WLAN Substrate Integrated Waveguide Filter with Novel Negative Coupling Structure

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Abstract

A fourth-degree Substrate Integrated Waveguide (SIW) crossed coupled band pass filter for WLAN band is designed by using a new negative coupling structure. It consists of two U shape microstrip lines on top and bottom planes with via holes at the center of them. This paper investigates the phase characteristics of negative and positive coupling structures and their effects. The design, fabrication and testing processes of the proposed filter are presented. The measured results seem to be consistent with the results obtained from simulator packages.

***Keywords*—**Band pass filter, negative coupling, substrate integrated waveguide (SIW), WLAN band.

I. INTRODUCTION

Band pass filters are most important components for mobile and communication systems where high selectivity performances are needed. Filters implemented with symmetric and asymmetric transmission zeros with both positive and negative coupling can be used to improve the selectivity [1]. The implementation of transmission zeros can be obtained by using the extracted pole technique [2] or using cross coupling technique between nonadjacent resonators [3]. Substrate integrated waveguide technology (SIW) facilitates its integration with other microwave and millimeter-wave components [4] and provides a base for implementing filters with different structures and specifications. A brief literature survey shows great effort in the field of SIW filter design. An SIW quasi-elliptic filter has been designed using extracted pole technique in [5]. A Planar negative coupling scheme has been utilized to design SIW band pass filters in [6]. A V-band cross-coupled SIW band-pass filter with an asymmetric U-slot negative coupling structure was reported in [7]. In this letter, design of a fourth-degree cross coupled quasi elliptic band pass filter in WLAN band with center frequency of 5.55GHz and 600 MHz ripple bandwidth were presented. Two symmetric transmission zeros at 4.95 and 6.15 GHz were allocated by introducing new negative coupling structure on SIW technology. Furthermore, phase characteristics of negative and positive coupling structures were compared.

The main differences between proposed filter and previous filters are in their frequency band and the scheme of extracting the coupling matrix. In the latter case, we have synthesized the coupling matrix based on Cameron's method reported in [8] for [N+1] * [N+1] order of matrix. Therefore, all the couplings between load and sources and resonators can be considered directly. Also, the filter can have N transmission zeros, in which N is the order of filter. A prototype of this filter has been implemented on RO4003 substrate and tested. The measured results show the accuracy and effectiveness of the design procedure.

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II. FILTER DESIGN

A. *Configuration and synthesis of BPF*

The configuration and coupling structure of the proposed quasi elliptic cross coupled band-pass filter is shown in Fig.1.The filter constructed by four SIW cavities in 5.55 GHz center frequency. Based on the coupling matrix extraction [8], the coupling between resonators 1 and 4 is negative while the other

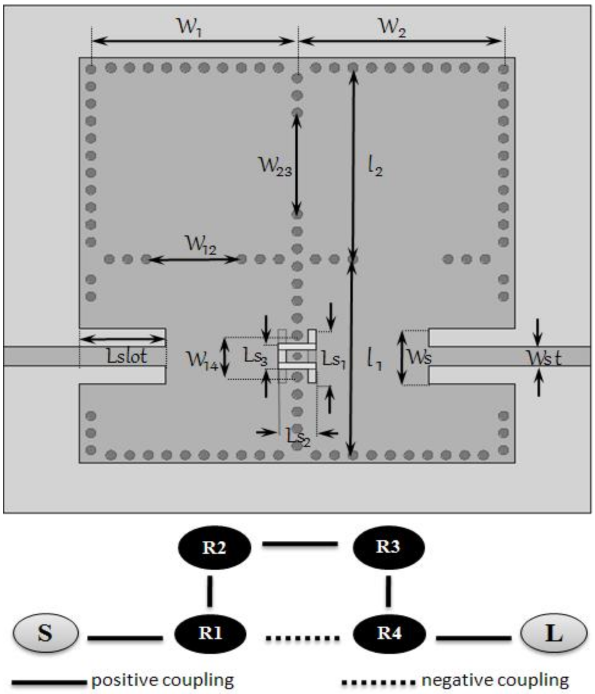

Fig. 1. Structure and coupling scheme of SIW cross coupled BPF.

