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MICROSTRIP QUARTER-WAVELENGTH BAND PASS FILTER DESIGN WITH SYMMETRICAL SHORT STUBS TECHNIQUES

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ABSTRACT

The quarter-wavelength stub coupled band pass filter (QWSCBPF) is presented in this paper. In applications, the QWSCBPF is characterized in terms of an ABCD matrix. Using the mathematical expressions of the Butterworth response, we establish an available table of the normalized admittances for designing. In addition, the tables of the normalized admittances for Chebyshev responses are also stated. Moreover, we report the complete procedure with flow diagram for the easy design of the symmetrical QWSCBPF. Both simulation results and experimental measurements on the filter are presented and discussed.

Key Words: quarter-wavelength microstrip, symmetrical short stub, Butterworth and Chebyshev response

應用對稱短路殘支技術於微帶線帶 λ/4 帶通濾波器之設計

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摘要

本文的目的是設計 λ/4 殘支耦合帶通濾波器 。在應用上，λ/4 殘支耦合帶通濾波器首先運用 ABCD 矩陣模式建立，再經 Butterworth 響應的數學運算，一張以均值化阻抗表示的表格，即可獲得以供設計。同時，兩張 Chebyshev 響應的均值化阻抗表亦可獲得。整個設計過程，逕以步驟流程呈現，簡單明瞭適於應用。由實驗與模擬的驗證，此一設計 λ/4 殘支耦合帶通濾波器的方法是適用的。

關鍵詞：λ/4 微帶線，對稱型殘支，Butterworth 響應， Chebyshev 響應

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I. INTRODUCTION

Microstrip lines are used extensively in constructing modern microwave integration circuits (MIC) because they are easily fabricated using printed-circuit technique. In MIC applications, filter design has utilized microstrip lines to construct a variety of microwave filters.

Many circuit configurations such as stub loaded low pass filter, step impedance low pass filter, direct coupled band pass filter, parallel coupled band pass filter, interdigital band pass filter, ground-stub coupled band pass filter, and ring resonant band pass filter are commonly used in the recent years [1]. Generally, the shorted quarter-wavelength stubs and the opened quarter-wavelength stubs are often being used as the fundamental structure to construct the filters.

In practice, the QWSCBPF was introduced [2, 3] and developed [4-10] for applications. In this paper, an alternative approach is proposed. Firstly, we characterize the QWSCBPF in terms of an ABCD matrix. Then, by using the mathematical expressions of the Butterworth response, we establish an available table of the normalized admittances for designing. In addition, the normalized admittances for Chebyshev responses are also introduced in table 1. Moreover, we report the complete procedure to the design of the symmetrical microstrip band pass filter. Finally, simulation and measurements of the filter are demonstrated by an experimental example.

II. EXPRESSIONS OF THE BUTTERWORTH RESPONSES

Usually, the ABCD matrix of a quarter-wavelength coupled microstrip line is expressed as:

$$\begin{pmatrix} A' & B' \\ C' & D' \end{pmatrix}' = \begin{pmatrix} \cos\theta & j\dfrac{\sin\theta}{Y_o} \\ jY_o\sin\theta & \cos\theta \end{pmatrix} \tag{1}$$

where Y_o is the characteristic admittance of the coupled line, θ is phase angle. For the shorted quarter-wavelength stub, the ABCD matrix is written as:

$$\begin{bmatrix} A'' & B'' \\ C'' & D'' \end{bmatrix}'' = \begin{bmatrix} 1 & 0 \\ -jY_n\cot\theta & 1 \end{bmatrix} \tag{2}$$

where Y_n is the admittance of the n-th shorted stub.

In this literature, the configuration of the QWSCBPF is considered in the analysis (see Fig. 1.). By using equations (1) and (2), the n-th order ABCD matrix of the QWSCBPF can be calculated as:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -jY_1\cot\theta & 1 \end{bmatrix} \bullet \begin{bmatrix} \cos\theta & j\dfrac{\sin\theta}{Y_0} \\ jY_0\sin\theta & \cos\theta \end{bmatrix} \bullet \begin{bmatrix} 1 & 0 \\ -jY_2\cot\theta & 1 \end{bmatrix} \bullet \cdots\cdots \bullet \begin{bmatrix} \cos\theta & j\dfrac{\sin\theta}{Y_0} \\ jY_0\sin\theta & \cos\theta \end{bmatrix} \bullet \begin{bmatrix} 1 & 0 \\ -jY_n\cot\theta & 1 \end{bmatrix} \tag{3}$$

According to the circuit theory, the Butterworth responses of the QWSCBPF are obtained by:

$$\frac{P_o}{P_L} = 1 + K_n \frac{\cos^{2n}\theta}{\sin^2\theta} \tag{4}$$

where n is the number of the resonators, K_n is a constant, and $\theta = \pi f / 2f_o$.

