2019 4th International Conference on Automatic Control and Mechatronic Engineering (ACME 2019)

Stub-Loaded Microstrip Bandpass Filter Design Using Reflection Theory and Monte Carlo Method

Chang Wang[a, *], Ye Yuan, Yuhong Ma, Ximeng Zhang, Chenxin Li, Qingping Wang and Naichang Yuan

State Key Laboratory of Complex Electromagnetic Environment Effects on Electronics and Information System, National University of Defense Technology, Changsha, Hunan, China

[a]275513557@qq.com

*Corresponding author

Keywords: Reflection theory, microstrip bandpass filter, stub-loaded filter, Monte Carlo method Classification: Microwave and millimeter wave devices

Abstract: In this paper, a novel method to design a kind of stub-loaded filters is proposed. This method is based on the reflection theory and Monte Carlo method. A stub-loaded bandpass filter (BPF) which can work on 8–11GHz is presents as an example to verify the applicability of our method. The comparison between calculated and practical dimensions of stubs shows a satisfactory fitting degree, and the calculated and measured S-parameters match well with each other. The performance of the BPF shows that our proposed method can be a good guidance in microstrip filter design.

1. Introduction

Microstrip filters has been widely used in modern wireless communication systems [1, 2], it is important to hunt for some convenient method to design microstrip filters. In this paper, a novel method to design multiple impedance transformer filters is established, this method is based on the reflection theory and it is a modified version of the method which it presents in [3]. The reflection theory is to consider the total reflection coefficient at the input port as the composite function of local reflection coefficients between the neighboring transmission lines [4]. The common applications of this theory is impedance matching design between load and source [5, 6]. Stepped impedance filters also apply the reflection theory to design low-pass filters (LPF) with good performance [7, 8, and 9]. However, when a design of bandpass filters (BPFs) the stepped-impedance filters will not be suitable enough because it has some limitations while the characteristic impedances between the neighboring stubs differ sharply [10]. In [3], we present a method based on the theory of small reflections to design arbitrary passband filters, but this method has some limitations because it use a approximation formula to calculate the reflection coefficient. This paper overcomes the shortcomings of the method in [3] and presents a more reliable and convenient method to design stub-loaded filters. By using our modified method, a BPF is designed, fabricated and measured.

2. Theory background

[4] Shows a famous method called the Theory of Small Reflection (TSR), this theory has been widely used in impedance matching design. In [3] it presents a modified method of the TSR to design microstrip filters with arbitrary passbands. The equivalent model of the filter structure proposed in [3] is shown in Fig. 1, where N represents the order of the filter, θ represents the electrical length of the main transmission line, Ln represents the length of the nth loaded stub, Γ_{Total} represents the reflection coefficient at the input port, Γ_n represents the nth local reflection coefficient. The reflection coefficient at the input port Γ_{Total} is given in (1):

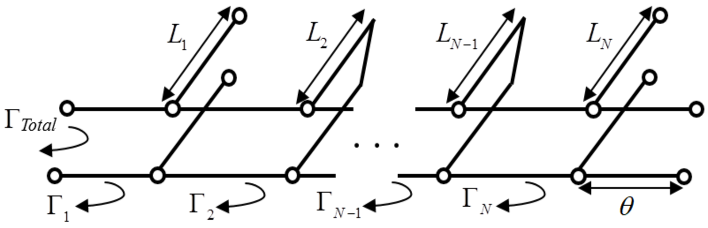


Figure 1. The equivalent model of multiple-stub impedance transformer.

$$\Gamma_{\text{Total}(f)} \approx \sum_{n=0}^{N} \Gamma_n(f)\exp(-2jn\theta) \tag{1}$$

The use of loaded-stub is to add an imaginary part on the Y0, then the Γn can be a function that depends on the frequency f. In [3] we use this equation to calculate the Γ_{Total}, but there are some limitation while using (1): If the impedance between two neighboring stubs has a large discrepancy, the approximate can be wrong. In this paper, we use the accurate equation to calculate Γ_{Total}. The structure shown in Fig. 1 can be decomposed into N parts of the structure shown in Fig. 2, where YL represents the equivalent admittance of the load, Yx and θx represent the characteristic admittance and the electrical length of the loaded-stub, respectively. The Γ of each part can be calculated by (2), and the Γ of the latter part is the Γ2 of the previous part.

