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Mathematical Quad Cross-Stub Stepped Impedance Resonator Application

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Abstract
This simulation study involved the use of a QC-SSIR (quad cross-tub stepped impedance resonator) to examine the behavior and performance of the MW-BPF (multi-wideband band pass filter). To evaluate the performance of the proposed model, it was compared to the case of the conventional resonator. In the results, MW-BPF was found o exhibit a superior performance in terms of the ease of fabrication, good transmission coefficients, and a wider fractional bandwidth. For the filter structure analysis, this study incorporated the ABCD matrix, with the design of the MW-BPF also based on the FR4 microstrip. The experimental conditions and parameters were set in such a way that for the substrate, tan □= 0.0265, thickness = 1.6 mm, and □r = 4.4, and thickness h = 1.6 mm. at 2.58GHz, 1.71 GHz, and 0.81 GHz, the proposed QC-SSIR-based MW-BPF achieved transmission coefficients/fractional bandwidths of 1.93dB/13.9%, 1.49dB/18.7%, and 0.60dB/49.3%, respectively. Relative to the filter size reduction, the FQC-SSIR (folded quad cross-tub impedance resonator) was incorporated. The resultant observations indicated a possibility of BPF size reduction up to 46%. Also, the proposed framework was found to yield (at 2.62, 1.80, and 0.82 GHz) 1.76dB/12.5%, 1.21dB/17.7%, and 0.57dB/49.6% transmission coefficient/fractional bandwidths, respectively. It is also worth indicating that the filter employed LTE2600, WCDMA1800, and GSM800.

Keywords: Cross-Stub, knowledge, mining, sentiment, tweet.

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1 Introduction

In the design of multiband microwave filter, a significant role is played by microstrip filters, which are beneficial relative to low cost, reduced loss, miniaturization, and fabrication simplicity [1-6]. Some of the approaches that have gained increasing use in the design of multiband bypass filters include crossed open stubs, DGS resonator and stub-loaded resonator, stub-loaded quarter wavelength resonator, tri mode stub-loaded resonators, stub-loaded resonators, loaded crossed resonators, cascaded multiband resonators, tri-section SIRs, and quarter-wavelength SIRs [7-10]. Indeed, in the design of the multi-band BPF, an emerging issue involves allowing various pass bands simultaneously while ensuring that the design freedom is not compromised. Another problem comes in terms of complex geometry and size increase. From recent scholarly studies, focus has been on the multi-band pass filter, with most of the findings demonstrating that the model exhibits a superior electrical performance [2, 4]. Despite this promising outcome, however, there tends to be a BPF size increase while the bandwidth becomes narrower. For studies that have focused on miniaturized microstrip bandpass filters, specific forms on the focus have included the microstrip Y-shape bandpass filter, microstrip E-shape bandpass filter, and the rectangular dual spiral resonator (DSR) [22-24]. In the current investigation, focus is on the QC-SSIR microstrip model proposal, aimed at supporting the MW-BPF design.

2 Methodology

As mentioned earlier, the COS method, previously proposed in some studies [3, 4, 6], was used in conjunction with the multi-band bandpass filter. Figure 1 demonstrates this approach. Equation 1 highlights the COS's ABCD matrix, demonstrating aspects of electrical length and the transmission line impedance [6, 16].

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos\theta_1 & jZ_1\sin\theta_1 \\ \frac{j\sin\theta_1}{Z_1} & \cos\theta_1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ \frac{j\sin\theta_2}{Z_2} & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ \frac{j\sin\theta_3}{Z_3} & 1 \end{bmatrix} \begin{bmatrix} \cos\theta_1 & jZ_1\sin\theta_1 \\ \frac{j\sin\theta_1}{Z_1} & \cos\theta_1 \end{bmatrix} \quad (1)$$

with θ_0 is set to λ/4 line or 90°, and Z_1, Z_2, and Z_3 can be found as follows [16]:

$$Z_1 = \frac{Z}{\tan\theta_1} \quad (2)$$

$$\frac{\tan\theta_2}{Z_2} + \frac{\tan\theta_3}{Z_3} = \frac{(1-\tan^2\theta_1)}{Z} \quad (3)$$

and the transmission zero created by [16]:

$$\frac{f_{\theta_2}}{f_0} = \frac{\pi}{2\theta_2} \quad (4)$$

Of importance to note is that the COS approach, a conventional technique, gains much application to scenarios involving narrow bandwidths. Therefore, this study sought to achieve bandwidth expansion in which the QC-SSIR model was proposed for purposes of BPF generation. The QC-SSIR structure in relation to its electrical length and impedance of transmission is shown in Figure 2. To achieve the QC-SSIR's ABCD matrix, we have:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = M_1 M_2 M_{34} M_5 M_2 M_{34} M_5 M_{34} M_2 M_5 M_{34} M_2 M_1 \quad (5)$$

with

$$M_1 = \begin{bmatrix} \cos\theta_1 & jZ_1\sin\theta_1 \\ \frac{j\sin\theta_1}{Z_1} & \cos\theta_1 \end{bmatrix} \quad (6)$$

$$M_2 = \begin{bmatrix} 1 & 0 \\ \frac{j\tan\theta_2}{Z_2} & 1 \end{bmatrix} \quad (7)$$

$$M_5 = \begin{bmatrix} \cos\theta_5 & jZ_5\sin\theta_5 \\ \frac{j\sin\theta_5}{Z_5} & \cos\theta_5 \end{bmatrix} \quad (8)$$

