Realization of Substrate Integrated Waveguide Filters Based on a Novel Coupling Topology

Ying CHENG [1], Xiao-jun LU [2], Yuan-yuan ZHOU [1] and Cheng-hua FANG [1]

[1]*School of Electronic Information Engineering*, Hefei Normal University, Hefei, Anhui 230601,.China
[2]*Information Centre*, Hefei Municipal Public Security Bureau, Hefei, Anhui 230041, China

***Abstract* — A novel coupling topology is proposed in order to achieve sharp transition from passband to rejection band and improve its frequency selectivity for a second-order substrate integrated waveguide (SIW) filter. Based on the characteristics of the proposed coupling scheme, a finite transmission could arbitrarily be located below or above the passband. For validating the efficacy of the topology, a commercial electromagnetic simulation tool is adopted to obtain the optimized dimensions of the SIW filters. Then they are fabricated with the standard printed circuit board (PCB) technology, demonstrating a finite transmission zero either at the left side or right side of the passband. Measurement results are in good agreement with the simulations.**

Keywords-fitler; frequency selectivity, substrate integrated waveguide (SIW), transmission zeros

Ⅰ. INTRODUCTION

Band-pass filter is one of the most important passive components in all sorts of modern wireless communication system. And high performance and low insertion loss bandpass filter is central to the research of scholars at home and abroad. Nearly ten years, the substrate integrated waveguide (SIW) has received extensive attention of academia and industry because of its unique properties. SIW technology is put forward based on waveguide structure integration thought. Through the SIW double-sided copper clad low-loss dielectric substrate fluctuation between the metal surface is introduced into periodic metallized hole array, and this metal surface is equal to the media fill the wide side of the rectangular waveguide. A large number of experiments show that compared with the traditional rectangular metal waveguide, the spread of substrate integrated waveguide also has good properties, and the structure is easy to integrate.

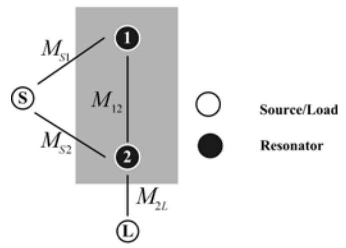
The substrate integrated waveguide filters based on different topology structure have been proposed [1]-[6], for example, in the literature [1] and [2] introduces respectively quasi elliptic cross coupling and cross coupling with mixed coupling substrate integrated waveguide filters. In literature [3] and [4], The TE102 and TE201 mode in a single cavity also be incentived to construct the dual mode substrate integrated waveguide filter. In addition, the literature [5] designed a horizontal substrate integrated waveguide filter, while the literature [6] implemented a substrate integrated waveguide filter loaded the complementary split ring resonator.

This paper designed two new coupling topology structure of the substrate integrated waveguide bandpass filter. By changing the nature of the coupling between two resonant cavities, a limited transmission zero point can be located flexibly at upper sideband or lower sideband of the pass band. Sample test results and the simulation results obtained from the commercial electromagnetic simulation software HFSS are highly consistent, so as to verify the correctness and effectiveness of the proposed theory.

Ⅱ. SUBSTRATE INTEGRATED WAVEGUIDE FILTER BASED ON THE NEW COUPLING TOPOLOGY STRUCTURE

A. The Topological Structure

On the basis of reference [7], this paper puts forward a new type of second order coupling topology, as shown in figure 1. Input end is coupled resonator 1 and 2 at the same time, the output end is only coupled with the resonator 2, while the coupling between resonator 1 and 2 can be the magnetic coupling (M_{12} >0) or electric coupling (M_{12} <0).



Fingure 1. Coupling Scheme of The Second-order SIW Filter.

According to the coupling topology in figure 1 can get the corresponding coupling matrix M , coupling matrix M can write:

$$[M]=\begin{bmatrix} 0 & M_{S1} & M_{S2} & 0 \\ M_{S1} & M_{11} & M_{12} & 0 \\ M_{S2} & M_{12} & M_{22} & M_{2L} \\ 0 & 0 & M_{2L} & 0 \end{bmatrix} \quad (1)$$