For the special case that the resonator is made of a quarter-wavelength shorted stub, K_n can be written as:

$$K_n = \left[\frac{y_1(y_2+2).....(y_n+2)}{2}\right]^2 \tag{5}$$

where $y_n = Y_n / Y_o$ is the normalized admittance of the n-th shorted stub.

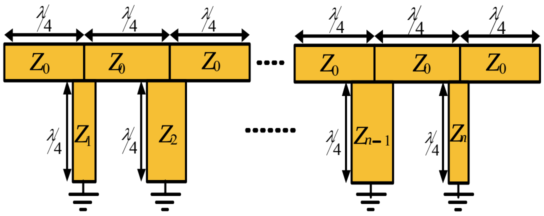


Fig.1. The schematics diagram of the n-th order microstrip QWSCBPF.

For a lossless transmission line circuit, (where the source impedance and the load impedance have the values of Z_o,) the ABCD matrix is the best way to describe the n-th order QWSCBPF. Thus, the transfer ratio P_o/P_L is expressed by the ABCD parameters as:

$$\frac{P_o}{P_L}=1+\frac{1}{4}\left[(A-D)^2-\left(\frac{B}{Z_0}-Z_0C\right)^2\right] \tag{6}$$

Substituting (3) into (6), and comparing it with (4), the relationship between the admittance of each stub can be obtained as shown in Table 1. It is observed that the admittance profile of Table 1 displays mirror image symmetry with keeping admittance equal to unity at both ends. Thus, the circuit pattern of the resulting microstrip filter shows a topologically symmetric pattern.

Table 1. Normalized admittances of Butterworth responses

n	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9	Y_{10}
2	1.000	1.000								
3	1.000	2.000	1.000							
4	1.000	2.416	2.416	1.000						
5	1.000	2.661	3.236	2.661	1.000					
6	1.000	2.735	3.737	3.737	2.735	1.000				
7	1.000	2.802	4.049	4.494	4.049	2.802	1.000			
8	1.000	2.849	4.264	5.031	5.031	4.264	2.849	1.000		
9	1.000	2.882	4.415	5.415	5.764	5.415	4.415	2.882	1.000	
10	1.000	2.910	4.532	5.712	6.330	6.330	5.712	4.532	2.910	1.000

III. CHARACTERISTICS OF THE CHEBYSHEV RESPONSES

Considering the symmetrical characteristics of Chebyshev circuits with odd orders, Table 2 and Table 3 represent the normalized admittances for Chebyshev responses with ripples of specified 0.1dB and 0.5dB, respectively.

As an example, a 5-th order Chebyshev response QWSCBPF is designed with center frequency f_o= 4 GHz and ripple = 0.1 dB by using of Table 2. It is considered that the microstrip is fabricated on a FR4 substrate with the transmission line characteristic impedance Z_o=50 Ω. From Table 2, the ratio Y1: Y2: Y3: Y4: Y5 = 1 : 1.196 : 1.723 : 1.196 : 1. We choose Z1=Z5=25 Ω, Z2=Z4=20.9 Ω and Z3=14.5 Ω. The frequency response of the resulting filter is plotted in Fig. 2.