resonators have positive couplings. The phase responses of the negative couplings are in the opposite to that of positive couplings [1]. Thus, the positive coupling and the negative coupling need to be out of phase. Positive coupling can be obtained by inducive iris or inducive window while the negative couplings can be produced by using U-shape slot. To invert the sign of the phase of coupling between 1 and 4 SIW cavity resonators, U shape microstrip line at the bottom and top of the plane. A metalized via at the center of them is used to realize two transmission zeros at 4.95 and 6.15 GHz. For a 20 dB return loss the general coupling coefficients, can be obtained as [8]:

$$M = \begin{array}{c|cccccc} & S & 1 & 2 & 3 & 4 & L \\ \hline S & 0 & 1.0476 & 0 & 0 & 0 & 0 \\ 1 & 1.0476 & 0 & 0.8705 & 0 & -0.1704 & 0 \\ 2 & 0 & 0.8705 & 0 & 0.7671 & 0 & 0 \\ 3 & 0 & 0 & 0.7671 & 0 & 0.8705 & 0 \\ 4 & 0 & -0.1704 & 0 & 0.8705 & 0 & 1.0476 \\ L & 0 & 0 & 0 & 0 & 1.0476 & 0 \end{array} \quad (1)$$

To obtain the design parameters, the generalized coupling matrix is de-normalized as following:

$$M_{ij} = \frac{f_0}{BW} k_{ij} \quad (2)$$

$$Q_e = \frac{1}{FBW.M_{S1}^2} \quad (3)$$

where BW is the absolute bandwidth, f_0 is the center frequency, and $Q_e$is the external quality factor of such a filter meeting these requirements. De-normalized coupling coefficients for this filter with $f_0 = 5.55$ GHz and $BW = 600$MHz are calculated as: $k_{12} = 0.094$, $k_{23} = 0.083$, $k_{14} = -0.018$, $Q_e = 8.43$.

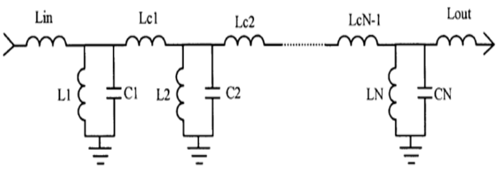

Fig. 2. Equivalent circuit of filter.

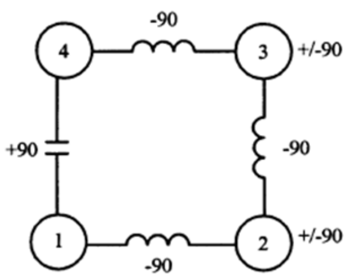

Fig. 3. Two paths for travelling signal from source to load.

TABLE I

PHASE DIFFERENCES FOR QUASI ELLIPTICFILTER

Path	Below Resonance	Above Resonance
Path 1-2-3-4	-90°+90°-90°+90°-90°= -90°	-90°-90°-90°-90°-90°= -450°= -90°
Path 1-4	+90°	+90°
Result	Out of phase	Out of phase

B. Equivalent circuit of filter with transmission zeros

The equivalent circuit of the filter is shown in Fig. 2.In which L_i,C_i represent the resonance scheme for each cavity while Lc_i is related to magnetic coupling (inductive window) between two adjacent resonators. Considering the capacitive coupling (negative coupling) between resonator 1, 4; it is obvious from Fig.3 that there are two paths for travelling signal from source (1) to load (4).

If we consider ±90° phase differences for each resonator in the S_{21} phase response, it can easily be found that the total phase difference between path 1-2-3-4 and path 1-4 make an out of phase frequency response for the filter which is useful for transmission zeros (Table 1).