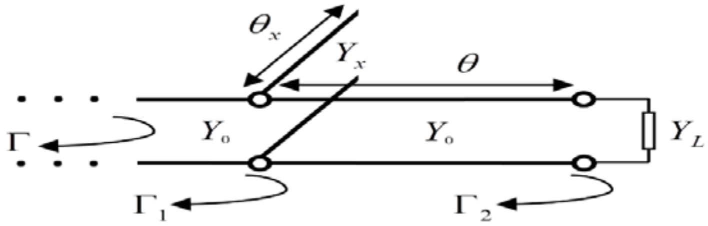


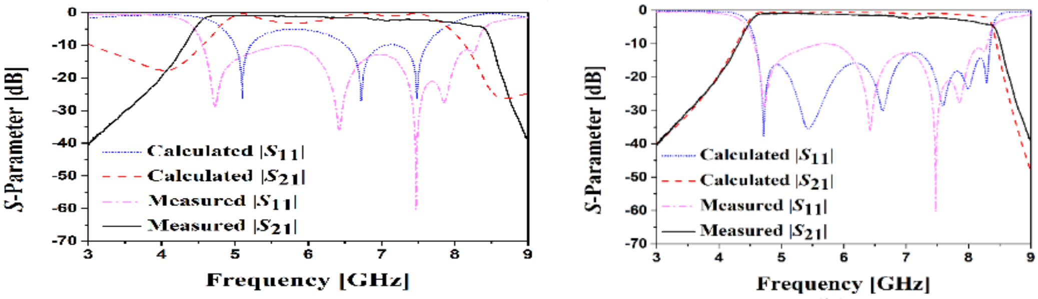
Figure 2. The equivalent model of multiple-stub impedance transformer.

$$\Gamma = \frac{|\Gamma_1| + |\Gamma_2|\exp(-2j\theta)}{1 + |\Gamma_1||\Gamma_2|\exp(-2j\theta)} \tag{2}$$

Here we use the opened-stub with different Yx as our loaded stub, and the Γ1 can be derived by using the transmission theory [4]:

$$\Gamma_1 = \frac{jY_x \tan\theta_x}{2Y_0 + jY_x \tan\theta_x} \tag{3}$$

By calculating N times from the Nth part to the 1st part, we can derive the Γ of the 1st part as our final $|\Gamma_{Total}|$ function. To verify the feasibility of this modified method, we recalculate the Filter 1 proposed in [3] and make comparison of the accuracy of the modified method and the method in [3].



(a) (b)

Figure 3. Comparison of the accuracy between the two method: (a) method in [3], (b) modified method in this paper.

As it is shown in Fig. 3, the modified method proposed in this paper has a better fitting effect. But to achieve this improvement, the cost is also obvious: by iterating (2) for N times, the $|\Gamma_{Total}|$ function can be an extremely complex formula, it can cause some troubles while reversely calculating the dimensions of the filter.

3. Bandpass filter design

In [3], we use the gradient descent method to search the optimal solution of (1), but when dealing with the non-convex function, it could reach local minimum in optimal searching, and the optimized results highly depend on the initialization. In this paper, we use the Monte Carlo method to reverse calculating the dimensions of the filter. Firstly, we need to choose our interested frequency band and set the suitable optimization goals F goal. Here a BPF is designed as an example, the optimization goals are shown in Tab. 1:

Table 1. Optimization goals

Frequency	Type	Parameters	F goal
8–11GHz	Passband	|S11|	0.1(−10dB)
5–7GHz	Stop-band	|S21|	0.01(−20dB)
12–14GHz	Stop-band	|S21|	0.01(−20dB)

Then randomly generate the dimensions of the stubs and put these value into $|\Gamma_{Total}|$ function. Finally we can obtain our objection function ε by calculating the 2-norm difference between Γ_{Total} and F goal, the ε are shown in (4), where fn represents the nth sampling point of frequency, Sp represents the calculated S-parameters of the filter (Sp represents the S11 in the passband and S21 in the stop-band):

$$\varepsilon = \sum \left[\left| S_p \right| (f_n) - F_{goal}(f_n) \right]^2 \tag{4}$$

By randomly generating the dimensions of the filter for M times, we can find the minimum value of $\varepsilon(\varepsilon_{\min})$ and the optimal dimensions of the designed filter. The flowchart of the design procedure are shown in Fig. 4:

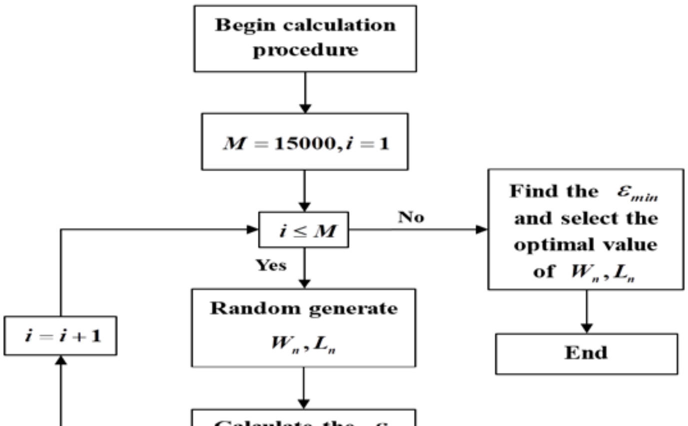
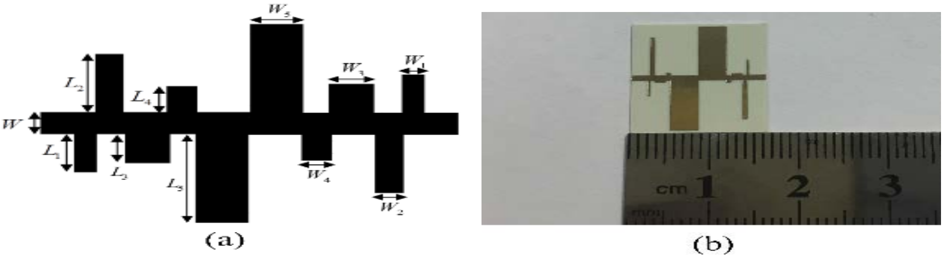


Figure 4. The flowchart of the design procedure

In this paper, the filter are designed by using Rogers RO4350 substrate of dielectric constant 3.66 and substrate height 0.254mm (10mil). We use the point symmetric structure (shown in Fig. 5(a)) to be the structure of our proposed filter in order to simplify the design procedure, then set the value of M as 15000. After the calculation, the final $\varepsilon_{\min}$ is approximately equal to 0.6. The dimensions of the designed BPF is shown in Tab. 2, and the fabricated BPF is shown in Fig. 5(b). Both measured and calculated S parameters are shown in Fig. 6, where |S11| and |S21| represents the reflection coefficient and the insertion loss, respectively. Fig. 6 shows that the BPF performs well both in passband and stop-band. The proposed filter has an evident passband between 8GHz and 11GHz, the center frequency is around 9.8GHz and the frequency band width (FBW) is 30%. The measured and calculated results fit well with each other. The designed filters only contain opened-stubs, the total dimensions shown in Fig. 5(b) depicted that our proposed BPF has a small size. Therefore, our proposed filter is easy to design and fabricate.



(a) (b)

Figure 5. Proposed BPF: (a) structure of the BPF, (b) Fabricated BPF.

Table 2. Dimensions of the BPF

Parameter/[mm]	L1	L2	L3	L4	L5	W	W1	W2	W3	W4	W5
Calculated	9.5	0.2	0.4	7.2	2.9	1	3.2	0.5	1.5	0.7	0.2
Practical	9.2	0.5	0.3	7.2	2.9	1	3.2	0.5	1.3	0.5	0.2

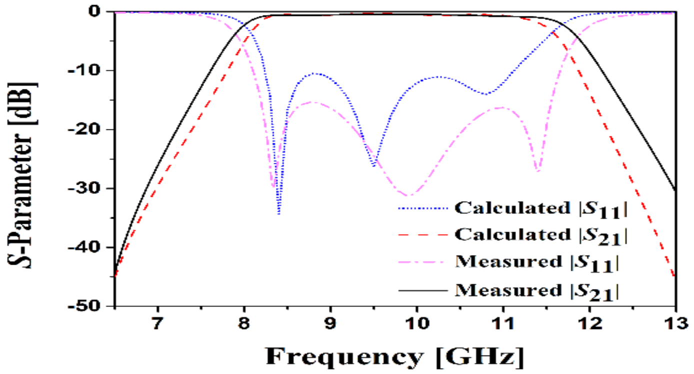


Figure 6. S-parameter of our proposed BPF.

Fig. 5 (b) depicted that our proposed BPF has a small size. Therefore, our proposed filter is easy to design and fabricate.

4. Conclusion

In this paper, a novel microstrip BPF is presented, the method to design this BPF is based on the reflection theory, and the calculation procedure for dimensions of filters is based on the Monte Carlo method. The details of design procedure are shown in Sec. 2 and 3. The dimensions and S parameters of the BPF are shown in Sec. 3, the calculated and practical results show the satisfactory matching. The design procedure is convenient and the fabricated filter is small in size. All these results verify that our proposed method has satisfactory guidance in microstrip filter design.

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