Table 2. Normalized admittances for Chebyshev responses with ripples = 0.1dB

n	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9
3	**1.000**	**0.687**	**1.000**						
5	**1.000**	**0.721**	**1.489**	**0.721**	**1.000**				
7	**1.000**	**0.724**	**1.518**	**0.774**	**1.518**	**0.724**	**1.000**		
9	**1.000**	**0.725**	**1.524**	**0.781**	**1.556**	**0.781**	**1.524**	**0.725**	**1.000**

Table 3. Normalized admittances for Chebyshev responses with ripples = 0.5dB

n	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9
3	**1.000**	**0.491**	**1.000**						
5	**1.000**	**0.511**	**1.406**	**0.511**	**1.000**				
7	**1.000**	**0.513**	**1.428**	**0.542**	**1.428**	**0.513**	**1.000**		
9	**1.000**	**0.513**	**1.433**	**0.546**	**1.457**	**0.546**	**1.433**	**0.513**	**1.000**

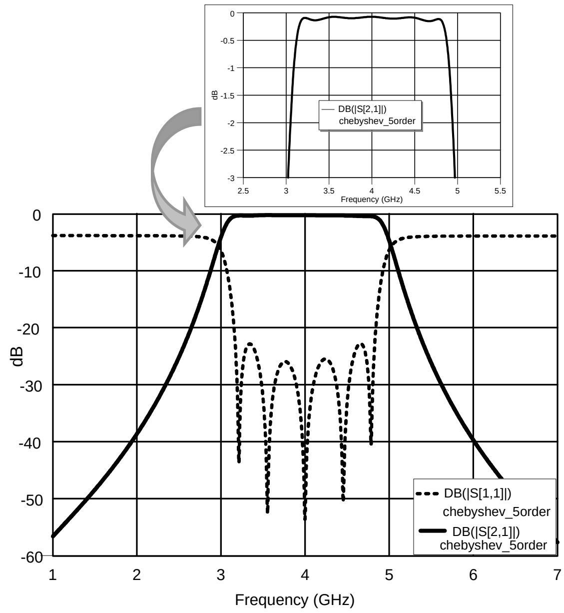


Fig.2. Frequency response of 5-rd order Chebyshev band pass filter.

It is observed in Fig. 2 that there are ripples of magnitude 0.1 dB existed over the pass-band (see the magnified figure) corresponding to the characteristics of a Chebyshev response. Moreover, the frequency response profile of the filter is symmetrically located relating to the center frequency of the pass-band.

VI. DESIGN EXAMPLE MEASUREMENT, ANALYSIS AND DISCUSSIONS

In application, according to the procedure in Fig. 3, we realize a 3-th order Butterworth band pass filter employed in the direct broad casting satellite (DBS) receiving system with center frequency f_o=1.2 GHz, bandwidth BW=500 MHz, and a symmetrical circuit structure.

Following the previous statement, a design procedure is proposed as shown in Fig. 4. At first, we determine the parameters of the FR4 substrate as: ε_r=4.6, loss-tangent=0.0245, H=1.5 mm, T=0.04 mm. Next, we find from Table 1 that Y1 : Y2 : Y3 = 1 : 2 : 1, and choose Z1=Z3=30 Ω, Z2=15 Ω, and the Q_T=2.13. Then, the circuit pattern is sketched by using Microwave-Office simulation software. The simulated circuit of 3-th order Butterworth symmetrical microstrip QWSCBPF is shown in Fig.4. Finally, the microstrip circuit is implemented and the S_{11} and S_{21} parameters are measured using HP-8510 network analyzer. In Fig.5, a comparison is made between the experimental data and the simulated result of the microstrip filter.

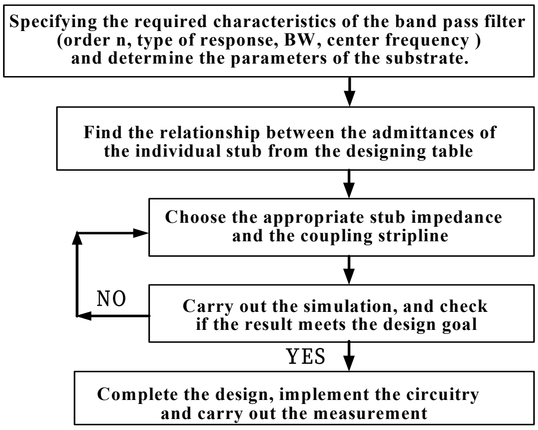


Fig.3. The flow chart diagram of the design procedure.