C. SIW cavity resonator

The initial size of the TE_{10}dominate mode of SIW cavity resonator is determined as [9]:

$$f_0 = \frac{c_0}{2\sqrt{\varepsilon_r}} \sqrt{\frac{1}{a_{eff}^2} + \frac{1}{l_{eff}^2}} \quad (4)$$

$$a_{eff} = a - \frac{d^2}{0.95p} l_{eff} = l - \frac{d^2}{0.95p} \quad (5)$$

where a and l are the width and length of SIW cavity. Also $d$and$p$ are the diameter of metalized via holes and center tocenter space between two adjacent via holes. $C_0$is the velocity of light in vacuum, and ε_r is the dielectric permittivity of the substrate.

D. Internal coupling

By using a full wave electromagnetic simulator, Ansoft HFSS and simulating two SIW cavity resonators with input and output ports, the internal coupling coefficients are determined.

Fig. 4 shows magnitude and phase response of positive coupling and negative coupling structures, respectively. The ports are very weakly coupled to the SIW resonators to ensure their less effect on coupling measurement accuracy [1]. In both cases, the two resonance peaks are clearly identified from the magnitude responses. As can be seen from magnitude response, the stronger the coupling, the wider the separation of the two resonance peaks and the deeper the valley in the middle. By comparing the phase responses in Fig. 4, we can observe that both positive and negative couplings are out of phase. This is the evidence that the two extracted coupling coefficients have opposite signs. Another simple way to find

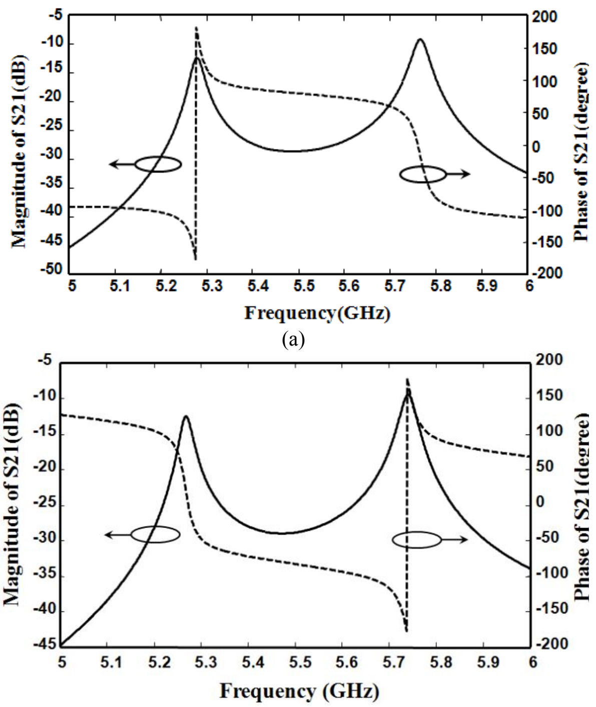

Fig. 4. Phase and magnitude response of internal coupled SIW resonators. (a) positive coupling (b) negative coupling.

whether the two coupling structures have the same signs is to apply either electric (short) or magnetic (open) wall to find the f_e or f_m of both the coupling structures where f_e and f_m are the frequency resonance peaks. In the magnetic coupling, $f_m < f_e$ and in the electric coupling, $f_m > f_e$ at the magnitude

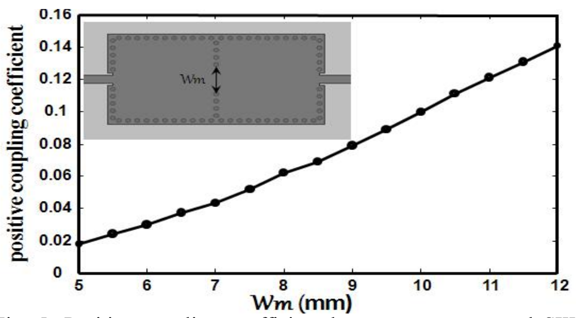

Fig. 5. Positive coupling coefficient between two proposed SIW resonators (d=0.45mm, p=1.7mm).

