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THE GENERALIZED CHEBYSHEV SUBSTRATE INTEGRATED WAVEGUIDE DIPLEXER

Han S. H., Wang X. L., Fan Y., Yang Z. Q., and He Z. N.

Institute of Electronic System Engineering
University of Electronic Science and Technology of China
Chengdu 610054, P. R. China

Abstract—A new generalized chebyshev substrate integrated waveguide diplexer is presented for high performance. The diplexer is designed with triplet topology based on substrate integrated waveguide technique, which exhibit the generalized chebyshev responses. The triplet topology can facilitate the resonator arrangements of diplexer design for compact size. This diplexer possesses of the advantages of SIW and the generalized chebyshev filters. All couplings, including the negative coupling, are realized by H-plane open windows. A diplexer is designed by using 3th order asymmetric generalized chebyshev filter. Measured results are good agreement with simulation results.

1. INTRODUCTION

The rapid growing microwave and millimeter-wave communication communications provided the major promotion for the improvements in microwave filter [1–5] and diplexer design over the past two decades. Waveguide diplexers [6] are widely applied to all kinds of electronic and communication systems such as base stations of mobile communications. Their applications are used in these systems in order to discriminate between wanted and unwanted signal frequencies.

It has been found that the rectangular waveguide resonators have wide range for microwave and millimeter-wave applications at high costs. The substrated integrated waveguide (SIW) resonator is firstly proposed probably by Piolote, Flanik and Zaki, which developed the idea of replacing the waveguide walls with a series of metallic holes via through the substrate to achieve the same effect of metallic walls [7, 8]. The SIW has more advantages, such as, high Q, low insertion, reduced size, low costs, and easily to be integrated with planar circuits. So, SIW are widely applied to all kinds of different filters [9–11] and diplexer [12] design. The paper [12] presented the normal chebyshev diplexer design. The negative coupling coefficients are realized by two-layer SIW [11]. The generalized chebyshev filters have equiple passband complitude characteristics and arbitrarily placed transmission zeros [13, 14]. Sharp selectivity and compact size make them very popular in the design of filters and diplexers. The generalized chebyshev filters have all kinds of topologies to be realized. The triplet is one of attracting topologies, which can facilitate the resonator arrangements of diplexer design for compact size with flexible coupling paths, shown in Fig. 1. Rosenberg [15] proposed that the negative coupling could be accomplished by the utilization of transformation properties of higher order cavity modes (e.g., TE_{102}). Paper [6] presented the E-plane filter and diplexer applications based on over-moded cavities.

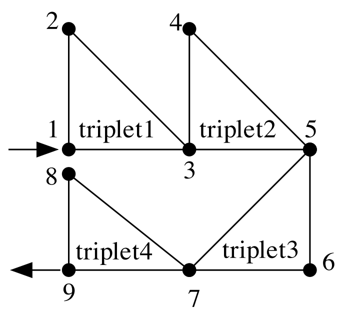

Figure 1. The generalized chebyshev filter with cascaded triplet topology.

In this paper, the generalized chebyshev diplexer is designed with triplet topology based on SIW technique. This diplexer possesses of the advantages of SIW, such as: reduced size, high Q, low insertion loss and easily integrated with planar circuits. What is more, it also possesses the advantages of the generalized chebyshev filters, such as: sharp selectivity, design flexibility and versatility. The negative cross-coupled coefficients are realized by the coupling between TE_{101} mode and higher mode TE_{102} mode. A comparison between simulation results and measured results shows excellent agreements.

2. FILTER AND DIPLEXER DESIGN

2.1. Synthesis of the Coupling Matrix

Atia and Williams [16] have firstly developed the coupling matrix synthesis methods of generalized chebyshev filters for symmetric filter responses. Cameron has proposed more advanced synthesis technique and new topology [17, 18]. Amari [19, 20] developed the gradients-based optimization methods to synthesis of the coupling matrix of generalized chebyshev. So, the coupling matrices of filters presented in this paper are extracted by the gradients-based methods. The first filter is 3th order. The center frequency is 12100 MHz and return loss is −20 dB. The bandwidth is 200 MHz. Finite transmission zero is positioned at 11770 MHz. The coupling matrix and frequency responses are given by following:

$$M = \begin{bmatrix} 0 & 1.0830 & 0 & 0 & 0 \\ 1.0830 & -0.0830 & 0.9910 & -0.3300 & 0 \\ 0 & 0.9910 & 0.3200 & 0.9910 & 0 \\ 0 & -0.3300 & 0.9910 & -0.0830 & 1.0830 \\ 0 & 0 & 0 & 1.0830 & 0 \end{bmatrix} \tag{1}$$