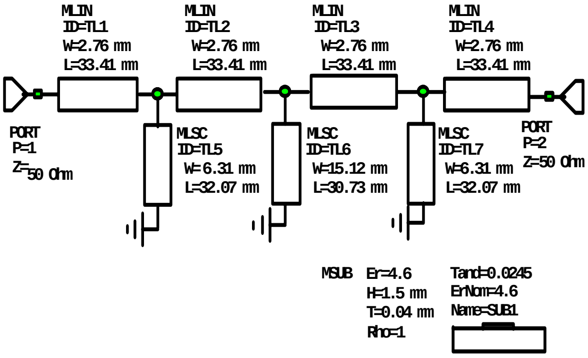


Fig.4. Simulated circuit of 3-th order Butterworth symmetrical microstrip QWSCBPF.

From the experimental and the numerical results, several important consequences are observed as in the followings:

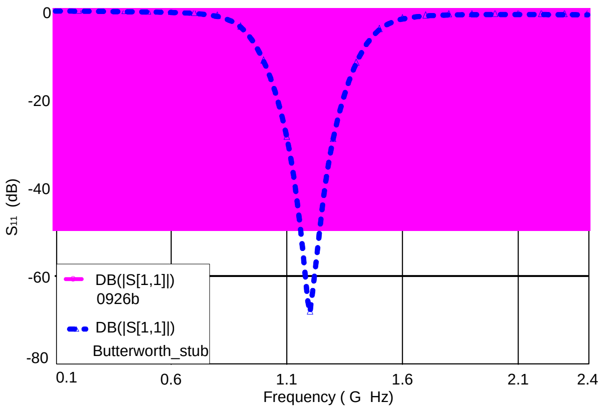
(1). The designed filter provides f_o=1.1191 GHz, f_L=0.931 GHz and f_H=1.45 GHz, which meets the design goal of f_o=1.2 GHz and bandwidth=500 MHz very well. As shown in the Fig. 5, it is evident that the experimental data are in a good agreement with the simulated results above 30 dB.

(2). On the design scheme, the reference of impedance matching is 50 Ω. Therefore, the simulated results show out a resonant frequency. However, the well impedance matching would have not been obtained in this experimental resultant. Inevitably, there are two resonant frequencies in the Fig. 5(a) of S_{11} graph.

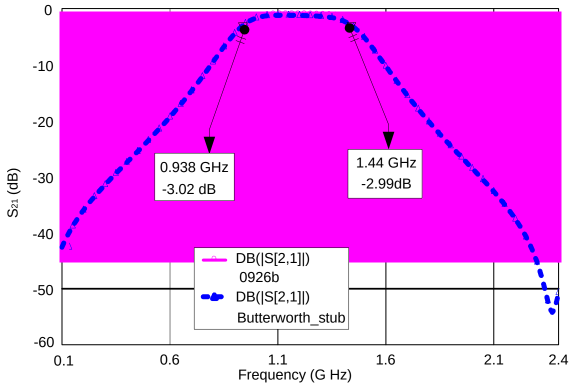
(3). The frequency response curve plotted using the experimental data as well as from the numerical results exhibit flat profile over the pass-band, which corresponds with the definition of the Butterworth band pass filter.

(4). The measured insertion loss is around the value of 0.9 dB for this example, which is fabricated on a FR4 substrate with loss-tangent=0.0245 (ideally loss-tangent=0). Obviously, the circuit performance (the insertion loss) strongly depends on the characteristics of the substrate.

(5). The dimension of the circuitry is related with the operating frequency according to the circuit realized by the quarter-wave microstrip stub.



(a) S_{11} graph (dashed line for simulated, solid line for experimental)



(b) S_{21} graph(dashed line for simulated, solid line for experimental)

Fig.5. The S_{11} and S_{21} comparison of is made between the experimental data and the simulated results of the microstrip filter.

V. CONCLUSIONS

We have designed and implemented a symmetrical microstrip QWSCBPF, and we have compared the experimental data with the simulated solutions. The following conclusions can be drawn in this study:

(1). Investigation of the symmetrical microstrip QWSCBPF shows that the filter is applicable in the frequency converter of the DBS receiving system owing to that the performance of the filter satisfies the system requirement.

(2). The design procedure for the symmetrical microstrip QWSCBPF, which we had established with the aid of the tables of the normalized stub admittances by using the Microwave-Office simulation software, is validated in practical application by the experimental verification in this work.

(3) Both the tables related to Butterworth and Chebyshev responses are derived for applications.

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