For the case of M_{34}, the step impedance resonator (SIR) structure determines its ABCD matrix. The resultant ABCD matrix comes in the form:

$$M_{34} = \begin{bmatrix} 1 & 0 \\ Y_{SIR\,(34)} & 1 \end{bmatrix} \quad (9)$$

Where:

$$Y_{SIR\,(34)} = jY_3 \frac{Z_3\tan\theta_4 + Z_4\tan\theta_3}{Z_4 - Z_3\tan\theta_3\tan\theta_4} \quad (10)$$

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When the same method is employed as that which has been proposed in some of the previous studies [16, 17], the λ/4 line is used to replace the QC-SSIR. For the λ/4 line, its ABCD matrix becomes:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos\theta_0 & jZ_1 \sin\theta_0 \\ \frac{j\sin\theta_0}{Z_0} & \cos\theta_0 \end{bmatrix} = \begin{bmatrix} 0 & jZ_0 \\ jY_0 & 0 \end{bmatrix} \quad (11)$$

When equations (11) and (5) are solved, we can obtain the electrical length and transmission line impedance values. In turn the S_{12} and S_{11} scattering parameters can be established through equations (13) and (12) [16, 17] in the form:

$$S_{11} = \frac{A + \frac{B}{Z_0} - CZ_0 - D}{A + \frac{B}{Z_0} + CZ_0 + D} \quad (12)$$

$$S_{21} = \frac{2}{A + \frac{B}{Z_0} + CZ_0 + D} \quad (13)$$

On the microstrip, the fabrication of the MW-BPF was achieved via: tan δ= 0.0265 and εr = 4.4, h=1.6 mm. Also, the QC-SSIR resonator was used to develop the filter – having considered a single layer substrate. With the QC-SSIR-based MW-BPF having its size set at 97 mm x 240 mm, specific experimental conditions were summarized as follows:

w_0 = 3.5 mm, l_0 = 25 mm, w_1 = 1.5 mm, l_1 = 1 mm, w_2 = 1.5 mm, l_2 = 1.5 mm, w_3 = 2.5 mm, l_3 = 77 mm, w_4 = 7.5 mm, l_4 = 20 mm, w_5 = 2.5 mm, l_5 = 9 mm

Regarding filter size reduction, the proposed approach entailed the folded QC-SSIR. To achieve the miniaturization process, l_3's length transmission line was rotated or folded to an extent that a length of 77 mm was achieved. For the first and fourth COS, two parts were obtained for l_3, which constitutes 36 mm and 41 mm. for the case of the second and third COS, there was the division of l_3 to obtain four parts in the form of 5, 11, 36, and 25 mm (see Figure 4). For the folded QC-SSIR-based MW-BPF, the total size stood at 97 mm x 130 mm. at this stage, 46% was the reduction in the total size of MW-BPF.

3 Results and Discussion

Results for the transmission coefficients' extraction are demonstrated, as well as the reflection coefficients' extraction, having varied the aspect of l_2. Particularly, the latter variation was in the range of 0.5 mm to 4.5 mm. from the results, it is evident that for f_1, f_2, and f_3, constant transmission coefficients are still achieved. Furthermore, the results suggest that for changes in l_2, only f_2 and f_3 are affected. Even at l_2 = 4.5 mm, it is also observed that for f_3, the reflection coefficients still rated below -10 dB. Findings reflect the transmission coefficient extraction, as well as the reflection coefficient extraction, having varied l_5. The variation in l_5 is in the range of 3 mm and 12 mm. results suggest that the values of the reflection coefficients affect the l_5 variation. However, the latter scenario is seen to pose a minimal impact on the shift in frequency. From Figure 6 (a), MW-BPF exhibits good isolation and also comes with three transmission zeros. The transmission zeros frequencies occur in 3.07, 2.16, and 1.2 GHz. The measured and simulated results for QC-SSIR-based MW-BPF are compared. Indeed, this MW-BPF framework incorporating QC-SSIR is seen to achieve 1.93dB/13.9%, 1.49dB/18.7%, and 0.60dB/49.3%, as the transmission coefficients/fractional bandwidth for 2.58, 1.71, and 0.81 GHz, respectively. The first frequency has λ_G as the wavelength and λ_G^2 =0.167 or 97 mm x 240 mm as the size of the filter. The proposed QC-SSIR sought to achieve the objective of filter size reduction. With a folded QC-SSIR incorporated in the MW-BPF, λ_G^2 =0.09 or 97 mm x 129 mm was the size.

46% was the final size after BPF size reduction, with the first frequency's wavelength being $\lambda_{G.}$ in Figure 8(b), the illustration demonstrates a comparative analysis of the outcomes between the measured and the simulated MW-BPF, having incorporated the folded SSIR. For the case of the FQC-SSIR, when MW-BPF was incorporated, the resultant structure or model achieved 1.76dB/12.5%, 1.21dB/17.7%, and 0.57dB/49.6% as the transmission coefficients/fractional bandwidth for 2.62, 1.80, and 0.82 GHz, respectively. These findings are summarized in Table 1, which provides a comparison of the performance of different BPF structures. It is also notable that the findings demonstrate that when the QC-SSIR model is incorporated, it can be used towards the production of the multiband band-pass filter for applications such as LTE2600, WCDMA1800, and GSM800. Similarly, there is an observed good agreement between the measured and the simulated outcomes, suggesting that the proposed design is valid and highly reliable.

4 Conclusion

In summary, a QC-SSIR model was proposed in this study. the proposed microstrip structure was responsible for MW-BPF generation. Also, there was the application of the folded QC-SSIR structure with the aim of reducing the size of the filter, reducing the size of MW-BFP to about 46%. From the outcome evaluation perspective, there was good agreement between the measured and the simulated results.

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