Node admittance matrix formula given in reference [8] :

$$\{-j[G]+\omega[W]+[M]\}[V] \\ =[A][V]=-j[I] \quad (2)$$

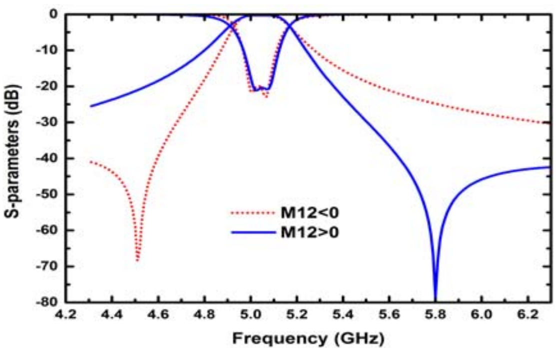
Among them, $[G]$ is a $(N+2)\times(N+2)$ diagonal matrix and element $G_{11}=G_{N+2,N+2}=1$, the remaining elements are zero. $[G]$ is the the coupling matrix; $[W]$ is a $(N+2)\times(N+2)$ diagonal matrix. And when the node k is in resonance, matrix elements $W_{kk}=1$, when in non-resonant, $W_{kk}=0$. The scattering parameters S of filter can be expressed as

$$S_{11}=1+2j\left[A^{-1}\right]_{1,1} \tag{3a}$$

$$S_{21}=-2j\left[A^{-1}\right]_{N+2,1} \tag{3b}$$

Make the transmission parameters $S_{21}=0$, the position of the filter finite transmission zeros is obtained by the following formula. The location of the normalized transmission zeros can be derived from formula (4). It is not difficult to find from the formula that the sign of normalized transmission zero position is depending on coupling properties between resonator 1 and 2. When the coupling coefficient M_{12} between resonator 1 and 2 is a positive number, transmission zeros in the pass band located on the right side. On the contrary, if the M_{12} is a negative number, transmission zeros will be located in the left side of the passband. At the same time, its location can be controlled by M_{S1}/M_{S2}.

$$\Omega=M_{S1}\cdot M_{12}/M_{S2} \tag{4}$$



Fingure 2. Synthesized S-parameters Corresponding to M1 and M2.

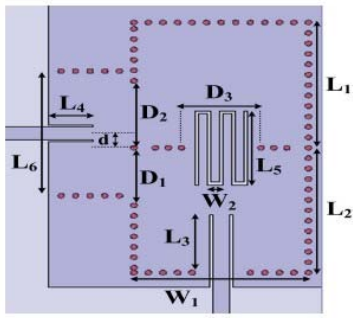
The filter center frequency and bandwidth are off for 5GHz and 150MHz. Based on the general coupled matrix method in literature [8], we comprehensively get the following two coupling coefficient matrix M_1 and M_2, as well as the corresponding integrated scattering parameters, as shown in figure 2. By shown in figure 2, when the value of coupling coefficient M_{12} is less than zero and greater than zero, which respectively have a transmission zeros in low resistance and high resistance.

$$M_1=\begin{bmatrix}0 & 0.65 & 0.1 & 0\\ 0.65 & -0.16 & -0.55 & 0\\ 0.1 & -0.55 & -0.3 & 0.77\\ 0 & 0 & 0.77 & 0\end{bmatrix} \tag{5}$$

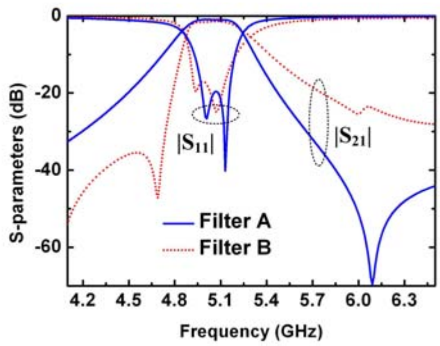
$$M_2=\begin{bmatrix}0 & 0.77 & 0.1 & 0\\ 0.77 & -0.35 & 0.6 & 0\\ 0.1 & 0.6 & -0.3 & 0.75\\ 0 & 0 & 0.75 & 0\end{bmatrix} \tag{6}$$

B. Substrate Integrated Waveguide Filter Design

Figure 3 shows the structure diagram of second-order substrate integrated waveguide filter. When two SIW resonator placed parallelly and a inductive window opened on the walls of public, at this time the coupling between SIW should be magnetic coupling, because the coupling occurred at the place where Magnetic field intensity is biggest. Literature [2] study the coupling principle between SIW and Co-planar Waveguide(CPW). CPW transmission electric field are mainly distributed between the band offline and slot. Therefore, the geometric structure of electric coupling between SIW cavities can be realized by etching out inter-digital slot-line (ISL) on the top of metal, as shown in figure 3. For convenience, the two second-order filters which had the positive and negative coupling coefficient M12 are named after filter A and B in this paper. Figure 4 shows the S parameters of filter A and B which are obtained by simulation software HFSS.



Fingure 3. Top View of The Second-order SIW Filter.