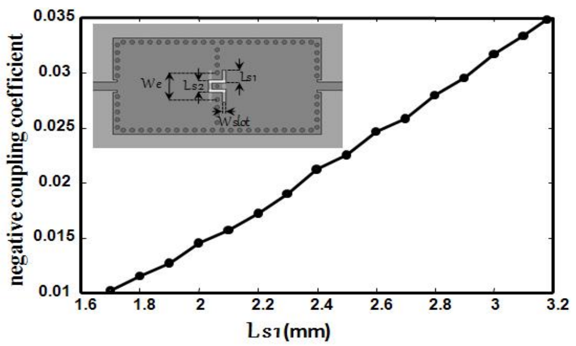

Fig. 6. Negative coupling coefficient between two proposed SIW resonators (d=0.45mm, p=1.7mm, W_e=3.2mm, W_{slot}=0.5mm, L_{s2}=2.4mm).

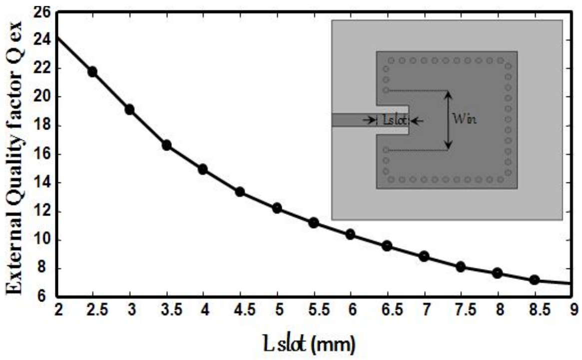

Fig. 7. External Q-factor of the proposed SIW resonators (d=0.45mm, p=1.7mm, Win=11mm).

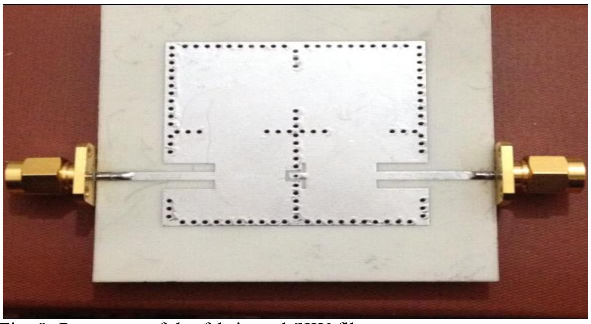

Fig. 8. Prototype of the fabricated SIW filter.

of S_{21} response [1]. The opposite frequency shifts indicate again that the two resultant coupling coefficients, should have different signs. With two resonance frequencies and using the following formula, the coupling coefficient extracted [1]:

$$k = \frac{f_1^2 - f_2^2}{f_1^2 + f_2^2} \quad (6)$$

where f_1 and f_2 stand for the high and low resonance frequency respectively.

Fig. 5 shows the design curve for positive coupling coefficient. As it can be seen, by increasing the width of post wall, the coupling is increased and the resonant peaks go far apart. Fig. 6 proposes negative coupling structure and curve. The negative coupling is controlled by changing the slot length (L_{s1}) between two SIW cavity resonators. By increasing the length of slot, the negative coupling is increased.

E. External coupling

To determine external coupling coefficient considered in group delay method [1], a SIW cavity resonator with Input signal line is simulated using HFSS. Fig. 7 shows calculated external coupling coefficient by using simulated external coupling structure. The external coupling is controlled by signal line coupling slot (l_{slot}), and external quality factor is then ready to be extracted using following formula [1]:

$$Q_e = \frac{f_0}{f_{\mp 90}} \quad (7)$$

where the resonance frequency f_0 can be determined from the peak of the group delay response, and $f_{\mp 90}$ are the frequencies at which the phase shifts ±90°.

