transmission zeros improves the stopband behavior significantly. The thickness of the metal inserts and the separating wall is chosen to be 100μm (suitable for low-cost metal etching techniques).

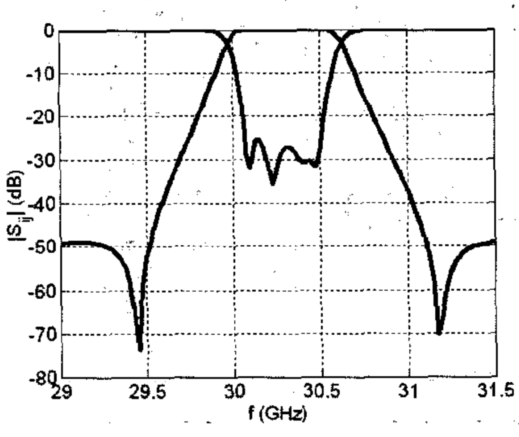

Fig. 4. Response of a cross-coupled E-plane filter with ridged waveguide sections.

E-plane Filters with Dispersive Stub

The design of E-plane filters with dispersive stub is initially based on a standard E-plane filter design to meet given specifications roughly. Then, the size of the third cavity is increased until a transmission zero is obtained in the higher stopband of the filter. This approach produces filters with asymmetric responses which, in most cases, is sufficient to meet the design goal. Two design examples for a 4-resonator filter are given in Fig.5. The transmission zero can be placed on either side of the passband, whereby the position of the coupling slot determines the location of transmission zeros. For example, the transmission zero is shifted to lower frequencies by moving the slot towards the first half of the cavity. The in-band return loss in both cases is 23dB with centre frequencies of 38.8GHz and 39.5GHz, respectively, and a bandwidth of 500MHz.

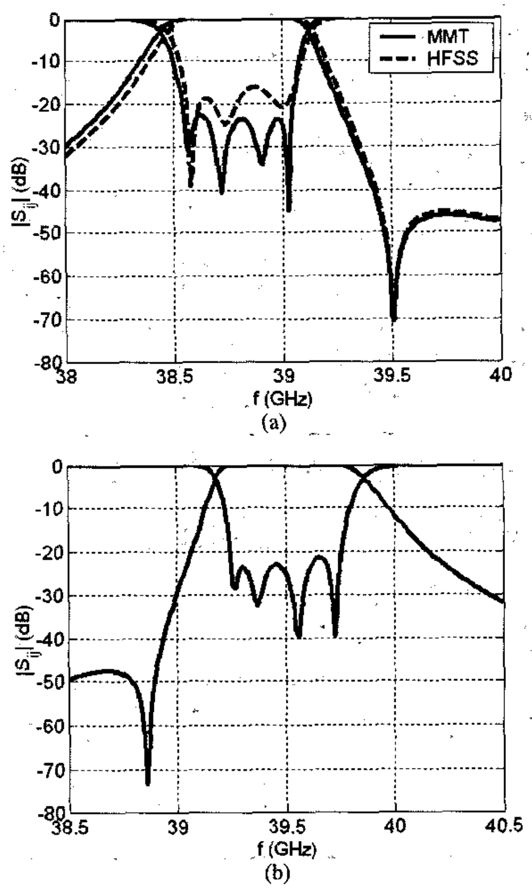

Fig. 5. (a) Response of a direct-coupled E-plane filter with strongly dispersive stub and transmission zero on the right side of the passband (computed with MMT: solid line; verified by HFSS: dashed line). (b) same as (a) but transmission zero on the left side of the passband.

For the diplexer application, two folded direct-coupled E-plane filters with only one transmission zero each are designed individually at center frequencies of 38.8GHz for Channel 1 and 39.8GHz for Channel 2, respectively. The guard band is about 500MHz. In a final optimization run the following dimensions are optimized: The power divider dimensions the individual waveguide, i.e., widths (a_i) and lengths (w_i), the distance between the bifurcation and the taper (L, Fig.3(a)), the distance between the filters and the start of the bifurcation (L_1,L_2, Fig.3(a)) and the first septa of the individual filters (S_1, S_2, Fig.3(a)). It was not necessary to change the remaining filter dimensions throughout the optimization. To improve the isolation between both channels the filter for the lower frequency (channel 1) is designed such that the attenuation pole is at the right side of the passband whereas for the filter of channel 2 the pole is placed on the left side of the passband. Fig.6 shows the performance of the entire diplexer structure after optimization.

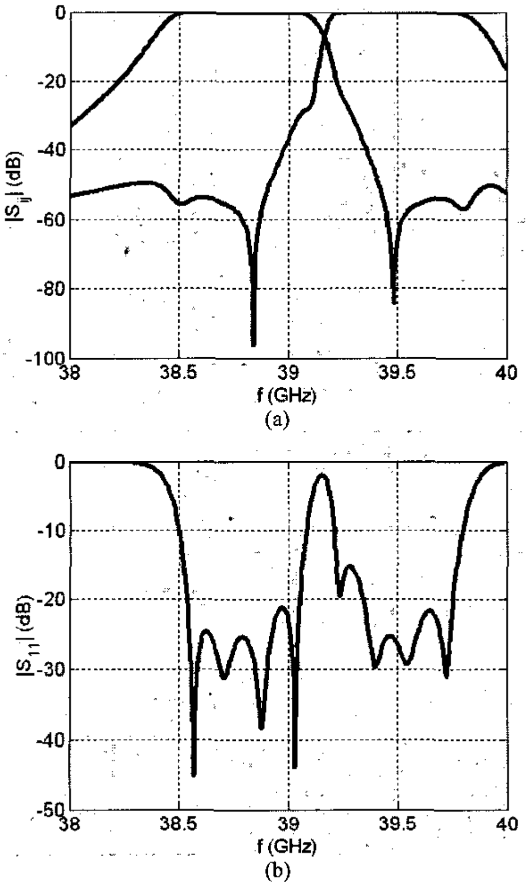

Fig. 6. (a) Insertion loss and (b) return loss of the optimized diplexer computed with the MMT.

IV. Conclusion

E-plane filters and diplexers based on cross-coupled resonators or dispersive stubs have been introduced. These filters are suitable for application in broadband millimeter wave links as low-cost, high performance and compact components. Coupling between resonators or dispersive stubs, as well as a combination of the above leads to a highly flexible class of filter structures suitable for applications in the frequency range from 10GHz to 100GHz.

Acknowledgment

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