The second filter is also 3th order. The center frequency is 11550 MHz. The return loss is same as the first filter. The bandwidth is 200 MHz. Finite transmission zero is positioned at 11920 MHz. Coupling topology is same as that of above filter. The coupling matrix is shown in (2) and Fig. 3 gives the frequency response of filter.

$$M = \begin{bmatrix} 0 & 1.0830 & 0 & 0 & 0 \\ 1.0830 & 0.0730 & 0.9990 & 0.2920 & 0 \\ 0 & 0.9990 & -0.2840 & 0.99190 & 0 \\ 0 & 0.2920 & 0.9990 & 0.0730 & 1.0830 \\ 0 & 0 & 0 & 1.0830 & 0 \end{bmatrix} \tag{2}$$

2.2. Substrate Integrated Waveguide

As the initial dimensions of the simulation software, the size of the SIW cavity is determined by the corresponding resonance frequency from [21] for the TE_{101} dominant mode:

$$f_{101} = \frac{c}{2\pi\sqrt{\mu_r \varepsilon_r}} \sqrt{\left(\frac{\pi}{w_{eff}}\right)^2 + \left(\frac{\pi}{l_{eff}}\right)^2} \tag{3}$$

where w_{eff} and l_{eff} are the equivalent width and length of the SIW cavity, they are expressed by:

$$\begin{cases} w_{eff} = w - 1.08 \cdot \dfrac{d^2}{p} + 0.1 \cdot \dfrac{d^2}{w} \\ l_{eff} = l - 1.08 \cdot \dfrac{d^2}{p} + 0.1 \cdot \dfrac{d^2}{l} \end{cases} \tag{4}$$

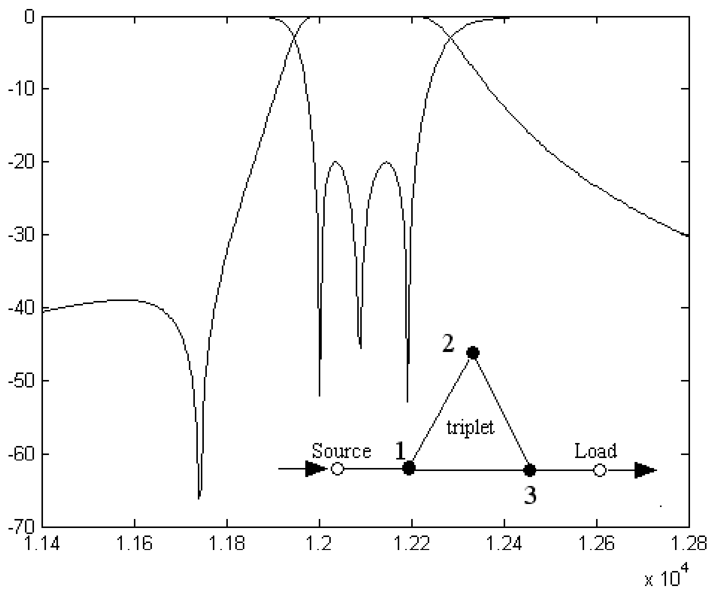

Figure 2. Frequency response of 3th order filter with transmission zeros below the passband.

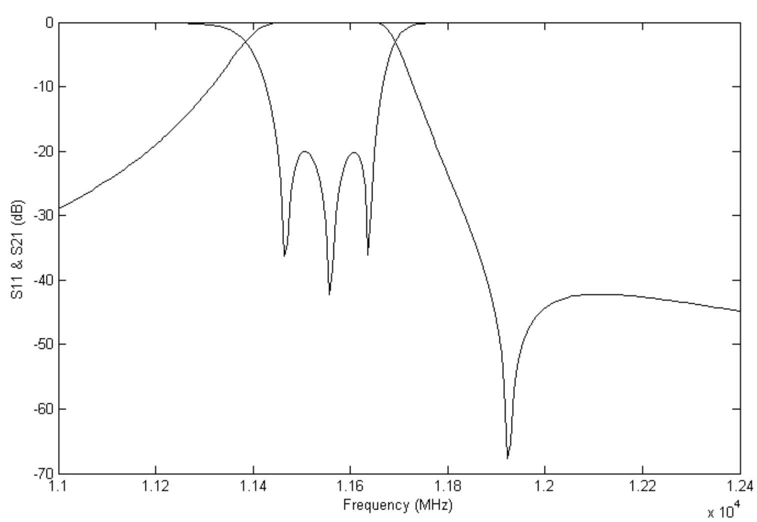

Figure 3. Frequency response of 3th order filter with transmission zeros above the passband.