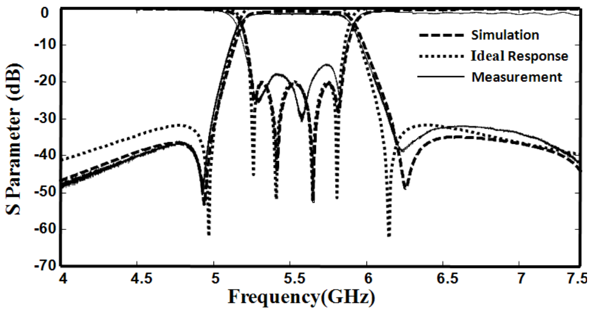

Fig. 9. Measured, simulatedand ideal responses of proposed SIW quasi-elliptic BPF.

TABLE II
DIMENSIONS OF SIW QUASI ELLIPTIC FILTER

Parameter	Value (mm)	Parameter	Value (mm)
W_1	18.85	W_{12}	9.35
W_2	18.85	W_{23}	9.12
l_1	19.1	W_{14}	3.2
l_2	18.85	L_{s1}	5.5
L_{slot}	7.8	L_{s2}	3
W_{st}	1.8	L_{s3}	2.4
W_s	5.5		

III. RESULTS AND DISCUSSIONS

Table II shows the dimensions of the SIW cross coupled BPF. The filter is fabricated on RO4003 substrate with a thickness of 1.8 mm. The diameters of the metallic via-holes in the SIW structures are 0.9 mm, and the spacings between them are 1.7 mm. The implemented SIW filter is shown in Fig. 8. Fig. 9 demonstrates the photograph of BPF at the top and the ideal response, simulation response and measured results of the filter at the bottom. The measured insertion loss is approximately 1.2 dB and return loss better than 15dB.

IV. CONCLUSION

A cross-coupled BPF using simple new negative coupling structure on the SIW technology has been presented in this paper. Two symmetric transmission zeroes implemented with cross coupling between non adjacent resonators. The filter has been designed, fabricated and measured. Simulation tools confirm the proposed filter design and obtained experimental results.

REFERENCES

[1] J.S. Hong and M. J. Lancaster, *Microstrip Filter for RF/MicrowaveApplications*. New York: Wiley, 2001, pp. 257–258.

[2] R. J. Cameron, "Advanced coupling matrix synthesis techniques for microwave filters," *IEEE Trans. Microwave Theory Tech*., vol. 51, no. 1, pp. 1-10, Jan. 2003.

[3] R. Levy, "Filters with single transmission zeros at real and imaginaryfrequencies," *IEEE Trans. Microwave Theory Tech*., vol. 24, pp. 172-181, 1976.

[4] D. Deslandes and K. Wu, "Accurate modeling, wave mechanisms, anddesign considerations of a substrate integrated waveguide," *IEEE Trans.Microwave Theory Tech*., vol. 28, pp. 1018-1028, 1980.

[5] X. P. Chen, W. Hong, and K. Wu, "Substrate integrated waveguidequasi-elliptic filter using extracted-pole technique," *Asia-PacificConference Proceedings*, suzhou, China, Dec. 2005.

[6] X. P. Chen, and K. Wu, "Substrate integrated waveguide cross-coupled filter with negative coupling structure," *IEEE Trans. Microwave TheoryTech*., vol. 56, pp. 142-149, 2008.

[7] Z. Guo, K. Chin, W. Che, and C. Chang, "V-band cross-coupled SIW band-pass filter with an antisymmetric U-slot negative coupling structure" *Journal of Electromagnetic Waves and Application*s, vol. 27, 953-961, 2013.

[8] R. J. Cameron, "General coupling matrix synthesis methods for chebyshev filtering functions," *IEEE Trans. Microwave Theory Tech.,* vol. 47, no. 4, pp. 433–442, Apr. 1999.

[9] Y. Cassivi, L. Perregrini, P. Arcioni, M. Bressan, K. Wu, and G. Conciauro,"Dispersion characteristics of substrate integrated rectangular waveguide," *IEEE Microw. Wireless Compon. Lett.*, vol. 12, no. 2, pp. 333–335, Feb. 2002.