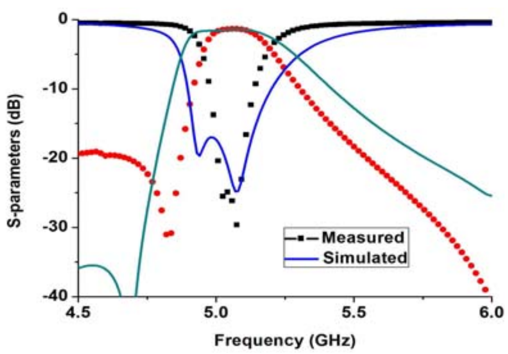
Fingure 4. Simulated S-parameters of the second-order SIW filters A and B.

All the geometric parameteris of filters in figure 3 are summarized in table Ⅰ. It's evident that the transmission zeros of filter A located at 6.1GHz. When the coupling coefficient M_{12} changes from positive to negative, zero position changes from upper sideband to lower sideband. It is important to note that the second-order filter mechanism of flexible zero position change is different from mechanism of around zero change in the dual-mode resonator filter.

TABLE Ⅰ. GEOMETRICAL SIZES (UNIT:MM)

Symbol	Filter A	Filter B	Symbol	Filter A	Filter B
L_1	25.2	26.0	W_1	25.46	27.0
L_2	24.0	26.0	W_2	0	1.3
L_3	8.0	12.0	D_1	9.6	12.0
L_4	0	7.0	D_2	14.0	14.0
L_5	0	15.5	D_3	10.0	12.3
L_6	26.0	26.0	d	4.0	1.0

III. EXPERIMENTAL VERIFICATION



Fingure 5. Simulated and Measured S-parameters of the Second-order SIW Filter.

In order to verify the proposed design, we implements a filter based on the single-layer PCB that the transmission zero point is located in the lower sideband. Substrate material is polytetrafluoroethylene(PTFE), its dielectric constant is 2.65, the thickness is 1 mm, dielectric loss angle tangent is 0.0033, the surface copper thickness is 0.035 mm, its hole diameter is 1 mm, port 50ohm microstrip line width is 2.7 mm. In figure 5 there is narrowband test results of the second-order SIW filter which test center frequency and bandwidth were 5.1GHz and 150MHz. The testing bandwidth in figure is slightly smaller than the simulation bandwidth which is mainly due to the error caused by machining in the process. As shown in figure, a transmission zeros is at 4.8 GHz. In-band test minimum insertion loss is 1.1dB, echo reflection is 17dB.

Ⅳ. CONCLUSION

A class of second order coupling novel topology is proposed in this paper which can locate zero position in the upper or lower stopband by changing coupling properties between two resonators. The novel structure is applied to substrate integrated waveguide bandpass filter design. The electrical coupling is achieved by etching groove lines on the surface. Finally, a SIW filter sample implements based on the PCB. Test and simulation results are in good agreement which verifies the correctness and effectiveness of the proposed theory.

REFERENCES

[1] Chen X P, *et al.* Substrate integrated waveguide cross-coupled filter with negative coupling structure [J]. *IEEE Trans. Microw. Theroy Tech*., 2008, 56(1): 142-149 (in English)

[2] Shen W, *et al.* Novel substrate integrated waveguide filters with mixed cross coupling(MCC) [J]. *IEEE Microw. Wireless Compon. Lett*., 2009, 19(11): 701-703 (in English)

[3] Chang C Y, *et al*. Novel planar, square-shaped, dielectric-waveguide, single-, and dual-mode filters [J]. *IEEE Trans. Microw. Theroy Tech*., 2002, 50(11): 2527-2536 (in English)

[4] Lee J H, *et al*. Design and development of advanced cavity-based dual-mode filters using low-temperature co-fired ceramic technology for V-band gigabit wireless system [J]. *IEEE Trans. Microw. Theroy Tech*., 2007, 55(9): 1869-1879 (in English)

[5] Li R Q, *et al*. Design of substrate integrated waveguide transversal filter with high selectivity [J]. *IEEE Microw. Wireless Compon. Lett*., 2010, 20(6): 328-330 (in English)

[6] Wu L S, *et al*. An extended doublet substrate integrated waveguide (SIW) bandpass filter with a complementary split ring resonator (CSRR) [J]. *IEEE Microw. Wireless Compon. Lett*., 2009, 12(12): 777-779 (in English)

[7] Rosenberg U, *et al*. Novel coupling schemes for microwave resonator filters [J]. *IEEE Trans. Microw. Theroy Tech*., 2002, 50(12): 2896-2902 (in English)

[8] Amari S, *et al*. Adaptive synthesis and design of resonator filters with source/load-multi-resonator coupling [J]. *IEEE Trans. Microw. Theroy Tech*., 2002, 50(8): 1969-1978 (in English)