where w and l are real width and length of the SIW cavity. d and p are the diameter of the metallic vias and the distance between adjacent vias. is the velocity of light in free space. μ_r and ε_r the relative permeability and relative permittivity of the substrate. For the TE_{102} mode, the length of cavity is double of that of TE_{101} mode. The equation (4) is also applied to determine the equivalent length and width of TE_{102} mode cavities.

2.3. Diplexer Realization

The SIW diplexer is design by combination with two above generalized chebyshev filters. The isolation between common and single ports in the respective band is less than $-38\,\mathrm{dB}$. The lengths of resonating cavity are determined by equations (3) and (4). The dimensions of coupling windows are obtained by equivalent circuit [24] methods or by simulations according to the normalized coupling matrix shown in matrix (1) and (2). Note that the resonating frequencies are not the same because of asymmetric frequency responses. The computation equations of coupling coefficients by simulation are given by [14]:

$$k = \pm\frac{1}{2}\left(\frac{f_{02}}{f_{01}} + \frac{f_{01}}{f_{02}}\right)\sqrt{\left(\frac{f_{p2}^2 - f_{p1}^2}{f_{p2}^2 + f_{p1}^2}\right)^2 - \left(\frac{f_{02}^2 - f_{01}^2}{f_{02}^2 + f_{01}^2}\right)^2} \tag{5}$$

where, f_{0i} means the resonating frequency of resonator without coupling windows and f_{pi} means the resonating frequency of resonator with coupling windows. $i = 1, 2$.

An optimization procedure is needed for direct integration of individual filters into common port to achieve good performance. In the process of simulation optimization, the radius of metallic hole is not changed. We can only change the distance of between the edges of two metallic holes. The design process of generalized chebyshev has two steps. Firstly, SIW diplexer firstly optimized by mode matching method developed by my research group when the diplexer is constructed with substrate waveguide and not with metallic holes. Then, after the length and width transformations of equations (4), the overall structure with metallic holes is optimized by HFSS (High frequency structure simulator) to eliminate the influence of metallic holes.

Fig. 4 depicts the configuration of the proposed generalized chebyshev SIW diplexer with its physical parameters after some optimizations. The diameter of metallic hole is 0.5mm without any change. The minima distance of between the edges of two metallic holes is 0.3 mm. All dimensions are the distances between the centers of metallic holes.

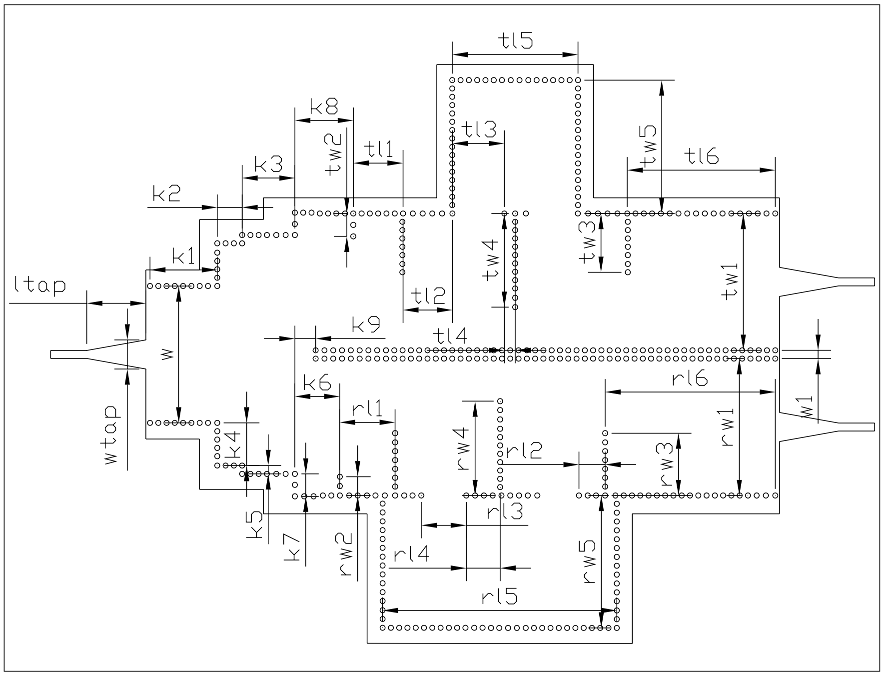

Figure 4. Configurations of the proposed generalized chebyshev SIW diplexer. The final dimensions of SIW diplexer are as following (Unit are all mm) after optimization:
Common: w = 13.14, w1 = 0.8, wttap = 2.8, ltap = 12.8, k1 = 6.5, k2 = 2.4, k3 = 5.1, k4 = 4.1, k5 = 0.8, k6 = 4.34, k7 = 2.15, k8 = 5.64, k9 = 2.
Filter1: tw1 = 13.14, tw2 = 2.2, tw3 = 5.65, tw4 = 9, tw5 = 12.8, tl1 = 4.8, tl2 = 4.77, tl3 = 5.02, tl4 = 1.04, tl5 = 12.14, tl6 = 14.3.
Filter2: rw1 = 13.14, rw2 = 1.8, rw3 = 5.98, rw4 = 9.05, rw5 = 12.72, rl1 = 5.34, rl2 = 2.53, rl3 = 4.34, rl4 = 3.27, rl5 = 22.62, rl6 = 16.44.

A generalized chebyshev diplexer is developed, and has been measured without any tuning. The structure was fabricated on Rogers RT/duriod 5880 substrate shown in Fig.5. The substrate has relative permittivity constants is 2.2 with 0.254 mm thickness and a loss of 0.0009. A SIW-microstrip tapered transition is designed with broadband response with return loss of less than −20 dB. The dimensions of SIW-microstrip are all shown in Fig. 4.

The comparison between simulation and measured results is given in Fig. 6. The measured results are good agreement with simulation results. The return losses of passband are all less than −14 dB. The

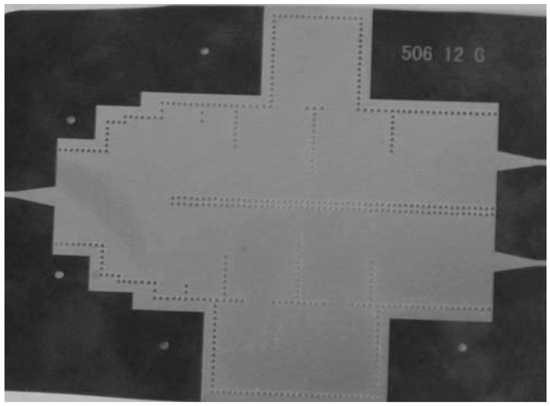

Figure 5. Photograph of the generalized chebyshev SIW diplexer.

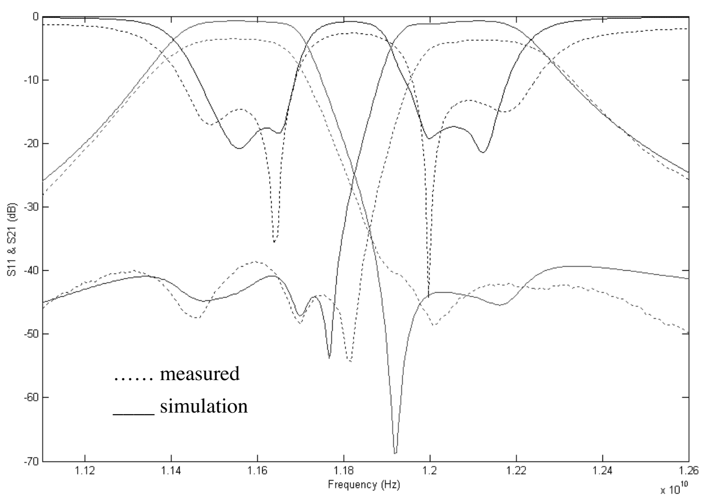

Figure 6. Simulation and measured results of the generalized chebyshev SIW diplexer.

isolation between common and single ports in the respective band is less than −38 dB. The insertion losses of two passband are all around −3.3 dB. The loss of SMA and SIW-microstrip transitions are also included.

3. CONCLUSION

A generalized Chebyshev SIW diplexer is presented with triplet topology in this paper. Higher mode is employed to realize the negative coupling coefficients. The triplet topology can facilitate the resonator arrangements of diplexer design for compact size. This diplexer possesses of the advantages of SIW and the generalized chebyshev filters. A generalized chebyshev SIW diplexer is fabricated and measured to show the high performance of this diplexer.

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